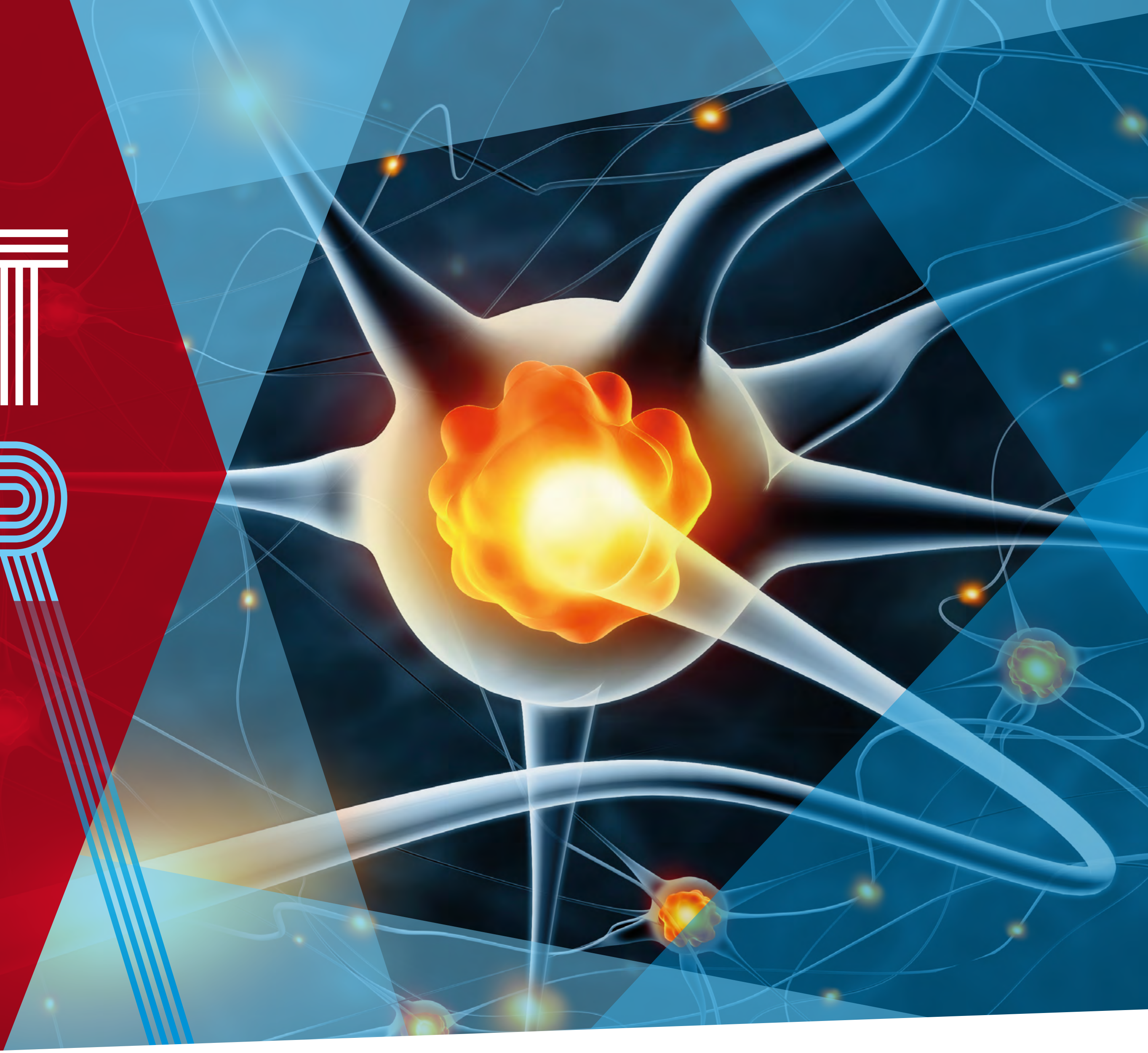
LIGHT SAVER

Engineering light *to help save lives*

Student guide



An upper primary and lower secondary STEM-focused resource that gives young learners the opportunity to explore how engineering and science work together in the healthcare service.

Pupils work collaboratively to develop their curiosity and creativity through a series of fun and engaging activities.

ROYAL ACADEMY OF ENGINEERING

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CONTENTS

INTRODUCTION

Advances in science and engineering have led to many new ways to save lives in the healthcare system.

Modern medicine and healthcare rely heavily on the sciences and engineering to prevent, investigate and treat illness. These technologies are vital to the delivery of successful health services through the NHS. However, in the health sector the contribution of science and engineering is sometimes overlooked.

What is science and why is it important?

Science is the study of the physical and natural world through observation and experiments.

What do engineers do and why are they so important?

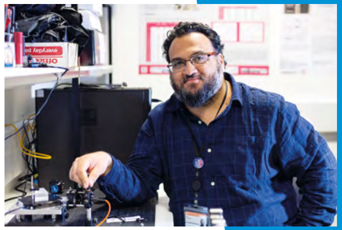
Engineers apply science and maths along with skills developed in many other subjects taught in schools. They find solutions to problems, make things work and then make them work better. Engineering is in everything and makes the world a better place to live in. Engineers need to be problem-finders and solvers, think creatively and work well in a team. They can adapt their ideas and learn by making mistakes. We call this Engineering Habits of Mind (EHOM).

Medical imaging

Metabolight is a team of engineers, scientists and doctors that have developed a new light-based technique to help diagnose and monitor the health of babies' brains. Detecting and monitoring brain activity is vital to help doctors treat these babies in a harmless way with new technology that uses the properties of light.

Metabolight and the Royal Academy of Engineering have worked together to create a series of STEM activities and practical teamwork challenges. These explore the role that engineers and scientists have in developing new technologies to save lives.

Find out more about the team behind this and what they do at https://metabolight.org



METABO LIGHT

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DEPARTMENT OF MEDICAL PHYSICS & BIOMEDICAL ENGINEERING

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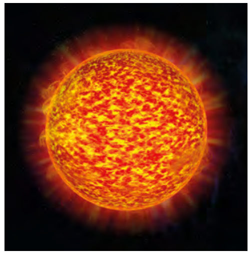
Scan the QR code on your phone, or go to http://stemresources.raeng.org.uk/student-survey/

WHAT IS LIGHT?

Life itself would be impossible without light! Imagine trying to pour milk into your cereal bowl for breakfast, or tying your shoe laces before going to school in the dark.

Light can transfer a small amount of energy. When you turn on a light switch, the bulb sends out beams of light. We call this **emitting** light and it always travels in straight lines. You can see objects because light bounces off them and into your eyes.

The Sun is our biggest light source. It emits light in all directions. Everywhere we look the Sun is lighting up our world. Light can do more than that, including helping us to save lives.

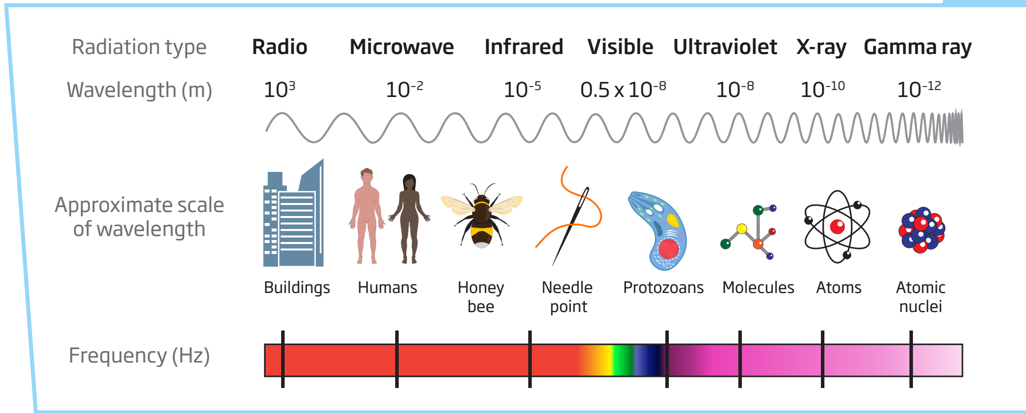


Time to calculate

Light travels at **300,000 km** (300 thousand kilometres) per second and the distance between the Earth and the Sun is **149,000,000 km** (149 million kilometres).

- How many minutes does it take for light to reach us from the Sun?
- Explain why you think it takes this amount of time. You can write your 'working out' as an equation.

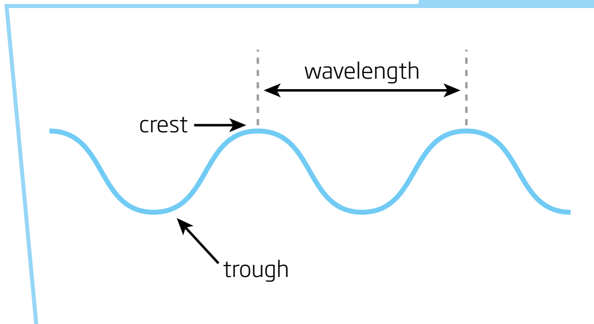
Diagram of the electromagnetic spectrum



Time to think

The Sun is just one source of light. What other light sources can you think of?

Light transfers energy



Light is a type of electromagnetic radiation that moves in waves – just like our oceans. It is not harmful to humans and it is the only part of the spectrum visible to the human eye.

Different lengths of **electromagnetic waves** are shown in this diagram of the electromagnetic spectrum. Notice how the as waves get closer together, the wavelength becomes smaller. Also notice how the colours of the rainbow in the frequency band aligns with the visible wavelength.

Light travels in the form of waves. This is called **oscillating**. Oscillating waves form a repeated shape with troughs and crests. The length of a single wave is called a **wavelength**.

Wavelengths come in different sizes. Some are thousands of metres long, while some are the size of an atom. Wavelength is measured by the distance between the crest of each wave.

DID YOU KNOW?

Electromagnetic waves carry energy from one place to another and travel at the speed of light.

Time to calculate

The power of 10

All wavelengths are measured in metres (m) and they are named by the power of 10. Look at the chart below, can you fill in the gaps?

Tip: Start in the middle and work your way up and then down

Calculation	Number		Power	Words	Radiation type wavelength
10 × 10 × 10 × 10 × 10	100,000			Hundred thousand	
	10,000		10^4		
	1,000		10^3	Thousand	
10 × 10	100				
	10		10^1	Ten	
10 × 0.1	1		10^0	One	
1 × 0.1	0.1	$\frac{1}{10}$	10^{-1}		
	0.01			One hundredth	Microwave
0.1 × 0.1 × 0.1	0.001		10^{-3}		
	0.0001		10^{-4}	Ten thousandth	
	0.00001	$\frac{1}{1000}$		Hundred thousandth	

Time to think and calculate

What patterns do you notice?

Using the information from the chart you completed above, show the following:

- What is the approximate length of a radio wave in metres?
- What is the approximate length of a microwave in metres?
- What is the approximate length of an infrared wave in metres?

Stretch and challenge

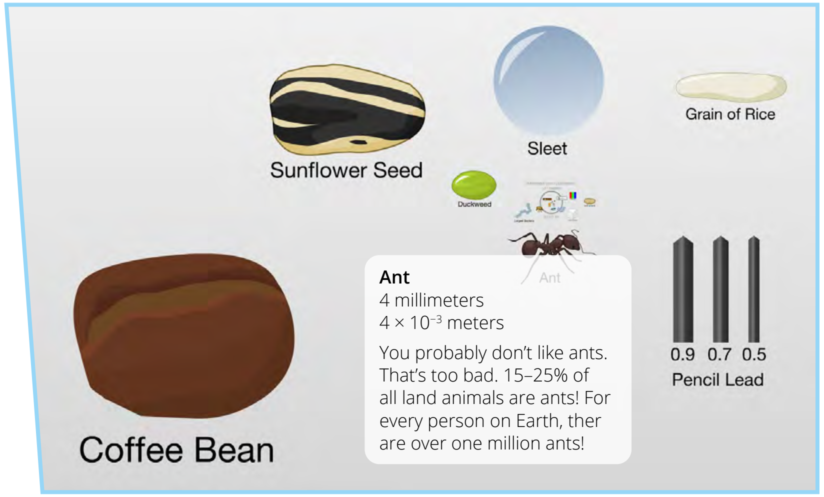
- What is the approximate length of a wave in the 'visible' spectrum?
- How much longer is a microwave wavelength compared to an infrared wavelength?

The scale of the universe

Comparing the size of different objects can help us get a better idea just how large or how small different things are!

If you have access to laptop, computer, smartphone or tablet visit www.scaleofuniverse.com and use the interactive tool to find out the size of the following objects and their wavelength. Human has been answered for you.

Tip: Click on the object to find out the size



Object	Size	The power of 10	Wavelength
Human	1.7 metres	1.7×10^0 metres	FM Radio wave
Apollo Lunar Buggy			
Mount Everest			
Grain of rice			
Y-chromosome			

DID YOU KNOW?

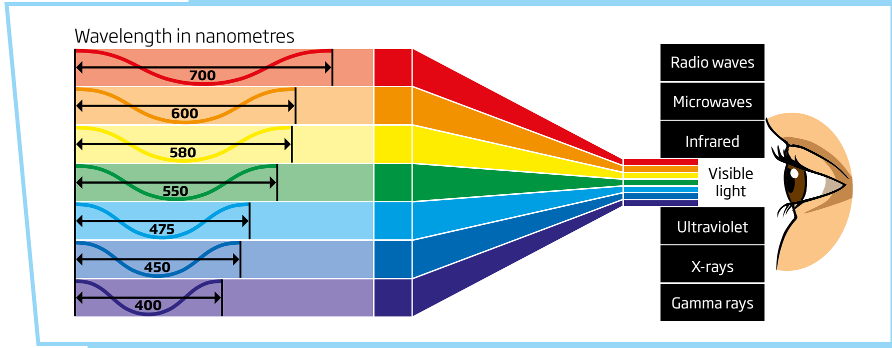
Something the size of a **nano** is very small indeed. In fact, it is one billionth of a metre. Scientists and engineers develop new materials on a molecule level. This is called **nano-technology**.

Nano-challenge:

- How many times smaller is the Apollo Lunar buggy than Mount Everest?
- Find the smallest creature visible to the naked eye.
- Find the smallest thing visible to an optical microscope.

The visible light spectrum

The part of the electromagnetic spectrum visible to the human eye is called the visible light spectrum. As you can see from the diagram the different colours we can see have different wavelengths. For example, the colour **red** is 700 nanometres (nm) long and the colour indigo is 450 nm long.



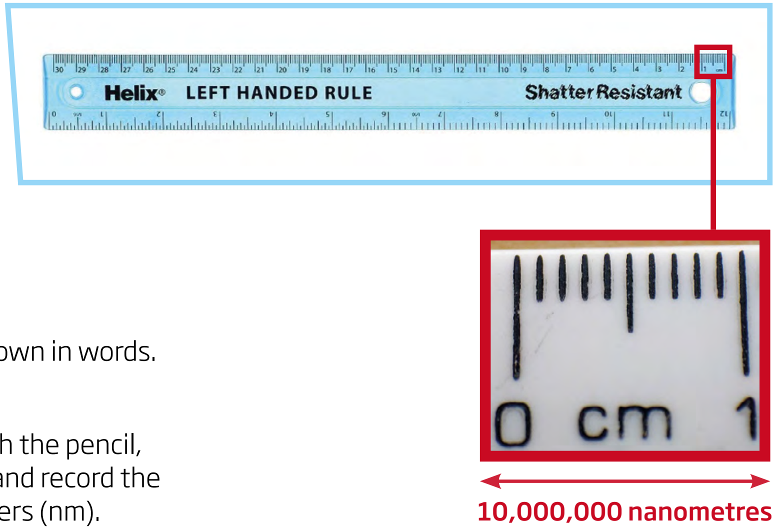
DID YOU KNOW?

White light is a mixture of all the wavelengths/colours of the visible light spectrum. The Sun is a natural source of white light.

But what is a nanometre and how small are we talking?

A **nanometre** is something very small. In fact, one nano is the length your fingernail will grow in one second. So you won't see it with your natural eye without the help of a super-microscope.

One nanometre is **0.000000001 metres**. Use the table on page 3 to write this number as a power of 10.



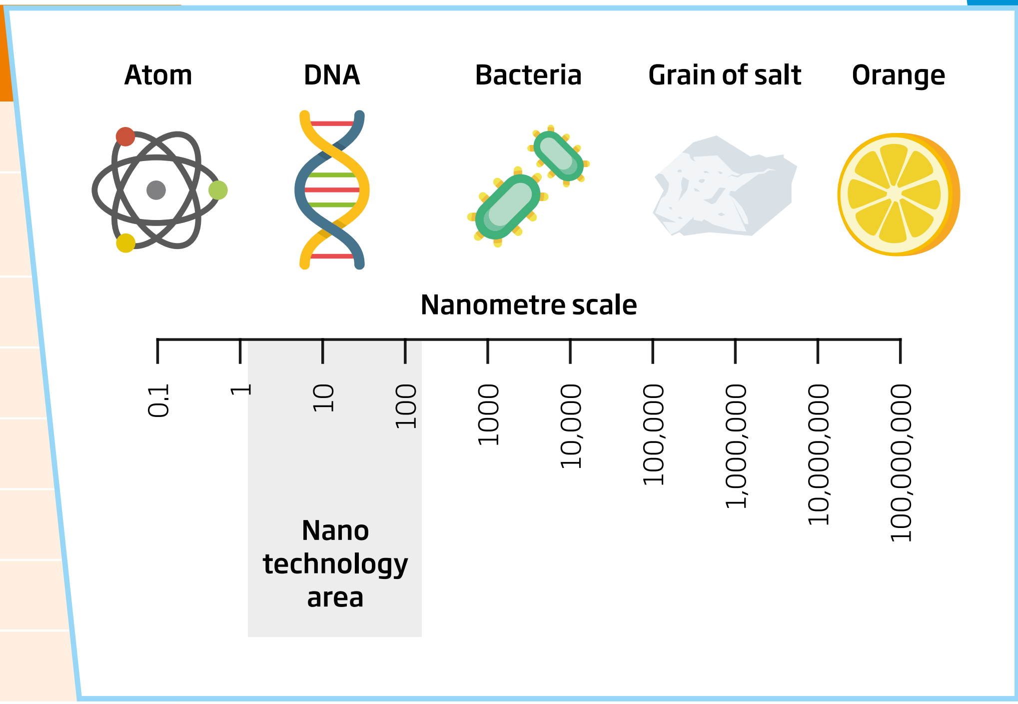
Time to measure

Using the nano-chart, let's work out some nano-lengths.

- How many nanometres (nm) is the slice of orange? Write this down in words.
- How long is the grain of salt in centimetres (cm)?

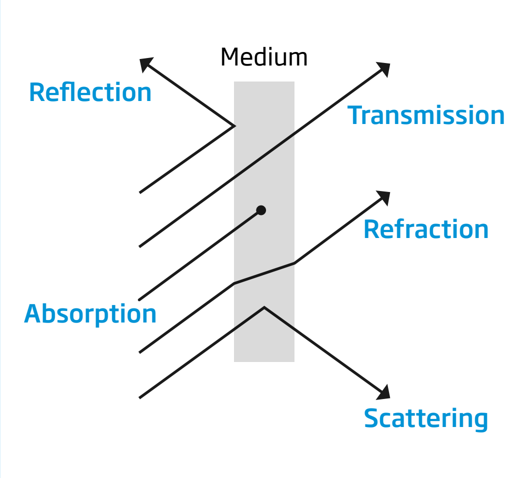
Calculate the nanometres of the objects in your pencil case. Start with the pencil, rubber and pencil sharpener and then add your own items. Measure and record the length of each in centimetres (cm) first and then convert to nanometers (nm).

Pencil case object	Measurement (cm)	Measurement (nm)
Pencil		
Full stop made by pencil		
Rubber		
Sharpener		



BEHAVIOUR OF LIGHT

Light waves behave in different ways depending on what object it meets, as shown in the diagram below. Let's look at these behaviours in more detail.



Transmission

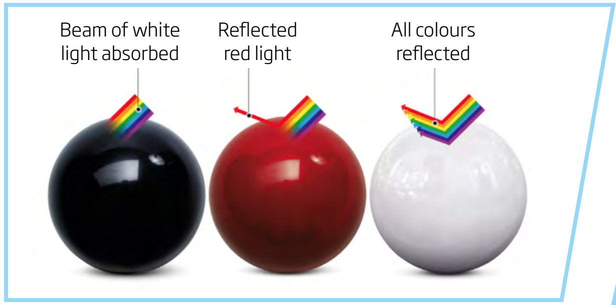
Transmission of light is the moving of electromagnetic waves through a material. Different objects transmit different amounts of light and for visible light the more **transparent** an object is, the more light will be transmitted. Light does not travel through **opaque** objects.

Reflection

Reflection of light is the bouncing back of a wave when it meets a surface that does not absorb all of the light energy. Mirrors and other smooth surfaces reflect light to form clear images.

Absorption

Almost all objects absorb light to some extent. If an object is white, all colours are reflected, if it is black, many of the colours are absorbed. Objects that absorb light become warmer because they convert the energy to heat.

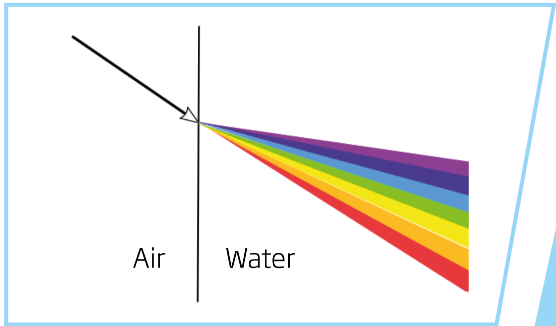


Refraction

When light passes from one medium to another medium of a different **density** (for example from air to water), the light bends. This is known as refraction of light.

How much the light is refracted depends on the wavelength of the light.

The shorter the wavelength, the more it bends. When white light passes from air to water, it refracts and the individual colours become visible as each one has a different size wavelength. This is how we see rainbows.



Scattering

Light scatters when it is forced to deviate from a straight path due to the structure of the medium.

DID YOU KNOW?

Density refers to the amount of stuff (mass) contained in a given space (volume). We see rainbows when the Sun shines through millions of tiny raindrops in the sky, all of which are bending the light.

Absorbing the light challenge

A British engineering firm, **Surrey NanoSystems** has developed the 'world's darkest material' which absorbs 99.96% of light. It's called **Vantablack** and you can watch a video on how dark it is at:

www.youtube.com/watch?v=fg2x0L4YAuU

Vantablack reflects so little light it is described as the closest thing to a black hole we will ever see. What do you think Vantablack is used for?

Time to think

Why do you think black objects radiate more heat?
Handy hint: remember light is a source of energy!

Time to experiment

Equipment

- Glass of water
- Torch (or ask your teacher to help you do this with a laser pointer for better results!)
- Blue food colouring

Fill a glass half full with water. Shine the torch (or laser pointer) through the glass.

Notice how the light travels through the glass. This is transmission.

Now try adding some blue food dye and shine your torch again.
What do you notice? Which behaviour is happening here?

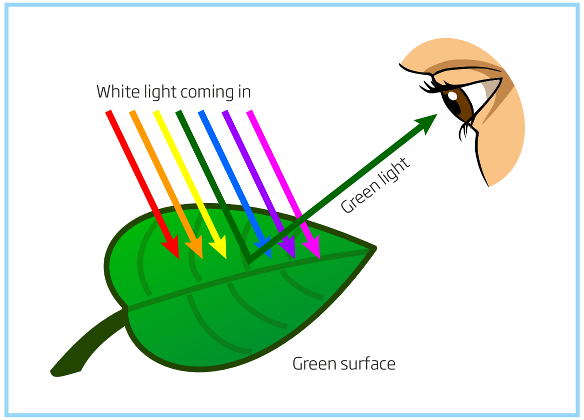
Now try replacing the blue dye with milk and shine your torch again.
What do you notice? And now which behaviour is happening?

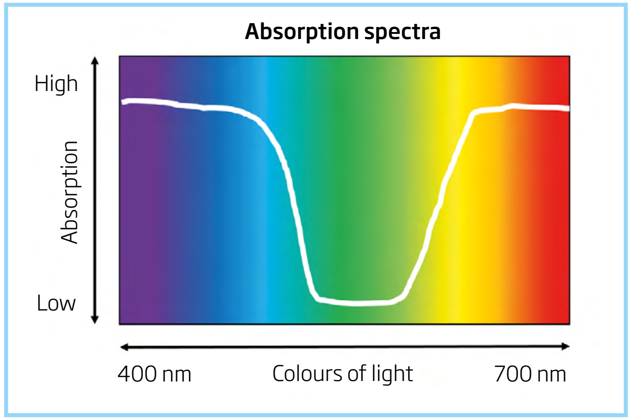
Absorption spectra

The **absorption spectra** measures the amount of light energy when it interacts with an object. The object in this case is a leaf from a tree.

Time to think

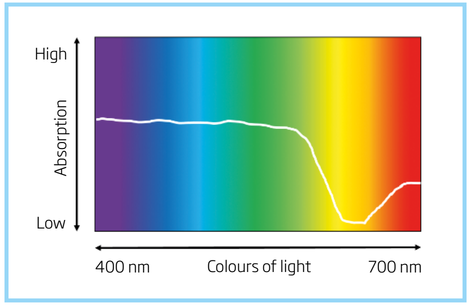
What do you notice about the green light the eye can see and the line on the absorption spectra graph?

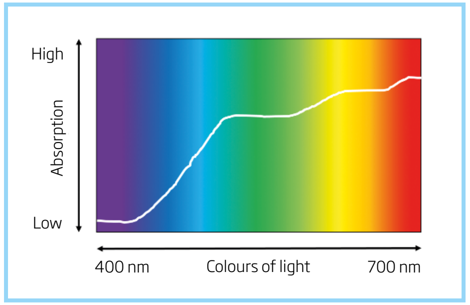


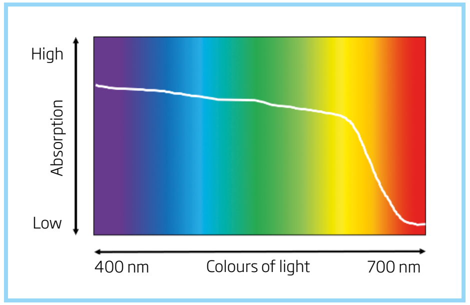


Time to calculate

Match the objects below to the correct absorption spectra graph.

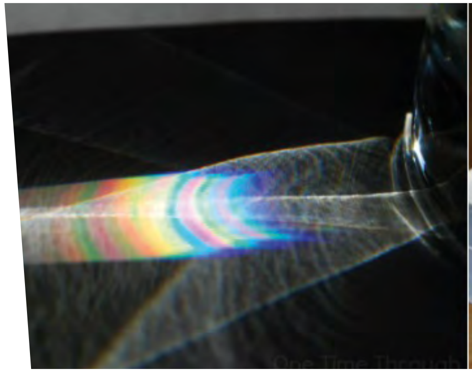


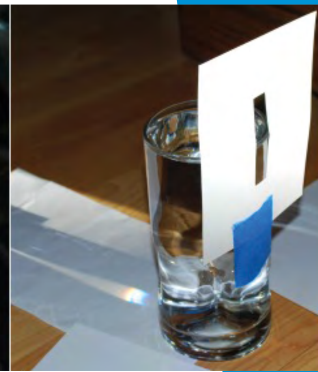




Making rainbows with a glass of water

When light goes through a glass of water – it also splits into a rainbow.





Time to investigate

To prepare take a piece of paper and cut a slot into the middle of it.

Tape this onto the side of a smooth/clear drinking glass so that the Sun's rays can pass through the opening onto the surface of the water in the glass.

You will need to do this on a very sunny day – or try a darkened room with a strong direct light source.

Make sure that the glass of water is full. Place the glass on a white floor or white piece of paper, making sure the Sun's rays are shining through the slot in your paper and hitting the surface of the water.

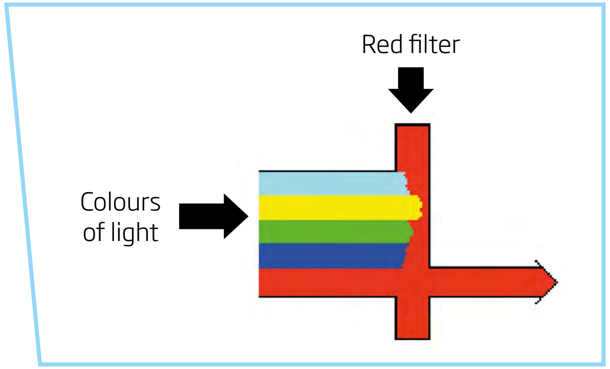
You should see a mini-rainbow appear below the glass!

Time to think

What is happening here? Why are we seeing the colours of a rainbow?

The Gummy Bear Challenge

We know that white light passes through transparent objects such as a window. However, when a red filter is placed over a light source, all the colours will be absorbed except the red. *See illustration*.



Therefore a light shined on a white gummy bear passes through, but only the red light will pass through a red gummy bear.

Time to think

What do you think will happen when a red light is shined on a green gummy bear? And what do you think happens when a green light is shined through a red gummy bear?

Time to investigate

Record your predictions and actual results on the data chart.

Equipment

- Different coloured gummy bears
- A torch
- Different coloured acetate paper – a sweet wrapper will do
- A dark room

Put different coloured gummy bears out on a table in a line. Cover the torch with a sheet of red acetate. You could hold it in place with an elastic band.

Turn the lights off and shine the torch on the line of gummy bears. What colours do they turn?

Repeat the experiment but cover the torch with green acetate this time.

What do you notice about the colours of the gummy bears and the colour acetate you are using?

Handy hint: think in terms of reflection and absorption.

	Clear Gummy Bear	Red Gummy Bear	Green Gummy Bear
Red light	Prediction	Prediction	Prediction
	Result	Result	Result
Green light	Prediction	Prediction	Prediction
	Result	Result	Result

LIGHT AND THE BODY

We have used properties of electromagnetic waves for many years in medicine to take images of the structures inside your body.

Role of the radiologist

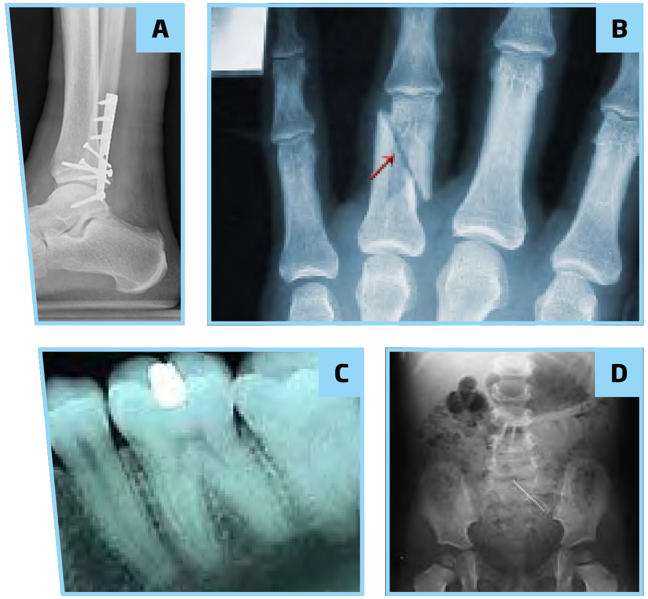
Look back at the diagram of the electromagnetic spectrum. Where do X-rays sit?

Their wavelengths are even shorter than visible light waves, measuring approximately 10 nanometres!

X-rays are absorbed by objects that have a higher density than our skin such as bones and metal.

A **radiologist** is a medical doctor who specialises in investigating and treating disease and injury using medical imaging techniques such as X-rays.

What observations can you make from these X-ray images?



Transmission through the body

Visible light waves can also be used to investigate and treat medical conditions. In the 'Behaviour of light' task, we learnt that if a light meets a transparent object, then the light will move through the object without being absorbed.

Some light waves will even travel through objects that are not transparent!

Shine a torch onto your fingers. What do you notice?

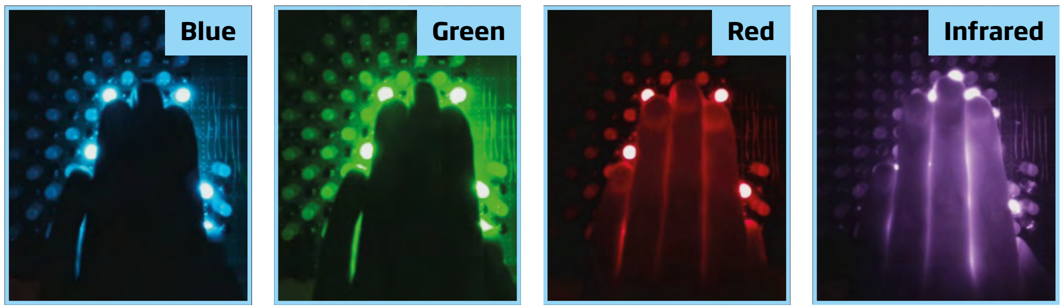
Time to think

Look at the images to see which colours of light travel through the hand and which don't. Why do some colours travel through the body?

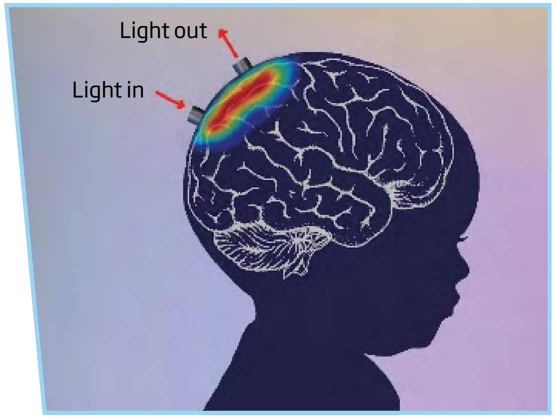
Test for yourself! You could use the acetate to change the colour of the light from the torch.

Notice that the red and the infrared light travels through the skin and the bone. This means that we can shine light through bone to investigate the colours beneath it in the body to find out what is going on inside.

Biomedical engineers used this property of light waves to develop a new technology that will monitor brain health in babies.



LIGHT AND THE BRAIN



I have a brainwave!

Red and **infrared** light waves can travel through the skull into the brain.

Biomedical engineers have developed a safe way of shining light through the brain and detecting it with a sensitive digital camera. This reveals detailed information about oxygen levels and blood supply, which could lead to vital and potentially life-saving information for doctors.

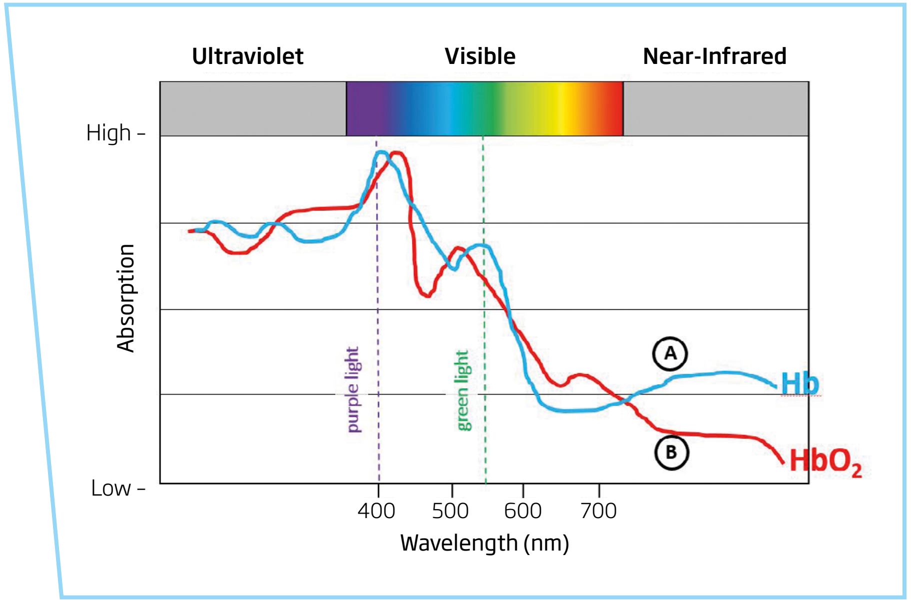
Biomedical engineers have been using the spectrum of colours to develop a new technology that monitors blood supply and oxygen levels in the brains of newborn babies.

Blood has many functions, one of which is carrying oxygen to all different areas within our body. The part of blood responsible for bonding with oxygen is known as **haemoglobin**.

Haemoglobin exists in two states.

Oxyhaemoglobin – carries oxygen and is bright red in colour.
Deoxyhaemoglobin – does not carry oxygen and is more purple in colour.

This is because of the absorption spectra of blood changes is dependent on the oxygen it is carrying:



Time to calculate

Look at the absorption spectra graph. It measures the amount of visible light energy absorbed in Oxyhaemoglobin (**HbO_2**) and Deoxyhaemoglobin (**Hb**) blood.

In the earlier absorption spectra task, the leaf absorbed all the colours of the spectrum except for green. Green reflected and this is the colour seen by the human eye.

Look at the absorption spectra graph.

Identify the green light (550 nm) dotted line. Which statement is correct?

- HbO_2 absorbs more green light than Hb
- Hb absorbs more green light than HbO_2
- Both HbO_2 and Hb absorb the same amount of green light

Now identify the purple light (400 nm) line. Which statement is correct?

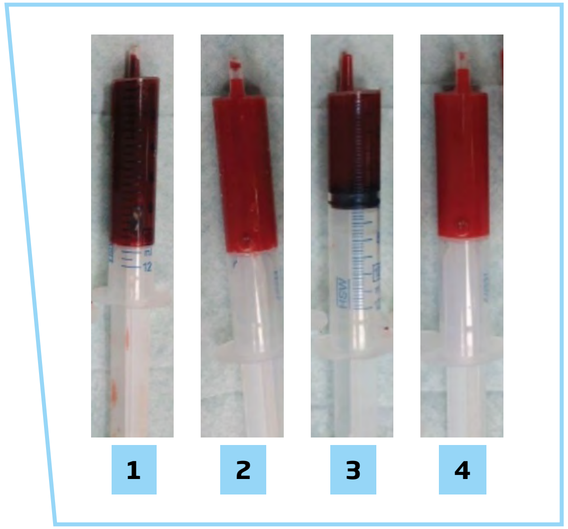
- HbO_2 absorbs more purple light than Hb
- Hb absorbs more purple light than HbO_2
- Both HbO_2 and Hb absorb the same amount of purple light

Now look at point A and B on the graph. Which of these statements is correct?

- HbO_2 absorbs less red light than Hb
- Hb absorbs less red light than HbO_2
- Both HbO_2 and Hb absorb the same amount of light at this wavelength

So, which blood type is redder in colour?

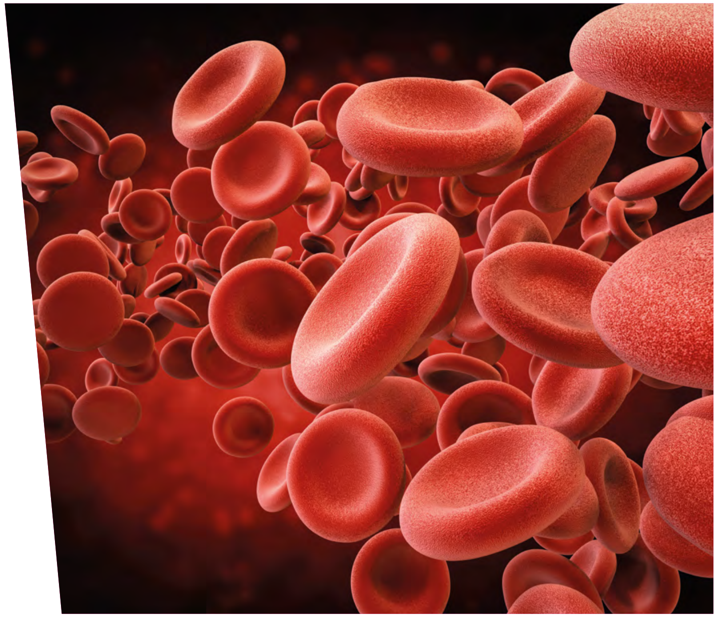
Why is blood red?



Time to investigate

Look at the colour of the blood in each syringe.

- Which one is filled with the least oxygenated blood?
- Which one is filled with the most oxygenated blood?



Time to think

The properties of the different light waves can help us measure the oxygen levels in the blood.

Why do you think blood that carries more oxygen is brighter in colour?

Handy hint: look at the absorption spectra of blood and think back to the absorption information spectra you learnt about before!

Using light to measure your oxygen levels

Doctors use a device called a **pulse oximeter** to measure heart rate and oxygen saturation, i.e. the amount of oxygen in the blood.

Two lights are used, usually red and **infrared** in colour, to measure the intensity of light that passes through the finger.

The red and infrared light waves react differently depending on the amount of oxygen in the blood.

This painless procedure allows doctors to check whether there is enough oxygen in the blood.

Time to calculate

Doctors need to measure the level of oxygen in a baby's blood to determine if it needs more medical treatment.

If oxygen levels are below 90%, the baby could be at risk.

Two babies' oxygenation levels have been measured. Determine which baby needs more medical treatment.

- **Baby A** has an oxyhaemoglobin count of 45 units and a deoxyhemoglobin count of 5 units.
- **Baby B** has an oxyhaemoglobin count of 36 units and a deoxyhaemoglobin count of 9 units.

Blood oxygenation is calculated as a percentage:

$$\frac{\text{Oxyhaemoglobin concentration}}{\text{Oxyhaemoglobin concentration} + \text{Deoxyhaemoglobin concentration}} \times 100\%$$

FINGER ON THE PULSE

When blood pumps through the blood vessels on a finger, the amount of light passing through it changes depending of the amount of blood. This helps us to find out a person's heart rate.

Time to calculate

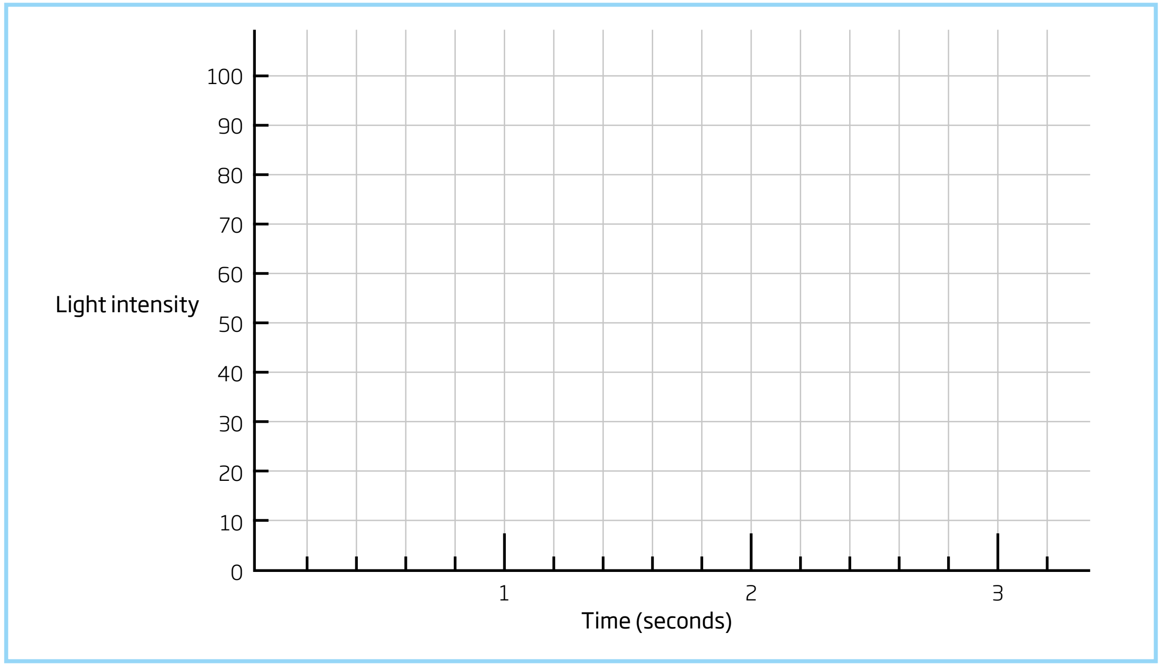
A pulse oximeter is clamped onto a patient's finger. Light shines through the finger and into a detector. The detector measures the light passing through the finger and reads five measurements per second, showing the following measurements:

20,51,90,43,10 22,53,89,42,11 21,56,95,41,10

Chart the measurements on the line graph and connect with a single continuous line.

When your heart beats it pushes more blood into your fingers so more light is absorbed, so the light intensity is lower.

- What pattern do you notice?
- What does this tell you about the patient's health?



Stretch and challenge

- What is the patient's heart rate per minute?

Measure your pulse

Engineers and scientists work together to develop technology to provide the health service with the tools it needs to save lives. Remember Engineering Habits of Mind (EHOM). This includes apps on a mobile phone.

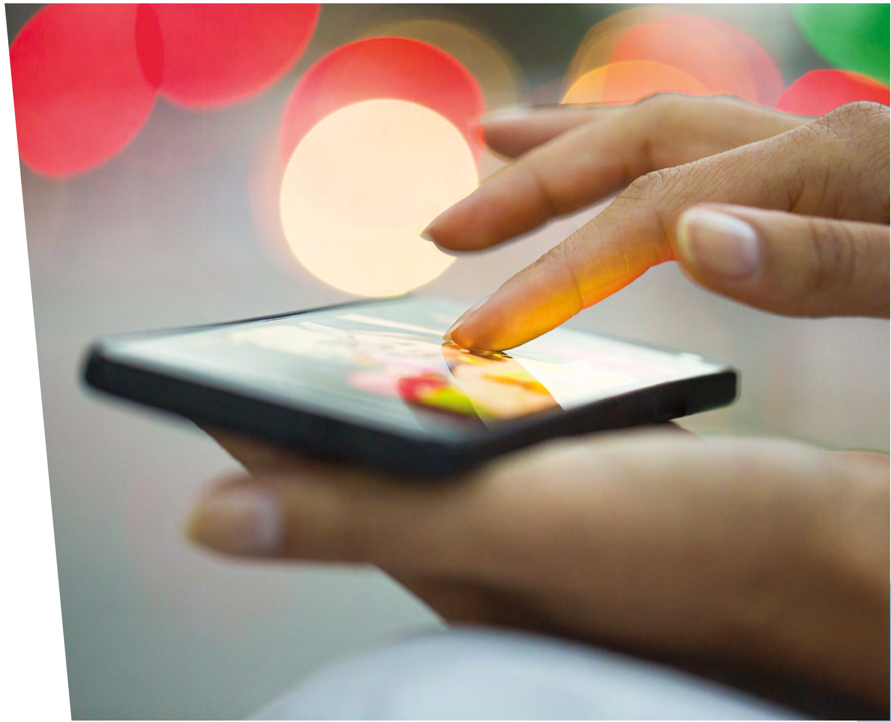
Use the torch and camera on a phone to measure your heart rate. You will need to ask permission from an adult to download one of the free apps.

1. Download one of the free apps for android or iPhone

   Android
   Accurate Heart Rate Monitor

   iPhone
   Cardiio: Heart Rate Monitor

2. Opening the app should turn the torch on. Put your finger on the torch and you should find that red light transmits through your finger.
3. Cover the light and camera with the same finger. The app should start detecting your heart rate and display this on your screen as Beats per Minute (BPM).



Time to investigate

In pairs or small groups, measure your heart rate while you are sitting.

Then do 20 star jumps.

Now measure your heart rate again. What happens? Compare with your friends and record your findings in a table.

Name	Sitting heart rate (bpm)	Heart rate after star jumps (bpm)

NOTES

Royal Academy of Engineering

As the UK's national academy for engineering and technology, we bring together the most successful and talented engineers from academia and business – our Fellows – to advance and promote excellence in engineering for the benefit of society.

We harness their experience and expertise to provide independent advice to government, to deliver programmes that help exceptional engineering researchers and innovators realise their potential, to engage the public with engineering and to provide leadership for the profession.

We have three strategic priorities:

- Make the UK the leading nation for engineering innovation and businesses
- Address the engineering skills and diversity challenge
- Position engineering at the heart of society

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