TEACHER PACK

THE WORLD LOOKS DIFFERENT AT DIFFERENT WAVELENGTHS

www.vision4thefuture.org

University of St Andrews

EPSRC
Engineering and Physical Sciences Research Council

FifeX

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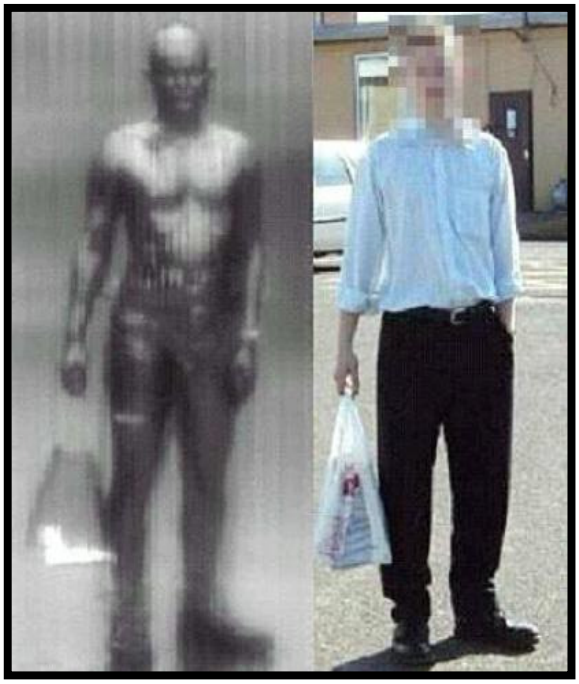
Introduction

What if you could see through terrorists' clothes to detect hidden weapons? Or look to see how a volcano is changing underneath all the cloud and smoke? Or land a plane safely on a fog-covered runway? Recent advances in millimetre wave imaging technology allow you to do just that.

But what are millimetre waves – they are just light! Light can be thought of as a wave: the different colours that you see in a rainbow correspond to different 'wavelengths'. Red light has a longer wavelength than blue light. The colours that we see are 'visible light' but there are lots of other wavelengths that we cannot see with our eyes ranging from very long radio waves to very short x-rays. Light at these different wavelengths have different properties and they are used in all sorts of different applications.

Millimetre waves are waves that have a wavelength between 1mm and 1cm. These waves have particularly interesting properties. They can pass through clouds like radio, TV and mobile phone signals but they can also form heat images like an infrared camera. This makes them useful for a whole range of applications, which are discussed later in this pack.

The variety of applications makes millimetre waves ideal for demonstrating to pupils the importance of the science in their everyday lives and this is what we aim to do as part of this outreach project.



QinetiQ Security Imaging

what can we offer?

Our workshop is pitched at a level for primary 6 and 7 and secondary 1 and 2 years. We have a wide variety of interactive teaching materials available depending on the size of the group and room. The workshop includes a short presentation with lots of videos and pictures demonstrating applications like car radar and seeing through clothes for security imaging. Then the class will be split into 4 smaller groups each with a demonstrator to lead them through interactive hands on experiments. These 4 workshops are entitled:

- **Seeing through stuff**
- **Picture Perfect**
- **Cops and Doppler**
- **Radar in a room**

The learning outcomes of each workshop and content are detailed later in this pack. The pupils are encouraged to nominate a speaker to tell the rest of the class what they found out from the workshop. There are also worksheets with a few simple questions on that each group should be able to fill in on the particular workshop they did. This encourages them to recap what exactly they have learned.

We also have a few surprises up our sleeves including an infra-red camera which allows pupils to see a heat map of their bodies. There are some easy experiments that they can all try in front of it which highlights some important concepts about light.

For a group of 30 to 40 pupils the workshop can be anywhere between 1 and 2 hours depending on your time restrictions. There is also an experiment that can be done at home.

IR Camera

Dav demonstrating to a group of boys

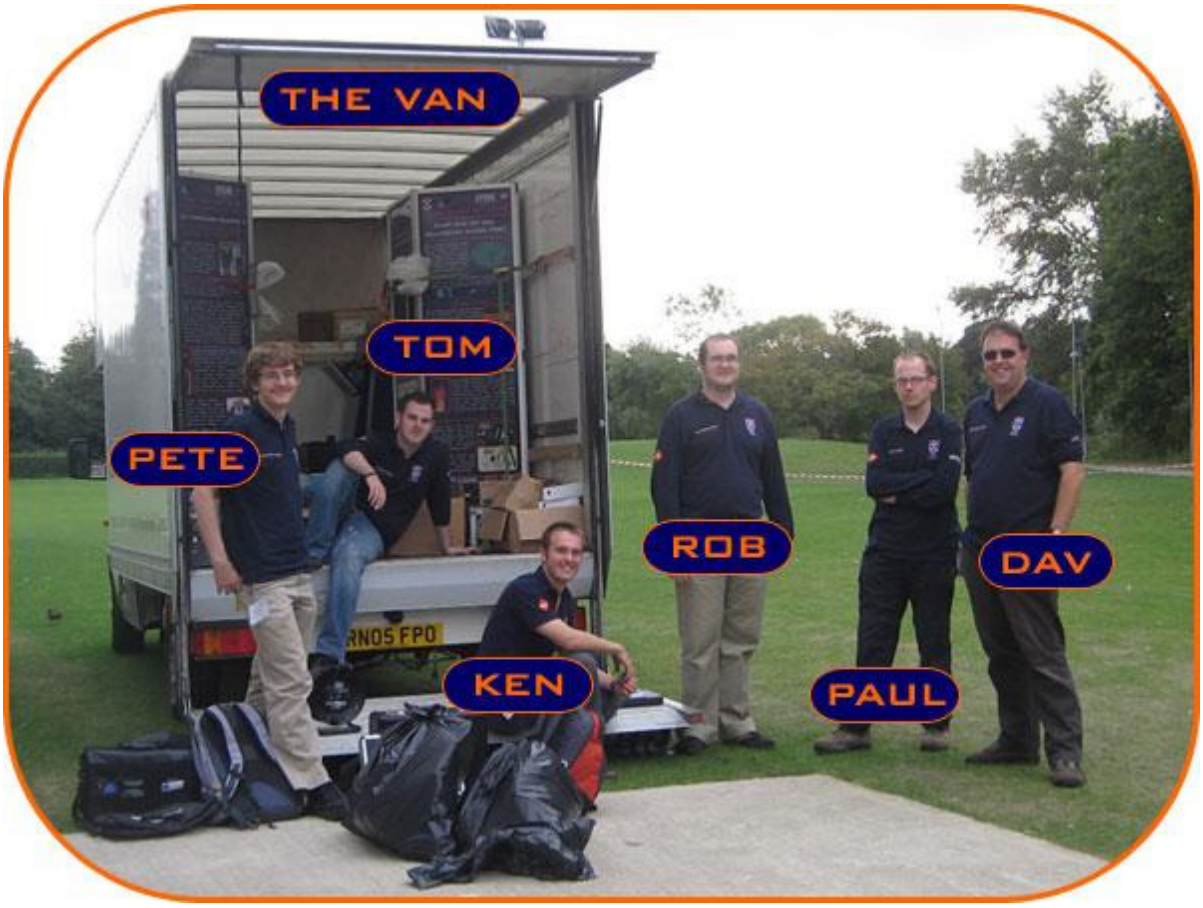
Girl and father

About Us

We are a group from the University of St Andrews Physics Department who research millimetre waves. In 2007 we started working on a public outreach project which aims to educate the world about millimetre waves, what they are and why they are interesting. There are many exciting applications of millimetre waves that we thought it was about time we told people about them.

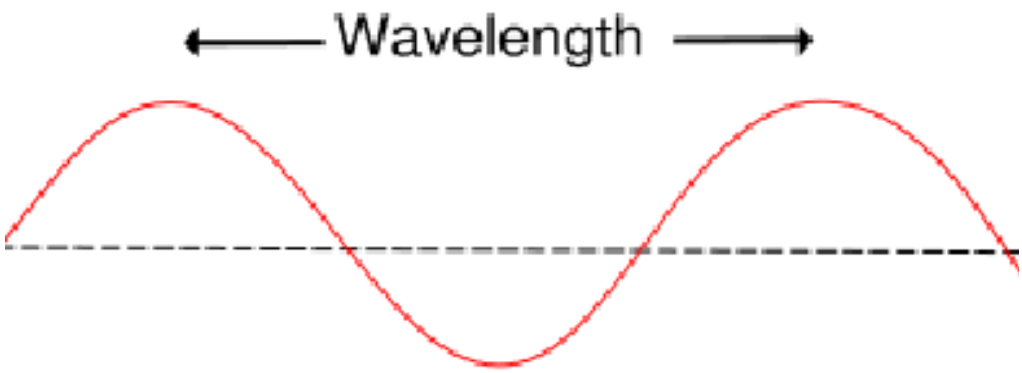
Under an EPSRC (Engineering and Physical Sciences Research Council) Partnership for Public Engagement Grant, we have teamed up with award-winning exhibit development company FifeX to put together a touring exhibition designed to showcase the alternative view of the world provided by millimetre waves. The project team is mainly made up of postdoc and PhD students as well as a number of enthusiastic undergraduate students. The range in experience offers an excellent resource of knowledge and enthusiasm for science which gives pupils a unique opportunity to ask questions and learn from scientists working on the cutting edge.

So far the project has had a great response from the public at science festivals and schools we have attended. We are constantly looking to improve our show so if you have any comments then please get in touch – contact details are at the end of this pack.

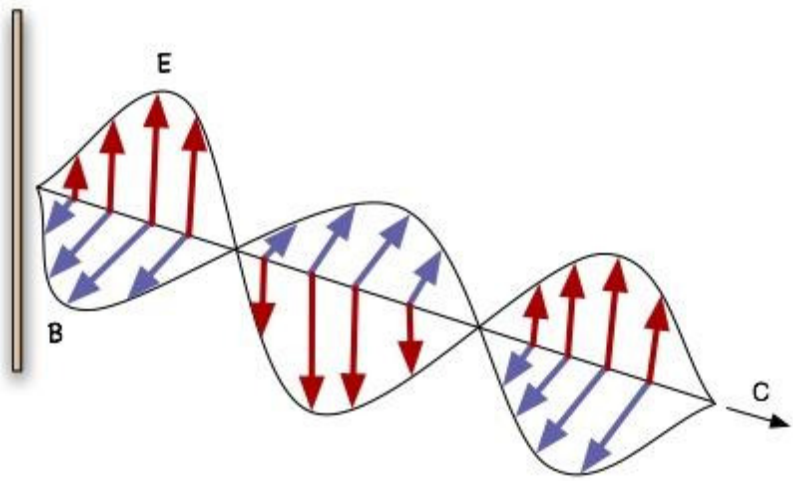


What is light?

'Light' another word for electromagnetic radiation. There are lots of different types of light but they can all be described by their wavelength, which is the distance between two peaks of a wave.

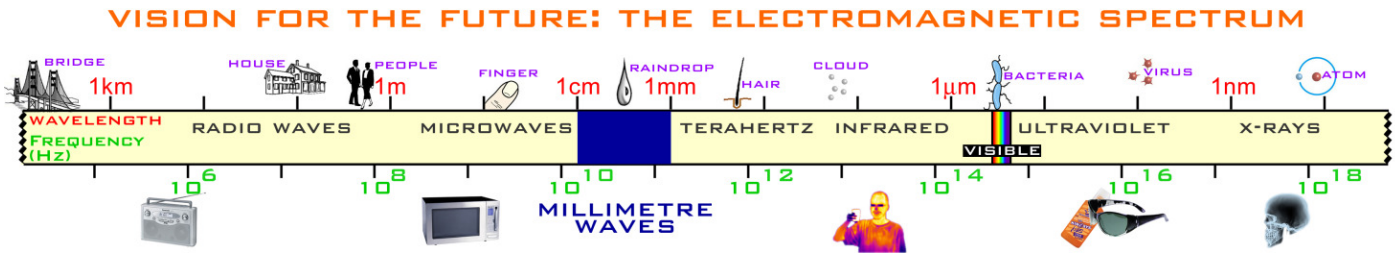


The name 'electromagnetic waves' comes from the fact that they have an electric part and a magnetic part and these are at right angles to each other.



E is the symbol for electric field, B is the symbol for magnetic field.

Electromagnetic waves with different wavelengths have different energies and thus can be used for different types of applications.



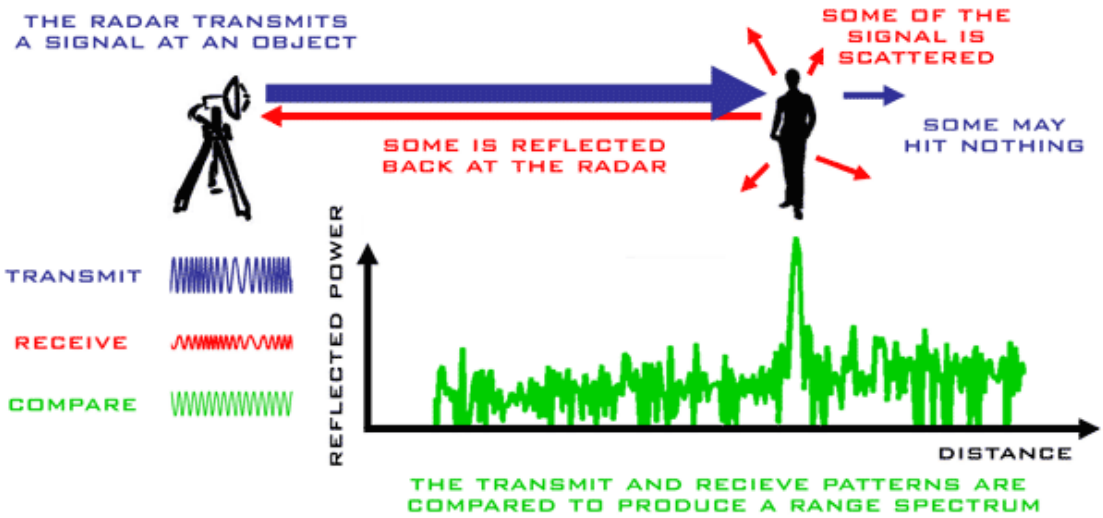
The picture above shows the electromagnetic spectrum with decreasing wavelength as we move from left to right, higher energy waves at the right and the low energy waves on the left. This scale also gives some examples of objects which are of the same size as the different types of waves, ie a raindrop is about 1mm in size as this is the wavelength of millimetre waves.

The longest light waves, which we are familiar with, are radio waves. These carry all the information for radio and television broadcasts. Another wave that most people have heard of is microwaves. This is the radiation which cooks our food in. Microwaves also carry mobile phone signals. Infrared (IR) is the wavelength range of heat radiation. An IR camera records the temperature of an environment. The wavelengths next to infrared are the visual wavelengths. As you can see they make up a very small part of the EM spectrum as a whole and yet we often only associate 'light' with these few. The different colours of light which our eyes can distinguish are the range of wavelengths which we can see. Red is the longest visible wavelength which we can see with the naked eye, longer wavelengths then moving into the IR (heat). Blue/purple lies at the other extreme, being the shortest wavelengths we can see, before moving into the ultraviolet. Green lies at the centre of our visual range. The ultraviolet wavelengths are the invisible type of radiation which comes from the sun which can burn our skin. Plants also need this kind of light to grow. The really short wavelengths are waves such as X-rays and because of their high energy can be very damaging.

All of these waves are forms of light - they differ only by their wavelength.

Radar

Radar is an application of electromagnetic waves which utilises many of the different wave types in the spectrum. Radar is a form of active imaging. Active imaging means that waves are emitted from the imager and then the waves are reflected back from the surrounding environment are recorded. The information from the reflected waves can give details about a large area or specific objects. Parameters such as distance, velocity, direction, density and size of an object in relation to its surroundings can be determined using radar. The wavelength of light used in the radar depends on the surroundings. It makes a difference whether it is outdoors or indoors and whether the atmosphere is clear or obscured by particles. The wavelength of the radar waves are chosen depending on the nature of the information we wish to acquire about the target and in how much detail. Longer and shorter wavelengths have different advantages and disadvantages. Longer wavelengths can image through many types of materials that may be obscuring the line of sight, like cloud, smoke or dust and they can image at much greater distances. However, shorter wavelengths will provide a much sharper image of the target, acquiring more accurate information but may not see through such atmospheric effects.



Radar works on the very simple principle of sending out a beam of waves and recording how much are reflected back and how long it takes for them to reach the receiver. This is directly analogous to an echo of a sound wave. The sound wave is produced and travels along a path, if it comes in contact with a solid surface it will reflect back towards its place of origin. An even simpler analogy is a ball being bounced against a wall. This is exactly what the waves from the radar do. The emitter and receiver are located at the same place, the waves are sent out and the radar waits to capture those that are reflected back.

Demonstrations

There are 4 interactive workshops are entitled:

- **Seeing through stuff** – Investigates how different wavelengths pass through various materials in different ways, illustrated by a comparison between visible, infrared and millimetre waves.

- **Picture Perfect?** - What is 'resolution' and how does it affect imaging? Explore the relationship between wavelength and resolution. What are the key factors that influence whether an object can be detected, recognised or identified?

- **Cops and Doppler** – Learn about the Doppler Effect and how it works. Hands-on demonstration of Doppler speed sensors and game to see who can go the fastest. Understand how the Doppler Effect is used in Police radar speed guns.

- **Radar in a room** – See a real-time radar map of the room and identify themselves and other objects in the image. Watch how radars can track movement. The internals of the radar as visible.

Demonstrations – Seeing through stuff

The demo is designed to increase awareness that different types of light can see through different materials. The physical concept behind this is transmission and absorption of light and is a relatively complex topic.

The **'Seeing through Stuff'** learning outcomes are:

- Able to draw a wave and indicate the wavelength.
- Realisation that some wavelengths can see through things that we cannot see through like clothes and wood.
- Appreciation of the applications of different wavelengths being about to see through stuff.

The workshop consists of 3 sets of wave emitters and receivers at visible wavelengths, millimetre wavelengths and infrared wavelengths. The pupils will have the chance to try putting different materials, like plastic, wood, materials and paper, between the emitter and receiver and find out whether that wave can see through the material.

BACKGROUND INFORMATION

Different wavelengths of electromagnetic radiation have different energies. Certain ranges of these energies cause things to happen to the structure of the particles in the material, which causes the radiation to be absorbed. This means that some wavelengths can pass straight though a material, while others can't. The exact position of these energy ranges in the spectrum is dependent on the particles that make up the material.

Transmission

When an electromagnetic wave strikes an atom or molecule, it will cause some part of this atom or molecule to oscillate. Which aspect depends on the wavelength of the electromagnetic wave. In most cases, the system will become an oscillating dipole, and will immediately re-radiate the electromagnetic wave at the same wavelength. The direction in which the wave is radiated is essentially random.

Absorption

However, in some small ranges of wavelengths, these will approach (and reach) a resonance, and the interaction will occur more strongly. At these resonances, the energy of the photons is absorbed by the atom or molecule. In the cases of near visible light wavelengths, this involves the promotion of outer electrons to upper energy levels. For other wavelengths, the mechanism involved in the absorption varies and not all of these mechanisms exist in all materials.

This energy must still be dissipated in some way by the atom or molecule that absorbed it. In the case of an isolated atom, it would eventually be re-radiated, possibly at the same wavelength, or possibly as a series of photons at different wavelengths. In the case of solids, liquids and dense gases, the energy will generally be dissipated as heat, through interactions between the molecules or atoms, before it has a change to be reradiated. When a material has no such resonances in the visible part of the spectrum, it will appear transparent.

Demonstrations – Picture perfect

'Picture Perfect' is a demonstration all about pixels and resolution which are important concepts for imaging in all wavelength regions including the visible – you will probably have heard of the term megapixel in relation to digital cameras.

The **'Picture Perfect'** learning outcomes are:

- Able to draw a wave and indicate the wavelength.
- Understand the term 'Picture Elements' or pixels as being the smallest single 'dots' within an image. The size of the pixels relative to the overall size of the image defines the image resolution. The bigger the pixels relative to the overall image size, the lower the resolution.
- Understand the term resolution. Resolution is actually defined in angular terms, so the further away a target is, the bigger the pixels will be at the plane of view since the rays will have diverged.
- Realisation that wavelength limits ultimate resolution.
- Understand that as well as the wavelength, other factors that can limit the resolution are the size and density of the sensors (such as in a digital camera, that is what the number of MegaPixels means), the quality and size of the optical elements and also atmospheric effects such as turbulence and bad weather.
- Observe the effects of resolution on image recognition

There are two main hands on demonstrations that pupils can play and learn with. The first is a set of pin boards with different sized pins. Small pins represent short wavelengths and large pins represent long wavelengths. By trying to imprint various shapes on the differing pin boards they will realise that the smaller pins give a better outline of the shape. This leads to the idea that smaller wavelengths give a better image.

The second demonstration highlights the effect of resolution on image recognition. The pupils will look at a variety of objects in increasing resolution and try and guess what the objects are as the image quality improves. 15 laminated images at increasing resolution are shown to demonstrate this. The first image of a table with objects on it has a pixel size of 1m x 1m so they will not see anything. As the resolution increases in successive images the effective pixel sizes goes down. As the resolution increases, the pupils see more objects appear and realise that some blobs contain several smaller objects close together. Gradually it will become clear what each object is.

To further illustrate this, they play with computer demos and games with the gradually resolving images and the webcam that pixelates the images it takes. With the resolving images, get pupils to guess what objects might be.

Pupils will find some images easier than others. An important point is the relevance when considering security imaging. How many pixels do you need to know if that is a gun or a hairdryer? Is that a pen or a knife?

Demonstrations – Cops and Doppler

The Doppler effect, first proposed in 1842 by Austrian Mathematician and physicist Christian Andreas Doppler, is the phenomenon of a change in wavelength as experienced from an observer moving relative to the source. Depending on the relative motion of the source to the observer, I.e. towards or away, will dictate the change in wavelength. If the source is approaching the observer, then the wavelengths will be "squashed" together, and the observer will experience a smaller wavelength that is emitted. If the source moves away relative to the source, the wavelengths are "stretched" out, and the observer experiences a larger wavelength than is emitted.

The **'Cops and Doppler'** learning outcomes are:

- Moving objects affect the way waves travel
- Light and sound waves have similar properties
- Light waves can be used to measure distances and velocities
- The change in wavelength is dependent on the original emitted wave – the smaller the wavelength the bigger the Doppler shift. This is the reason why millimetre waves are important
- Millimetre waves are useful for detecting motion

The **'Cops and Doppler'** workshop set up consists of three different millimetre wave emitters with different wavelengths in the millimetre range. There is a box that processes the wavelength shift and this is fed into a computer which allows you to see the change. It is also fed into a speaker so that the change can be heard as sound. The Doppler boxes can measure speed so the pupils can play a game to see who can move the fastest.

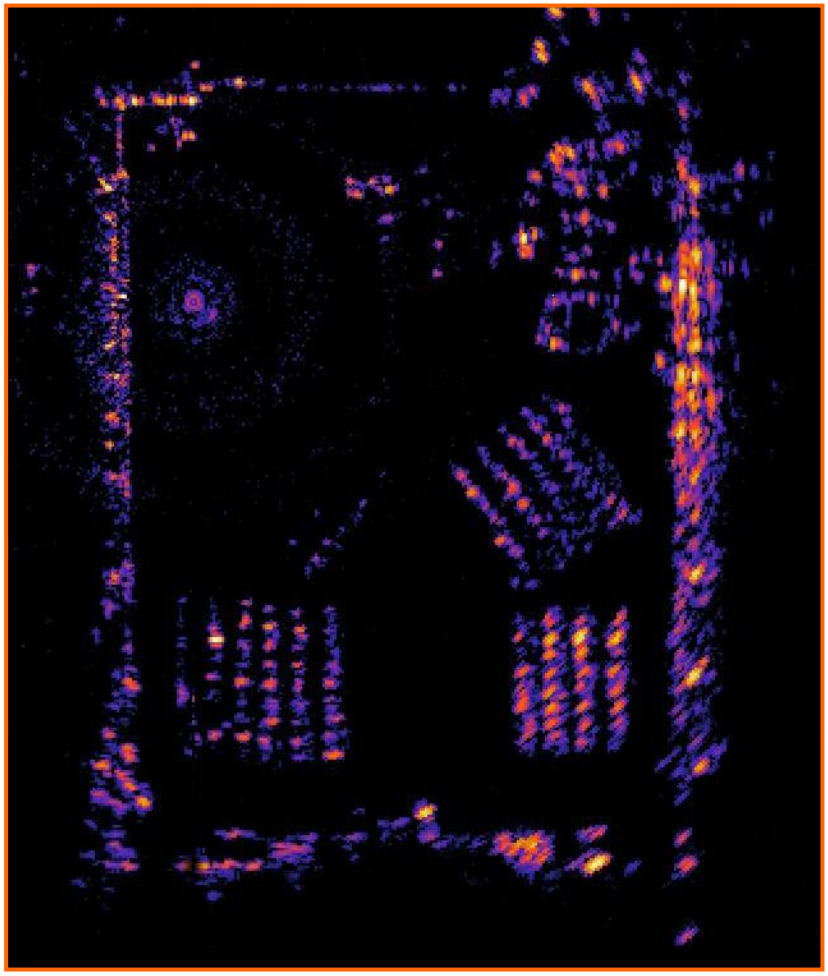
Screenshot of the Doppler Game

Demonstrations – Radar in a room

With a purpose built radar pupils will see a real-time image of themselves and the room taken with the radar. They will have the change to identify objects in the image and track themselves as they move around (much like Harry Potter's Marauders Map). With the tracking on they can spell out letters and simple pictures by moving about the room.

The **'Radar in a Room'** learning outcomes are:

- Reinforce the concept that there are many types of light with which to make an image and view your surroundings
- Viewing an environment with different light wavelengths will produce very different images
- Some advantages and disadvantages of using other wavelengths of light
- How a radar forms an image by sending out waves



A radar scan of Montrose Academy School Hall
Note the rows of chairs ready for assembly

Demonstrations – IR Camera

The world appears quite different when you look at it with wavelengths of light beyond the 'visible' part of the spectrum which we see with our eyes. To do this requires cameras which collects the non-visible wavelengths turning them into pictures which we can see

The IR (infrared) camera shows a heat map of the body. At the end of the presentation, pupils will have the chance to stand in front of the camera and do a series of short experiments that demonstrate a variety of physics concepts.

The first thing to note in the photo below is the temperature scale on the right. Black is cold and white is hot. You can see that the glasses appear dark on the image. This is because they are cold (as they are made of glass) and they are at the same temperature as the room. Also her hair is hotter at the top than at the bottom as so the top is a lighter shade than the bottom. This is due to the top parts of her hair being heated by her head whereas the bottom parts are nearer room temperature. The face and hands are the hottest parts of the body and they appear white in the IR camera's image. IR cannot see through clothes (unlike millimetre waves) so the temperature of her shirt is the temperature of the material itself rather than her body.

The first experiment is to press your own hand against your shirt. Your hand is hotter than your shirt so it will heat the material. After holding it there for a few seconds when the hand is taken away there is a heat handprint left of the shirt where the material was heated. After a few seconds the handprint disappears as the shirt cools back down to its original temperature.

When shoes are removed and pupils walk around, they leave a heat print of their feet on the floor. This shows the same phenomena as the heat handprint.

When a balloon is held in front of the IR camera, it can see straight through the balloon. However if water is sprayed on the balloon then it becomes opaque. This is because IR light cannot see through water even if we (with our visible light tuned eyes) can.

Worksheets

At the end of the workshop pupils are encouraged to do a short question sheet to consolidate what they have learned. There is a different worksheet for each workshop. Below the 4 worksheets have been provided with and without answers.

Question Worksheets

- Seeing Through Stuff
- Picture Perfect?
- Cops and Doppler
- Radar in a Room

Answers

- Seeing Through Stuff
- Picture Perfect?
- Cops and Doppler
- Radar in a Room

MM-Waves: Vision for the Future

Questions Worksheet for

Seeing Through Stuff

Group:

Now that you have had a short demonstration on mm waves, here are a few questions for you to answer as you get to play with the Transmission Boxes.

Draw a simple picture of a wave and show the wavelength.

Can you suggest the best kind of light to see the following?

Looking for a missing person at night? _____

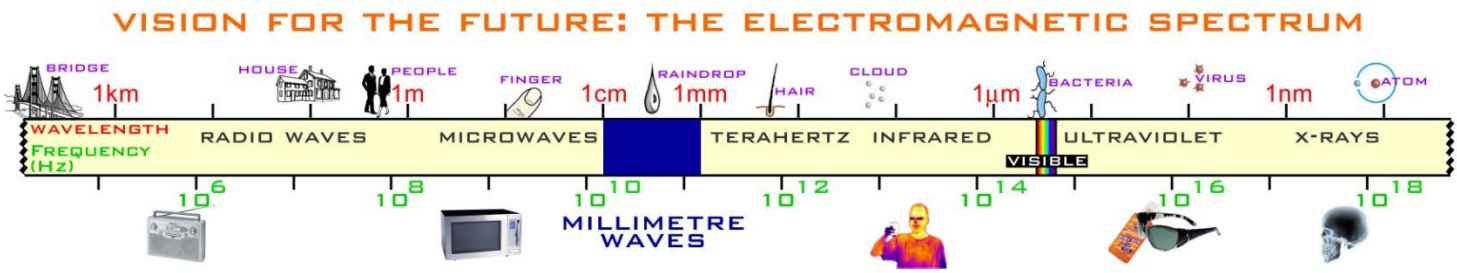
Mapping an erupting volcano? _____

Looking for hidden weapons on a terrorist? _____

Seeing fish in a pond? _____

Out of the different types of waves you have tried, which can see through the most materials?

_____



MM-Waves: Vision for the Future

MM-Waves: Vision for the Future

Questions Worksheet for

Picture Perfect?

Group:

Now that you have had a short demonstration about resolution, here are a few questions for you to answer as you work with the experiments.

Draw a simple picture of a wave and show the wavelength.

Do the big pixels or little pixels give a better shape of your hand?

_____

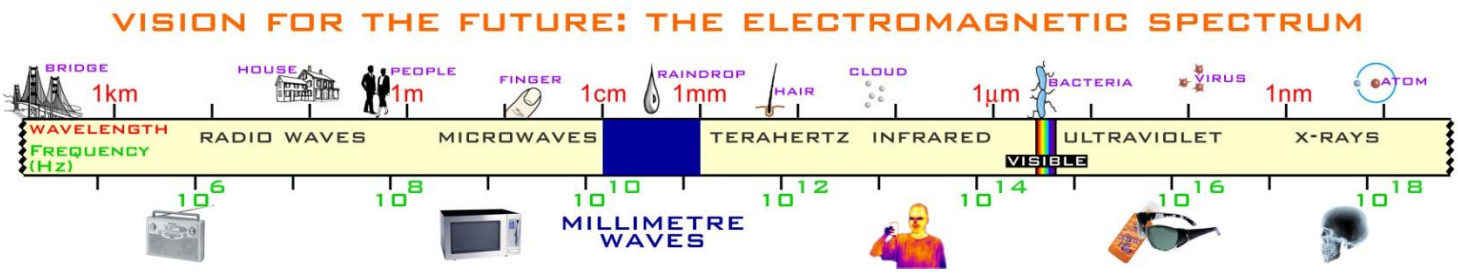
Put the following wavelengths of light in the order of increasing resolution:
1) X-ray machine 2) mm-wave radar 3) Digital camera 4) Infra-red camera 5) Radio telescope

_____ _____ _____ _____ _____

5 x 5 | 10 x 10 | 20 x 20 | 40 x 40 | 200 x 200

In the pictures above, which image do you think you can first recognise the object?

_____



MM-Waves: Vision for the Future

Questions Worksheet for

'Cops and Doppler

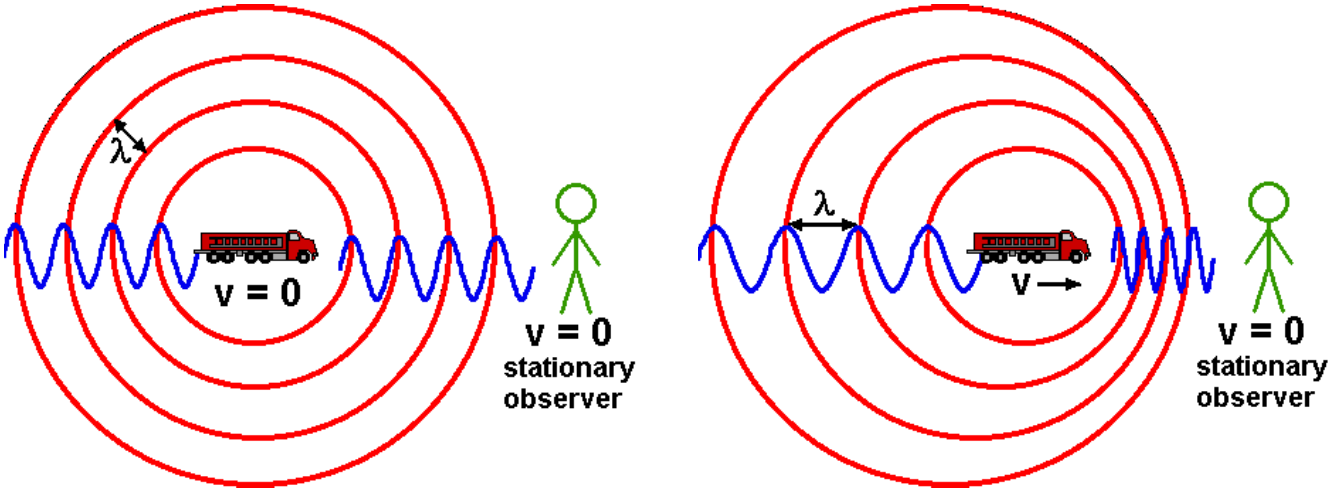
Group:

Now that you have had a short demonstration on mm waves, here are a few questions for you to answer as you get to play with the Doppler system.

Draw a simple picture of a wave and show the wavelength.

Can you think of an example of the Doppler effect you might see every day?

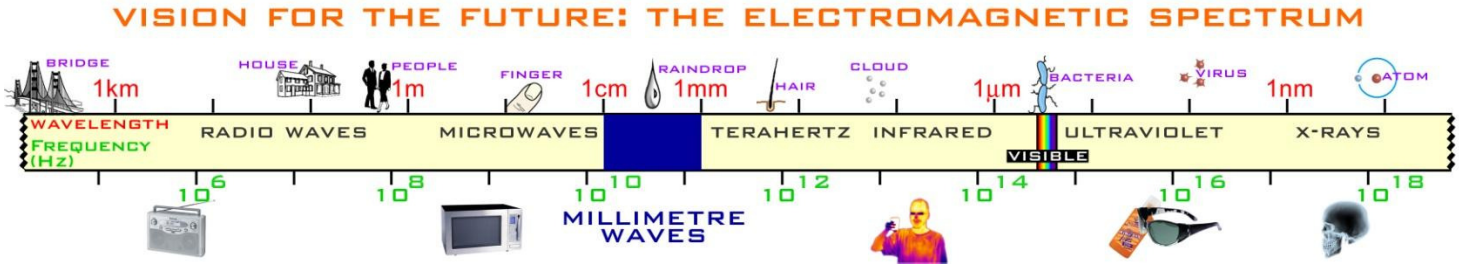
_____



The Doppler effect works with light and sound. When a car goes past you at high speed how does the sound change?

_____

_____



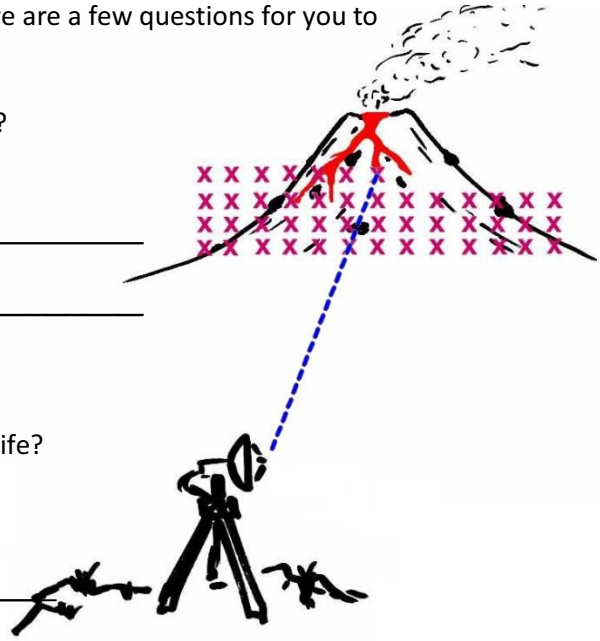
MM-Waves: Vision for the Future

Questions Worksheet for

'Radar in a Room'

Group:

Now that you have had a short demonstration on mm waves, here are a few questions for you to answer as you get to play with the SAFIRE radar



What does the term *"RADAR"* stand for and what can it measure?

_____

_____

Can you think of examples of where radars are used in everyday life?

_____

What advantages do mm-wave radars offer compared to conventional microwave radar systems?

_____

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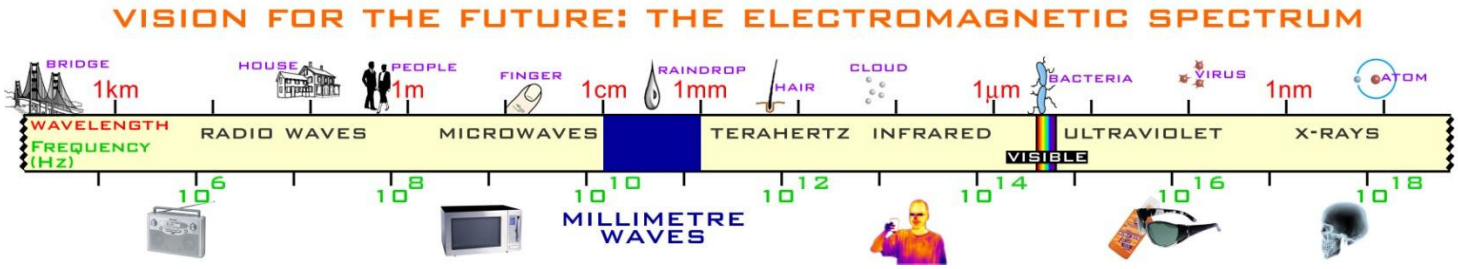
If they are better, why are they not used so often?

_____

_____



ANSWERS

Seeing Through Stuff

MILLIMETRE WAVES

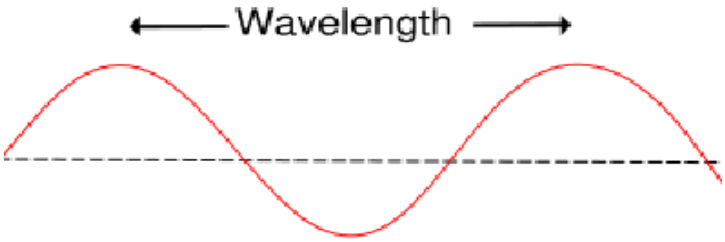
VISION FOR THE FUTURE

AN OUTREACH PROGRAMME FROM THE UNIVERSITY OF ST ANDREWS

Group:

Now that you have had a short demonstration on mm waves, here are a few questions for you to answer as you get to play with the Transmission Boxes.

Draw a simple picture of a wave and show the wavelength.



Can you suggest the best kind of light to see the following?

Looking for a missing person at night? Infra red

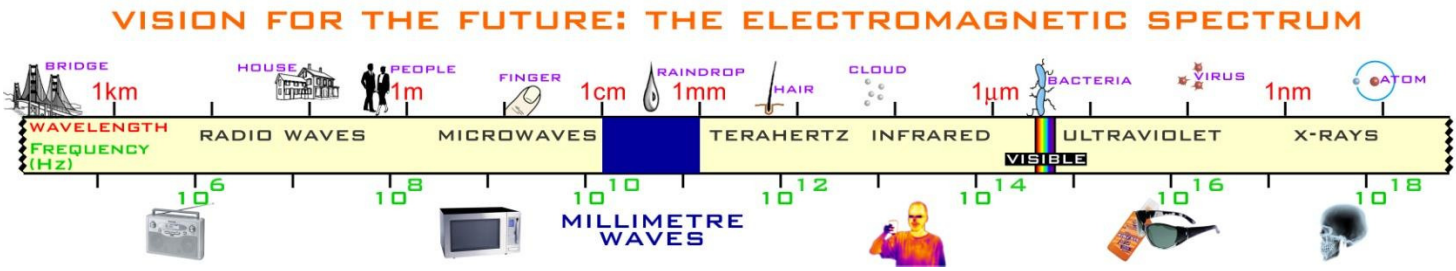
Mapping an erupting volcano? Millimetre waves

Looking for hidden weapons on a terrorist? Millimetre waves

Seeing fish in a pond? Visible light or microwaves

Out of the different types of waves you have tried, which can see through the most materials?

Millimetre waves



ANSWERS

Picture Perfect?

MILLIMETRE WAVES

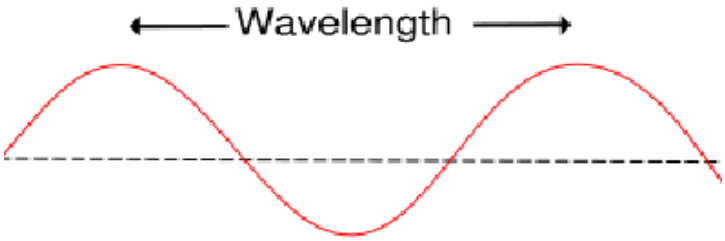
VISION FOR THE FUTURE

AN OUTREACH PROGRAMME FROM THE UNIVERSITY OF ST ANDREWS

Group:

Now that you have had a short demonstration about resolution, here are a few questions for you to answer as you work with the experiments.

Draw a simple picture of a wave and show the wavelength.



Do the big pixels or little pixels give a better shape of your hand?

___Little_____

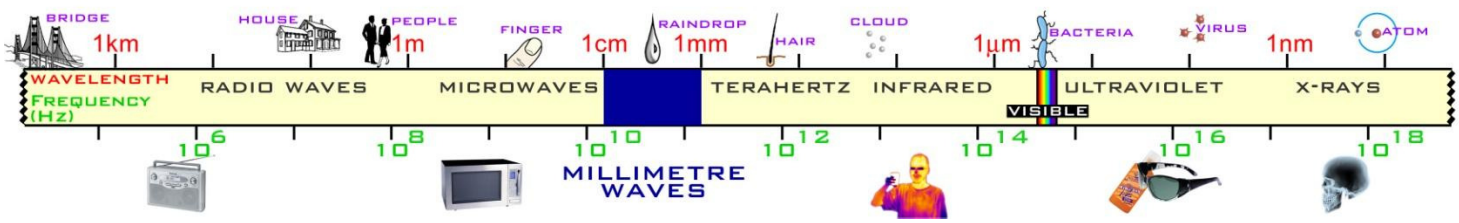
Put the following wavelengths of light in the order of increasing resolution:
1) X-ray machine 2) mm-wave radar 3) Digital camera 4) Infra-red camera 5) Radio telescope

__5____ ___4___ ___3____ ___2____ ___1___

5 x 5 10 x 10 20 x 20 40 x 40 200 x 200

In the pictures above, which image do you think you can first recognise the object?
____20x20 or 40x40_____

VISION FOR THE FUTURE: THE ELECTROMAGNETIC SPECTRUM



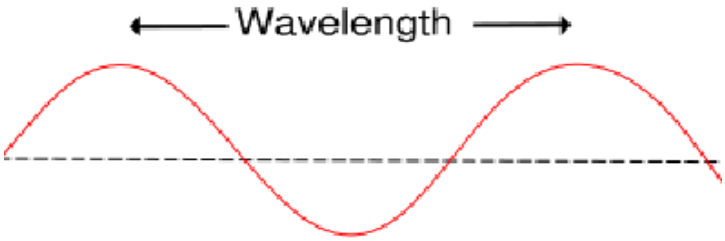
ANSWERS

Cops and Doppler

Group:

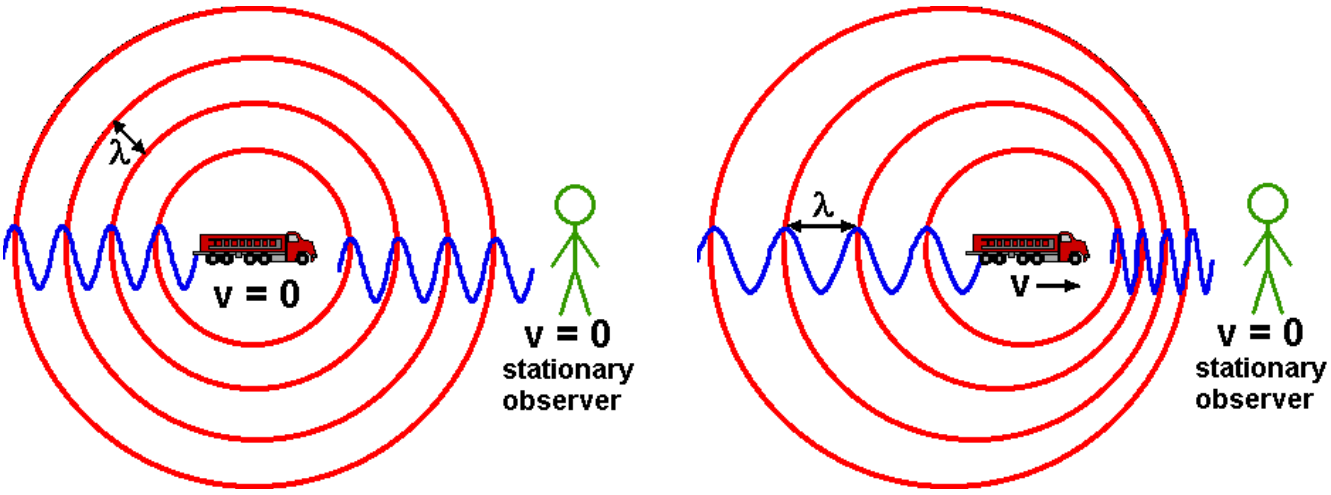
Now that you have had a short demonstration on mm waves, here are a few questions for you to answer as you get to play with the Doppler system.

Draw a simple picture of a wave and show the wavelength.



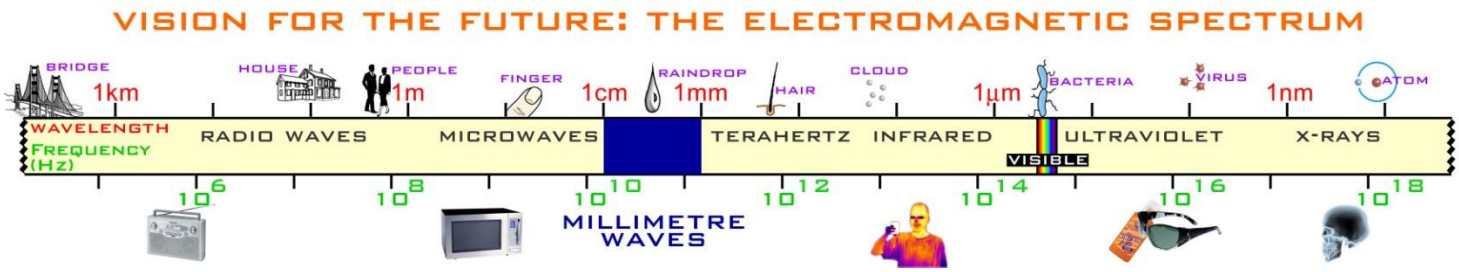
Can you think of an example of the Doppler Effect you might see every day?

When a car or ambulance goes past you at high speed you hear the Doppler effect as a lower pitch



The Doppler effect works with light and sound. When a car goes past you at high speed how does the sound change?

Before the car goes past it has a high pitch noise in comparison to when it has gone past it is lower.



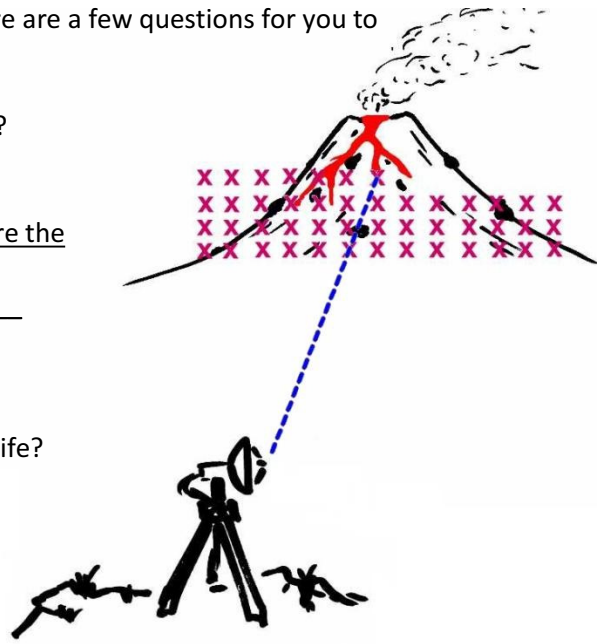
VISION FOR THE FUTURE
AN OUTREACH PROGRAMME FROM THE UNIVERSITY OF ST ANDREWS

ANSWERS

Radar in a Room

Group:

Now that you have had a short demonstration on mm waves, here are a few questions for you to answer as you get to play with the SAFIRE radar



What does the term *"RADAR"* stand for and what can it measure?

_RADAR stands for radio detection and ranging and it can measure the

Distance to an object, the speed it is moving at and the direction__

Can you think of examples of where radars are used in everyday life?

_____Car radars, radars in aircraft_____

What advantages do mm-wave radars offer compared to conventional microwave radar systems?

___As they have a shorter wavelength they can produce higher resolution images._____

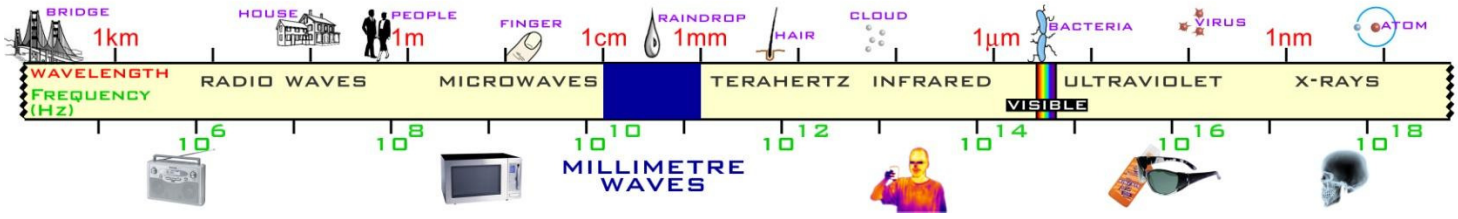
_____

If they are better, why are they not used so often?

___They are expensive!_____

_____

VISION FOR THE FUTURE: THE ELECTROMAGNETIC SPECTRUM



Measure the Speed of Light!

Einstein realised that the speed of light is a constant value in the Universe. Ever heard of $E=mc^2$? Well the **c** represents the speed of light. And you can measure it at home with a microwave, chocolate bar, ruler (and maybe a calculator).

Important!

Get an adult's permission before you try this at home. Also try not to make too much of a mess! Make sure there is no foil on the chocolate.

Experiment Time!

1. Remove the revolving tray from your microwave
2. Put your chocolate bar (we tried a Mars Bar) on a plate and put it in the microwave
3. Put the microwave on full power until it starts to melt. This will probably take about 30 seconds
4. Measure the distance between the melted spots with a ruler
5. Most microwaves have a frequency of 2.45 gigahertz (if you want you can check in the manual)
6. Multiply the distance between the spots on the chocolate bar by 2
7. If your distance is in cm then divide it by 100
8. Multiply this distance by 2,450,000,000 (that's 2.45 gigahertz expressed as hertz)
9. Be amazed when your result is so close to 299,792,458 metres per second – the speed of light

***Don't leave it in too long or it'll explode*!**

What actually happens?

Measuring the distance between the two melted points means that you can work out the wavelength of the microwaves. If you know the wavelength and the frequency then you can work out the speed at which the waves are travelling. The equation you are using is $c = f\lambda$ where c is the speed of light, f is the frequency and λ is the wavelength.

The chocolate bar stays still in the microwave and the waves keep hitting it in the same places and these are the bits that get hot and melt. The distance between the melted bits is half of a wavelength because the microwave passes through the bar both on its way back and forth. Multiplying the distance that you measure by two gives the distance for a full wavelength.

Microwaves are part of the electromagnetic spectrum and they travel at the speed of light. The frequency of the waves is the number of waves that go past a point every second. This means that 2,450,000,000 waves pass through the chocolate bar per second!

Scientists spent 50 years trying to measure the speed of light and these days you can do it in your microwave. Incidentally, the cooking power of microwaves was first discovered when a scientists stood too close to a microwave experiment and the chocolate bar melted in his pocket.

Challenge – Seeing Through Stuff

On the left there are photos of a hand through air, glass and heavy material. Can you draw lines to match up the visible images with the IR and mm-wave images? Remember which waves can see through which materials.

Image 1

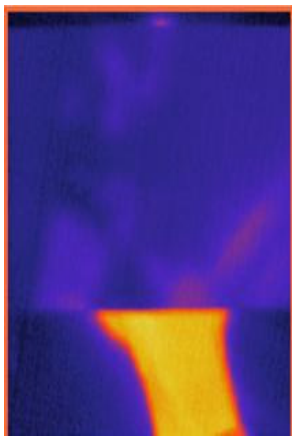


Image 2

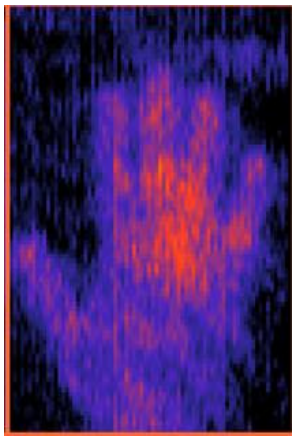


Image 3

Image 4

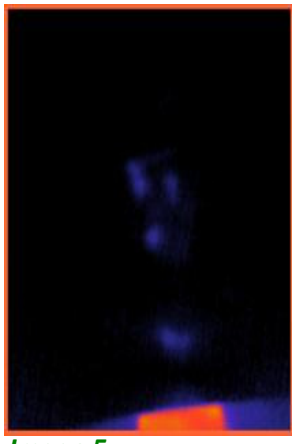


Image 5

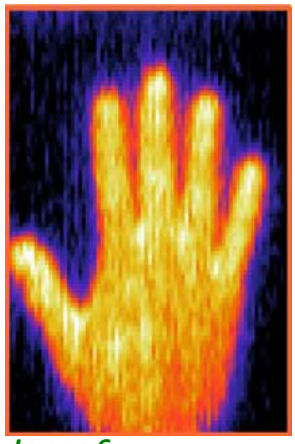


Image 6

Image 7

Image 8

Image 9

ANSWERS

Seeing through material	Visible	Infrared	Millimetre Wave
Air	Image 1	Image 8	Image 6
Glass	Image 4	Image 2	Image 4
Heavy Material	Image 7	Image 5	Image 9

Web Links

Here are some web links to fun science websites:
Null Hypothesis – **www.null-hypothesis.co.uk**
Light hearted science journal that likes to explore the fun and wacky side of science

BBC Science – **www.bbc.co.uk/schools/websites/4_11/site/science.shtml**
Science for primary schools

Planet Science - **www.planet-science.com**
Science experiments for kids

I Love Bacteria – **www.ilovebacteria.com**
Science experiments for kids

A link to Vision for the Future
http://www.vision4thefuture.org

A link to the Millimetre Wave Group's university website
http://www.st-andrews.ac.uk/~mmwave/mmwave/index.shtml

Contact Information

Exhibition details and event booking

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Website

Further information can be found on our website

http://www.vision4thefuture.org/