Square Kilometre Array

Level 6

Science

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Ministry of Economic Development
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New Zealand
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www.anzska.govt.nz

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Introduction

This resource has several student science activities reinforcing aspects of the 'big idea' in astronomy: that everything we know about the universe is from "messages" in the electromagnetic radiation we receive from beyond planet Earth.

The activities at this level are part of a series for Years 7–13 (up to Level 8). If your students had not experienced the earlier activities a selection of them would be a useful introduction to the 'big idea'.

The previous activities in this series included how common devices encode messages in light, exploring wavelengths of light, the properties and behaviour of waves, using radiation to measure temperature, colour temperature, etc.

The activities support the 'Nature of Science' and 'Physical World' sections of the Science curriculum as well as the 'Planet Earth and Beyond' section.

	Activity						
NZQA standard	*1*	*2*	*3*	*4*	*5*	*6*	*7*
90941			×		×		
90942	×	×	×	×	×		×
90943	×						
90946	×						×
90936	×	×	×	×	×		×
90937			×		×		
90938	×	×	×	×	×		×
90138						×	

The Level 6 student activities

These activities introduce several 'big ideas'.

1. Identifying metals by their radiation.
2. Radio transmission bands.
3. Detecting radio signals.
4. What affects your cell phone reception?
5. Polarisation of signals.
6. Random signals 1.
7. Direction finding.

Each of the activities varies in the time required, from about 45 minutes if equipment is ready to use, with students in groups of 3–4, to two or three times that.

Starting with the familiar

The intention is to use everyday examples to show some of the concepts of electromagnetic radiation that astronomers utilise to gain information about the universe. The strength of the linkage between these common examples and astronomy will depend on the particular objectives you may have in this area. While the concepts are not difficult, their practical realisation in astronomy can be complex and beyond the level of understanding required at this level.

An additional aspect is that activities are designed as much as possible to use simple, easily obtained and often cheap materials, so they could be carried out by students as individual or group projects.

As your time is limited, the teacher guide for each activity attempts to provide essential information. The 'extensions' section suggests topics for student project work, or for alternative group activities. References are given as URLs, mostly to Wikipedia as they are likely to remain available, to be updated, with diagrams often under the Wikimedia Commons licence so may be freely used.

Assessment

Assessment examples have not been included, although outcomes may be suggested.

Radio telescopes

This resource is part of the Square Kilometre Array (SKA) Project, the largest international science project so far attempted. It would consist of an extensive array of radio telescopes providing a total collecting area of about one square kilometre, hence the project name. Australia has been short-listed as a location and it would also involve New Zealand to give a 5,500 km baseline—the longer the baseline the higher the resolution. The sensitivity and resolution of this array would enable it to see further into the universe, almost as far back in time as when it was formed.

From an educational perspective, the SKA project provides a context for several curriculum areas at different levels. It may also be where some of your students could work in the future.

For details of the whole SKA project see:
http://www.skatelescope.org/

For the Australian and NZ part of it:
http://www.ska.gov.au/Pages/default.aspx

For the NZ part of the project see:
http://www.ska.ac.nz/news

For an overview:
http://en.wikipedia.org/wiki/Square_Kilometre_Array

Identifying Metals by their Radiation

This activity follows on from the Level 5 activity of using a spectroscope to analyse the structure of the light (emission spectra) from luminous objects. The concept of absorption spectra is not included. While most activities focus on the Physical world, this activity is in the Material world. The link is that we again utilise the big idea of "messages" encoded in light.

Rationale

When an atom is heated its electrons absorb energy, boosting them to more energetic orbitals. When these electrons return to their normal (or 'ground') state the energy is emitted as electromagnetic radiation. As each element has a unique pattern of electrons, the radiation emitted has a unique pattern for each element, in effect a unique radiation 'fingerprint'. A spectroscope enables the pattern to be clearly identified. In this way the elements in stars can be identified.

Only a few elements emit easily recognised light in the visible region of the electromagnetic spectrum when heated in a bunsen flame. These are generally Group I and Group II metals: e.g. lithium (carmine-red), sodium (bright yellow), potassium (pale lilac), rubidium (yellow-violet), caesium (blue), calcium (brick-red), strontium (crimson), barium (pale green / yellow-green), copper (green / blue-green). The chlorides of these metals are used for flame tests as they are the most volatile. Note that some colours are quite dim and a darkened room is required.

One problem with flame tests is that more than one metal is likely to be present, sodium especially. Sodium is a common contaminant and its intense yellow light can mask the colours of other metals present. If the flame tests are viewed though a CD spectroscope (or spectroscope spectacles) the colours are separated so can be more easily identified. While elements in various salts of these metals will emit their own distinctive radiation, it is not readily identifiable in the visible light region.

Although the flame test can detect very low concentrations of sodium due to the intensity of sodium's distinctive yellow colour, a manual test can not detect low concentrations of most other metals. An atomic emission spectrometer is sensitive and can provide the precise line spectra to identify the 'fingerprint' of specific elements at low concentrations. There are many applications of this technique, e.g. identifying environmental pollutants, poisons in body tissues, contaminants in water and food, etc.

You may wish to mention the concept of a line spectrum in contrast to a continuous spectrum. Sunlight has a continuous spectrum, easily seen through a diffraction grating or a piece of clear CD, where there are no gaps in the spectrum from longest to shortest visible wavelengths. A line spectrum is where only a few colours are present as lines of colour in the positions corresponding to their wavelengths in the continuous spectrum. It is the precise positions (wavelengths) of the lines on the electromagnetic spectrum (including UV, infrared and radio) that constitutes an element's 'fingerprint'.

Hydrogen is the most abundant element in the universe, followed by helium. Stars are mostly hydrogen, especially when young. The intense pressures and temperatures in stars causes the hydrogen atoms to fuse to give helium and radiant energy. Later in the life of a star the helium becomes the fuel, fusing into heavier elements, which in turn fuse together. Iron is the heaviest element formed in stars, heavier elements still are formed in super-novae. Astronomers identify the elements in stars from their emission spectra 'fingerprints'. Radio telescopes can identify interstellar hydrogen unable to be 'seen' any other way.

Choices of techniques

The student worksheet gives no instructions for a particular technique; these are below. There are several ways of carrying out flame tests and the choice is yours depending on your resources.

For all methods these salts are suggested, either as tiny amounts of solids or as 0.5 M solutions: barium chloride, sodium chloride, calcium chloride, potassium chloride, copper chloride. Note that barium chloride is toxic and care must be taken in its use, but only tiny quantities are used for a flame test. If doubtful about its use leave it off the metals to be tested. Make up sets of labelled test tubes with a small quantity of the solutions in each tube. Obviously, great care must be taken to avoid contamination of the tubes. Solutions should be made with distilled or de-ionised water, the sample tubes should obviously be very clean.

Students require safety glasses for all of these methods, plus hand-washing facilities. A darkened room is required to clearly see the colours.

To view the spectra of the colours a piece of about quarter to a fifth of a CD is required. Use masking tape to pull the silver coating off the label side of the disk, starting at an edge; cutting it under water is easiest.

1. **Using a nichrome wire loop and a bunsen flame.** This is the most reliable and best method, especially if the heated wire is simply dipped into the solid salts. In addition to the solutions above, 1 M hydrochloric acid is required to clean the loop.
   a. First clean the nichrome wire loop. Dip the wire loop into hydrochloric acid, then into distilled or de-ionised water. Hold the loop just to the side of the inner blue cone of the Bunsen flame. It should not show any colour. If it does, clean it again.
   b. Dip the wire loop into the solution in one of the tubes and hold it in the flame. Note the colour.
   c. Clean the loop, heat to check it shows no colour, repeat the test for the next tube. Take great care to not cross-contaminate the sample tubes.
   d. Repeat the cleaning and sampling procedure for the remainder of the sample tubes.

2. **Using pre-prepared wooden splints, tooth picks or ice-block sticks.** This method is commonly suggested, using the same solutions as above. Tongs will be required to hold the wood samples. This is not a particularly reliable method as the colour of the burning wood (which invariably contains sodium) can mask other elements. If you elect to use this method we suggest testing it first; we did not find it as convincing as the nichrome wire loop method.
   a. First soak the sticks or toothpicks to wash out any other materials and to ensure they are all alike. Test one to check that no bright sodium colour especially is present. Set aside some to use as a control.
   b. Soak sufficient pieces in the solutions overnight, then leave to dry. Take care to keep each batch separated to avoid cross-contamination. If the pieces are sufficiently long one end can be left out of the sample solutions and used to hold them without the need for tongs. Mark the 'hold' end with a felt pen. This method reduces contact with the skin.
   c. Provide students with one of each sample, plus a control (untreated), having them taped on a piece of paper keeps them separated. Students then place each sample in a flame, holding them in the flame only long enough to heat to show the colour, not sufficiently long for the wood to catch fire.
   d. Provide a beaker of water to extinguish and hold the used pieces.

3. **Dissolving samples in methanol, ethanol or methylated spirits and lighting the sample in a darkened room.** Be sure to have a solvent-only sample for comparison. The method is suitable for class demonstrations, not for individual student work. While reported as a reliable method it is more difficult to make it work.

References

http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/student-worksheet-flame.html

http://www.amazingrust.com/experiments/how_to/flame_test.html

http://chemistry.about.com/od/analyticalchemistry/a/flametest.htm

http://www.ul.ie/~childsp/CinA/Issue63/TOC25_FlameTest.htm

http://atlantis.coe.uh.edu/texasipc/units/properties/flame.pdf

Fireworks
http://chemistry.about.com/od/fireworkspyrotechnics/a/fireworkcolors.htm

http://www.explainthatstuff.com/howfireworkswork.html

Diffraction grating spectacles
http://www.vuw.ac.nz/scps-demos/demos/Light_and_Waves/DiffractionGratingGlasses/DiffractionGratingGlasses.htm

Outcomes

Students should be able to explain to others how astronomers identify elements by their unique emission spectra, using examples of metals which have readily recognisable visible emission spectra.

Extensions

1. **Fireworks:** the colours of fireworks are from the emission spectra of the metal salts included in the fireworks mixture, or from the metal itself burning (e.g. magnesium filings provide the brilliant white sparks and high temperatures).

2. Emergency flares utilise the red emission of strontium (as strontium nitrate) along with magnesium to provide a bright light plus a sufficiently high temperature, and an oxidiser to help ignite it and maintain the combustion.

3. **Lighting:** some lamps, e.g. sodium and mercury vapour lamps, utilise the emission spectra of various elements to produce light.

Student Activity One

Identifying Metals by their Radiation

Everything we know about the universe is from "messages" in the electromagnetic radiation we receive from beyond planet Earth. Encoded in the radiation from objects in the universe is their temperature, the elements and compounds present, distance, motion, and even clues to the beginning of the universe.

In this activity you will examine the light given off by some metal salts when they are heated. When an atom is heated, some of the energy is absorbed and causes electrons to move to a 'higher' orbital with more energy (an 'excited' state). The higher orbitals are not stable so the electrons return to their original (or 'ground') state, emitting electromagnetic radiation as they do so. As each element has a unique arrangement of electrons, the pattern of wavelengths of radiation they emit is also unique.

The metal salts you will use emit much of their radiation in the visible light region. Each element has a unique 'fingerprint' of emitted radiation allowing them to be identified, even from astronomical distances. A spectrometer is used to spread out the light spectrum to make identification more accurate.

Your teacher will explain the precise procedure you are to use, as there are different methods. The procedure is to heat a sample of a metal salt, usually a chloride, and to see what colours are produced. Some metals produce intense and bright colours, others are dim and more difficult to see.

1. Write down all essential steps of the procedure you will be using.

2. What step was included to provide a control or comparison?

3. It is important to avoid mixing or contaminating any of the samples when carrying out the tests. Why?

4. Record the name of each sample and the colour it produced.

Sample	Colour

5. Sodium is very common and readily forms soluble compounds difficult to remove from samples. Describe its colour and intensity and why this is a problem when carrying out a flame test.

6. If you can carry out flame tests in a dark room (so no other light sources are present) you can look at the flame through a diffraction grating, or a clear piece of a CD or a CD spectrometer, to see the emission spectrum more clearly.

   If you did do this, draw a picture of the spectrum for one of the metals. Metal: ______________________

7. What causes each element to have a unique spectrum which can be used to recognise it?

8. Emergency flares contain magnesium which burns with a very bright white light to attract attention, as well as providing heat to cause other metal salts to emit colours. Find which metal gives off a bright red light when heated and which is used in these flares.

Radio Transmission Bands

This is essentially a web or textbook research activity. The radio spectrum is very wide and used extensively for communications of various types. A band is a small defined section within the radio spectrum, usually as frequency bands of 3×10^n so each band is ten times higher in frequency than the previous one. A band is likely to have many defined channels which are very narrow frequency spaces.

The use of frequencies within bands and channels is controlled by governments according to international treaties, specially for frequencies used internationally (as in aircraft, ships, navigation, etc.) and those likely to be transmitted beyond the borders of a country. See: http://en.wikipedia.org/wiki/Bandplan

The transmission distance depends on the transmission power, frequency and atmospheric conditions. Some frequencies are reflected by the ionosphere, especially at night, some form a ground wave, while others are line-of-sight and consequently have limited range. Frequency allocation of limited range transmissions may vary between countries, so (e.g.) a PRS walkie-talkie for NZ (476.425–477.400 MHz band) may be used in Australia but not in the EU which uses PMR channels in the 446 MHz band.

Interference is a major risk with all radio devices. As any electrical device with high frequency alternating currents will transmit at radio frequencies all such devices must be licensed for each country of use. A computer for example will show the agencies which have approved its use.

As radio telescopes utilise frequencies widely used by consumers (e.g. cellular phones) but which have short ranges, they need to be placed in remote areas so they are as free from interference as possible.

Rationale

This is a useful exercise to reinforce the relationship between frequency and wavelength within a practical application context.

References

http://en.wikipedia.org/wiki/Radio_frequency

http://en.wikipedia.org/wiki/Radio_waves

http://www.rsm.govt.nz/cms/tools-and-services/chart-of-radio-spectrum-allocations-in-new-zealand

http://www.rsm.govt.nz/cms (home page)

http://en.wikipedia.org/wiki/UHF_CB

Outcomes

Be able to discuss the practical division of the radio frequency region of the electromagnetic spectrum, and to describe the use of one of the bands.

Extensions

Interference of radio signals is often a problem for commonly used devices. People should be aware of the services offered in finding and eliminating sources of interference; see:

http://www.rsm.govt.nz/cms/consumers/reception-problems

Radio Transmission Bands

Radio signals occupy a wide spectrum of radio frequencies from 3 Hz up to 300 GHz. This spectrum is divided up into bands of frequencies. Within each band a range of frequencies is allocated to a particular use. For example AM (amplitude modulated) radio occupies frequencies between about 500 kHz to 1600 kHz in the MF band. This is not the same as Japan, which is why cars imported from Japan's domestic market have to have 'band expanders' fitted, so the radio in the car is able to be tuned to the full range of New Zealand frequencies.

Different frequencies are absorbed differently and behave differently in the atmosphere and around obstacles, leading to widely different uses of each frequency band. The radio spectrum is divided up into 11 bands as shown in the table below.

What to do

1. Some of the information is missing. Fill in the gaps in the table below with the missing information. You should be able to do this from the pattern of the rest of the information.
2. Research the radio usage in two of the 11 bands from ELF to EHF in the table above. Your teacher may specify which ones you are to examine, or may allow you to choose your own. You may present your work as a poster, folder of work, Powerpoint or any other suitable format. You need to give radio usage within that band and give, where possible, reasons why the band was used for that purpose. You should consider transmission and reception, interference, and signal absorption in your research.

Reference

Wavelength: in metres (m)

nanometre: 1 nm = 10^{-9} m or 0.000000001 m

micrometre: 1 µm = 10^{-6} m or 0.000001 m

millimetre: 1 mm = 10^{-3} m or 0.001 m

Frequency: in hertz: 1 Hz = 1 cycle per second

kilohertz 1 kHz = 10^3 or 1,000 Hz

megahertz 1 MHz = 10^6 or 1,000,000 Hz

gigahertz 1 GHz = 10^9 or 1,000,000,000 Hz

terahertz 1 THz = 10^{12} or 1,000,000,000,000 Hz

speed of light (c) = frequency (f) × wavelength (λ)

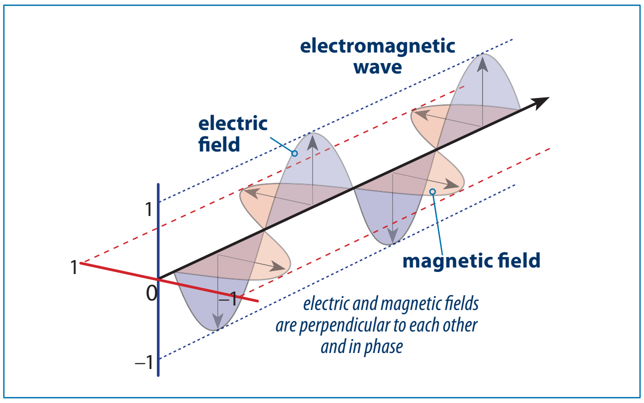
frequency (f) = speed of light (c) / wavelength (λ)

speed of light in a vacuum is 3×10^8 m s^{-1}

Frequency	Wavelength	Designation	Abbreviation
3 to 30 Hz	105 km to 104 km	Extremely low frequency	
	104 km to 103 km	Super low frequency	SLF
300 to 3000 Hz		Ultra low frequency	ULF
3 to 30 kHz	100 km to 10 km		VLF
	10 km to 1 km	Low frequency	
300 kHz to 3 MHz			MF
3 to 30 MHz	100 m to 10 m	High frequency	HF
30 to 300 MHz	10 m to 1 m	Very high frequency	
	1 m to 10 cm	Ultra high frequency	UHF
		Super high frequency	SHF
30 to 300 GHz	1 cm to 1 mm	Extremely high frequency	EHF

Detecting Radio Signals

The big idea here is that electromagnetic signals are a form of energy transmitted as electric and magnetic fields. The loop of wire has a detectable current induced in it by the changing electric field.



One end of the loop is connected to a sensitive digital multimeter (DMM) on its mV scale, the other to a small signal diode. The other end of the diode is connected to the DMM to complete the circuit. There is nothing special about this loop except the total length, including the DMM leads, should be of the order of one wavelength.

A germanium diode is used because it needs only a low forward voltage to cause it to conduct. A suitable diode would be an OA91 or equivalent available from any electronics component supplier, or even a diode clipped from a junk circuit board.

If the detecting loop is about one wavelength then a standing wave could be set up in the loop causing a bigger reading, resulting in more sensitivity. It was found that the length of the DMM leads connected directly to the diode, without any other wire at all, is much longer than a wavelength and still worked well for investigations using a PRS walkie-talkie inside a room. The disadvantage of this is that there is no big fluctuation in reading when the orientation of the diode changes, which there is with the coil. It was found that a coil of a few turns gave sufficient variation to enable rudimentary direction finding. The size and number of turns was not critical for strong signal sources, such as a transmitting PRS walkie-talkie set in the room.

A possible extension to this idea would be to place or hide some sources of electromagnetic radiation in the room and get the students to look for them using the detector loop. Possible sources could be a couple of PRS walkie-talkie sets set to transmit but on different channels (low settings if available), bluetooth transmitters, or garage remotes, etc.

If discussion arises on radio telescopes note that the dish is merely a collector, reflecting the radio waves to the antenna at the focus of the dish.

Equipment

Per group of 3–4:

1. A digital multimeter and leads.
2. A germanium diode (OA91 or similar).
3. Suitable wire if required.
4. Sources of radio signals, eg. PRS walkie-talkies, a garage door remote opener. Ensure mobile phones are turned off.

Important! If using a PRS walkie-talkie for the radio signal do not use these channels:

- 1–8 (these are repeater channels and you do not need to take up repeater space, with channel 5 for emergency use only).
- 22, 23 (these are telemetry channels only).
- 35 (this is for emergency use only).

It is advisable to first listen on the channel selected for use to find if there is anyone already using it.

References

http://en.wikipedia.org/wiki/Radio_waves

http://en.wikipedia.org/wiki/Electromagnetic_radiation

Outcomes

Able to describe how to detect the electric wave portion of an electromagnetic signal.

Background information

A PRS (Personal Radio Service, UHF CB) walkie-talkie has 40 channels utilising frequencies from 476.425 MHz to 477.400 MHz (around 0.63 m). Garage radio remote controllers operate on 433 MHz (around 0.7 m), although most utilise multi-frequency signals with changing digital codes for greater security.

Mobile phones transmit at 0.9–3 GHz (3.3–10 cm), the NZ GSM bands are (MHz): 900, 1800 (and UMTS 2100).

Any device that has high frequency oscillating electrons produces radio waves.

Extensions

1. Detecting radio 'bugging' devices. While a simple detector like the one in this activity lacks the sensitivity required to detect a radio transmitter placed to covertly 'bug' a room, the principle of such a detector is similar.

   A mobile phone detector may be useful! See:
   http://electroschematics.com/1035/mobile-bug-detector-sniffer/

2. Use of radio responders, such as RFID tags being used on merchandise; see:
   http://en.wikipedia.org/wiki/RFID_tag

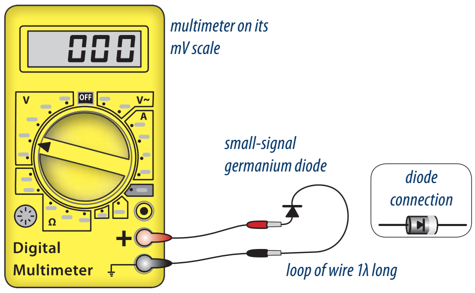
Detecting Radio Signals

Detecting the existence of nearby sources of radio frequency electromagnetic radiation.

This investigation uses a search coil, a small-signal germanium diode, and a digital Multimeter set to its mV scale.

What to do

Take the coil and diode connected in series with the digital multimeter terminals, as shown below.



Note any reading on the meter and see if it changes as you move around. Slight fluctuations in readings would be normal for background radiation, but if the signal changes significantly as the coil is rotated or changes position then there is a source of radio signal. The source will be nearby as the search coil and digital multimeter are not a particularly sensitive combination. Explain what you did and the results you gained, with an explanation for the results:

What Affects Your Cell Phone Reception?

Radio reception is affected by several factors. Obviously, signal strength is the most important, but environmental or other factors which attenuate the signal will make reception more difficult.

At the frequencies used by mobile cellular phones, reception is generally within line-of-sight of the cell towers, so objects between a cell tower and the cell-phone will have some effect on the signal. However, the effect depends on the type of objects: as radio waves travel through non-metallic objects, cellular phones receive signals inside buildings, through car windows, etc., yet it is still essentially line-of-sight reception.

This activity is about the materials transparent to radio waves.

Equipment

Per group of 3–4:

1. Cellular mobile phone with signal strength indicator.
2. Dry cloth, wet cloth, size sufficient to wrap fully around a mobile phone.
3. Metal mesh, of the type used for screen doors; soft aluminium mesh is easy to use, note that the metallic looking but soft fibreglass mesh is useful only to compare metal and non-metal mesh.
4. Sheet materials: cellophane, plastic, etc.

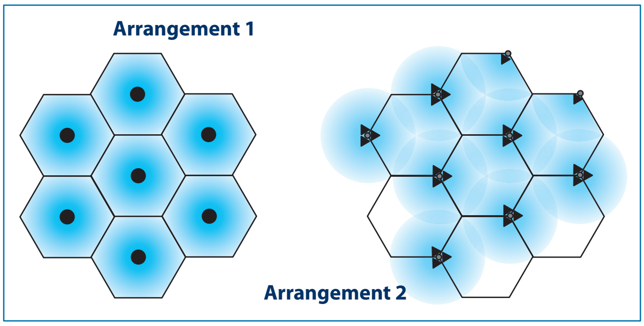
References

http://en.wikipedia.org/wiki/Radio_propagation

Background information

Cell phone reception has greatly improved in recent years. The expectation of the public in the modern age is that there will be coverage wherever they go and irrespective of which provider they sign up with. To remain competitive the telecommunication companies ('telcos') have provided better service and expanded their areas of coverage so that even relatively remote areas get coverage today. The problem, and the challenge for the telcos, is that it costs as much to put in a cell phone tower to supply coverage for a sparsely populated rural community as it does for a densely populated urban one. The reason they do this seems to relate to gaining market share. A better coverage map than the opposition is an attractive proposition for many users. Cell phone frequencies are high (900 MHz or higher), which means that there is little diffraction around objects like buildings or vegetation. Consequently, reception is almost entirely line-of-sight. The ideal cell network would have one cell's coverage finishing on the boundary of the next cell. The reality is the edges of the cells overlap so that a transceiver on the boundary between cells would be able to communicate with either cell tower of the two adjacent cells. Some cell boundaries miss the next cell boundary causing a reception 'hole' where reception cannot be obtained. The process of transferring reception from one cell to the next is called 'hand-off', and this is achieved between the cellular phone and the new cell's transmitter when the new signal becomes significantly stronger than the old.

Cell phones operate on a range of high frequencies. The higher frequencies have the disadvantage that the effective cell size is reduced for transmitters operating at those higher frequencies. For example, GSM 1800 at 1800 MHz starts to 'see' walls as opaque, causing reception problems inside buildings, whereas reception at lower frequencies like GSM 900 would be fine. The advantage for the service providers is that the increased frequency means more users can access the cell before it is overloaded, resulting in fewer users' calls being dropped when connected at the higher frequencies. There are essentially two types of cell architecture: the first being where the transmitter is at the centre of the cell and emits an omnidirectional signal. The second is where the transmitter transmits on three different frequencies through three directional antennae, each pointing to the centre of one of the three cells meeting at that point. In either system the adjacent cell operates on a quite different frequency so there is no interference or problem during 'hand off'. The diagram illustrates these two different cell architectures:



With these design factors in mind, cellular reception is always going to be a bit of a lottery. This exercise looks at ways the students can improve the reception of their phones by simple changes in the way they make a call. It is using equipment they have in abundance and will appeal to them as an activity they can do at home.

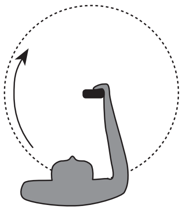
What Affects Your Cell Phone Reception?

The reception of radio signals is affected by several factors, some related to the radio frequency. A cell phone operates at frequencies similar to those used by radio telescopes.

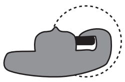
What to do

You will need a cellular mobile phone with signal strength indicator and a range of materials, including metal mesh.

1. Choose a position where the signal strength is about half the maximum indication (e.g. about 3 bars if the indicator has 5 bars). Holding the phone upright and away from you, move around in a circle, keeping the phone as close as possible to the same spot. Observe changes in the signal strength. Note your observations below.



2. Hold the phone close to your body at about waist height and again move around in a circle keeping the phone position fixed at the centre of the circle. Observe the signal strength as you go around in the circle and note your observations below.



3. In the original position of medium signal strength, and without changing the position or orientation of the phone, wrap your hands around the phone and observe any changes in the signal strength. It may take about 10 seconds for any changes to cause a change in the signal display, so do not be in too great a hurry. Note your observations below.

4. Repeat this experiment with a dry towel wrapped around the phone. Did this have an effect? Describe it.

5. Now try again with a wet towel. Did this have more effect? Describe it.

6. Explain the difference (if any) between the last two results.

7. Repeat the experiment with metal mesh wrapped around the phone (while you could use foil, the problem is seeing the signal strength indicator). Note your observations below.

8. Open the mesh slowly, starting with a small gap, and note the effect on the signal strength indicator. Allow time for it to change. Continue opening the mesh. What was the effect of opening the mesh?

9. Metal mesh is mostly empty space. You can easily see through it. Was the effect on the radio signal similar to the effect of the mesh on light waves? If it was different, what is the reason for the difference?

10. Try with other materials, such as cellophane (it is a form of paper), plastic, etc. Record your results.

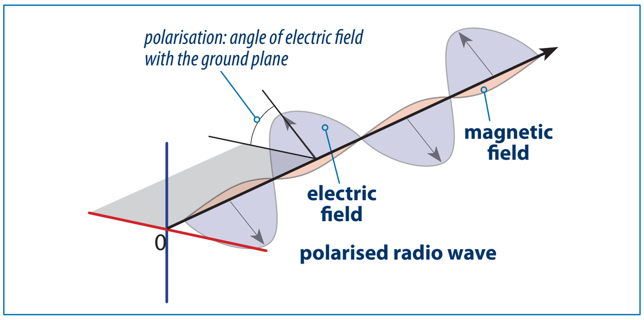
11. If a friend lived in a weak reception area, what three suggestions could you make to your friend to help them have the best reception possible in the way they hold their phone.

Polarisation of Signals

The big ideas here are that electromagnetic signals can be polarised or non-polarised, and that the orientation of the transmitter and its mode of operation will determine the plane of polarisation of the signal.

The second big idea is that a non-polarised signal can be polarised by reflection (specular polarisation) and that radiation from space can come from polarised sources like the radio lobes in galaxies and radio emission from pulsars.

Polarisation is the non-random orientation of electric (and magnetic) fields in an electromagnetic wave, usually regarded as the electric field being constrained to one plane. The polarisation of radio waves is normally horizontal, vertical or circular. With a vertical antenna the electric field is transmitted as a vertically polarised signal. This is common in the communication radio signals of both AM and FM radio. Most TV signals in both the UHF and VHF frequencies are horizontally polarised, so that a receiving aerial for these signals must also be horizontal. Two different signals can be transmitted on the same frequency if their planes of polarisations are at right angles to each other.



The second part of the activity is to detect polarisation of a CB signal. It uses the same materials and procedures as Activity Three. The diode will give a different meter reading if it is oriented horizontally or vertically, showing the polarised nature of the signal. Best reception was detected with the diode horizontal and along the axis to the transmitter.

Rationale

Polarisation is a practical topic to also enhance understanding of electromagnetic radiation.

Equipment

Per group of 3–4:

The first part of the activity: polarisation of light

1. Small sheets of polarising material or lenses from old polarising sunglasses.

The second part: polarisation of radio signals

2. A digital multimeter and leads.
3. A germanium diode (OA91 or similar).
4. Suitable wire if required.
5. Sources of radio signals, eg. PRS walkie-talkies, a garage door remote opener. Ensure mobile phones are turned off.

Important! If using a PRS walkie-talkie for the radio signal do not use these channels:

- 1–8 (these are repeater channels and you do not need to take up repeater space, with channel 5 for emergency use only).
- 22, 23 (these are telemetry channels only).
- 35 (this is for emergency use only).

It is advisable to first listen on the channel selected for use to find if there is anyone already using it.

References

http://en.wikipedia.org/wiki/Polarization_(waves)

http://www.air-stream.org.au/Polarization

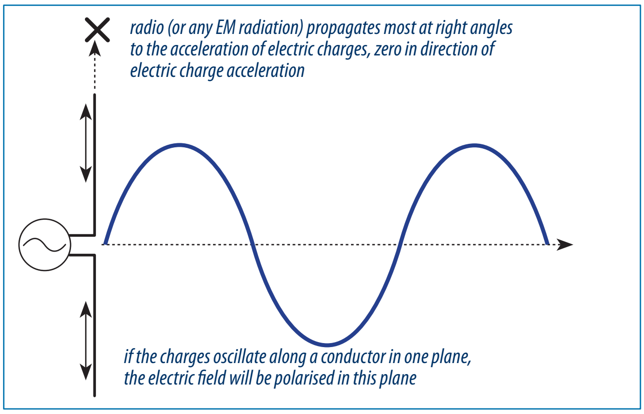
http://en.wikipedia.org/wiki/Polarization_(antenna)

Outcomes

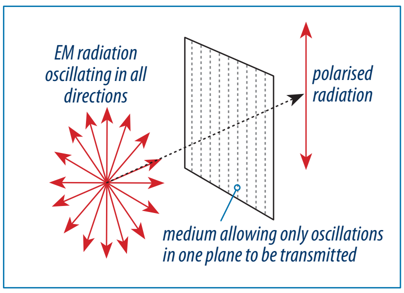
Students should be able to describe polarisation in terms of the angle of oscillation of an electric field, and explain the effect of polarising media.

Background information

The angle of polarisation of a radio wave is the angle between the major plane of the electric field and the ground plane. EM radiation is produced by the acceleration of electric charges. A radio signal from a single conductor will propagate at right angles to it.



If the charges are accelerated in all or random directions, as occurs in any environment above absolute zero, then the electric field (and of course its matching magnetic field) oscillates in all directions. If the radiation passes through a medium which is transparent to radiation oscillating in only one plane the emerging radiation will be polarised: the electric field would



be oscillating in only one plane (linear polarisation), although the magnetic field is still present. The now-polarised radiation will have about half its intensity as some has been absorbed.

As EM radiation propagates at right angles to the direction of acceleration of charges, a radio aerial consisting of a conductor in one plane will propagate radio waves polarised in that plane.

A diode rectifies the oscillating current induced in the aerial.

Sunlight has some polarisation from scattering in the atmosphere. Photographers utilise the polarisation at 90° to the sun to darken the sky with a polarising filter, which they rotate to block the polarised light. Blue light is scattered more than other wavelengths and loses its polarisation, so a polarising filter blocks the other (still polarised) colours, making the sky appear a deeper blue in photographs. A polariser with its axis of polarisation at right angles to polarised light will block it. As light is polarised when reflecting off a surface, photographers with cameras using light from a mirror for autofocus need to use circular polarising filters to ensure the autofocus will work. Circular polarisation is when the electric and magnetic fields are 90° out of phase.

Light reflected off water surfaces is horizontally polarised within a certain range of incident angles, so sunglasses with a vertical polarisation axis will block the glare from the reflected light.

Many animal species can detect the polarisation of light and utilise it for navigation.

Extensions

Television aerials: When travelling, students are likely to have seen TV aerials in either the horizontal or the vertical plane. What would a reason for these aerial orientations?

Polarisation of Signals

Many frequencies of electromagnetic radiation can occur as polarised signals.

Light is an electromagnetic signal that is non-polarised when created in the sun, but is polarised by scattering in the atmosphere (scattering is also responsible for the blue colour of the sky). Polarisation is when the light waves are oscillating in only one plane; non-polarised light oscillates in all planes.

Polarising sunglasses contain a plastic polarising filter which only allows one plane of polarisation through the filter. Our eyes do not detect polarisation but will respond to the decreased brightness when a polarising filter removes all the light that is not polarised in the same plane as the filter.

What to do

PART 1: EXAMINING THE POLARISATION OF SUNLIGHT.

1. Look at the sky through a polarising filter and observe the effect. What happens as the filter is gradually rotated?

2. What happens if one polarising filter is placed on top of another filter and one is gradually rotated? Explain the observation.

3. Look through the filter at a water surface with sunlight reflecting off it when the sun is at an angle of about 30°–60° above it. What do you notice when you rotate the filter held in front of your eye? Give an explanation for what you see.

   What was the effect of reflection on electromagnetic radiation in terms of polarisation?

PART 2: EXAMINE THE POLARISATION OF A RADIO SIGNAL.

For this activity you will be using a PRS walkie-talkie radio and a diode and digital multimeter radio signal detector circuit.

4. Set the radio on low power if possible. Do **not** use channels 1–8, 22, 23, 35.

   Take the signal detector a suitable distance away so that the signal reading is still much stronger than the background unwanted signal.

   With the CB set in transmit mode, gradually rotate the transmitter until the aerial is horizontal. The aerial should be pointing in a direction 90° away from the sight-line to the receiver. Note what has happened to the signal reception during this rotation.

   Observation 1:

5. While keeping the transmitter horizontal, the receiver is now gradually rotated through the same angle. The transmitter is still 'on'. Note what happened to the signal strength during this second rotation.

   Observation 2:

6. Now move the horizontal transmitter in a horizontal rotation so that its aerial is now pointing directly at the receiver and note what happens to the reception. The transmitter is still 'on'. (Note this is not a polarisation effect in this situation.)

   Observation 3:

7. What does observation 3 indicate about the direction of the strongest transmitted signal?

8. A metal grid with parallel bars will act as a polariser for radio signals.

In an investigation a polariser with metal bars running vertically was put in front of a transmitter aerial, but there was no change in the received signal. Explain why this was the case, and also describe what would happen if the metal grid polariser was rotated through 90°.

9. What would be the effect of using a plastic grid similar in size to the metal one in the previous question? Explain your answer.

10. A radio telescope rotates its receiver in a circle while receiving radio signals from a distant source. As the receiver rotates through a circle in the focal plane of the telescope, the received signal changes in detected strength. Explain what this tells the astronomers about the distant radio source.

11. A person wishes to transmit two different data signals at the same frequency and from the same location, but without causing them to interfere with each other, which would degrade the data and make the signal useless. Explain how could this be achieved.

Random Signals 1

The big idea here is that if something is random then that is a property that can be used to isolate it. Random things behave predictably over a large number of samples. In this case the random samples are being modelled using a die and a coin.

Rationale

In astronomy the signals, whether in visible light, radio or other wavelengths, are very weak because of the enormous distance from the sources. All signal receivers produce 'noise', random signals arising from the operation of the receivers, plus there may be other sources of 'noise' (non-signal voltages). Consequently the signal to noise ratio is low. Noise reduction techniques are essential, along with the challenge of distinguishing noise from the signal.

Equipment

Per group of 2–3:

- Sufficient dice and coins for the number of groups.

References

http://en.wikipedia.org/wiki/Noise_reduction

Outcomes

An understanding of the idea of 'random' noise, and why it is important to identify and eliminate it.

Background information

In visible light and infrared astronomy, digital sensors have to operate at very low light levels. As photons ('signal') are absorbed by the photosites of each pixel they are converted to electrons, which the camera then counts when the exposure is complete and converts to a brightness numeric value to create a picture. At low light intensities the signal may not be greater than the base noise. Cooling the sensor is one of the techniques to reduce the sensor noise.

Digital sensors always have a random number of electrons present from the circuitry, the effect of temperature, etc. If this 'noise' is truly random it can be subtracted from the signal data to give a more accurate picture. When operating at low light levels the signal to noise ratio is very low, so eliminating noise is essential in producing a high quality image.

Many consumer digital cameras have an automatic noise subtraction system for long exposures, where a second 'long exposure' but blank 'picture' is taken which is actually only the random noise from the sensor. This data is then subtracted from the real exposure so a more detailed picture with less noise is obtained.

Extensions

1. Noise cancelling microphones; see: http://en.wikipedia.org/wiki/Noise-canceling_microphone
2. Noise cancelling headphones; see: http://en.wikipedia.org/wiki/Noise-cancelling_headphones
3. Sensor noise subtraction from long exposures by digital cameras; see: http://www.astropix.com/HTML/I_ASTROP/SIGNAL.HTM
   http://qsimaging.com/ccd_noise.html
4. How digital cameras work; see: http://www.cambridgeincolour.com/tutorials/camera-sensors.htm
   http://electronics.howstuffworks.com/cameras-photography/digital/question362.htm

Random Signals 1

This activity introduces the idea of using averaging techniques to eliminate random signals.

Random signals have no pattern (which is what random means!). The following exercise is a simplification of one of the processes that might be used to eliminate random background radio signals from 'real' signals that have meaning and importance.

There are several applications of removing random signals, usually referred to as 'noise' to distinguish it from the 'signal' data. Your digital camera may have a 'long-exposure' correction, where it takes a 'blank' picture after your long-exposure and then subtracts the 'blank' image from the real image to remove the noise. Signals from stars are very faint, as they are so far away, so removing 'noise' from devices receiving the signals from stars is essential to obtain good quality images.

What to do

You will need a six-sided die and a coin.

In this exercise you will use a die as an analogue of a random signal. It has limitations in the fact that it can only generate signals at six discrete values, but will serve for the purpose of this exercise. You could throw two dice instead, and add their face values together each time. This would increase the range of signal values to 12.

Signal voltages can be positive or negative. You need to decide whether each random signal voltage (as shown on the face of the die) is positive or negative. The easiest way to do this is to toss a coin for each result, with "heads" being positive and "tails" being negative.

1. Carry out 30 rolls of the die and tosses of the coin to obtain your set of random signal values.
2. Write down your list of random signal voltages from die throws. Thirty results should be enough to illustrate the important points of the exercise. For each result allocate a + or – to it (by tossing a coin or similar method).

#	+ value	– value	#	+ value	– value
1			*16*		
2			*17*		
3			*18*		
4			*19*		
5			*20*		
6			*21*		
7			*22*		
8			*23*		

#	+ value	– value	#	+ value	– value
9			*24*		
10			*25*		
11			*26*		
12			*27*		
13			*28*		
14			*29*		
15			*30*		
			Totals		
			Averages		

INTERPRETING THE DATA

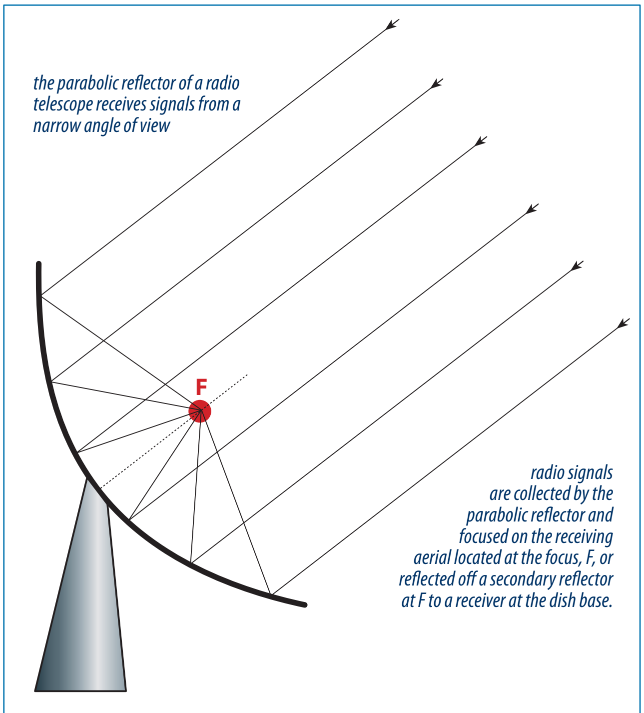
3. Add all the results up and average them. What do you notice about the final average value?

4. How could this be applied to radio signals coming from a particular point in the sky to decide if the signal is random or not?

5. This averaging process assumes each signal was the same shape and acted for the same time. Give a difference between 'real' signals and your model ones.

Direction Finding

The big idea here is that all telescopes, including radio telescopes, are directional devices and can be used to locate a source that is far away. This depends on the aperture resolution of the device which will be considered in more detail in the Level 8 resources. The second part of that big idea is that the accuracy of locating distant sources means that parallax can be used to calculate distances from us to astronomical objects.



Rationale

The idea of a 'window' in the atmosphere for certain frequencies is not only important in astronomy, but also in ordinary life. That ultra-violet is largely blocked is important to the survival of many species. The difference in opacity to different wavelengths of infrared is of significance in the so-called "greenhouse effect" and its impact on global climate.

Equipment

No equipment is required.

References

http://astronomyonline.org/Science/RadioAstronomy.asp

Outcomes

Students should be able to discuss the way radio telescopes (or any telescope) can be used to calculate the distance to objects beyond our solar system.

Background information

Radio telescopes work by receiving radio signals from space and focusing them to a point where a detector collects and transfers the data for processing. A parabolic reflector keeps the reflected signals in phase.

The atmosphere is a 'window' to much of the radio spectrum of frequencies, but is opaque to most other radiation except the visible light frequencies and some UV and infrared. Unlike optical telescopes, radio telescopes can operate at all times of the day and during a wide range of weather.

Radio telescopes are very useful in 'seeing' objects where the luminance of the dust in visible light obscures objects behind it. The centre of our galaxy, the Milky Way, is hidden behind dense clouds of gas and dust; it was not until radio telescopes reached a sufficient level of resolution that details of the centre were determined.

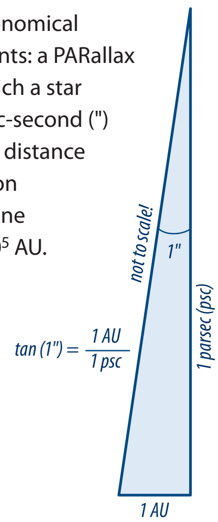
Parallax is viewing something from two different positions where the angle of view differs. The simplest demonstration is to use one eye to line up a distant object with a finger on an outstretched hand, and to then, without moving your hand or head, to close that eye and open the other. The finger appears to have moved in relation to the distant object as the finger and object are now viewed from a different position.

The stellar parallax is the angle between the directions a star appears to us when viewed six months apart from opposite sides of the Earth's orbit. This provides a baseline of 3×10^8 km, allowing triangulation to measure distances to objects in the galaxy.

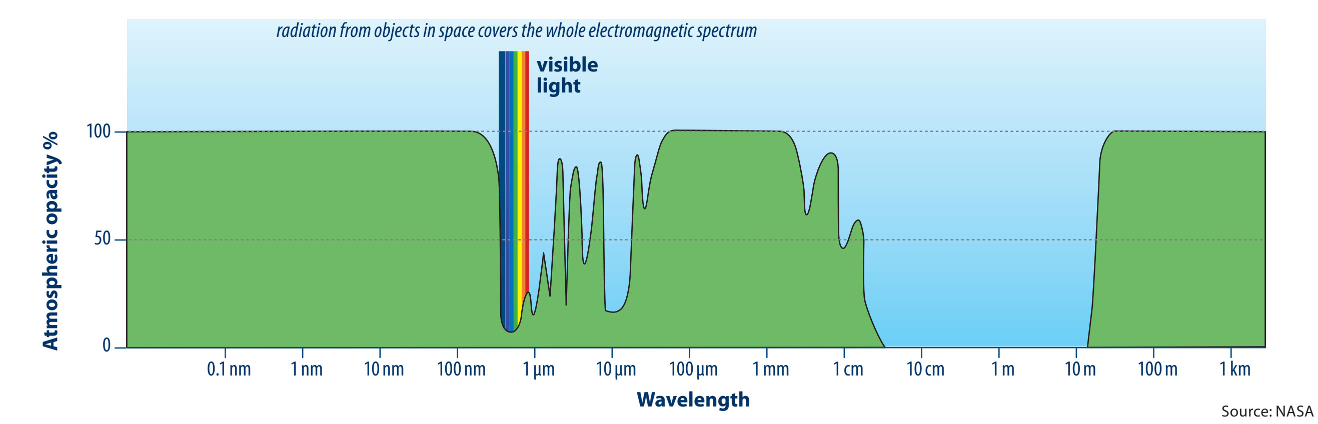
Extensions

How astronomical distances are expressed and why these units (parsecs, light years) are used.

The parsec is a non-metric measure of astronomical distance and is named after what it represents: a PARallax + SECond. One parsec is the distance at which a star would appear to shift its position by one arc-second (") during the time in which the Earth moves a distance of one astronomical unit (AU) in the direction perpendicular to the direction to the star. One parsec = 3.26168 light years or 2.062648×10^5 AU. One AU is the average distance between the Earth and the sun (150×10^6 km). There are 60 seconds in one minute, 60 minutes in a degree, 360 degrees in a circle, so there are $60 \times 60 \times 360$ arc-seconds in a circle.



Direction Finding



A radio telescope receives signals from a very narrow angle of view and focuses them, in phase, on to an aerial or detector. However, a radio telescope must look through the atmosphere which, fortunately for our health, blocks much of the higher energy radiation. The diagram above shows the wavelengths of radiation that can pass through the atmosphere 'windows'. Visible light obviously passes through the atmosphere with only a small amount blocked.

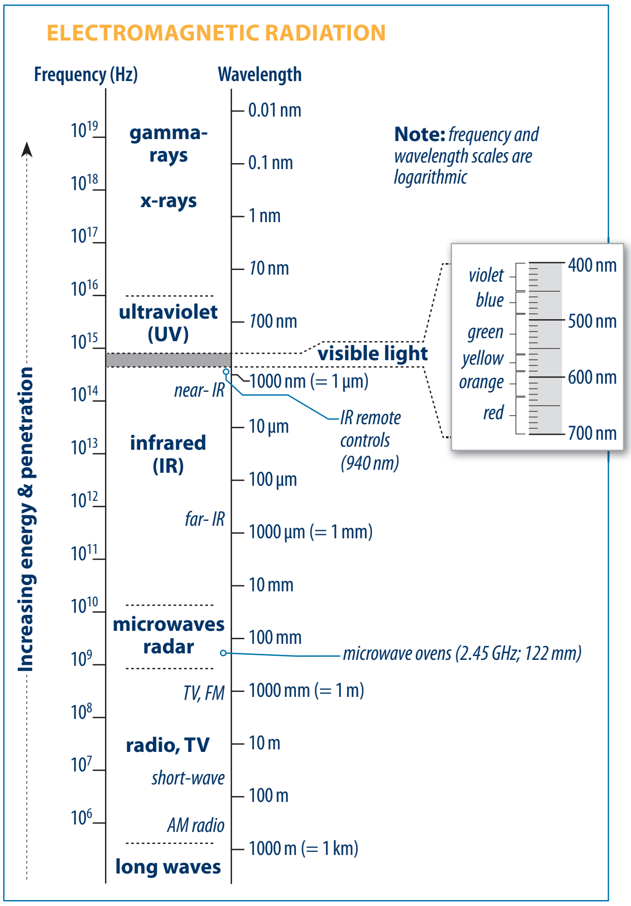
What to do

1. What is the range of wavelengths permitted by the atmosphere windows?

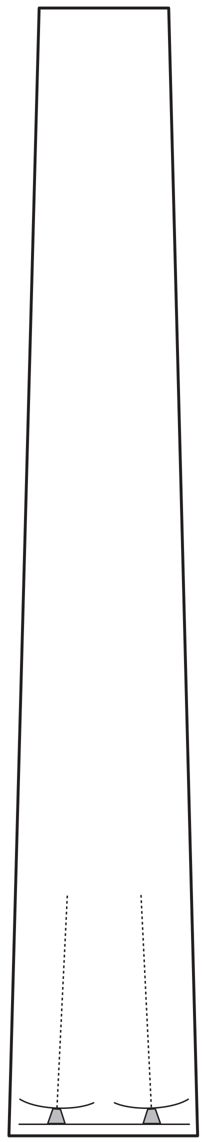
2. On the right is a reference chart of the electromagnetic spectrum. What are the names of the bands of wavelengths which are permitted by the atmosphere windows?

3. Explain what wavelengths telescopes in space could best utilise and the extra astronomical information they could provide that we cannot get down on earth.

4. Telescopes utilising visible light (e.g. the Hubble telescope) are placed in space and provide much clearer pictures than telescopes on Earth, even though they are smaller. What are some reasons for this?



5. Radio telescopes can also provide information about how far away from earth a source of radio signals is. One method is by simple triangulation. The diagram at the right illustrates the principle. Both radio dishes are pointing at the same radio source. Draw construction lines to locate where the source is. Note that this diagram is not to scale!



6. Why could one telescope at one time not tell us how far away the source is?

7. Would more telescopes give a more accurate position of the source? Explain.

8. What would happen to the accuracy of the estimate of the position if the telescopes were further apart?

9. If a single telescope was to find the position of a distant radio source, mark on the diagram below the positions of the earth in its solar orbit that would result in the most accurate 'fix' of the radio source's position.