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Technical Documentation: Navigation

Common Content for Teachers and Students

Humans and animals have always navigated across landscapes.

Animals use a variety of techniques including landmarks and celestial bodies, smells perception of the Earth's magnetic field and even detection of polarised light to navigate between points.

Today, humans use maps and satellites to help us move across land, but before these we used a variety of methods to navigate, especially the Night Sky.

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Key Facts

Understanding mapping and directions (north, east, south, west as well as latitude and longitude) is crucial for navigation.

To understand maps, you need to understand scale.

It is essential for emergency services to understand your exact coordinates to provide the best chance of relief and rescue.

The Night Sky

Aboriginal and Torres Strait Islander peoples have been able to navigate over thousands of years by observing how patterns in the sky, line up with many features on the land.

This great traditional knowledge about the skies in the Southern Hemisphere has been shared with Astronomers all over the world. Stories within different Aboriginal and Torres Strait Islander Nations about the night skies have been handed down over thousands of years.

You may have good knowledge of the night skies from listening to stories within your communities, or you might like to ask elders in your community to teach you more about the skies. The skies have spiritual significance for Aboriginal and Torres Strait Islander cultures as the stars are believed to be the home to ancestors and a guide for everyday living, and storytelling is a big part of this.

The information in the following section has been adapted from the Australian ACARA (2025) document Science as a Human Endeavour - Teacher background Information.

Star maps that were developed by Aboriginal and Torres Strait Islander peoples have been compared with published road maps of Australia and they are very similar.

The aspects that are well understood by many Aboriginal and Torres Islander peoples are how the pattern of the stars rotate from east to west during the night and how these change over a year.

For thousands of years Aboriginal Peoples used star maps to guide them to the Bunya Mountains in Queensland. The traditional custodians of the Bunya Mountains are the Waka Waka, Barrungam, Jarowair and Djaku-nde Peoples.

In the Bunya mountains there are huge bunya pine trees, and they produce large pinecones with tasty seeds. Aboriginal peoples travelled for 700 kms or more to these mountains to be able to celebrate together when the seeds were ready to eat. They used star maps which were memorised and preserved in a songline to guide them.

Songlines are described by Wardaman Elder, Bill Harney, and Ray Norris, an astronomer, as spoken maps of the land.

These maps allow navigational skills to be passed on with words where there is no writing as part of communication. Travel routes have been memorised and integrated into songlines that were matched with the position of stars and constellations in the night sky.

Torres Strait Islander peoples for thousands of years have used their observations of the night skies for their navigation through sometimes dangerous waters of Torres Strait.

The following videos may contain images or content of people who have died.

- Aboriginal Elder Uncle Ghillar Michael Anderson from the Euahlayi Nation tells the story of the Wurrum-Boorrool.
- Through Our Eyes - Dhinawan 'Emu' In The Sky with Ben Flick from the Kamilaroi language group of north-western NSW,

The Southern Cross

The Southern Cross constellation has various names in Aboriginal and Torres Strait Islander language groups depending on the language group. You might know this group of stars by a different name.

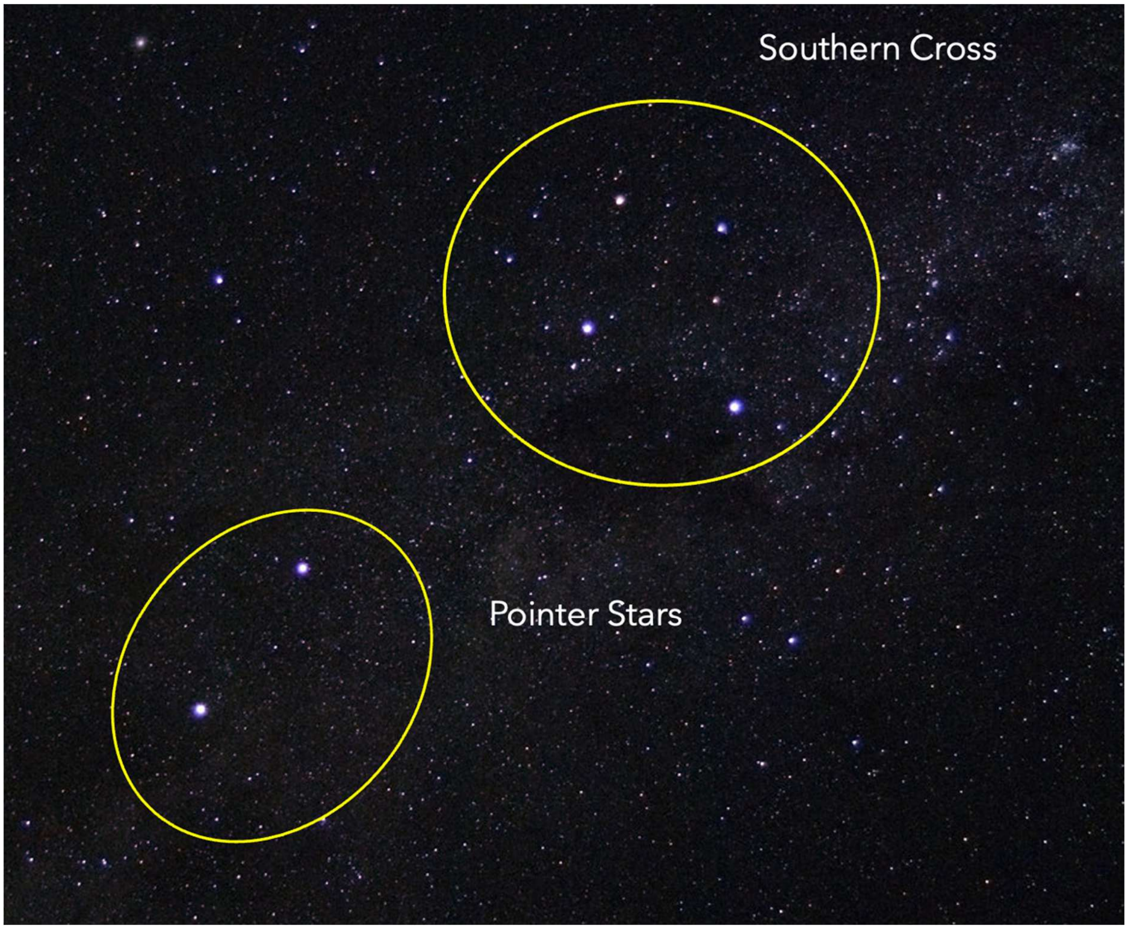
The Southern Cross (or Crux which is the Latin word for cross) is often shining brightly in the night skies in Australia. Just as other stars and constellations have been used for thousands of years for navigation, it is possible to navigate in the Southern Hemisphere by using the Southern Cross to find South.

The Southern Cross has four bright stars in the shape of a cross. You can see these stars standing out in the photo below as they are brighter compared to the other stars.

There are two bright stars that appear to point to the southern cross; these are sometimes called the Pointer stars. You may also have other names for these two stars.

The Astronomical names for the pointer stars are Alpha Centauri and Beta Centauri. Alpha Centauri appears further away from the cross.

The Alpha Centauri star system is the nearest star system to Earth (but of course our sun is our nearest star).



Have a look at the link which has diagrams showing you how to find South using the Southern Cross ABC Science link.

If you draw an imaginary line through the Southern Cross from the top to the bottom of the cross, then extend it four times the length of the Southern Cross (from the footer star of the cross) you have found the south celestial pole.

If you draw an imaginary line down from the south celestial pole to the ground, you have found South. See the link for the diagram.

This following link gives you more information about the Southern Cross

Mapping

People have used maps for thousands of years to be able to represent and understand features of the Earth, particularly when it comes to navigation. The oral maps of the Aboriginal songlines (discussed earlier) are examples of early use of mapping.

Maps are often two dimensional. Paper maps or maps in books were used more in the past but now maps on mobile phones or computers are commonly used.

To be able to read a map it is important to know which direction north is, and understand the points of a compass, north, south, east, and west. We also need to understand the points that are in the middle between the main points, which are north-east, north-west, south-east, and south-west.

You can make a compass using a magnet. See the link: Making a compass

National Geographic has some excellent information about compasses in this link.

Compasses are essential for navigation. If you tried making a compass from the link, first you would have magnetised the needle. Then you would have placed the needle through a slice of cork or something else and allowed it to float on water so the needle could turn freely in the water.

The metal would have lined up with the Earth's magnetic field (if it was magnetised properly) and if you had checked with a compass on your phone or a regular compass, you would have seen that the end of the needle pointed to the north magnetic pole.

A mobile phone compass is different to a traditional compass. It uses sensors that work out the Earth's magnetic field as well as sensors that use acceleration movement and gravity to determine the phone's positioning. The information from the sensors is combined to determine the direction the phone is pointing in. Mobile phone compasses may not be as accurate or reliable as regular compasses.

Cool Animal Navigation Facts

- Interestingly dung beetles use the milky way in the sky for their navigation to be able to line up their dung balls. A research study by the University of South Australia found that this same type of navigation dung beetle's use could be adapted for use by robots, drones and other smaller aircraft (University of South Australia, 20205).
- Animals, including some insects, birds and fish, use the sun in various ways for navigation. Some insects of the night, use the moon for navigation.
- Pigeon's brains behave like a magnetic compass where they use the Earth's magnetic field for direction.

Scale

To understand maps, you need to understand scale. This National Geographic link gives you excellent overview of scale. The information here has been adapted and summarised from this link.

It is important for a map to have some sort of scale to be able to interpret it accurately. There are different forms of scale, we will concentrate on map scale here.

Map scales can be represented in words such as 'one centimetre on the map equals one kilometre in real life'.

Map scales can be represented as a graphic scale (drawing scale) where you have a line drawn as a ruler that represents the distance on Earth. For example, a line of one centimetre on a map represents 1 kilometre in real life.

If this is represented in a fractional scale it would be 1:100,000.

Maps can be described as large scale and small scale. Large scale maps have smaller ratios such as 1:10,000, and small-scale maps have larger ratios such as 1:1,000,000. A medium scale map is around 1:100,000.

Latitude and Longitude

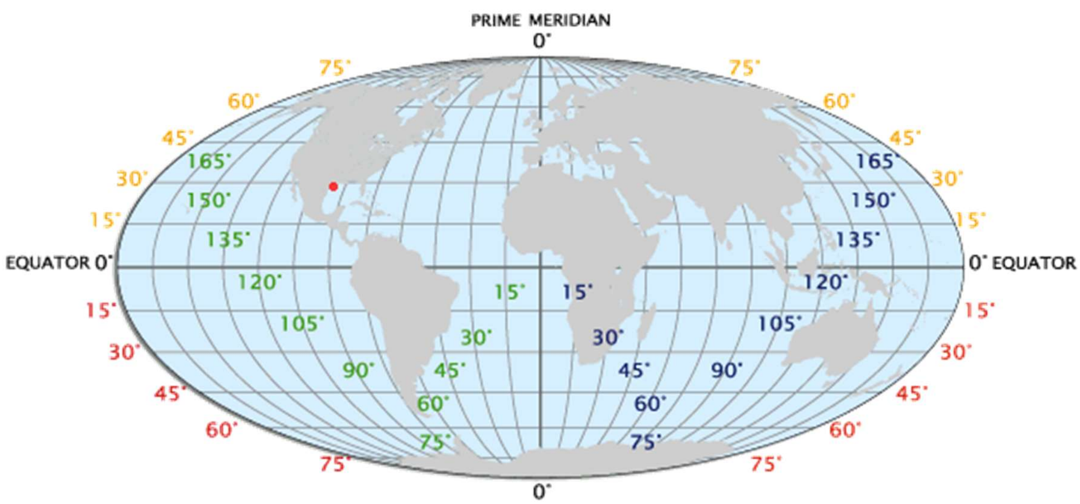
To be able to understand navigation techniques it is important to learn about Latitude and Longitude.

Latitude and longitude are central to navigation. This link is to a video by the NSW Education Department: [Explaining Latitude and Longitude.]()

The following information is a summary of the information from the NSW Education Department link above.

Planes and other navigation systems, like apps on your phone, use latitude and longitude to navigate and calculate exactly where you are on Earth.

Latitudes are imaginary lines going around the Earth from east to west. You might know the equator, which is a latitudinal line which separates the northern and southern hemispheres and is situated at 0° (degrees).



The South Pole is 90° south of the Equator, and the North Pole is 90° north of the Equator. See the equator in the diagram above.

The two other latitudinal lines that are important are the Tropic of Capricorn and the Tropic of Cancer. The Tropic of Capricorn is 23.5° south of the Equator. The Tropic of Cancer is 23.5° north of the Equator.

Wherever you are on Earth, you can construct an imaginary latitudinal line that is calculated by how many degrees you are either north or south of the equator.

Longitudinal lines go from the North Pole to the South Pole. See the longitudinal lines on the diagram above. There is one very important longitudinal line (or meridian) and that is the one that runs through Greenwich in London, England, which is known as the prime meridian. Longitude is measured using this meridian.

Wherever you are on Earth, you can calculate a longitudinal line that runs north of the point where you are and south of the point where you are. It is calculated by how far East or West it is from this prime meridian longitudinal line.

So, the point you are at is somewhere from 0° to 180° from the prime meridian. If you want to know where you are on Earth, your location is calculated where these latitudinal and longitudinal lines intersect.

If you go to a map app on your phone or on a computer, you can pinpoint your location. Click on the dot where you are, and it should give you the coordinates. The first coordinate is latitude and the second is longitude. If your coordinates are 12.45129°S, 130.84207°E, that means that you are 12.45129° South of the Equator and 130.84207° East of the Greenwich Meridian.

Your location is calculated where these two lines intersect, and these lines from the coordinates above intersect in Darwin. It is very important for emergency services to be told your coordinates, but you need to be careful who you share your coordinates with and never share them publicly.

To understand how these coordinates are determined by your phone, you need to understand how satellites work. (See the Technical Document on Satellites for more information)

Technical Documentation: Planning and Risk

Common Content for Teachers and Students

This explainer relates to planning in terms of roads and access, vehicles and associated risks.

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You may need a permit to drive a vehicle or land an aircraft (including drones) in national parks in Australia.

Helicopters are very useful when people and supplies need to get to places that cannot be reached by any other vehicles. Helicopters are used during fire and flood events and for search and rescue missions.

Navigation Apps on your phones or computers are also helpful for planning a route for travel and for calculating distances.

Country

The following website hyperlink provides you with a map of Australia with social groups and nations of Aboriginal lands of Australia that you need to acknowledge in the planning of your project:

- The Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS)

Vehicles

When planning for the kind of vehicles to use in your mission, you need to be aware of some key information, such as how helicopters and planes work, and the risks associated with using these vehicles. Also, what sort of conditions you are planning for if you are using road vehicles and what type of vehicle would be most suitable.

4WD

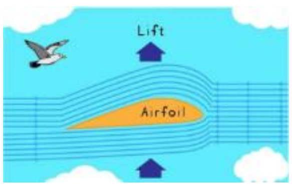
4x4 off-road vehicles typically have gearing that is high and low range. Low range is suitable for driving in steep rough conditions. There are many vehicles with all wheel drive, but genuine off-road vehicles are usually referred to as 4WD (4 Wheel Drive) vehicles. You will need to also work out the size of the vehicles you plan to use particularly if vehicles need to drive in rough conditions.

For further information relation to vehicles, click on the hyperlink below:

- The RACV website

How Aeroplanes and Helicopters Fly

Although Aeroplanes and helicopters use the same basic principles of flight, which are lift, weight, thrust and drag, they have very different ways of flying.

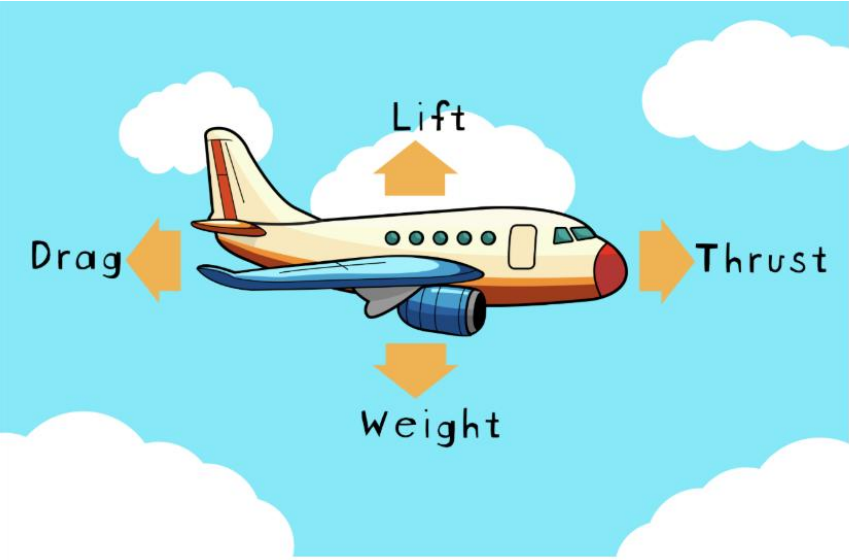


Air flows over the top of the plane's wings, which are curved at the top and flatter on the bottom. The shape of the wings allows the air to flow faster over the top than the bottom. This means the air pressure on top of the wings is less than under the wings. So, the wings (and the plane that is attached to the wings) move up, and that is lift.

The plane's lift needs to overcome the weight of the plane to be able to take off, which is the pull of gravity in the opposite direction.

To propel the plane forward, it needs thrust, which comes from the engine of a jet plane or the propeller of a smaller plane.

The thrust needs to overcome drag, which is caused by the plane moving fast through the air that is pushing against it.



For more on principles of flight, click on the following reference and hyperlink:

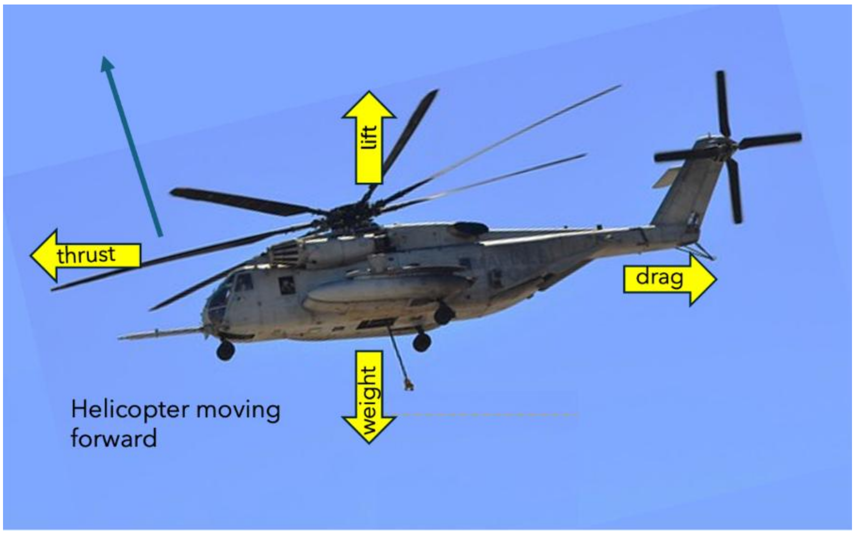
- NASA (2025)

Helicopter rotor blades (also shaped with a curved top and flat bottom) spin very fast to create lift, which overcomes weight.

The spinning blades also create thrust that overcomes drag when the helicopter is flying forward.

The helicopter pilot can control the angle of the rotor blades, and by tilting them different ways, the helicopter can fly forward, backward, or sideways.

Planes need to travel fast down a runway, forcing air over their wings to create lift and allow them to take off. Helicopters have spinning rotor blades that allow them to lift into the air without a runway.



Some Further Useful Information about Helicopters versus Planes

This information is adapted from the following hyperlink:

- Southern Utah University

Helicopters can both take off and land without a runway or any special infrastructure. They can also take off and land in some areas that are not accessible to aeroplanes. However, they do need a clearing and a relatively flat area to be able to land.

Helicopters can move in a range of ways that aeroplanes cannot. Helicopters can take off vertically and make tight turns. They can move sideways and backwards, fly extremely slowly, and hover. Planes need to keep moving at a reasonable speed.

Helicopters are very useful when people and supplies need to get to places that cannot be reached by any other vehicles. Helicopters are used during fire and flood events and for search and rescue missions.

The speed of a helicopter depends on the type of helicopter. Helicopters can fly fast, but they generally do not fly as fast as light planes, but this is not always the case.

Before assigning vehicles, you need to be very aware of the weather conditions and wind strengths in the areas of flight, if using a helicopter or a plane.

Although helicopters at times have flown in extreme weather conditions, it can be dangerous for them to fly in conditions like wild storms, cyclones, lightning, and extremely strong winds. Helicopters are impacted more than aeroplanes by wind and storms because of their design where they use rotor blades that are very sensitive to wind speeds.

A typical distance that a helicopter can go without refuelling is about 400 to 800 km but some specialised long-range helicopters like military helicopters have flown over 1,000 km.

The average height that most helicopters fly for safety reasons is about 1,500 to 22,000 metres above the ground and this also avoids the low oxygen levels of higher altitudes. This can vary with different types of helicopters. Planes can fly at higher altitudes.

Helicopters need to have all items and passengers secured in place for safety reasons as objects can become projectiles in turbulence. It can be challenging for helicopters with turbulence. Planes also need items secured particularly during take-off and landing.

Helicopters and planes need permission to fly in Australia. The Civil Aviation Safety Authority (CASA) governs helicopter and plane operation and all aviation in Australia.

People might be able to fly helicopters or small planes on their own property without permission, but in many other places, helicopters and planes need permission to fly or land, and some national parks might not permit helicopters due to environmental damage such as noise that disrupts wildlife.

Further Helicopter planning can be located in the hyperlinks below:

- The Civil Aviation Safety Authority
- Vertical Aviation Industry

(Also see the Explainer on Drones)

Roads

When planning a route for road travel and deciding which roads to use for your vehicles to travel on, it is essential to be aware of the condition and classification of the roads, particularly in times of flooding.

The following hyperlinks have more information:

- Update on road-related information in Victoria
- Vic Traffic for traffic incidents in Victoria
- NSW Government Transport
- Queensland Government Department of Transport and Main Roads
- The National Heavy Vehicle Regulator (NHVR) is an independent body that provides planners and networks of maps for heavy vehicles in Australia.

Navigation Apps on your phones or computers are also helpful for planning a route for travel and for calculating distances.

Road Incidents

Contacting Police in Victoria, NSW and Queensland:

- Emergency contact in all states: 000

Information relating to traffic accidents in each state are in the hyperlinks below:

- Victoria Police
- NSW police
- Queensland Police
- Vehicle breakdown assistance in each state:
- Roadside assistance in Victoria
- Roadside assistance in NSW
- Roadside assistance in Queensland
- Incident Report Service in Victoria for road incidents

Access to National Parks

You may need a permit to drive a vehicle or land an aircraft (including drones) in national parks in Australia.

The following hyperlinks are to national parks in Queensland, NSW and Victoria:

- Access to national parks in Queensland
- Access to national parks in Victoria
- Access to national parks in NSW

Cyclones and Flooding

Explainer for Students (Years 7-10) and Teachers

Cyclones

You might wonder what the difference is between cyclones, hurricanes and typhoons - these are all tropical cyclones but are called different names depending on where they are.

Near Australia and in the Indian Ocean we have tropical cyclones. In parts of Asia, they call these cyclones typhoons, and in the Atlantic and Eastern Pacific regions cyclones are called hurricanes.

There are several factors that cause cyclones, but the most important factor is the surface temperature of the ocean which needs to be above 26.5 degrees Celsius for a cyclone to form. Cyclones usually form in tropical and subtropical areas because the water is warmer in these areas.

Cyclones are low pressure systems that form over the ocean when it is warm. The low-pressure system causes the warm moist air above the ocean to rise and cool and then the water vapour condenses into water droplets.

As the air rises the low-pressure system starts to spin which draws in more air near the surface to take the place of the air that has risen. This moving air is the strong wind that is characteristic of a cyclone.

The spin is helped by the spin of the Earth. Cyclones usually form at least 500 km away from the equator as the Earth's spin (or Coriolis force) is stronger further from the equator.

Cyclones are given names and in Australia the Bureau of Meteorology names them such as Alfred which crossed the Queensland coast in March 2025.

For a low-pressure system to develop into a cyclone it needs to have very strong winds (sustained winds of more than 118 km/h). Wind gusts of up to 280 km/h winds have been recorded in cyclones.

Cyclones can last several days and usually intensify as they build over the ocean. Sometimes they dissipate (reduce to a rain depression) while over the ocean and do not reach land.

When a cyclone approaches land, it can cause wind damage to trees and property as the winds are so strong. The cyclones often cause beach and foreshore erosion along the coast. Storm surges which are raised domes of water can cause serious coastal flooding.

When a cyclone moves across the land (after initially being intense and possibly causing wind damage) it loses energy as it can no longer draw in the warm moist air that was provided by the ocean and then it rapidly weakens.

The remains of the cyclone (that becomes a rain depression) contain large amounts of moisture that was accumulated when the cyclone was over the ocean.

As this rain depression moves inland it releases the huge amounts of moisture as rain which can be extremely heavy and cause extensive flooding.

The flooding can occur a long way from where the cyclone crossed the coast such as in central and southern areas of Australia.

Click on the sites below for more information on cyclones

- Bureau of Meteorology site on Cyclones
- Fact sheet on how cyclones work (University of Western Australia)
- Australian Climate Service
- Queensland – Preparing for cyclones
- Climate Council Fact Sheets

Flooding

The main cause of flooding in Australia is heavy rainfall. Usually flooding occurs when there is an overflow of water from a lake, river or creek onto land that is usually dry.

Flooding can be either riverine or flash flooding.

Flash flooding is where a river or creek floods very soon after heavy rainfall and might not last very long.

Riverine flooding might happen when the banks of a river breaks and the water flows out and covers the surrounding land. King tides and storm surges can also cause flooding.

Riverine flooding can sometimes take a few days after heavy rain to occur and can last for long periods of time.

In Australia as it is so large it can take weeks or months after rain for the slow-moving flood waters to reach inland rivers.

Click on the following sites to find out how states/organisations prepare for floods

- Bureau of Meteorology with key information for each state
- Preparing for floods in Victoria
- Preparing for floods in NSW
- Traveling in times of floods

Technical Documentation: Drones

Common Content for Teachers and Students

Drone usage in the STEM Challenge will be a likely source of data and potential transportation.

Contained in this document will be information about:

1. Definition
2. Drone Sizes
3. Telemetry
4. Drone Piloting
5. How Drones Fly
6. Drone Flight Stabilisation
7. Drone Navigation
8. How a drone works with GNSS
9. Geofencing
10. Battery Life and Limitations

Key Facts

Drones can be useful for surveillance, inspections, search and rescue, mapping and lifting.

The battery is a big constraint in drone design and performance.

Satellite navigation improves flight accuracy, improves stable hovering, and ensures automatic return to the launch point when the signal is lost or the battery is low.

What is a Drone?

A drone is an unmanned aerial vehicle (UAV) that flies without a human operator on board and can be flown by a human pilot or autonomously using sensors. Drones are used for surveillance, inspection, search and rescue, mapping, and lifting.

How Drones fly

The below videos illustrate how drones fly.

Drones explained in five minutes. Hey! Guess What

https://www.youtube.com/watch_popup?v=ubPYuJ4mDgI

Drones: The complete flight dynamics. Sabine Civil Engineering
https://www.youtube.com/watch_popup?v=C0KBu2ihp-s

Drone Size

Drones come in different sizes related to their use. The size determines how drones are licensed and regulated in Australian airspace.

The standard way to size drones is by the diagonal measurement. This determines the class of drone and how much payload it can carry.

The diagonal drone measurement is the distance between two motors diagonally opposite each other on a multirotor drone, which is usually a quadcopter (quad = four).

To measure your drone: Place the drone on a flat surface, then use a ruler or measuring tape to measure from the centre of one motor to the centre of the diagonally opposite motor.

Nano drones have a diagonal measurement of less that 20 cm (200mm) while large drones have a diagonal measurement over 2 metres (2000mm).

Telemetry

Telemetry is the term for the real-time transmission of data between a drone and a ground station/controller.

Telemetry is important for flight awareness - knowing where the drone is and how it's performing, and safety as real time warnings like low battery or a weak signal help prevent crashes.

Drone piloting

An operator, known as a drone pilot, can control a drone using a joystick that sends radio signals (900 MHz, 2.4 GHz or 5.8 GHz) to a receiver on the drone.

A pilot can control a drone from a laptop, or a from ground station connected by Wi-Fi, Bluetooth, cellular or satellite telemetry.

Electronic signals control drone flight, including altitude (height from the ground), yaw (the rotation left or right), pitch (forward or backward tilt), and roll (left or right tilt).

Drones send real time signals back to the operator.

The signals include flight metrics (altitude, speed, and orientation); environmental information (temperature and humidity); system status (battery usage and signal strength) and data logging for postflight analysis and regulatory compliance.

A drone camera typically shows a live video feed from the drone's point of view. Waypoints and flight paths can be pre-programmed and monitored with good satellite navigation coverage.

Drone flight stabilisation

To avoid crashing, drones are equipped with sensors to stabilise their flight.

Sensors include global navigation for position hold, return-to-home, and waypoints; an inertial measurement unit (IMU) for stability; an altimeter to maintain or change altitude; and obstacle sensors to avoid collisions.

An IMU is an electronic device that measures linear acceleration (speed changes), angular rotation rate (angular velocity), and orientation in the Earth's magnetic field using an accelerometer, a gyroscope and a magnetometer. These data are crucial for maintaining stability and control during flight.

The IMU is the most important sensor on the drone.

See: What is an IMU? https://www.youtube.com/watch_popup?v=l-9f_iXdTow

Consumer type drones use low powered MEMS (micro-electro-mechanical system) IMUs. Quartz MEMS IMUs offer greater reliability and tactical-grade IMUs offer higher precision and accuracy for full autonomous navigation.

Drone Navigation

Global Navigation Satellite Systems (GNSS) are satellite-based navigation systems that provides precise location data, including latitude, longitude, and altitude, to electronic devices on Earth.

Drones equipped with GNSS receivers connect to a network of satellites to determine their position. The information is used by a drone's electronic flight control system to navigate, maintain altitude, and return to home.

Satellite navigation improves flight accuracy, improves stable hovering, and ensures automatic return to the launch point when the signal is lost, or the battery is low.

Autonomous flight is when a drone flies a pre-programmed route or follows pre-defined flight plans using GNSS.

How a drone works with GNSS

The Earth is surrounded by GNSS' satellites that continuously send out information about the satellite's location and the exact time of signal transmission.

The GNSS unit inside the drone receives signals from multiple satellites simultaneously.

The more satellites a drone can connect to, the more accurate the positioning.

The in-drone satellite navigation unit calculates the time it takes for each signal to travel from the satellite to the drone. By measuring time, the drone determines the distance to each satellite.

Using these distances from at least four satellites, the drone triangulates its exact location in three-dimensional space on the Earth's surface. The drone then 'knows' its latitude, longitude, and altitude.

Drones use satellites from different agencies for faster lock-on and increased accuracy. This is called multi-GNSS use. [See Satellite Technical Documentation]

Geofencing

The creation of virtual, geographic boundaries is known as geofencing - a geofence is a digital (electronic) boundary.

Geofencing restricts a drone's flight area. This prevents the drone from flying too far away or from flying into restricted zones such as Special Protection Areas (SPAs), Special Areas of Conservation (SACs), and Sites of Community Importance (SCIs).

Battery life and limitations

Drones run on electricity provided by onboard batteries. The battery is a big constraint in drone design and performance. Many drones use multicell LiPo (Lithium polymer) or Li-ion (Lithium ion) batteries.

Voltage depends on the number of battery cells and is the electrical potential needed to power the motors, the flight controller, camera, and other onboard systems. Voltage is a critical factor in determining how powerful, efficient, and stable the drone is during flight. More battery cells give higher voltage.

Capacity is measured in milliamp-hours (mAh). The higher the mAh, the longer the possible flight. Heavier batteries provide more energy but reduce efficiency due to extra weight.

Pilots need to consider how long a fully charged battery will power a drone flight. Variables include drone weight, payload weight, wind strength, drone speed, age of battery and temperature as cold reduces battery performance.

Managing batteries and battery charging is an important part of drone piloting.

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Technical Documentation: Electromagnetic Spectrum (EMS)

Common Content for Teachers and Students

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Key Facts

We give off electromagnetic radiation by maintaining our body temperature. The heat we give off is thermal energy in the form of infrared radiation.

When satellite communication is not working in severe weather events, people can use two-way radio communication with portable radios, as it can sometimes be the most reliable communication in floods, storms, or other emergencies.

Thermal electromagnetic energy is vital for life on Earth.

Waves – Electromagnetic Spectrum

There are many types of waves in our world. Think about waves in the ocean, these are called mechanical waves, but they need solids, liquids or gases to travel through. Sound waves are also mechanical waves, and they can travel through gases, liquids or solids.

Whales can hear calls from other whales up to 1,000 km away underwater, as waves can travel well in water, better than they can in air. In space, there are no particles to carry the sound so sound cannot travel through space.

As we explore electromagnetic spectrum in this document, we are looking at different waves. This includes types of waves that are all around us, as well as those that can travel through space, solids, liquids and gases. These waves are called electromagnetic waves or electromagnetic radiation.

We might think that electromagnetic radiation is something that is dangerous, but we need it to survive.

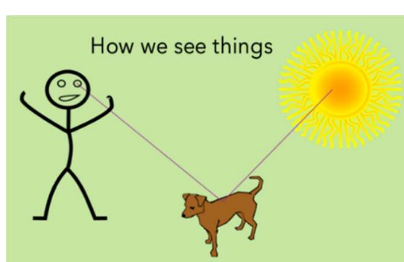
There are a several types of electromagnetic waves, many you may have heard of. Some we can see, these are visible light waves. But we can't see many of them including Radiowaves, Infrared (heat), Ultraviolet light, X-rays, Microwaves and Gamma Rays.

Electromagnetic Spectrum We Can See - Visible Light

The visible part of the Electromagnetic Spectrum is very important to our survival on Earth.

The sun is the main source of visible light for us. There are other natural sources of visible light such as fire and artificial visible light from light bulbs that humans generate particularly at night.

We see the visible light from the sun when it is reflected from objects, and into our eyes. Our brain plays a crucial role in transforming the light reflected from the object into the visual image that we can see.

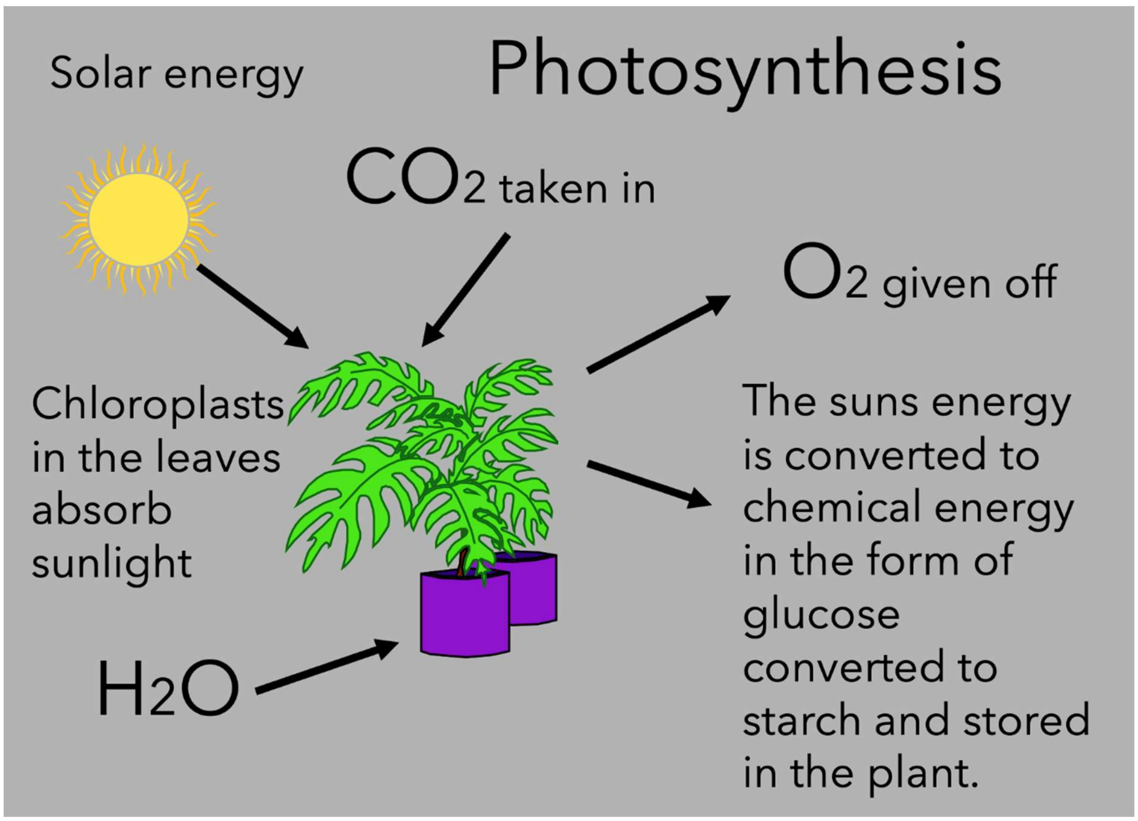


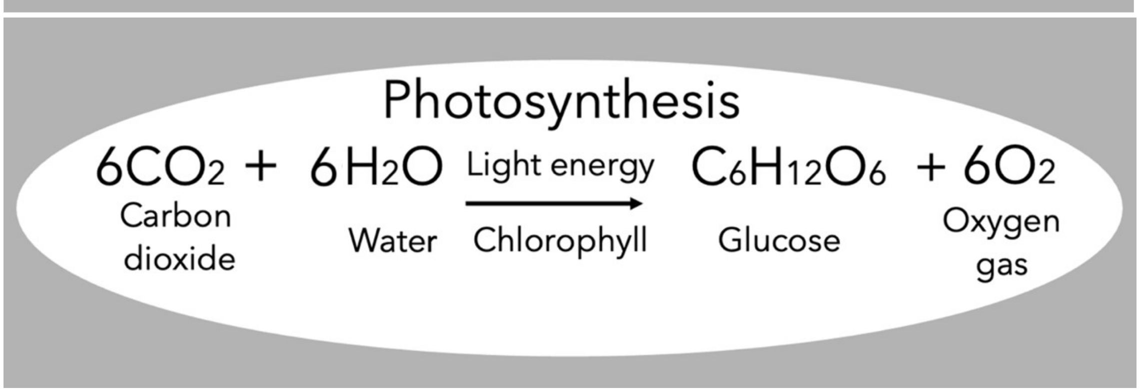
There are different forms of electromagnetic radiation, but first, it is important to understand how vital visible light is to our survival. Visible light energy is electromagnetic radiation and is made up of little packages called photons. Plants use this energy from the sun to produce their food through a process called photosynthesis.

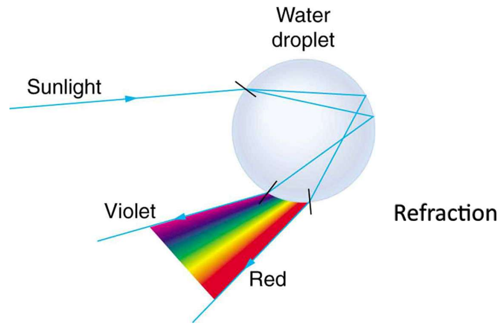
Green pigment called chloroplasts in the leaves of plants absorb this visible light and they use carbon dioxide and water to make glucose and oxygen gas.

When converting the sun's energy to food, plants take carbon dioxide gas out of the air and give off oxygen in the process.

Plants store glucose as starch. Most living things, including us, need to get this energy to live, through eating the starch stored in plants.







When visible light goes through a prism it separates into different colours.

Satellites use the visible light that is reflected from the surface of the Earth for photographs and observations. Scientists use special instruments that use visible light to learn about the composition of planets and their atmospheres. Visible light also is used to calculate the heat of various objects in space.

Humans have been making use of electromagnetic radiation technologies for millions of years such as generating heat and light by making fires and of course using light and heat energy from the sun (like other living things).

Over the last three centuries, humans have developed various technologies using electromagnetic waves, in particular, for medical practices and communication.

Electromagnetic radiation plays a huge role in our lives in so many ways with things that we have come to depend on all day, every day.

Electromagnetic Spectrum That We Cannot See

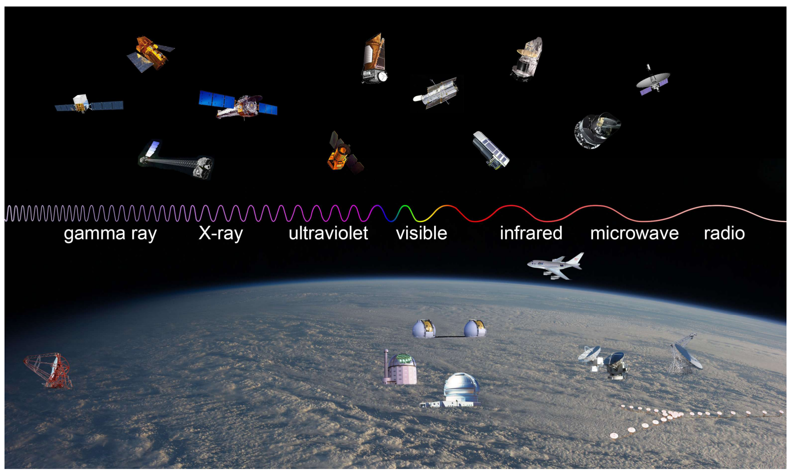
Most of the electromagnetic spectrum we cannot see. We use electromagnetic spectrum when we watch TV, send a text message, use a microwave to heat up noodles, use a radio, have an Xray, and in many other ways.

The sun provides the full spectrum of electromagnetic energy including visible light, but it also bombards the atmosphere with other electromagnetic waves such as ultraviolet waves, gamma rays, and x-rays.

These waves can be harmful, but the Earth's atmosphere protects us against most of these harmful waves.

The gases in the atmosphere absorb most harmful electromagnetic radiation with small wavelengths but allow waves which are not harmful and have longer wavelengths to pass through, such as radio waves, infrared light, and visible light.

The atmosphere keeps us protected on Earth but satellites in space have been used to study electromagnetic radiation as they measure the electromagnetic energy outside of the Earth's atmosphere.

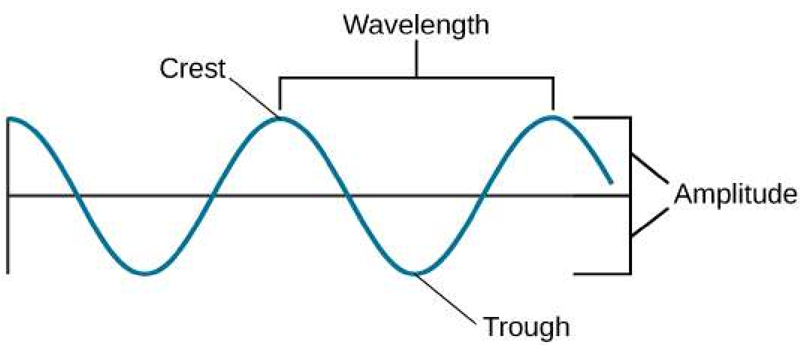


For more information on thermal radition emissions, See this hyperlink:

- NASA (Shuk-min, 2010, Hong Kong Observatory)

Wavelength

It is important to understand wavelength when looking at electromagnetic waves. Wavelength is a measure of the distance between the crests of a wave. The crest is the top of a wave. Think of waves in the ocean they have peaks at the top which are the crests, and troughs at the bottom. Electromagnetic waves also have crests and troughs.



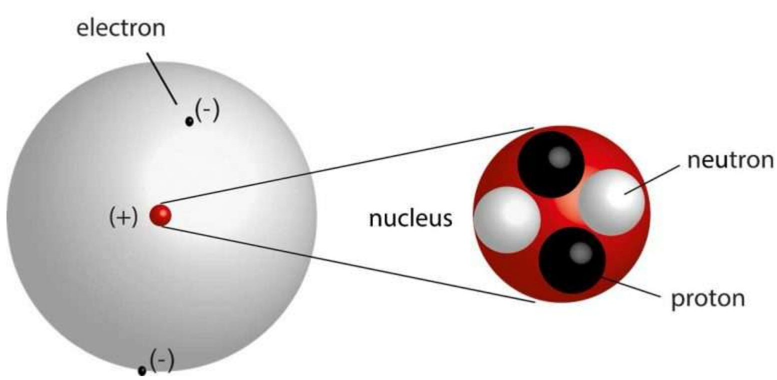
(NASA)

Electromagnetic waves come in many different wavelengths. Some wavelengths are longer than the diameter of the Earth and some wavelengths are miniscule (shorter than the size of atoms).

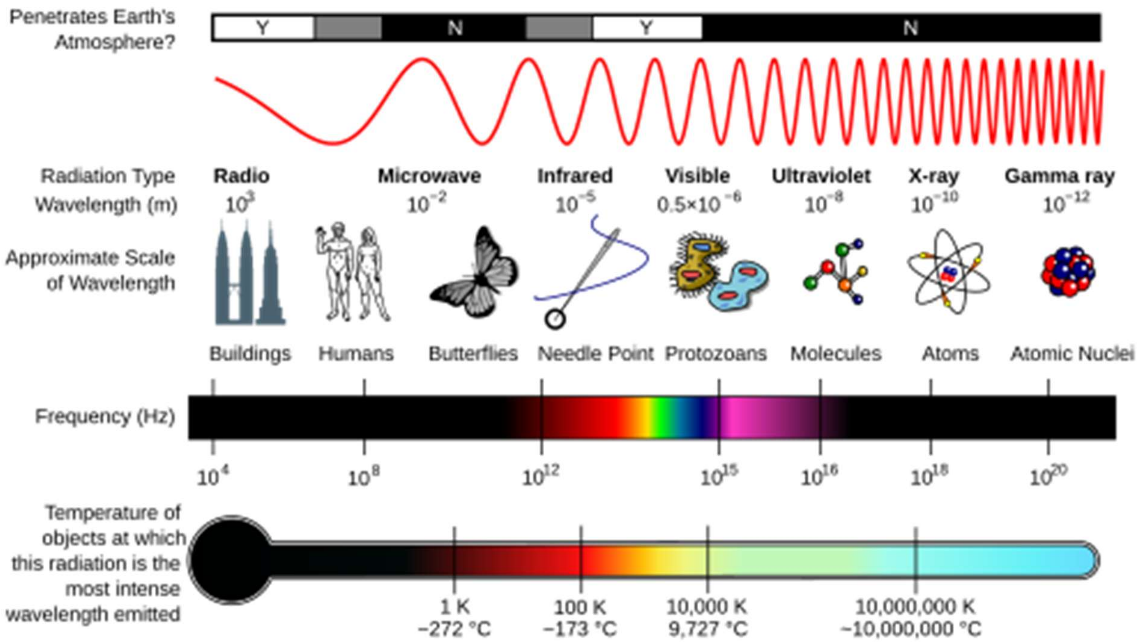
Frequency

Frequency of a wave refers to the number of crests of a wave that pass a certain point every second.

Electromagnetic waves are generated from the energy when particles move such as electrons and protons with a positive or negative charge. These moving particles create electromagnetic fields, and these fields carry energy from place to place.



Sometimes electromagnetic radiation is referred to as electromagnetic waves or light. It is all the same thing, electromagnetic energy. When referring to electromagnetic waves, light waves, it is the whole electromagnetic spectrum that is being referred to, and only a portion of electromagnetic light waves are visible light that we can see.



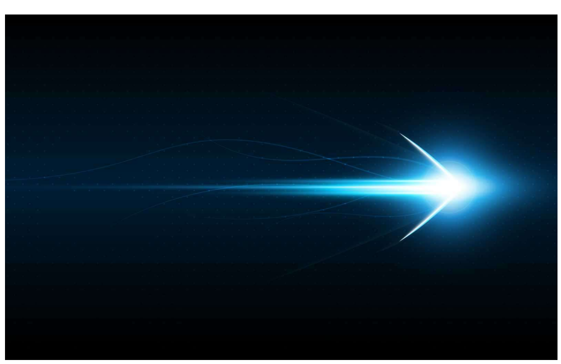
Understanding the behaviour of light waves to be familiar with how they are used in communications is important. Light waves (electromagnetic waves) behave in a certain way.

These waves can be reflected, absorbed, diffracted, scattered and refracted.

NASA has provided clear descriptions in the following link about these very important wave behaviours.

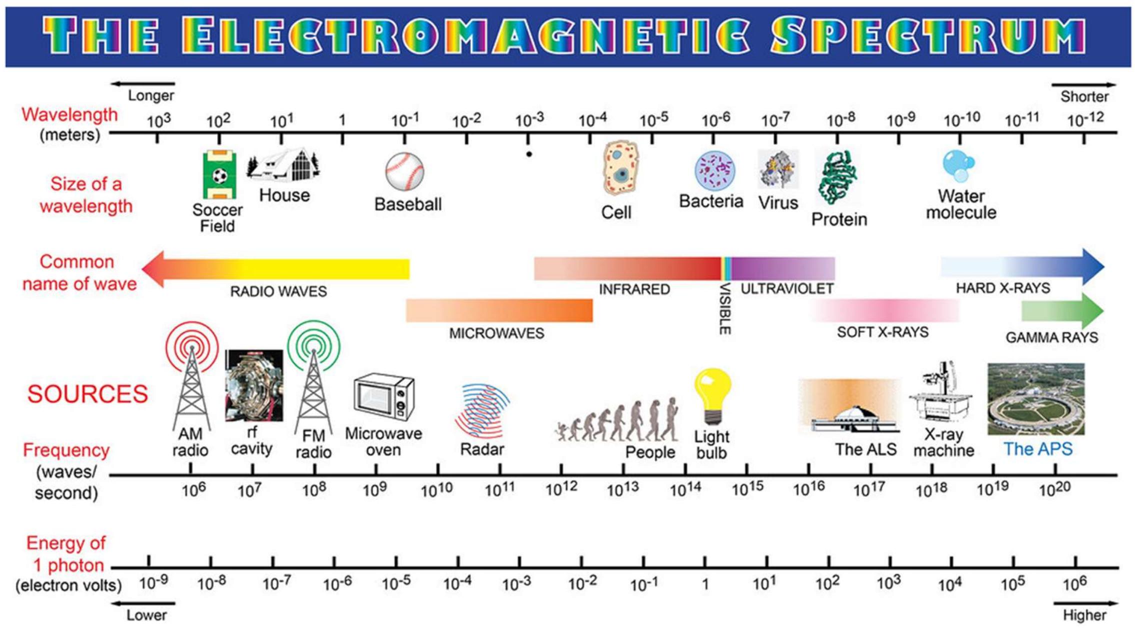
- https://science.nasa.gov/ems/03_behaviors/

Interestingly, even though the wavelength of electromagnetic waves differ considerably in length and frequency, all electromagnetic waves travel at the same speed, the speed of light, which is around 300 million metres every second. Sound waves (which are mechanical waves) travel much, much, slower at only 344 metres every second.



We cannot see electromagnetic waves that have longer wavelengths than visible light, such as radio waves, microwaves, and infrared waves or that have shorter wavelengths than visible light, like ultraviolet light, x-rays and gamma rays.

Another diagram of the spectrum has been included here as it is good to look at a range of diagrams to get a thorough understanding of various features of electromagnetic waves.



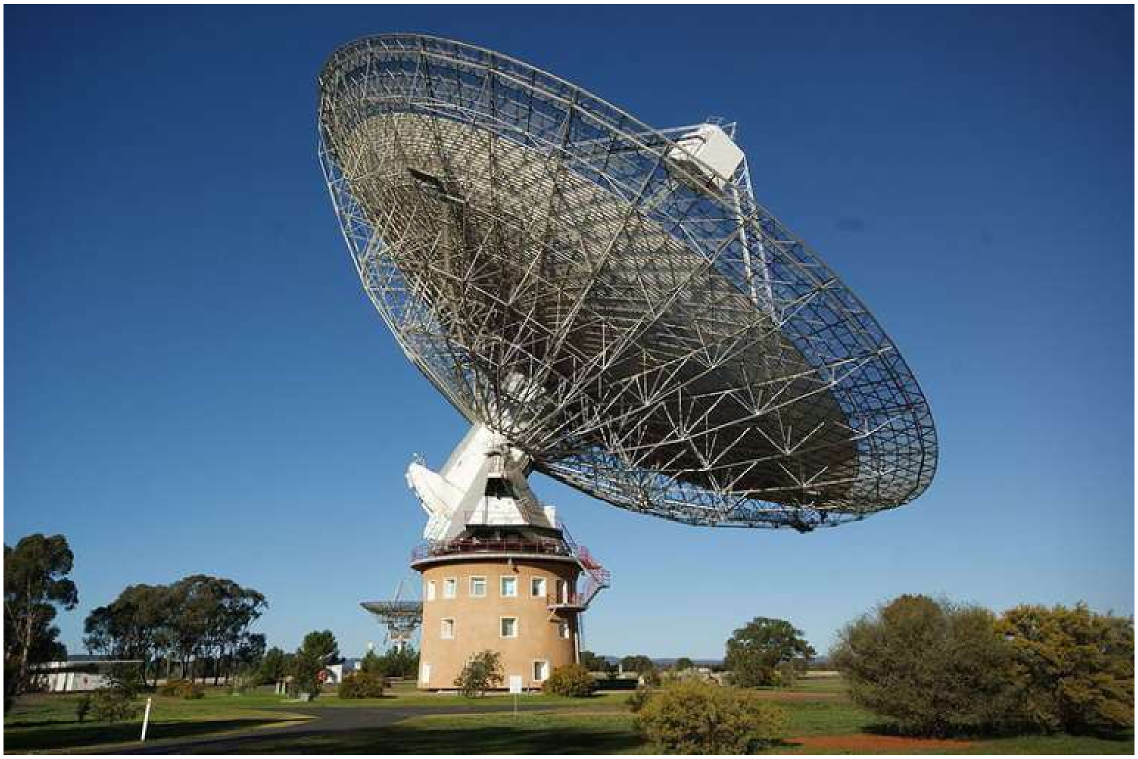
Radio waves

Radio Waves have the longest wavelengths of all electromagnetic waves. The sun emits radio waves as do other stars. Radio waves are significant when it comes to communication technologies and were first used as artificial communication technology in the 19^{th} Century.

Radio waves are generated by a transmitter and travel through the air or atmosphere from an antenna where they are received by a receiver antenna and processed by a radio receiver.

Radios can be tuned to different frequencies for different radio stations and the signals carried by the radio waves are converted to mechanical sound waves in the radio device. You might tune into radio when you are in a car. Radio waves are used for radios, television broadcasting, communication satellites, wireless computer technology, and radio navigation systems.

Radio telescope observations are not impacted by sunlight, clouds or rain. Radio telescopes are used for observations in the universe. The Parkes telescope, in Parkes NSW, has been used for 60 years including working with NASA during the Apollo 11 mission in 1969 (when humans landed on the moon), and with NASA space missions more recently.



(Parkes Radio Telescope Australia)

Sometimes when satellite communication is not working in severe weather events, people can use two-way radio communication with portable radios, as it can sometimes be the most reliable communication in floods, storms, or other emergencies.

A portable two-way radio can both send and receive radio waves and radio signals. Each handset has an antenna, transmitter, and receiver, and the radio signals go directly from one radio handset to the other.

Mobile phones also receive low powered radio waves carrying radio signals from a cell tower and convert the radio signals to sound waves, so you can hear the voice of the person you are speaking to.

Your mobile phone also converts your voice to a radio signal and transmits the radio signal via radio waves to the cell tower and then it is sent through the network and connected to the phone of the person you are talking to.

As radio waves travel at the speed of light (like all other electromagnetic waves), it makes them very effective for communication.

Microwaves

Microwaves of course, are used by many people daily in microwave ovens to heat food. Microwaves are a form of radio waves but have shorter wave lengths. Some microwaves (such as medium length microwaves) can pass through clouds and dust which means they are excellent for use with our communication satellites and space observations.

Mobile phones use radio waves to communicate to a mobile cell, and mobile cell towers use microwaves to communicate with satellites.

Click on the following hyperlink for more information: BBC bitesize.

As some microwaves can pass through even the dense clouds of a cyclone, the weather underneath the clouds of a cyclone can be observed. Although some microwaves can also be impacted by bad weather.

The Global Satellite System microwaves, that people use for navigation in their cars, can also pass through the trees to the soil underneath to measure soil moisture.

Radars are instruments that give off a microwave pulse and the energy that reflects from objects in its path such as rain, is sensed by the radar.

Australia uses remote sensors such as radars and scatterometers for weather observations. Scatterometers make use of the scattering behaviour of electromagnetic microwaves from the surface of the Earth to calculate windspeed and direction.

Infrared Waves

We cannot see infra-red light with our ordinary eyes, but we know it is there as we feel it as heat. Visible red light (which has the longest waves in the visible spectrum) has shorter wavelengths than infrared radiation.

Infrared means 'beyond the red', therefore as it is beyond red light on the spectrum we cannot see it. **The sun is the main source of infrared radiation.**

Infra-red can penetrate through dust and gas in space so are used in some telescopes. Television remote controls use infra-red waves so we can change the channel.

When we are sick with a high fever infrared thermometers or cameras can be used to calculate our body temperature.

Cool Facts:

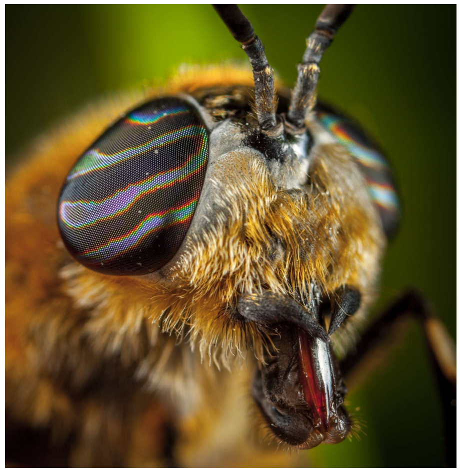
- Mosquitos and some snakes such as pythons can detect the infra-red radiation from other animals such as birds and mammals.
- We can use infrared cameras to allow us to detect animals by their warmth in the dark.
- Some satellites use infrared waves to detect bushfires.

Ultraviolet Light

Ultraviolet Light is not able to be seen by humans with our ordinary eyes. The name ultraviolet means it is beyond violet. Visible violet light has the shortest wavelengths that we can see but ultraviolet light has even shorter wavelengths, so we cannot see it.

Cool Fact:

- Insects, some birds, and reptiles, can see ultraviolet light. This ultraviolet light can guide these animals to flowers for pollination.



Ultraviolet light is classified into three groups, UV-A, UV-B, and UV-C. UV-C is the most harmful of the UV rays and has the shortest wavelength. UV-C rays are almost completely absorbed by our atmosphere.

The rays that cause sunburn are UV-B. Most of these rays are absorbed by ozone gas in the atmosphere but we need to ensure we protect ourselves from any harmful rays that do get through, by wearing hats and sunscreen when in the sun.

UV-A is not absorbed by the atmosphere and reaches the Earth's surface. UV-A is the longest of the UV rays and is not harmful ultraviolet light.

Scientists use an ozone sensing instrument aboard a NASA satellite which senses ultraviolet radiation to monitor the chemistry of the Earth's atmosphere including the amount of ozone gas in the atmosphere.

NASA uses telescopes with both ultraviolet and visible light to learn about the structure and formation of galaxies in space. Ultraviolet light shows the clouds of gas where stars are formed as they glow brightly in the ultraviolet light, whereas visible light shows the yellow and red light of older stars. By using both types of electromagnetic waves scientists can compare the images to learn more about galaxies in space.

Hyperlink: NASA Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA/JPL-Caltech/Steward/O.Krause et al

X-rays

X-rays have even shorter wavelengths than ultraviolet rays and we cannot see them. When a star explodes in a supernova it sends x-rays across the galaxy and these x-rays provide information for scientists about the supernova.

X-rays are used frequently for medical and dental purposes. X-rays reveal broken bones and dentists can check our teeth more effectively using x-rays.

NASA's Rover on Mars used x-rays to identify minerals such as zinc and nickel in the rocks on the red planet.

X-rays have been explored for use in place of radio waves such as when radio waves are disrupted during re-entry of a spacecraft through the Earth's atmosphere (Hyperlink Wei Zhou, 2019).

Gamma Rays

Gamma Rays are the shortest waves in the electromagnetic spectrum and have the greatest energy. They are created by the most violent and hottest events in the universe such as neutron stars, pulsars, supernovas, and the area around black holes.

Photo of lightning by Alan Logan

Gamma rays travel through space and are absorbed by the Earth's atmosphere. Gamma rays are produced in the corona of the sun and are also generated by lightning, during nuclear explosions, and by radioactive decay.

The element, Uranium, produces a small amount of gamma rays during radioactive decay. Gamma rays are used in medical technology such as radiation therapy and can be effective in treating cancer.

Gamma rays travel through things more deeply than other forms of radiation. Gamma rays have been used to find out what other planets are made of and the type of soil on Mars.

Gamma rays are not usually used in communications as they have high energy and extremely short wavelengths which makes them not suitable.

An artist's imaginary drawing of a black hole

AROSE
Australian Remote Operations for Space and Earth

AVISTA

Technical Documentation: Satellites

Common Content for Teachers and Students

Understanding how satellites function and are used will be beneficial in choosing a plan conducive to maintaining timely reports of the weather situation, as it evolves, visual data for terrain and security of information.

Contents

Introduction 2
What is GPS? 2
What are Orbits? 3
Types of Satellite Orbits 4

When learning about satellites for communication, it is good to start with GNSS - the **Global Navigation Satellite System**.

The Next Generation Science video in this link is an excellent video to explain how GPS works.

When it comes to satellites, we need to understand orbits.

Introduction

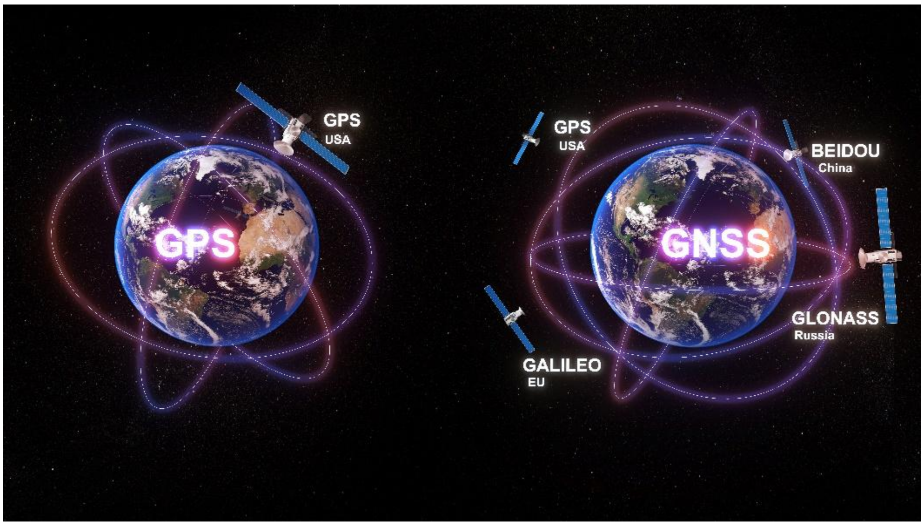
When learning about satellites for communication, it is good to start with GNSS - the **Global Navigation Satellite System**.

GNSS: You have probably heard of GPS (Global Positioning System). GPS is just one type of global radio navigation satellite system that is widely used and the most widely used GNSS in Australia.

Australia accesses a range of GNSS, in addition to GPS. Australia has accessed Russia's (GLONASS), Europe's (Galileo), China's (BeiDou) and regional navigation systems developed by Japan (QZSS), and India (IRNSS). Using more than one navigation system increases reliability and accuracy in positioning.

The information in the GPS video (below) has been adapted in the following summary:

> A few decades ago, to find their way around, people in cars or on foot used street directories which were like books with maps of our towns, or large paper maps.
>
> GPS changed all that and now people use phones and computers to find directions. GPS can give you the exact position of where you are on Earth.



What is GPS?

GPS uses many satellites orbiting Earth to work out where we are on Earth. Our mobile phone (or navigation system in the car) picks up signals from satellites above.

Each time we want to find out where we are, our phone picks up signals from at least four satellites above. Each satellite receiver works out how far away the phone is, and by using geometry and a grid system based on latitude and longitude, the satellite receivers calculate where we are.

GPS was first developed by the United States Department of Defense. In the 1980's the United States Government decided to allow everyone all over the world to have access to GPS as it was such a useful system.

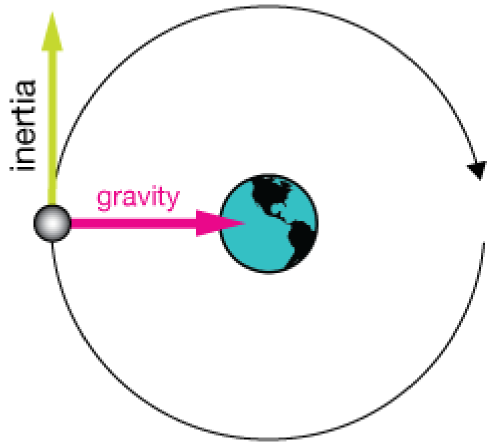
In addition to finding our way around, GPS is now used widely by many people and services. GPS connects us to ride share and food deliveries, or helps our parents know where we are. GPS helps scientists study animals, habitats, earthquakes, or cyclones. It can help farmers work out where to plant crops and keep track of ripening crops.

The VirtualBrain [ENG] video in this link gives a very detailed explanation of GPS and how it uses geometry to work out our positioning on Earth. You might like to look at part of it or the whole video if you want some highly technical information about how GPS works.

What are Orbits?

The European Space Agency website explains orbits. The information is summarised below:

An orbit is when an object in space such as a satellite, asteroid, or planet, because of gravity, travels in a curved direction around another object in space. The moon orbits the Earth. The Earth orbits the sun. Satellites orbit the Earth.



As a result of gravity, objects in space that have mass move towards each other. If the force of gravity has enough momentum, it can cause objects to orbit each other.

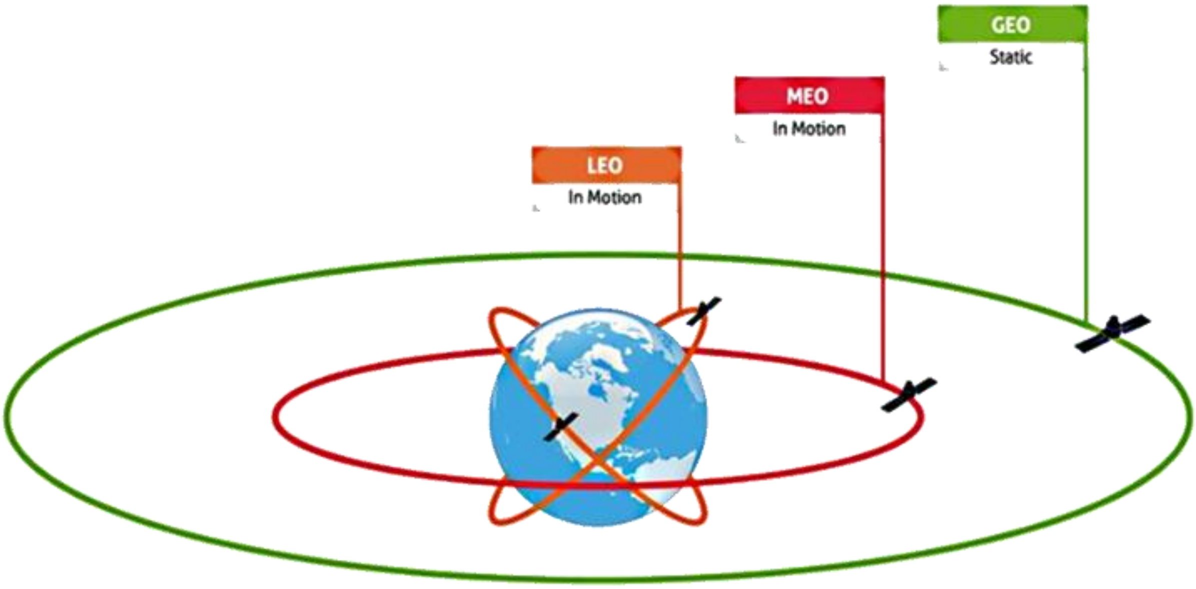
Two objects around the same size might orbit each other without either one being in the centre of the other's orbit. Objects with a smaller mass generally orbit objects with a greater mass like the Earth and other planets orbiting the sun, or satellites orbiting the Earth.

Rockets travel through the dense part of the Earth's atmosphere and launch their satellites hundreds or thousands of kilometres above the Earth. Gravity keeps the satellites in orbit around the Earth.

The satellite is essentially falling due to gravity, but it never reaches the ground due to its sideways motion. Although gravity helps keep it in motion, it moves fast enough to defeat the gravitational pull towards the Earth and stay in the curved path around the Earth.

Types of Satellite Orbits

When it comes to satellites orbiting the Earth, there are different kinds of orbits. It depends on where they are positioned as to how effective they are for their purposes. To learn more about how satellites stay in orbit you may want to visit this United States National Environmental Satellite Data and Information Service site.



See the link that provides information about satellite orbits by SES (which is a satellite communication service provider). This information has been adapted below:

GEO: The Geostationary orbit that is called GEO is about 36,000 km above the Earth. The GEO satellites rotate at the same speed as the Earth rotates, so it is like they are stationary above the Earth because they are moving with the Earth.

As they are so high, they cover a larger area of the Earth's surface. There does not need to be very many. The GEO satellites and antennas are very large. GEO satellites are used for observing weather, television broadcasting, and some communication that requires slower speeds.

MEO: The medium Earth orbit satellites (MEO) are often used for navigation like GPS and other satellite systems. MEO satellite orbits are between GEO and LEO satellites. They are about 5,000 km to 20,000 km above the Earth and are large satellites.

MEO Satellites can circle the Earth twice in one day. MEO satellites are also used by offshore platforms in the ocean, and for emergency relief operations. They have been used by service providers for Government and Commercial use, and for communication.

LEO: Low Earth Orbit satellites (LEO) are in the orbit closest to Earth. They are about 500 to 1,200 km above Earth. There are thousands of LEO satellites, and they are smaller satellites and cheaper.

LEO satellites are used for communication, particularly in areas where there is no access to mobile cell phone coverage. They are also used increasingly for Internet access.

The lowest LEO satellite is in orbit around ten times higher than a plane flying. Because LEO satellites are closer to Earth, compared with the orbits of MEO and GEO satellites, it allows for high resolution images (very clear images) in LEO.

The International Space Station (ISS) is in LEO. The ISS orbits the Earth around 16 times a day. There is a risk of more space debris as there are so many satellites and spacecraft in LEO and there are already millions of pieces of space junk in LEO.

It is important to be aware of Jamming and Spoofing. Read Technical Documentation: Jamming and Spoofing for more information.

Reference: Photos and diagrams used in this document are licensed under CCBY and Adobe.

Communication Technologies: Principles of Telemetry

Common Content for Teachers and Students

Contents

Telemetry 2

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Radio Wave Telemetry 3

Key frequency ranges within the radio wave spectrum 4

Electronic Sensors 5

LiDAR 6

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Telemetry is the wireless transmission of data using sensors, transmitters, antennae and receivers.

BLOS stands for beyond line-of-sight wireless communications.

BVLOS stands for beyond visual line-of-sight wireless communications.

Wireless communication in the 21st century relies on the mass generation of artificial electromagnetic radiation from technological devices.

Telemetry

Telemetry is the wireless transmission of data using sensors, transmitters, antennae and receivers.

Telemetry is used to monitor the location, performance and stability of satellites, spacecraft and aircraft.

As well as defence, telemetry is used to gather information for civilian transportation systems, Earth and space navigation and communication, meteorology, agriculture, IT systems and healthcare systems.

Safe wireless transmission relies on devices to sense then encode data into lower frequency, electromagnetic radiation waves generated by transmitters.

Packets of data are sent at the speed of light from transmitter antenna to receiver antenna, where a designated receiver and processing unit decodes and utilises this data.

Revising the fundamentals

Electromagnetic radiation (EMR) is the wave-like flow of packets of energy (quanta) at the speed of light.

The range of frequencies of electromagnetic radiation extends from very low values from radio waves, television waves, and microwaves to infra-red, visible light, and ultraviolet light to the much higher frequencies of x-rays and gamma rays.

The speed of electromagnetic radiation (c) at every frequency (v) is a universal constant – speed does not vary.

The speed of light is exactly 299,792,458 metres per second (m/s).

$c = \lambda v$ where λ is wavelength and v is frequency of temporal change in the wave function.

The natural source of electromagnetic radiation is the sun.

Wireless communication in the 21st century relies on the mass generation of artificial electromagnetic radiation from technological devices.

The creation of artificial electromagnetic radiation requires an energy source.

In electronic communications technology, the energy source is electrons that come from mains electricity, a battery or a solar panel.

Further elaboration on the EMS

- National Aeronautics and Space Administration (NASA) Science series on the Electromagnetic Spectrum. NASA Science: The Electromagnetic Spectrum Introduction https://science.nasa.gov/ems/
- Tour of the Electromagnetic Spectrum (pdf) https://science.nasa.gov/wp-content/uploads/2023/08/tour-of-the-ems-tagged-v7-0.pdf
- NASA Science EMS Series: Wave Behaviours https://science.nasa.gov/ems/03_behaviors/

Radio Wave Telemetry

Radio waves are a form of electromagnetic radiation (EMR) located at the lower frequency end of the electromagnetic spectrum (EMS).

Radio waves are used for long range communications because they have the lower frequencies and the longest wavelengths and are generally safe for living things.

We now live in a dense field of radio waves.

For further explanation, see the website:

NASA Science EMS Series: Radio Waves https://science.nasa.gov/ems/05_radiowaves/

Key frequency ranges within the radio wave spectrum

Low Frequency (LF): Below 300 kHz

Medium Frequency (MF): 300 kHz to 3 MHz

High Frequency (HF): 3 MHz to 30 MHz

Very High Frequency (VHF): 30 MHz to 300 MHz

Ultra High Frequency (UHF): 300 MHz to 3 GHz

Super High Frequency (SHF): 3 GHz to 30 GHz

Extremely High Frequency (EHF): 30 GHz to 300 GHz

Frequency (v) refers to the oscillation rate of the wave past a fixed point.

Frequency is measured and expressed in Hertz units (Hz).

One Hz = one wave cycle per second.

One kilo Hertz (kHz) is 1000 wave cycles per second.

One mega Hertz (MHz) is 1,000,000 wave cycles per second.

One giga Hertz (GHz) is 1,000,000,000 wave cycles per second.

The unit Hz is named after the German Physicist Heinrich Hertz (1857-1894) who demonstrated that light and heat are forms of electromagnetic radiation and who built the first radio antennas for transmitting and receiving radio waves.

Radio waves are generated artificially by an electronic device called a transmitter.

The radio waves are emitted, that is, or radiated, by an antenna or aerial.

Radio waves are received by another antennae or aerial connected to a radio receiver. The signal is then processed.

The mathematics of operating and building antenna for different purposes and technologies can be quite complicated.

Videos to explore

- Radio Antenna Theory 101. Electronic Notes https://www.youtube.com/watch_popup?v=6v75TcVn72A
- How Does an Antenna Work? weBoost https://www.youtube.com/watch_popup?v=PPKEpJEt_cM

The radio wave transmission communication system was invented by Italian electrical engineer Guglielmo Giovanni Maria Marconi, 1st Marquess of Marconi (1874 - 1937) who shared the 1909 Nobel Prize in Physics with German physicist and electrical engineer Karl Ferdinand Braun (1850 – 1918) for their work in developing modern telemetry.

Electronic Sensors

A sensor is a device that receives and responds to a signal or stimulus.

The signal or stimulus is some type of physical property, quantity or condition that is able to be sensed.

Sensors can be natural (organic in origin) or artificial (designed and built by humans).

An artificial sensor is designed and built to be sensitive only to the measured physical property and should not influence the measurement of that property (a sensor is not quantum).

Electronic sensors are designed by electrical engineers.

An electronic sensor converts a property to be measured, such as electromagnetic radiation (heat, light, radio waves, x-rays, gamma rays), sound, motion and touch into electrical signals. These signals are passed through an interface that converts them into a binary code for processing and transmission.

A transducer is a sensor component that changes one form of energy into another.

A sensor can have a detailed resolution, but the accuracy of the sensor is dependent on how the digital output can be resolved and transmitted. Sometimes the accuracy of a sensor is lower than its resolution.

Because they are electronic equipment, sensors can be sensitive to environmental conditions such as changes in temperature.

References to explore

- Electricity and Sensors, New Zealand Government Science Learning Hub https://www.sciencelearn.org.nz/resources/1602-electricity-and-sensors
- A sensor can be active or passive. What are passive and active sensors? NASA https://www.nasa.gov/general/what-are-passive-and-active-sensors/
- How do motion sensors actually work? History of Simple Things https://www.youtube.com/watch_popup?v=vfDgmuE3N0Q
- How does Bluetooth Technology Work? History of Simple Things https://www.youtube.com/watch_popup?v=ObcBJyVS10E

LiDAR

Light waves are a form of electromagnetic radiation (EMR) that we can sense with our eyes (natural sensors) and with artificial sensors.

LiDAR stands for Light Detection and Ranging and is a remote sensing technology that excels in challenging environments.

LiDAR units are typically mounted on a drone, airplane or ground moving vehicles and creates precise, three-dimensional landscape information and is commonly used for mapping topography and other scientific inquiry.

LiDAR uses light energy in the form of rapid laser pulses (over 100,000 pulses per second) to measure distances thereby forming a picture of the topography.

Topography refers to the arrangement of all the features, living and non-living, natural and built, on the Earth's surface. Topography comes from the Greek topographia, "a description of a place," from topos ("place") and -graphia ("description of").

A laser is a manufactured, powerful beam of light energy that is collimated (highly focussed), intense (very bright), monochromatic (a single colour) and coherent (all the light waves are synchronised).

Laser stands for Light Amplification by Stimulated Emission of Radiation.

Geographic or topographic LiDAR uses near-red infrared laser as red spectrum light can penetrate air.

Bathymetric LiDAR uses green light laser as green spectrum light can penetrate water (rivers, lakes, seawater)

The emitted laser light bounces off surfaces and returns to the onboard sensor of a LiDAR unit that is mounted on a drone or airplane. The system measures the time it takes for each pulse to return.

GPS and an Inertial Measurement Unit (IMU) are used to record the exact position and orientation of the sensor at the time each pulse is emitted.

Because the speed of light (c) is known (299,792,458 metres per second), the distance to the object can be calculated using the formula $d = c \times t/2$ where d is distance, c is speed of light, t is time all divided by 2, as the light is pulsed down and bounces back.

For further information

- LiDAR – Introduction to Light Detection and Ranging, Neon Science https://www.youtube.com/watch?v=m7SXoFv6Sdc
- How Does LiDAR Remote Sensing Work? Light Detection and Ranging, Neon Science. https://www.youtube.com/watch_popup?v=EYbhNSUnIdU

- Photogrammetry vs LiDAR – Which is Better? Dylan Gorman https://www.youtube.com/watch_popup?v=NF2k8e6kvUY
- Australian Government Defence: Defence Digital Strategy and Roadmap (2024) file:///Users/edu-hlw/Downloads/Defence-Digital-Strategy-and-Roadmap.pdf

Advances in BLOS Telemetry

BLOS stands for beyond line-of-sight wireless communications.

BVLOS stands for beyond visual line-of-sight wireless communications.

The majority of wireless communications systems require a transmitter and receiver to be within a straight, line-of-sight (LOS) or visual line of sight (VLOS) of each other.

For example, smartphones switch between base stations to stay connected and enable voice and data transmission when the phone moves.

BLOS technology extends the range of wireless communications systems beyond VLOS limits.

Programming BLOS communication technology requires complex mathematical tools to account for the relative motion of objects in airspace/space, the consequent time dilations, and the curvature of the Earth.

Civilian use of BLOS drones is highly controversial in all countries where drone flight is regulated. Consult the CASA regulations about legal and illegal drone flight.

Military and emergency services BLOS applications include BVLOS control of drones (unmanned aerial vehicles), radars able to see targets over-the-horizon, and the communications networks set up for disaster relief.

See the video

- Beyond Line of Sight Drones Get Their Own Frequencies, Geeksvana https://www.youtube.com/watch_popup?v=nq_i3L9H1HI

Communication Technologies 2: Signal Interference

Common Content for Teachers and Students

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Geopolitical signal interference remains a risk to every nation. A national risk management strategy minimises the risk to the continuity, validity and reliability of satellite telemetry data on which a nation like Australia depends.

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Introduction

Signal interference interrupts electronic satellite and earthly communications and telemetry.

Natural signal interference is mainly caused by inclement weather such as clouds, rain, snowstorms, and dust storms. Solar events can also cause signal disruption. Natural conditions are accounted for in technology design and are actively and passively managed.

Malicious signal interference is caused directly by human individuals or groups who act maliciously to interfere with telemetry signals. Aggressive attacks must be actively managed. Newer technologies are developed to improve technological resistance to what are known as 'bad actor' attacks.

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Part One: Natural signal interference

The electromagnetic spectrum (EMS) is used for telemetry using the lower frequencies of radio waves, microwaves, infra-red waves, and visible light waves.

Space weather such as solar winds, solar flares, and other solar events can cause signal interference. The Challenge assumes no abnormal solar radiation is happening.

On Earth, clouds and storms can interfere with radio waves, microwaves and light waves transmitted from satellites, drones, airplanes and from transmitters at ground level.

The degree of signal interference, also known as signal loss, depends on wave frequency. Generally, the higher the frequency of the EMS signal, the harder it is to send and receive messages in wet and stormy weather. Conversely, the lower the frequency of the EMS signal, the easier it is to send and receive messages in wet and stormy weather. However, a lower wave frequency means a smaller bandwidth, meaning receivers (antenna) have to be larger to capture more complete amounts of electronic data.

In general:

- Radio waves are only slightly affected by rain, storms, clouds and dust.
- Rain fade is the term for signal loss due to precipitation (snow and rain).

- Lower frequency radio waves with longer wavelengths are better suited for communication use in the tropics and in other areas of known high rainfall.

Low frequency radio waves such as VHF, UHF, and L-Band are used for GNSS, satellite phones and data transmission as these radio waves pass through clouds, rain and fog with very little signal loss.

VHF waves in the range of 30 to 300 MHz are used for 2-way radio, FM radio, aviation and marine communication.

UHF waves in the range of 300 MHz to 3GHz are used for TV, mobile phones, Wi-Fi, GNSS, Bluetooth and radar. UHF radio wave signals can be affected by buildings and terrain but are widely used for telecommunications in Australia.

L-Band frequencies of 1 – 2 GHz are a subset of UHF with specialized uses. L-Band are critical for GNSS (GPS, Galileo, etc.), satellite phones, air traffic control radars and satellite-to-ground communication due to low rain fade sensitivity.

Microwaves are EMS waves in the general range of 1 GHz to 300 GHz. Microwave frequencies over 30GHz are sensitive to weather. Microwaves are affected by the water and ice particles in clouds.

Mid-frequency C-Band microwaves are used for satellite and long distance communication, broadcasting and remote sensing. There is only a slight attenuation (loss) of the signal in heavy rain and thick cloud cover. The narrower bandwidth requires larger satellite dishes (antennae and receivers).

Mid-frequency X-Band microwaves are used for military and government communications such as synthetic aperture radar (SAR), air traffic control, weather monitoring and space communications such as the Deep Space Network (DSN). X-Band waves can be affected by storms and heavy rain.

High frequency microwaves such as Ku-Band (10-30GHz), Ka-Band (30-100GHz), V-Band and high-band-5G are used for high speed internet, shorter distance mobile phone communication and satellite TV. These signals face significant interference from thick clouds, heavy rain and snow and ice crystals.

Higher frequency microwaves interact with water and ice particles in clouds. The scattering and absorption of microwave energy weakens the signal.

Light waves include the visible light spectrum, infrared and near-infra red sections of the electromagnetic spectrum (EMS) and as these wavelengths are shorter than radio waves and microwaves, they are more sensitive to natural signal interference.

Light telemetry is affected by the natural water vapour and ice particles in clouds, the particles of dust in dust storms, and the air pollution particles produced by combustion processes in vehicles and factories.

Visible light telemetry does not work well in polluted cities. Visible light waves are scattered, absorbed or blocked by particles in the atmosphere.

Infra-red light is used for thermal sensors (i.e. heat sensors) for thermal imaging. Infra-red waves are affected by clouds distorting the accuracy of the thermal signal.

Optical laser signals are completely blocked by clouds therefore optical communication between satellites and ground stations is impeded in cloudy weather. Lasers cannot pass through clouds because the laser light wave is synchronised and condensed. Even thin clouds can stop a laser signal.

Remote optical sensing systems like cameras and LiDAR cannot penetrate thick clouds.

Radar technology uses microwaves for cloud penetrating Earth and object observations.

Summary Table

Wave Type	**Cloud Interference**	**Reason**
Radio (low freq.)	Low	Long wavelengths pass through
Microwaves	Moderate	Affected by water/ice particles
Light (visible, IR)	High	Scattered or absorbed by cloud particles
Laser (optical comms)	Very High	Blocked by even thin clouds

Articles to explore

- The electromagnetic spectrum: NASA Goddard Space Flight Centre https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html
- Lechner, G. (2019) https://theconversation.com/were-using-lasers-and-toaster-sized-satellites-to-beam-information-faster-through-space-126344

"All space communications use electromagnetic waves that propagate through space. But the electromagnetic spectrum we are able to use with current technology is a finite resource and is now completely occupied. Old services have to make room for new ones, or higher frequency bands have to be used. One promising way forward is optical communication."

Part Two: Malicious signal interference

There are different methods of malicious signal interference. Common methods are known as 'jamming', 'de-authentication', 'spoofing' and 'masquerading'.

Jamming

Jamming refers to unauthorized transmission of radio wave signals at the same or similar frequency and at the same modulation as an authorized service.

Jamming is used in warfare to evade tracking or mount defence strategies.

Civilian jammers and other 'bad actors' (such as extremist groups) can jam radio wave signals in order to cause havoc in normal communication systems

Signal jamming effectively drowns out the desired signal preventing clear transmission and reception of wireless communications.

The jamming interference overwhelms authorised antennae receivers, making these unable to distinguish the intended data transmission.

Types of jamming include disrupting radio broadcasts; blocking mobile phone signals to prevent calls; interfering with GNSS signals to affect navigation and other location-based services; and blocking Wi-Fi and Bluetooth services.

Jamming technology use by civilians is completely illegal.

Electronic counter measures (ECM), and electronic counter-counter measures (ECCM) are protection strategies against jamming.

ECM and ECCM include frequency hopping, use of IDS technology other sophisticated network monitoring systems.

Frequency hopping is when a transmitter and a receiver are programmed to change frequencies according to a set pattern known only to those antennae and that receiver.

Intrusion Detection System (IDS) technology monitors network traffic and proactively block jamming attacks by identifying unusual patterns.

Network monitoring can also check for unusual frequency levels or inconsistent noise ratios which might indicate bad actor attempts at jamming.

Strong encryption processes and maintaining strong cybersecurity protocols minimize communication vulnerabilities.

Videos to explore

- GPS Jamming (& Spoofing) Explained. Flight Trader https://www.youtube.com/watch_popup?v=wm9B-oofY9g
- Russia GPS – Jamming Civilian Aircraft. Mentour Now https://www.youtube.com/watch_popup?v=8xPeZfEExy8
- De-auther or Jammer: What's the Difference? spacehuhn (A clear explanation of how GPS/GNSS works and how satellite signals can be jammed) https://www.youtube.com/watch_popup?v=gOyfD44A7rE

  NOTE: All jammer technology is ILLEGAL. This is emphasised in this video.

- Electronic Warfare – The Unseen Battlefield (18.13 min) Covert Cabal https://www.youtube.com/watch_popup?v=fBLHZwEXKeA

  NOTE: Unsuitable for some classrooms. This is a video about real warfare.

Deauthentication

Deauthentication is a WiFi jamming technique that exploits a weakness in the IEEE 802.11 protocols that underpin all Wi-Fi systems.

Wireless communication infrastructure is a cornerstone of digital society, yet it remains vulnerable to a persistent threat of wireless jamming.

Deauthentication packets are sent to impersonate both the target device and the access point. Attackers then create radio interference to overshadow legitimate signals, leading to denial of service attacks.

The broadcast nature of radio signal propagation makes such attacks possible in the first place.

Articles to explore

- A new Wi-Fi jamming technique "enables attackers to selectively disconnect individual devices from networks with surgical precision, raising alarms across cybersecurity and telecommunications industries." See https://gbhackers.com/new-wi-fi-jamming-attack/

- Makensen, P. et al. (2024) Spatial-Domain Wireless Jamming with Reconfigurable Intelligent Surfaces, https://arxiv.org/pdf/2402.13773
- The Network and Distributed System Security (NDSS) 2025 Symposium You Tube Channel has recent presentations on telecommunications security. https://www.youtube.com/ndsssymposium
- For further extension, the GBHackers on Security website delivers up-to-date coverage on breaches, emerging threats, malware, vulnerabilities, and global cyber incidents. See https://gbhackers.com

Spoofing

Spoofing is a security breach or a hacking event, that causes communication failures, navigation errors, loss of mission-critical data, and can be life-threatening.

There are many different types of spoofing. In general, spoofing is the deliberate transmission of false or fake signals designed to deceive a communication system. A spoofing attack on telemetry services means normal telemetry signals are interfered with as fake signals mimic authorized services. Receivers are sent the wrong data to process.

Spoofing attacks on GNSS (GPS etc.) can disable whole navigation operations, including aircraft flights and on-ground wayfinding.

Satellites, drones, ships, aircraft, and vehicle receivers can mistake their true location. This is dangerous.

Uplink spoofing is when an attacker imitates a ground station to send wrong data commands to a satellite. Downlink spoofing is when a satellite transmissions are hacked, and the satellite sends wrong data to ground-based receivers.

Stopping spoofing ensures the integrity of satellite-derived data.

Countermeasures include signal authentication and encryption and use of multi-constellation GNSS satellites (e.g., GPS + Galileo + GLONASS) to detect inconsistencies.

United Nations Agency for Digital Technologies

Articles to explore

- UN agencies warn of satellite navigation jamming and spoofing https://www.itu.int/hub/2025/03/un-agencies-warn-of-satellite-navigation-jamming-and-spoofing/
  "Global satellite navigation systems are at risk from increasingly frequent jamming and spoofing of signals, threatening the safety and security of ships and aircraft worldwide."
  United Nations Agency for Digital Technologies
- ITU issues warning on interference with radio navigation satellite service. https://www.itu.int/hub/2022/08/warning-harmful-interference-rnss/

  "The blocking, jamming or serious degradation of services that rely on radio waves can be accidental or intentional. Either way, harmful interference poses a significant and growing threat to critical infrastructure and safety services used every day, from commercial aviation to energy distribution to satellite navigation systems."

- GPS Jamming and Spoofing – How Does It Work and Who's Doing IT? (19.50) Scott Manley. https://www.youtube.com/watch?v=sAjWJbZOq6I

  Jamming and spoofing global navigation systems are serious security breaches that cause navigation errors, communication failures, loss of mission-critical data, and can be life-threatening. **This video mentions war crimes.**

Masquerading

Masquerading is a specific type of spoofing. The attacker impersonates or masquerades as a legitimate user, device, or system to gain unauthorized access to carry out malicious activities such as a denial of service (DoS) attack.

An unauthorized individual or entity impersonates a legitimate user, electronic device or system to gain unauthorized access to a communication system and its resources, by deceiving security mechanisms or bypassing authentication processes.

Masquerading attacks the vulnerabilities of trust between electronic devices and communication systems and are difficult to detect because the malicious attacker masquerades as a legitimate user or as a legitimate device.

The risk can be reduced by strengthening device to device trust and using techniques such as using multi-factor authentication, strong access controls, careful system monitoring, and auditing system logs to detect unusual and unauthorized activities.

Part Three: Geopolitical signal interference

> "You have probably used space at least 20 times today. Satellites let you buy a coffee with your phone, book a rideshare, navigate your way to meet someone, and check the weather.
>
> Satellites are also essential for monitoring floods, cyclones and bushfires, and supporting the people they affect. Farmers depend on satellite data, too, as does everyone trying to understand and tackle climate change, not to mention our military.
>
> Yet Australia's access to space services depends almost entirely on satellites owned and run by foreign governments and companies."
>
> Steer, C. (2025) https://theconversation.com/from-gps-to-weather-forecasts-the-hidden-ways-australia-relies-on-foreign-satellites-256440

In an increasingly uncertain world, having our own sovereign space technology is becoming even more important for security.

Australia's earth observation (EO) data is vulnerable to geopolitical upheavals and as a nation, we need to better manage and secure our EO data.

For a quick explainer, see https://policybrief.anu.edu.au/how-australia-can-avoid-a-satellite-data-disaster/

Technical Documentation: Jamming and Spoofing

Jamming

Radio waves are used widely by satellites for communication.

If radio waves are produced with the same frequency as those coming from a satellite, it can cause what is called jamming which interferes with communication coming from the satellite.

(See EMS Explainer for more information on wavelengths and different frequencies)

Jamming can be intentionally done by producing the same frequency wavelengths to purposely overpower and block communication. Equipment problems and space weather such as solar winds, solar flares, and other solar events can also cause jamming.

As satellites are widely used for navigation, including planes, ships or emergency services, jamming can be very problematic.

The article hyperlinked in the following title provides some information on jamming.

- The United Nations Agency for Technical Services

Spoofing

Spoofing is different from jamming and is also problematic.

Spoofing is when a signal that is false is purposely generated to interfere with satellite communication and positioning systems.

These spoofing signals sometimes pretend to be signals from GNSS. The receiver thinks it is a genuine signal when it is a false signal from a radio transmitter and this can lead to miscalculation of positioning, for example positioning of an aircraft.

Governments and other organisations have developed a range of technologies and strategies to detect and prevent spoofing and jamming attacks involving GNSS and are continuing to mitigate these ongoing problems.