anzska
Square Kilometre Array ›
Australia › New Zealand

Australian Government  New Zealand Government  CSIRO  The Government of Western Australia

# Square Kilometre Array

# Level 5

## Science

© Crown Copyright
First published June 2011
Ministry of Economic Development
PO Box 1473
Wellington
New Zealand
www.med.govt.nz

**Permission to reproduce:** The Ministry of Economic Development authorises reproduction of this work, in whole or in part, provided no charge is made for the supply of copies.

**www.anzska.govt.nz**

**This resource has been produced to support the delivery of the New Zealand Curriculum, with funding from the New Zealand Government, through the Ministry of Economic Development.**

# 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, and the properties and behaviour of waves, from mechanical waves to the electromagnetic spectrum.**

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

## The Level 5 student activities

These activities introduce several 'big ideas'.

1–3: The 'big idea' is that a satellite TV dish is a form of radio telescope:

1. Finding the dish direction.
2. Finding the signal.
3. Reflecting microwaves.
4. Measuring time, including a sundial.
5. Wavelengths and information, utilising a digital camera and an infrared thermometer.
6. The relationship between temperature and electromagnetic radiation.
7. Colour temperature.

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.

## Prior knowledge and skills required

Little or no specific prior knowledge is assumed for each activity.

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

## For teacher resources:

Download the 'Window to the Universe' teacher resource (5.7 MB):

http://www.ska.edu.au/educators/assets/window_to_the_universe.pdf

# Theme: Using a Satellite TV Dish to Locate a Geostationary Satellite

Today, a satellite dish on a private home is a common sight all over the world. Each dish has to be aimed precisely at a geostationary transmitting satellite to receive its signals. Dishes in different locations will have different angles and directions in order to point directly at a satellite. As a geostationary satellite is invisible during the day, the direction and elevation given for each site provides an initial aiming point for a dish, with precise adjustment using the strength of its signal.

Good access to the internet is required, with references to URLs numbered in square brackets [ ].

## Rationale

A single activity on locating a satellite with a satellite dish would be too detailed, so three activities are included instead. This guide provides background information for all three activities:

- Finding the dish direction
- Finding the signal
- Reflecting microwaves

These activities with a satellite dish [1] are suggested for the following reasons.

1. It is a familiar technology and is having a significant cultural impact in different countries.
2. The 'big idea' is that a satellite dish is really a form of radio telescope, being a reflector designed to focus incoming radio waves from a narrow angle on to a receiving element. Information, as pictures and sound, is encoded in the radio signal.
3. Locating a distant transmitting target introduces the challenges of locating a tiny source of radio signals, although at an elementary level, and introduces the concept of coordinates to specify the direction and elevation of a location [2];
4. It is an opportunity to apply knowledge about magnetism, a topic in the science curriculum, in a familiar context.

Unlike the use of a radio telescope, this example is simplified by the use of a stationary target, as a geostationary satellite maintains the same position relative to the Earth's surface, although in reality there is some drift [3]. In addition to coordinates for direction and elevation, a third aspect, linking to previous activities, is the polarisation of the signal (see Level 4, activity 2).

The coordinates for the Optus D1 [4] satellite used by Freeview are usually given as azimuth (magnetic compass bearing) and elevation (degrees above the horizon or horizontal surface). As magnetic lines have local variations (18°–25° E in NZ) [5], and magnetic north drifts slowly [6], it is best to use an on-line calculator [7] for the current values at your location.

This activity contains some aspects of technology, but is a useful reminder that science usually requires instruments, which need to be designed, developed and manufactured.

## Equipment

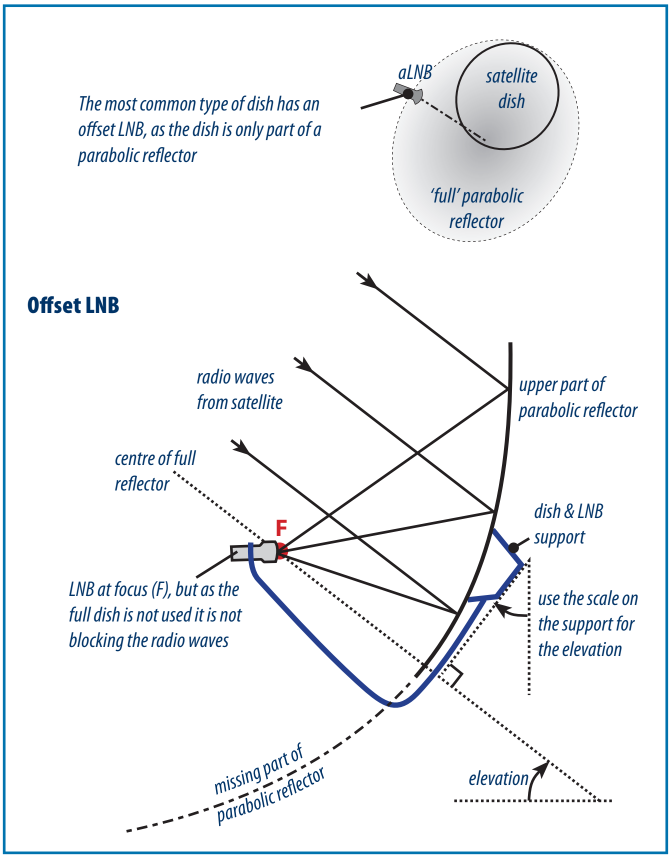
This activity could be carried out by having contributions from small groups of students.

Using a satellite dish to receive a signal must be done outside, or at least through an open north-facing door or window. Signals are attenuated by glass, trees, or buildings, so there should be no objects in the 'view' of the satellite dish.

The equipment needed would be:

1. A magnetic compass (assume it is suitable for NZ), and a simple inclinometer or spirit level and protractor. [6, 8]
2. A 65 cm satellite dish plus a matching $K_u$ band (11.7–14.5 GHz) working LNB [9].

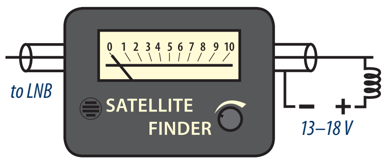
   It would be likely that someone has a 'Sky' dish they are no longer using and would be prepared to lend it for this activity. It should to be checked in advance to ensure that its LNB is working. The dish would need to be mounted so that its azimuth can be changed easily—a base sitting on a desk would be suitable, as the dish is not required to be permanently fixed. The simplest method of adjusting the elevation is to use a spirit level to ensure the mounting clamp is vertical and utilise the degree



scale on the mount. Dishes with an offset LNB usually have the vertical mount as the reference (see the diagram below). The elevation adjustment is usually a bolt through a slot. Tighten the bolt only a little so it can be easily moved but then hold its position.

Note that the azimuth on the Freeview website suggested for students is in degrees from magnetic north. In effect, on the compass face included for them, the 'N' mark becomes magnetic north, not true (geographic) north. An azimuth is a horizontal angle measured clockwise from a north base line (magnetic north, true north, or grid north).

3. Signal strength meter (or 'satellite finder'), RG6 cable to connect the signal meter to the LNB with F-type connectors (the meter usually comes with a cable). This type of meter indicates the average strength of all frequencies (see the Background information section). The azimuth provides only an approximate direction as it is difficult to precisely align a dish to a compass bearing. Use the meter while rotating the dish a little at a time (from east to west) to fine-tune its position. A Freeview decoder and TV set would be the best option, as it would not require a separate power supply (below) and the signal being received could be confirmed.
4. If a decoder is not available to supply the LNB, a portable 13–18 V DC source will be required, e.g. a battery pack of 12 × 1.2 V AA rechargeable batteries, connected to the signal meter as shown in the diagram. The batteries need to supply about 300 mA (ensure the RF choke has sufficient DC current capacity). It would be useful to arrange a visit from a satellite TV installer for Activity Two.




*include any small RF choke in series on the power supply positive lead*

5. Materials for testing signal penetration, e.g. sheets of particle board, glass, plastic, steel, aluminium foil, cloth (dry and wet), metal mesh, etc., sufficiently large to cover the front of the LNB.

## References

Mostly Wikipedia references are included as they are generally brief, reliable, and organised so detail is not initially overwhelming.

**[1]** http://en.wikipedia.org/wiki/Satellite_dish

**[2]** http://www.astronomy.org/astronomy-survival/coord.html
http://www.kidscosmos.org/kid-stuff/celestial.html

**[3]** http://www.satobs.org/geosats.html

**[4]** http://www.optus.com.au/aboutoptus/About+Optus/Network+Coverage/Satellite+Network/D1+Information

**[5]** http://www.teara.govt.nz/en/magnetic-field/1
http://www.teara.govt.nz/en/magnetic-field/1/4

**[6]** http://en.wikipedia.org/wiki/North_Magnetic_Pole
http://en.wikipedia.org/wiki/North_Pole
http://www.teara.govt.nz/en/magnetic-field/1/5

**[7]** http://www.freeviewshop.co.nz/dish-angle-calculator-i-16.html
http://www.satmax.co.nz/support.htm (note: true north, not magnetic)
www.satsig.net/maps/satellite-tv-dish-pointing-australia-new-zealand.htm

**[8]** http://www.satsig.net/pointing/how-to-make-inclinometer.htm
http://www.satsig.net/azelhelp.htm

**[9]** http://www.satmax.co.nz/Techsupport/typicalsetup.htm

**[10]** http://en.wikipedia.org/wiki/Geostationary

**[11]** http://en.wikipedia.org/wiki/Geosynchronous_satellite

**Additional references which may be useful:**

Installing a Freeview satellite dish:
www.celto.co.nz/freeview/diy_satellite_installation.pdf

This document describes a radio telescope that could be made from a satellite dish:
http://www.setileague.org/articles/lbt.pdf

— and this site has more details on building it:
http://www.aoc.nrao.edu/epo/teachers/ittybitty/procedure.html

Another reference to using a satellite dish and signal meter as a radio telescope:
http://www.ehow.com/how_6630765_make-simple-radio-telescope.html

## Outcomes

Key outcomes for the three activities should be: greater understanding of the Earth's magnetic field; how to use a magnetic compass; the use of a coordinate system to locate a signal transmitter; that a communication satellite remains over the same place on the Earth's surface; its signals can be reflected and focused on a receiver; and that receiving satellite TV by using a dish is similar to the way a radio telescope works.

## Background information

1. **A geostationary satellite** [10] orbits directly above the equator (0° inclination) at a distance of 35,784 km above the Earth's surface, its orbit taking exactly the same time as the Earth does to rotate 360° (23 hours, 56 minutes), so it remains over the same spot above the equator. Most 'geostationary' satellite orbits are not exactly over the equator so, while they have the same orbital period as the time of Earth's rotation, they do not maintain the same precise location and are said instead to be in a geosynchronous [11] orbit (their orbit time but not their location is synchronised); they have thrusters to correct position and orientation drift. A communication satellite has a life of around 10–15 years, the limiting factor is usually running out of fuel for the thrusters.

Each location on Earth has a specific azimuth and elevation for a satellite dish as the target is so small.

2. **A magnetic compass** is a small magnet balanced for one of five world zones. It may be on a pivot, or on a floating card. The compass needle's north magnetic pole tends to point northwards. Located near the geographic north pole (the point where the axis of Earth's rotation meets the surface) is a south magnetic pole, which attracts the north pole of the compass needle.

   The north (and south) magnetic pole is where the magnetic field lines point vertically downwards, as the magnetic poles are located beneath the Earth's surface. The magnetic field lines are not parallel, as they converge at the poles and are also affected by local materials, both factors causing local variation, so a magnetic compass will not point directly at magnetic north. The vertical angle of the magnetic field lines with the Earth's surface (called the angle of dip or inclination) varies according to location, becoming more vertical approaching the poles. See:

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

   As a magnetic compass needle will line up with the Earth's magnetic field, horizontally and vertically, a pivoted needle needs to be balanced for the angle of dip. Consequently, a compass is made for one of several world zones; e.g. see: http://www.mapworld.co.nz/global.html

   When using a magnetic compass care must betaken to ensure that there are no ferrous or magnetic objects near the compass. Obviously, a magnetic compass is used in metal objects, such as a ship, so needs to have small magnets nearby to cancel the effect of the metal around it, referred to as swinging a compass.

3. **LNB:** Low Noise Block down-converter, also called an LNBF (F: feedhorn). It filters out noise and amplifies the satellite TV programme signals (at 12.25–12.75 GHz), then converts them to a lower frequency range (950–1450 MHz ) to send via a cable to the decoder, which also powers the LNB. An LNB needs to be at the appropriate polarisation angle, which is done by rotating it in its mounting collar using the cable socket as a reference when viewed looking into the dish. You will need the instructions for the LNB to find its polarisation angle. Some require the cable socket to be at the 6 o'clock position, others at the 8 o'clock position for Freeview. The Optus D1 satellite broadcasts both Sky and Freeview signals, so if you have obtained a dish and LNB previously used for receiving either signal, use the polarisation as it is. A simple signal meter shows only the strength of a signal, not what the signal is. To know which signal you are receiving you would need the appropriate decoder. For more information see:

   http://www.satmax.co.nz/Techsupport/lnb.htm

   http://en.wikipedia.org/wiki/Low_noise_block-downconverter

4. **Signal meter** ('Satellite Finder') and cable. If making your own cable note that the central conductor needs to protrude about 2 mm above the threaded outer ring of the LNB connection; one common cause of the meter not registering a signal is the lack of connection to the LNB. When connecting the cable to the LNB be careful to not over-tighten it—finger-tight is sufficient to avoid damaging the LNB. Note: the DSE Satellite Finder, Cat. DSNZ_L4724, or the Jaycar meter, Cat. LS3300, are suitable low-cost signal meters.

   If you wish to make your own signal meter from a microammeter, instructions are in this PDF: www.satsignal.eu/wxsat/atovs/SatelliteMeter-ArneVanBelle.pdf

   When using coaxial cable to connect the LNB to the meter and battery pack, RG6 cable and F-type connectors must be used, as other coaxial cable types are not suited to transmitting digital signals.

5. **A decoder** is required for satellite TV as the signal is compressed and, if from a pay-TV provider such as Sky, is also encrypted. A decoder for Freeview decompresses the signal, extracts the channel information, and sends it to the TV set at selected channel frequencies. In addition to decompressing the signal, a Sky decoder unscrambles the encryption protecting their signal from unauthorised viewing.

   Terrestrial Freeview TV transmission is not in the microwave range used by satellites and is not compressed or encrypted, requiring only that a TV set have a tuner for those digital channels.

# Locating a Signal from a Satellite

Satellite TV dishes are a common sight on homes all over the world. These receive television programmes broadcast from satellites orbiting around the Earth's equator at about 36,000 km above the surface. At that distance a satellite is a very tiny target!

A satellite dish is really a small radio telescope focused on a source of radio waves. It has a receiver at the focus. The radio signals it receives carry information as sound and pictures and must be decoded to make sense of this information.

When wanting to receive satellite TV, the first problem is to locate the satellite. It is similar to a radio astronomer locating astronomical objects.

## Activity 1: Finding the dish direction

1. The Optus D1 satellite that transmits Sky and Freeview TV programmes remains in direct view of a satellite dish. A satellite must orbit the earth at high speed or it will fall down. However, a geostationary satellite can remain above the same place on the Earth's surface. Explain how this is possible.

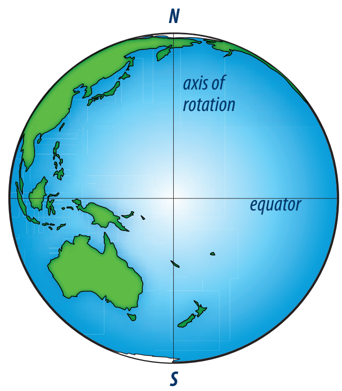
   See: http://en.wikipedia.org/wiki/Geostationary

2. The Optus D1 satellite is at latitude 160° E in a geostationary orbit. The first step in finding out where to point a satellite dish to receive TV signals from this satellite is to find its azimuth from where you are. The azimuth is its horizontal direction in relation to north. See:

   http://www.freeviewshop.co.nz/dish-angle-calculator-i-16.html (note that the "Click here to find your Latitude and Longitude" window may pop under the current window)

| *For your location, record:* | |
|---|---|
| Latitude: | |
| Longitude: | |
| Magnetic variation: | |
| *and for the Optus D1 satellite from your location:* | |
| Azimuth (horizontal degrees from magnetic North): | |
| Elevation: | |

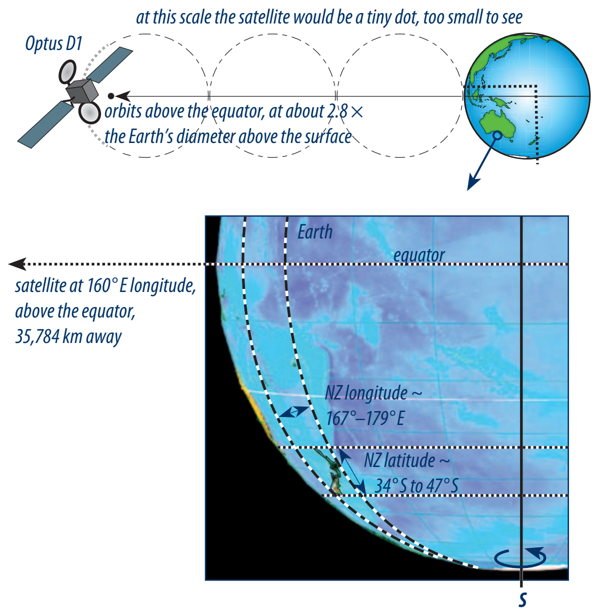
3. On the circle below, representing the Earth, draw lines to show latitude and longitude (and show where lines of longitude begin and end).




4. What is meant by the azimuth of the dish?

5. What is meant by the elevation of a dish?

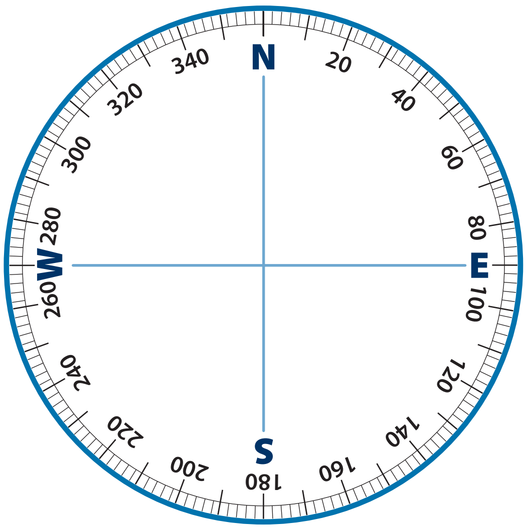
6. Why does every location in NZ need a different satellite dish azimuth and elevation? *Hint: On the diagram below draw lines from parts of New Zealand out to a satellite position, look at the horizontal and vertical directions.*



7. A magnetic compass needle is a small magnet, balanced so it is free to turn. If the north-seeking end of the compass needle is really a north pole, then is the north magnetic pole of the Earth really a magnetic south pole? Explain.

8. When using a magnetic compass to aim the dish (azimuth), what source of error would you need to be aware of to ensure an accurate compass bearing? *(Hint: what materials are magnets attracted to?)*

9. On the compass face below, draw the position of the needle of a magnetic compass, and mark the direction that you would need to point the satellite dish, using the information you found for Q. 2.




10. Below, draw a diagram showing the azimuth line and how the satellite dish should be aligned to this direction: is the satellite dish surface parallel to, or at right angles to, the azimuth line?

11. If you saw a photograph of a house with a satellite dish pointing vertically upwards, what would be the probable latitude of the house?

## Activity 2: Finding the signal

From Activity One you will have the required azimuth and elevation for aiming a satellite television dish at your location.

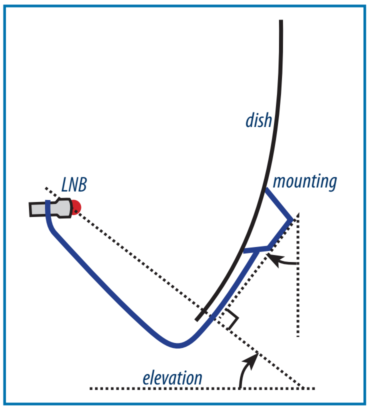
This activity requires a satellite dish and working LNB receiver at its focus. It will need to be mounted so that its azimuth and elevation can be easily altered. It also needs to be in a position where it has an unobstructed 'view' of the sky.

1. From Activity 1, what is the required azimuth?

2. Describe how best to mark out the azimuth for the dish. Perhaps you may use a string in the right direction. Include the precautions you must take when using a magnetic compass to find the direction.

3. From Activity 1, what is the required elevation?

   What is the reference plane that this elevation value refers to, i.e. what are you supposed to measure the elevation from?




On the back of the dish as part of the mounting is likely to be a scale of degrees elevation. Does it refer to the angle from the vertical mounting, or from the horizontal?

If it refers to a vertical mounting, how would you find the vertical plane?

4. When you have set up the dish according to the azimuth and elevation coordinates, it is likely to not find the signal. The reason is that it is extremely difficult to align the dish accurately to the coordinates. Even aiming the dish to within 1° is difficult.

   While you could calculate this mathematically, the drawing below shows a line diverging only 1° from the base line, and about 0.175 m long. Over this short length the divergence is about 0.003 m. The Optus D1 satellite you are aiming for is 36,000,000 m away. If you were 1° off in your azimuth how far away from the satellite would the aiming point be?


5. To accurately locate the satellite a signal meter (or 'satellite finder') is used. It shows when the signal strength is at its highest, showing that the dish is aimed precisely at the satellite. When using the meter, why must the dish be moved only a tiny amount at a time? (Hint: see your answer to the previous question.) Imagine how difficult it is to precisely aim a radio telescope at something several light years away!

6. Satellite TV dishes are mounted outside, but broadcast television (even terrestrial digital Freeview) can be received from indoor aerials. The difference is because satellite TV signals are a much higher frequency, referred to as microwaves, and are absorbed by various materials.

   Ensure that the dish is receiving a signal. Adjust the meter sensitivity to give the maximum deflection. Place various materials in front of the LNB (signal receiver) to see whether they affect the strength of the signal. Some suggested materials are in the table below, with spaces left for you to test other materials, e.g. tree/shrub branches. If the meter is at maximum deflection (e.g. signal level 10) you could record the actual meter reading in your results.

| Material | Reduced signal Y/N |
|---|---|
| particle board | |
| glass | |
| plastic | |
| metal sheet (e.g. aluminium foil, 'tin can') | |
| metal mesh (e.g. aluminium whitebait mesh, insect mesh) | |
| cloth – dry | |
| cloth – wet | |
| | |
| | |
| | |

7. Which of these materials least absorbed the signal?

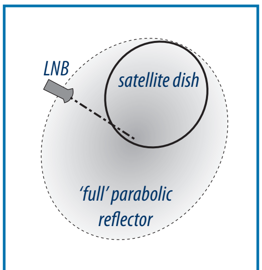
   The front (receiving) part of the LNB would need to be made of a material which does not stop microwaves. What material does it appear to be made of and would you have selected this from your results above?

## Activity 3: Reflecting microwaves

1. Activity Two was about locating a satellite using a satellite dish and signal meter. What are two major functions of the dish?

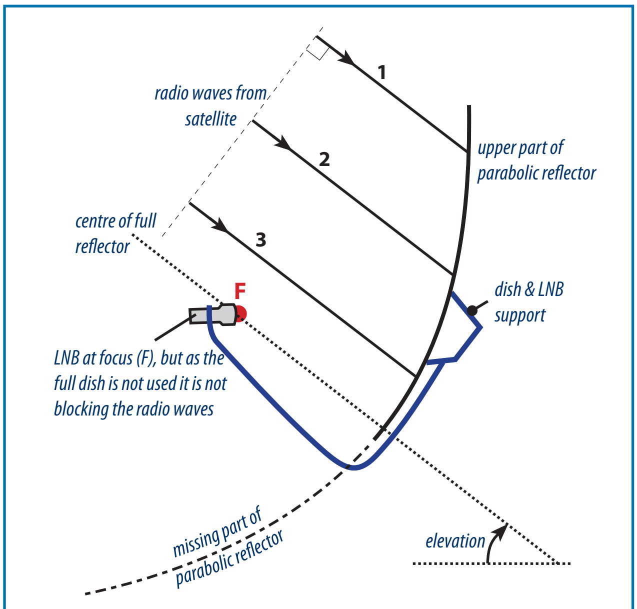
2. A larger dish could provide a stronger signal to the TV set. If a dish was made twice the diameter, would it gather twice the amount of radio signals, or more than that? Show your reasoning.

3. A satellite dish where the receiver unit (the LNB: Low Noise Block down-converter) is not at the centre is usually only a part of a parabolic reflector, as shown here. However, the LNB is located at the focus of reflected radio waves even though this is not at the centre of the dish.




An offset receiver does not block the radio waves. On larger dishes the same-size receiver is at the centre of the dish, where it would block some of the waves. Why does it matter more on a small dish to keep the receiver from blocking some of the radio waves? *(Hint: see your answer to Q. 2.)*

4. One important property of a parabolic reflector is that the waves have the same length of pathway to the focus so they do not arrive out of phase and cause interference effects.




On the diagram above, complete the wave pathway by adding the reflected waves, and measure the total length of the wave pathways to see if the total lengths are the same.

Lengths of each wave (mm):

**1** ____________ **2** ____________ **3** ____________

5. The radio waves are reflected from the dish on to the receiver in the same way as visible light is reflected off a mirror. In other words, the Law of Reflection applies to any form of radiant energy. State this Law.

6. The wavelength of radiant energy affects how it is reflected. Radio waves are reflected off any metal surface. The surface does not have to be shiny. With longer wavelengths the surface can even be in the form of a mesh, which acts as a solid surface. Visible light waves have a much shorter wavelength than radio waves and require a smoother surface for reflection (otherwise the light is scattered in all directions).

A satellite dish could act as a solar oven, by focussing sunlight on to the LNB receiver, which would cause it to overheat. Look at a dish. What features of the dish stop it from cooking the LNB receiver?

7. A TV satellite does not store TV programmes. It receives them from a ground station on one set of frequencies and re-transmits them on another. To efficiently transmit programmes to the satellite, the ground station aims its beam precisely at the satellite. What sort of transmitter aerial would be the most efficient at beaming a signal at a geostationary satellite? (Hint: the radio waves should have the same length of pathway to avoid interference).

Sketch the aerial and its radio waves and label as appropriate.

8. Television broadcasts require a receiver to be in view of the transmitter. What is a major advantage of satellite TV transmissions compared to ground-based TV transmissions?

If you wish to see the 'footprint' of the coverage of Optus D1 satellite, see:

http://www.optus.com.au/aboutoptus/About+Optus/Network+Coverage/Satellite+Network/D1+Information
(click on the D1 coverage button)

# Teacher Guide to Activity Four

## Measuring Time

Time is one of the seven base units of measure from which all other SI units are derived. Apart from being a base unit in science, time is one of our fundamental personal experiences.

The previous activity utilised coordinates of direction and elevation to locate a satellite. Star maps usually utilise declination and right ascension as coordinates, which correspond to latitude and longitude. Just as longitude can also be expressed as time from a reference (the prime meridian), right ascension is measured in hours and minutes.

## Rationale

The 'big idea' is that our measurement of time utilises periodic events, such as the apparent motion of the sun causing day and night.

The word 'time' refers to two concepts: when something happens (its date), and the interval or length of time between things happening. The date is a fixed moment in a continuum, where events occur in an irreversible succession from the past, through the present, to the future. Because time is always changing, we can measure it only by something also 'running': a stopped 'clock' can not measure time. The problem is to define a unit of time.

The second was originally defined as a fraction of a solar day: 1/(24 × 12 × 60) of 24 hours, but is now based on a fundamental property of an atom.

Time is a significant topic as it is fundamental to our lives, as well as a base unit in science. It can also be used to introduce elements of the 'Earth and Beyond' curriculum topic.

A large radio-telescope array would not be possible without atomic clocks as each telescope's observations must be synchronised. The larger the spread of radio-telescopes the higher the resolution, but the greater distances apart means that signals from each telescope would arrive at a central processing area at different times (even if the differences are very small!).An atomic clock allows the signals to be recorded and 'time-stamped' for later processing.

## Equipment

Access to suitable references or to the internet. If making a sundial, a protractor and compass will be required (used in the previous activity).

## Background information

The base SI units are: metre (m, length);  kilogram (kg, mass); second (s, time); ampere (A, electric current); kelvin (K, temperature); candela (cd, luminous intensity); mole (mol, amount of substance).

An Egyptian sundial from about 1,500 BCE is evidence of when dividing a day into equal divisions was first attempted. As a sundial is of no use at night, the problem remained of defining a fixed length for a time division, such as an 'hour'. It was not until mechanical clocks appeared that time began to be measured with increasing accuracy, allowing division of an 'hour' into smaller and smaller parts.

Personal timepieces based on the vibrations of a quartz crystal are very accurate, but not sufficiently accurate nor reliable for the coordination of communications, GPS navigation, power distribution, etc., that our modern civilisation requires. Atomic clocks are used for this, where atoms of caesium-133 produce or absorb radiation at a frequency of 9,192,631,770 cycles per second as they move between two energy states. The higher the frequency of a periodic event the better the accuracy and reliability of time measurements.

Although the second is based on the Earth rotating once in 24 hours, the rotation time depends on the frame of reference. All motion is relative. A day can be measured relative to the sun (solar day) or to the stars (sidereal day). The time between one midday and the next (a solar day), when the sun is at its zenith, has an annual average of 24 hours (mean solar day), but is 24 hours at only four times a year. At other times the varying speed of the Earth in its orbit, which is slightly elliptical, plus the effect of the obliquity of its axis, means that a 'solar day' is longer or shorter than 24 hours. The differences are shown in the Equation of Time graph.

The time taken for the Earth to rotate 360° is about 23 hours, 56 minutes, 4.09 seconds. This is called the sidereal day and is (almost!) constant. For the sun to appear overhead each solar day, the earth has rotate nearly 361° as it has moved on in its orbit.

As time is based on the Earths' rotation, local time would be different at every degree of longitude. This would be unworkable in a modern society, so we have time-zones at about 15° (one hour) intervals but modified to suit the needs of the countries within each time zone.

The difference between local apparent time and standard time can be shown by a sundial and by calculation. New Zealand extends from longitude 178°33' E (East Cape) to 166°25' E (West Cape, Fiordland), but all of New Zealand has the same time for convenience: UTC+12, (Coordinated Universal Time+12, previously called GMT+12), and UTC+13 for daylight saving time.

Using the proportion of a longitude away from the 15° 'hour lines', midday (ie. the sun at its zenith) for a location can be calculated. For example, Wellington is about longitude 174.8° E. Midday would be ((180° – 174.8°) ÷ 15) hours after UTC midday, i.e. 5.2/15, or about one-third of an hour (20 mins) after midday according to the 'time pips' on the radio, at 12.20 pm.

One extension is making a sundial. A plan of an equatorial dial is included on the next page as that type of sundial better shows the relationship between the style of the gnomon (the edge of the part casting a shadow on the dial) and the Earth's axis of rotation.

For information on true north and magnetic north see the previous activity.

## References

**SI base units:**
http://en.wikipedia.org/wiki/SI_base_unit
http://physics.nist.gov/cuu/Units/units.html

**Earths' rotation in relation to local time:**
http://en.wikipedia.org/wiki/Prime_Meridian
http://en.wikipedia.org/wiki/Earth's_rotation
http://en.wikipedia.org/wiki/Local_apparent_time
http://en.wikipedia.org/wiki/Foucault_pendulum (A pendulum day is the time needed for the plane of a freely suspended Foucault pendulum to complete an apparent rotation about the local vertical. This is one sidereal day divided by the sine of the latitude.)

**Measuring time:**
http://en.wikipedia.org/wiki/Time_in_physics
http://en.wikipedia.org/wiki/Time
http://en.wikipedia.org/wiki/Second
http://en.wikipedia.org/wiki/Time_in_New_Zealand
http://www.rasnz.org.nz/SRSStimes.htm (sunrise and sunset times for NZ locations)
http://www.timeanddate.com/worldclock/ (one of many sites giving local times, can be configured for time, weather, sunrise, etc. at any location)

(a more detailed history of time from the US National Institute of Standards and Technology)

http://www.e.govt.nz/standards/network-time-protocol (how NZ standard time and radio 'time-pips' are maintained)

## Sundials

If you are interested in further developing the topic of sundials, the best reference is: Sundials: Their Theory and Construction by Albert Waugh, Dover Publications, 1973 (it's still available). See the list of URLs for sundials below.

## Outcomes

Students will be able to discuss the basis of time-keeping, what time-zones are and how local and standard time differ and why. In addition, depending on extension topics, they may also be able to discuss why accurate time-keeping is essential to modern communications systems and to navigation.

## Extensions

http://www.aresearchguide.com/time.html (comprehensive links as a research guide for students)

1. **Time zones**
   http://en.wikipedia.org/wiki/Time_zone
2. **History of time-keeping**
   http://www.britannica.com/clockworks/main.html
   http://www.beaglesoft.com/maintimehistory.htm
   http://www.nawcc.org/index.php/just-for-kids/about-time/how-does-it-work
   http://www.nist.gov/pml/general/time/index.cfm
3. **Making sundials for your location**
   http://www.squidoo.com/sundial (a comprehensive site with many links)
   http://en.wikipedia.org/wiki/Sundial
   http://www.sundials.co.uk/home3.htm (a comprehensive sundial site, the 'Projects' link describes making several sundials, but need transposing for the southern hemisphere, it also has a link to the Timaru sundial trail, an interesting community project)
   http://www.skyandtelescope.com/letsgo/familyfun/Make_Your_Own_Sundial.html (has a link to a simple southern hemisphere equatorial sundial, similar to the one included here)
   http://www.analematic.com/documents/op.pdf (pdf file on how to calculate and make an analemmatic dial, although northern hemisphere based)
   http://safalra.com/science/astronomy/how-to-make-a-sundial/ (plan for a less common sundial)
   http://en.wikipedia.org/wiki/Equation_of_time
4. **How a GPS receiver uses time to find its location**
   http://www.nasm.si.edu/gps/work.html
   http://www.trimble.com/gps/index.shtml
5. **Calendars**
   Is a calender a human invention, or is it an integral part of nature? Some people believe that future natural events predicted by ancient calendars could happen. Is there any evidence that a calendar influences natural events? Or are our calendars based on natural events?

# Student Activity Four

## Measuring Time

When we measure something we need to define the units we use. In science we use the SI system of units. It has seven base units of measure from which all other SI units are derived. One of the base units is the second (s) as a measure of time.

Time is difficult to measure as it is always changing or flowing: now, before now, and after now. Time can refer to a date (when something happens), or to the interval between things happening.

A second is 1/86,400 of a day, based on a day of 24 hours, each hour having 60 minutes, each minute having 60 seconds. The day was originally defined as the time between one midday and the next — the time of one revolution of the Earth. This is called a solar day to indicate that the sun is the reference.

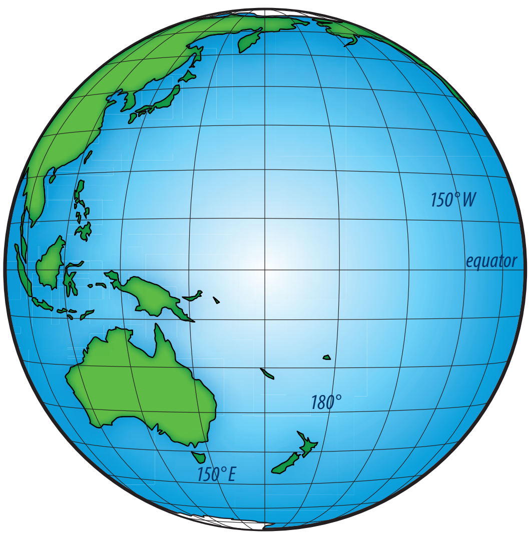
Accurate time measurement is essential today for communication, navigation, and the coordination of everyday events.

## What to do

1. If the Earth rotates once in 24 hours, how many degrees per hour does it rotate?

2. Which way does the earth rotate: east to west, or west to east? What is your evidence?

3. Label latitude and longitude on this diagram. Then label these evenly spaced lines of longitude with hours from the prime meridian (0°), shown as + or –. Show the direction of Earth's rotation. For assistance, see: http://en.wikipedia.org/wiki/Time_zone




4. The time of the Earth's rotation can be used to determine your longitude, degrees east or west, from a reference point: the prime meridian at 0° longitude. If you were at a location where the local time was 6 hours ahead of the time at the reference location of 0° (e.g. 4 pm at your location, 10 am at the reference location), what would be your likely longitude? Include whether it would be east or west of the reference.

5. What is the time at your location when the sun will reach its highest point in the sky (i.e. at its zenith)?

   Because the Earth rotates, the sun will be at its zenith at different times in different places. To avoid having different local times for each location the world uses time zones based on longitude. New Zealand is in the time zone 180° East of the prime meridian (0°). Our time zone is UTC +12, (Coordinated Universal Time +12, previously called GMT +12), i.e. we are 12 hours ahead of the standard time at the prime meridian.

   New Zealand is located between longitude 178°33′E (East Cape) and 166°25′E (West Cape, Fiordland).

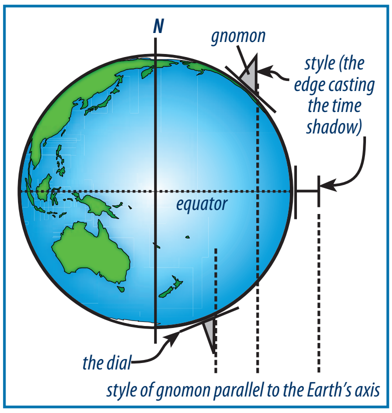
   To find when the sun is overhead at your location (your local apparent time), you use the proportion the longitude at your location is from 180° longitude, the +12 hour meridian.

   What is the longitude at your location? Record it to the nearest 0.1° (there are 60 minutes, written as 60′, in one degree).

   Subtract your longitude from 180°, then divide it by your answer to Q. 1. This will give the number of minutes later than 12 midday that the sun will be overhead at your location. If it is daylight saving time you need to subtract an hour in addition to the minutes. What is the local time of midday at your location? The formula is:

   (180° minus your longitude) divided by your answer to Q.1, the answer expressed as a fraction. This is the fraction of an hour that your local midday is after 12 midday on a clock. Convert this fraction of an hour to minutes after midday. Record your local midday:

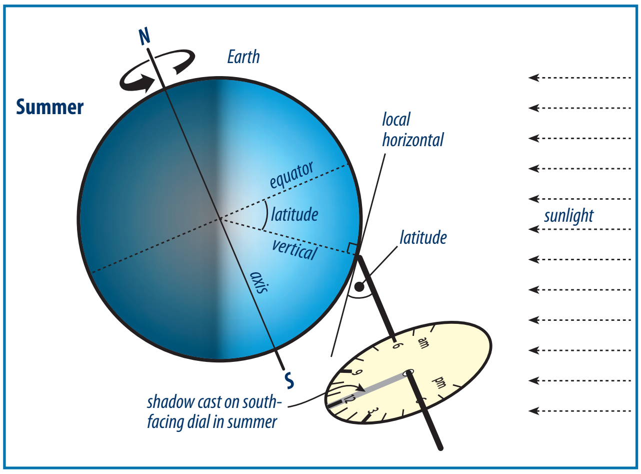
**6.** A sundial provides the local solar time because it uses the position of the sun at your location. There are many forms of sundials. All of them require that the edge (or style) of the gnomon, the part casting the shadow on its dial, be parallel to the Earth's axis, as shown in the diagram.

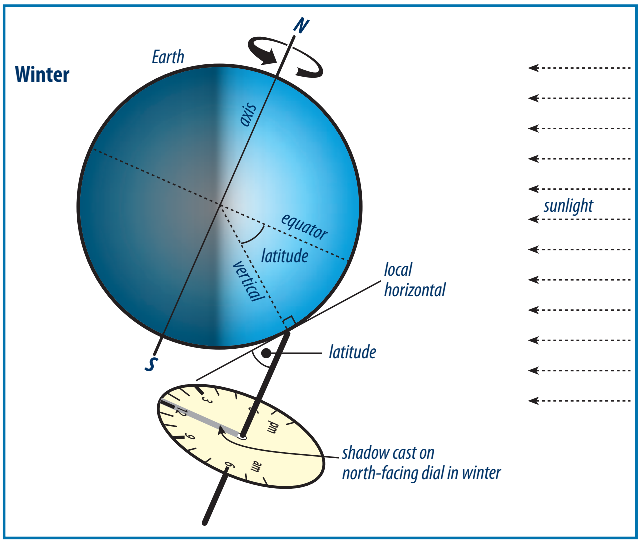



A vertical stick in the ground is often thought of as a sundial, but there are only two places on the Earth where that is true. What are those two places?

**7.** If you bought a sundial in Singapore, designed to be used there, would it show the local time accurately in Auckland? What is the evidence supporting your answer? (Hint: look up the latitude of Singapore).

**New Zealand, Midday, summer and winter**




**8.** An equatorial sundial has the dial parallel to the equator and the style of the gnomon parallel to the Earth's axis. When setup correctly the sun will cast a shadow on one side of the dial in summer, and on the other side in winter, as shown below.

To make and use an equatorial sundial you will need to know the direction of true north (not magnetic north) and your latitude.

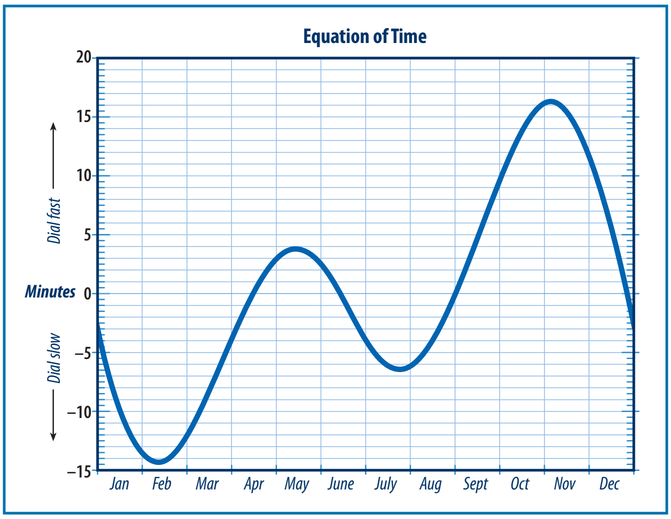
Why must it face true north and not magnetic north?

What is your latitude?

Why do you need to know your latitude?

9. Because the Earth's orbit is a slight ellipse its speed of orbit around the sun changes during a year, plus its axis is tilted. Your sundial will sometimes be ahead ('fast') of the mean (clock) time and at other times it will be behind ('slow'). The Equation of time graph allows you to correct for this. See: http://en.wikipedia.org/wiki/Equation_of_time

   Read the time of your sundial, note the day and date, then from the Equation of Time graph (included below), decide whether the sundial time is 'fast' or 'slow' for that date.




10. If possible, read the sundial time at midday and see whether it agrees with the calculation you did for Q. 5. Now include the correction for whether the sun was fast or slow for that date. If you used a sundial in conjunction with the Equation of Time graph, would your sundial be sufficiently accurate for you to use to ensure you arrive at appointments on time? Explain.

## Extensions

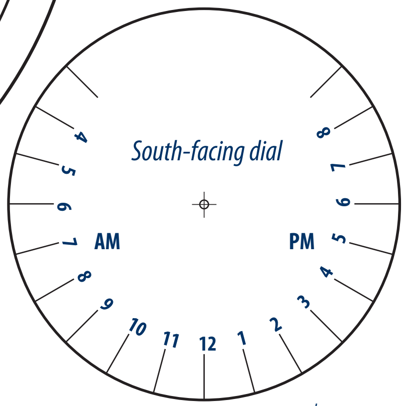
1. What were the major ways of measuring time in the past, and how is time measured accurately now?
2. What is the smallest division of the second that can now be timed accurately?

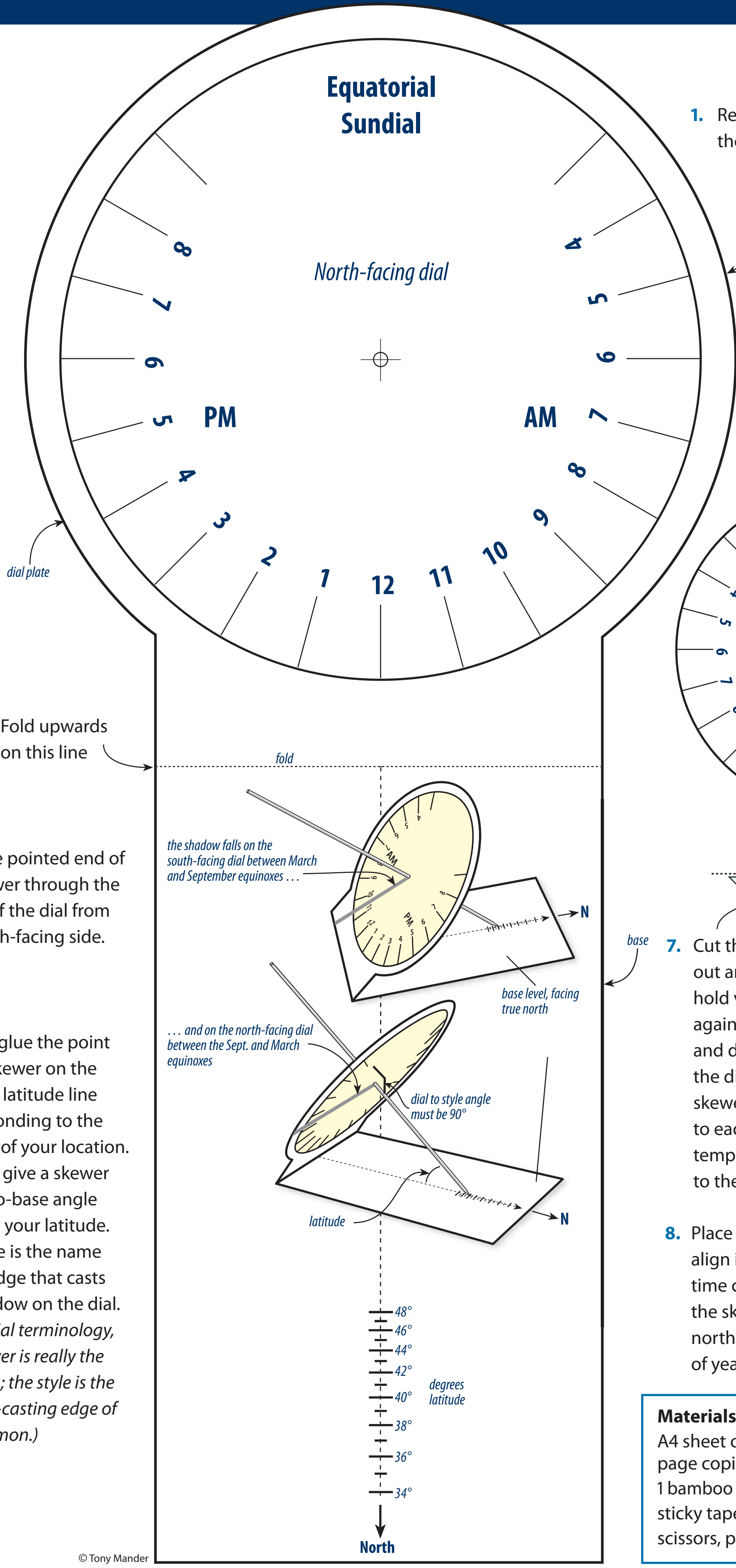
# Equatorial Sundial

1. Read all the instructions and identify the parts before starting construction.

2. Cut around the outline.

3. Draw the south-facing dial on the other side (hold it gently against a window and trace the hour markings through the paper and add the numbers); its appearance is shown below:



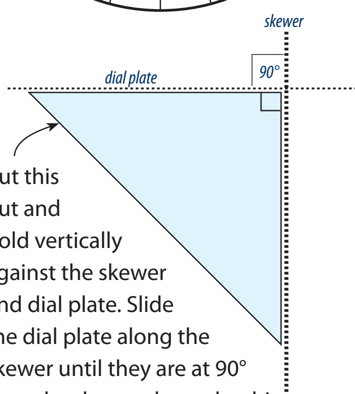




© Tony Mander

4. Fold upwards on this line

5. Push the pointed end of the skewer through the centre of the dial from the south-facing side.

6. Tape or glue the point of the skewer on the degrees latitude line corresponding to the latitude of your location. This will give a skewer (style)-to-base angle equal to your latitude. The style is the name of the edge that casts the shadow on the dial. *(In sundial terminology, the skewer is really the gnomon; the style is the shadow-casting edge of the gnomon.)*




7. Cut this out and hold vertically against the skewer and dial plate. Slide the dial plate along the skewer until they are at 90° to each other as shown by this template, then glue or tape the dial to the skewer (style) at that position.

8. Place the base on a level surface and align its centre true north. Local apparent time can be read from the shadow of the skewer on either the south-facing or north-facing dial depending on the time of year.

**Materials, tools**
A4 sheet of white card (140–160 gsm, this page copied on it)
1 bamboo skewer (~150 mm long, 2.5 mm thick)
sticky tape or glue
scissors, pen

# Teacher Guide to Activity Five

## Wavelengths and information

Astronomy utilises as many wavelengths as possible because different wavelengths provide different information. We see only a very small part of the electromagnetic spectrum. While our eyes tell us the shape and colour of objects, they can not tell us their composition, their temperature, or even that what we see is actually what exists, as some objects may not produce visible light.

Infrared light is utilised by common devices, as an earlier activity in this series investigated. This activity compares the information we gain from a visible light picture, using a digital camera, with the information about objects from an infrared thermometer from the same viewpoint. We can not see infrared, but we can feel near-infrared with our skin by its warming effect when it is absorbed.

Infrared thermometers are in common use. In medicine they allow rapid and accurate temperature readings (aimed inside the ear for example). Enabling temperatures to be measured from a distance is useful for fragile items, for hazardous processes, where there is a risk of contamination by contact thermometers, for moving objects, and for quickly finding 'hot-spots' that are otherwise difficult to detect such as faulty electrical wiring inside a wall, or even tumours inside body organs (not that the thermometer is not 'seeing' inside, it can only receive IR transmitted from the surface, which may indicate an abnormal source of heat beneath.

Infrared thermography cameras can produce a digital image calibrated to display temperatures in colours. Thermographs are especially useful to quickly gain an idea of temperature distribution, with many applications from medicine to manufacturing. The cameras are expensive, but your local electrician may have one and be prepared to visit the class to show its use. Digital cameras are highly sensitive to IR, but have IR filters to prevent IR affecting the visible light image.

## Rationale

There are two interdependent 'big ideas' (1) different wavelengths of light carry different 'messages', and (2) that all bodies radiate energy when above absolute zero (0 K, –273.16 °C), with the wavelengths and their intensity depending on the temperature.

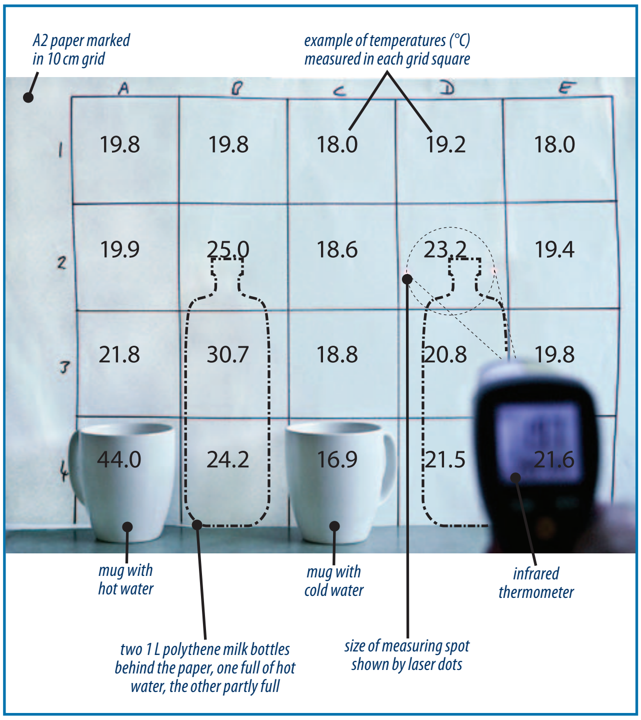
Using an infrared (IR) thermometer also introduces other ideas: that an object's characteristics can be measured remotely, that a thermometer must be calibrated, that an instrument utilising radiation has a particular field of view and resolution.

## Equipment and procedure

**Per group of 3–4:**

1. An A2 sheet of heavy paper or light card (any colour), suitable objects to include in front of it, e.g. mugs (one containing hot water, another with ice cubes), a container of hot water behind the paper but in contact with it to provide a 'hot spot', etc.
2. A metre rule and suitable pen (or white string and tape) to mark a grid on the paper or card.
3. A digital camera (only one is needed for a class, as it can be shared).
4. An infrared thermometer (again, it can be shared).

A typical experimental setup would look like this:




A 10 cm grid has been drawn on the card. One of the mugs in the photograph contains hot water (but not so hot steam rises from it), the other has cold water (but better if ice cubes had been added). Milk bottles with hot water are taped behind the paper, also acting as supports for the paper. Sample temperatures have been included. This provides a good opportunity to discuss resolution.

Students photograph their setup with a digital camera, then proceed to measure the temperature of each grid. For objects in front of the grid they may need to move closer to ensure only radiation from the object is being measured. At the completion they may wish to re-measure the hotter parts to see if there has been a change. Finally, they should photograph it again.

An extension is to black-out the room and repeat the exercise. The camera is unlikely to take a usable photograph, although students will see the objects and paper background sufficiently to aim the IR thermometer. The intention here is to show that the emitted radiation is not connected to the illumination and that measurements could be taken in darkness.

When presenting their data students need to consider how best to relate the information from the photograph (the shape, colour, size, location, etc. of objects seen in visible light) with the temperature from infrared light. As we are best able to see patterns when presented visually, a colour code for temperature ranges would allow a print of the photograph to be coloured for temperature.

Consider how to calibrate the IR thermometer, e g. use several mugs/beakers with masking tape on their outer surface, filled with water at known temperatures (using an ordinary thermometer).

There are similarities between this activity and how data from radio telescopes is presented. For an explanation and activity see:

http://www.gb.nrao.edu/epo/image.html (has activity sheets showing using colours representing radio signal values)

http://www.gb.nrao.edu/~glangsto/lessons/lessonMapping.html (explains how a radio telescope scans the sky to gain a 'picture')

## References


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

http://mcdonaldobservatory.org/teachers/classroom/Galaxies.html (has worksheets, teacher guides, etc.)

http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_astronomy/ (good introduction to all wavelengths)

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

http://www.allqa.com/IR.htm

http://www.ehow.com/how-does_4965130_infrared-thermometers-work.html


## Outcomes

Students should be able to describe how visible light and infrared light can provide different information about objects. They should also be able to describe how the resolution could be increased.

## Background information

The hotter something is the higher the frequency and intensity of infrared (IR) it emits and the greater the amount of energy in the radiation. IR (or optical) thermometers receive and focus IR radiation on to a detector. The detector absorbs and converts the total IR radiant energy to an electric signal, which is displayed and calibrated as a temperature.

The material and surface characteristics of an object affect the amount of radiation they emit or reflect. Shiny metal surfaces reflect infrared from adjacent sources, and do not emit radiation readily. We utilise these characteristics of shiny metallic surfaces in radiant heater reflectors, fire-fighter clothing, survival blankets, vacuum flasks, etc. An object's material and surface appearance give specific emission characteristics, or emissivity.

Emissivity is the ratio of the energy radiated by an object at a given temperature to that emitted by a perfect radiator (blackbody) at the same temperature. A perfect radiator emits (and also absorbs) the maximum amount of energy at a given temperature, so would have an emissivity of 1.0.

Dull, black surfaces have a high emissivity; highly reflective surfaces have a low emissivity. For example, highly polished aluminium at 100 °C has an emissivity of 0.09, but if only roughly polished it has twice the emissivity at 0.18. Polished aluminium radiates much less energy than would be expected from its temperature. To accurately measure the temperature of a shiny metal object with an infrared thermometer it is necessary to first paint or tape over the surface.

Temperature also affects the emissivity, which usually increases with increasing temperature for the same material and surface.

Most common materials, except shiny metal surfaces, have an emissivity of around 0.8–0.95.

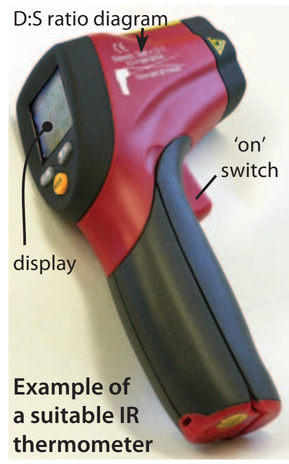
Infrared thermometers usually have a default emissivity of 0.95; those allowing the emissivity to be adjusted come with a table of the emissivity of common materials; detailed emissivity tables are also available on the internet.

The range of wavelengths for infrared is 0.74–1000 μm, divided into Near IR: 0.74–3 μm; Mid IR: 3–50 μm; Far IR: 50–1000 μm. Infrared thermometers generally utilise IR at 8–20 μm and measure the intensity of received IR in this narrow band. At normal body temperatures people radiate IR most strongly at about 10 μm (μm: $10^{-6}$ m).

## Choosing an infrared thermometer

The key characteristics to be considered are:

1. **Laser aiming:** a two-spot laser guide is easier to use than a single-spot laser guide, which merely indicates the centre of the measuring circle and requires a distance to spot ratio calculation to be sure that the area being measured is smaller than the target. The two-spot laser guide shows the diameter of the measuring circle.




Example of a suitable IR thermometer

2. **The Distance to Spot (D:S) ratio (resolution):** the thermometer lens has a specific field of view, so the greater the distance from the target the larger the collecting area will be. The higher the D:S ratio the smaller the spot size that can be measured. A D:S ratio of 12:1 is recommended, higher D:S ratios (e.g. 50:1) are expensive. The D:S ratio determines the distance from the target for an accurate reading. The spot size should always be smaller than the target so it is not receiving IR from objects behind the target. If your spot size must be no more than 100 mm in diameter, then for a 12:1 ratio thermometer you should be less than of 12 × 100 mm, or 1.2 m, from the target.

3. **Temperature range:** the general (affordable!) range of –50 °C to 650 °C is sufficient.

4. **Emissivity adjustment:** increases the usefulness of an IR thermometer.

## Using an infrared thermometer

- Avoid polished metal surfaces, otherwise first cover with masking tape and allow a minute or two for the tape to reach the temperature of the surface beneath. An IR thermometer can not distinguish between IR given off by the object being measured and IR that may be reflected from nearby objects; it measures only the total IR it receives. A useful demonstration of this characteristic is to use an aluminium frying pan which has a black non-stick coating on the inside but a polished metal surface on the outside. Heat it and take a reading of a side, first from inside then from the outside at the same spot.
- Aiming at a glass container may not give an accurate temperature of the contents as it reads the emission from the surface.
- Allow a few minutes for the unit to reach the ambient temperature of where it is to be used.
- Temperatures of liquids can be taken from the surface, but stir the liquid first to ensure an even temperature distribution, and ensure the unit does not get steam on its lens as it will affect its accuracy.

## Extensions

Investigate how we utilise infrared, e.g. 'night-vision' devices, surveillance cameras, remote control units, etc.

# Student Activity Five

## Wavelengths and information

Our eyes obviously see our world in 'visible light'. Most of the electromagnetic spectrum is invisible to our eyes. We utilise most of this spectrum: radio, TV, radar, microwaves, ultraviolet, x-rays, infrared, etc. are familiar names of different wavelengths of the electromagnetic spectrum.

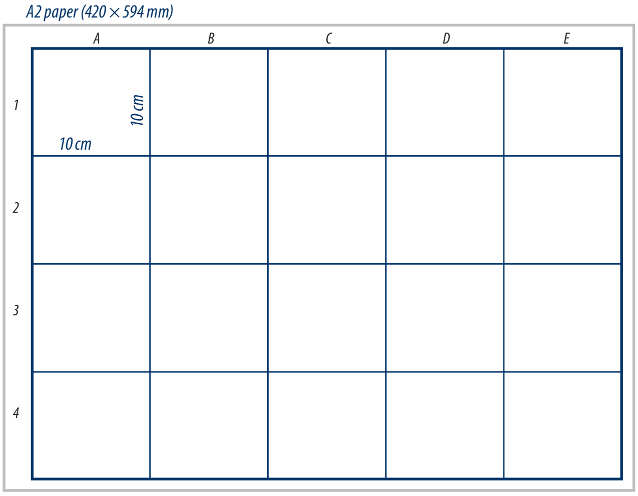
This activity compares the information contained in different wavelengths of electromagnetic radiation.

## What to do

You will need a digital camera and an infrared thermometer. The purpose is to compare the information you gain from a scene as seen in visible light by a camera and by an infrared thermometer.

1. Draw a grid of size no greater than 10 cm on a sheet of A2 heavy paper or light card. Label the rows and columns. This will act as a background.

*A2 paper (420 × 594 mm)*




2. Set the paper vertically and in front of it arrange some objects, such as mugs, one with hot water in it, another with cold water plus some ice cubes to cool it, perhaps bottles of hot and cold water behind the A2 sheet but in contact with it to give hot and cold spots (and also to support the paper—milk bottles are ideal).

   An alternative is to have someone else set up the scene so you do not know which has hot or cold water, or if anything is behind the paper.

3. Take a photograph of the scene with a digital camera, ensuring that the whole of the paper, but no more, is photographed.

4. Take a temperature reading of each grid with the digital thermometer. Where an object is in front of the grid, move closer to be sure that the object is fully within the view of the thermometer (if it has one laser spot it shows the centre of the view and you will need to calculate the size, if it has two laser spots they mark the diameter of the view). Record the temperatures in each grid square to the nearest 0.5 °C on the 'Results' chart below.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |

5. Decide on 5–6 significant temperature ranges, e.g. would 5–15 °C, 15–30 °C, etc., (i.e. 10 °C intervals) be sufficient, or would greater or lesser intervals be better? The table below is divided into six temperature ranges. Add your temperature ranges to the top row.

| Temperature °C | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| Colour code | | | | | |

6. Devise a colour code for the temperatures. The usual convention is to have 'warm' colours representing the higher temperatures and 'cool' colours the lower temperatures, e.g. cold to hot: black, purple, blue, red, orange, yellow, white. Add the colour code for your temperature ranges to the lower row of the table above.

7. When you print your digital photograph, either colour it with the colour code for temperatures or create a coloured transparent overlay. Attach it to your worksheet.

8. What information about the 'scene' did the visible light image give you?

9. Over time, the objects would all reach the temperature of the surrounding air. Would you expect this change to be obvious if you took another photograph? Explain.

**10.** A camera can not take photographs in the dark as no visible light would be present. Would an infrared thermometer be able to accurately read temperatures in the dark? Explain.

If you can black-out the room, or place an item in a light-tight container with a small hole for the thermometer to 'look' through, test it to see if it can read temperatures in the dark.

**11.** Sometimes a movie or TV programme may give the idea that an infrared camera can see through walls. An electrician may use an infrared camera to see if wiring in a wall is faulty and overheating. Are these cameras actually seeing through a wall, or is the camera only showing a temperature rise from heat transferred from an object in the wall? Explain.

**12.** The 10 cm grid is rather large to accurately locate the shape of a warmer or cooler area of the paper from an object in contact with it. If you drew a 5 cm grid and went closer with the thermometer to sample each smaller grid square, how many more measurements would you need to make?

The additional measurements would increase the resolution of the temperature 'picture'. Image resolution generally refers to the amount of detail or information in an image. How does making the grid squares smaller increase the resolution?

# Teacher Guide to Activity Six

## Temperature and radiation

The 'big idea' in this series is that everything we know about the universe is from "messages" in the electromagnetic radiation we receive from beyond planet Earth. One of the messages in visible light is its perceived colour.

This is a continuation of the 'big ideas' from the previous activity, in particular that all bodies radiate energy when above absolute zero (0 K, –273.16 °C), with the wavelengths and their intensity depending on the temperature. Temperature is a measure of the average vibrational kinetic energy of particles. At absolute zero there would be no particle movement.

## Rationale

The colour of stars is one of the ways of identifying their temperature and position on the sequence of stellar evolution. Cooler stars are red, while high temperature stars are blue-white. This is best illustrated by the Hertzsprung–Russell diagram, a scatter graph of stars showing the relationship between the luminosities of stars, their spectral types, and temperatures. Our sun is small and white in colour. It is often referred to as yellow because most of its visible light is emitted in the yellow-green part of the spectrum and the atmosphere scatters much of the blue light making the illuminating light appear yellowish.

This activity uses a standard 12V, 36W car headlight lamp commonly used in optical activities. The rheostat needs to the wire wound 'laboratory' type, with as high a resistance as possible within the 36W load limit. The power supply needs to have at least 3A output at 12V.

Do not attempt to measure the temperature of the lamp filament. The filament temperature will quickly exceed the limits of an infrared optical thermometer (as used in the previous activity). Tungsten filaments operate at around 2500 °C, far above any readily usable (and affordable!) thermometer. For this reason a subjective assessment of temperature by feel is suggested instead. It provides a good opportunity to discuss absolute measurements and comparative measurements.

Although a light meter could be used to measure light output from the lamp, these are generally calibrated for the visible light part of the electromagnetic spectrum. Most of the initial output is in the infrared area, and this continues to increase with the increase in temperature. A light meter would be of use only as the lamp approaches its maximum output. If you wish to use a photometer, see:

http://ircamera.as.arizona.edu/NatSci102/NatSci102/sun_measurements.pdf

## Equipment

**Per group of 3–4:**

1. A standard 12V, 36W car headlight lamp.
2. 12V DC source (laboratory power supply).
3. Ammeter (5A range).
4. Rheostat, 36W capacity, as high a resistance as possible.
5. Hookup wire.

## References

http://outreach.atnf.csiro.au/education/senior/cosmicengine/stars_colour.html#colourtemp

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

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

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

http://en.wikipedia.org/wiki/Hertzsprung-Russell_diagram

http://en.wikipedia.org/wiki/Wien's_displacement_law

## Outcomes

An understanding that the colour of celestial bodies and of ordinary objects indicates their temperature.

## Background information

Hot objects emit radiation at all wavelengths. The relationship between temperature and radiation is readily obvious in the visible light part of the electromagnetic spectrum. The hotter the object the shorter the wavelength of visible light emitted. In a dark room we can just see an object hotter than about 400 °C, by about 500°C the object would have a dull-red glow. At 1700 °C it would emit orange light similar to the glow of a candle flame. At about 6000°C, which is the temperature of the surface of the sun*, it would emit brilliant white light (although at this temperature materials would be vaporised). (*The interior of the sun is around 15 million °C.) Not only does the colour (peak wavelength) change with increasing temperature but the intensity, or amount of radiant energy, also increases.

## Extensions

The efficiency of lighting sources is of significant when considering energy usage and sustainability. The input in watts in relation to 'unwanted' radiation such as infrared could be considered from this activity.

# Student Activity Six

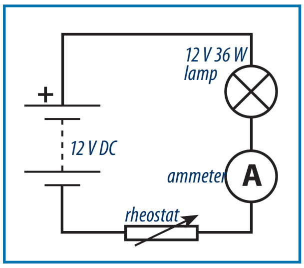
## Temperature and radiation

The colour of a hot object can indicate its temperature, for example, it could be described as "red-hot", or even "white-hot" when it becomes very hot.

Everything warmer than absolute zero (0 K, –273.16 °C) radiates energy. The amount of energy and the wavelength of the energy can indicate the temperature of an object. This activity uses an incandescent lamp to investigate the relationships between its power consumption, temperature, and colour. As you will not have suitable instruments to directly measure these relationships you will use instead your senses of 'feel' (no, not touch!) and sight. An incandescent lamp uses an electric current to heat a filament until it gives off light.

As you trying to detect small differences in light intensity it would be best if the room could be at least partially blacked-out.

## What to do




1. Assemble this circuit. The rheostat should have sufficient resistance to allow only a small current to pass when set at its maximum resistance.
2. Before connecting the power supply, hold your hand above the lamp, at about 1 cm from it. Can you feel warmth? As any object, including your body, gives off energy above absolute zero, why would you not expect to feel any radiation from the lamp? *(Hints: 1: is your hand warmer than a lamp at room temperature; 2: does your hand indicate absolute temperature, as a thermometer does, or relative temperature: hotter or cooler than your hand?)*
3. Move the rheostat control to its maximum resistance (lowest current) ***before*** connecting the power supply. As you are investigating the relationship between temperature and radiation why is it necessary to start at the coolest temperature?
4. Connect the power supply. Note the reading on the ammeter. Then hold your hand above the lamp (don't touch the glass) at the same distance as before. Can you feel any heat radiating from the lamp filament? Can you see any light from the filament? Record your results in the table below.
5. Repeat, but move the rheostat control a little at time to increase the current.

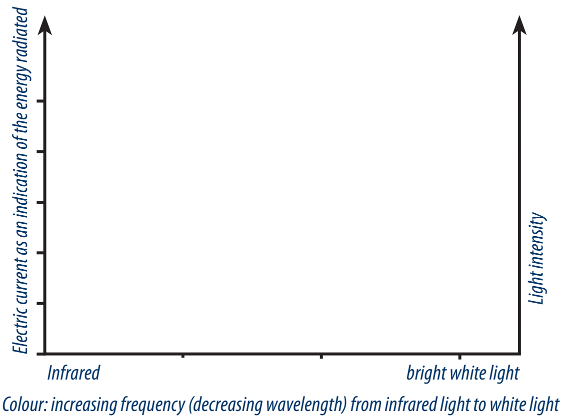
   When recording the results, it would be best to have standard descriptions, e.g. for feeling heat: none, slight warmth, warm, hot, very hot; light requires two descriptors: colour and brightness.

| Current (A) | Heat | Light colour | Light intensity |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

6. This activity is about radiation. So why should you be careful to **not** touch the glass of the lamp (apart from not wishing to burn your hand!)?
7. If you could not *see* any radiation, or see it as a faint red colour, yet *feel* warmth radiated from the lamp, you would have been feeling infrared radiation (we can't see infrared). Did you continue to feel infrared as more current passed through it and the lamp gave off more light? We want lamps to give off visible light, so does continuing to give off infrared reduce its efficiency as a lamp? Explain.

## Interpreting your data

1. Your table of data may show some interesting trends. The challenge now is to translate it into a visual form that may show at a glance what the trends are. One approach is to make a simple graph, as shown below:




2. What was the relationship between the increasing amount of energy radiated (electrical energy converted to radiant energy), temperature, and the colour of the light?

## Colour temperature

The previous activity demonstrated a relationship between temperature and the colour and intensity of radiation emitted as an object, especially a black body object, becomes hotter. As the temperature increases the peak radiation shifts from infrared, to red, orange, yellow, white, and eventually blue-hot. Beyond this the peak radiation would be in the ultra-violet region.

Stars are classified according to their colour and temperature. Temperature indicated by the colour of visible light is referred to as the colour temperature.

## Rationale

Colour temperature is a basic concept in astronomy, but is also used in everyday life, so this activity aims to help students make sense of the concept. It is encountered especially when taking photographs or when selecting lamps. In these applications it refers to the quality of the light, not necessarily to the emitting object's temperature.

Colour temperature is expressed in kelvins, K, the unit of absolute temperature. Note that the phrase 'degrees kelvin' is not used, only kelvins.

Light sources, for example, have a stated colour temperature but obviously do not operate at those temperatures. A 6000 K lamp may emit light of a colour corresponding to the actual radiation of a 'black body' at 6000 K, but that is the only similarity.

As a spectroscope is a key instrument in analysing colour of stars, this activity includes making a simple diffraction grating spectroscope. This is then used to examine and compare sources of colour of different colour temperatures.

Note that colour-blind students will need additional assistance.

## Equipment

1. **Making the spectroscopes:** two models are provided. Both use pieces of compact disks as a diffraction grating. One model reflects the light off the disk, the other transmits the light through the disk. Both work well. The instructions are included in the student activity. The materials required are: Reflection model: photocopied plans, thick black paper, sticky tape, scissors or cutting knives and cutting boards.

   *Transmission model:* 110/120 g toothpaste boxes, sticky tape, black card, masking tape to remove the CD coating.

   *For both models:* an old or blank CD (for the transmission model a blank CD is best, avoid a 'burnt' disk); strips of black card cut cleanly with a sharp knife to form the slit. Cut a strip to length, tape in place, insert a piece of light card to make the width of the slit and tape the second strip of black card against it, remove the light card. The slit could be formed in this way on both types of spectroscope.

2. **Light sources:** Compact fluorescent lamps (CFL), one of each of the three commonly available colour temperatures: 2700 K (warm white), 4100 K (white), and 6500 K (cool white or cool daylight).

   When turned on side-by-side the differences are quite obvious: the 2700 K lamp looks yellow compared to the 6500 K lamp, which looks blue. When they are the only sources of illumination the differences are much less obvious. When turned on in a room lit by sunlight the 6500 K lamp looks less blue than when beside the warm white lamp. This illustrates how the human eye adapts to different colours of lighting, seeing them as 'white'. A camera sees them for what they are (note that a digital camera needs to be set for 'daylight' white balance).

   Examining and comparing the CFL lamps with a spectroscope shows clearly how the proportions of the different phosphors are varied to achieve the desired colour quality to match a specific colour temperature. Examining an incandescent lamp will show its continuous spectrum, although as it has a colour temperature around 2700 K it will have more red than the spectrum of sunlight, around 5000 K. Ensure students examine sunlight only reflected from white paper, they are never to aim their spectroscope directly at the sun.

## References

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

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

www.optics.arizona.edu/academics/KidsDiffractionGratings.pdf

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html

## Outcomes

An understanding of the meaning of 'colour temperature' and knowledge of the likely quality of a particular colour temperature in Kelvins. In particular, the realisation that 'white' light from various sources is composed of a mixture of colours.

## Background information

About 8% of males and 0.5% of females have some kind of colour 'blindness', making it difficult for them to see differences between some colours. Total colour blindness is extremely rare. The majority form of colour 'blindness' is difficulty distinguishing between red and green.

A CD has pits in a single very closely spaced spiral track which acts like the parallel grooves of a diffraction grating. The tracks on a CD are 1.6 µm apart, which gives 625 tracks per millimetre. As light is reflected off the tracks, or pass through the transparent spaces ('slits') between tracks, different wavelengths are bent differently. Longer wavelengths (i.e. at the red end of the spectrum) are bent more than the shorter wavelengths. This is different to the way white light is dispersed through a glass prism, where the shorter wavelengths (i.e. at the blue end of the spectrum) are bent the most.

Prisms work by refraction. A prism separates different wavelengths in visible light by slowing the wave-front as it enters the glass, the wave-front regaining its speed as it exits. A diffraction grating utilises diffraction, where light bends at an edge. A diffraction grating has grooves which causes light to bend as it passes through the space between the grooves (which act as a narrow slit with closely-spaced edges) or reflected by each space. Each wavelength is bent differently and the waves from each slit interfere with each other. The interference can be destructive or constructive. Destructive interference is where a peak of one wave and a trough of an adjacent wave meet and cancel each other. Constructive interference is where the peaks or troughs of wave meet and add together. When slits are many and spaced closely together all you are left with are the waves which have added together so bright bands of different colours appear. Diffraction gratings have a much higher resolution than prisms, so are used in spectrometers to separate wavelengths. This is important in astronomy as each element has a distinctive 'fingerprint' of different wavelengths they emit when heated.

Radio waves behave in the same way, where constructive and destructive interference of waves provides a similar pattern of maximum and minimum strengths of separated wavelengths.

## Extensions

1. Scattering of light, making the sky blue and causing orange or red colours of sunset and sunrise, and how this affects the colour temperature of illumination.
2. The problems of taking photographs when light sources have differing colour temperatures.

# Student Activity Seven

## Colour temperature

In the previous activity you investigated the relationship between temperature and colour. The hotter an object became the more light it emitted and the colour of the peak emission went from red to orange, yellow, and to white. The colour of an object can be expressed as a temperature on the Kelvin scale, which begins from absolute zero (0 K, which is –273.16 °C). A temperature expressed in kelvins is not written with degrees, but only as the value in kelvins, K.

Sunlight is around 5500 K at midday with a clear sky, but in the early morning and evening it is less than that and has a red-orange colour (the sun hasn't changed, but more of the blue light has been scattered away by the atmosphere). What causes visible light to have different colour temperatures?

## What to do

The first step is to make either of the simple spectrometers described in the boxes below.

Both spectrometers use pieces of compact disks. One reflects light off the CD surface, the other uses light transmitted through a clear piece of disk (the aluminium coating is removed for this type).

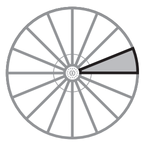
**1.** A compact disk has pits arranged in a single spiral closely-spaced track. The pits act as a groove. The track spacing is 1.6 µm. How many tracks would there be per centimetre diameter?

### Reflection spectrometer

*(light **reflects** off the CD diffraction grating)*

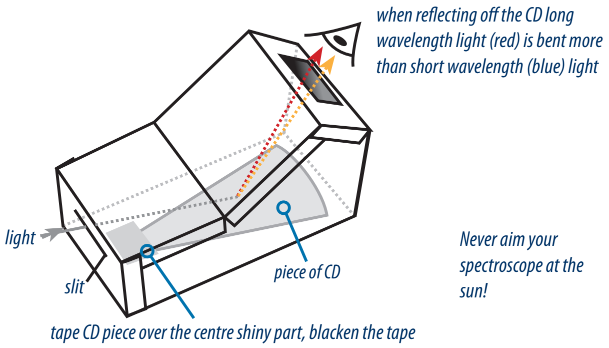
To see how to make this spectrometer, go to:
https://pantherfile.uwm.edu/awschwab/www/specweb.htm

To download a PDF of the plan, see:
https://pantherfile.uwm.edu/awschwab/www/specweb_files/3ScopesUWMChem3.PDF



Cut an old CD into 16 pieces and use one piece per spectroscope.

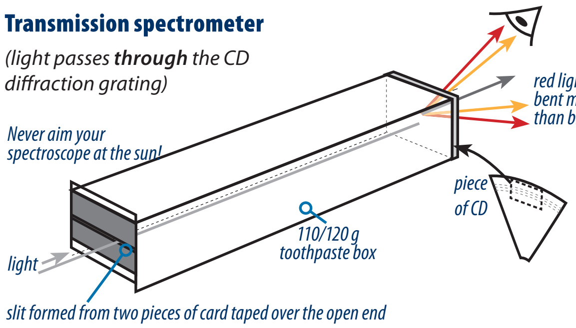
(1) Print the plan; (2) tape the photocopy to black thick paper or light card; (3) crease the folds through the plan; (4) cut out through the photocopy and black paper/card; (5) tape a piece of CD to the base; (6) blacken the tape over the shiny centre part; (7) assemble; (8) put your eye close to the viewing hole, aim the slit at the light, move it until you see the colours.




*An easier way to cut a slit is to make the slit larger and tape two pieces of card over it, using a piece of light card for the slit width.*

### Transmission spectrometer

*(light passes **through** the CD diffraction grating)*




(1) Cut the ends off a 110/120 g toothpaste box; (2) cut some black card strips, tape to one end with a gap between them (use a piece of light card to make the gap); (3) use masking tape to pull off the aluminium coating on a blank CD, cut a piece from the outer part the same size as the end of the box, with the CD tracks parallel to the slit at the front; (4) tape the CD piece across the end of the box with the track direction parallel to the slit; (5) point the slit at a light source and view from the CD end above or below the centre.

When passing through the piece of clear CD the long wavelength light (red) is bent more than the short wavelength light (blue), while some light goes straight through.

**2.** Light is bent when passes through the narrow transparent slits between the grooves, or is reflected off the grooves. This causes light waves from each slit to interfere with each other, resulting in the different wavelengths becoming separated. The colours in the light can be seen spread out in separate bands. Spectrometers are useful tools in seeing which colours are present in light.

Examine a range of light sources and draw the appearance of their spectra below.

| Light source | Appearance of its spectrum |
|---|---|
| Compact fluorescent lamp (CFL) 2700 K | |
| CFL 4100 K | |
| CFL 6500 K | |
| Incandescent lamp (2700–3000 K) | |
| LED | |
| | |

**3.** How did the spectra of the various sources differ, especially in relation to their colour temperature?