Vectors

Scalars and Vectors

All physical quantities can be categorised into 2 groups:

scalars - have only magnitude (size)

vectors - have both magnitude (size)and a direction.

Some scalars have a vector equivalent.

Examples:

Scalars	Vectors
distance	displacement
speed	velocity
-	acceleration
time	-
-	force
mass	weight
energy	-

Displacement and Velocity

Distance is a scalar quantity which relates the length of the path travelled in a journey. Displacement is a vector quantity which gives the separation between the start and finish points of the journey in a straight line, along with a direction (often a bearing). Speed and velocity can be calculated using the following equations

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

(scalar)

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

(vector)

Scalar Addition

Two scalars can be combined as long as they are of the same quantity and units.

For example:

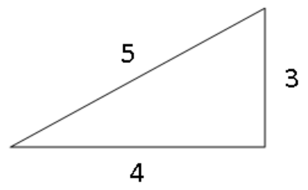
100 **m** + 50 **m** = 150 **m** can be added

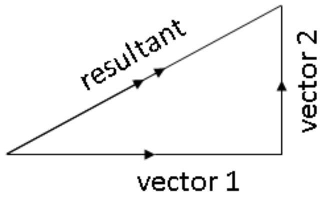
10 **m** + 50 **cm** cannot be added 10 **m** + 0.5 **m** =10.5 **m**

Vector Addition

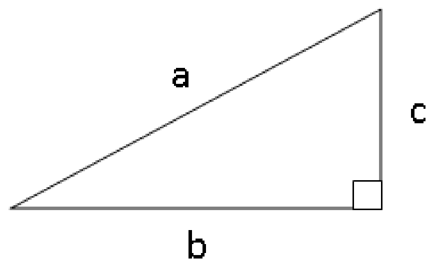
Adding vectors is more complicated, since they also require consideration to be taken for their direction. Vectors should be added "tip to tail", where the tip of the first vector is the starting point for the tail of the second vector.

At this level we only ever need to consider adding 2 vectors positioned at right-angles to one another. and even then it is usually a 3,4,5 triangle:





Helpful Triangle Rules



Pythagoras Theorem

$$a^2 = b^2 + c^2$$

Trigonometry

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

Motion

Speed

Speed is the distance travelled by an object in one second (usually expressed in metres per second, m/s or m s^{-1}).

Speed, Distance and Time

$$speed = \frac{distance}{time}$$

$$v = \frac{d}{t}$$

$$t = \frac{d}{v}$$

$$d = vt$$

Average and Instantaneous Speed

The **average speed** of an object is the average for the whole journey (total distance travelled divided by time taken).

Example: Travelling 70km in 2 hours by car

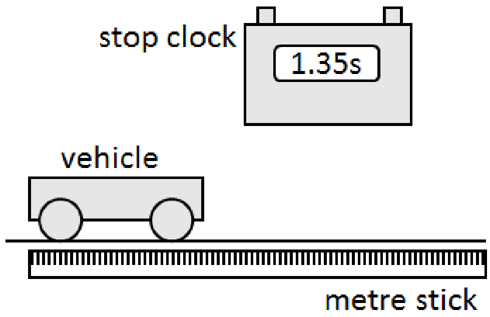
The **instantaneous speed** of an object is its speed at one particular point during the journey.

Example: Looking at the speedometer in the car

Measuring Average Speed

Measure distance travelled with a ruler.
Measure time taken to travel with a stop clock.

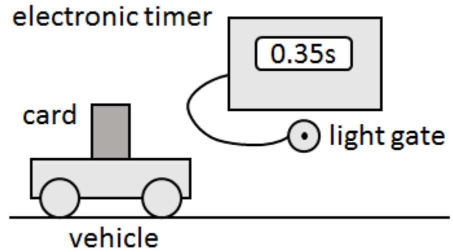
$$average\ speed = \frac{total\ distance\ travelled}{total\ time\ taken}$$



Measuring Instantaneous Speed

Measure length of card with a ruler.
Measure time taken for card to pass through light gate with an electronic timer.

$$instantaneous\ speed = \frac{length\ of\ card}{time\ taken\ to\ break\ beam}$$



Acceleration

Acceleration is the rate at which speed changes, how much it changes each second.

Acceleration is usually measured in metres per second per second (m/s/s or m/s^2 or $m\,s^{-2}$) although miles per hour per second (mph/s) can also be used sometimes.

Acceleration can be calculated by dividing the change in speed by the time taken for the change.

Calculating acceleration

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time}}$$

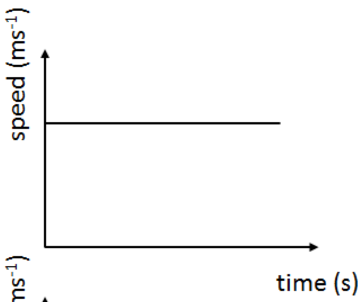
$$a = \frac{v - u}{t}$$

$$t = \frac{v - u}{a}$$

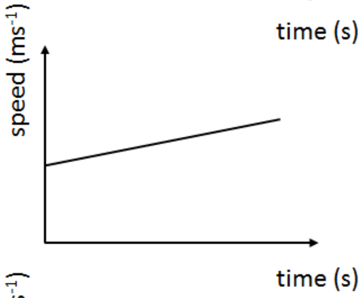
$$v = u + at$$

$$u = v - at$$

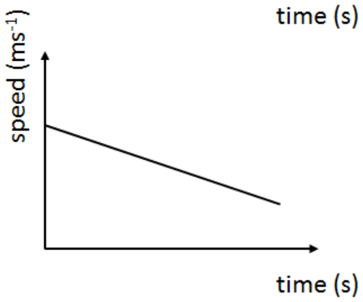
Speed-time graphs



constant speed



increasing speed (constant acceleration)



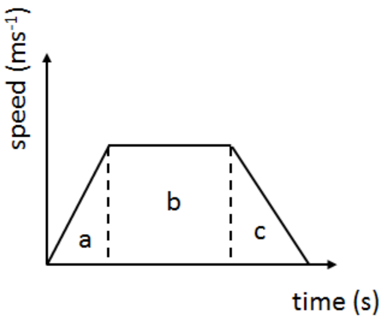
decreasing speed (constant deceleration

Using speed-time graphs

Acceleration and deceleration can be calculated from a speed time graph.

Acceleration is the gradient of the line. If it is positive the object is accelerating. If it is negative the object is decelerating.

The distance travelled by an object or vehicle can be calculated by finding the area under the graph.



distance travelled = area a + area b + area c

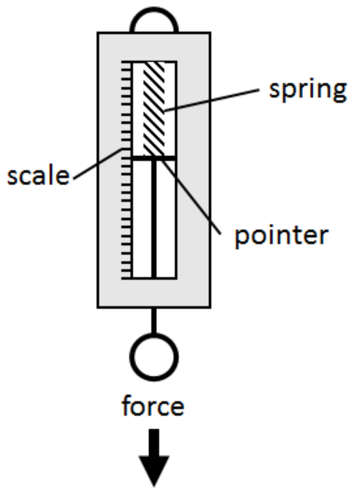
Forces

Forces

Forces can **change the shape, speed and direction** of motion of an object.
Force is measured in units called **newtons** (N).

Newton Spring Balance

The instrument used to measure forces is called a **Newton balance**.



When a force is applied to the balance the spring becomes longer. The increase in length is directly proportional to the force applied.

Weight

The **weight** of an object is the force on it due to the Earth's gravitational pull. Since it is a force weight is measured in newtons (not kilograms!)

The **mass** of an object is the amount of matter that makes up the object and is measured in kilograms.

To calculate the weight (in newtons) of an object on Earth multiply the mass (in kilograms) by 9.8.

The mass of an object remains the same no matter where the object is in the universe but the weight depends on the gravitational field strength at that point in space.

Gravitational Field Strength

The **gravitational field strength, g,** of a planet is the *force exerted per unit of mass* of an object (that is on that planet). Gravitational field strength therefore has units of N kg^{-1}.

For example, on earth the gravitational field strength, g, is 10 N kg^{-1}. On Mars this would be 3.8 N kg^{-1}.

Calculating Weight

W – weight
m – mass
g – gravitational field strength

$$\boxed{W = mg}$$

$$m = \frac{W}{g}$$

$$g = \frac{W}{m}$$

Friction

Friction is a force that opposes the motion of an object.

Air resistance, or drag, is the force of friction due to an object's motion through the air.
Situations in which friction is **increased** include:
i) applying the brakes of a car
ii) opening a parachute
iii) wearing rubber soled shoes for rock climbing

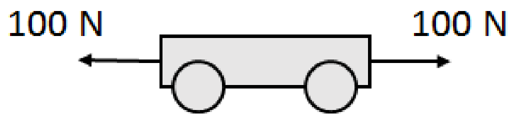
Situations in which friction is **decreased** include:
i) making racing cars streamlined
ii) oiling moving parts in a car engine
iv) using an air cushion on an 'air hockey' table

Seatbelts

When a car brakes (or crashes) there is a force acting against the car slowing it down. If the passenger was not wearing a seatbelt they would (according to Newton's First Law of Motion) continue to move forwards at constant speed (until they hit the windscreen or dashboard). A seatbelt is therefore used to provide a backwards force to stop the passenger from continuing to move forward at constant speed.

Balanced Forces

When *equal forces act in opposite directions* they are called **balanced forces**.

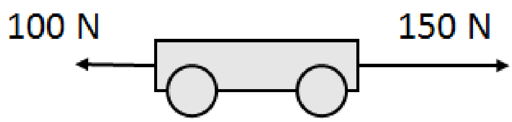


Balanced forces are equivalent to no forces at all.

When balanced forces (or no forces at all) act on an object it remains at rest or continue to move at a steady speed in a straight line. This is known as **Newton's First Law of Motion**.

Unbalanced Forces

When unbalanced forces act on an object the object changes speed (or direction). The acceleration due to an unbalanced force depends on the mass of the object and can be calculated using **Newton's Second Law.**



These two forces can be replaced by a single force of 50N acting to the right. This is known as the unbalanced or resultant force.

Newton's Second Law of Motion

$$\text{unbalanced force} = \text{mass} \times \text{acceleration}$$

$$\boxed{F = ma} \qquad a = \frac{F}{m} \qquad m = \frac{F}{a}$$

If more than one force is acting on the object it is necessary to determine the unbalanced force acting on it first, before using the above equation.

When the unbalanced force stays constant and the mass increases the acceleration decreases.
When the mass stays constant and the unbalanced force increases the acceleration increases.

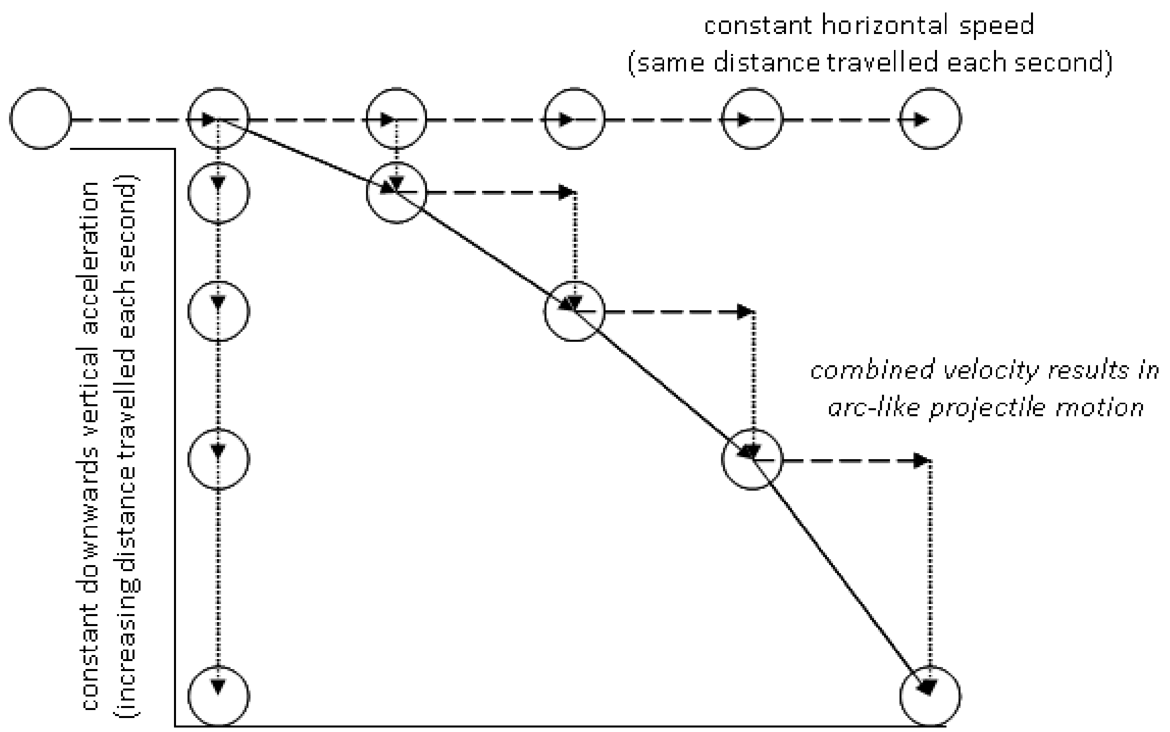
Projectiles

Projectile Motion

A projectiles is an object that has been launched and is travelling through the air. They experience 2 components to their motion. A horizontal one and a vertical one.

Vertical Motion - this component is under the influence of the gravitational field in which the object moves. This means that it will experience a **constant downwards vertical acceleration**.

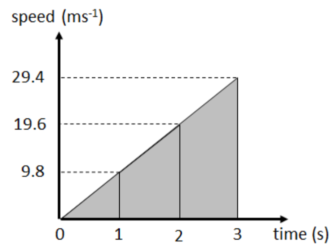
Horizontal Motion - this component is not under the influence of external forces. This means it will experience a **constant horizontal speed.**



Calculations

For horizontal motion we can use the speed equation since speed will be a constant. Therefore horizontal distance travelled will always be given by $d=vt$.

For vertical motion the projectile accelerates and we can us $v = u + at$. To calculate the distance travelled we would have to use a speed time graph, where the gradient is 9.8, to reflect the acceleration of the projectile distance travelled = area of graph



Orbits

A satellite orbit is a scaled up version of projectile motion. The satellite falls towards the centre of the Earth but misses each time. With enough horizontal speed a stable orbit is achieved.

The satellite will continue to travel with constant speed and at a constant height.

Newtons's Third Law of Motion

Newton's Third Law states that:

"In the absence of external forces, if object A exerts a force on object B, then object B exerts an equal and opposite force on object A"

These two forces are often know as an action force and a reaction force.

- When you walk you exert a backwards force on the floor - action
- The result is that the floor exerts a forwards force on you - reaction - you move forwards

Rockets and jet engines work on a similar principle:

- The engine exerts a backwards force on the gas - action
- The gas exerts a forwards for on the engine - reaction - the craft is propelled forwards

Freefall

When a spacecraft is in orbit it is constantly falling. Anything inside will fall in the same way. As a result the astronauts inside a space capsule will experience "weightlessness". They are actually in freefall (since they are still in the Earth's gravitational field and still have weight!)

This is similar to a passenger in a falling elevator. Both fall at the same rate (due to the gravitational field of the Earth), without windows the passenger feels "weightless".

To be truly weightless you would have to find a place where there is no gravitational field. These places are very hard to find.

Terminal Velocity

Terminal velocity occurs when a falling object experiences air resistance. Eventually the weight of the object will be perfectly balanced by the air resistance and the balanced forces will lead to constant speed. This constant speed is known as terminal velocity.

Space Exploration

Space exploration may refer to sending people into Earth's orbit or to the Moon, future plans to explore other planets or the sending on automated probes to carry out this exploration for us. Mankind has sent a variety of space probes to the Moon, Mercury, Venus and Mars. Probes have been sent past the gas giants too, taking decades to reach their destinations and send back their findings. The voyager spacecraft are even now leaving our solar system behind them as they race off into the vast emptiness of space beyond the limits of our solar system.

Space exploration may also refer simply to the use of satellites, placed in orbit around the Earth.

Satellites

The Moon is a natural satellite. Mankind has launched many artificial satellites over the last 6 decades. Their main uses include:

Communications Satellites	allow for worldwide audio and video communications with minimum delay, includes telephone & television
Weather Satellites	monitor global and local weather systems for use in weather forecasting and early warning of natural disasters
Space Telescopes	allow for astronomical observations without the interference of the Earth's atmosphere or light pollution
Global Positioning Systems	makes use of triangulation to determine the users location
Environmental Monitoring	monitoring land and sea temperatures, climate and climate change, as well as atmospheric composition

Benefits of Space Travel

Besides the most direct application of space travel, to find out more about the Universe and our place in it, there are many other benefits. Some are more obvious than others, such as the use of satellites, and some benefits and technologies exist because they were develop to support the space program. Areas that have benefited include:

Light Emitting Diodes	Anti icing systems	Freeze drying
Infrared thermometers	Chemical detection	Water purification
Artificial limbs	Video enhancement	Solar cells
Invisible braces	Firefighting equipment	Powdered lubricants
Scratch resistant lenses	Temper foam	Mine safety
Space blankets	Cordless Vacuums	Food safety

Risk of Space Travel

There are of course also risks associated with space travel and there have been a few accidents and disasters as well as successes. Astronauts and spacecraft designers must take these into account for both manned and unmanned missions.

Rocket Propulsion	There are always underlying risks when using rocket propulsion, miscalculations or accidents can lead to wrong and even dangerous trajectories or even explosions
Micrometeorites	Small pieces of rock in orbit or crossing the paths of satellites or spacecraft can do a great deal of damage
Solar flares and Radiation	There is a constant risk of high levels of ionising radiation from the Sun
No Atmosphere	There is no air and so no oxygen in space. All astronauts require specialised self-contained breathing and support systems to survive
Space Junk	Man made debris, including old disused satellites, are in orbit around the Earth and lie in the path of new space missions. Collisions in space have disastrous consequences
Re-entry into the Atmosphere	Gravitational potential energy is converted into kinetic energy as a space craft re-enters the atmosphere. Due to air resistance a great deal of heat energy is also generated. This can lead to extreme changes in temperatures. (See heat topic $\mathbf{E_H = cm\Delta T}$ and $\mathbf{E_H = ml}$)

Cosmology

Definitions

Planet a rocky or gaseous body, usually spherical, which orbits a central star. Reflects light from stars but does not produce its own light. The Earth is an example of a planet.

Moon a rocky body which orbits a planet. Reflects light from stars but does not produce its own light. Our Moon is an example of a moon.

Star a massive ball of gas which is undergoing nuclear fusion. Produces vast quantities of light and heat through this process. The Sun is a star.

Solar System a system consisting of a central star and all objects which are gravitationally bound to it, including planets (and their moons), asteroids and comets

Exo-planet a planet which is in orbit around a star other than our own

Galaxy a collection of several million stars and their planets, gravitationally bound and moving through the Universe as a single system. The Milky Way is our galaxy.

Universe everything we know to exist, all stars planets and galaxies.

Scale of the Universe

Earth to the Moon	384,400 km	1.3 light seconds	
Earth to the Sun	150 million km	8 light minutes	1 Astronomical Unit
Solar System Radius		approx. 2 light years	(objects under Suns influence)
Nearest Star		4 light Years	
Diameter of Galaxy		100,000 light years	
Diameter of observable Universe		approx. 93 billion light years	

1 light year = 365 x 24 x 60 x 60 x 300,000,000 = 9.5 x 10^{15}m

Life of the Universe

Origin – Expansion - Future

Origins Evidence points to all the matter that has been observed in the universe having originated in the same point. We think of this origin event as a Big Bang at the start of the universe

Expansion There is evidence to show that all matter in the observable universe is moving away from us (this does not mean that we are at the centre). If this is the case the universe must be expanding.

Future Will the Universe continue to expand forever? Will the Universe ever stop expanding? Will the Universe begin to collapse into a Big Crunch?

Age Based on the observed expansion of the Universe it is estimated to be 13.8 billion years old.

Observing the Universe

Astronomy

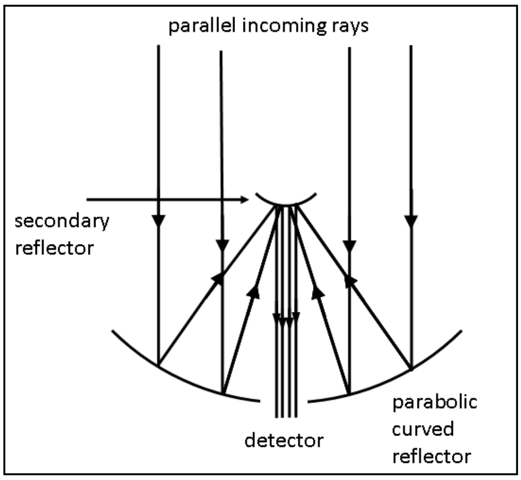
Astronomer use all 7 parts of the electromagnetic spectrum to observe the universe. Different parts of the spectrum help us in identifying and finding different pieces of evidence.

For example visible light is not able to penetrate the dense clouds of dust that are spread throughout the galaxy. To observe stars within or behind these clouds astronomers observe the Infrared radiation emitted by the stars, since their visible light will not reach us.

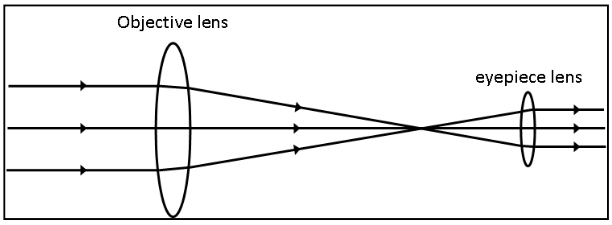
Telescopes

There are 2 main types of telescopes. The principles for both for visible light can generally be applied to most of the other parts of the electromagnetic spectrum.

Reflecting Telescope



Refracting Telescope

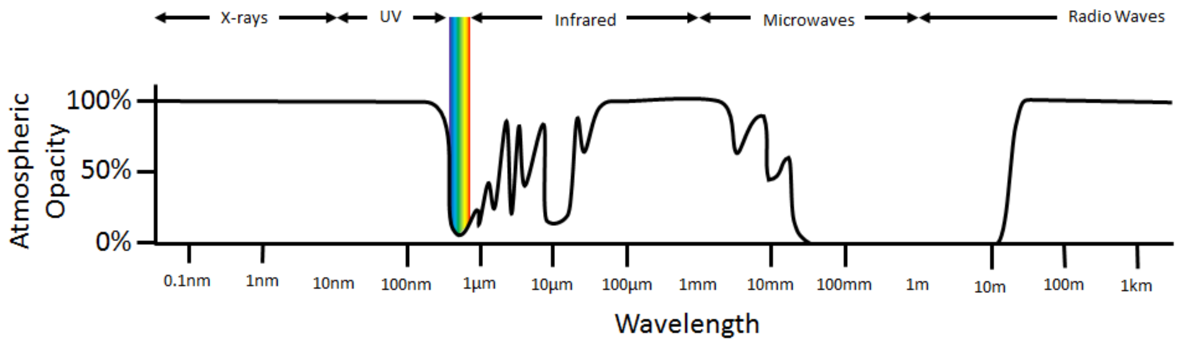


The larger the primary mirror or objective lens, the more light can be captured and therefore the better the image received.

The majority of modern telescopes use curved reflectors as large lenses are very heavy, easily damaged and difficult to transport, especially into space.

Opacity of the Atmosphere

The atmosphere is not transparent at all wavelength of the Electromagnetic spectrum. Some parts of the spectrum never reach the Earth's surface. To these types of radiation the atmosphere is said to be opaque.



Radio Astronomy

Radio waves are barely affected by Earth's atmosphere. Observations can be made during the day and even on cloudy days!

A special technique called interferometry allows 2 telescopes to act as one large telescope with an equivalent size of the separation between them. This allows for very high resolution images. This is also why radio telescopes are often seen arranged in large arrays, as opposed to individually. Two telescopes on opposite sides of the Earth will have an equivalent dish the size of the Earth! Imagine the effective size of a radio telescope in space paired with one on Earth!

Radio waves are **emitted** by stars and galaxies, as well as newly identified classes of objects, such as radio galaxies, quasars, pulsars, and masers.

Radio waves are **detected** using a curved reflector with **aerial**/antenna.

Microwave Astronomy

Most microwave frequencies are blocked by the Earth's atmosphere. For this reason space based telescopes are used. Astronomer have detected microwaves from all directions in space, this is known as the Cosmic Microwave Background and is a remnant of the Big Bang. These microwaves are electromagnetic waves which have lost their energy since they were **emitted** after the Big Bag, shifting from infrared radiation into the microwave part of the spectrum.

Similar to radio waves, Microwaves can also be **detected** using a curved reflector with **aerial**/antenna

Infrared Astronomy

Infrared radiation is mostly blocked by the Earth's atmosphere. It is absorbed by the moisture in the air. To overcome this, infrared observatories are placed in dry climates and at high altitude locations. This includes at the top of mountains and occasionally in the back of specially modified jumbo jets. Heat is a part of Infrared section of the Electromagnetic spectrum. Infrared telescopes (and their surroundings) must be super cooled to prevent them from detecting themselves, as **all warm objects emit some form of infrared radiation**.

Heat radiation lies in the far infrared region of the spectrum. The emitted wavelength can be used to determine the temperature of the source. Your body emits infrared radiation! Even cold objects emit infrared radiation with a longer wavelength.

Infrared radiation is **detected** using similar methods as visible light. Detectors similar to those found in digital cameras can detect near infrared radiation. Modifications and slightly different digital detectors are required for far infrared detection. In the simplest of cases a **blackened thermometer** or **photodiode** can be used.

Visible Spectrum Astronomy

Visible astronomy is almost as old as mankind itself. Visible light is able to pass through the atmosphere, provided the sky is clear of clouds. Visible light is however distorted by the atmosphere, it refracts when entering different gas densities at different altitude and temperatures. Again observatories are often found at high altitudes and away from populated areas, since light pollution will have a negative effect on observations.

Space based telescopes will produce much better images as they can totally remove the atmospheric distortion.

Visible light is **emitted** by **stars**. This allows us to observe them as well as the galaxies and star clusters that they make up. Planets, moons and nebulae (clouds of gas in space) all reflect light from nearby stars allowing us to observe them too. By observing visible light we can determine the composition of stars and nebulae (see spectroscopy section)

Visible light is classically **detected** using **photographic film** but is now most likely detected using an electronic detector such as a CCD or a CMOS detector like those found in modern digital cameras as well as the human **eye**, of course

Ultraviolet Astronomy

Ultraviolet light is absorbed by the atmosphere. All ultraviolet observations must be made using space based telescopes. These are very similar in design and construction as visible telescopes beside some modifications to filters

Ultraviolet radiation is mostly **emitted** by **very hot young stars**, although our sun produced UV too. UV radiation is ionising.

Ultraviolet light can be **detected** by special films, similar to photographic film and **fluorescent materials**. Digital detectors also exist, with similar construction to those for visible light.

X-ray Astronomy

X-rays are also blocked by the Earth's atmosphere. X-rays do not reflect as easily as lower frequency waves. Reflections must be at very large angles (measured from the normal) such that the barely graze the surface of the reflector. As a result X-ray telescopes must be very long. This makes X-ray telescopes difficult to launch into space as they require particularly powerful rockets to overcome their mass.

X-rays are **emitted** by **incredibly hot gases and objects** with temperatures from about one million kelvin (K) to hundreds of millions of kelvin.

X-rays are **detected** using **photographic film**. Digital detectors now also exist for X-ray radiation.

Gamma-ray Astronomy

Gamma rays are blocked by the Earth's atmosphere. They are also possible to reflect and detectors are very different from the other parts of the electromagnetic spectrum. They are more likely to rely on specially designed "masks" which cast a gamma ray shadow on the sensor allowing us to determine direction but not much detail. Gamma rays can also be **detected** using a **Geiger counter**, in this case no direction or detail of the source is provided.

Gamma rays are **emitted** by pulsars, black holes, active galaxies and unidentified objects responsible for high energy gamma ray bursts.

Spectroscopy

Continuous Spectrum

White light consists of a combination of all of the colours in the visible spectrum. A spectrum which consists of all these wavelengths is known as a continuous spectrum.

Emission and Absorption Line Spectra

The light emitted by stars (which are hot) can tell us a great deal about their composition. Hydrogen gas, for example only produces specific emission lines at specific wavelengths of light. These wavelengths relate to specific colours.

The emission lines for helium, lithium and beryllium etc. are all different and unique to that element, like a fingerprint. By observing the emission lines of stars we can determine their composition. The spectrum produced by a star can be observed using a spectroscope, which, like a prism, separates the colours of visible light.

When white light passes through a cold gas, the elements in the gas absorb light of specific wavelengths (and therefore colours). These lines are identical in wavelength to the emission lines and again identify the elements present.

These diagrams all show the emission and absorption lines for Hydrogen.