Cumbernauld Academy

Physics Department

Unit 1 Our Dynamic Universe

Booklet 3

Gravitation and Cosmology

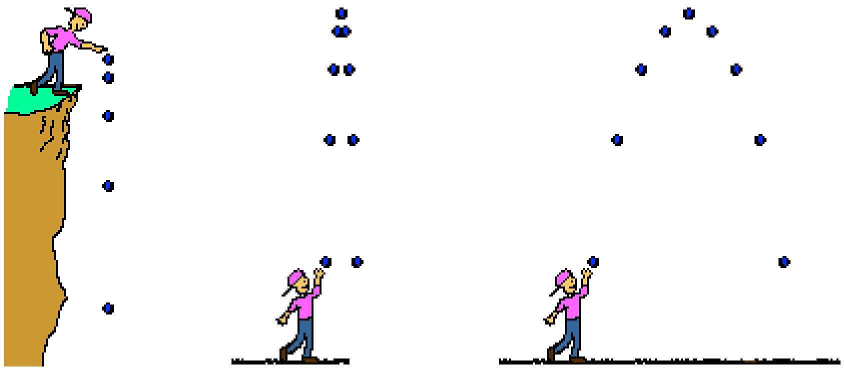
Summary Notes

1.4 Gravitation

Projectile Motion

Projectiles

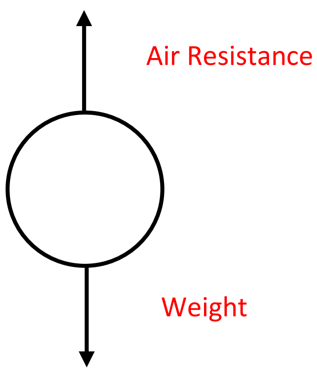
A projectile is any object, which, once projected, continues its motion by its own inertia and is influenced only by the downward force of gravity.



Most projectiles have both __horizontal__ and __vertical__ components of motion. The two components are not undergoing the same kind of motion and must be treated __separately__. Only the __vertical__ direction experiences an unbalanced force that effects the movement of the object.

Freefall

When an object travels through the air, there are multiple forces acting upon it.



If an object falls towards the centre of the Earth (vertical downwards motion) it will experience an _acceleration_. This acceleration occurs because of the force due to gravity – the object's _weight_ – acting on it.

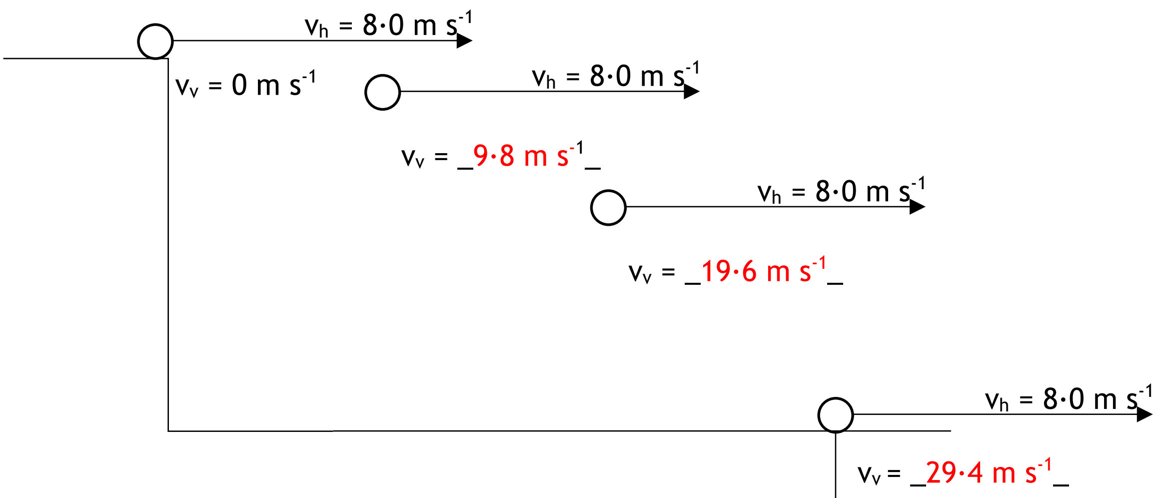
The object will also experience _air resistance_. This is a force that acts in the _upwards_ direction. The larger the speed of the object, **the larger the air resistance the object experiences.**

If an object falls a larger enough distance, the air resistance will increase to become the same _magnitude_ as the weight of the object. This means the two forces are balanced and the object will fall with a constant velocity, known as __**terminal velocity**__.

Horizontal Projection

An object is kicked horizontally off a cliff as shown.

Horizontally, there are no forces acting upon the object, so the horizontal velocity is __constant__. Vertically, there is a constant acceleration from the force due to gravity. This mean the vertical velocity is __increasing__. The combination of these two motions causes the __curved__ path of a projectile.



The horizontal velocity remains constant - __8·0 m s^{-1}__.

The vertical velocity increases by __9·8 m s^{-1}_ every second.

<u>Example</u>
The cannonball is projected horizontally from the cliff with a velocity of 100 m s^{-1}. The cliff is 20 m high.
Determine:
(a) the vertical speed of the cannonball, just before it hits the water; (3)
(b) if the cannonball will hit a ship that is 200 m from the base of the cliff. (3)

<u>Solution</u> **(Hint: time is the only quantity which can cross the horizontal and vertical barrier. Calculate t on one side and use it on the other)**

Horizontal (use d = vt)	Vertical (use 3 equations of motion)
d = ?	s = 20 m
v = 100 m s^{-1}	u = 0
t = ?	v = ?
	a = 9·8 m s^{-2}
	t = ?

(a)
$$v^2 = u^2 + 2as$$
$$v^2 = 0^2 + 2 \times 9{\cdot}8 \times 20$$
$$v^2 = 392$$
$$v = 19{\cdot}8 \text{ m s}^{-1}$$

(b)
$$v = u + at$$
$$19{\cdot}8 = 0 + (9{\cdot}8 \times t)$$
$$t = \frac{19{\cdot}8}{9{\cdot}8}$$
$$t = 2{\cdot}02 \text{ s}$$

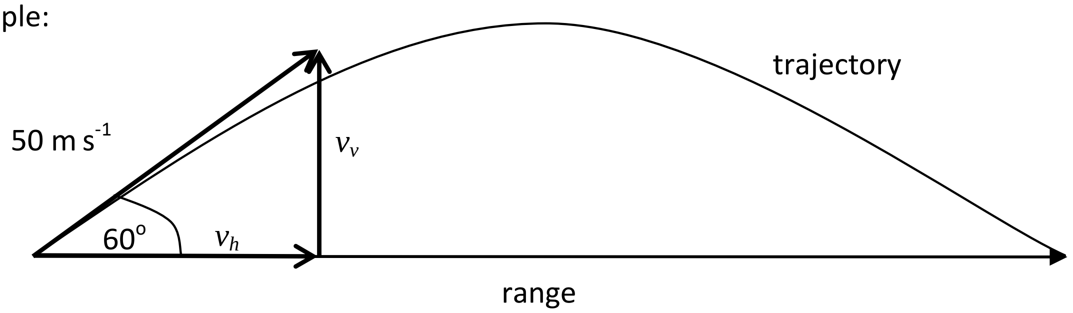
(b) ctd
$$d = vt$$
$$d = 100 \times 2{\cdot}02$$
$$d = 202 \text{ m}$$

The cannonball will hit the ship.

Projection at an angle

Projectiles launched at an angle require us to break the motion into vertical and horizontal components. This allows us to understand the motion of the projectile.

Example:



There is still only the single force due to gravity acting upon the object, so horizontal and vertical motions must still be treated separately. We must split the velocity at an angle into _vertical_ and _horizontal_ components before we do any other calculations. You will **never** use the velocity at an angle directly in any calculation ($50ms^{-1}$ in above example).

Important points to remember:

1. The path of the projectile is symmetrical around the highest point. This means:

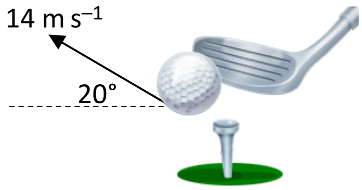
   Initial vertical velocity = - final vertical velocity

   _u_v = $-v_v$_

2. The time of flight = _2 x the time to the highest point _

3. The vertical velocity at the highest point is _zero_

Projection at an Angle Calculation



Example

A golfer hits a stationary ball and it leaves his club with a velocity of 14 ms^{-1} at an angle of 20° above the horizontal.

(a) Calculate:

(i) the horizontal component of the velocity of the ball; (1)

(ii) the vertical component of the velocity of the ball. (1)

(b) Calculate the time for the ball to reach its maximum height. (3)

(c) Calculate the total time of flight of the ball (3)

(d) How far down the fairway does the ball land? (3)

Solution

Horizontal	Vertical
d = ?	s = ?
v = 13.1ms^{-1}	u = 4.8ms^{-1}
t = ?	v = 0 (at top)
	a = -9.8ms^{-2}
	t = ?

(a) (i) $v_H = v \cos \Theta$

$v_H = 14 \cos 20$

$v_H = 13.1\ ms^{-1}$

(a) (ii) $v_H = v \sin \Theta$

$v_H = 14 \sin 20$

$v_H = 4.8\ ms^{-1}$

(b)
$$v = u + at$$
$$0 = 4{\cdot}8 + (-9{\cdot}8 \times t)$$
$$9{\cdot}8 \times t = 4{\cdot}8$$
$$t = \frac{4{\cdot}8}{9{\cdot}8}$$
$$t = 0{\cdot}49\ s$$

(c) total time = 2 x 0.49 s

(d) $d = v_H t$

d = 13.1 x 0.96

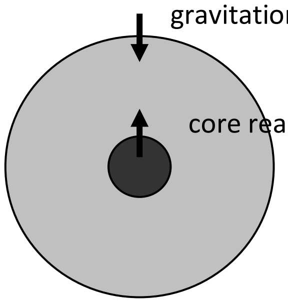
d = 12.8 ms^{-1}

Gravity

(can speak about Newton Thought experiment)

Gravity is caused by _mass_. Any object that has mass will have its own _gravitational field_. The magnitude of the field depends on the _size_ of the object. Everything has it's own gravitational pull, even you! But the gravitational force you exert is miniscule. In comparison, the gravitational pull of the Earth is 9.8Nkg^{-1} , and the Earth has a mass of 5.97×10^{24}kg.

Gravity is a force that permeates the entire universe; scientists believe that stars were formed by the gravitational attraction between hydrogen molecules in space. The attraction built up, over time, a large enough mass of gas such that the forces at the centre of the mass were big enough to cause the hydrogen molecules to fuse together, generating energy. This is what is happening in the centre of the sun. The energy radiating outwards from the centre of the sun counteracts the gravitational force trying to compress the sun inwards.



In time the hydrogen will be used up, the reaction will stop and the sun will collapse under its own gravity. If you expect to live for 4 or so billion years you could worry about this.

Newton's Universal Law of Gravitation

Newton produced what is known as the Universal Law of Gravitation:

$$\boxed{F = \frac{Gm_1m_2}{r^2}}$$

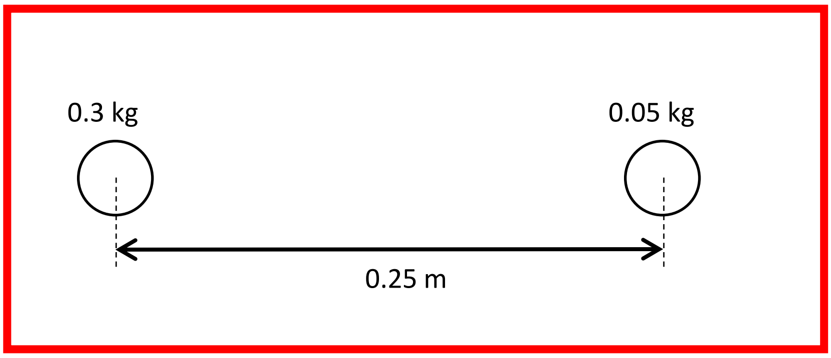
G is the universal constant of gravitation = _$6.67 \times 10^{-11} m^3kg^{-1}s^{-2}$_
m_1 and m_2 are the _masses of each of the objects_
r is the _distance that both objects are apart_
F is the _force due to gravity_.

Gravitational force is always _attractive_ (objects more towards each other).

The distance, r, between the two objects is the distance between their _**centres of mass**_. This is especially important when considering planetary bodies. For example, the radius of the orbit of the moon is only the distance from the surface of the Earth to the surface of the Moon, not the distance between their centres of mass.

Example
Consider a folder, of mass 0.3 kg and a pen, of mass 0.05 kg, sitting on a desk, 0.25 m apart. Calculate the magnitude of the gravitational force between the two masses. (Assume they can be approximated to spherical objects).

Solution



$F = ?$
$m_1 = 0.3$ kg
$m_2 = 0.05$ kg
$r = 0.25$ m
$G = 6{\cdot}67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$

$$F = \frac{G\, m_1\, m_2}{r^2}$$

$$F = \frac{6.67 \times 10^{-11} \times 0.3 \times 0.05}{0.25^2}$$

$$F = 1.6 \times 10^{-11}\ N$$

(Can discuss applications of gravitational force – the slingshot effect)

1.5 Special Relativity

Relativity

Introduction to Relativity

Einstein originally proposed his theory of special relativity in 1905 and it is often taken as the beginning of modern Physics. It was one of four world changing theories published by Einstein that year, known as the Annus Mirabilis (miracle year) papers. Einstein was 26.

Relativity has allowed us to examine the mechanics of the universe far beyond that of Newtonian mechanics, especially the more extreme phenomena such as black holes, dark matter and the expansion of the universe, where the usual laws of motion and gravity appear to break down.
Special Relativity was the first theory of relativity Einstein proposed. It was termed as 'special' as it only considers the 'special' case of reference frames moving at **constant** speed. Later he developed the theory of general relativity which considers accelerating frames of reference.

Reference Frames

Relativity is all about _observing_ events and _measuring_ physical quantities, such as distance and time, from different _reference frames_. Here is an example of the same event seen by three different observers, each in their own frame of reference:

Event 1: You are reading your Kindle on the train. The train is travelling at 60 mph.

Observer	Location	Observation
1	Passenger sitting next to you	You are stationary
2	Person standing on the platform	You are travelling towards them at 60mph
3	Passenger on train travelling at 60mph in opposite direction	You are travelling towards them at 120mph

This example works well as it only involves objects travelling at relatively low speeds. The comparison between reference frames does not work in quite the same way, however, if objects are moving close to the speed of light.

Event 2: You are reading your Kindle on an interstellar train. The train is travelling at 2×10^8 m s^{-1}.

Observer	Location	Observation
1	Passenger sitting next to you	You are stationary
2	Person standing on the platform	You are travelling towards them at 2×10^8 ms^{-1}
3	Passenger on train travelling at 2×10^8 m $^{-1}$ in opposite direction	You are travelling towards them at **4×10^8 ms^{-1}**

The observation made by observer 3 is impossible as an object cannot travel faster than the _speed of light_ in any reference frame and it would certainly be impossible to watch something travel faster than light, so this scenario is impossible.

The Principles of Relativity

(YouTube: Special Relativity: Crash Course Physics #42 or minute physics series)

The Principles of Relativity - Introduction

Einstein came up with two principles, or postulates, to explain the problem of fast moving reference frames. These were later proved with a vast array of data from many different experiments and became very clear once we started communicating with satellites, in orbit.

The postulates of Special Relativity:

1. **When two observers are moving at _constant speeds_ relative to one another, they will observe the same laws of physics.**
2. **The speed of light (in a vacuum) is the _same_ for all observers.**

This means that no matter how fast you go, you can never catch up with a beam of light, since it always travels at _$3{\cdot}0 \times 10^8$ ms^{-1}_ **relative** *to you*.

If you (or anything made of matter) were able to travel as fast as light, light would still move away or towards you at $3{\cdot}0 \times 10^8$ ms^{-1}, as you are stationary in your own reference frame.

The most well-known experimental proof is the Michelson-Morley interferometer experiment. Maxwell's electromagnetism equations also corroborated these postulates.

Example: If a car ship is travelling through space at 90% of the speed of light and then switches on its headlights.

The passenger of the car will see the beams of the headlights travel away from them at _3×10^8 ms^{-1}_.

An observer on Earth will also observe light of the beams travelling at _3×10^8 ms^{-1}_.

The speed of light, **c**, is _constant_ in and between all reference frames and for all observers.

These principles have strange consequences for the measurement of distance and time between reference frames.

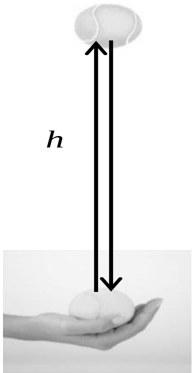
Time Dilation

Time Dilation

We can conduct a thought experiment of our own, showing that one consequence of the speed of light being the same for all observers is that **time experienced by all observers is not necessarily the same.** There is no universal clock that we can all refer to – we can only make measurements of time as we experience it.

Time is different for observers in different reference frames because the path they observe for a moving object is different.

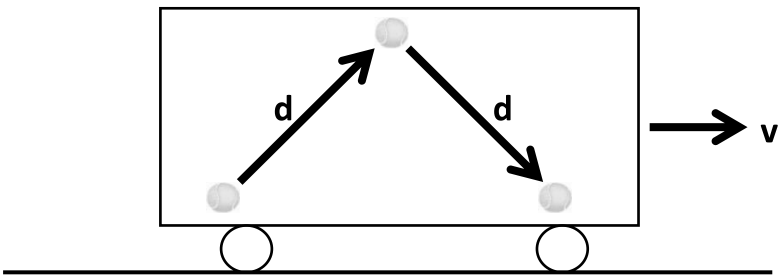
Event 1: Inside a moving train carriage, a tennis ball is thrown straight up and caught in the same hand.



Observer 1: standing in train carriage, throws tennis ball straight up and catches it in the same hand.
In Observer 1's reference frame they are stationary and the ball has gone straight up and down.
Observer 1 sees the ball travel a total distance of _**2h**_.
The ball is travelling at a speed _**v**_.
The period of time for the ball to return to the observers hand is:

$$t = 2h / v$$

Observer 2, standing on the platform watches the train go past at a speed, **v,** and sees the passenger throw the ball. However, to them, the passenger is also travelling horizontally, at speed **v**. This means that, to Observer 2, the tennis ball has travelled a horizontal distance, as well as a vertical one.



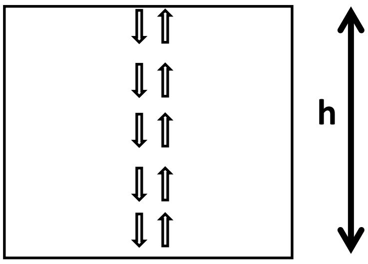
Observer 2 sees the ball travel a total distance of _**2d**_.
The period of time for the ball to return to the observers hand is:

$$t' = 2d / v$$

For observer 2, the ball has travelled a greater distance, in the same time.

Time Dilation (continued)

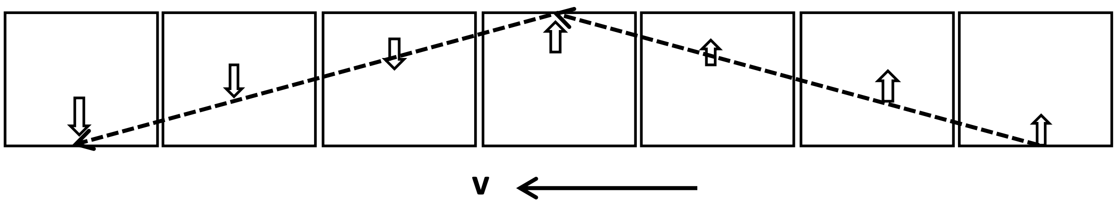
Event 2: You are in a spaceship travelling to the left, at speed **V**. Inside the spaceship cabin, a pulsed laser beam is pointed vertically up at the ceiling and is reflected back down. The laser emits another pulse when the reflected pulse is detected by a photodiode.



Reference frame 1: you, inside the cabin.
The beam goes straight up, reflects of the ceiling and travels straight down.

Period of pulse $t = 2h / c$

Reference frame 2: Observer on another, stationary ship.



Period of pulse $t' = 2d / c$

The time for the experiment as observed by the stationary ship, **t'**, is greater than the time observed by you when moving with the photodiode **t**, i.e. what you might observe as taking 1 second could appear to take 2 seconds to your stationary colleague. Note that you would be unaware of any difference until you were able to meet up with your colleague again and compare your data.

Time Dilation Equation and the Lorentz Factor

$$\mathbf{t'} = \frac{\mathbf{t}}{\sqrt{\mathbf{1} - \left(\frac{\mathbf{v^2}}{\mathbf{c^2}}\right)}}$$

Note this is often written as: $\mathbf{t' = \gamma t}$

where γ is known as the Lorentz Factor. It is used often in the study of special relativity and is given by:

$$\boldsymbol{\gamma} = \frac{\mathbf{1}}{\sqrt{\mathbf{1} - \left(\frac{\mathbf{v^2}}{\mathbf{c^2}}\right)}}$$

t' is always observed by the _stationary_ observer, observing the object moving at speed. E.g. the person on a train platform watching the train go by, or an observer on Earth watching a fast moving ship.

Example:

A rocket is travelling past Earth at a constant speed of 2.7×10^8 ms^{-1}.
The pilot measures the journey as taking 240 minutes.
How long did the journey take when measured by an observer on Earth?

Solution:

t = 240 minutes
c = 3×10^8 ms^{-1}
v = 2.7×10^8 ms^{-1}
t' = ?

$$t' = \frac{t}{\sqrt{1 - \left(\frac{v^2}{c^2}\right)}}$$

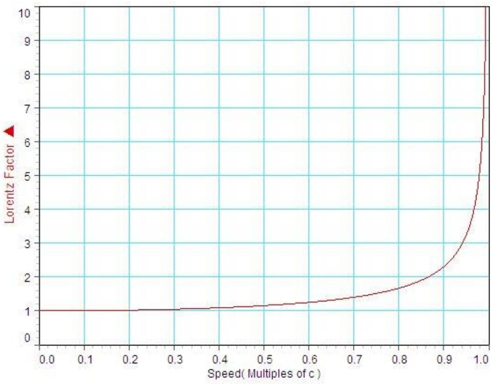
$$t' = \frac{240}{\sqrt{1 - \left(\frac{2.7 \times 10^8}{3.0 \times 10^8}\right)^2}}$$

t' = 550 minutes

Why we do not notice relativistic time differences in everyday life?

A graph of the Lorentz factor versus speed (measured as a multiple of the speed of light) is shown.

We can see that for small speeds (i.e. less than 0.1 times the speed of light) the Lorentz factor is approximately 1 and relativistic effects are negligibly small.



Application of Time Dilation

Further evidence in support of special relativity comes from the field of particle physics, in the form of the detection of a particle called a muon at the surface of the Earth. Muons are produced in the upper layers of the atmosphere by cosmic rays (high-energy protons from space). The speed of muons high in the atmosphere is 99·9653% of the speed of light.

The half-life of muons when measured in a laboratory is about 2·2 μs.

<u>Example:</u> Show, by calculation, why time dilation is necessary to explain the observation of muons at the surface of the Earth.

<u>Solution:</u>

$t = 2.2\ \mu s = 2.2 \times 10^{-6}$ s

$v = 0.999653 \times 3.00 \times 10^{8} = 2.998956 \times 10^{8}\ ms^{-1}$

$d = ?$

$d = vt$

$d = 2.998956 \times 10^{8} \times 2.2 \times 10^{-6}$

$d = 660$ m

$$t' = \frac{t}{\sqrt{1 - \left(\frac{v^2}{c^2}\right)}}$$

$$t' = \frac{2.2 \times 10^{-6}}{\sqrt{1 - (0.999653)^2}}$$

$t' = 84$ s

$d' = vt$

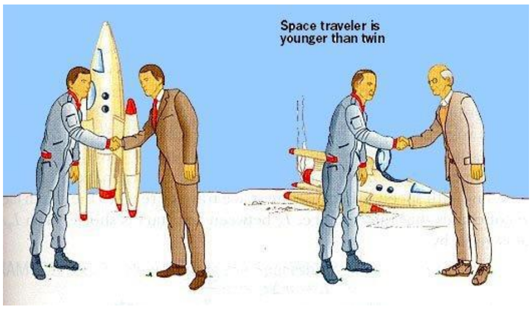
$d' = 2.998956 \times 10^{8} \times 84 \times 10^{-6}$

$d' = 2.52 \times 10^{4}$ m

In the reference frame of an observer on Earth the half-life of the muon is recorded as 84 μs and therefore from this perspective, the muon has enough time to travel the many kilometres to the Earth's surface.

A Twin Paradox

You leave Earth and your twin to go on a mission in a spaceship travelling at 90% the speed of light on a return journey that lasts 20 years. When you get back you find that 46 years will have elapsed on Earth. Your clock will have run slowly compared to one on Earth, however as far as you were concerned the clock would have been working correctly on your spaceship.



You will look 26 years younger than your twin.

Length Contraction

Another implication of Einstein's theory is the shortening of length when an object is moving. Consider the muons discussed above. Their large speed means they experience a longer half-life due to time dilation. An equivalent way of thinking about this is that the fast moving muons observe a much shorter (or contracted) distance travelled, by the same amount as the time has increased (or dilated). A symmetrical formula for length contraction can be derived.

$$\boxed{l' = l\sqrt{1-\frac{v^2}{c^2}}}$$

Where **l** is the distance measured by an observer who is _stationary_ and **l'** the distance observed by the observer who is moving at _speed_.

<u>Example</u>

Let's take the example of a space ship flying away from Earth towards Proxima Centauri, our nearest star, to study the observations due to length contraction. The distance to Proxima Centauri is 4.2 ly. Length contraction only takes place in the direction that the object is travelling. For the pilot of the space ship, this means that they will measure the distance, in front of them, between Earth and Proxima as less than the distance measured by a stationary observer. Let's say the spaceship is travelling at 0.8 c.

<u>Solution</u>

$$l' = l\sqrt{1-\frac{v^2}{c^2}}$$

$l = 4.2$ ly
$l' = ?$
$v = 0.8$ c

$$l' = 4.2\sqrt{1-0.8^2}$$

$$l' = 2.52$$

$$l' = 2.5 \text{ ly}$$

So the Pilot of the ship measures their journey as 2.5 ly.

<u>Formal Homework 5 – Gravitation & Special Relativity</u>

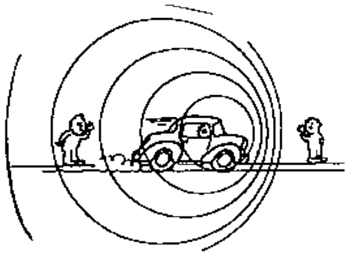
1.6 The Expanding Universe

The Doppler Effect and Redshift

The Doppler Effect

The Doppler Effect is the change in the observed frequency of a wave, when the source or observer is moving. In this course we will concentrate on a wave source moving at _**constant speed**_ relative to a stationary observer.

You have already experienced the Doppler Effect many times. The most noticeable is when a police car, ambulance or fire engine passes you. You hear the pitch of their siren _increase_ as they come towards you and then _decrease_ as they move away.



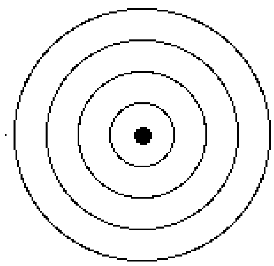
The Doppler Effect applies to all waves, **including light**.

Uses of the Doppler Effect

- Police radar guns use the Doppler effect to measure the speed of motorists.
- Doppler is used to measure the speed of blood flow in veins to check for deep vein thrombosis [DVT] in medicine.

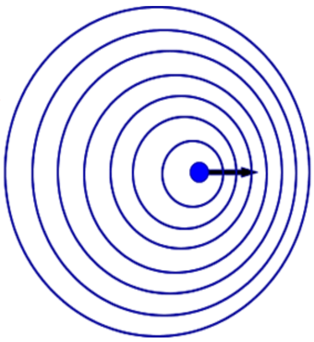
Stationary Source

A stationary sound source produces sound waves at a _constant frequency **f**_, and the wavefronts propagate symmetrically away from the source at a constant speed, which is the speed of sound in the medium. The distance between wave-fronts is the _wavelength_. All observers will hear the same frequency, which will be equal to the actual frequency of the source: _$\mathbf{f = f_0}$_.



Moving Source

The sound source now moves to the right with a _speed $\mathbf{v_s}$_. The wavefronts are produced with the same frequency as before, therefore the period of each wave is the same as before. However, in the time taken for the production of each new wave the source has moved some distance to the right. This means that the wavefronts on the left are created further apart and the wavefronts on the right are created closer together. This leads to the spreading out and bunching up of waves you can see to the right and hence the change in frequency.



The frequency of the source will remain constant, it is the observed frequency that changes.

The Doppler Effect Equations

More relevant to our learning in this section, the Doppler Effect is highly prominent in our observations of the universe and provides some of the strongest evidence for major theories such as the Big Bang and an expanding universe.

For a stationary observer with a wave source _**moving towards them**_, the relationship between the frequency, $\mathbf{f_s}$, of the source and the observed frequency, $\mathbf{f_o}$, is:

$$f_o = f_s\left(\frac{v}{v - v_s}\right)$$

v = speed of the wave
v_s = speed of source
f_s = frequency source
f_o = observed frequency

For a stationary observer with a wave source _**moving away from them**_, the relationship between the frequency, $\mathbf{f_s}$, of the source and the observed frequency, $\mathbf{f_o}$, is:

$$f_o = f_s\left(\frac{v}{v + v_s}\right)$$

This second scenario is exactly what is observed when we look at the light from distant stars, galaxies and supernovae, evidence that the universe is expanding. These relationships also allow us to calculate the speed at which an exoplanet is orbiting its parent star, or the velocity of stars orbiting a galactic core, which has lead us to theorise the existence of dark matter.

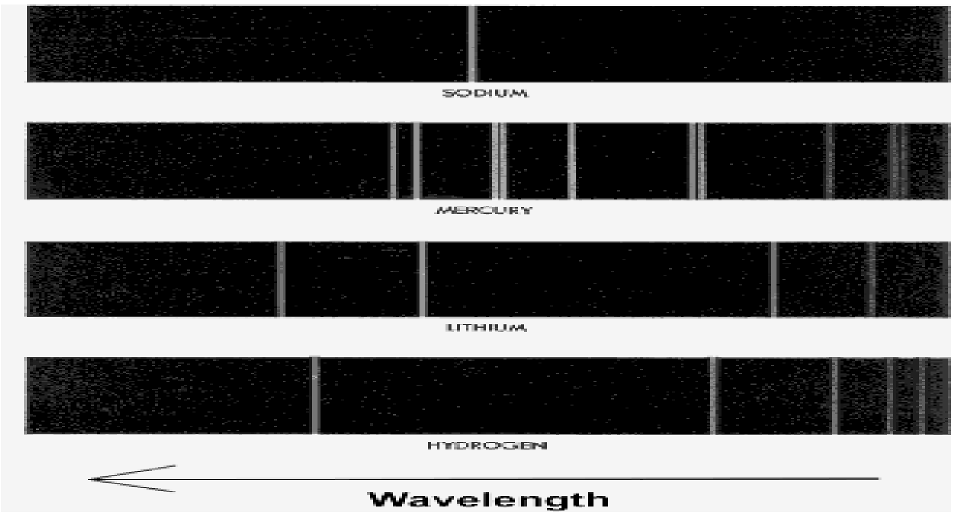
An Example of the Doppler Effect - Red Shift

Redshift is an example of the Doppler Effect. The light from stars, as observed from Earth, is always reduced in frequency and shifted towards the red (longer wavelengths) end of the spectrum. This is because the stars and galaxies are sources of light which are moving away from us.

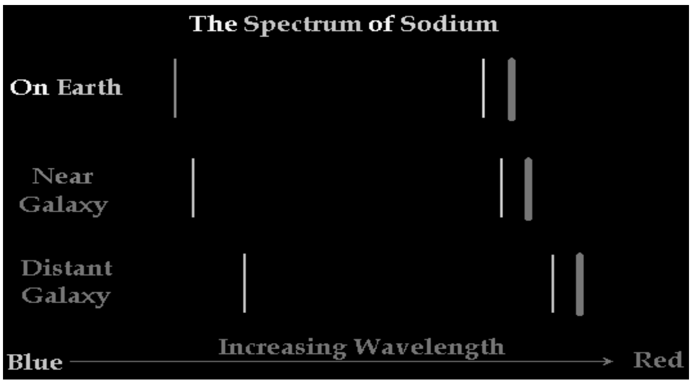
Redshift has always been present in the light reaching us from stars and galaxies but it was first noticed by astronomer Edwin Hubble, in the 1920's, when he observed that the light from distant galaxies was shifted to the red end of the spectrum (longer wavelengths).

The light emitted by a star is made up of the line spectra emitted by the different elements present in that star. Each of these line spectra is an identifying signature for an element and these spectra are constant throughout the universe. Since these line spectra are so recognisable, we can compare the spectra produced by these elements, on Earth, with the spectra emitted by a distant star or galaxy.

Examples of line spectra of different elements



Hubble examined the spectral lines from various elements and found that the spectra emitted by each galaxy were shifted _**towards the red**_ by a specific amount. This **shift** was due to the _**galaxy moving away from the Earth**_ at speed, causing the Doppler Effect to be observed. The **bigger the magnitude of the shift the faster the galaxy** was moving.



Redshift of a Galaxy Equation

Redshift, **z**, of a galaxy is given by:

$$z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}} = \frac{\Delta\lambda}{\lambda_{rest}}$$

Redshift of galaxies, travelling at non-relativistic speeds, can also be shown to be the ratio of the velocity of the galaxy to the velocity of light:

$$z = \frac{v_{galaxy}}{c}$$

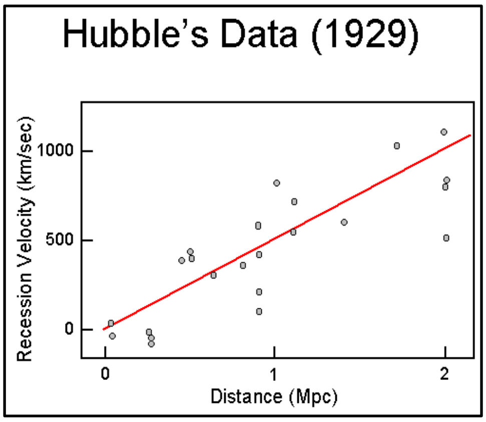
As redshift is always calculated from the ratio of quantities with the same unit, it has _**no unit of its own**_.

Over the course of a few years Hubble examined the red shift of galaxies at varying distances from the Earth. He found that the further away a galaxy was the faster it was travelling away from us. The relationship between distance and speed of a galaxy is known as Hubble's Law.

Hubble's Law

The graph below shows the data collected by Hubble. It shows the relationship between the velocity of a galaxy **v**, as it recedes from us, and its distance **d**, known as _**Hubble's Law**_.

The gradient of the line is known as H_o – Hubble's constant.



$$H_o = v / d$$

or

$$v = H_o d$$

The value of the Hubble constant is not known exactly, as the exact gradient of the line of best fit is subject to much debate. However, as more accurate measurements are made, especially for the distances to observable galaxies, the range of possible values has reduced. It is currently thought to lie between 50 – 80 kms^{-1} Mpc^{-1}, with the most recent data putting it at 70.4 ± 1.4 kms^{-1} Mpc^{-1}.

Calculating the Age of the Universe

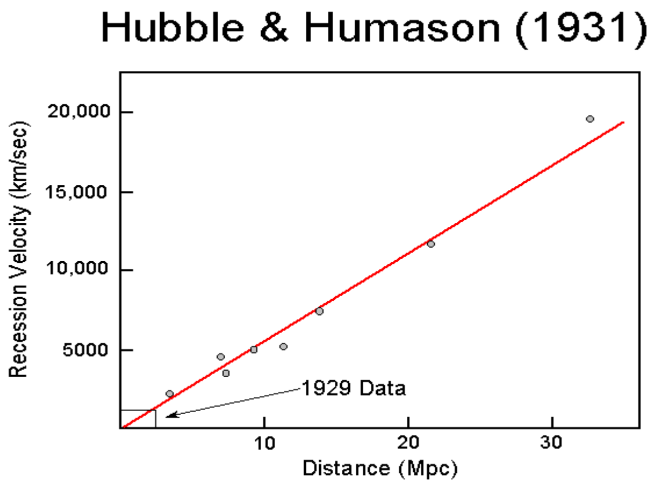
Hubble's observations show that galaxies are moving away from the Earth and each other in all directions, which suggests that the universe is expanding. This means that in the past the galaxies were closer to each other than they are today. By working back in time it is possible to calculate a time when all the galaxies were at the same point in space. This allows the age of the universe to be calculated.

v = speed of galaxy receding from us
d = distance of galaxy from us
H_0 = Hubble's constant
t = time taken for galaxy to travel that distance, **i.e. the age of the universe**

$$t = \frac{d}{v} \qquad (v = H_o d)$$

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

$$t = \frac{1}{H_o}$$



Currently, using this method, NASA estimate the age of the universe to be _**13·7 billion years**_. Since Hubble's time, there have been other major breakthroughs in astronomy and our ability to make accurate observations of very distant objects. All of these support the findings of Hubble, but allow the age of the universe to be calculated even more accurately.

Evidence for the Expanding Universe

It is generally accepted, based on the evidence given previously, that the universe is expanding. What is not known however is, what is going to happen to the universe in the future? There are essentially two scenarios.

1. Closed universe: the universe will slow its expansion and eventually begin to contract.
2. Open universe: the universe will continue to expand forever.

Which of the two scenarios is more likely depends on one factor, what is the mass of the universe?

How can we measure the mass of objects in space?

Astronomers can estimate the mass of a galaxy by measuring the _orbital speed_ of the starts within it.

The problem is that the masses measured seem to be bigger than the mass that can be accounted for by the number of stars present in a galaxy.

This leads to the theory of _ **'Dark Matter'**_. Basically there appears to be stuff there that we can't see and don't know what it is, so for the moment give it a name and hope we find out what it actually is later.

How fast is the Universe Expanding?

The universe is expanding at a greater rate than astronomers would expect. It seems that something appears to be opposing the gravitational force. Astronomers call this _ '**Dark Energy'**_

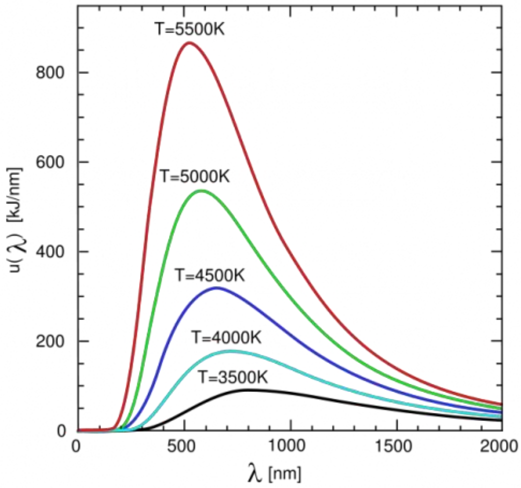
Big Bang Theory (phet physics simulation for T/ʎ graph)

The universe started with a sudden appearance of energy which consequently became matter and is now everything around us. There were two theories regarding the universe

- The Steady State Universe: where the universe had always been and would always continue to be in existence.
- The Created Universe: where at some time in the past the universe was created.

What was the evidence that finally swung the balance towards the Big Bang theory?

We first need to consider how it is possible to determine the temperature of distant stars and galaxies. You will have seen what happens to a piece of iron as it is heated, as it gets hotter its colour changes from dull red to bright red to orange then yellow.



The peak wavelength (the wavelength at which most light of that colour is emitted) is shorter for hotter objects, and longer for cooler objects.

As can be seen from the graph, the hotter the object, the more radiation is emitted. This means that over time, hot object emit more radiation than cooler objects.

What this means is that by examining the spectrum of a distant star, its temperature can effectively be determined.

Cosmic Microwave Background Radiation (CMBR)

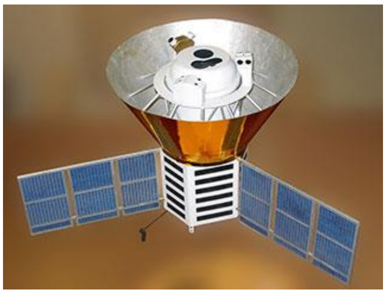
Gamow, Alpher and Herman, three physicists, had produced a paper in 1948 that if the Big Bang had actually taken place then there would be a residual background EM radiation, in the microwave region, in every direction in the sky representing a temperature of around 2.7K.

This value for the wavelength of the light and it's consequent equivalent temperature was arrived at by considering how the light produced at the Big Bang would have changed as the universe expanded.

The discovery of this background radiation was another example of scientists finding something they weren't looking for.

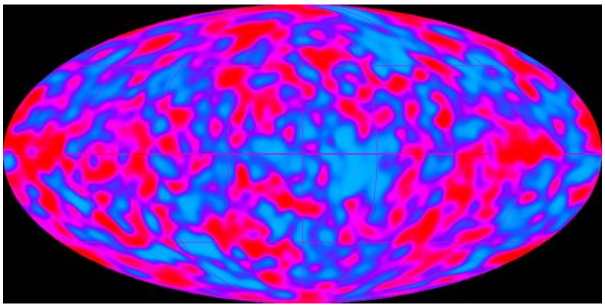
Arnold Penzias and Robert Wilson were working for Bell Labs in the USA. They were working with a special radio telescope experimenting with satellite communication.

They were getting a residual signal that seemed to come from outside the galaxy. At first they though it was actually due to pigeon droppings from the pigeons that roosted in the horn. Finally they realised that they had found the echo of the Big Bang.



In 1989 a satellite was launched to study the background radiation, it was called the Cosmic Background Explorer [COBE].
In 1992 it was announced that COBE had managed to measure fluctuations in the background radiation. This was further evidence to support the Big Bang theory.

An image of the fluctuations is shown below.



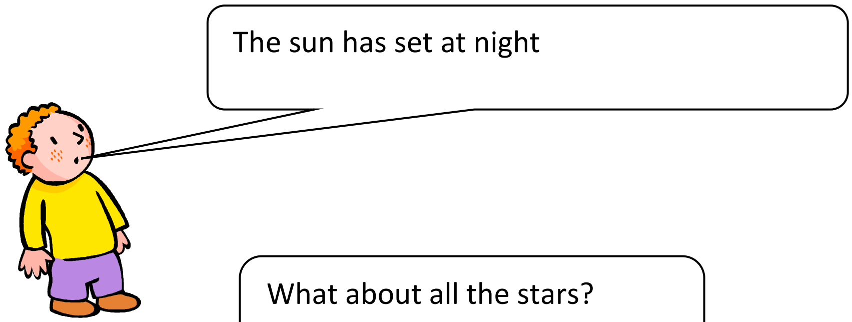
Abundance of Light Elements

Other evidence to support the Big Bang theory includes the relative abundances of hydrogen and helium in the universe.
Scientists predicted that there should be a significantly greater proportion of hydrogen in the universe. The next most abundant should be helium.
The elements present in the universe can be determined by spectroscopy, which you will study later in unit 3.
The latest proportions are given in the table shown. These observations conform to the predicted proportions.

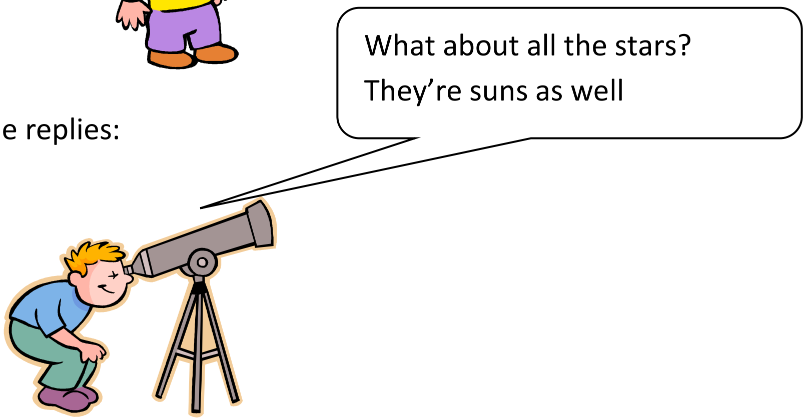
Element	Relative Abundance
Hydrogen	10 000
Helium	1 000
Oxygen	6
Carbon	1
All others	1

Olber's Paradox

Another is the explanation for Olber's paradox. His paradox was in answer to the question, "why is the sky dark at night?"
This is not as obvious as you first might imagine.



Wullie replies:



If the universe followed the Steady State model then there should be an even distribution of stars in all directions. All the stars in the universe should be visible. This means the light from the stars should reach Earth and the sky should be bright.

The Big Bang theory gives a finite age to the universe, and only stars within the observable universe can be seen. This means that only stars within the distance of 15 000 light years will be observed. Not all stars will be within that range and so the dark sky can be explained.

Redshift Galaxies

The Big Bang theory states that the universe is expanding, and hence we should observe the majority of galaxies travelling away from us (Redshift).

With the exception of a few galaxies in our 'local' cluster, all galaxies are travelling away from us, and hence experience redshift.

Formal Homework 6 – The Expanding Universe