CfE SPACE PHYSICS — B McMULLEN

Some useful definitions

- **Universe** — This is the name given to the whole of space that we can observe.
- **Galaxy** — A galaxy is made up of billions of stars. (The universe is estimated to contain millions of galaxies)

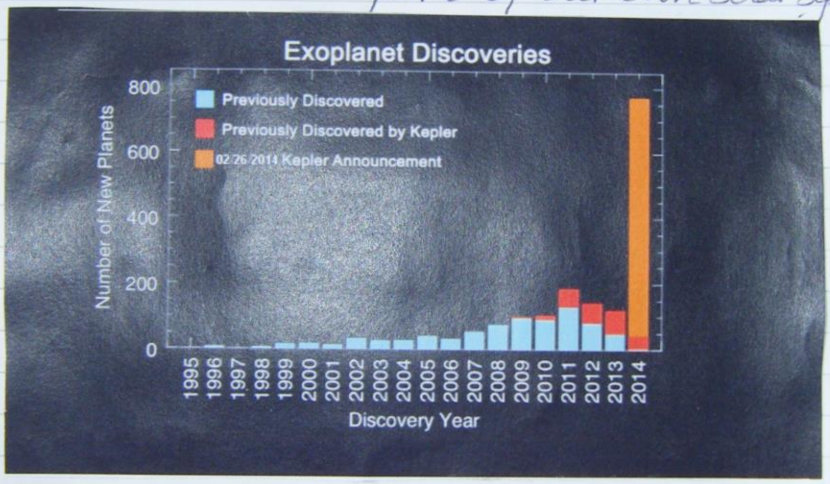
Star — A large ball of burning gas. The nearest star to Earth is the Sun. Stars emit e-m radiation.

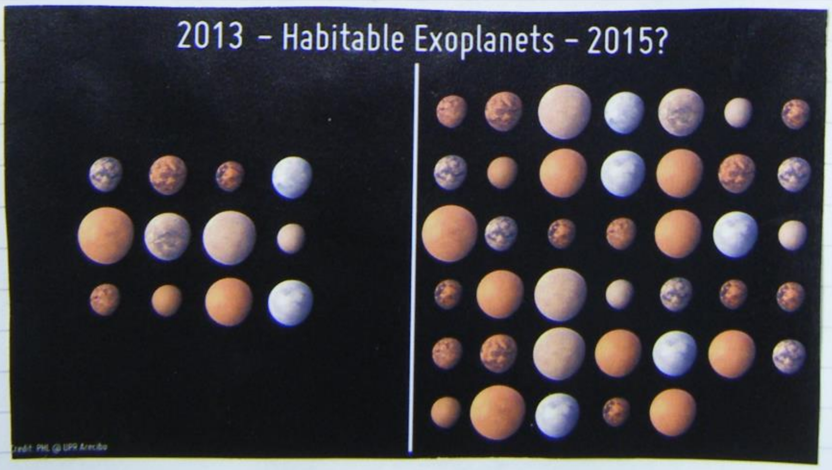
Planets — Planets orbit a star. In our solar system there are 8 planets orbiting the Sun.

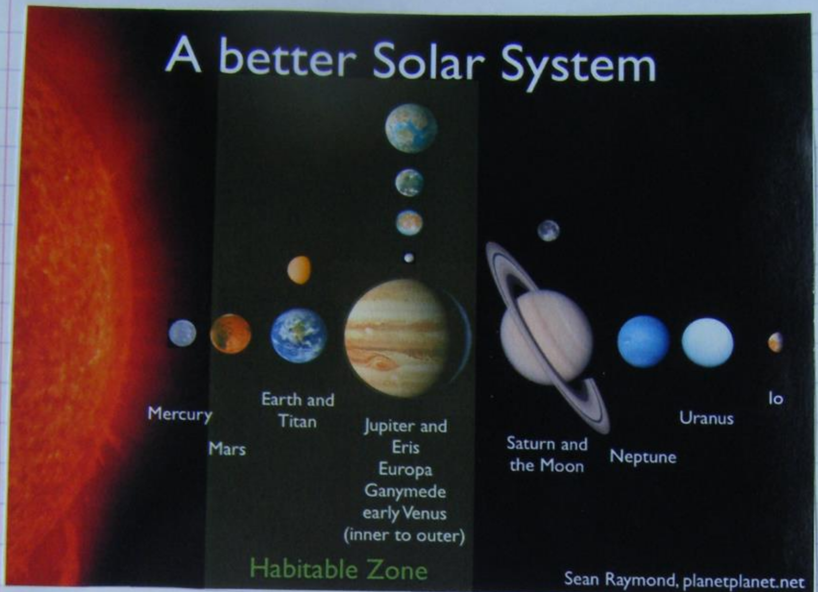
Pluto was originally the ninth planet in the solar system, but it has been re-classified as a dwarf planet.

- **Satellite** – These are objects which orbit planets.
  The Earth has a natural satellite called the moon, but some planets have as many a 12 natural satellites.

- **Exoplanet** – This is the name of a planet that is not part of our own solar system.





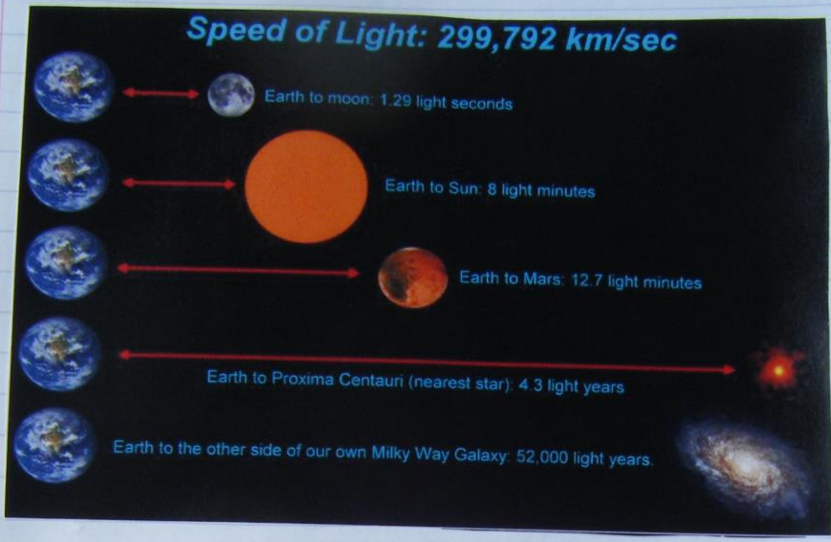


The habitable zone which is sometimes colloquially known as the Goldilocks zone, is where planetary-mass objects have sufficient atmospheric pressure, that will support liquid water at their surfaces.

Light years – This is the distance that light will travel in one year.

The distance between stars and galaxies are so large that we use light years as a special measurement of distance.

3b



Q What is the Milky Way?

A This is the galaxy within which our own solar system exists.

Q What is a black hole?

A Black holes are the remains of collapsed stars. The force of gravity around the star is so strong that even its own light is sucked in, making it invisible. This is a black hole in space.

Q What is the hottest planet in the solar system?

A Venus, which reaches 480°C.

Q Which is the largest planet in the solar system?

A Jupiter, which has a diameter of 142,800Km.

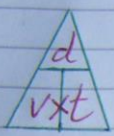
Ex1

Calculate 1 light year in metres.

$d = ?$

$v = 3 \times 10^8 ms^{-1}$

$t = 1 \text{ year} = 365 \times 24 \times 60 \times 60 = 31{,}536{,}000s.$



$d = v \times t = 3 \times 10^8 \times 31{,}536{,}000$

$\Rightarrow d = 9.46 \times 10^{15} m$

ie 1 light year $= 9.46 \times 10^{15} m$

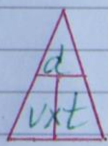
Ex2

If it takes 8 minutes for light from the Sun to reach the Earth, then calculate the distance from the Sun to the Earth.

$d = ?$

$v = 3 \times 10^8 ms^{-1}$

$t = 8 \text{ minutes} = 8 \times 60 = 480s$



$d = v \times t = 3 \times 10^8 \times 480 = 1.44 \times 10^{11} m$

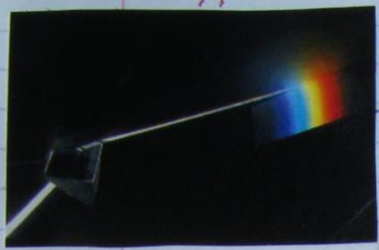
Ex3

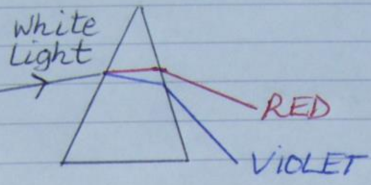
The distance from the Next Nearest Star to Earth is $4.1 \times 10^{16} m$.

Show that it will take 4.3 years for light to travel from the Next Nearest Star to Earth.

Spectra

White light can be split into seven different colours using a prism.





ROYGBIV

Red → Orange → Yellow → Green → Blue → Indigo → Violet.

- Red light has the highest wavelength $\approx$ 700nm $= 700 \times 10^{-9}$m $= 7 \times 10^{-7}$m
- Green light $\approx$ 550nm $= 550 \times 10^{-9}$m $= 5.5 \times 10^{-7}$m
- Violet light has the lowest wavelength. $\approx$ 400nm $= 400 \times 10^{-9}$m $= 4 \times 10^{-7}$m

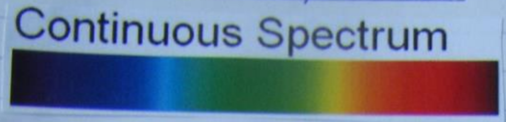
* The higher the wavelength the smaller the frequency and vice-versa *.

- Red light $\lambda \uparrow$ and $f \downarrow$
- Violet light $\lambda \downarrow$ and $f \uparrow$

* Wavelengths can be converted into frequencies and vice-versa using

$v = f\lambda$, where $v = 3 \times 10^{8} ms^{-1}$ *

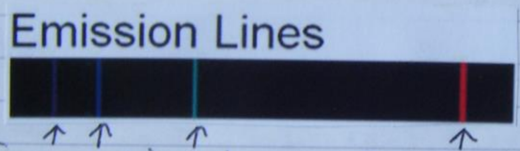
Continuous Spectra



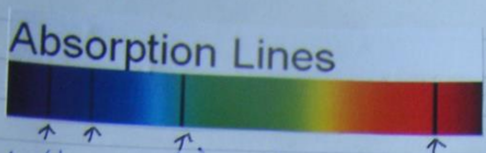
Many light sources produce a continuous spectrum (visible spectrum) containing all the wavelengths of visible light.

An example of this type of source is an ordinary light bulb.

Line Spectra



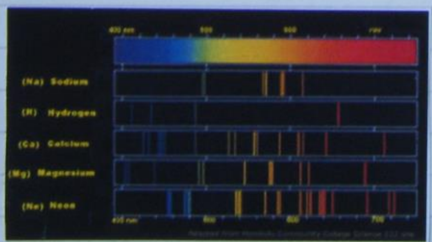
- Some light sources emit only particular wavelengths of light. They produce a line spectrum.
- The lines correspond to a particular wavelength of light which can be emitted by atoms in the source.
- Each chemical element has its own line spectrum pattern.
- Line Spectra can be produced in the lab using sodium or Neon lamps.
- Line Spectra can be used to tell us about the chemical composition of stars.



When light passes through a cool gas, some particular wavelengths of the light will be absorbed.
This can be clearly seen in the Absorption Spectra above. This can be clearly seen by the thin black lines.

If you look at the Emission Lines diagram and the Absorption Lines diagram very carefully, you will be able to see the four lines each at the same point. This shows that the emission and absorption lines diagrams are from the same element.

∴ Emission lines diagram + Absorption lines diagram = Continuous Spectrum



Sodium, Hydrogen, Calcium, Magnesium and Neon have very different Line emission spectra.

A line spectrum can be produced when light from a star is viewed through a prism. The spectrum from the star is made up from the spectra of all the elements present.

Temperature of stars.

The temperature of a star is related to the wavelength of light and therefore the colour of light that it emits.

The shorter the wavelength of the light emitted the higher the temperature of the star.

- Violet light → low wavelength
  → high temperature of the star.

- Red light → high wavelength
  → low temperature of the star.

Ex4

Star	Colour of wavelength in the visible spectrum
Arcturus	Orange-red
Rigel	Blue
Betelgeuse	Red

Q a) Which star has the highest temperature? Rigel

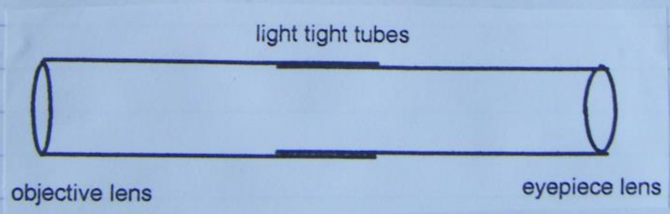
b) i) Is Arcturus hotter, colder or the same temperature as Betelgeuse?
hotter

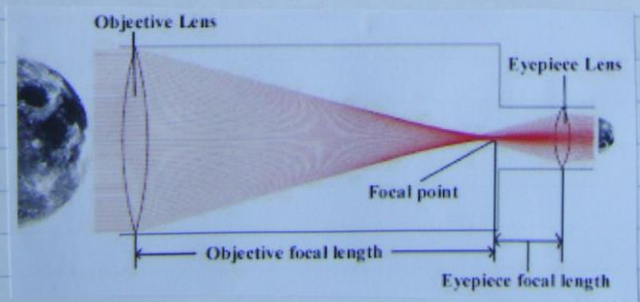
ii) Explain your answer in i).
Orange-red light has a lower wavelength.

Telescopes.

The refracting telescope has two convex lenses enclosed in a light tight tube.

- Objective lens has a long focal length. (Long focal length → thin lens)
- Eyepiece lens has a short focal length. (short focal length → thick lens)
- The objective lens collects the light and produces an image.
  The greater the diameter of the objective lens then the greater the light collected and the brighter the image produced.
- The eyepiece lens will magnify the image produced by the objective lens.





Rockets at take-off

↑ Upthrust force

↓ Weight

- On take-off Upthrust force > Weight.
- Unbalanced force on the rocket = Upthrust force − Weight
- As an unbalanced force acts on the rocket acting upwards then the rocket will accelerate upwards where

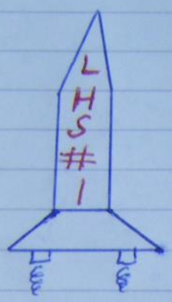
$$a = \frac{F}{m}$$ (Newtons 2nd Law of motion)

$$\text{acceleration} = \frac{\text{Unbalanced force}}{\text{mass}}$$

$$\Rightarrow \text{acceleration} = \frac{\text{Upthrust force} - \text{Weight}}{\text{mass}}$$

* If a module was going to descend on the moon then the Upthrust force > Weight. This allows the module to decelerate to rest on the surface of the moon. *

Ex5



A rocket of mass 40,000kg is launched from its take-off pad with an upthrust force of 600,000N.

(Weight, $W = mg = 40{,}000 \times 9.8$

$\Rightarrow W = 392{,}000N$)

Q a) Label the forces and their directions acting on the rocket

b) Calculate the unbalanced force acting on the rocket.

c) Calculate the initial acceleration of the rocket on take-off.

d) How will the acceleration of the rocket vary during its flight within the Earth's atmosphere?

A a) ↑ Upthrust force ↓ Weight

(Air Resistance or drag force acts downwards if it has to be taken into consideration.)

b) Unbalanced Force = Upthrust force − Weight

$\Rightarrow$ Unbalanced force $= 600{,}000N - 392{,}000N = 208{,}000N$

c) $a = \frac{F}{m} = \frac{208,000}{40,000} = 5.2\,ms^{-2}$

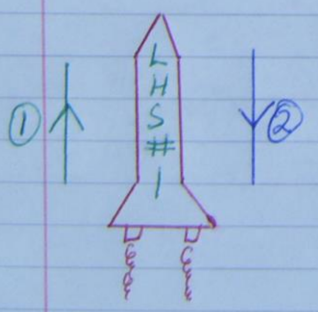
d) The acceleration of the rocket will increase during its flight within the Earth's atmosphere.

- The mass of the rocket decreases as the fuel is burned off during the flight
- As the mass of the rocket decreases the weight of the rocket decreases. This will increase the unbalanced force on the rocket as Unbalanced force = Upthrust − Weight force

$\therefore \uparrow a = \frac{F \uparrow}{m \downarrow}$

EXTRA POINTERS

PAIRS OF FORCES (NEWTON III) ⇒ Newtons 3rd law



For every action force there is an equal and opposite reaction force.

① ↑ Reaction force → force of the exhaust gases on the rocket

② ↓ Action force → force of the rocket on the exhaust gases.

Re-entry

When an object falls back to Earth through the atmosphere it will reduce its speed. This means that it will lose kinetic Energy.

The loss in kinetic energy will be converted into heat energy. This is due to frictional forces caused by the air resistance in the atmosphere.

(This is similar to a car reducing its speed by changing kinetic energy into heat energy in the brakes.)

Ex6

A 2kg meteorite made up from Iron, enters the Earth's atmosphere at $2500ms^{-1}$.

If all of its kinetic energy is converted into heat energy, then calculate the rise in temperature of the meteorite.

$(C_{IRON} = 450 JKg^{-1} {}^oC^{-1})$

$E_K = \frac{1}{2}mv^2 = \frac{1}{2} \times 2 \times 2500^2 = 6.25 \times 10^6 J$

As $E_K \rightarrow E_H$

$\Rightarrow E_H = cm\Delta T \Rightarrow 6.25 \times 10^6 = 450 \times 2 \times \Delta T$

$\Rightarrow \Delta T = \frac{6.25 \times 10^6}{450 \times 2} = \frac{6.25 \times 10^6}{900} = 6944^oC$

* most meteorites burn up and vapourise as they pass through the Earth's atmosphere. *

Re-entry of a spacecraft

Spacecraft re-entry at an angle.

- Too steep an angle
  Too much heat energy produced causing burn up.
- Too shallow an angle
  The spacecraft will 'skip' off the atmosphere and continue back into space.

The heat energy build up during the re-entry to the Earth's atmosphere needs to be carefully considered.

The thermal protection is provided by silica.

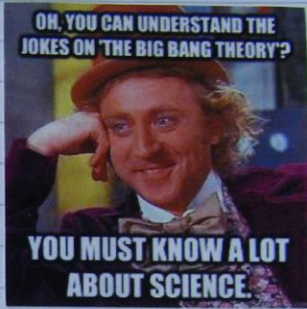
- A coating of silica on the top
- Flexible sheets of silica on the sides and
- Silica tiles everywhere else.

On the nose and leading edges of the wing the tiles are strengthened with carbon reinforcement.

- This thermal protection known as the heat shield uses the various forms of silica listed above to absorb the heat energy build up during re-entry.
- This will melt the silica but will protect the rest of the spacecraft from extreme temperature.
- The nose of the spacecraft is designed blunt. This causes millions of air particles to be spread out and reduce the heat energy generated.

Origins of the Universe

Astrophysicists devote their time to the study of the Universe.
The Big Bang Theory is widely accepted which describes the birth of the Universe and how it has developed.



Edwin Hubble observed that galaxies are moving away from the Earth and each other in all directions.
This suggests that the Universe is continually expanding.

Using Hubble's Law, NASA estimate the age of the Universe to be 13·7 billions years old. Further breakthroughs in Astronomy and technology will allow the age of the universe to be calculated more accurately.

Pieces of evidence to support the Big Bang.

- The presence of Cosmic microwave radiation.
- Cosmic microwave background radiation. (must be in words not CMBR!!)
- Doppler effect, which shows that stars are continually moving further away.
- Abundance of light elements eg H, He

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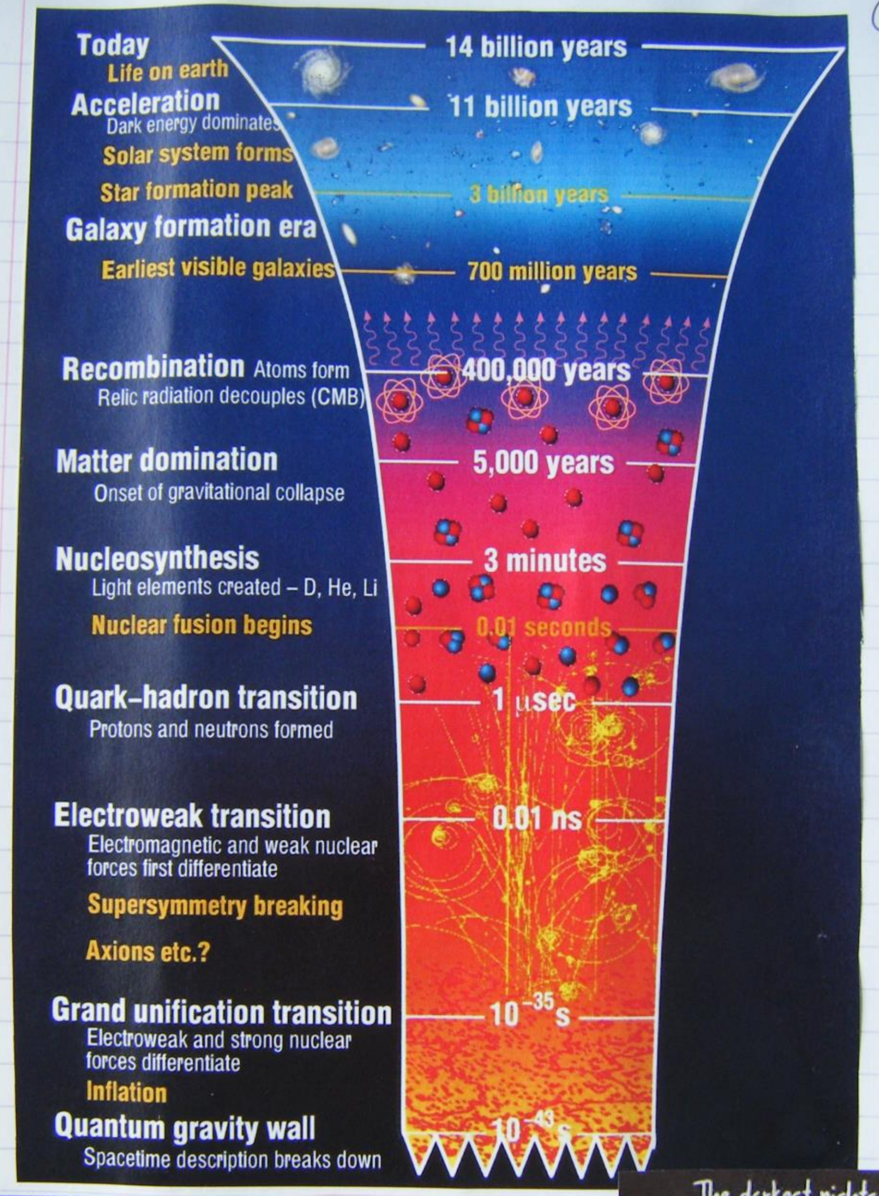
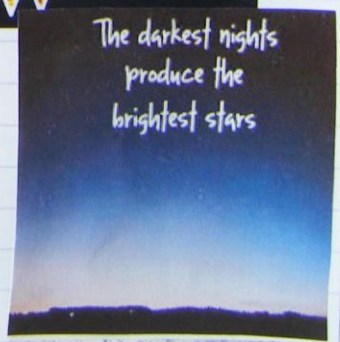

Today
Life on earth
14 billion years
Acceleration
Dark energy dominates
11 billion years
Solar system forms
Star formation peak
3 billion years
Galaxy formation era
Earliest visible galaxies
700 million years
Recombination Atoms form
Relic radiation decouples (CMB)
400,000 years
Matter domination
Onset of gravitational collapse
5,000 years
Nucleosynthesis
Light elements created – D, He, Li
3 minutes
Nuclear fusion begins
0.01 seconds
Quark–hadron transition
Protons and neutrons formed
1 μsec
Electroweak transition
Electromagnetic and weak nuclear forces first differentiate
0.01 ns
Supersymmetry breaking
Axions etc.?
Grand unification transition
Electroweak and strong nuclear forces differentiate
10^-35 s
Inflation
Quantum gravity wall
Spacetime description breaks down
10^-43 s


The darkest nights
produce the
brightest stars

Walking on the Moon

Although the Moon is a natural satellite and not a planet the same principles will hold for any planet.

CASE 1. An astronaut is jumping up and down on the surface of the moon.

The motion undergone by the astronaut would be the same as that on Earth. ie They would be decelerating upwards and then accelerating downwards.

However g on Earth $= 9.8\,NKg^{-1}$ and
g on the Moon $= 1.6\,NKg^{-1}$

This means that the astronaut will decelerate less on the upward motion and accelerate less on the downward motion on the Moon. This results in the astronaut reaching a greater height above the Moons surface compared to the same event on the Earth's surface.

CASE 2. If a 1kg bag of feathers and a 1kg bag of bricks are dropped from the same height on the Moon, they would hit the Moons surface at the same instant. If the same experiment took place on Earth then the 1kg bag of bricks would hit the ground first. Why? We must take into consideration the air resistance on Earth.

Astronauts in Space

Q Why do astronauts float about in their space stations in outer space?

Q Is there any gravity in space?

A Astronauts are always accelerating vertically towards the Earth. As they are in freefall, this causes them to appear weightless.

A There must be gravity in space otherwise the space stations would not be able to orbit.

The orbiting process involved here is the same idea as a Geostationary Satellite, which has the 24 hour period of the Earth.

- Vertical velocity continually increasing
- Horizontal velocity staying constant
- The combination of the vertical and horizontal components producing a projectile motion.
- The Earth's surface moves away from the Geostationary satellite so it never hits the Earth.
- The period of 24 hours means that the Geostationary satellite stays above the same point on the Earth's surface.