North Berwick High School

Department of Physics

National 4/5

Summary Notes

Unit 1

Dynamics and Space

Section 2

Space Exploration & Cosmology

The coloured boxes contain National 5 material.

Newton's Third Law

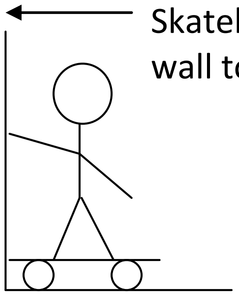
"For every action, there is an equal and opposite reaction".

Newton noticed that forces occur in pairs. He called one force the **action** and the other the **reaction**. These two forces are always **equal in size, but opposite in direction**. They do not both act on the same object.

If an object A exerts a force (the action) on object B, then object B will exert an equal, but opposite force (the reaction) on object A.

Examples

Skateboarder pushes wall to the left (action



Wall pushes skateboarder to right (reaction force)

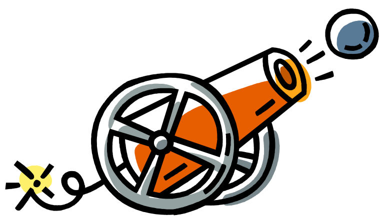
Water pushes swimmer to left (reaction force)

Swimmer pushes water to right (action force)

Fuel forces rocket upwards (reaction force)

Rocket forces fuel downwards (action force)

Cannon fires cannonball to the right (action force)



Cannonball forces cannon back to the left (reaction force)

These action and reaction forces are also known as **Newton Pairs.**

<u>Free Fall and Weightlessness</u>

Any object which is falling "freely" towards the Earth's surface is said to be in "free fall".
All objects accelerate downwards towards the Earth at the same rate of 10 m/s^2 (if no air resistance).
An object in free fall inside a box would fall at the same rate as the box and would appear to be weightless.

Astronauts in orbit around the Earth are in a constant state of free-fall. The spaceship, the astronauts and everything inside are all accelerating towards the Earth due to gravity.
This is known as apparent weightlessness. The effects are because of gravity, and **not** because they have escaped from the gravitational field of the Earth.

Re-entry into the atmosphere

- When a spacecraft re-enters the Earth's atmosphere, it is travelling at a velocity of around 11 000 m/s.
- The force of air resistance from the Earth's atmosphere is huge at these velocities.
- Air resistance does **work** on the spacecraft which changes the **kinetic** energy to **heat** **($E_k \rightarrow E_h$)**.
- The heat absorbed can cause a temperature increase of around 1300 °C

Heat Shield Design

Case Study – the Shuttle

The Shuttle was the first (and only) reusable spacecraft. The first Shuttle mission was launched in 1981 and the final mission was in July 2011.

The part of the Shuttle that returns to Earth is called the *Orbiter* and its shape resembles an aircraft.

(For more information, see http://www.nasa.gov/mission_pages/shuttle/main/index.html).

- The Shuttle Orbiter is made from aluminium alloy covered in special tiles to protect it from the intense heat generated during re-entry.

- The Shuttle needs around 34 000 thermal protection tiles (all of different shapes and sizes).
- The tiles are made of a material called silica, which has a high specific heat capacity and a high melting point *(c=1040 J/kg ℃, melting point = 1610 ℃).*
- The tiles are painted black so that heat is lost to the surroundings. The air around the shuttle heats up. The temperature increase of the shuttle is therefore not as great.

Protection by vapourisation

Heat shields are also designed with coatings that vapourise. The temperature of the craft is stabilised since the coating absorbs heat at a constant temperature while it melts and boils (E_h=ml).

Example

A heat shield on a spacecraft has a mass of 50 kg.

The spacecraft is travelling at 1000 m/s. On re-entry into the Earth's atmosphere, the velocity of the spacecraft is reduced to 200 m/s.

(a) Calculate the change in kinetic energy of the heat shield.
(b) Calculate the change in temperature of the heat shield. (Assume all of the kinetic energy is changed to heat in the heat shield material).

Specific heat capacity of heat shield material = 1040 J/kg°C

Solution

(a)

m = 50 kg   u = 1000 m/s   v = 200 m/s E_k = ?

Change in E_k = initial E_k – final E_k

$= (½mu^2) – (½mv^2)$

$= (½x50x1000^2) – (½x50x200^2)$

$= 2.5x10^7 – 1.0x10^6$

$= \underline{\underline{2.4x10^7 J}}$

(b)

$\Delta E_h = \Delta E_k = 2.4x10^7 J$ c = 1040 J/kg°C   m = 50 kg
ΔT = ?

$E_h = cm \Delta T$

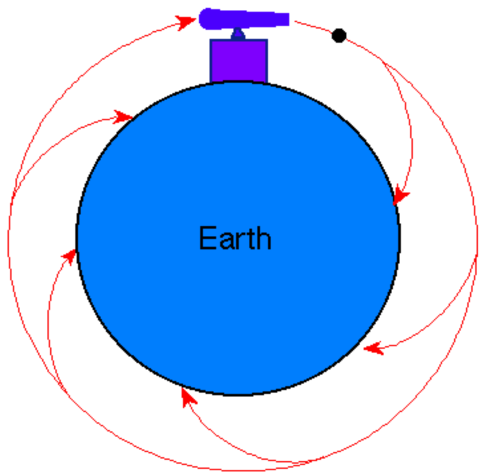
$2.4x10^7 = 1040x50x \Delta T$

$\Delta T = \frac{2.4x10^7}{1040 \times 50}$

$\Delta T = \underline{\underline{460 °C}}$

Satellites and Projectile Motion

Newton's Thought Experiment



Newton's thought experiment allowed us to understand satellite orbits.

If a projectile is launched with sufficient horizontal velocity (v_h), it will travel so far that the curvature of the Earth must be taken into account.

Now imagine a projectile launched with such a great horizontal velocity that it never reaches the ground! It will continue to circle the Earth until its horizontal velocity decreases.

Satellites must therefore have a:

Constant horizontal speed (v_h), which is not large enough for the satellite to move away from the Earth.

Constant downwards attraction (v_v), towards the Earth's surface due to the attractive force of the Earth's **gravity.**

Satellites have allowed us to make observations of the Earth.

Important observations of the environment have been made using monitoring satellites in orbit around the Earth, including:

- reduction of rainforest
- melting of polar icecaps

Technologies arising from space exploration

Some examples include

- Weather forecasting
- GPS and Sat Nav
- Global communication
- Satellite TV
- Protective paints

NASA has a website called "Spin-off" which shows how technologies developed in their Space Programme have benefits in everyday life –

http://spinoff.nasa.gov/index.html

http://spinoff.nasa.gov/Spinoff2008/tech_benefits.html

http://www.nasa.gov/externalflash/nasacity/index2.htm

For any technology that you provide, you must be able to describe the impact that it has on our everyday life.

Geostationary Satellites

Geostationary Satellites are satellites which travel round the equator and take 24 hours to complete one orbit. As the Earth also takes 24 hours to complete one orbit, the satellite remains over the same point on the surface of the Earth.

Cosmology

Current understanding of the universe

What we know about the Universe is a result of humankind's continual curiosity about our existence. This has led to a remarkable understanding of our Universe which is continually developing. Much of this can be attributed to our continual observation of space along with our exploration of the Solar System and beyond.

Big Bang Theory (http://big-bang-theory.com)

- The Big Bang theory is an effort to explain what happened at the very beginning of our universe.
- Discoveries in astronomy and physics have shown beyond a reasonable doubt that our universe did in fact have a beginning. Prior to that moment there was nothing; during and after that moment there was something: our universe.
- Our universe sprang into existence as a "singularity" around 13.7 billion years ago.
- Singularities are zones which defy our current understanding of physics. They are thought to exist at the core of Black Holes.
- Black holes are areas of intense gravitational pressure. The pressure is thought to be so intense that finite matter is compressed into infinite density.
- Our universe is thought to have begun as an infinitesimally small, infinitely hot, infinitely dense singularity.
- After its initial appearance, the universe inflated, expanded and cooled, going from very, very small and very, very hot, to the size and temperature of our current universe.
- It continues to expand and cool to this day and we are inside of it!
- There is currently debate as to whether the universe will continue expanding, or whether it will start to contract.

Big Bang Theory - Evidence for the Theory

- Galaxies **appear to be moving away from us** at speeds proportional to their distance. This is called "Hubble's Law," named after Edwin Hubble (1889-1953) who discovered this phenomenon in 1929. This observation supports the expansion of the universe and suggests that the universe was once compacted.
- **"Doppler red-shift"** also provides evidence that **galaxies are moving away from us.** The light from galaxies appears to be more red than it should be, and the decreased frequency of the light tells us that the galaxies are moving away from us.
- If the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, Arno Penzias and Robert Wilson discovered a 2.725 degree Kelvin (-270.425 degree Celsius) **Cosmic Microwave Background radiation (CMB)** which pervades the observable universe. This is thought to be the remnant which scientists were looking for. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery.
- The **abundance of the "light elements" Hydrogen and Helium** found in the observable universe are thought to support the Big Bang model of origins.

Age of the universe

Current thinking dates the age of the universe as approximately **14 billion years.**

Observable universe

- The **universe** consists of many galaxies separated by empty space.
- A **galaxy** is a large cluster of stars (e.g. theMilky Way).
- A **star** is a massive ball of matter that is undergoing nuclear fusion and emitting light and heat. The Sun is a star.
- The sun and many other stars have a solar system. A **solar system** consists of a central star orbited by planets.
- A **planet** is a large ball of matter that orbits a star (e.g. Earth or Jupiter). Planets do not emit light themselves. An **exo-planet** is a planet which is not found in our solar system.
- Many planets have moons. A **moon** is a lump of matter that orbits a planet (e.g. the Moon orbits the Earth. Deimos and Phobos orbit Mars.

These are features of the **observable** universe. The universe also contains matter that cannot be observed directly, e.g. **dark matter.**

Black Holes

When a large star runs out of fuel it can no longer support its heavy mass. The star collapses and shrinks during the final phases of its life. The pressure from the star's massive layers of hydrogen press down forcing the star to get smaller and smaller. Eventually the star will get even smaller than an atom. When matter gets so dense that light cannot escape from it, the region that it is in becomes a black hole.

Hubble Deep Field

This is a picture taken by the Hubble space Telescope (HST). The HST was pointed at a tiny area of seemingly empty space for ten days. The resulting image was full of galaxies.

Optical Telescopes

An optical telescope is a telescope which is used to gather and focus light mainly from the visible part of the electromagnetic spectrum to directly view a magnified image for making a photograph, or collecting data through electronic image sensors.

A telescope's light gathering power and ability to resolve small detail is directly related to the diameter of its objective lens (the primary lens or mirror that collects and focuses the light). The larger the objective lens, the more light the telescope can collect and the finer detail it can resolve.

<u>Electromagnetic Spectrum</u>

increasing wavelength →

Gamma rays X-rays Ultraviolet Visible light Infrared Microwaves Radio + TV

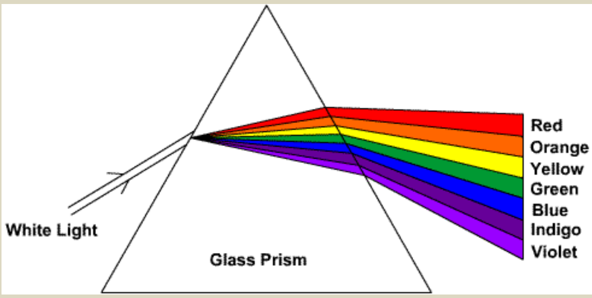
← *increasing frequency*

<u>Detectors of electromagnetic radiation</u>

Radiation	Detector
Gamma rays	Geiger-Müller tube
X-rays	Photographic film
Ultraviolet	Fluorescent paint
Visible light	Photographic film
Infrared	Charge-coupled diode (CCD)
Microwaves	Diode
Radio + TV Waves	Aerial

Spectra

- White light is made up of a range of colours.
- These colours can be separated by splitting white light with a **prism** to obtain a **spectrum**.



- A spectrum can also be produced using a **diffraction grating.**

- A **line absorption spectrum** consists of a complete (continuous) spectrum with certain colours missing which appear as black lines in the spectrum.

- A **line emission spectrum** consists of lines of light of distinct colours rather than a continuous spectrum.

- Every element produces a unique line spectrum. Studying line spectra allows the elements present in a light source (e.g. a star)to be identified
- This can help to identify the type, distance, age or speed of a star.

The Light Year

- The "light year" is a measurement of **distance.**
- 1 light year is the distance that light travels in 1 year.

Example

(a) Calculate the number of metres in 1 light year.

(b) Proxima Centauri, the next closest star after the Sun, is 4.3 light years from the Earth. Calculate this distance in metres.

Solution

(a) d = ? $v = 3\times10^8$ m/s   t = 1 year

$d = vt$

$d = 3\times10^8\times(365.25\times24\times60\times60)$

$d = \underline{\underline{9.47\times10^{15}\ m}}$

(b)

1 light year = 9.47×10^{15} m

4.3 light years = $4.3\times9.47\times10^{15}$ m

= $\underline{\underline{4.07\times10^{16}\ m}}$

Proxima Centauri is 4.07×10^{16} m from Earth.