HSC Physics Notes - Space

9.2 - 1. The Earth has a gravitational field that exerts a force both on it and around it

1. define weight as the force on an object to a gravitational field
Mass is the measure of how heavy an object it. Every object has a *mass which is static* and does not change with any force exerted on it or from it.

However, weight is the **force** which is exerted upon an object when it comes into **contact with or nearby a gravitational field** of some strength. Weight is a force ∴ a **vector quantity**.

$$W = mg$$

2. explain that a change in gravitational potential energy is related to work done
In order to a change in an object's gravitational potential energy in a gravitational field, work must be done to achieve this. I.e. To be able to move an object within a gravitational field, **work must be exerted on the object in order to make it move**.

Work must be done in order to transform the energy of an object into a different entity so that is can move. In this case, from gravitational potential energy to kinetic energy.

$$G_p = mgh$$

G_p = Gravitational Potential Energy (J)
m = Mass of the object (kg)
g = Acceleration due to gravity/gravitational field (m.s^{-2})
h = Height above the Earth's surface (m)

This equation is only valid when the object is close to the Earth's surface.

3. define gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field
The gravitational potential energy is a **measure of the work done in moving an object from infinity to a point in a gravitational field**. As an object falls toward a gravitational field (such as Earth's) the object's acceleration increases and thus the velocity of the object speeds up. It is defined as:

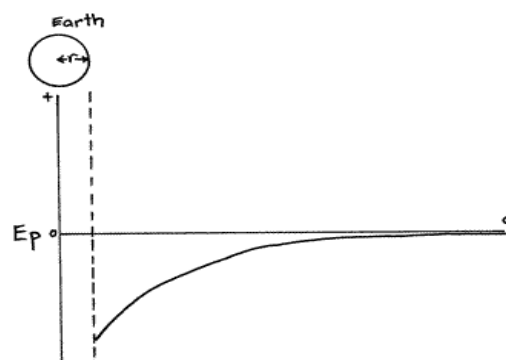E_p = 0 at a distance of infinity.

$$E_p = -G\frac{m_1 m_2}{r}$$

E_p = Gravitational Potential Energy (J)
G = Universal Gravitation Constant = 6.67x10^{-11}
m_1 = Mass of first object (kg)
m_2 = Mass of second object – often the Earth (kg)
r = distance from the centre of the Earth (m)

1. perform an investigation and gather information to determine a value for acceleration due to gravity using pendulum motion or computer-assisted technology and identify reasons for possible variations from the value 9.8m.s^{-2}
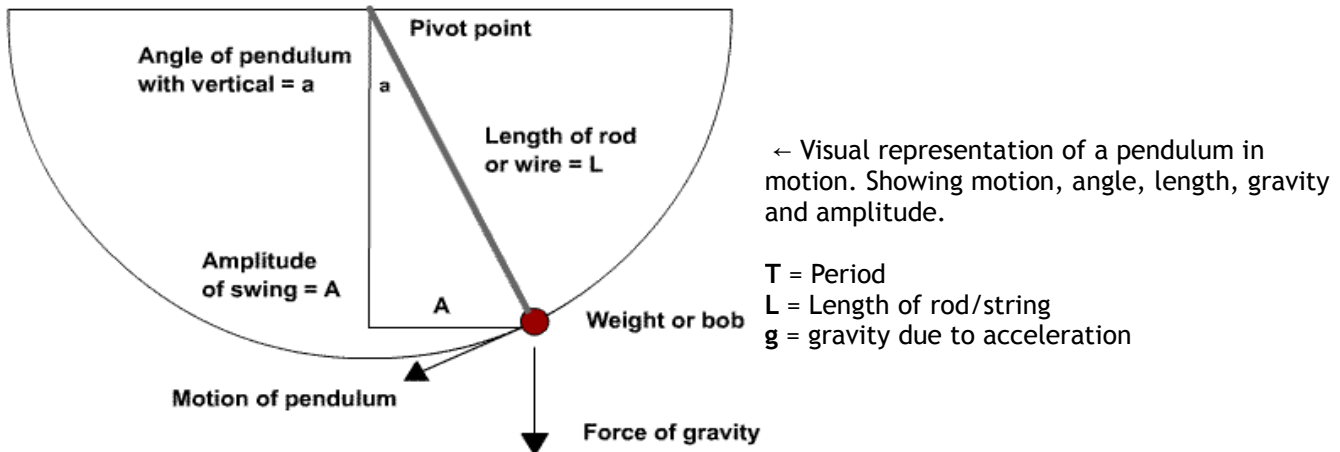One way to determine the variations in acceleration due to gravity (g) is to use a **pendulum** by observing the direct falling movement of the pendulum. Using the experiment of pendulum movement:

In this experiment, a string is anchored to the bottom of a surface and then a mass is attached to the other end of the string in which gravity forces the mass to hang from the string a certain distance. The mass is pulled to the side to form an angle of <10° to the vertical and released to begin the swinging/pendulum motion. Each swing of the mass and then returns is called an **oscillation**. The time for 10 oscillations is recorded on varying lengths of string (which is the factor that will alter the value for

acceleration due to gravity – 9.8m.s^{-2}). These values for time and then used in the calculation of acceleration due to gravity.

The period of pendulum is given by: $T = 2\pi\sqrt{\dfrac{L}{g}}$

(This formula only applies to masses of a pendulum which are raised to an angle <10° to the vertical).

← Visual representation of a pendulum in motion. Showing motion, angle, length, gravity and amplitude.

T = Period
L = Length of rod/string
g = gravity due to acceleration

It can be seen that (from the formula) length of string and period of the pendulum affect the value of g. Therefore, the mass and angle at which the mass is raised do not directly affect g, but do change T (period).

To improve the accuracy of the experiment, the pendulum was allowed to complete several oscillations, back and forth, and then taking the average of these times. This reduced human response time error when using the stop watch. Also, a longer string was used to extend the length of the period, thus the accuracy of the value for g.
Using computer-assisted technology to record the data, valid results can be concluded with instant response times.

After gathering data and using average of results, the result is not the defined 9.8m.s^{-2} but rather slightly off. We can conclude that you will not always get the perfect or same value for g as it will vary due to inability to record accurate data or air resistance.

On Earth, there are numerous factors that will affect the value of g. There discrepancies are:

- **Altitude** – As your position on Earth changes, so too does the value of gravity.
- **Latitude** – As the Earth is not perfectly spherical, it is flatter at the poles, thus if you are standing at one of the poles, then you would be closer to the centre of the Earth compared to when at the Equatorial region/belt.
- **Centripetal Force** – The Earth rotates. There is the strongest centripetal force at the equator.
- **Varying Earth Density** – The Earth does not have consistent density due to its elemental composition beneath the crust.

2. gather secondary information to predict the acceleration due to gravity on other planets

3. analyse information using the expression: F = mg to determine the weight force for a body on Earth and the same body on other planets
Using information such as a planet's mass and other information the following equation can be applied to determine the acceleration due to gravity on other planets:

$$g = \frac{Gm_p}{r^2}$$

The formula can also be used to calculate the acceleration due to gravity and its effect on satellites which are huge distances away. Required data will be supplied in the exam.

2. Many factors have been taken into account to a successful rocket launch, maintain a stable orbit and return to Earth

1. describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components
When an object is launched from the Earth's surface, it is undergoing projectile motion and the body that is fired is known as the projectile. The **trajectory of the projectile is the path it traces** out. Parabolic.

Since velocity is a vector quantity, it can be divided into its **horizontal** (x) and **vertical** (y) components and when summed together achieve the overall velocity and direction of the particle. Using Pythagoras' Theorem and trigonometry laws we can split the motion up a achieve results:

$$V_x = V cos\,\Theta \qquad V = \sqrt{V_x^2 + V_y^2}$$

$$V_y = V sin\,\Theta \qquad \Theta = tan^{-1}(\frac{y}{x})$$

- The horizontal (x) component is constant velocity and has no acceleration
- The vertical component has velocity = 0. Has acceleration for to gravity = 9.8ms^{-2}

Other formulas that will be used include:

$$s \;=\; ut + \frac{1}{2}at^2 \qquad v \;=\; u + at \qquad v^2 \;=\; u^2 + 2as$$

2. describe Galileo's analysis of projectile motion
Experimentally it is found that **if two objects of the same or different mass are released from the same height and allowed to fall straight down, they reach the ground at the same time** (neglecting air resistance).

He also discovered that projectile motion can be split into the horizontal motion (with no acceleration) and vertical motion (with acceleration due to gravity) component and that the trajectory of motion is parabolic.

3. explain the concept of escape velocity in terms of the:
Escape velocity is the velocity needed to propel a body into space so that it will not return to Earth due to its gravitational field. The direction in which the object is projected does not matter. The escape velocity is defined as:

$$V_{escape} \;=\; \sqrt{\frac{2GM_E}{r}}$$

– gravitational constant
From the equation derived for v, we determine the relationship that: **v ∝ √G** since **M$_E$ and r are constants of mass and distance**

– mass and radius of the planet
Also, we can see that **v ∝ M** and **v ∝ 1/r** – thus, as the **mass of a planet increases so too must the escape velocity** of the projectile and that as the **radius increases, the escape velocity decreases**.

4. outline Newton's concept of escape velocity
Newton proposed the idea that if a projectile is launched from the top of a very high building or mountain so that it it would not return to Earth – this is the concept of escape velocity.

As the launched velocity was increased, the distance that the object would travel from the Earth would increase until such a time that the velocity would be sufficient to put the projectile into orbit around the Earth. Newton reasoned that **the higher you make the velocity, the further the object will travel**

around the Earth before crashing back into the Earth's surface. Being in a circular or elliptical orbit would prevent the object returning to Earth.

Acceleration forces or '**g-forces**' as they are more commonly known **are measured in units of gravitational acceleration** (g).

If a body moves **against the force of gravity** which pushes down on the Earth's surface, then that body will experience **a heightened level of g-force**.

During launch, the apparent weight felt by the occupant astronaut is far greater than if the astronaut was stationary on Earth. Thus **astronauts experience a significantly large amount of 'g-force'** during rocket launch.

$$g\,force \;=\; \frac{apparent\ weight}{true\ weight}$$

Because the Earth rotates in a circular motion, both on its own axis and around the sun, the horizontal velocity of a rocket launched will be equal to the rotational speed of the Earth plus the orbital velocity of the Earth at that point. Since the Earth does rotate on its own axis (from north to south poles), then **a rocket launched from the equator will receive the greatest velocity boost due to the Earth's rotational motion**

The Earth rotates on its own axis toward the East, thus launching a rocket in the same direction as the Earth's orbital and rotational motion will result in a velocity boost.

The momentum of a rocket during launch in conserved and kept the same. So as fuel and fumes are expelled during launch, the mass of the rocket decreases – therefore the velocity of the rocket must increases proportionally as to conserve momentum.

During the launch of a rocket, there are two main forces acting upon the propulsion of the rocket into space. **Thrust** (T) and the **weight** (mg) of the rocket, pulling the rocket back to Earth. The pushing force felt by astronauts is the deceiving strength of g-force. **Net Force = T - mg**

Circular motion is a two dimensional motion. The motion of an object in a circular path with constant speed is known as the uniform circular motion of that object.
The magnitude of the velocity of an orbiting body is constant, but the direction is changing.

A satellite in orbit under going centripetal force due to the uniform circular motion is provided by the force of gravity between the two masses. Centripetal force is given by:
$$F \;=\; \frac{mv^2}{r}$$

Low Earth orbit:
Satellites in low Earth orbit, **orbit the Earth at a speed different to the rotational velocity of the Earth**. Low Earth orbital satellites from where they orbit the earth, approximately 250-1000km above the Earth's atmosphere. The satellites are in such a range of orbit that **they observe the Earth at different parts of the day** and will see different parts of the earth.
These satellites have such a low altitude so that the **velocity** required to keep them in orbit is **extremely high**. These include **weather satellites**.

Geo-stationary orbit:

A geo-stationary orbit is one in which the **satellite has a period of 24 hours. If the orbit is in the equatorial plane.** Satellites that are geo-stationary orbits have the same velocity as the Earth's rotation and are in circular orbits.

Geo-stationary satellites orbit at a much **higher altitude** compared to the low Earth satellites and the fact that these geo-stationary satellites have the same position on the Earth gives them practical use. Are often used for **TV satellites** so the receiver dish does not have the track the satellite.

10. define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

r = radius of orbit (*m*) **T** = time for one orbit/period (*s*) **M** = mass of central body. Mass of Earth (*kg*) **G** = gravitational constant (6.67×10^{-11})

Orbital velocity is the speed that an object in orbit is travelling at and required to travel to stay on its orbital path. From Kepler's Law of Periods, the orbital velocity can be determined

$$v = \sqrt{\frac{Gm_E}{r}}$$

Orbital velocity can also be obtained by equating the centripetal force of an object in orbit with the gravitational force between the two bodies, as the centripetal force is the gravitational force.

It can also be found that: $T = \frac{2\pi r}{v}$ through the manipulation of Kepler's law.

11. account for the orbital decay of satellites in low Earth orbit

Low Earth orbiting objects such as the low Earth satellites are orbiting at such an altitude where there is still very thin atmosphere and despite this **friction between the satellite and air particles results in the gradual slowing down** which causes it to mover closer to the Earth. As the satellite moves even closer to the Earth, the atmosphere becomes thicker and the slowing effect increases further. **The orbit gradually decays because the orbital velocity is no longer maintained** and cannot be reached to keep the satellite in orbit.

12. discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface

There are significant technical difficulties that are involved in the safe re-entry of a spacecraft into the Earth's atmosphere. Two of these being the heating effects of the atmosphere and the strength of g-forces.

Heat is a major concern for the re-entry of a spacecraft back to Earth because the atmosphere provides aerodynamic drag on the craft and thus results in the **high temperatures experienced** – which are generated by friction with air molecules. Because of this, spacecraft are designed to minimise the effect that heat has on the astronauts and the craft.

The effect of heat friction on the spacecraft and its occupants is reduced by:
- **The shape of the craft** – blunt or rounded noses to the craft are used to spread the heat, rather than focusing it with a sharp nose.
- A **protective material** on the outside on the craft that will initially vaporise, preventing the spacecraft from vaporising. This protective layer can be made from a ceramic or even air type substance.

G-Forces are a major concern for the well being of the occupants in the rocket – thus a major issue is created for the safe re-entry of a spacecraft. G-forces may cause black-out or blood rush to organs.

To reduce the effect that g-forces have on the astronauts, they are made to lie down in **specialised seats which minimise the effect** of the feeling of g-forces. By lying down, **the force is spread out across the body** and also prevents the eye balls of astronauts popping under the intense stress.

The **angle of re-entry** becomes the most integral part when bringing a spacecraft back into the Earth's atmosphere. If the angle of re-entry is **too shallow** then the **craft will bounce off the atmosphere**, returning to space. If the angle is far **too steep**, the **g-forces experienced** by the astronauts will be far too great and **result in bodily harm**.

13. <u>identify</u> that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle
Since the angle is critical to the safety of the craft and to the safety of the passengers (to prevent the damage to the body) – there is an optimum 'window' of angle for re-entry.

This optimum re-entry angle lies between approximately **5.7˚ – 7.2˚** to horizontal.

1. solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using:

$$v_x^2 = u_x^2 \qquad v_y^2 = u_x^2 + 2a_y\Delta y \qquad v = u + at \qquad \Delta x = v_x t \qquad \Delta y = u_y t + \frac{1}{2}a_y t^2$$

The above equations describe the motion of a projectile in the horizontal and vertical components. Velocity is a vector quantity with both speed and direction (if an angle is required then this must be included in the answer).

Note: Many questions will require the application of Pythagoras' Theorem and the application of trigonometric functions.

2. perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis
Refer to Assessment Task #1

3. identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, **Goddard,** Esnault-Pelterie, O'Neill or von Braun
Robert H. Goddard

- Acknowledge as the **father of modern rocketry** – was an American pioneering scientist
- First to prove that rockets did not require air 'to push against' for propulsion, thus can still work in a **vacuum**
- Analysed the **energy yield** and thrust per unit mass of various fuels – and was the first scientists to use **liquid fuelled** petroleum and oxygen for the combustion
- Collected **200 patents** relating to rocketry in his career
- Used a **gyroscope for navigation**
- **Increased efficiency** of rockets from 2% - 64% by utilising the *de Laval nozzle*, which was the most efficient conversion of energy of hot gasses into forward propulsion

4. solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using:
Simply practice questions and practical situations where the following formula can be used:

$$F = \frac{mv^2}{r}$$

5. solve problems and analyse information using:
- Kepler's third law, where the right hand side is a constant for the centre mass.
- SI units must be used.

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

3. The Solar System is held together by gravity

1. <u>describe</u> a gravitational field in the region surrounding a massive object in terms of its effects on other masses in it

A gravitational field surrounds all masses and the interaction of the masses in this gravitational field results in a force between the two masses. The concept of Newtonian gravity is the **attracting force** between two masses.

The larger the force, the greater the gravity and attraction that surrounds the two masses. In the case of massive planets, such as Jupiter, the gravitational pull is significantly greater than that of Earth's.

2. <u>define</u> Newton's Law of Universal Gravitation

Newton's **Law of Universal Gravitation states that every mass in the universe is attracted to every other mass in the universe by a force of gravitation**. This can be calculated by:

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

3. <u>discuss</u> the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites

Gravitation provides the centripetal force that produces the circular motion that is the satellite's orbit around a planet. Therefore, it can also be said that:

==*Gravitational force = Centripetal Force*==

This equation shows that the required orbital velocity of a satellite depends upon the mass and the orbital radius. It can be used to determine Kepler's law of periods and also the escape velocity of a projectile. Therefore, **without an understanding of Newton's Law of Universal Gravitation, the motion of planets cannot be understood.**

4. <u>identify</u> that a slingshot effect can be provided by planets for space probes

Many of today's pace probes to distant planets use a **gravitational slingshot effect** that brings the probe closer to other planets to increase the probes velocity. The slingshot effects **allows probes to change their motion, direction and velocity** according to the force of gravity exerted by the planet(s) that the probe passes.

The probe will 'swing' between planet's attraction.

The **slingshot effect relies on the transfer of energy from potential to kinetic energy.**

1. present information and use available evidence to discuss the factors affecting the strength of the gravitational force

$$g = \frac{Gm_p}{r^2}$$

We can see from this relationship that gravitational force is proportional to the constant and also the mass of that planet, such that **G/M ↑ - g ↑**. However, gravity is inversely proportional to the square of the radius of the planet. As radius increases; gravitational force decreases.

2. solve problems and analyse information using:

The factors affecting the strength of gravitational force are derived from Newton's law of Gravitational Force of Attraction between two (or more) masses. The include the **mass** of the objects, the **distance** between the two objects and the individual **gravitation field** which is exerted as a result of the masses and radii of the two planets. With reference to:

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

4. Current and emerging understanding about time and space has been dependent on earlier models of the transmission of light

1. outline the features of the aether model for the transmission of light

A major feature and reasoning behind the idea of **aether** is that a Frenchman Descartes believed that **motion could be carried from one piece of matter to another through only contact with other matter.**
- Permeate all space and matter
- Transparent
- Low density

2. describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether

Michelson and Morley attempted to measure the relative speed of the Earth through the aether, a substance **conjectured to be the medium in which light is propagated**, that filled all space. Their method involved splitting a beam of light, from a single source into two beams that travelled perpendicular to each other.
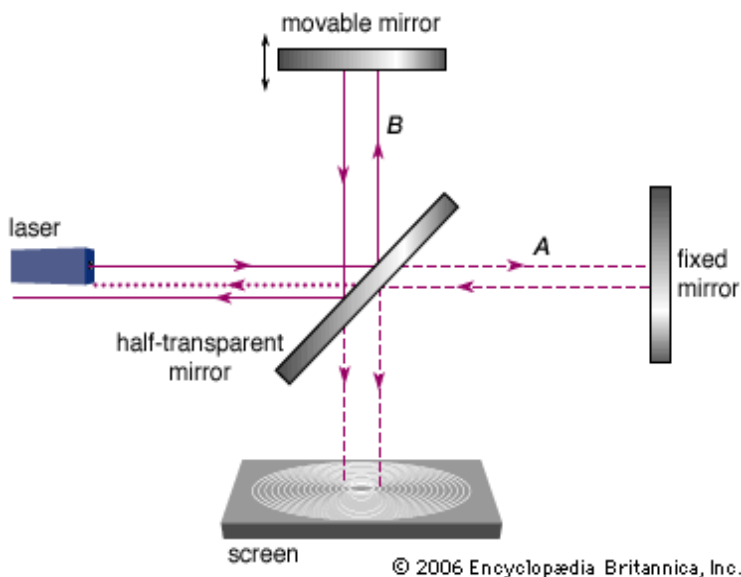
The two beams were brought together and shown on a screen, creating an interference pattern. **If the Earth moves relative to the aether, then the speed of one beam will be different from that of the other**, just as the speed of a boat going first upstream and then downstream is different from that of a boat travelling across the stream. **The difference in speed of the two beams would alter the interference pattern** when the apparatus is rotated through 90°. **No such alteration was found.**

This and similar **failures to detect the motion of the Earth through the aether led later to the development by Einstein of the special theory of relativity**, and the subsequent abolishment of the ether theory.

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3. discuss the role of the Michelson-Morley experiments in making determinations about competing theories

The 'null result' for the Michelson-Morley experiment could only mean that there was no aether and that the **speed of light in a vacuum was independent of the speed of the source and the observer**. The Michelson-Morley experiment was **crucial because it enabled one of the main predictions of the aether model to be experimentally tested.**

The experiment has been able to help scientists of the twentieth and twenty-first century to reject the aether model and accept Einstein's relativity.

The Michelson-Morley experiment contradicted Galilean relativity.

4. outline the nature of inertial frames of reference

Galilean relativity. A frame of reference where Newton's first law is obeyed is called an **inertial frame of reference**. Inertial frames of reference are moving at a constant velocity and are not undergoing acceleration or experiencing any force. There is no difference between standing still and moving with constant velocity in a straight line; everything we do is identical. → This is why we can walk around in a fast moving plane, yet still accurately pour water into a glass.

An inertial frame is where a person travelling at a constant speed or stationary will experience the same forces (or lack of) as the same as others in inertial frames.

5. discuss the principle of relativity

Galileo's principle of relativity states that all steady motion is relative and cannot be detected without reference to an outside point. Thus you can only measure inertial motion with reference to a frame of reference.

It is the idea that if you are travelling in a vehicle which is in a constant motion and were to close all the windows and remove any bumps in the road then you would not be able to tell you are moving. This is because the physics and mechanics are experienced the same by all occupants in inertial frames of reference (stationary or at a constant velocity). **The principle poses the concept that one can only perceive that they are moving if they look out the window and observe the surroundings rushing by.**

To detect your velocity, you refer to external reference point. There is not a way to measure an 'absolute' velocity and according to the principle you can only measure you relative velocity between the difference of the two frames. No frame is preferred.

6. describe the significance of Einstein's assumption of the constancy of the speed of light

Einstein's **assumption that the principle of relativity must be obeyed** in all situations resulted in the **constancy of light** as always be seen and therefore the traveller and a person on an embankment must observe light as 3×10^8 m.s^{-1} and that it is not relative to either time nor distance.

In Newtonian physics, distance and velocity can be relative terms, but time is an absolute and fundamental quantity. By this, in the case of a train a person on an embankment would record precisely double the distance of the journey of light; however record the same time. However by Einstein's theory, this will not occur. Instead **both the traveller and observer will record the same value for the speed of light 'c'**.

Therefore, **Einstein's assumption** along with the principle of relativity has helped develop the idea that light has constancy and therefore, **time, distance and mass are relative entities**.

7. identify that if c is constant then space and time become relative

If the speed of light is defined as constant, then by simple velocity equals distance divided by time, then distance (space) and time must change accordingly to ensure that c does not change. As time decreases, then distance must increase to maintain light's velocity.

8. discuss the concept that length standards are defined in terms of time in contrast to the original metre standard

Originally, 1 metre was defined as the length of a metallic block which was located in Paris. Under the SI system, the understanding of length has been standardised to account for relativity. **Length standards are now defined as the length that light travels in a vacuum in a given amount of time**. Since the speed of light is constant.

9. explain qualitatively and quantitatively the consequence of special relativity in relation to:
   – the relativity of simultaneity

As a result of Einstein's relativity and his assumptions he concluded that simultaneous events in one frame of reference are not necessarily observed to be simultaneous in a different frame of reference. This can be explained with reference to a train analogy where the traveller is inside the train and an observer is on an embankment.

At one instance when the train passes the observer, the traveller opens the light activated doors. The two stationary people will observe this situation differently. *The traveller in the train will see the doors open at the same time as he will see light travelling at the same speed in either direction*. The observer, however, will as a result of the speed of the train will see the back door open before the front. The light will *appear* to travel further.

Thus as a result, the **instantaneous situations are not the same in the different frames of reference**.

   – the equivalence between mass and energy

If you speed up an object it becomes heavier. The extra mass comes from the energy used to speed up the object and is defined by Einstein's famous formula: $E = mc^2$

Because the value for *c* is so large, then it follows that **you need a massive amount of energy simply to get a small mass increase**. But as an object approaches the speed of light, then it's mass approaches infinity. Thus, changes in mass (or mass dilation) are a direct result of energy input into the system.

The relationship between energy and mass is given by Einstein's formula where:
E = rest energy (*J*)
m = mass (*kg*)
c = speed of light (3 x 10^8m.s^{-1})

– length contraction
As a consequence of perceiving time differently, observers in differing frames of reference also perceive length differently – *lengths that are parallel to the direction of motion*.

In the train situation, the traveller will perceive light speed as it's rest frame. But as a result of the trains speed and perceiving time differently, *the observer will see the train a little further in it's motion and thus the train will be shorter and light will not take as long to return*. This is known as **length contraction**.
Length contraction is defined by the formula:

$$L_v = L_o \sqrt{1 - \frac{v^2}{c^2}}$$

where;
L$_o$ = the length of an object measured from its rest frame (i.e. the source)
L$_v$ = the length of an object measured from a different frame of reference (i.e. away from the source)
v = relative speed of the two frames of reference
c = speed of light

It is seen that the faster an object travels, the shorter it becomes for an observer in a different frame of reference.

– time dilation
Time Dilation is the result of the principle of relativity. It directly comes from the extremely fast speeds or relationship with the speed of light. The degree of dilation relates to the velocity of the object.

The question posed is how long does it take for light to travel from one point and back again from its rest frame and a different inertial frame of reference (such as an observer on an embankment):

$$t_v = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where;
t$_o$ = time taken in the rest frame of reference (proper time)
t$_v$ = time taken as seen from the frame of reference in relative motion to the rest frame (dilated time)
v = velocity of the train
c = speed of light

The closer the object approaches the speed of light, the greater the time dilation will become.

– mass dilation
As you speed up an object, it becomes heavier due to the energy input (as stated by Einstein's formula for the relationship between energy and mass). Mass dilation, the changes in mass was derived as a result of Einstein's assumption that the *conservation of mass must be obeyed in all inertial frames of reference*. The mass dilation equation is given by:

$$m_v = \frac{m_o}{\sqrt{1 - \dfrac{v^2}{c^2}}}$$

where;
m_o = mass measured in the rest frame of reference (rest mass)
m_v = mass as seen from the frame of reference in relative motion to the rest frame
v = velocity
c = speed of light

10. <u>discuss</u> the implications of mass increase, time dilation and length contraction for space travelling

Mass increase poses large problems for realistic space flight. By the definitions of mass dilation and as an implication of the resulting mass increase, it means that spacecraft cannot travel at an exceeding velocity to reach or go beyond the speed of light. Approaching the speed of light would increase the mass of the spacecraft indefinitely and thus require massive amounts of force to 'push' on the craft to propel it forward. It also poses problems that human occupants can become too heavy for life.

Time dilation, however, helps space travel as if relativistic speeds can be achieved. Because time is now a relative value (because of Einstein's assumptions and relativity) then it is possible for occupants of spacecraft to travel to distant stars and planets with lesser ageing than that would occur on Earth. If all parts of relativity are true and that time dilation does occur, then this would enable occupants in the inertial frame of reference (spacecraft) to live longer over their travel. However a problem arises with this concept of ageing and space travel.

- *idea of twin paradox*

Length Contraction also works in beneficial ways for space travel. Using Einstein's postulate that physics are the same for all observers (and that no frame of reference is preferred), then those in a spacecraft could say that they experience their spacecraft stationary as space moves past them. With this, one could say that there is less space to travel and therefore less fuel/force required to move the spacecraft to its destination. Although we tend to acknowledge that the spacecraft would be moving through space, according to Newtonian Physics and for all practicality.

1. gather and process information to interpret the results of the Michelson-Morley experiment

This may have reference to a **boat analogy** where boats travel in different directions but the current of the water will affect their velocity. Assessing the validity and reliability of data from primary and secondary sources.

2. perform an investigation to help distinguish between non-inertial and inertial frames of reference

A simple measure to test and distinguish between inertial and non-inertial frames of reference is to hang a ball from a piece of string and hold onto it. Because we know that an **inertial frame** of reference is one where **Newton's laws of physics are observed**, then we can distinguish between that an a non-inertial frame which will be accelerating.

Holding a small mass from a string a walking forward at a constant velocity (any velocity) **will result in the mass hanging straight down.**
However is you are to move forward at an accelerating pace, the mass will experience a force acting upon in it in the opposite direction to the movement – therefore the mass will deviate an angle. **In this accelerating frame we can see that Newton's laws are not obeyed and therefore a non-inertial frame of reference.**

An *accelerometer* can also be used to measure a force acting upon an object (such as bathroom scales). It is said that the object will be in a non-inertial frame. But the force responsible may be a result of gravity.

3. analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality

One experiment conducted by Einstein was one that analysed whether one would be able to see their reflection in a mirror if they were travelling in a train at the speed of light. There are dilemmas posed:

- *The reflection will NOT be seen*. This is a result of the *aether theory* and that light can only travel as fast as 3 x 10^{8}m.s^{-1} through the aether. The aether theory stated that if the train was travelling at the speed of light, then **the light could never catch up to the train** and thus a reflection would never be seen. However this violated the theory of relativity.

- *The reflection WILL be seen*. According to the principle of relativity, it would not be possible for the person in the train to tell whether the train was moving (as it would be an inertial frame of reference). However a p**erson on an embankment would observe the light travelling from your face as twice the speed of light!**

Einstein believed that the principle of relativity must always hold true so therefore:

- the **reflection would show**
- the **person at the side of the track sees light travelling at its normal c speed**. But, time passes differently as a result of this assumption and belief, resulting in **time dilation**
- The aether model was superfluous

4. analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it

Atomic Clocks: Experimental evidence for time dilation is two gather two atomic clocks set to the exact same time down to microseconds – leave on on Earth and send another in a spacecraft around the Earth at a constant velocity. Sending the craft in the opposite direction to the Earth's rotation to maximise the relative velocity.
When the two clocks are brought back together after a series of a few times around the Earth, <mark>the clock that had been on the journey should record a lesser time than the one left on Earth</mark>. This is because the spacecraft will have travelled as such a fast speed that time would have recorded slower on the shuttle, as a result of *<mark>time dilation</mark>*.

Muons: Experimental data which proves the existence of time dilation is the detection of muons. When high-energy sub-atomic particles collide with the Earth's atmosphere, muons are produced. Muons are extremely unstable and have a very short life-span of about 2 microseconds. To reach Earth's surface with a life-span of this time, they would need to travel at the speed of light but due to *time dilation* they do not need to. We observe them to exist for 16 microseconds. <mark>Because muons still travel extremely fast, time goes slower as observed by those on Earth</mark>. As a result of this time dilation muons can be seen on the Earth's surface (approximately 10km below their formation point).

5. solve problems and analyse information using:

$$E \ = \ mc^2 \qquad L_v \ = \ L_o\sqrt{1-\frac{v^2}{c^2}}$$

$$t_v \ = \ \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}} \qquad m_v \ = \ \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

Note: Any units can be used when using a time/mass dilation or length contraction equation, since the units will cancel out (as v and c will be in the same units).