Module 1: Space

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

Students learn to:

- **Mass** is the physical amount of matter contained by an object, it is irrespective of gravitational field position. **Weight** is the force exerted on a body due to a gravitational field. In a **uniform gravitational field,** weight is described by $F = mg$ known as the **Weight Formula,** where g represents the gravitational field vector and is acceleration due to gravity.
- An object suspended in a gravitational field has **Gravitational Potential Energy** (GPE). A change in gravitational potential energy requires **work to be done** on a body to move it away from the attractive force. Thus higher objects have greater gravitational potential energy.
- As work is done to create GPE, it can be described as **work done to move an object higher in a gravitational field**. Equating **work,** $W = Fs = mgh$, and **Newton's Law of Universal Gravitation**, $F = G\frac{m_1 m_2}{d^2}$ (discussed later), and as GPE is defined by work, therefore $E_p = G\frac{m_1 m_2}{d^2} \times d$. Potential energy is gained from increasing your distance from the centre of mass in the field. By definition E_p at an infinite distance equals zero. Therefore E_p at infinity is greater than E_p at any given distance. Therefore Gravitational Potential Energy is negative and described by the formula $E_p = -G\frac{m_1 m_2}{r}$.

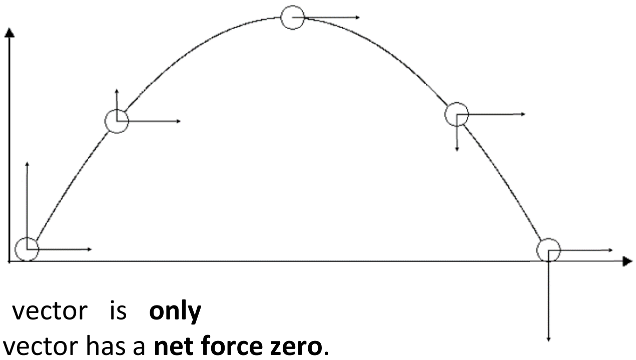
Students:

- **Practical Investigation – Acceleration due to Gravity from a Pendulum. Aim:** to calculate local gravitational field using the relationship between gravity, the period and the length of a pendulum. **Independent Variable:** the length of the pendulum. **Dependent Variable:** the period. **Background:** for pendulum swings of less than 15°, this holds true, $T = 2\pi\sqrt{l/g}$. When squared, we can plot period (T) squared against length of pendulum where the gradient $= 4\pi^2/g$ which rearranged can isolate the **gravitational field vector**. **Method:** Set up pendulum. Record period of 10 swings for 5 varying lengths. Divide by 10 to find period and then plot period squared against length in Excel. Find gradient and rearrange to isolate g. **Results:** the calculated value for g was 9.68 ms^{-2}. Whilst this wasn't particularly accurate, many steps were taken to minimise error. The first was to let the **pendulum swing ten times**, reducing human error by a factor of ten. We also used **multiple observers** averaging results effectively resulting I experimental repetition. Finally, the use of a computer to graph results was far more accurate in analysing data then hand graphing or individual averaging, a **trendline** (supported by an r^2 of 0.9986) produced by **least squares** produces a more accurate and valid average. Thus it must be concluded that there were **external factors resulting in variations from $9.8\ ms^{-2}$**. These could include the **altitude**; changing the distance from the centre of mass affects field strength, but at 10 metres above sea level, this would be negligible. The **latitude** also affects the field as the earth bulges at the equator due to centrifugal forces creating **altitude discrepancies**. At 40°, CHSC would by average. The **material underground** also has an effect but as this is not known, it cannot be included. Thus the most probable discrepancy is **energy loss in the pendulum** from friction in the axel and air resistance.
- **Using data** including **mass of planet** and its **radius**, and by combining Newton's Law of Universal Gravitation and the weight formula, $g = G\frac{m_p}{r^2}$ is found, where m_p is the mass of the planet and r is the distance from centre of mass or radius of planet. This can be applied for all planets to determine g. **Note**: the mass of an object affected locally by a gravitational field is irrelevant in determining the acceleration achieved.
- Using the weight formula, $F = mg$, object's weight can be discovered on other planets.

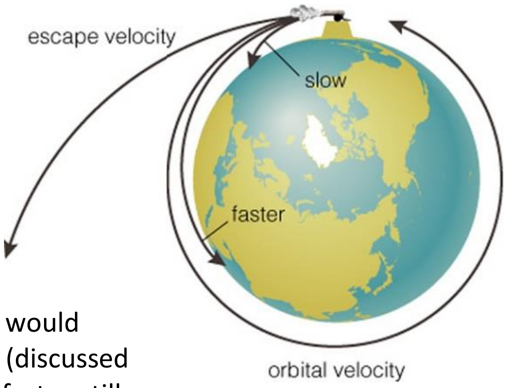
2. Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit, and return to Earth.

Students Learn To:

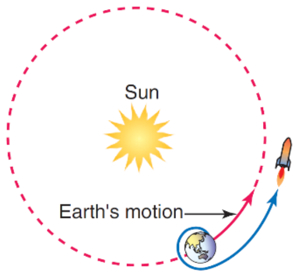
- A **Projectile** is anything that is launched into the air or space without further **propulsion**. When air resistance is ignored, projectiles are only subject to their own inertia and gravity forming a **parabolic trajectory**. Because projectiles are usually fired at some angle to the horizontal, predictions can be made by breaking the velocity into **two vectors perpendicular** to each other and hence independent. By rearranging uniform motion equations (refer to Preliminary syllabus) we can create equations that describe both the **vertical and horizontal vectors**, discussed below. The vertical vector is **only accelerated by gravity** while the horizontal vector has a **net force zero**.



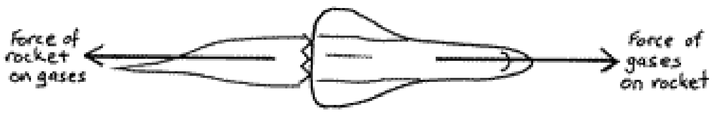
- **Galileo Galilei** realised that **all masses fall at the same rate** regardless of mass or shape, when air resistance is ignored. Thus there is **only one force acting on all projectiles**. He also recognised that Projectile motion could be separated into **two perpendicular vectors** as described above.
- For an object to escape the gravity of the earth, its **kinetic energy** has to be **greater** than the **change in gravitational potential energy** required to escape the field. Therefore $\frac{1}{2}mv^2 > G\frac{mM}{r}$. Thus **escape velocity** is defined where $v > \sqrt{2G\frac{M}{r}}$ where G is the **gravitational constant**, M is the **mass of the object being escaped from** and r is **the radius of that object**.



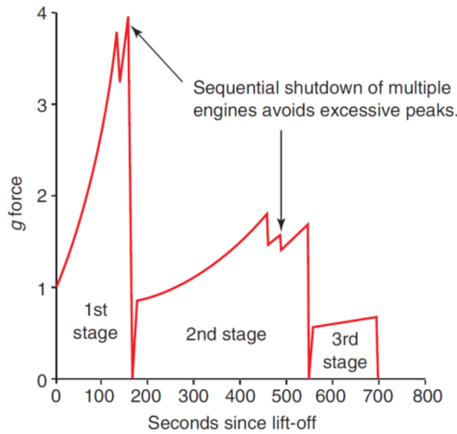
- **Isaac Newton** postulated that if a cannon was positioned on a high mountain and fired fast enough, the shell would continue to fall but the earth's surface would curve away at the same rate. This is called an **orbit** (discussed later), however he also postulated that if it was fired faster still, the shell would **escape the effect of earth's gravity completely**, it would never curve back in. He also realised that because of the effect of gravity, it would **not matter which direction** the shell was fired, that if it achieved this velocity it would escape, just via different paths.
- **G forces** are defined as a ratio between an **object's apparent weight** and its **true weight**. They are used to quantify the amount of force applied to an astronaut and it's useful as it gives a **relative measure of the stress** on the astronaut through comparison of perceived and normal weights. They are defined by $g\ force = \frac{apparent\ weight}{normal\ true\ weight}$ which rearranged becomes $g = \frac{g+a}{9.8}$. When g forces are **greater than one, the frame of reference is accelerating** so the reaction force is equal to the object's weight plus the acceleration. When an object **decelerates, the g forces are less than one** as some reaction force is relieved by inertia. **During free fall, the g's are zero** as the frame is accelerating under gravity with no other force to stop it.
- Just like a cricket bowler who runs up to bowl the ball, the moving and rotating earth can also **provide additional velocity** to **rocket launches** timed correctly. As the earth is already moving, both **orbiting the sun** and **rotating on its axis** (east to west), its initial velocity can be harvested to provide some of the velocity of **orbital or escape veolcity** thus reducing the force required by a rocket to get into orbit and to other planets by providing a "boost". **Launching from the equator** is



most beneficial as it is moving fastest. If you were to **work against these motions**, you would have to overcome both the initial rotation and then the relative veolicty required for the trajectory. Thus it is necessary that these forces be **factored in launch patterns** as it becomes virtually impossible (and pointless) to work against them. This favours certain times called **launch windows** which adds further complications to rocket launches.



- A rocket **achieves thrust** from the **Conservation of Momentum**. The law says that the velocity times the mass of both the **rocket and exhaust** must be equal and opposite, ie $P_{rocket} = -\Delta P_{gases}$. So when the exhaust is ejected through the nozzle the rocket will **gain forward velocity**. Of course the rocket has a large mass while the gases have a small mass so the velocity is only small. However a rocket's mass reduces as fuel is burnt and as such the **net force on the rocket will increase**, thus the rocket accelerates at an accelerating rate. This also **increases g-forces** to a peak as the force becomes greater to keep the astronaut accelerating as well. To the right shows the g's on the multi stage rocket, *Saturn V*, the jagged peaks represent **sequential shutdown** to avoid excessive peaks and the dips show the **free fall** between stages.



- **Orbiting** the earth is an example of **Uniform Circular Motion**. UCM occurs when a force always acts at right angles to the velocity of the object. The force which causes UCM is referred to as the **centripetal force** and is described by the formula $F = \frac{mv^2}{r}$ which when equated to $F = ma$ isolates centripetal acceleration, $a_c = \frac{v^2}{r}$. Analysing the formula, to allow F to equal 9.8 (it has to as gravity is the centripetal force) it means that for every orbit radius there is a **specific velocity required** for the same body. Other examples of UCM are a **ball on a string** held by the tension of the string, **a cornering car** held by the friction of road on tyres, and a **charged particle in a magnetic field** held by electromagnetism.

-

	Low Earth Orbit's (LEO)	Geostationary Orbit's (GEO)
Altitude	160 – 2000 km. Average 300 km.	35,786 km.
Period	≅ 90-300 min. Speed of 7750 ms^{-1}.	23:56 hours. Speed of 3070 ms^{-1}.
Van Allen Belt	Inside. No protection required.	Outside. Needs to be protected from solar radiation.
Examples	ISS, HST, Space Shuttle, GPS, etc.	Optus-Aussat, TV Satelites, etc.
Notes		Geosynchronous (T=24h) and Equatorial orbit, Below horizon if latitude > 80°.

- **Kepler's Law of Periods**, discerned empirically from the study of the planets, is used to relate the radius and period to the gravitational constant and the mass of the body orbited, ie $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$. As a perfect orbit is an example of **uniform circular motion**, the following relation can be applied; $v = \frac{2\pi r}{T}$. When integrated into Kepler's law, $\frac{r^3}{(\frac{2\pi r}{v})^2} = \frac{GM}{4\pi^2}$, velocity is defined by $v = \sqrt{\frac{GM}{r}}$. This is the **orbital velocity** required by any satellite to achieve a **circular orbit**. The orbital velocity is the **instantaneous velocity** at any point in its circular or elliptical motion. Thus the velocity required to orbit is **inversely proportional to the radius** of that orbit. If the velocity is greater than orbital velocity but less then escape velocity, then the orbit is **elliptical**.

- **Orbital Decay** occurs because in Low Earth Orbit, the **atmosphere creates drag** which decreases the **orbital energy** (its kinetic and gravitational potential energy) of a satellite and thus lowers its altitude. This is a **compounding effect** as the lower the satellite goes, the denser the atmosphere and the greater the drag. Thus the satellite **spirals to earth** until eventually the friction becomes so great it **vaporises** the spacecraft. As thin as the atmosphere is at 1000 km, this effect is still prevalent enough to have a significant effect and once the satellite is below 200 km, it only has a few hours and no human intervention can save it.
- The **Extreme Heat** associated with re-entry is caused because all of the kinetic and gravitational potential energy of a space craft must be lost as heat. The friction and pressure caused will be so great that it will vaporise ill designed spacecraft. To overcome this, scientists discovered that a **blunt nosed** spacecraft was best as it created a **shockwave** of air in front which took the brunt of the friction. A layer of ablative ceramic material designed to slowly vaporise, protected the space craft and was designed to prevent any further friction. The space shuttle uses porous fibre glass tiles which need to be retreated every flight, it uses its flat belly for a blunt nose. The **Decelerating g forces** are also an issue, studies showed that astronauts could be subjected to up 20g during re-entry, the max tolerable was then 8g. Studies were conducted which showed that a **transverse application**, where blood is not forced away from the brain, helps so astronauts were placed lying down. **Eyeballs-in** was also easier to tolerate, thus astronauts would face up. Also **supporting the body** in as many places as possible helped, thus astronauts had specially modelled chairs. The **Ionisation Blackout** was also an issue; during re-entry, the friction causes enough heat to ionise the particles around the spacecraft, **preventing radio communications** from transmitting to and from the craft. The *Apollo* capsules experienced about 3-4 minutes whilst the space shuttle experienced about 16 minutes. Finally, actually **landing on the ground** is achieved in many different ways. The *Apollo* craft deployed **parachutes** and landed in the ocean whilst the soviet rockets **ejected the pilot** at a suitable altitude to float to earth. The space shuttle has **wings** and can thus fly down to earth like a plane.
- Taking all of the above into account, an **optimal angle of re-entry** is required for each spacecraft. If it is too shallow the craft will **skip off the surface** of the atmosphere like a stone skips off water and be unable to return. If it is too steep, the above factors will cause the **craft to vaporise**. For the *Apollo* capsules, the re-entry angle was between 5.2° and 7.2°.

Students:

- Where x represents the horizontal vector and y represents the vertical vector:

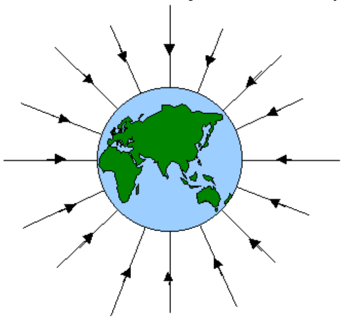
  $$v_x = u_x \qquad \Delta x = u_x t \qquad v_y = u_y + at \quad {v_y}^2 = {u_y}^2 + 2a\Delta t \qquad \Delta y = u_y t + \frac{1}{2}at^2$$

  Note: in horizontal equations $a = 0$; for vertical equations $a = -9.8\ ms^{-1}$ where up is positive.
- **Practical Investigation – Projectile Motion. Aim:** To explore projectile motion using a data logger. **Independent Variable:** the path of projectile. **Dependent Variable:** predicted values. **Method:** Use *Videopoint* software to analyse a ball toss by marking the centre of the ball throughout its flight. Export Cartesian values to excel and plot a graph with a linear trend line and r^2 value. Rearrange $v_y = u_y + at$ to $y = mx + b$ form and evaluate the a value for both horizontal and vertical vectors. Substitute these values into other equations to further discover.
- **Wernher von Braun**, originally a **Nazi rocket scientist**, developed the first long-ranged combat-ballistic missile, the **V-2**, to bomb London. It was the first object to **enter outer space**. After WW2 he was emigrated to the United States where he worked on developing their **first ballistic missile**, the **Redstone Rocket** which carried the first nuclear warhead. He also helped the launch of **Explorer 1 satellite** who first detected the Van Allen belt. He developed the *Saturn V* rockets that were used in the *Apollo* missions to land on the moon, the heaviest rockets ever launched. Thus he was the father of **applied space exploration** and responsible for America's dominance.
- **Centripetal forces on a satellite** can be analysed by equating universal gravitation and centripetal force, $F = G\frac{m_1 m_2}{d^2} = \frac{mv^2}{r}$. This can be rearranged but is also **independent of the satellite's mass**.

3. The Solar System is held together by gravity.

Students learn to:

- **<u>Gravity</u>** is defined as the **force of attraction between two masses** and acts on both objects. Gravity exerts itself as a **<u>vector field</u>** (much like electric and magnetic fields, refer to preliminary summary), having both magnitude and direction. On earth, the field lines are effectively parallel as the curvature isn't noticeable.



- To describe a gravitational field, **<u>Newton's Universal Law of Gravitation</u>** is applied, $F = G\frac{m_1 m_2}{d^2}$, where *F* is the net force, *G* is the Universal Gravitational Constant ($6.67 \times 10^{-11}\ Nm^2kg^{-2}$), m_1 and m_2 are the masses involved and *d* is the distance between the centre of gravity for both objects. This formula only applies for two masses, to work out more than that the net force must be derived from vectors addition of multiple individual interactions.
- To calculate any force of gravity that's not a **uniform field**, Newton's law must be applied. Thus, in terms of orbiting satellites, it was crucial to understand interactions in terms of this law. **<u>Gravity</u>** is the **centripetal force** in orbital motion, thus equating **centripetal motion** and **universal gravitation** you can derive **orbital velocity**. By substituting $v = \frac{2\pi r}{T}$ into this equality, Newton's law can also be used to independently prove **Kepler's Law** theoretically as right. Thus, Newton's law is **<u>crucial in calculations</u>** involving satellites.

$$F_c = \frac{mv^2}{r} = G\frac{mM}{d^2}$$

$$v^2 = \frac{GM}{r}$$

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

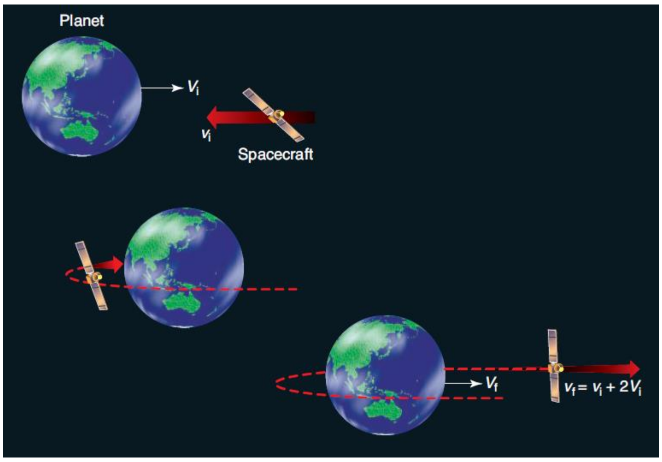
In orbit $v = \frac{2\pi r}{T}$;

$$\therefore \frac{2\pi r}{T} = \sqrt{\frac{GM}{r}}$$

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

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

- The **<u>slingshot effect</u>** is manoeuvre a space probe achieves around a planet. It can be used to **accelerate** or **decelerate** a spacecraft with very little effort. While the initial and final velocity **relative to the planet are the same**, relative to the sun the spacecraft can gain or lose velocity. By slingshotting **behind** the planet in its orbit, **acceleration** is achieved while slingshotting in **front** causes **deceleration**. The effect can be thought of as an **<u>completely elastic collision</u>** where the spacecraft harvests some of the **planet's momentum**. The equation describing the velocity achieved is $v_f = v_i + 2V$.



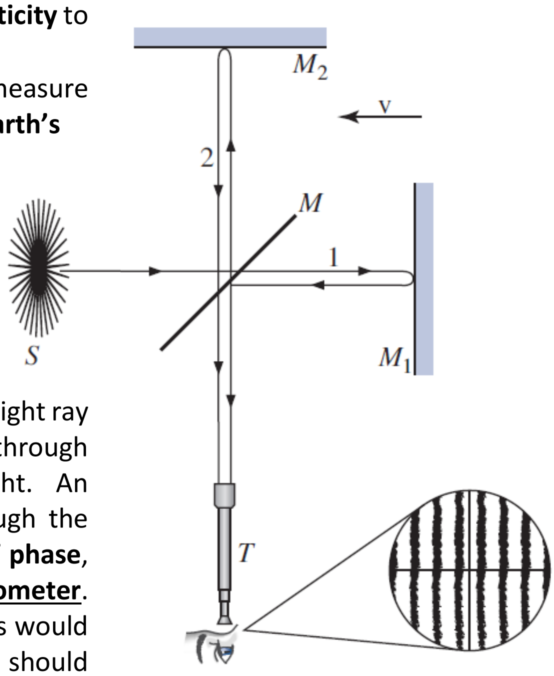
Students:

- **<u>Factors that affect the gravitational force</u>** include the varying masses of the objects and the distance between the two objects, as described by Newton's Law of Universal Gravitation. This is crucial in explaining the varying gravitational fields on earth not explained by using the average for g.

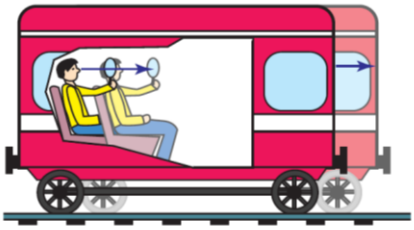
4. Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light.

Students learn to:

- It was thought when light was first discovered to be a wave that it too would need a medium to travel through. Although no medium was observable, scientists invented the **luminferous aether**, a medium which **filled all of space**, had **low density**, was **perfectly transparent**, **permeated** and was **permeable** to **all matter**, and had **great elasticity** to support and propagate light.

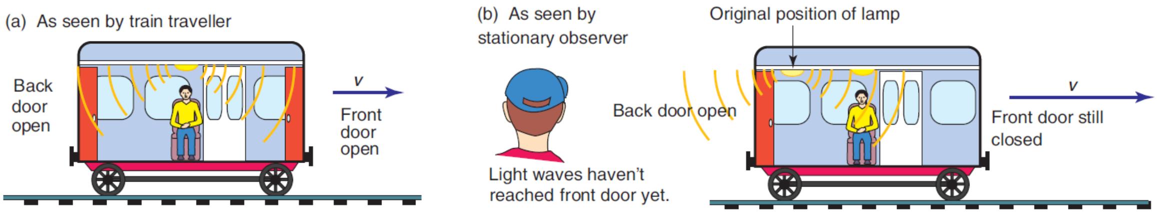


- One way to test the **aether's** existence was to measure the **aether wind**, invariably produced by the **earth's motion through the aether** at an expected $30\ kms^{-1}$. In a similar way to boats racing across a **river current** opposed to up the river, it was thought that by sending light in different directions across the aether wind, a very small but measurable **difference in speed** would be noted. Using a **half-silvered mirror**, **A. A. Michelson** and **E. W. Morley** split a light ray by 90° then reflected those light beams back through the mirror to a telescope; as shown right. An **interference pattern** would be observed through the telescope as one of the waves would be **out of phase**, and thus the apparatus was termed an **interferometer**. When the device was rotated 90° the lightwaves would be **interposed** and thus the interference pattern should shift, confirming the aether wind. Michelson and Morley repeated the experiment at different times of the **day** and **year** but no interference shift was ever recorded. As the experiment was deemed **accurate, reliable and valid** enough to test the current model, this **null result** was extremely significant in determining between **two competing scientific theories**. It created a **measurable result** where other's couldn't and undoubtedly answered the aim, although scientists at the time had difficulty **adapting to the ramifications**.
- To prove a **scientific theory**, **experimental evidence** is used to test a **prediction of the theory**. Due to the **inherent uncertainty** of experimental work, one experiment **will not prove** or disprove a theory, especially if it merely fails to observe the phenomena; an **empirical consensus** is required. In the case of the MMX, the **null result** eventually **could not be attributed** to experimental error, thus the aether model was concluded to be unfavourable or a **limited model**, but crucially **did not disprove** the aether model. When Einstein's special relativity came along and explained the properties of light without the need for an aether, the aether model was **discarded as inconsequential** as to satisfy MMX, it **could not make testable predictions**. Thus MMX made a **determination** by challenging the predictions and rendering one competing theory useless.
- An **Inertial Frame of Reference** is one where Newton's first law holds; ie a frame of reference **not undergoing acceleration**. Thus, inertial frames of reference staisfy the **principle of relativity.**
- The **Principal of Relativity**, first stated by Galileo and supported by Newton, is that all motion is relative to the observer and that within an **ineirtal frame of reference**, there is **no mechanical experiment or observation** that you can perform to determine whether you are stopped, or moving in uniform velocity, without referring to another frame of reference.
- **James Maxwell's equations** for light indicated (with significant evidence) that the **speed of light was always constant through the aether**. Since the aether was supposedly **stationary in space** and light had a **fixed veolcity** through the aether, if an observer was moving through the aether, then an **optical experiment** could be performed within the inertial frame of reference to **prove they were moving**, as the light would appear slower t. Einstien in his examination, used a thought



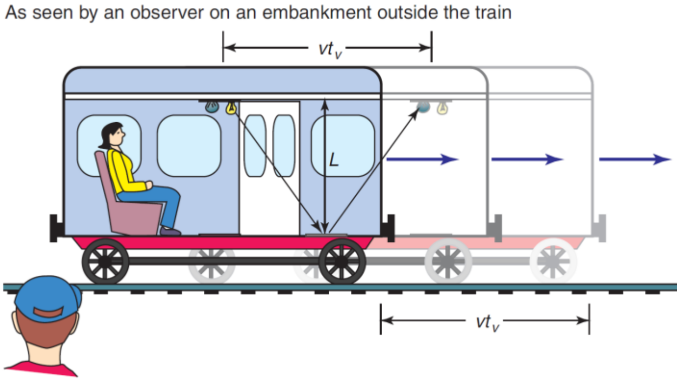
experiment; if he were in a train travelling at the speed of light and held up a mirror, would he be able to see himself? The light could never catch up to the mirror through the aether, **thus violating relativity**. Einstein postulated that "*Light always propagates in empty space with a definite velocity, c, that is independent of the state of motion of the emitting body*." He thus concluded that the **aether was superfluous** in explaining how light behaved as if special relativity held, the aether model could no longer make **testable predictions**.

- However the removal of the aether did not solve the issue of **multiple observers** where similar problems were encountered; effectively replace the aether with a stationary observer relative to the train tracks. If **Newtonian relativity** is to be followed, the stationary observer views the light travelling twice the distance to the mirror over the same time, thus doubling c; as right. To solve this, Einstein realised that for the velocity of light, c, to be the same for both observers, their **measured time and distance must be different**; as $velocity = distance/time$. Thus if c or velocity is constant, **then space and time must be relative**.
- Previously, the metre was defined as **ten millionth** of the length of the Earth's quadrant passing through Paris or as a **platinium-ridium alloy bar** from which copies were made. However as distance can vary with the speed of the observer, using an object as the universal definition for the **metre is no longer accurate**. Instead the current definition of the metre uses the **constancy of the speed of light** in a vacuum (299792458 ms^{-1}) and the accuracy of the **definition of one second** (9129631770 oscillations of the ^{133}Cs atom), to achieve a definition that is both highly accurate and consistent with the idea of relative space–time. One metre is now defined as the length of **the path travelled by light in a vacuum during the time interval of c^{-1} of a second**.
- The consequences of relativity and a constant speed of light produce these strange results:
  - **The Relativity of Simultaneity:** One consequence of special relativity on time is the concept of similtaneity. In the thought experiment right, a train with light activated doors passes two observers. For one, the doors open simultaneiously, however the other, due to the movement, clearly sees the two events as independent. Thus, **simultaneity between two frames** of reference with relative motion, is **also relative.**



  - **The Equivalence between Mass and Energy:** Einstein proposed the concept of **mass-energy equivalence** with his equation $E = mc^2$, although the proper, full equation is $E^2 = (mc^2)^2 + (pc)^2$. Here he states that when **energy** is added to or taken from a system (like in the form of kinetic or binding energy), the system's **measurable mass changes**. This does not suggest that it **physically gains more particles**, any particle has a consistent rest mass, however the extra energy **interacts with space-time** (according to general, warps space time) such that it has the effect of interacting with more mass, although it does suggest **intrinsic masses** can be **converted to energies**. Einstein was able to prove this relation with Special Relativity (although some argue his was a botch job) by considering the **differing kinetic energies** of **two opposite pulses of light** emitted from a body in different **frames of reference**. Thus, the premise of Special Relativity results in this extraordinary observation that predicts many phenomena like energy discrepancies in **nuclear transmutation** and **antimatter interactions** by replacing the separate conservations of mass and energy with the **Conservation of Mass-Energy**.

- **Time Dilation:** states that the physical passing of time in a moving frame of reference (t_v) will be observed as slower **when compared** to the observer's frame of reference (t_0). Thus, if a spaceship moves past you at relativistic speeds, you would view the events on the spaceship **occurring slower**. These results are produced when analysing the actions of a vertical **light clock** (a beam of light is recorded bouncing along a tube) to maintain a constant c. The light must travel a **longer path** (a triangle) for the observer and thus he must see time on the train travelling slower for the **light to catch up** and travel the longer distance at the same speed. Time dilation defined mathematically is right.



$$t_v = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

- **Length Contraction:** states that distances **parralel to the direction of motion** will be observed shorter in moving frames of reference as opposed to the observer's frame. Thus lengths at velocity (L_v) will **always be shorter** than the proper length (L_0). Hence a passing spaceship will be seen as shorter than if it was stopped. These results were predicted by the effects of time dilation (and a **horizontal light clock**), if the observer sees time dilating on the train, the train driver must see length around him contract in his direction of motion as this compensates for the planets moving. Length contraction described mathematically is right.

$$L_v = L_0\sqrt{1-\frac{v^2}{c^2}}$$

- **Mass Dilation:** Einstein's 1st postulate was all the laws of physics **must be obeyed throughout all reference frames**. To ensure the conservation of momentum holds at relativisitc speeds with time dilation, **momentum at relativistic speeds** is defined as $p_v = p_0/\sqrt{1-\frac{v^2}{c^2}}$ and as **velocity is independent** of the observer, we cancel the velocities and are left with mass dilation, described mathematically as right. This increase in mass can be considered by the **mass-energy equivalence**, as more energy is put in to approach the speed of light, the dilated mass approaches infiinity and thus a massive particle can **never move at *c*.**

$$m_v = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

- By travelling at **relativistic speeds** relative to earth, interstellar distances can be shortened and the **time taken slowed down** which could assist greatly with **Space Travel**. At 0.9999c, distances and times have contracted **to 1.4%** of their original value. For instance at this speed, the 4 year journey to *Alpha Centuri* would only take 20 days. Thus, by slowing down the times and making the distances shorter, it would be **possible for human travel**. However the **energy cost** required to compensate for **mass dilation** to accelerate to these speeds make it **incredibly inefficient** to the point of impractical. It is also important to note that acceleration is a barrier as humans can only withstand certain **g-forces** making acceleration a challenge. The reason why this doesn't violate special relativity (as all frames are relative) is because the spacecraft would **no longer be an inertial frame of reference**; to reach that speed it would have had to undergo acceleration relative to earth which is what affects the time, not the relativistic speeds. **The twins' paradox** as such can be deconstructed by examining the frames of reference so when one twin goes on the interstellar journey and returns, he has **broken his inertial frame** by accelerating and thus appears younger, however the dilation caused by acceleration is beyond the scope of this course.

Students:

- **Practical Investigation – Inertial and Non-Inertial Frames of Reference. Aim:** To determine between an inertial and non-inertial frame of reference. **Independent Variable:** motion of vehicle. **Dependent Variable:** motion of plum bob. **Method:** Drive around in a vehicle with someone holding a plum bob or pendulum. Perform various manoeuvres like accelerating, braking, coasting, turning corners, etc. Record what the pendulum does and thus discern which the inertial or non-inertial frames of reference were. (alternate prac is some scales in an elevator)
- Einstein used a whole host of **speeding train thought experiments** in his considerations of special relativity. Thought experiments are useful because they enable to **analyse impossible scenarios** thus testing our theories to the limit. However as they are products of thought, they **cannot be experimentally tested** and as nature is known to behave in **illogical patterns**, this can cause problems which **contradict the scientific method**. By comparing predictions of various theories, **contradictions in predictions** can be predicted. Thus thought experiments are theoretically useful but as thought is a product of the mind and thus **independent of reality**, it cannot be confirmed as fact.
- Both of **Einstein's theories** on Special and General Relativity were **developed long before there was evidence to test the predictions they made**, however they were still accepted as they successfully predicted every theoretical test thrown at them. Today, nearly **100 years** after they were created, we now have the technology to test these theories. The **Hafele-Keating experiment** was where two **Caesium atomic clocks** where flown in commercial airliners while two were kept on the ground. When the clocks where reunited, the difference in time recorded by the clocks where exactly as predicted by the relativity theories. This experiment was only able to be conducted because of the **very accurate atomic clocks**, not available in Einstein's time. Another example is measuring **Muon lifetimes**. When produced static in the laboratory the Muons had a lifetime of about **2.2 μs** however when they are produced by cosmic rays in the upper atmosphere travelling at **0.98c** they last up to **five times longer**, thus independently proving time dilation; but this experiment was limited until **we discovered Muons** and could produce them using **high energy particle accelerators,** also not available during Einstein's time. The scientific method dictates **empirical evidence** is required to **support predictions** before a theory can be considered as accepted. Thus Einstein's theories reveal an increasing gap between theory and technology meaning modern day science is **limited by the development of technology.**
- It is essential in **relativistic calculations** to work out **who is the still frame of reference**. Generally, if the question involves a **spaceship** travelling from Earth to some distance **celestial object**, **earth** is **considered the rest frame** thus sees a normal distance with the ships time dilation and hence $v_E = l_0/t_v$. The **ship** is the **moving frame** and thus uses their normal time but a contracted length, hence $v_s = l_v/t_v$. Draw a picture and all will be good.