9.2 Space (30 indicative hours)

Contextual Outline

Scientists have drawn on advances in areas such as aeronautics, material science, robotics, electronics, medicine and energy production to develop viable spacecraft. Perhaps the most dangerous parts of any space mission are the launch, re-entry and landing. A huge force is required to propel the rocket a sufficient distance from the Earth so that it is able to either escape the Earth’s gravitational pull or maintain an orbit. Following a successful mission, re-entry through the Earth’s atmosphere provides further challenges to scientists if astronauts are to return to Earth safely.

Rapid advances in technologies over the past fifty years have allowed the exploration of not only the Moon, but the Solar System and, to an increasing extent, the Universe. Space exploration is becoming more viable. Information from research undertaken in space programs has impacted on society through the development of devices such as personal computers, advanced medical equipment and communication satellites, and has enabled the accurate mapping of natural resources. Space research and exploration increases our understanding of the Earth’s own environment, the Solar System and the Universe.

This module increases students’ understanding of the history, nature and practice of physics and the implications of physics for society and the environment.
CONCEPT MAP

Projectile Motion

Gravitational Field

Space Travel

Rockets

Planets

Earth

Orbits

g Forces

Rocket Structure

Astronauts

Re-entry

Communication

Satellites

Principle of Relativity
# Space Module Plan

Module Length: 7 weeks

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Time</th>
<th>Concept</th>
<th>Resources</th>
<th>Practical</th>
</tr>
</thead>
</table>
| 1. The Earth has a gravitational field that exerts a force on objects both on it and around it | 3 | 1. define weight as the force on an object due to a gravitational field  
2. explain that a change in gravitational potential energy is related to work done.  
3. define the change in gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field  
\[ E_p = G \frac{m_1 m_2}{r} \] | Humphreys’ Set 16 Contexts II: pp. 1-10 | 1. **(Exp 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 9.8 ms\(^2\)  
2. **(Act 2)** gather secondary information to predict the value of acceleration due to gravity on other planets  
3. **(Act 2)** analyse information using the expression  
\[ \vec{F} = m\vec{g} \]  
to determine the weight force for a body on Earth for the same body 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 | 4 | 1. describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components  
2. describe Galileo's analysis of projectile motion | Humphreys’ Set 17 Dyett 25-28 Contexts II: pp. 11-16 | 1. **(Act 3)** solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using  
\[ \vec{v} = \vec{u} + \vec{a}t \]  
\[ v_{x}^2 = u_{x}^2 \]  
\[ v_{y}^2 = u_{y}^2 + 2ay\Delta y \]  
\[ \Delta x = u_{x}t \]  
\[ \Delta y = u_{y}t + \frac{1}{2} ay t^2 \] |
| | 3 | 3. explain the concept of escape velocity in terms of the:  
- gravitational constant  
- mass and radius of the planet  
4. outline Newton’s concept of escape velocity | Humphreys’ Set 21 Contexts II: pp. 28-44 | 2. **(Exp 4)** perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range, time of flight of a projectile, for a range of situations by using simulations, data loggers and computer analysis |
<p>| | 2 | 5. identify why the term ‘g forces’ is used to explain the forces acting on an astronaut during launch | | |</p>
<table>
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<tbody>
<tr>
<td></td>
<td>2</td>
<td>discuss the effect of the Earth’s orbital motion and its rotational motion on the launch of a rocket</td>
<td></td>
<td>3.(Act 5) 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</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>analyse the changing acceleration of a rocket during launch in terms of the: – Law of Conservation of Momentum – forces experienced by astronauts</td>
<td>Contexts II: pp. 17-23, 45-52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>analyse the forces involved in uniform circular motion for a range of objects, including satellites orbiting the Earth</td>
<td>Humphrey’s Sets 21, 72, 76 Dyett 17-20</td>
<td>4.(Act 6) solve problems and analyse information to calculate centripetal force acting on a satellite undergoing uniform circular motion about the Earth using F=mv²/r</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>compare qualitatively low Earth and geo-stationary orbits</td>
<td></td>
<td>5.(Act 6) solve problems and analyse information using: ( \frac{r^3}{T^2} = \frac{GM}{4\pi^2} )</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>account for the orbital decay of satellites in low Earth orbit</td>
<td>Contexts II: pp. 53-62</td>
<td></td>
</tr>
<tr>
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<td>Resources</td>
<td>Practical</td>
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<td>---------------------------------------------------------------------------</td>
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</tbody>
</table>
| 3. The Solar System is held together by gravity                            |      | 1. Define Newton’s Law of Universal Gravitation                         | Contexts II: pp. 73-89 | 1. *(Act 7)* Present information and use available evidence to discuss the factors affecting the strength of the gravitational force.  
2. *(Act 7)* Solve problems and analyse information using \( F = \frac{G m_1 m_2}{d^2} \) |
|                                                                            |      | 2. Describe a gravitational field in the region surrounding a massive object in terms of its effect on other masses in it.       |                      |                                                                           |
|                                                                            |      | 3. Discuss the importance of Newton’s Law of Universal Gravitation in understanding and calculating the motion of satellites.   |                      |                                                                           |
|                                                                            |      | 4. Identify that a slingshot effect can be provided by planets for space probes.                                        |                      |                                                                           |
| 4. Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light |      | 1. outline the features of the aether model for the transmission of light                                               | Contexts II: pp. 90-114 | 1.*Act 8)* gather and process information to interpret the results of the Michelson-Morley experiment |
|                                                                            |      | 2. describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether       |                      |                                                                           |
|                                                                            |      | 3. discuss the role of the Michelson-Morley experiments in science in making determinations about competing theories        |                      |                                                                           |
|                                                                            |      | 4. outline the nature of inertial frames of reference                                                                     |                      |                                                                           |

1. *(Act 7)* Present information and use available evidence to discuss the factors affecting the strength of the gravitational force.  
2. *(Act 7)* Solve problems and analyse information using \( F = \frac{G m_1 m_2}{d^2} \)
<table>
<thead>
<tr>
<th>Focus Area</th>
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<th>Resources</th>
<th>Practical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5. discuss the principle of relativity</td>
<td></td>
<td>3. <strong>(Act 10)</strong> analyse and interpret some of Einstein’s thought experiments involving mirrors and trains and discuss the relationship between thought and reality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. describe the significance of Einstein’s assumption of the constancy of the speed of light</td>
<td>Humphrey’s Set 77</td>
<td>4. <strong>(Act 10)</strong> 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</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. identify that if c is constant then space and time become relative</td>
<td></td>
<td>5. <strong>(Act 11)</strong> solve problems and analyse information using:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. discuss the concept that length standards are defined in terms of time in contrast to the original metre standard</td>
<td></td>
<td>(E=mc^2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9. explain qualitatively and quantitatively the consequence of special relativity in relation to: – the relativity of simultaneity – the equivalence between mass and energy – length contraction – time dilation – mass dilation</td>
<td></td>
<td>(m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12. discuss the implications of mass increase, time dilation and length contraction for space travel</td>
<td></td>
<td>(L = L_0 \sqrt{1 - \frac{v^2}{c^2}}) and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}})</td>
</tr>
</tbody>
</table>
**HSC Physics C1: Space Experiment 1: Acceleration due to Gravity**

Aim: To 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 9.8 ms\(^{-2}\).

Outcomes Assessed
- carrying out the planned procedure, recognising where and when modifications are needed and analysing the effect of these adjustments (12.1a)
- identifying and using safe work practices during investigations (12.1d)
- using appropriate data collection techniques, employing appropriate technologies, including data loggers and sensors (12.2a)
- measuring, observing and recording results in accessible and recognisable forms, carrying out repeat trials as appropriate (12.2b)

Materials
- String
- mass & mass carrier
- stopwatch
- metre ruler
- Computer
- data loggers
- motion sensor

Method 1: Using Simple Harmonic Motion
1. Measure the length of a pendulum that is approximately slightly less than one metre.
2. Time how long it takes to complete 20 full swings.
3. Calculate the period of the pendulum

4. Using the equation \( T = 2\pi \sqrt{\frac{l}{g}} \), calculate the value of acceleration due to gravity where \( T \) is the period of the swing and \( l \) is the length of the string.
5. Repeat the method for several different lengths.
6. Make a graph of \( T^2 \) against \( l \). Calculate the value of gravity from the gradient.

Method 2: Using computer-triggered falling objects
Your teacher will demonstrate the use of the data loggers and computer to calculate the value of gravity for a falling object.

Discussion
1. Do the two methods agree in their results? If not, why?
2. What experimental errors are involved in both methods? Hence, which one is more accurate?
3. How and why would the value of gravity changed if the measurement was made
   (a) on top of the Himalayas?
   (b) deep in an ocean trench?
**HSC Physics C1: Space Activity 2: Gravity on Various Planets**

**Aim:**
1. To gather secondary information to predict the value of acceleration due to gravity on other planets.
2. To analyse information using the expression \( \vec{F} = mg \) to determine the weight force for a body on Earth for the same body on other planets.

**Outcomes Assessed**
- identify and apply appropriate mathematical formulae and concepts (12.4b)
- evaluate the validity of first-hand and secondary information and data in relation to the area of investigation (12.4d)
- assess the reliability of first-hand and secondary information and data by considering information from various sources (12.4e)
- assess the accuracy of scientific information presented in mass media by comparison with similar information presented in scientific journals (12.4f)
- design and produce creative solutions to problems (14.3a)
- propose ideas that demonstrate coherence and logical progression and include correct use of scientific principles and ideas (14.3b)
- apply critical thinking in the consideration of predictions, hypotheses and the results of investigations (14.3c)
- formulate cause and effect relationships (14.3d)

For a mass of 100 kg, research the shaded areas and calculate other areas in the table below:

<table>
<thead>
<tr>
<th>Planet</th>
<th>Value of gravity at surface (ms(^{-2}))</th>
<th>Weight of 100 kg mass at surface</th>
<th>Mass of planet</th>
<th>Mass of largest moon</th>
<th>Orbital distance of largest moon</th>
<th>Obey’s Universal Gravitation (y/n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Saturn</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Neptune</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Uranus</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pluto</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HSC Physics C1: Space Activity 3: Projectile Motion

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

\[ \vec{v} = \vec{u} + \vec{a}t \]

\[ v_x^2 = u_x^2 + 2v_y a_y \Delta y \]

\[ \Delta x = u_x t \]

\[ \Delta y = u_y t + \frac{1}{2} a_y t^2 \]

Outcomes Assessed

- identify trends, patterns and relationships as well as contradictions in data and information (14.1a)
- identify and explain how data supports or refutes an hypothesis, a prediction or a proposed solution to a problem (14.1c)
- use models, including mathematical ones, to explain phenomena and/or make predictions (14.1f)
- design and produce creative solutions to problems (14.3a)
- propose ideas that demonstrate coherence and logical progression and include correct use of scientific principles and ideas (14.3b)
- apply critical thinking in the consideration of predictions, hypotheses and the results of investigations (14.3c)
- formulate cause and effect relationships (14.3d)

1. Do Humphrey’s Set 17.
2. Do Dyett problems 25 –28
3. Robin Hood was trying to send maid Marian an arrow mail while she was in the castle. If Robin stood 30 m away from the base of the castle wall and was trying to shoot the arrow into a window 6 m above the moat, how fast should Robin shoot the arrow at 45° if his chest height is 1.2 metres?
4. A basketball question for the enthusiasts. Joanne (who is 2 metres tall) trains for basketball here at school, where the rings are lower than at the stadium. If Joanne stands 3 metres horizontally from the rings at school and throws the ball at 3 m/s at 30° to the horizontal, she swishes the ring (that is, it goes in without touching it). The same shot at the stadium is consistently 0.5m below the ring.
   (a) How high are the rings at school and at the stadium?
   (b) At what angle should Joanne shoot the ball to get it in at the stadium?
5. The starship Enterprise, commanded by Captain Kirk, had landed on an asteroid that was one-fifth the mass of the earth. Kirk was passing time throwing stones off the bridge into a crater below as shown the diagram:

   ![Diagram](image)

(i) Which of the following statements is true about the stone’s motion?
(a) the stone will move horizontally at a slower rate compared to the earth.
(b) the stone will fall faster than it would on earth.
(c) the time of flight would be longer than that measured on earth.
(d) the stone will move horizontally at a faster rate compared to the earth.
(e) Kirk threw a stone at 25 m/s at 45° to the horizontal. What was its time of flight?
**HSC Physics C1: Space Experiment 4: Measuring Projectile Motion**

**Aim:** To perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range, time of flight of a projectile, for a range of situations by using simulations, data loggers and computer analysis.

**Outcomes Assessed**
- carrying out the planned procedure, recognising where and when modifications are needed and analysing the effect of these adjustments (12.1a)
- identifying and using safe work practices during investigations (12.1d)
- using appropriate data collection techniques, employing appropriate technologies, including data loggers and sensors (12.2a)
- measuring, observing and recording results in accessible and recognisable forms, carrying out repeat trials as appropriate (12.2b)

**Materials**
- Digital camera
- Computer
- Projectile board
- Ball bearing
- (each student to provide a floppy disk)

**Method**
A motion picture of a ball bearing projected using various trajectories is taken whilst the ball is moving against the projectile board background:
- (a) ground to ground motion
- (b) height to ground motion (from moving start)
- (c) ground to height motion

Each movie is taken as a Quicktime movie with a frame rate of 15 frames/sec.

Your teacher will demonstrate how to analyse the images on the computer using Windows Media Player.

**Analysis**
1. For each motion, create a table of instantaneous speed in both the horizontal and vertical directions as follows:

<table>
<thead>
<tr>
<th>Interval (1/15 sec)</th>
<th>0-1</th>
<th>1-2</th>
<th>2-3</th>
<th>3-4</th>
<th>4-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Draw a graph of velocity versus time for each motion. Graph both directions on the same graph.

**Discussion**
1. Is the horizontal speed constant? Explain your answer.
2. Calculate the acceleration on the ball when the velocity changes.
**HSC Physics C1: Space Activity 5: Historical Contributions to Space Exploration**

**Aim:** To 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.

**Outcomes Assessed**
- accessing information from a range of resources, including popular scientific journals, digital technologies and the Internet (12.3a)
- extracting information from numerical data in graphs and tables as well as written and spoken material in all its forms (12.3c)
- summarising and collating information from a range of resources (12.3d)
- identify and apply appropriate mathematical formulae and concepts (12.4b)
- select and use appropriate methods to acknowledge sources of information (13.1c)

Write a 300 word report on EACH of the above scientists and a 700 word report on ONE scientist in particular.
A bibliography must be included and in-text referencing used.

**HSC Physics C1: Space Activity 6: Circular Motion and Slingshots**

**Aim:** 1. To solve problems and analyse information to calculate centripetal force acting on a satellite undergoing uniform circular motion about the Earth using $F=mv^2/r$
2. To solve problems and analyse information using $\frac{T^2}{\pi^2} = \frac{GM}{4}$

**Outcomes Assessed**
- identify trends, patterns and relationships as well as contradictions in data and information (14.1a)
- identify and explain how data supports or refutes an hypothesis, a prediction or a proposed solution to a problem (14.1c)
- use models, including mathematical ones, to explain phenomena and/or make predictions (14.1f)
- design and produce creative solutions to problems (14.3a)
- propose ideas that demonstrate coherence and logical progression and include correct use of scientific principles and ideas (14.3b)
- apply critical thinking in the consideration of predictions, hypotheses and the results of investigations (14.3c)
- formulate cause and effect relationships (14.3d)

1. Do Humphrey’s Sets 21, 72 and 76.
2. Do Dyett problems 17 – 20

Read
**Derivation of the law of universal gravitation using Kepler’s third Law**

Consider a planet in a circular orbit about the Sun:

Centripetal acceleration \( a_c = \frac{v^2}{R} \), so \( a_c = \frac{4\pi^2 R}{T^2} \), since \( v = \frac{2\pi R}{T} \)

Now from Kepler’s Third Law:

\[
\frac{R^3}{T^2} = K_s \quad \therefore T^2 = \frac{R^3}{K_s} \quad \therefore a_c = \frac{4\pi^2 K_s}{R^2}
\]

From Newton’s Second Law:

\[
F_{sp} = m_p a_c = \frac{4\pi^2 K_s m_p}{R^2}
\]

Now \( K_s \) depends upon the sun, so let \( 4\pi^2 K = Gm_s \) where \( G \) is a universal constant, thus

\[
F_{sp} = G \frac{m_p m}{R^2}
\] towards the Sun

**Newton’s verification that \( F \propto \frac{1}{R^2} \): the link between celestial and terrestrial mechanics**

Newton used the fact that the Earth has a moon to test whether a celestial object (the moon) obeys the same laws as a terrestrial object (such as a falling stone) by testing whether \( F \propto \frac{1}{R^2} \) is true for both.

**Prediction of the centripetal acceleration of the moon in its orbit using Newton’s Law of universal gravitation**

Gravitational force on a stone near the surface of the Earth

\[
F_{ev} = m_e a_e = G \frac{m_e m}{R^2}
\]

Gravitational force on the moon at its orbital distance from the Earth

\[
F_{em} = m_m a_e = G \frac{m_m m}{R^2}
\]

\[
\therefore \frac{a_m}{a_e} = \left( \frac{R_e}{R_m} \right)^2 \frac{m_m}{m_e}
\]

Now if our stone has the same mass as the moon

\[
a_m = a_e \left( \frac{R_e}{R_m} \right)^2 \approx 9.81 \times \left( \frac{1}{60} \right)^2 \approx 0.00272 \text{ m/s}^2
\]

Thus acceleration of moon in its orbit

**Calculation of the moon’s centripetal acceleration using the formula from terrestrial mechanics** \( a_c = \frac{v^2}{R} \) to check the predicted value obtained:

\[
a_e = \frac{v^2}{R_m} = \frac{4\pi^2 R_m}{T_m^2} = \frac{4\pi^2 \left( 3.8 \times 10^8 \right)}{\left( 2.36 \times 10^6 \right)^2} = 0.00272 \text{ m/s}^2
\]
The agreement is exceptionally good and was the first quantitative correlation between an earthbound phenomenon and a heavenly phenomenon. This Newton did when he was about 24 years old, at a time when he had retired from Cambridge due to the plague. He wrote:

“… and the same year I began to think of gravity, extending to ye orb of the moon, and… from Kepler’s rule (Kepler’s third Law)... I deduced that the forces which keep the planets in their orbits must be reciprocally as the squares of their distances from the centres about which they revolve: and thereby compared the force requisite to keep the moon in her orb with the force of gravity at the surface of the Earth and found them answer pretty nearly. All of this was in the two plague years of 1665 and 1666, for in those days I was in the prime of my age…”

Ver **eification that force is proportional to mass and the determination of G: the Cavendish experiment**

Verification that the gravitational force acting between two bodies is directly proportional to the product of their masses was not forthcoming until a century and a half after Newton had published his law. In 1798 Henry Cavendish developed an instrument to measure the feeble force between two objects in the laboratory:

\[ F = \frac{GMm}{d^2} = k\theta \therefore G = \frac{k\theta d^2}{Mm} \]

where \( k \) = torsional constant of the quartz fibre

Cavendish’s value \( G = 6.754 \times 10^{-11} \)

Today’s value \( G = 6.673 \times 10^{-11} \)

(Heyl & Chranowski, 1942) thus Cavendish’s value differs by only 1.5%!

Corollary: Weighing the Earth

For a satellite of the earth, such as the moon:

\[ 4\pi^2 k_c = Gm_e \] where \( k_c = \frac{R_m^3}{T_m^2} \)

\( R_m = 3.80 \times 10^8 \) m

\( T_m = 27.32 \) days = \( 2.36 \times 10^6 \) s

\( \therefore m_e = \frac{4\pi^2 k_c}{G} = 5.8 \times 10^{24} \) kg

Today’s value \( m_e = 5.98 \times 10^{24} \) kg
HSC Physics C1: Space Activity 7: Universal Gravitation Equation

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

2. To solve problems and analyse information using

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

Outcomes Assessed
- selecting and using appropriate methods to acknowledge sources of information (13.1c)
- apply critical thinking in the consideration of predictions, hypotheses and the results of investigations (14.3c)

The Relation between \( G \) and \( g \) (at the earth’s surface)

Gravitational force: \( F = mg = G \frac{m_1 m_2}{R_e^2} \) \( \therefore g = \frac{G m_e}{R_e^2} \)

Variations in \( g \)

The value of \( g \) varies over the earth due to a number of factors:

1. Distance from the earth
   - (a) \( g = \frac{G m_e}{R^2} \) if \( R \geq R_e \)
   - (b) \( g = G m_e R \) if \( R < R_e \)

2. The rotation of the earth on its axis
3. The non-spherical shape of the earth. The earth is about 15 metres higher at the North pole than it is at the South pole.
4. The non-uniform density of the earth.

Satellites and Projectiles

1. Energy of a Satellite
   \( E_T = \text{constant} = PE + KE \)
   \( \therefore E_T = -\frac{G m_1 m_e}{R} + \frac{1}{2} m_s v^2 \)
   if \( E_T < 0 \) then the satellite is bound to the earth and orbits it.
   If \( E_T \geq 0 \) then the satellite is free from the earth and escapes.

2. Orbital Velocity

A satellite orbits the earth when \( E_T < 0 \) and centripetal force \( F_c = \) gravitational force \( F_g \)

\[ \frac{m_s v_o^2}{R_o} = G \frac{m_1 m_e}{R_o^2} \therefore v_o = \sqrt{\frac{G m_e}{R_o}} \]
3. **Minimum Escape Velocity**
A satellite will just escape the earth’s gravitational influence when \( E_I = 0 \). Let the satellite’s launch velocity when this occurs be \( v_{es} \), ie

\[
-\frac{G m_e m_s}{R_e} + \frac{1}{2} m_s v_{es}^2 = 0 \quad \therefore \quad v_{es} = \sqrt{\frac{2Gm_e}{R_e}}
\]

Given the following information:

- Radius of Earth \( R_e = 6.37 \times 10^9 \) m
- Mass of the Earth \( m_e = 5.98 \times 10^{24} \) kg
- Universal Gravitation \( G = 6.673 \times 10^{-11} \) Nm\(^2\)kg\(^{-2}\)

Solve the problems below:

4. (a) What is the orbital speed of a satellite of mass 45 kg in low earth orbit at an altitude of 200 km.
   (b) What is its total energy?
   (c) What is its minimum escape velocity?

5. Newton conjectured that it is possible to throw a ball fast enough horizontally such that it would never fall to ground but orbit the earth. Ignoring air resistance, what is this speed for a 2 kg ball?

6. A few centuries later, Tsiolkovsky hypothesised his "orbital tower" that would also launch satellites. What orbital speed is needed for a 200 kg satellite launched from a 150 km high tower?

7. Into this century and several people, most notably Isaac Asimov, have suggested building "space elevators" where an orbiting satellite drops a cable to earth (ground level). Materials are then transported up the cable directly into orbit.

   (a) Why are only geostationary satellites suitable for space elevators? At what height do geostationary (also called geosynchronous) satellites orbit?
   (b) Aside from the need for a very long cable, what other properties would such a **space tether** require?
   (c) The tether can be set up as a conveyor belt so that for each kilogram going up, a kilogram comes down. This way materials get a "free ride" into space with no energy input into the system. Is this possible? Why / why not?
   (d) A few years ago, NASA tried generating electrical energy using a free-ended space tether rolled out from a space shuttle. The experiment met with some success but technologically it was a failure. Research why this was so.

8. All satellites carry a small amount of fuel for minor course corrections in orbit.

   (a) Why do low earth orbit satellites require more fuel than geosynchronous satellites?
   (b) There are two positions called Lagrange points L1 and L2 where the need for fuel is particularly minimal. Research why this is so and find how far these Lagrange points are from earth.

HSC Physics C1: Space Activity 8: The Michelson-Morley Experiment

Aim: To gather and process information to interpret the results of the Michelson-Morley experiment.

Outcomes Assessed
- carrying out the planned procedure, recognising where and when modifications are needed and analysing the effect of these adjustments (12.1a)
- identifying and using safe work practices during investigations (12.1d)

Background

Michelson-Morley Apparatus
In 1887 Albert Michelson and Edward Morley measured the speed of the earth with respect to the ether, a substance postulated to be necessary for transmitting light. Their method involved splitting a beam of light so that half went straight ahead and half went sideways. If the apparatus (attached to the earth) moves relative to the ether, then light going in one direction will travel at a different speed than light going in the other, just as boats going downstream travel faster than boats going across. The difference in speed causes the beams to interfere, creating a distinctive pattern of light and dark bands at the telescope. No such pattern was found, however, which led not only to the demise of the ether theory, but to the development of the Special Theory of Relativity by Albert Einstein 18 years later.

Microsoft Illustration
(From Encarta 95 CD-ROM)
**HSC Physics C1: Space Experiment 9: Frames of Reference**

**Aim:** To perform an investigation to help distinguish between non-inertial and inertial frames of reference

**Outcomes Assessed**
- carrying out the planned procedure, recognising where and when modifications are needed and analysing the effect of these adjustments (12.1a)
- identifying and using safe work practices during investigations (12.1d)

**Materials**
- Digital camera with movie capability or video camera
- Inanimate object for foreground
- Very long poster for background.
- Three dynamics trolleys

**Method**
1. Arrange each of the materials on a dynamics trolley as shown below:

   ![Diagram of dynamics trolley with background, foreground object, and camera]

2. Record several trials where either the camera, foreground or background moves relative to the other layers (Hint: do NOT run out of background!)
3. Replay these trials and assess which object(s) were moving and which were stationary for each trial.
4. Repeat the experiments using an accelerating (non-inertial) frame of reference

**Discussion**
1. Is it possible to predict which object(s) is/are stationary and which is/are moving from the replay of the inertial frames of reference?
2. Is it possible to predict which object(s) is/are stationary and which is/are moving from the replay of the non-inertial frames of reference?
3. So what does the phrase “it’s all relative” mean?
HSC Physics C1: Space Activity 10: Relativity Thought Experiments

Aim:
To analyse and interpret some of Einstein’s thought experiments involving mirrors and trains and discuss the relationship between thought and reality
To 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

Outcomes Assessed
- propose ideas that demonstrate coherence and logical progression and include correct use of scientific principles and ideas (14.3b)
- apply critical thinking in the consideration of predictions, hypotheses and the results of investigations (14.3c)
- formulate cause and effect relationships (14.3d)

Method
Read through the following stimulus material:
3. A Theory of Some Gravity New Scientist Inside Science No. 31
7. An End to Uncertainty New Scientist 6 March 1999 pp. 25-28

Discussion
2. “God does not play dice” Einstein is quoted to have said. What did he mean by this?
3. General relativity was published before any solid experiments were done.
   (a) What is one observation in astronomy that it explained?
   (b) In 1919, a special expedition was organised to check some predictions of general relativity. What was the purpose of this expedition?
   (c) Does general relativity hold up well today or does it still need modification?
4. Why is quantum mechanics “not sensible”?
5. Why is a measurement uncertain until it is done?
6. What properties does (quantum) entanglement give rise to?
7. What type of technologies can be built from entanglement?
HSC Physics C1: Space Activity 11: Relativity and Length/Time/Mass Dilation

Aim: 1. To solve problems and analyse information using: \( E=mc^2 \)

\[
m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad L_\ast = L_0\sqrt{1 - \frac{v^2}{c^2}} \quad \text{and} \quad t_\ast = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}
\]

2. To gather, process, analyse information and use available evidence to discuss the comparative energy costs associated with space travel at speeds approaching the speed of light.

Outcomes Assessed
- propose ideas that demonstrate coherence and logical progression and include correct use of scientific principles and ideas (14.3b)
- apply critical thinking in the consideration of predictions, hypotheses and the results of investigations (14.3c)
- formulate cause and effect relationships (14.3d)

1. Do Humphrey’s Set 77.

2. Read the following articles:

“Negative Energy, Wormholes and Warp Drive”  
Scientific American Jan 2000  pp.30-37
The Legend of G  
Black Holes and the Centrifugal Force Paradox  
Scientific American Mar 1993  pp. 26 – 31
The Fifth Element  
New Scientist 3 April 1999  pp. 29-32

Try this one next you’re pulled over for running a red light. It is possible to move fast enough such that a red light (wavelength 650 nm) can appear green (wavelength 560 nm).

(a) How fast do you need to move to make a red light appear green?
(b) What would the police officer book you with instead?

From your reading of the above articles and your general knowledge,

(a) Is interstellar space travel feasible using
   (i) the warp drive mechanism as outlined by "Star Trek"?
   (ii) wormhole technology (of a decent size)?
   (iii) Other space/time folding methods?

Hyperspace technologies generally rely on using faster-than-light particles called tachyons.

(a) What happens to a tachyon when slows to light-speed?
(b) What happens to slower-than-light particles as they approach light-speed i.e. what happens to the kinetic energy?
(c) Thus, how can starships make a "hyperjump" from below light-speed to above light-speed?

What other technologies might be usable to cover interstellar distances in human lifetimes?