TOPIC 2.2: LOW EARTH ORBIT

S4P-2-6 Compare the Law of Universal Gravitation with the weight (mg) of an object at various distances from the surface of the Earth and describe the gravitational field as $g = \frac{Gm_{\text{Earth}}}{r^2}$.

S4P-2-7 Outline Newton's thought experiment regarding how an artificial satellite can be made to orbit the earth.

S4P-2-8 Use the Law of Universal Gravitation and circular motion to calculate the characteristics of the motion of a satellite.

Include: orbital period, speed, altitude above a planetary surface, mass of the central body, and the location of geosynchronous satellites

S4P-2-9 Define microgravity as an environment in which the apparent weight of a system is smaller than its actual weight.

S4P-2-10 Describe conditions under which microgravity can be produced.

Examples: jumping off a diving board, roller-coaster, free fall, parabolic flight, orbiting spacecraft

S4P-2-11 Outline the factors involved in the re-entry of an object into Earth's atmosphere.

Include: friction and g-forces

S4P-2-12 Describe qualitatively some of the technological challenges to exploring deep space.

Examples: communication, flyby and the "slingshot" effect, Hohmann Transfer orbits (least-energy orbits)

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SPECIFIC LEARNING OUTCOME

S4P-2-6: Compare the Law of Universal Gravitation with the weight (mg) of an object at various distances from the surface of the Earth and describe the gravitational field as

$$g = \frac{Gm_{\text{Earth}}}{r^2}.$$

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Newton's Law of Universal Gravitation was covered in the previous topic. The strength of Earth's gravitational field was represented in Senior 3 Physics as the force per unit mass.

Notes to the Teacher

We know that the force of gravity on an object near the surface of the Earth is $F_g = mg$.

The concept of the gravitational field constants is often misunderstood. In general, the strength of a gravitational field is the force per unit mass exerted by one mass on another nearby "test" mass (1 kg). Near the surface of the Earth, the force exerted on 1 kg of mass is 9.8 N. As long as we stay near the surface of the Earth, the field is constant. Consequently, the field near the surface is called a **local constant**. As we move away from the surface of the Earth, the force of gravity decreases and the field constant changes. We can compare the Law of Universal Gravitation with the weight (mg) of an object at various distances from the surface of the Earth to determine the value of g at any point in space.

$$F_g = F_G$$

$$mg = \frac{GMm_{\text{earth}}}{r^2}$$

$$\text{and } g = \frac{Gm_{\text{earth}}}{r^2}$$

The above relation is valid not only for objects on Earth's surface, but also for objects above the Earth's surface. For objects above Earth's surface, r represents the distance from an object to the Earth's centre and, except for objects close to Earth's surface, g is not 9.8 N/kg. The same equation can be used for other planets and stars by substituting the appropriate mass M.

Remember: g is local, G is universal.

Student Activity

Is there gravity in space? A common misconception is that there is no gravity in space. Students can calculate the gravitational constant (g) at the orbit of the shuttle (500 km above the Earth) and at the orbit of geosynchronous satellites (1000 km above the Earth).

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-2d: Estimate and measure accurately using SI units.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe and appreciate how the natural and constructed worlds are made up of systems and how interactions take place within and among these systems (GLO E2)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students solve problems to calculate the value of the local g for different locations (top of a mountain, equator versus the poles, on the moon, or on another planet).

Students use compare and contrast frames (SYSTH) to differentiate between the universal gravitational constant G and the local constant g.

General Learning Outcome Connection

Students will…

Identify and appreciate contributions made by women and men from many societies and cultural backgrounds toward increasing our understanding of the world and in bringing about technological innovations (GLO A4)

Specific Learning Outcome

S4P-2-7: Outline Newton's thought experiment regarding how an artificial satellite can be made to orbit the Earth.

Suggestions for Instruction

Notes to the Teacher

This topic is intended to capture the student's imagination with a current topic in physics. Earth's artificial satellites, space probes, and planetary exploration are widely reported in the media. Challenge students to answer the question, What is a satellite and how do we get one in space?

Newton thought of a satellite as a projectile that could orbit the Earth (even though he couldn't launch one).

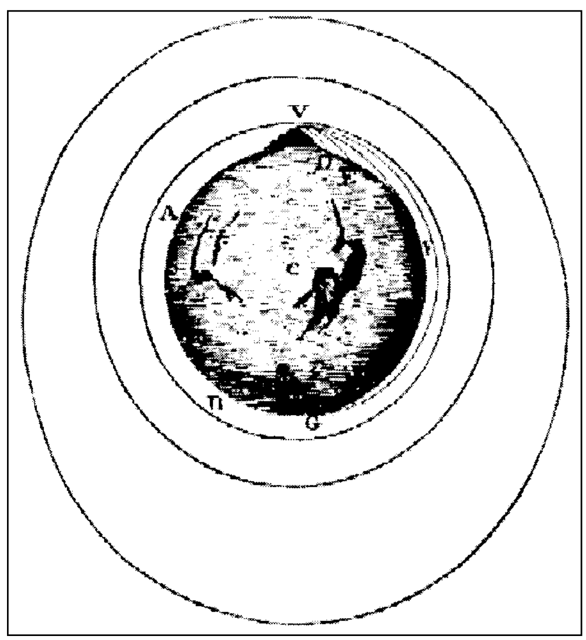
Prior Knowledge Activity

Students complete a KWL or rotational graffiti (SYSTH) chart for projectiles and satellites. Some questions might be:

- What happens as we increase the speed of a projectile that is launched horizontally?
- Can a projectile orbit the Earth?
- Wouldn't a projectile fall toward the Earth?
- How fast is a satellite moving?
- Will satellites eventually fall to the Earth?
- How high are satellites in their orbit?
- Is their gravity in space?
- Does friction slow down a satellite?

Newton's Thought Experiment (horizontal projectile)

Newton imagined a tall mountain above the surface of the Earth and asked himself, What if a powerful cannon, mounted on top of a mountain, fired cannonballs parallel to the ground? Newton knew that gravity would act on the fired cannonball, pulling it to the ground, but he considered how faster and faster cannonballs would go further and further. Eventually, he surmised that if a cannonball were fired with sufficient velocity, it would fall around the entire Earth.



SKILLS AND ATTITUDES OUTCOME

S4P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

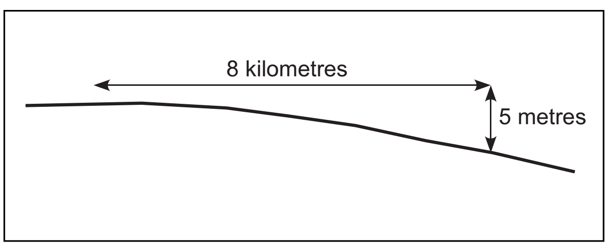
Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

SUGGESTIONS FOR INSTRUCTION

Class Discussion

Earth satellites orbit high above the atmosphere, such that their motion is mostly unrestricted by forces of air resistance. Satellites are projectiles in the sense that only the force of gravity is acting on the satellite. Without a force of gravity, a satellite would continue in a straight-line path tangent to the Earth (Law of Inertia). Indeed, a satellite does fall towards the Earth; it just never falls into the Earth. Remember that the Earth is not flat, it is round and curves about 5 metres downward every 8 kilometres. Therefore, in order for a satellite to orbit the Earth, it must travel a horizontal distance of 8000 metres before falling a vertical distance of 5 metres.

How far will a horizontally launched projectile fall in its first second of motion (from Topic 1.4)?



SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students solve problems to calculate the range of a projectile at various speeds.

SUGGESTED LEARNING RESOURCES

Many Java applets can be found on the Internet, which permit the user to control the speed of a projectile and launch it into orbit. Google “projectile java” or “satellite orbits java.”

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Identify and appreciate contributions made by women and men from many societies and cultural backgrounds toward increasing our understanding of the world and in bringing about technological innovations (GLO A4)

SPECIFIC LEARNING OUTCOME

S4P-2-7: Outline Newton's thought experiment regarding how an artificial satellite can be made to orbit the Earth.

SUGGESTIONS FOR INSTRUCTION

$$\Delta d_y = v_y \Delta t + \frac{1}{2} a \Delta t^2$$

Since $v_y = 0$

$$\Delta d = \frac{1}{2}(10)(1^2)$$

$$\Delta d = 5 \text{ metres}$$

Therefore, when a projectile is launched with a horizontal speed of 8000 m/s, the projectile will fall toward the Earth with a trajectory that matches the curvature of the Earth. Consequently, the projectile "falls" around the Earth, always accelerating towards the Earth under the influence of gravity, yet never colliding into the Earth since the Earth curves at the same rate. Such a projectile becomes an orbiting satellite.

Demonstration

See demonstration in Topic 1.6.

Skills and Attitudes Outcome

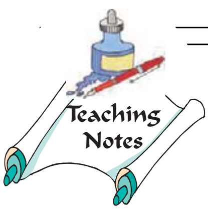
S4P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

General Learning Outcome Connection

Students will…

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

Suggestions for Instruction



Suggestions for Assessment

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SPECIFIC LEARNING OUTCOME

S4P-2-8: Use the Law of Universal Gravitation and circular motion to calculate the characteristics of the motion of a satellite.

Include: orbital period, speed, altitude above a planetary surface, mass of the central body, and the location of geosynchronous satellites

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Circular motion and the Law of Universal Gravitation have been covered in Topic 1. These laws are now applied to the case of satellite motion.

Notes to the Teacher

Most satellites are either in a circular or near-circular orbit. The force of gravity acts as a centripetal force, holding each satellite in its own unique orbit. Therefore

$$F_{gravity} = F_{centripetal}$$

$$\frac{Gm_E m_S}{R^2} = \frac{m_S v_S}{R^2}$$

where m_E is the mass of the Earth, m_S is the mass of the satellite, and R is the separation between the Earth and the satellite (i.e., the radius of the Earth plus the height of the satellite above the surface of the Earth). From this comparison it is easy to calculate the speed, mass, and altitude ($R = R_{\text{earth}} + h$). The period of the satellite can be found from other characteristics of circular motion such as

$$a = \frac{4\pi^2 R}{T^2} \text{ and } v = \frac{2\pi R}{T}.$$

A satellite in geosynchronous orbit stays the same point above the surface of the Earth as the Earth rotates. Therefore, the period of an object in geosynchronous orbit is 24 hours. From this information, it is easy to calculate the other unknowns.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-1e: Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature.

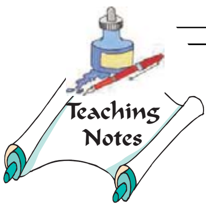
S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Students use process notes (SYSTH) to outline the steps to solve for different characteristics of satellite motion.

Pencil-and-Paper Tasks

Students solve problems to find various characteristics of satellite motion.

SUGGESTED LEARNING RESOURCES

Reference: p. 236, *Physics 12*, McGraw-Hill Ryerson, 2003

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Distinguish critically between science and technology in terms of their respective contexts, goals, methods, products, and values (GLO A3)

SPECIFIC LEARNING OUTCOMES

S4P-2-9: Define microgravity as an environment in which the apparent weight of a system is smaller than its actual weight.

S4P-2-10: Describe conditions under which microgravity can be produced.

Examples: jumping off a diving board, roller-coaster, free fall, parabolic flight, orbiting spacecraft

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Apparent weight in a moving elevator was covered in Senior 3 Physics.

Notes to the Teacher

Gravity is a force that governs motion throughout the universe. Gravity holds us to the Earth, keeps the Moon and satellites in orbit around the Earth, and the Earth in orbit around the Sun. Students often believe that there is no gravity above the Earth's atmosphere (i.e., "in space") since astronauts "float" aboard the space shuttle. A typical orbital altitude of a shuttle is about 500 km above the surface of the Earth and the gravitational field constant at this altitude can easily be calculated as described in learning outcome S4P-2-6.

$$mg = \frac{GMm}{R^2}$$

$$g = \frac{GM}{R^2}$$

$$g = \frac{6.67\times10^{-11}\left(5.98\times10^{24}\right)}{\left(6.38\times10^{6}\right)^2}$$

$$g = 8.7 \text{ N/kg}$$

The gravitational field 500 km above the surface of the Earth is about 89% of its strength at the surface of the Earth!

Microgravity occurs when the apparent weight of an object is small compared to its actual weight. Any object in free fall experiences microgravity conditions. As the object falls toward the Earth, its acceleration is equal to that due to gravity alone, and the apparent weight of the object is near zero.

Class Discussion

Begin by discussing the elevator problems from Senior 3 Physics. Imagine riding an elevator to the top floor of a building. The force that the floor of the elevator exerts on you is your apparent weight. The total force acting on you is the force of gravity plus the force of the elevator. In this case, your apparent weight is due to the acceleration of the elevator ($F_e = ma_e$) minus the force of gravity ($F_g = mg$). That is,

$$\text{Apparent Weight } (W) = F_e - F_g$$

$$W = ma_e - ma_g$$

$$W = m(a_e - a_g)$$

Now, imagine that the elevator cables have been cut and the elevator is falling freely. Since the elevator will fall with an acceleration of g (i.e., $a_e = a_g$), your apparent weight is zero and you are "weightless" even though you are still in a gravitational field.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-4c: Demonstrate confidence in their ability to carry out investigations in science and to address STSE issues.

S4P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe and appreciate how the natural and constructed worlds are made up of systems and how interactions take place within and among these systems (GLO E2)

SUGGESTIONS FOR INSTRUCTION

Spacecraft orbiting the Earth follow a trajectory such that the craft is always falling toward the Earth in a path parallel to the curvature of the Earth. Consequently, a microgravity environment is established. Remember that the spacecraft is not falling toward the Earth, it is falling around the Earth. However, since all objects in the space shuttle are falling at the same rate, objects inside the shuttle appear to float in a state we call microgravity.

The apparent weightlessness of free fall has not always been well known. Albert Einstein commented

> *"I was sitting in a chair in the patent office at Bern when all of a sudden a thought occurred to me: if a person falls freely, he will not feel his own weight. I was startled."*

Microgravity can be created in several different ways. First of all, we could venture into deep outer space such that the Earth's gravitational field is effectively zero. However, we would need to travel millions of kilometres away from the Earth. Another way to achieve microgravity, as we have already noted, is with free fall. We can experience microgravity for a short period of time in activities such as diving off a board or in sensations experienced in free-fall rides in amusement parks. In this situation, microgravity is only experienced for a short period of time. Drop facilities are used to create a microgravity environment for a longer period of time. The NASA Lewis Center has a

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students calculate the apparent weight for different accelerations.

Research/Report

Students research and report on microgravity experiments in space and on Earth.

SUGGESTED LEARNING RESOURCES

NASA's Teachers Guide for microgravity is an invaluable resource for this topic. The guide includes many student activities, is accessibly written, and is quite comprehensive. It can be found in pdf form and downloaded at:

<http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Microgravity/>

Many more space science-related teacher-developed materials can be freely accessed at:

<http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EG>

General Learning Outcome Connection

Students will…

Distinguish critically between science and technology in terms of their respective contexts, goals, methods, products, and values (GLO A3)

Specific Learning Outcomes

S4P-2-9: Define microgravity as an environment in which the apparent weight of a system is smaller than its actual weight.

S4P-2-10: Describe conditions under which microgravity can be produced.

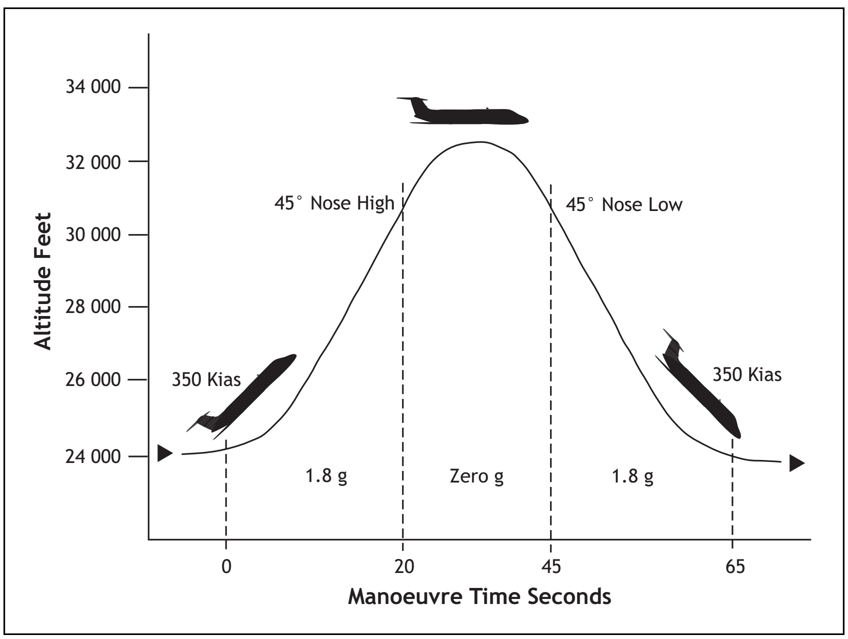
Examples: jumping off a diving board, roller-coaster, free fall, parabolic flight, orbiting spacecraft

Suggestions for Instruction

132-metre drop facility, which is similar to a very long mine shaft. Microgravity can be achieved for a period of about five seconds. The longest drop time currently available is in a 490-metre mine shaft in Japan.

Airplanes can achieve a microgravity environment for about 20 seconds if the plane flies in a parabolic path. During the "nose high" and "nose low" phases, accelerations of up to 2 *g* are experienced. However, during the "pull up" phase (zero *g* in the diagram), the acceleration will closely match the acceleration due to gravity, and weightlessness will be experienced. These flights are used as astronaut training exercises, which the astronauts lovingly refer to as the "vomit comet." The effect is similar to traversing a hill on a roller- coaster ride.

In the movie *Apollo 13* (1995), the producers were actually allowed to use NASA's "anti-gravity" aircraft KC-135 to film the sequence in which the actors seem to be floating around the cabin. The aircraft first reaches an altitude of 30,000 feet (use 10,000 m as an approximation) with a speed of near Mach 1 (300 m/s is an approximation). The aircraft then descends, following roughly a parabolic curve, ascends again, and is able to complete many cycles. The people inside are actually in free fall for 23 seconds for each descending part of the cycle. A typical flight may last several hours, involving as many as 40 short periods of free fall, allowing crew members to do their experiments.



SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-4c: Demonstrate confidence in their ability to carry out investigations in science and to address STSE issues.

S4P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe and appreciate how the natural and constructed worlds are made up of systems and how interactions take place within and among these systems (GLO E2)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time (GLO B2)

SPECIFIC LEARNING OUTCOME

S4P-2-11: Outline the factors involved in the re-entry of an object into Earth's atmosphere.

Include: friction and g-forces

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Friction has previously been discussed in Senior 3 Physics and in Topic 1.

Notes to the Teacher

The density of Earth's atmosphere depends on the altitude above the surface of the Earth. In low Earth orbit the sparse friction of the atmosphere will slow a satellite over time and cause the satellite to fall to a lower orbit and eventually re-enter Earth's atmosphere. As the satellite, or a spacecraft on re-entry, falls toward Earth, the density of the atmosphere increases. The heat that the satellite creates is not only due to the frictional effects but also due to a pressure wave that is created in front of the spacecraft as it moves at high speeds into the atmosphere. As the pressure increases, the temperature must also increase. Burning up of a satellite on re-entry is minimized by heat-resistive tiles that cover the spacecraft. These tiles must have an extremely low thermal conductivity.

As a consequence of re-entry, several problems arise:

- If the angle of re-entry is too shallow at the point where the effects of atmospheric density are significant (about 120 km), the spacecraft will bounce off the atmosphere and be propelled back into space.
- If the angle is too steep, the spacecraft will descend too quickly and the g forces and heat build-up will be unmanageable.
- In any case, astronauts in the spacecraft must be protected from the extreme heat build-up. A blunt nose and specially designed protective surfaces (heat tiles) are used to protect the occupants.
- The extreme heat generates a layer of ionizing particles, which prevents radio communication for a period of time.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-3a: Analyze, from a variety of perspectives, the risks and benefits to society and the environment when applying scientific knowledge or introducing technology.

S3P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION

SUGGESTED LEARNING RESOURCES

See the site maintained by Dr. David Morrison, *Asteroid and Comet Impact Hazards*:

Synopsis: The Earth orbits the Sun in a sort of cosmic shooting gallery, subject to impacts from comets and asteroids. It is only fairly recently that we have come to appreciate that these impacts by asteroids and comets (often called Near Earth Objects, or NEOs) pose a significant hazard to life and property. Although the annual probability of the Earth's being struck by a large asteroid or comet is extremely small, the consequences of such a collision are so catastrophic that it is prudent to assess the nature of the threat and prepare to deal with it.

<http://impact.arc.nasa.gov/index.html>

SUGGESTIONS FOR ASSESSMENT

Interpretation of Media Reports of Science

Re-entries of shuttle missions are extensively covered in the media. Students can review a newspaper article, or other media report, and evaluate the accuracy of the physics of re-entry.

SUGGESTED LEARNING RESOURCES

Metz, D., and A Stinner, "Deep Impact: The Physics of Earth-Asteroid Collisions," *The Physics Teacher* 40 (2002): 487–492.

Internet

Metz and Stinner (see above) also maintain an interactive website related to the dynamics of asteroidal impacts. Students can alter the parameters of an impact event (e.g., size and composition of the impactor) and model what the results might be (e.g., crater size, ejecta distribution area, etc.).

The Physics of Earth-Asteroid Impacts
<http://io.uwinnipeg.ca/~metz/asteroids.html>

General Learning Outcome Connection

Students will…

Recognize that science and technology interact with and advance one another (GLO A5)

Specific Learning Outcome

S4P-2-12: Describe qualitatively some of the technological challenges to exploring deep space.

Examples: communication, flyby and the "slingshot" effect, Hohmann Transfer (least-energy orbits)

Suggestions for Instruction

Entry Level Knowledge

Relative velocity was addressed in Topic 1.

Notes to the Teacher

Space explorers face several interesting problems as they probe deep space. A few examples are described but teachers and students are encouraged to investigate other technological challenges of space travel they find interesting.

Ask students to brainstorm how they would communicate with a satellite probe.

- How does it take and store a picture?
- How does it send the picture?
- How do we receive the picture on a rotating Earth?

These are all obstacles to consider. Students can investigate NASA's deep space network at: <http://deepspace.jpl.nasa.gov/ds.>

Class Discussion: Gravity Assist

The energy for a space vehicle to escape the gravitational attraction of the Earth comes from the chemical propulsion of the rocket booster. However, chemical rockets have limitations if we want to send spacecraft beyond the Moon. Even to go to Mars, the next logical destination in space, a spacecraft would require so much fuel that large amounts would have to be produced on the planet for the return trip. Consequently, spacecraft intended for the outer reaches of the solar system must use a more natural means to accelerate into space.

The slingshot effect or "gravity assist" involves conservation of momentum and energy along with the relative velocity of the space probe to the Sun. First, consider the simple analogy of bouncing a marble off a bowling ball. If the bowling ball is still and you throw a marble at it 5 km/h, the marble rebounds at 5 km/h (ideally). If the bowling ball is moving toward you at 30 km/h, from the frame of reference of the bowling ball, the marble comes toward it at 30 + 5 = 35 km/h, and it rebounds off at 35 km/h. The momentum of the marble increases while the bowling ball loses a little momentum. However, since the mass of the bowling ball is much greater than the marble, its change in momentum is minute. A gravitational interaction with a planet is just like bouncing off of it. However, the interaction is not a head-on collision but a "glancing" blow.

As a probe approaches a planet, its velocity with respect to the Sun is equal to the vector sum of its velocity with respect to the planet and the velocity of the planet with respect to the Sun. The magnitudes of the approach and departure velocities with respect to the planet are equal, but the direction of the departure velocity is changed by the gravitational attraction of the planet. In effect, the trajectory is bent.

SKILLS AND ATTITUDES OUTCOME

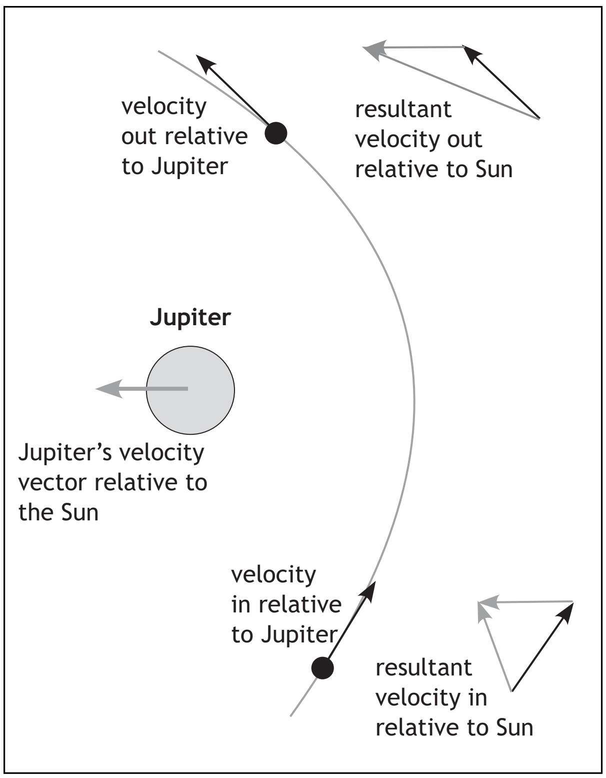
S4P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as the result of new innovations in technology.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time (GLO B2)

SUGGESTIONS FOR INSTRUCTION



As the probe leaves the planet, its velocity with respect to the Sun has changed because the vector sum of its velocity with respect to the planet and the planet's velocity has changed. The vector diagram of the relative velocities helps to clarify the situation. On approach, the planet moves with a constant velocity V and the probe has a velocity v (relative to the planet). Since the direction of the velocity vector is changed, the velocity of the probe relative to the Sun increases.

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students draw vector diagrams of the motion of a space probe as it passes a planet in a gravity assist.

Gallery Walk

Students research various technological challenges and present a multimedia gallery display.

SUGGESTED LEARNING RESOURCES

See orbital energies, p. 237, *Physics 12*, McGraw-Hill Ryerson, 2003

NASA website: <http://deepspace.jpl.nasa.gov/dsn/>

Stinner, A., "Hitchhiking On An Asteroid: A Large Context Problem," *Physics in Canada* (Jan/Feb. 2000): 27–42.

Hohmann Transfer Orbits:

<http://www.astronomynotes.com/gravappl/s9.htm>

<http://liftoff.msfc.nasa.gov/academy/rocket_sci/satellites/hohmann.html>

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that science and technology interact with and advance one another (GLO A5)

SPECIFIC LEARNING OUTCOME

S4P-2-12: Describe qualitatively some of the technological challenges to exploring deep space.

Examples: communication, flyby and the "slingshot" effect, Hohmann Transfer (least-energy orbits)

SUGGESTIONS FOR INSTRUCTION

The first spacecraft to experience a gravity assist was NASA's Pioneer 10. In December 1973, it approached a rendezvous with Jupiter, the largest planet in the solar system, travelling at 9.8 kilometres per second. Following its passage through Jupiter's gravitational field, it sped off into deep space at 22.4 kilometres a second—like when you let go of a spinning merry-go-round and fly off in one direction.

In October 1997, NASA launched the probe Cassini on a six-year journey to explore Saturn. The probe was launched with a speed of 4 km/s. However, Saturn is much higher up the Sun's gravitational potential well than the Earth, and a probe requires at least 10 km/s to escape its binding energy. NASA engineers devised a trajectory such that Cassini would interact with Venus and Jupiter in a slingshot effect to propel Cassini to the outer reaches of the solar system.

Demonstration

Place a tennis ball on top of a basketball and let them fall together from some height (a stepladder works well). The bounce of the basketball will send the tennis ball off at very high speeds, demonstrating the result of transferring energy from a large mass to a small mass.

Class Discussion: Hohmann Transfer Orbits ("least-energy" orbits)

Changing a spacecraft's orbit involves firing an engine to change the magnitude or the direction of the spacecraft's velocity. Remember that if the spacecraft's velocity increases, there is a corresponding increase in the radius of orbit. Firing a spacecraft's engine requires fuel so the path that requires the least amount of burn is critical in space manoeuvres. A Hohmann Transfer is a fuel-efficient way to transfer from one orbit to another that is in the same plane. To change from a lower orbit to a higher orbit, an engine is fired to add velocity to the vehicle. When the desired orbit is achieved, the engine is fired again to slow the spacecraft into a stable orbit. Hohmann found that the most efficient path of transfer is an ellipse that is tangent to both orbits. Hohmann Transfer orbits are used to travel to Mars, and therefore the Earth and Mars must be aligned properly for the transfer. This explains why only certain "windows" of time are permitted for deep space exploration.

SKILLS AND ATTITUDES OUTCOME

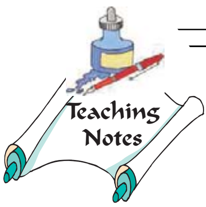
S4P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as the result of new innovations in technology.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time (GLO B2)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Notes