TOPIC 2.1: EXPLORATION OF SPACE

S4P-2-1 Identify and analyze issues pertaining to space exploration.

Examples: scale of the universe, technological advancement, promotion of global co-operation, social and economic benefits, allocation of resources shifted away from other pursuits, possibility of disaster

S4P-2-2 Describe planetary motion using Kepler's three laws.

Examples: relate Kepler's Third Law to objects other than planets, such as comets, satellites, and spacecraft

S4P-2-3 Outline Newton's Law of Universal Gravitation and solve problems using $F_g = \frac{Gm_1m_2}{r^2}$.

S4P-2-4 State the gravitational potential energy as the area under the force-separation curve and solve problems using $E_g = \frac{-Gm_1m_2}{r}$

S4P-2-5 Solve problems for the escape velocity of a spacecraft.

Include: Law of Conservation of Energy, binding energy

General Learning Outcomes Connection

Students will…

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

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

Specific Learning Outcome

S4P-2-1: Identify and analyze issues pertaining to space exploration.

Examples: scale of the universe, technological advancement, promotion of global co-operation, social and economic benefits, allocation of resources shifted away from other pursuits, possibility of disaster

Suggestions for Instruction

Entry Level Knowledge

Research has indicated that students want to address contemporary topics in physics that they read about in the news and see on television. They have tremendous interest in expeditions such as Mars explorations, cosmology, and the new observations of the Hubble telescope.

It is highly recommended that teachers use a space exploration context to approach the topics of universal gravitation and Kepler's laws. An excellent way to begin is with a student-initiated project that connects to learning outcome S4P-2-1. Projects could address different topics and take on many different forms. The historical analysis of technology, such as the development of the telescope from Galileo to Hubble, helps address the Nature of Science skills outcomes. Other students might focus on STSE issues. Students could also use a variety of presentation modes including web pages, a Web Quest, bulletin boards, photo album, video, PowerPoint, or alternative media. Refer to the appendix for Internet resources associated with specific issues.

Notes to the Teacher

The scale of the universe serves as an excellent introduction to the exploration of space. Students should be confronted with the macro scale and the micro scale. The Powers of Ten applet found on many websites can be used to introduce the scale. Encourage the construction of scale models.

Demonstration

Microsoft's *Streets and Trips* software has a facility to mark locations along a given radius. Using the scale factors given in the table, students mark different locations relative to their home or school for the planets in the solar system.

Planet	Distance to Sun (million km)	Scale Factor
Mercury	58	0.39
Venus	108	0.72
Earth	150	1.00
Mars	228	1.52
Jupiter	778	5.19
Saturn	1,427	9.51
Uranus	2,871	19.1
Neptune	4,497	30.0
Pluto	5,913	39.4

SKILLS AND ATTITUDES OUTCOMES

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

S4P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S4P-0-3a: Analyze, from a variety of perspectives, the risks and benefits to society and the environment when applying scientific knowledge or introducing technology.

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…

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)

SUGGESTIONS FOR INSTRUCTION

SKILLS AND ATTITUDES OUTCOMES (CONT'D)

S4P-0-3c: Identify social issues related to science and technology, taking into account human and environmental needs and ethical considerations.

S4P-0-3d: Use the decision-making process to address an STSE issue.

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

S4P-0-4d: Develop a sense of personal and shared responsibility for the impact of humans on the environment, and demonstrate concern for social and environmental consequences of proposed actions.

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

SUGGESTIONS FOR ASSESSMENT

Students conduct a "Space Day" Gallery Walk of student projects.

SUGGESTED LEARNING RESOURCES

<http://education1.nasa.gov/home> is an excellent resource with up-to-date information on the latest NASA projects.

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-2-2: Describe planetary motion using Kepler's three laws.

Examples: relate Kepler's Third Law to objects other than planets, such as comets, satellites, and spacecraft

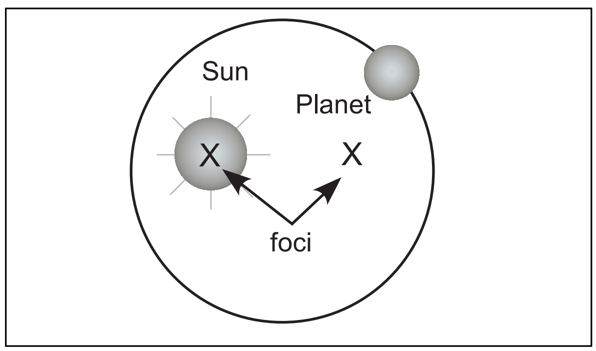
Suggestions for Instruction

Notes to the Teacher

Tycho Brahe provided a wide array of quantitative scientific observations but it was Johannes Kepler (1571–1630), who went to Prague to become Brahe's assistant, who was able to develop those observations in a theoretical framework. In the 16th century, most people believed in a geocentric model of the solar system, following the ancient ideas of astronomer Ptolemy. In 1543, Nicolaus Copernicus proposed an idea that the planets and Earth orbited around the Sun. However, Copernicus's new theory was no better at predicting the positions of the planets in the sky than Ptolemy's Earth-centred theory. More than 50 years later, Johannes Kepler set out to refine the Copernican system as he studied Tycho Brahe's observations of Mars. Kepler used Brahe's observations to guide the development of his laws of planetary motion, rather than fit the data to a predetermined view.

In 1609, Kepler published his first and second laws of planetary motion, the Law of Ellipses and the Equal-Areas Law. Ten years later he published a third law, the Harmonic Law. Kepler's three laws of planetary motion are:

- **First Law:** Each planet moves around the Sun in an orbit that is an ellipse, with the Sun at one focus of the ellipse.



Note: The diagram is an exaggeration of the orbit. In reality, the foci are very close together, such that the orbit is very nearly circular.

Skills and Attitudes Outcomes

S4P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

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

General Learning Outcome Connection

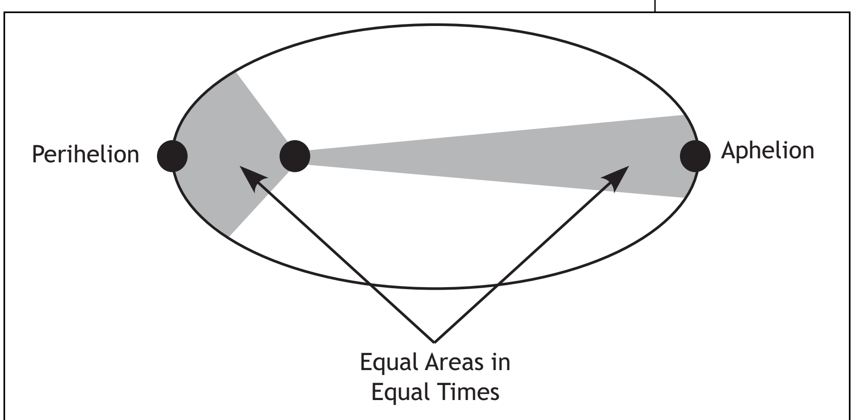
Students will…

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

- **Second Law:** The straight line joining a planet and the Sun sweeps out equal areas in space in equal intervals of time. (Each planet moves most rapidly when closest to the Sun and least rapidly when farthest from the Sun.)

To demonstrate that the shaded areas are equal, draw the ellipse on a piece of paper (see instructions below) and cut out the pie-shaped wedges. Weigh the two pieces of paper on a scale (since the thickness of the paper is the same for each piece, the weight is proportional to the area).



Suggestions for Assessment

Observation

Observe students and ask questions as they draw their ellipses.

Pencil-and-Paper Tasks

Students solve problems to calculate either radius of orbit or period, using Kepler's constant.

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-2-2: Describe planetary motion using Kepler's three laws.

Examples: relate Kepler's Third Law to objects other than planets, such as comets, satellites, and spacecraft

SUGGESTIONS FOR INSTRUCTION

- **Third Law:** The squares of the orbital periods of the planets around the Sun are proportional to the cubes of the orbital semi-major axes.

If you know the time of a planet's orbit around the Sun, you can calculate its average distance from the Sun (or vice-versa). The ratio of the cube of the radius of orbit to the square of the time is a constant, and Kepler's Third Law can be stated as:

$$K_S = \frac{R^3}{T^2}$$

Students can use astronomical data from known tables to calculate and compare K for different planets.

Prior Knowledge Activity

Students create a KWL chart (SYSTH). Sample questions might include:

Know

- What is an orbit ?
- What are some things that orbit?
- What is the shape of an orbit?
- Do all orbits have the same shape?
- Are orbits natural or human-made?

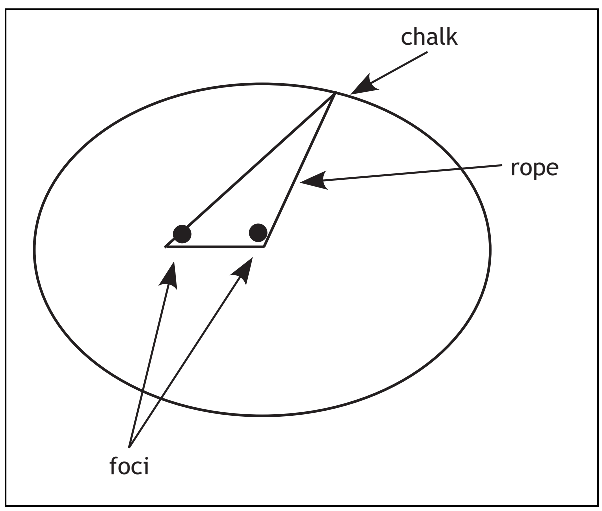
Want to Know

- What do we want to learn about planetary orbits?
- Why don't planets travel in straight lines?
- What's in the middle of the orbit?

Ellipse Activity

Procedure

1. In a smooth, open area, mark two foci some distance apart. Place a stake in the ground at each focus, labelling one focus as the Sun.
2. Tie the ends of the rope together and loop the rope around the stakes at the foci.



SKILLS AND ATTITUDES OUTCOMES

S4P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

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

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

3. Pull the rope tight, as shown, and, using the chalk, draw the ellipse as shown. Notice that for every point on the ellipse, the distance to one focus plus the distance to the other focus is always the same. Have students record the measurements to see the pattern for themselves.
4. Direct students to move around the path, slowing down as they get farther from the "Sun" and speeding up as they get closer.

The above exercise can also be done at a desk using paper and pencils, and pins.

SUGGESTIONS FOR ASSESSMENT

SUGGESTED LEARNING RESOURCES

Reference: p. 279, *Nelson Physics 12*, Thomson Nelson, 2003

Activity: Drawing and comparing ellipses, p. 273, computerized simulation of Kepler's Second Law, *Nelson Physics 12*, Thomson Nelson, 2003

Michael J. Ruiz, "Kepler's Third Law without a Calculator," *The Physics Teacher* 42 (December 2004): 530–538.

In this article, Ruiz presents an interesting and accessible procedure (based on the popular "Fermi Questions" approach) whereby students can use "mental mathematics" techniques (for instance, use of squares, cubes, cube roots of common values) to determine values for "R" (semi-major axis) and "T" (period) for planetary bodies, comets such as Halley, and spacecraft travel and its relation to least-energy orbits (also known as Hohmann transfer orbits (see learning outcome S4P-2-7). Designed for an astronomy course for college-level non-majors, the technique could be particularly useful in building student confidence in working with a numerical mode of representation. Kepler's Third Law is simply stated in the form:

$$R \times R \times R = T \times T$$

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)

SPECIFIC LEARNING OUTCOME

S4P-2-3: Outline Newton's Law of Universal Gravitation and solve problems using

$$F_g = \frac{Gm_1m_2}{r^2}.$$

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Students have studied gravity near the surface of the Earth in Senior 3 Physics.

Notes to the Teacher

One of Isaac Newton's greatest ideas follows from the legend of the apple falling on his head. Newton surmised that if the force of gravity reaches to the top of the highest tree, might it not reach even further? Could the force of gravity extend all the way to the Moon? Then, the orbit of the Moon about Earth could be a consequence of the gravitational force and, further, could the force of gravity extend indefinitely? Newton concluded that any two objects in the universe exert a gravitational attraction on each other that is proportional to the product of their masses, and inversely proportional to the square of their separation.

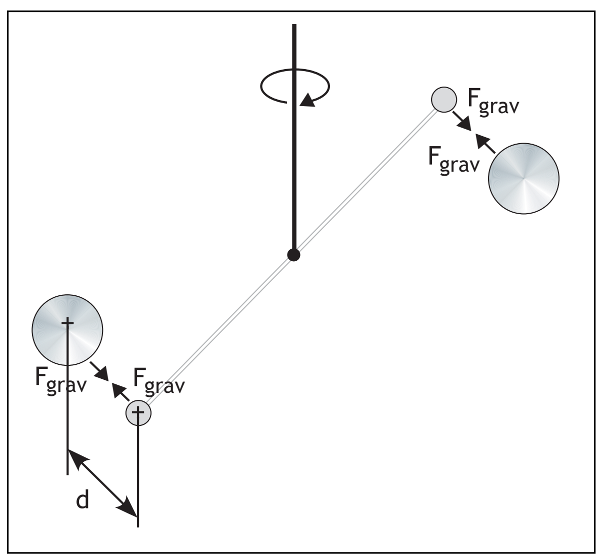
$$F \alpha \frac{m_1m_2}{R^2}$$

Introducing a constant of proportionality (*G*), the law becomes:

$$F = G\frac{m_1m_2}{R^2}$$

A gravitational field exists in the space surrounding an object and a force is exerted on any mass in the field. The law holds for any two masses and the constant *G* is universal.

The value of *G* is found experimentally and was first measured by Henry Cavendish using a torsion balance. Cavendish attached two spheres to the ends of a rod suspended by a wire. The force of gravity exerted by two other, nearby, heavy objects caused the rod to twist. The angle of the torsion was proportional to the force of gravity exerted by the masses.



Cavendish's Torsion Balance

SKILLS AND ATTITUDES OUTCOME

S4P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

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

In this way, Cavendish was able to determine the gravitational force of attraction between the masses, and the value of G could also be determined. The currently accepted value of G is 6.67259×10^{-11} N m^2/kg^2. The value of G is very small, indicating that the force of gravity is only appreciable for objects with large masses. Although any two masses (including students) will exert gravitational forces upon each other, these forces are too small to be noticeable. However, in the case of planets, the gravitational force becomes much larger and noticeable.

Student Activity

Students calculate the weight (force of gravity) on an object near the surface and, using compare and contrast frames (SYSTH), compare to the force of gravity as calculated by Newton's Law of Universal Gravitation.

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students solve problems using Newton's Law of Universal Gravitation.

SUGGESTED LEARNING RESOURCES

Problems: pp. 276–277, *Nelson Physics 12,* Thomson Nelson, 2003

Reference: pp. 275–277, *Nelson Physics 12,* Thomson Nelson, 2003

Reference: pp. 182–184, *Conceptual Physics*, Pearson, 2002

Problem Sets: p. 275, *Nelson Physics 12*, Thomson Nelson, 2003

General Learning Outcome Connection

Students will…

Demonstrate appropriate problem-solving skills while seeking solutions to technological challenges (GLO C3)

Specific Learning Outcome

S4P-2-4: State the gravitational potential energy as the area under the force-separation curve and solve problems using

$$E_g = \frac{-Gm_1m_2}{r}.$$

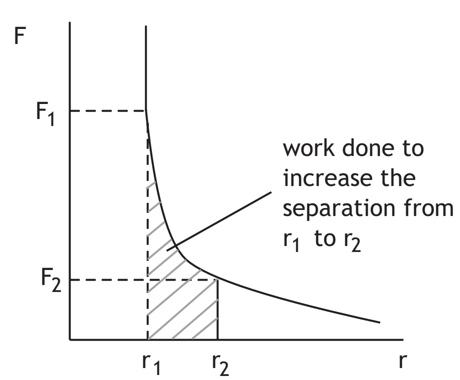
Suggestions for Instruction

Entry Level Knowledge

Work and gravitational potential energy near the surface of Earth are introduced in Topic 1. The concepts are now extended to the general case.

Notes to the Teacher

Near the surface of Earth, work done lifting an object above the surface of Earth is stored as potential energy. Similarly, we must do work separating all masses. In the general case, the gravitational force is not constant, so work can only be calculated as the area under the force-separation curve. Calculus is required to find this area. At this time, most students are unprepared for integral calculations and the formula must be given. However, the idea of the area under a force-separation graph is covered in Topic 1 and can be extended to the limiting case in this example.



In the force-separation graph, the area under the curve for the interval r_1 to r_2 is equal to the work done in increasing the separation of the two masses.

To increase the separation of the two masses from r_1 to r_2 requires work to be done to overcome the force of attraction. As a result of this work being done, the gravitational potential energy of the system increases. At maximum separation (infinity), the gravitational potential energy is zero. Since energy was added to the system to "raise" it to zero, the initial energy is stated as a negative. The work done to change the separation from r_1 to r_2 equals the change in gravitational potential energy from r_1 to r_2.

Students are often confused by the fact that the initial potential energy is negative. The negative sign indicates an attractive force and requires that energy be added to move towards a potential of zero. As the separation (r) approaches infinity, the potential energy must approach zero. Physicists often refer to these types of energy problems as "potential wells." An object at the bottom of a well requires energy to get it out of the well. If the top of the well is assigned a value of zero potential, then the bottom of the well must be negative potential. It is important to remember that the negative provides us with information about the situation.

SKILLS AND ATTITUDES OUTCOME

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

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Demonstrate appropriate problem-solving skills while seeking solutions to technological challenges (GLO C3)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Tasks

Students solve simple problems using gravitational potential energy.

SUGGESTED LEARNING RESOURCES

Problems: pp. 276–277, *Nelson Physics 12,* Thomson Nelson, 2003

Reference: pp. 275–277, *Nelson Physics 12,* Thomson Nelson, 2003

Reference: pp. 182–184, *Conceptual Physics,* Pearson, 2002

Problems: p. 275, *Nelson Physics 12,* Thomson Nelson, 2003

Problems: p. 286, *Nelson Physics 12,* Thomson Nelson, 2003

Reference: pp. 285–288, *Nelson Physics 12,* Thomson Nelson, 2003

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-2-5: Solve problems for the escape velocity of a spacecraft.

Include: Law of Conservation of Energy, binding energy

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Conservation of energy problems are introduced in Topic 1.

Notes to the Teacher

If you throw an object straight up, it will rise as the acceleration of gravity slows it down and then returns it to Earth. The energy as the object leaves your hand is all kinetic energy. As the object rises, it slows down, the kinetic energy decreases, and the potential energy increases. At the maximum height, the potential energy reaches a maximum and the kinetic energy is zero. At every point, the total energy is a constant and $E_T = E_g + E_k$. Since the gravitational force decreases as the separation between the object and the Earth increases, there will be some point at which gravity is not strong enough to pull the object back to Earth. The gravitational binding energy of any mass is the amount of energy it needs to escape the effects of the Earth's gravitational field. On the surface of the Earth the gravitational binding energy is

$$E_g = \frac{GMm}{r}$$

where *m* is the mass of the object, *M* is mass of the Earth, *G* is the gravitational constant, and *r* is the radius of the Earth. **Escape velocity** is defined as the minimum velocity an object must have to escape the gravitational field of the Earth. That is, we must supply enough kinetic energy to overcome the gravitational binding energy.

Thus,

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

and the escape velocity is

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

Near the surface of the Earth, the escape velocity is about 11 km/s. Note that the escape velocity is independent of the mass of the object; however, rockets of larger mass will require more fuel to achieve this velocity.

An object that has this velocity at the surface of the Earth will totally escape the Earth's gravitational field (ignoring the losses due to the atmosphere). Although you can escape the Earth at this speed, the Sun also exerts an attraction on the satellite and additional energy is required to escape the solar system.

Math Connection

Students use a spreadsheet to calculate and record binding energies at various altitudes above the surface of the Earth. Graph the results.

SKILLS AND ATTITUDES OUTCOME

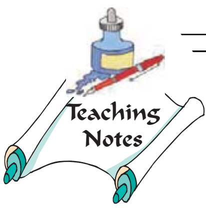
S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

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

Pencil-and-Paper Tasks

Students solve problems to find escape velocity for different orbits around the Earth.

Students solve problems to calculate escape velocity for different planets and the Moon.

SUGGESTED LEARNING RESOURCES

Reference: pp. 230–235, *Physics 12,* McGraw-Hill Ryerson, 2003

pp. 230–235, *Nelson Physics 12,* Thomson Nelson, 2003

pp. 207–211, *Conceptual Physics,* Pearson, 2002

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