

# Around The World

## Objective:

- To create a model of how satellites orbit Earth.

## Science Standards:

- Science as Inquiry
- Physical Science
  - position and motion of object
- Change, Constancy, & Measurement
  - evidence, models, & exploration

## Science Process Skills:

- Observing
- Communicating
- Making Models
- Defining Operationally Investigating

## Mathematics Standards:

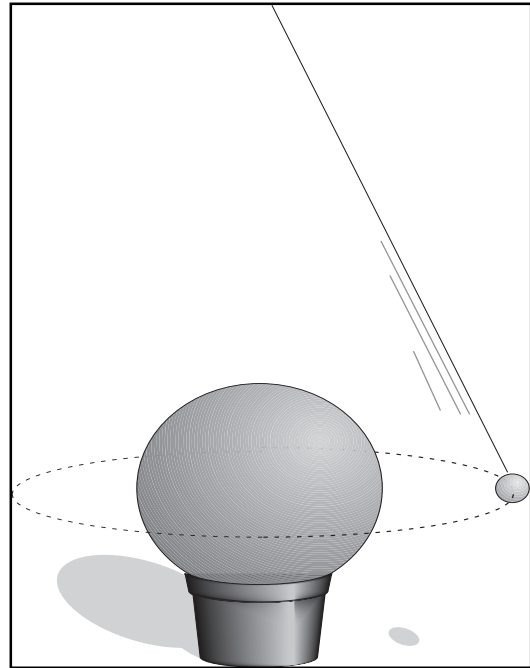
- Communication
- Geometry

## Activity Management:

This activity can be conducted as a demonstration or a small group activity at a learning station where student groups take turns.

Pick a small ball to which it is easy to attach a string. A small slit can be cut into a tennis ball or racquetball with a sharp knife. Then, a knotted string can be shoved through the slit. The slit will close around the string. A screw eye can be screwed into a solid rubber or wood ball and a string attached to it.

If using this as an activity, have students work in groups of two. The large ball and flowerpot should be placed on the floor in an open area. Tell students to imagine the



A ball on a string circles a ball to simulate the orbits of satellites around Earth.

### MATERIALS AND TOOLS

- Large ball\*
- Small ball
- 2 meters of string
- Flower pot\*

\* A world globe can substitute for the large ball and flower pot

ball is Earth with its north pole straight up. One student will stand near the ball and pot and hold the end of the string the small ball is attached to. This student's hand should be held directly over the large ball's north pole, and enough string should be played out so that the small



ball comes to rest where the large ball's equator should be. While the first student holds the string steadily the second student starts the small ball moving. The objective is to move the small ball in a direction and at a speed that will permit it to orbit the big ball.

Save the student reader for use after students have tried the activity.

### Additional Information:

This model of a satellite orbiting around Earth is effective for teaching some fundamentals of orbital dynamics. Students will discover that the way to orbit the small ball is to pull it outward a short distance from the large ball and then start it moving parallel to the large ball's surface. The speed they move it will determine where the ball ends up. If the small ball moves too slowly, it will arc "down" to Earth's surface. NASA launches orbital spacecraft in the same way. They are carried above most of Earth's atmosphere and aimed parallel to Earth's surface at a particular speed. The speed is determined by the desired altitude for the satellite. Satellites in low orbits must travel faster than satellites in higher orbits.

In the model, the small ball and string become a pendulum. If suspended properly, the at-rest position for the pendulum is at the center of the large ball. When the small ball is pulled out and released, it swings back to the large ball. Although the real direction of gravity's pull is down, the ball seems to move only in a horizontal direction. Actually, it is moving downward as well. A close examination of the pendulum reveals that as it is being pulled outward, the small ball is also being raised higher off the floor.

The validity of the model breaks down when students try orbiting at different distances from the large ball *without* adjusting the length of the string. To make the small ball orbit at a higher altitude without lengthening the string, the ball has to orbit faster than a ball in a lower orbit. This is the opposite of what happens with real satellites.

### Assessment:

Use the student pages for assessment.

### Extensions:

1. Investigate the mathematical equations that govern satellite orbits such as the relationship between orbital velocity and orbital radius.
2. Learn about different kinds of satellite orbits (e.g., polar, geostationary, geosynchronous) and what they are used for.
3. Look up the gravitational pull for different planets. Would there be any differences in orbits for a planet with a much greater gravitational pull than Earth's? Less than Earth's?
4. Use the following equation to determine the velocity a satellite must travel to remain in orbit at a particular altitude:

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

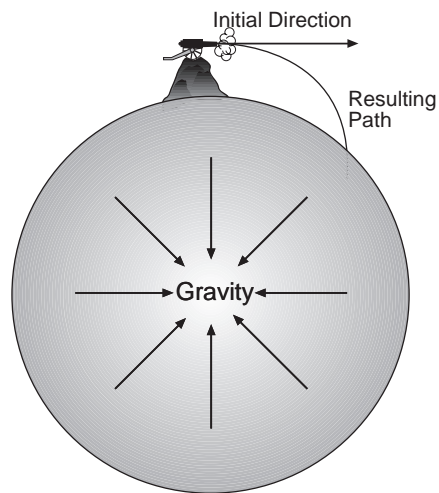
- $v$  = velocity of the satellite in meters  
 $GM$  = gravitational constant times Earth's mass (3.99x10<sup>14</sup> meters<sup>3</sup>/sec<sup>2</sup>)  
 $r$  = Earth's radius (6.37x10<sup>6</sup> meters) plus the altitude of the satellite



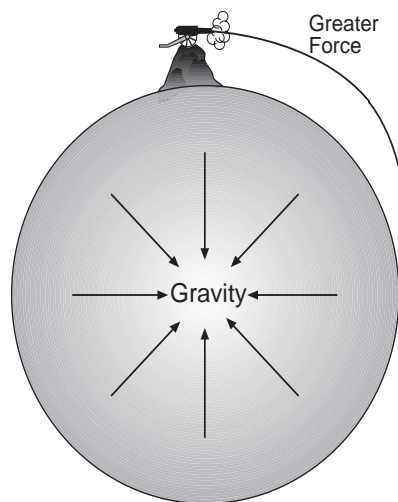


A microgravity environment is created by letting things fall freely. NASA uses airplanes, drop towers, and small rockets to create a microgravity environment lasting a few seconds to several minutes. Eventually, freefall has to come to an end because Earth gets in the way. When scientists want to conduct experiments lasting days, weeks, months, or even years, it is necessary to travel into space and orbit Earth. Having more time available for experiments means that slower processes and more subtle effects can be investigated.

To see how it is possible to establish microgravity conditions for long periods of time, it is first necessary to understand what keeps a spacecraft in orbit. Ask just about anybody what keeps satellites and Space Shuttles in orbit and you will probably hear, "There is no gravity in space." This is simply not true. Gravity is what keeps a satellite or Space Shuttle from drifting into space. It does this by bending an orbiting object's path into a circular shape. To explain how this works, we can use an example presented by English scientist Sir Isaac Newton. In a book he wrote in 1673, *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy), Newton explained how a satellite could orbit Earth.



Newton's cannon fires the first cannonball. The combination of the cannonball's initial velocity and the pull of Earth's gravity causes the cannonball to arc to the ground near the mountain.



A second cannonball is fired using a larger charge of black powder. The force exerted on the cannonball causes it to travel faster than the first cannonball. Gravity bends its path into an arc but because of the greater speed, the cannonball travels farther before it lands on Earth.

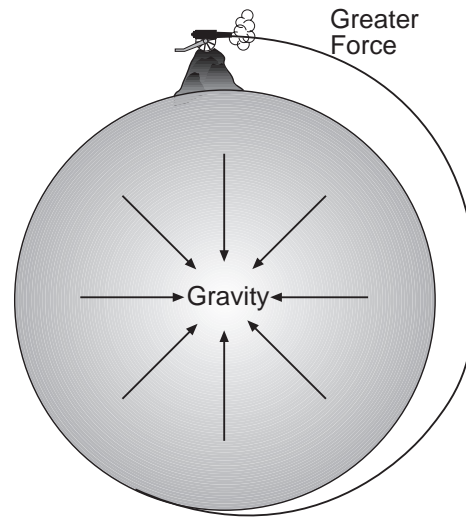
Newton envisioned a very tall mountain on Earth whose peak extended above Earth's atmosphere. This was to eliminate friction with Earth's atmosphere. Newton then imagined a cannon at the top of that mountain firing cannonballs parallel to the ground. As each cannonball was



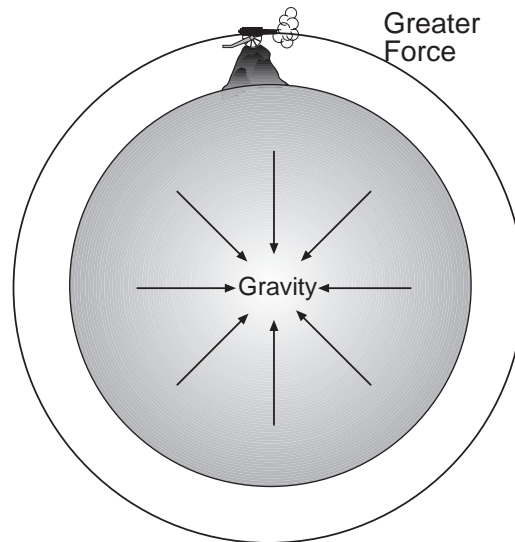
fired, it was acted upon by two forces. One force, due to the explosion of the black powder, propelled the cannonball straight outward. If no other force were to act on the cannonball, the shot would travel in a straight line and at a constant velocity. But Newton knew that a second force would also act on the cannonball: Earth's gravity would cause the path of the cannonball to bend into an arc ending at Earth's surface.

Newton demonstrated how additional cannonballs would travel farther from the mountain if the cannon were loaded with more black powder each time it was fired. With each shot, the path would lengthen and soon the cannonballs would disappear over the horizon. Eventually, if a cannonball were fired with enough energy it would fall entirely around Earth and come back to its starting point. This would be one complete orbit of Earth. Provided no force other than gravity interfered with the cannonball's motion, it would continue circling Earth in that orbit.

In essence, this is how the Space Shuttle stays in orbit. The Shuttle is launched on a path that arcs above Earth so that the Orbiter is traveling parallel to the ground at the right speed. For example, if the Shuttle climbs to a 160-kilometer-high orbit, it must travel at a speed of about 28,300 kilometers per hour to achieve an orbit. At that speed and altitude, the Shuttle's falling path will be parallel to the curvature of Earth. Because the Space Shuttle is freefalling around Earth, a microgravity environment is created that will last as long as the Shuttle remains in orbit.



This cannonball travels halfway around Earth because of the greater charge of black powder used. The cannonball's falling path nearly matches the shape of Earth.



The black powder charge in this final cannon shot propels the ball at exactly the right speed to cause it to fall entirely around Earth. If the cannon is moved out of the way, the cannonball will continue orbiting Earth.

# Around The World

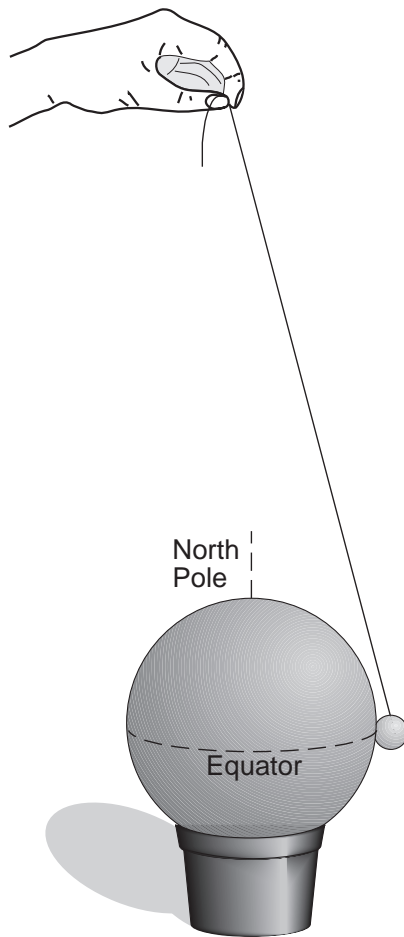
## Orbital Deployment Team Members:

1. \_\_\_\_\_

2. \_\_\_\_\_

### Procedure:

1. Set up your equipment as shown in the picture. One team member stands above the large ball and holds the end of the string. The second team member's job is to move the small ball in different ways to answer the following questions. Write down your answers where indicated and draw pictures to show what happened. Draw the pictures looking straight down on the two balls.



1. What path does the satellite (small ball) follow when it is launched straight out from Earth?

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Show what happened.



Student Worksheet - 2

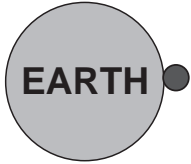
2. What path does the satellite follow when it is launched at different angles from Earth's surface?

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Show what happened.



3. What effect is there from launching the satellite at different speeds?

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4. What must you do to launch the satellite so it completely orbits Earth?

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5. Using the results of your investigation and the information contained in the student reader, write a paragraph that explains how satellites remain in orbit.

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6. Why will the International Space Station be an excellent place to conduct microgravity research?

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