Gateway Globe Lesson Plan:
Understanding Orbits

Location of Gateway Globe

Gateway to Space

Overview of Gateway Globe

The Gateway Globe is a 36-inch wide spherical projection system which shows two different movies on it. One movie shows examples of parabolic flight paths of future space planes, and one shows examples of existing satellite orbits around the Earth. This lesson will allow students to learn how to describe the different kinds of satellite orbits.

Lesson Background Information

This lesson plan/unit could be used independently or to prepare for (or to extend the learning after) a visit to Spaceport America. It can be used by teachers or parents wishing to make the Spaceport visit a richer learning experience (for everyone!).

An object that orbits the Earth is essentially falling around the Earth, but because of its horizontal velocity it never hits the ground. To understand this concept, you have to first understand a few of the basic laws of physics. You can do some simple experiments outdoors with your students that will help them grasp these basics.

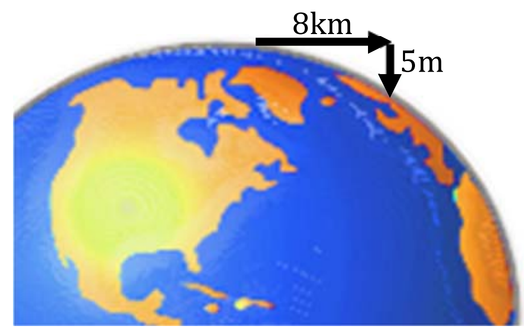
For both experiments, you will need two identical baseballs. Ask two students to throw the baseballs (forward) into the air while your other students watch. Then ask your class what they notice about the path of the balls. (The paths are curved.) This is because the force of the throw is causing the balls to go *forward*, but the force of gravity is also pulling the balls "down" *toward the center of the Earth*. This makes the paths curved.

The faster they throw the ball, the farther it seems to go. This might lead your students to (incorrectly) believe that the faster they throw the ball, the longer it takes to hit the ground. So, while standing on *flat ground* (very important!) ask two students to test that hypothesis. The first student should throw a ball as far as he/she can. At the time the first student releases the ball, the second student should drop a ball straight down from the same height that the first student releases the ball. What will they see? Both balls will hit the ground at the same time. Let other students try the experiment to further test the results. Done correctly, the results will not vary.

Why is this so? While the ball thrown horizontally is moving forward, it is also falling toward the Earth at the same rate as the ball that was simply dropped from the same height. The horizontal motion is independent of the vertical motion. Gravity is working on both balls equally, therefore, they hit the ground at the same time.

What would happen if your students went to the top of a mountain and threw the baseballs with as much force as they could muster? Chances are, the balls would travel farther before hitting the ground, *but* they would still fall at the same rate of speed.

How fast would a baseball need to go to get into orbit? Earth is basically a sphere. The surface "falls" or "curves down" five meters vertically for every eight kilometers horizontally. So if you were able to throw a baseball 7.9 km/second, its path would match the curvature of the Earth exactly. Assuming no *drag*, (air resistance), gravity would continue to pull it down five meters for every eight kilometers it travels forward, and it would travel around the Earth at a constant height. If it was thrown slower than 7.9 km/s, it would eventually fall to Earth.



Earth's Curvature*: The surface of the Earth curves down about 5 meters for every 8 kilometers.*

No matter how fast a ball is thrown, the *trajectory*, (path), of the ball is one of four shapes: a circle, an ellipse, a parabola, or a hyperbola. A circle is the result of an orbit of 7.9km/s. An ellipse is the result of a ball thrown slightly faster. If the ball is thrown too fast, it would leave Earth's orbit completely in a parabolic or hyperbolic trajectory.

How do you describe the orbit of a satellite? When flying an airplane, you have six bits of information that will communicate where you are: latitude, longitude, altitude, horizontal velocity, heading, and vertical velocity. This works for airplanes because they fly relatively slowly and close to the Earth's surface. For spacecraft and satellites orbiting many miles above the Earth, we need a different system. Johannes Kepler developed a method for describing orbits. His Classical Orbital Elements (COEs) allow us to visualize the size of an orbit, shape, orientation, and where a spacecraft might be in that orbit. There are six COEs:

1. **Orbit Size (a)**: described by the *semimajor axis* which is half (semi) the distance of an orbit's long (major) axis.

2. **Orbit Shape (e)**: Its *eccentricity* determines an orbit's shape. (For a simple hands-on activity to help students understand eccentricity, see the "Place in Space" lesson plan.)

3. **Inclination (i)**: Imagine a plane that passes through the equator of the Earth (the equatorial plane). Now imagine an orbit sitting on another plane that passes through the Earth (the orbital plane). The *inclination* is the tilt of the orbital plane in relation to the Earth's equatorial plane expressed as an angle from 0° to 180°. An orbit with an inclination of 0° or 180° is an *equatorial orbit* because it always stays over the equator. If the orbit has an inclination of 90°, it is a *polar orbit* because it travels over the North and South Poles.

   Inclination (i) also tells us what direction the spacecraft is moving.
   - If $0° \leq i < 90°$ then the spacecraft is moving in an easterly direction (with the Earth's rotation). This is called a *direct* or *prograde* orbit.
   - If $90° < i \leq 180°$ then the spacecraft is moving in a westerly direction (against the Earth's rotation). This is called an *indirect* or *retrograde* orbit.

4. **Right ascension of the ascending node (Ω):** To understand this concept, let's break it down into its two parts. First, imagine the line formed where the equatorial plane and the orbital plane intersect. This is called the *line of nodes*. The two points where *the orbit* passes through the equatorial plane are the *nodes*. The *ascending node* is where the spacecraft passes from below the equator to above the equator. (When the spacecraft crosses the equator heading south, it is called the *descending node*.)

   Right ascension is similar to longitude except that its reference point is the *vernal equinox* which is a line that passes through the center of the earth, through the equator, and to a star (Aries) that is so far away that it seems fixed in space every night. This is called the *principal direction*. Right ascension is an angle that is measured starting at the vernal equinox and traveling eastward along the equator to the ascending node. It acts like a celestial map reference to give us the swivel of the orbit, helping us to better understand its orientation in space. Its range of values is $0 \leq \Omega < 360$. See Figure 1, below.

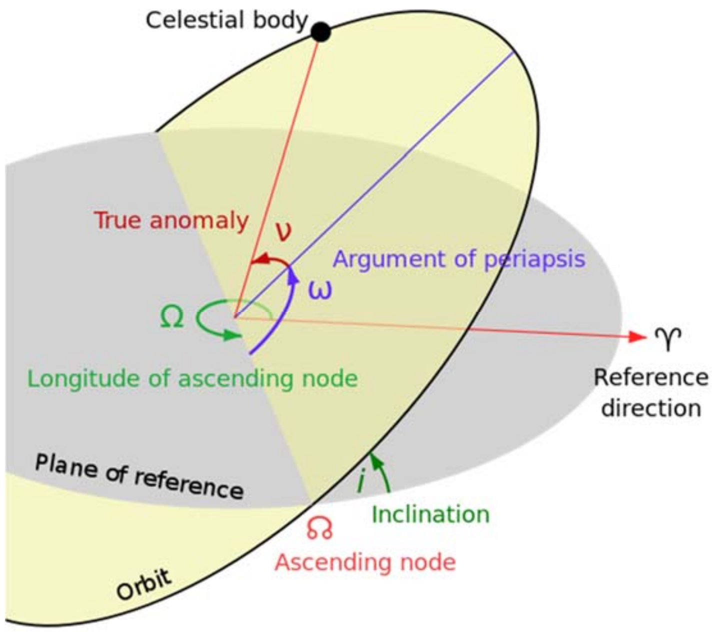


***Figure 1 – Right Ascension of the Ascending Node**: This angle describes the swivel of the orbital plane with respect to the principal direction.*

5. **Argument of perigee**: The angle measured in the direction of the spacecraft's motion and along the orbital path between the ascending node and perigee (when the object is closest to the Earth).

6. **True anomaly**: The angle measured in the direction of the spacecraft's motion and along the orbital path from perigee to the spacecraft's position vector. Of all the Classic Orbital Elements, true anomaly is the only one that changes over time.

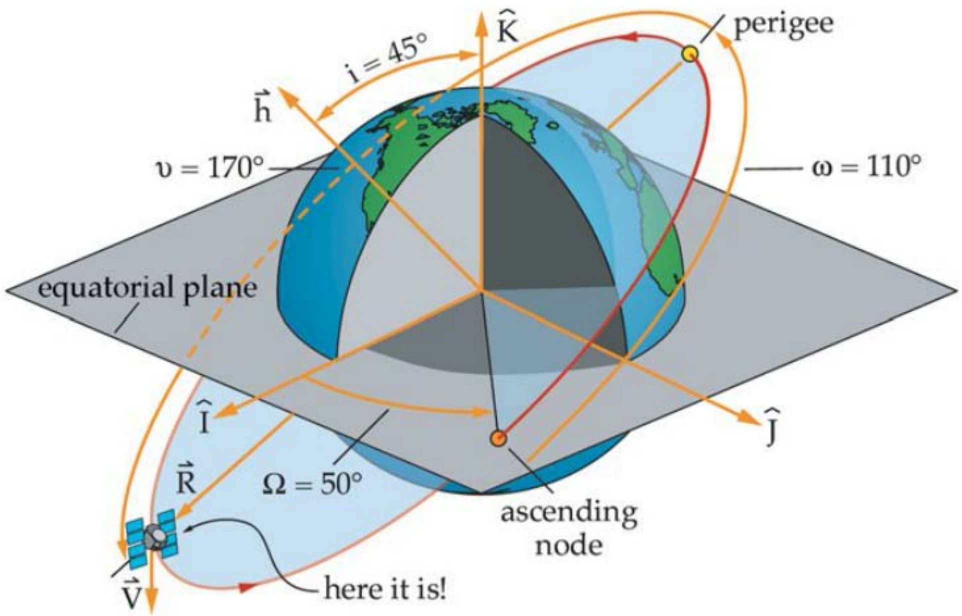


***Figure 2** – This represents a satellite with the following COEs:*
a = 50,000 km, e = .04, i = 45° Ω = 50°, ω = 110°, ν = 170

Different missions require different orbits. There are some specific kinds of orbits that are displayed using the Gateway Globe.

- Polar orbit – Goes around the earth from pole to pole.
- Geostationary orbit – This orbit is circular with a period of about 24 hours and an inclination of 0°. It appears motionless over the Earth.
- Geosynchronous orbit – This orbit is slightly inclined with a period of about 24 hours.
- Semi-synchronous orbit – This orbit is inclined with a period of about 12 hours.
- Sun-synchronous orbit – This is a special kind of polar orbit where the satellite passes over the same part of the Earth at roughly the same local time each day.

Grade Level

7-12

Learning Objectives

Students will:

- Recognize that a ball thrown from a given height and a ball dropped from the same height will hit the ground at the same time.
- Describe an orbit.
- Recognize a polar orbit.
- Recognize an equatorial orbit.

- Describe the location of a satellite using Kepler's Classical Orbital Elements method.

Assessment

Students will be able to sketch the orbit of a satellite given its eccentricity and inclination. Advanced students will be able to roughly sketch the location of a satellite given its COEs.

Required Materials

- Two baseballs
- Globe of the Earth for visualization purposes
- Two hula hoops (or two pieces of flexible pvc tubing that can be made into circular/elliptical shapes to surround the globe for visualization of the equatorial plane and the orbital plane)

Time Required

One class period

Step-By-Step Procedures

1. Using the two baseballs, perform the two demonstrations as noted in the lesson background information.
2. Using the globe and one hula hoop, demonstrate a polar orbit and an equatorial orbit.
3. Using the globe and two hula hoops, demonstrate each of Kepler's Classical Orbital Elements as taught in the lesson background information.
4. Challenge your students to draw approximate orbits based on the following COEs:
    - e = 0 and i = 90 (circular polar orbit)
    - e = 0 and i = 180 (circular equatorial orbit)
    - e = 0 and i = 0 (circular equatorial orbit)
5. Challenge your advanced students to sketch the location of a satellite given the following COEs.
    - a = 60,000 km, e = 0, i = 50° Ω = 50°, ω = 100°, v = 160

Alignment to Standards

This lesson aligns with the following Next Generation Science Standards:

- MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.
- HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

This lesson aligns with the following Mathematics Common Core Standards

- MP.4 Model with mathematics. (HS-ESS1-1),(HS-ESS1-4)

Other Resources:

- **"Understanding Space: An Introduction to Astronautics"** by Jerry Jon Sellers and Wiley J. Larson (editor), is a very thorough astronautics textbook designed to provide the reader with a conceptual overview of important topics in astronautics. While there is math in the book, math is not required for understanding of the concepts. There is also a teacher manual and a workbook that goes with the textbook. Version 4 of the book is available digitally in the Inkling store: https://www.inkling.com/store/book/sellers-understanding-space-4th/?ia_search_q=understanding%20space&ia_view_type=all&ia_result_type=book
- An excerpt from the above textbook is a fantastic primer on orbital mechanics from which the information in this lesson was taken can be found here: http://www.insight3d.com/resources/educational-alliance-program/astro-primer/primer1.htm