CENTRIPETAL FORCES AND SATELLITE ORBITS

Students will learn how mass, radius and period are related to the centripetal force needed to keep a satellite in orbit.

LESSON PLAN

Introduction
As a satellite orbits the Earth, Earth's gravity keeps the satellite from flying off into space. The initial push from a rocket gets the satellite into space and the satellite's orbital speed keeps it in space. At the same time, gravity constantly pulls at the satellite and keeps it in orbit. There is an optimum orbital speed a satellite must maintain; otherwise, it is pulled closer and closer to Earth. The farther away from Earth a satellite is traveling, the weaker the Earth's gravitational pull. Because the pull of gravity is less, the satellite can then orbit at a slower speed without being pulled back to Earth.

Lesson Objective
In this lesson, students will learn how mass, radius and period are related to the centripetal force needed to keep a satellite in orbit.

Learning Objectives:

The students will
- Learn about centripetal force.
- Learn about the effects of mass on keeping a satellite in orbit.
- Learn how changes in radius affect the orbit.
- Build and experiment with a simple demonstration model.

Procedures:
- Build the demonstration model. The rubber stopper will represent a satellite. Washers or nuts suspended from the string attached to the "satellite" will supply the centripetal force. The narrow tube provides a grip for the student to control the movement.
- Take the ball-point pen apart. Remove the ink cartridge and use the barrel of the pen or narrow tube as a grip to swing the "satellite."
- Thread the piece of string through the barrel of the pen. (Use the smoother end of the barrel as the upper end around which the string will move in a circle.) Tie the upper end of the string to the rubber stopper. To the lower end of the string tie a washer or nut. The weight of these washers or nuts provides the centripetal force needed to make the satellite move along a circular orbit.
- Arrange the rubber stopper satellite so that its center is about 3 feet from the top of the pen or narrow tube.

Grade Level: High School

Ohio's Learning Standards/Mathematics (2017):

Algebra
A.CED.4: Rearrange formulas
Functions
F.IF.4: Interpret functions in applications

Ohio's Learning Standards/Science (2018):

High School Physical Science:
PS.FM.1: Motion
PS.FM.2: Forces
PS.FM.3: Dynamics

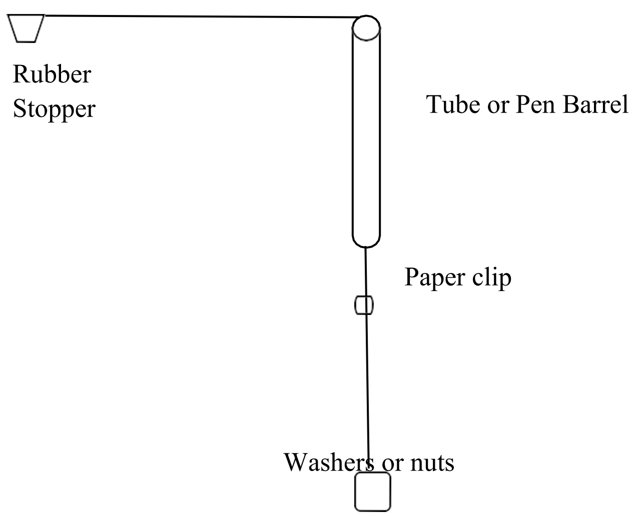
High School Physics:
PM – Motion:
P.M.2: Problem Solving
P.F – Forces:
P.F.1: Newton's Laws Applied to Complex Problems
P.F.2: Gravitational Force and Fields
P.F.6: Forces in Two Dimensions

Materials Required:

- Narrow rigid tube (ballpoint pen barrel, straw, etc.)
- Piece of white string about 6' long
- Two rubber stoppers
- Washers or nuts from bolts
- Two paper clips
- Tape
- Allow plenty of space for the orbits
- Safety glasses
- Appendix A: Worksheet

Procedures, continued

- A paper clip can be attached to the string about an inch below the barrel or tube.
- When the student swings the satellite in its orbit, keep this paper clip about an inch below the barrel to ensure that the radius of the orbit remains constant. Another option: Use white string and make a black mark above and below the cylinder to show where the string should remain.
- Also mark the string half way between the top of the cylinder and the “satellite” to show ½ radius.
- Work in teams of at least three students. One student as the timer. One student to spin the satellite. Another student to count the revolutions. All students should wear eye protection.
- Once the student has the satellite moving smoothly at a radius of 3 feet, another team mate should count the number of revolutions made by the satellite in 30 seconds. (A revolution is one time around the circular orbit.) The time required for the satellite to make one revolution is its period. Determine the period by dividing 30 seconds by the number of revolutions that were counted.
- Refer to the worksheet for the following questions.
- Ask the students: What is the period of your satellite? Why is it better to measure the time for many revolutions rather than just one?
- Have the students double the force by doubling the number of washers or nuts at the bottom of the string and perform the procedure again.
- Ask the students: How would you make the centripetal force four times as big? How much force is needed to halve the satellite's period? If you halve the radius of the orbit, what force is needed to keep the period the same?
- Have the students tape or tie another identical rubber stopper to the first one to double the mass of the satellite. With the same orbital radius of 3 feet, ask the students if the period remains about the same when you double the centripetal force acting on twice the mass?



Extension:
Have the students change the radius of the orbit and observe the results.

Key Points:

- Objects in a circular motion are accelerating towards the center of the circle
- The string in the demo is kept taut by the stopper's inertia
- Experiment in advance to determine the best ratio between the mass of the stopper and the number/size of washers that you use to achieve a good balance for a smooth, predictable spin.
- The stopper's inertia would make the stopper fly tangentially away, but the string pulls it continuously inward (= centripetal force) – just like the Earth pulling the moon (or a satellite) in orbit [for the sake of this demo, we are talking about circular orbits]
- Speed equals distance divided by time
- Velocity is measured in meters per second. It is defined as speed plus direction
- Acceleration is a change in velocity. A change in velocity is caused by a change in speed, direction or both
- Acceleration is caused by a net force (the total effect of all forces) acting on the object
- Acceleration is measured in meters per second per second
- In this demo, time equals one revolution around the circle and therefore equals the circumference of the circle which is $2\pi r$
- One revolution around the circle is known as the period
- The speed is the distance traveled around in one revolution (the circumference or $2\pi r$) divided by the time to complete on revolution (the period)

$$v = 2\pi r/t$$

- The formula to use for the calculations: Centripetal force (a net force) is equal to the mass of the object times velocity squared divided by the radius of the circle or

$$F_c = m(v^2/r)$$

Resources (accessed 24 April 2020):

- How an orbit works interactive (Newton's Cannonball demo): https://spaceplace.nasa.gov/how-orbits-work/en/
- What is an orbit: https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-orbit-58.html
- Centripetal force: http://hyperphysics.phy-astr.gsu.edu/hbase/cf.html
- Circular motion and satellite motion: https://www.physicsclassroom.com/class/circles and https://www.physicsclassroom.com/class/circles/Lesson-4/Mathematics-of-Satellite-Motion

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APPENDIX A: MEASURING CENTRIPETAL FORCES

1. Count the number of revolutions made by the satellite in 30 seconds: ______________

2. The time required for the satellite to make one revolution is its period. Determine the period of your satellite: ______________

3. Why is it better to measure the time for many revolutions rather than just one:

    ____

4. How would you double the centripetal force: ___________________

5. How would you make the centripetal force four times as big: ___________________

6. How much force is needed to halve the satellite's period: ___________________

7. If you halve the radius of the orbit, what force is needed to keep the period the same:

    ____

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ANSWER KEY: MEASURING CENTRIPETAL FORCES

1. Count the number of revolutions made by the satellite in 30 seconds: _______________

   The answer will vary for each team. For our example, we will say the average was 57.6 revolutions.

2. The time required for the satellite to make one revolution is its period. Determine the period of your satellite: _______________

   To find the answer, divide 30 seconds by the number of revolutions that were counted. For our example, the answer is 0.52 seconds.

3. Why is it better to measure the time for many revolutions rather than just one:

   Answer: averaging allows for variations thus more accurate.

4. How would you double the centripetal force: ____________________

   Answer: Double the number of washers at the bottom of the string.

5. How would you make the centripetal force four times as big: ____________________

   Answer: Add 4 times the number of washers (or for extra credit: increase the radius by 4 or halve the period).

6. How much force is needed to halve the satellite's period: ____________________

   Answer: 4 times the force.

7. If you halve the radius of the orbit, what force is needed to keep the period the same:

   Answer: Half of the force.