6.2: Hooke’s Pendulum

Robert Hooke and Isaac Newton were great rivals both in European science and mathematics, as well as in the Royal Society for Science and Mathematics where Newton was president. Both men were fiercely competitive, and jealous of their work and fame. When Newton published his theory of gravity in the book ***Principia Mathematica***, he struggled and failed to develop a simple and convincing demonstration for the mathematical concept that only a center-seeking force (gravity) and the straight line motion of a mass (momentum) are needed to create an orbit. Robert Hooke’s simple pendulum experiment achieved this and was considered a great triumph!

Academic Standards

Science and Engineering Practices

- Developing and using models.
- Constructing explanations.
- Obtain, evaluate, and communicate information.

Crosscutting Concepts

- Cause and effect.
- Systems and system models.

Next Generation Science Standards

- Forces and interactions (K-5, 6-8, 9-12).
- Gravitation and orbits (6-8, 9-12).

For the Educator

Facts you need to know

1. For any body in orbit such as a moon or planet, the force of gravity always pulls toward the center of the primary body. For example, the Earth’s gravity always pulls the Moon directly toward the center of the Earth.
2. If you draw a line from the center of the Moon to the center of the Earth, the Moon’s momentum is always perpendicular to this. In other words, the Moon’s momentum would take it off into space on a straight line. This is true for any body in orbit.
3. It is the combination of straight-line momentum, and a center-seeking gravitational pull that produces a smooth, elliptical orbit. The realization that an orbit required only two things acting on a moon or planet was Robert Hooke’s stroke of genius.

Teaching and Pedagogy

One thing that Galileo noted about a simple pendulum – a weight suspended by a string – is that the pendulum mass always passes under its point of rest. That is, if we hang a weight by a string, and mark the point directly under the unmoving weight, we have found the ***point of rest*** for that pendulum. Pull the weight back and release it, the weight will travel straight back and pass over that point, ***no matter which direction we start from.***

You may also notice that if the pendulum is at rest, the string points ***directly to the center of the Earth.*** Any time we drop an object, letting it fall straight downward, the object also falls directly toward the center of the Earth. It is this connection between gravity and pendulums that Robert Hooke noticed and later used in his demonstration.

Gravity always pulls objects toward the center. Every object on our planet falls toward the center of the Earth, every planet is pulled toward the center of the Sun. Gravity is a ***centripetal,*** or center-seeking force. Pointing out this connection between gravity and pendulums will start your students thinking more deeply about gravity!

This is a fun and simple activity, but it seems to fascinate everyone. Students of all ages love to play with this mechanism and see how circular or how elliptical an orbit they can create! My suggestion to you is: let them play! As we have seen before, playing with scientific models is a wonderful way to build deep cognitive understanding of how Nature works. Our job as teachers is not to limit the play, but to reinforce the intuitive learning and help students acquire the vocabulary and fluency to express what they have learned to others (and on assessments!)

If you have a ‘Back to School’ night or PTA night, even a science fair, this is a great project for students to use to demonstrate what they have learned. The adults who see this will be just as impressed as the children were the first time they saw the demonstration;

not because you can make a weight circle a pendulum, but because of the deep links that can be drawn between the pendulum's elliptical motion and the Moon's orbit in space!

Student Outcomes

What will the student discover?

1. Gravity is a ***centripetal***, or center-seeking force.
2. Gravity's center-seeking action is at play whether we consider a pendulum, or a moon in orbit around a planet.
3. Center-seeking gravity and a perpendicular momentum are the only things necessary to produce a smooth planetary orbit.

What will your students learn about science?

1. Sometimes science progresses not because of great friendships, but because of great rivalries. Isaac Newton and Robert Hooke were bitter rivals who competed with each other almost all their lives.
2. Hooke's pendulum is an extremely simple idea. People have wondered for centuries why Newton didn't think of the idea himself, but sometimes genius can be found in simplicity as much as in complexity.

Conducting the Activity

Materials

1. A pendulum weight and a string for each student or group of students (see Activity 13).
2. A piece of paper with a large dot on it (dot stickers, markers or crayons work well).

Building Hooke's Pendulum

1. You can use the same pendulum materials you constructed for Activity #14; a board suspended between two chairs or two desks with a cup-hook attached underneath.
2. Hang your pendulum mass by attaching its string to the hook beneath the board. It is essential for this experiment that the board is sturdy and that it is held firmly in place so that it cannot wobble or move as the pendulum swings.
3. Place a piece of paper with a central dot on the floor beneath the pendulum – it is best if the pendulum weight hangs no more than a few centimeters above the center dot. Now your apparatus is ready to go.

Exploring Hooke's Pendulum

1. Hold the string so the pendulum is motionless with the weight suspended over the dot. Pull the pendulum back a few inches and release the weight carefully.
2. Notice that whichever direction you pull the weight back, the pendulum always swings straight back toward the dot in the center. Hooke said this 'modeled gravitational attraction', that is, like gravity, the pendulum is always pulled toward the center. The Sun's gravitational pull tugs every planet straight toward the center of the solar system in this way.
3. Now try something different: pull the pendulum weight back as before and give the weight a little shove toward the side as you release it.
4. Instead of swinging straight back toward the dot in the center, the weight now ***orbits around the center***. With a little experimentation, the students will find that it is almost impossible to make the weight go around in a perfect circle. Instead, the weight most naturally follows and ***elliptical path***, an off-center oval shape which causes the weight to travel sometimes closer to the center, and then sometimes farther away again.

Discussion Questions

1. How do we know that the pendulum is always pulled back into the center just like gravity?
   - **Answer** Pull the pendulum weight in any direction you wish. Hold it for a moment, then release it; the weight always swings right back toward the center point! If you drop a rock from anywhere on Earth, it will do the same thing – it will fall directly toward the center of the Earth; we call this 'falling straight down.'
2. Is it really impossible to have the pendulum weight go in a perfect circle?
   - **Answer:** No, just very difficult. You must precisely balance the force of your shove (momentum) with the pull toward the center (gravity). Even if you do this, the friction at the top of the pendulum will slow the weight down and cause it to shift into an elliptical motion in just a few seconds.
3. Is this really the way that gravity and orbits work?

- **Answer** Yes. Among other things, Robert Hooke took the time to prove mathematically that his pendulum and an orbiting moon are mathematically identical!

Supplemental Materials

Going Deeper

Robert Hooke lived at the same time as Isaac Newton, but he is far less well known. Some of Hooke's work included designing mechanical devices and the use of the microscope to describe accurately small insects, animals, and cells.

Dive into some of Robert Hooke's work and see how much the little-known man contributed to modern science!

Being a Scientist

The ***elliptical orbit*** (oval shaped) is known to be the universal form for all orbiting bodies in the universe. Circular orbits are possible, but this is an unstable arrangement, like balancing a pencil on its point. As a pencil will quickly fall one way or another if balanced on its point, any circular orbit will quickly decay into an elliptical form.

Can you make a circular orbit using a pendulum? How many rotations does it take before the orbit becomes definitely elliptical (oval) in shape? Experiment with Hooke's pendulum and see what you can find out!

Following Up

Natural orbits are one thing, controlled orbits are another. Do an internet search and see if you can find the flightpath for the Apollo moon missions, one of the Mars rover spacecraft, or the Cassini or Juno space probes. These spacecraft have beautiful and complex orbits, controlled by engines and precise controls either from astronauts or from ground control scientists.
