Activity 2: Orbits

Materials List:
Computer with an Internet connection
Analog bathroom scale & elevator (or YouTube)

Last time we learned about the force of gravity and Newton's realization that the force that pulls an apple to the Earth is the same force that holds the Moon in orbit around the Earth. But if that's the case, then why doesn't the Moon fall down to the Earth just like the apple did? Why doesn't the Moon collide with the Earth? Today we will investigate that question and in the process learn about the nature of orbits.

Part 1: Newton's Cannon[1]

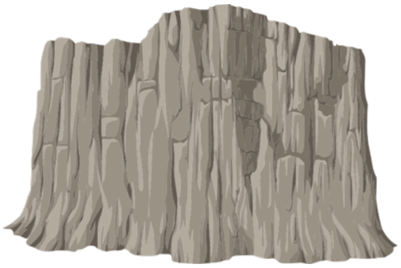
Isaac Newton performed a famous thought experiment that we now call "Newton's Cannon."

Aside:

A **thought experiment** is an experiment that you conduct in your mind only, because (perhaps given the limitations of technology) it is not an experiment that you could actually conduct physically. We will frequently conduct thought experiments throughout the semester in this class.

In this case, we will repeat Newton's thought experiment and then use a simulation to explore it further.

STEP 1: Imagine you are standing at the edge of a tall cliff. You throw a football off the cliff. Draw a line that shows the path the football might take. (First draw yourself standing at the edge of the cliff, if you want.) To simplify the path of the ball, let's assume that you initially threw the football horizontally.



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[1] Parts of this activity adapted from the Hands-on-Science lab manual from UTeach, College of Natural Sciences, The University of Texas at Austin.

Now an NFL quarterback stands at the edge of the cliff and throws a football. Draw another line for the possible path of his football throw. Again, assume he throws it perfectly horizontally (but with much more force than you did).

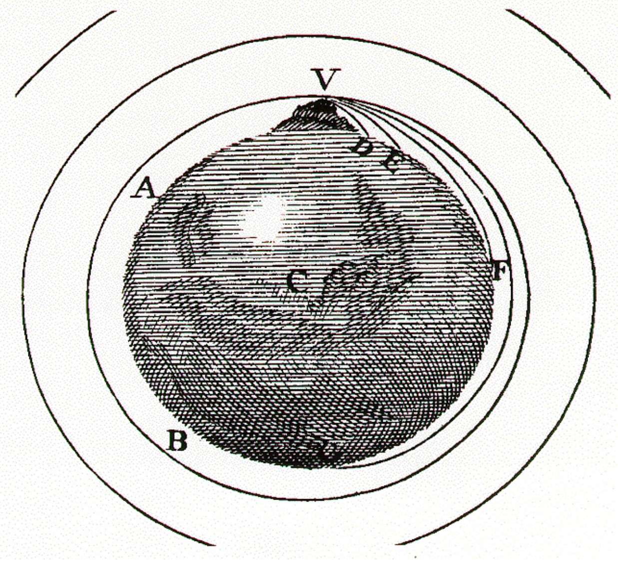
What if, instead of an NFL quarterback, we had a cannon? Say we use the cannon to fire the ball horizontally. What would happen to the path the ball takes compared to the quarterback's toss? Draw another line on the cliff above.

Suppose we had an even bigger (more powerful) cannon and tried it again. And then an even bigger cannon. What is going to change about the path of the balls (and their ultimate resting places) as the cannon gets more and more powerful?

STEP 2: The ground is not really flat. Over large distances it is noticeably round. So when we fire the ball out of the cannon, where is the ball going to land, taking into consideration the fact that the surface of the Earth is curved? Let's investigate this using a simulation.

Open the simulation at the following URL:
http://galileoandeinstein.phys.virginia.edu/more_stuff/flashlets/NewtMtn/home.html

This simulation was made based on a drawing published by Newton himself in 1687 (pictured at right). Experiment with the simulation and see what happens as you increase or decrease the initial velocity of the cannon ball.



What is causing the cannonball's path to curve? In other words, why doesn't it move in a straight line going away from the cannon?

What does it mean to say something is "falling"? Try to answer this question without using the word "down". Hint: Remember last week when we discussed what *down* actually means.

Using your definition above, would you say the cannonball is “falling” when it follows the paths that land at D, E, or F in Newton’s drawing? Why or why not?

Would it be possible to give the ball a speed that causes it to come all the way back around and hit you in the back of the head? Try to find out using the simulator.

Write down the initial velocity of the cannonball that circled all the way around the Earth.

In the case where the cannonball came back to hit you in the back of the head, would you still say the cannonball is falling (i.e., does it still meet your criteria for “falling”)? Why or why not? Discuss your answer with the instructor.

If you double the firing speed you wrote down above, what happens to the cannonball’s path?

If you halve the firing speed you wrote down above, what happens to the cannonball’s path?

SQ1: Summarize in your own words what it is that determines whether an object will circle the Earth and hit you in the back of the head (versus landing on the Earth or escaping from the Earth).

What we have just done is repeated Newton’s thought experiment that showed that orbiting and falling are not two distinct things, but rather the same thing.

And as the cannonball falls, it keeps overshooting the Earth because the Earth curves away, and so it never stops falling.

Orbits

When something is **orbiting**, it is **falling**!

When something "falls forever", we call this an **orbit**.

Part 2: Orbits

STEP 1: Let's experiment with orbits now using another simulation. Open the following http://galileoandeinstein.phys.virginia.edu/more_stuff/Applets/Kepler/kepler.html

Play around with the simulation. Can you make a planet orbit the Sun?

In some cases, you have probably accidentally made a planet that crashes into the Sun (if not, try to make it do so). What were some of the circumstances that led to a planet crashing into the Sun?

In general, for an object to orbit, roughly what direction could its speed initially be (select one or more answers below)? If you're unsure, use the simulation to find out.

a) Directly towards the Sun
b) Directly away from the Sun
c) Perpendicular to the direction gravity is pulling

STEP 2: Create a planet with a speed that is perpendicular to the direction that gravity is pulling it. Give it a small velocity. What happens to it?

Now repeat the previous step (placing a planet with a speed perpendicular to the pull of gravity) but give it a large velocity. What happens to it? Note: If the planet goes out of view, try a slightly smaller velocity.

How are these two scenarios (small velocity vs large velocity) and their outcomes similar to what you saw while doing the Newton's Cannon thought experiment?

STEP 3: Can you create a (nearly) circular orbit? Try it now, paying attention to how far away from the Sun you start the planet and how big its initial velocity is. It is helpful here to turn on “Predict orbit when dragging”.

Repeat the previous step (creating a nearly-circular orbit) but this time make the initial velocity *slightly smaller* than the velocity required for a circular orbit (but still big enough that it doesn’t crash into the Sun). Describe the *shape* of the orbit in your own words.

Repeat the previous step again but this time make the initial speed *slightly larger* than the speed required for a circular orbit (but not so large that it leaves the view). Describe the *shape* of the orbit in your own words.

STEP 4: If you said “oval” in your previous two answers, great. The word that scientists and mathematicians use is **ellipse**. An orbit that is shaped like an ellipse is called an **elliptical orbit**.

SQ2: By now you’ve seen four possible outcomes for an orbit, which are listed below. For each outcome, write a short description of what the initial perpendicular velocity of the planet is in order to create that outcome. The first one has been done for you.

Circular Orbit	The speed is “just right”; not too fast, not too slow
Collides with Sun	
Escapes from the Sun	
Elliptical Orbit	

Could your answers in the previous table also apply to Newton’s Cannon, in which a cannonball did or didn’t orbit the Earth? Why or why not?

Part 3: Is There Gravity in Space?[2]

A common belief among the public is that: if astronauts on the space station are weightless, then there must not be gravity in outer space. In this Part, we will examine that belief.

Earth's gravity pulls on the Moon (and by Newton's 3rd Law, the Moon pulls on the Earth, too) which is why the Moon is in orbit around the Earth.

The International Space Station is also orbiting the Earth and it orbits much closer than the Moon does. Do you think Earth's gravity pulls on the space station? Why or why not?

Suppose you are an astronaut floating in-between the Earth and the Moon. Would there exist a gravitational pull on you from either the Earth and/or the Moon? Why do or don't you think so?

If you answered yes to the previous question, then why would one say there is no gravity for astronauts that are in orbit? Of course we've all seen videos of astronauts that are "weightless" in the space station. Why are they weightless? Let's find out.

As you may have noticed when riding an elevator, it seems like your weight fluctuates during the elevator ride. Does it really? What would happen if you were to stand on a bathroom scale while riding an elevator? Let's try it.

> NOTE: If you do not have access to an elevator, you may watch the following video in which Prof. Baumann performs the experiment and then use his results to answer the questions below.

https://youtu.be/Qi3bXvN2a-4

Take the bathroom scale and assign one person in your group to be the guinea pig (who doesn't mind their weight being revealed; if no such person exists, the instructor will be your guinea pig) and one person to be the recorder.

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[2] Parts of this activity adapted from the Hands-on-Science lab manual from UTeach, College of Natural Sciences, The University of Texas at Austin.

STEP 1: Have the guinea pig stand on the scale in the classroom. Record the scale's reading (which we're calling your "weight") when they are standing still.

Classroom Weight =

When you are standing in the classroom, let's think about whether the forces on you are balanced (i.e., net force is zero) or unbalanced (i.e., net force is nonzero).

Besides the force of gravity, the only other force you need to consider on you right now is how hard the scale is pushing up against the bottoms of your feet. This is called the **normal force**. So gravity pulls down and the normal force pushes up. They are in opposite directions. Are they equal or unequal? How can you tell based on your motion? Use Newton's Laws!

STEP 2: Walk down the hall to the 3rd floor elevator (or watch the YouTube video of Prof. Baumann linked above). The guinea pig need only bring the bathroom scale and only the recorder needs to bring a pen and this paper. The rest of the group should go along for the ride. Read the entire procedure below BEFORE getting on the elevator.

PROCEDURE: Starting on the 3rd floor (where the classroom is), get on the elevator (going down) and select the 1st floor. Before letting the doors close, let the guinea pig step onto the scale. The guinea pig should carefully watch the scale throughout the elevator ride. When you get down to the 1st floor, select the 3rd floor. The second half of the experiment happens while riding up.

> During the ride, have your guinea pig answer the following questions (the circumstances will occur in the order given):

1) What happens to your weight when you're on the 3rd floor and the elevator *first begins* its descent? Compared to your classroom weight, does the reading go up, down, or stay the same?

2) What happens to your weight when you're on your way down moving *at a steady pace*? Again, compare to your classroom weight.

3) What happens to your weight when you're on the 1st floor and the elevator *first begins* its ascent? Compare to your classroom weight.

4) What happens to your weight when you're on your way up moving *at a steady pace*? Compare to your classroom weight.

Once you have these four observations you can now return to the classroom.

The scale's reading changed during the elevator ride. Do you think that the Earth's gravitational pull on you changed while riding in the elevator? Hint: If you were standing on a scale on the 3rd floor and then standing on a scale on the 1st floor, would you expect the readings to be noticeably different?

The scale only reports what force it pushes with (i.e., the *normal force*), which is *not* necessarily the same as what the force of gravity is. To prove this to yourself, place the scale flat against a wall and push it with your hands. Does the reading still go up? Is that because the pull of Earth's gravity on you changed?

Gravity and the normal force in our experiment were always in opposite directions. But how did their *strengths* compare during the experiment? Let's do this carefully, case by case.

For each scenario below, answer the following questions:

(a) What would you conclude about the force of gravity and the normal force: are they equal or unequal?
(b) What is your evidence for your answer to (a)? Think about your motion and use Newton's Laws and balanced/unbalanced forces.
(c) If the forces are unequal, which one is smaller?
(d) What is your evidence for your answer to (c)? Use what we learned about unbalanced forces and the *direction* of motion.
(e) And, does the measurement you took on the scale agree with your answer in (c)? How so? If it doesn't, you might want to reconsider your analysis of the scenario (i.e., parts a through d).

1) When you first begin your descent and your *speed is changing*: you're going from being at rest to being in motion going downward.

(a) Normal force (=) / (≠) Force of gravity

(b) Justify your answer to (a) using your motion and Newton's Laws.

(c) If ≠, which force is smaller? Normal force Force of gravity

(d) Justify your answer to (c) in terms of unbalanced forces and the direction of your motion.

(e) Did the scale's reading agree with your answer to (c)? How so?

2) While you are moving downward a steady rate and your speed is *not changing*.

(a) Normal force (=) / (≠) Force of gravity

(b) Justify your answer to (a) using your motion and Newton's Laws.

(c) If ≠, which force is smaller? Normal force Force of gravity

(d) Justify your answer to (c) in terms of unbalanced forces and the direction of your motion.

(e) Did the scale's reading agree with your answer to (c)? How so?

3) When you first begin your ascent and your *speed is changing*: you're going from being at rest to being in motion going upward.

(a) Normal force (=) / (≠) Force of gravity

(b) Justify your answer to (a) using your motion and Newton's Laws.

(c) If ≠, which force is smaller? Normal force Force of gravity

(d) Justify your answer to (c) in terms of unbalanced forces and the direction of your motion.

(e) Did the scale's reading agree with your answer to (c)? How so?

4) While you are moving upward at a steady rate and your speed is *not changing*.

(a) Normal force (=) / (≠) Force of gravity

(b) Justify your answer to (a) using your motion and Newton's Laws.

(c) If ≠, which force is smaller? Normal force Force of gravity

(d) Justify your answer to (c) in terms of unbalanced forces and the direction of your motion.

(e) Did the scale's reading agree with your answer to (c)? How so?

SQ3:

(a) Only one force is changing during the elevator ride. Which force is it, the force of gravity or the normal force? Explain your reasoning.

(b) Of the four scenarios that we examined, during which was the normal force smallest? If we think of the normal force as the force exerted upward on us by the floor of the elevator, why does it make sense that it would be a minimum when it was?

(c) During which was the normal force largest? Why does it make sense that it would be a maximum when it was?

SQ4:

(a) If the elevator were to make a more sudden drop in scenario 1, how would the normal force be different than the one you measured during your elevator ride?

(b) Taking this to the extreme, if someone were to "cut the cable" on the elevator and let it drop with you inside it (this is called "**free fall**"), what do you think the reading on the bathroom scale would be? Remember, the scale is only reporting the *normal force*.

Weightlessness

When we say **weightless**, what we *really* mean is: *the normal force is zero*.

Free fall **is** weightlessness, because in free fall the normal force on you is zero (the bathroom scale reads zero).

The fact that *free fall is weightlessness* is used to train astronauts.

The photo of the weightless astronauts at right (taken in 1959) was taken on an airplane, not in space. The airplane flew up to a high altitude and then allowed itself to plummet towards the Earth, putting the airplane and everyone inside of it into free fall.

Well before crashing into the ground, the airplane pulls up sharply and returns to its original altitude, and then plummets again for another bout of weightlessness. This up-and-down flightpath is repeated 40 to 60 times. You can probably imagine why astronauts nicknamed this airplane the "vomit comet".

https://commons.wikimedia.org/wiki/File:Mercury_Astronauts_in_Weightless_Flight_on_C-131_Aircraft_-_GPN-2002-000039.jpg

Was gravity pulling on the astronauts during the airplane's descent? If so, then why did they experience weightlessness?

A similar technique was used to film the weightless scenes in the movie *Apollo 13* (*optional homework:* If you've never seen *Apollo 13*, go watch it!) by putting the actors, set, personnel, and the studio equipment inside a large empty airplane. Each period of weightlessness (while the airplane is in free fall) lasts about 25 seconds. If you watch *Apollo 13* closely you might notice that all of the weightlessness scenes are made up of many short takes. Why is that?

SQ5: Is there gravity in space? Give one or two astronomical examples that support your answer.

SQ6: If there is gravity in space, then why do astronauts feel weightlessness on the space station? Hint: Look back at the two boxed statements in this Activity (pages 4 and 12) and see if you can connect them.