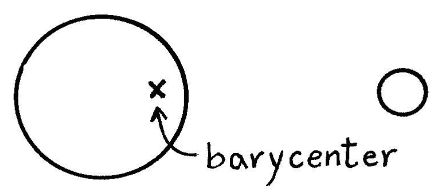
HOW GRAVITY WORKS IN OUTER SPACE

We all know how gravity works on earth. We drop an object and it falls to the ground. But what about in outer space? Is there gravity in outer space?

Isaac Newton declared that the same gravitational force that pulled apples to the ground also keeps the moon in orbit. The moon is very far away, so earth's gravity must reach far into space. Because we see astronauts floating around in space we assume that there is no gravity there. But if the earth can keep the moon in orbit, its gravity must be strong enough to keep a space ship in orbit! In fact, there is almost as much gravity pulling on the space ship when it is in space as there is when it is resting on the ground before launch. The difference in small. So what's the deal with zero gravity? The answer is that the astronauts are actually in continuous free fall, which looks and feels like zero gravity, but isn't. The earth's gravity is pulling on them, but since they are falling (as they orbit) they don't feel the effects of gravity. It's free-fall, not zero gravity.

For a short video discussing the apparent weightlessness of astronauts in space, search YouTube using keywords "Veritasium, why are astronauts weightless." The video is brief, fun and very informative. Another short video you might enjoy is "Scishow, Is there gravity in space."

The moon, also has gravity. In fact, every object in the universe has gravity. Large objects have a lot of gravity and small objects have a small amount of gravity. All objects pull on each other. The earth pulls on the moon and the moon pulls on the earth. We can see the pull of the moon when be observe the ocean tides. In fact, it is slightly incorrect to say that the moon orbits the earth. Technically, they orbit each other. However, the earth is so much larger, and its pull so much greater, that it looks very much like the moon is going around the earth. If the earth and the moon were the same size, they would circle each other. It would look like they were swirling around some central point in space. As it is, the earth and moon do swirl around a central point, but that mathematical point is inside the earth, somewhere between the center and the crust. It is around that point that the earth and moon orbit each other. But that point is close enough to the center of the earth that it appears to us that the moon is simply orbiting the earth.

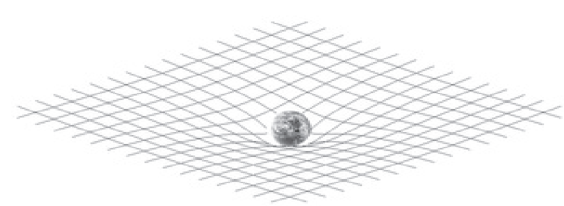


The point about which the earth and moon orbit is shown by the X and is called the "barycenter."

Earth's gravity dominates every object on, or near, the earth. There is no way we can accurately simulate the environment of deep space because every part of our experimental equipment would be affected by gravity. (Okay, we could go up in that special airplane, the "Vomit Comet," where you can experience weightlessness for about 30 seconds at a time, but that is hardly long enough to run many experiments, and you still have not really *escaped* earth's gravity anyway.) The only semi-valid way to experiment with gravitational effects in space is to make a fabric vortex, But first we must know why this model is valid.

Einstein spent almost a decade thinking about gravity and began to question the traditional concept of gravity (as a force that pulls things down). He came up with a stunning new concept about how gravity works. His theory stated that gravity should not be thought of as a force pulling things down, but rather a warping of the "fabric" of space. Einstein believed that empty three-dimensional space is not nothing. Space itself is something. It is a three-dimensional "field" that gets warped and twisted by objects. Small objects don't warp it very much. Large objects warp it substantially. A two-dimensional model of space can be created by putting a piece of stretchy fabric over the top of a round ring, like the rim of a bowl. If you set a ball in the middle of the fabric, it will pull the fabric down into a circular V shape. A heavier ball will sink further, pulling and stretching the fabric down even more. The entire area affected by the weight of the ball can be called the "sphere of influence" of the ball.

For a short video showing the "fabric of space" search YouTube for "Brian Green, Einstein's gravity." This will likely give you a short video taken from the longer NOVA program called "The Elegant Universe." This short video shows a computer animation of how Einstein visualized gravity.



Our stretched fabric model of gravity is not perfect for two main reasons. First, it is not three-dimensional. Second, there will be a high amount of friction as we roll balls across the fabric. In outer space there is basically no friction. Without friction, objects in space can travel for a very long time without slowing down. On the fabric, our balls will slow down quickly because of the friction created as they roll across the fabric. We could get rid of some of the friction by making the curved surface perfectly smooth, like those coin vortex things you see at museums and in malls. The coins roll for a very long time because the surface is so smooth. However, the drawback to using plastic is that your surface is not flexible. You are stuck with that particular vortex shape and can't change it. With our stretchy fabric model we can make a shallow vortex with a small ball or a very deep vortex with a heavy ball. We can also place multiple objects on it, making several smaller dents. Thus, we must decided to put up with more friction in order to have the flexibility of being able to change the shape of the vortex.

In our fabric model, the circular dent the object makes into the fabric is going to represent its gravitational field, or its "sphere of influence." According to Einstein, gravity is the warping of a field, so our model has some validity, albeit in a two-dimensional way.

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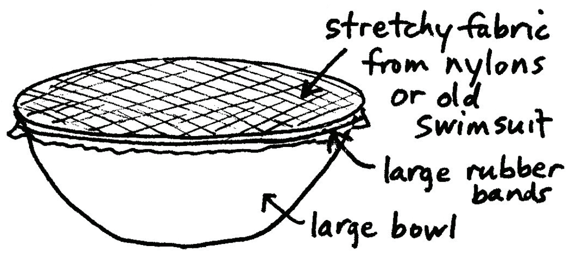
How to make your experimental device:

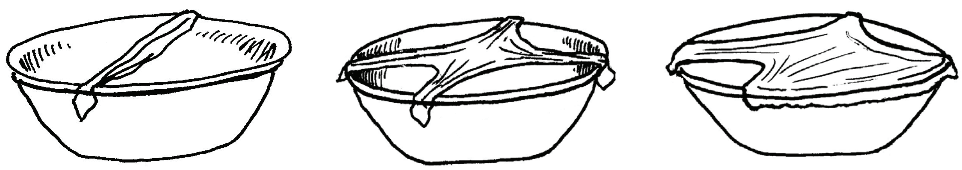


<u>You will also need:</u>
-- half a dozen marbles
-- two golf balls
-- a ping pong ball (two, if possible)
-- some tiny balls (such as BBs, or any tiny, round balls smaller than peas)
-- other balls you want to experiment with

NOTES:

If you have a very large mixing bowl, try to get a queen size pair of nylons ("panty hose") so you have plenty of fabric to work with. Cut a large piece of nylon that has no seams in in. An old bathing suit (made out of Spandex) might work, too, if you can't get a pair of nylons. Office supply store carry very large rubber bands.

Put the rubber bands under the rim of the bowl. (Mulitple bands are recommended, but you might be able to use just one.) Tuck one part of the fabric under the bands on one side of the bowl. Then tuck a bit of fabric under on the opposite side. Then do the perpendicular sides. Now begin pulling the fabric under, bit by bit, around the remaining portions, between those tucks, until you have the fabric stretched tightly and evenly across the top.



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EXPERIMENTS:

1) How large is a marble's sphere of influence?

Set two marbles onto the fabric, far enough apart that they stay put and don't roll toward each other. If they can remain motionless then neither is being affected by the other's gravity. Now move them toward each other just a bit. They will probably still be able to remain motionless when you take your fingers away. Now move them a tiny bit closer. Again, a tiny bit closer. You will reach a point at which their spheres of influence (where they are warping the fabric) will overlap. At this point, as their spheres of influence touch, they will no longer be able to remain stationary. They will start to roll toward each other. Try it again and see if you get the same results.

Conclusion:
The sphere if influence of my marbles seems to be about __________ in diameter.

2) Which (primarily) determines an object's sphere of influence: volume or mass?

We've already determined a marble's sphere of influence. Now what about some other objects? Try the same experiment with tiny balls (such as BBs or any other round objects you might have that are smaller than the size of a pea), with ping pong balls, and with golf balls. Estimate the approximate sphere of influence for each object. (You can use centimeters or inches.)

Spheres of influence:
Ping pong ball: __________________ Tiny ball: _________________
Golf ball: ___________________ ___________________: _____________
other

A ping pong ball is much larger than a marble. Does it have the same sphere of influence? _________
A ping pong ball and a golf ball are about the same size. How do their spheres of influence compare? ___
____
If you had a lead ball that was the same size as a marble, how do you think its sphere if influence would compare to that of a regular marble? ____
Imagine a large soap bubble landing on the fabric. Would it press down the fabric very much?_________

Conclusion:
Which has more effect on an object's sphere of influence-- mass (weight) or volume (size)? _________

3) What happens to individual particles floating in space?

Put several marbles onto a smooth, flat plate. The plate cannot be stretched because it is a hard surface. It is not a good model for gravity experiments, but it does let us see what would happen if objects did not have any gravity. Roll the marbles around on the plate and see what happens. Do they join together for form a group, or do they stay separate? Move the plate and try to get them to join. Can't do it? The plate is modeling the absence of gravity—something that does not exist as far as we know. You can't remove gravity from the universe. But it is helpful to us to see what might happen (or not happen) without gravity.

Now move the marbles to the fabric. Place them far enough apart that they are out of, or at the edges of, each other's spheres of influence. Begin to gently move the bowl around. This gives the particles some kinetic (movement) energy without having to touch them. As the particles begin to move around they will begin to come within each other's spheres of influence. What happens? Do they all eventually join together? Roll them around on the fabric. Our experiment with the plate proved that the marbles have no natural attraction for each other. What is keeping them together? In our model, the fabric is being indented. This indentation represents the force of gravity (according to Einstein's way of thinking about gravity).

Conclusion:
If individual particles meet in space and get close enough they are likely to __________________________

4) What happens to moving particles (or objects) in space?

What if particles (or even larger objects) are moving through space when the meet each other? What happens then? There are several ways objects could meet in outer space. They could be moving in opposite directions, they could at an angle, or they could be traveling in a somewhat parallel direction. What would happen in each of these scenarios?

Take 2 marbles and roll them across the fabric, heading toward each other. Do this a number of times. Do they ever collide? What happens when they barely miss? Do they ever join together? (When they reach the other side, they will naturally reverse their course and head back toward center. Stop the marbles before they do this. In this experiment, each "trial" will be over after the marbles make one pass across the fabric.)

Now roll the marbles at a perpendicular angle. How often do they collide? Do they ever join? (Remember, stop the marbles when they get to the edge, then start a new trial.)

Now try rolling them in a similar direction. They don't have to be exactly parallel. Do this a number of times. What happens? Do the marbles ever join together before they get to the other side? Did this happen in our past two trials?

Lastly, roll them in the same direction but at different speeds. Do this a number of times. Does traveling at different speed help or hinder them from joining? ________________________

Conclusion:
Objects traveling in space are much more likely to join together if they are traveling __________________ ____

EXTENSION:

Comets are clumps of ice crystals, gas molecules, and particles of dust and rock, very loosely held together by their own gravity. (A comet has the density of meringue. It can be pulled apart very easily.) How likely is it that these particles would have joined together if they were wandering randomly (at different directions and different speeds) in space? How likely is it that they would join together if they were all traveling in the same direction at about the same speed?

5) How might a planet "capture" a moon?

Place a golf ball in the center of the fabric, then place a marble at the edge of the fabric. Gently push the marble toward the golf ball. Try not to give the marble much momentum. You want the only force acting on the marble to be the sphere of influence of the golf ball. What is the end result of this interaction? Where did the marble end up?_______________ Did the marble go into orbit around the golf ball?_____ (An orbit is defined as a making at least one complete circle around the golf ball.)

Now start a second trial, but give the marble some velocity this time. Roll the marble quickly, aiming so that the marble goes past the golf ball. What is the end result? Now push down on the golf ball, as if it weighed more (had more mass). Now roll the marble again. The marble should start swirling around the golf ball. It is now in orbit! (The orbiting won't last very long, as the marble is constantly being slowed down by the friction created by the fabric. In space, there is no friction so the marble would keep on going for a long time.)

What happens if you give the marble a whole lot of velocity?____________________________

What would happen, then, if an object drifted past a planet at a very slow speed? Would it go into orbit or would it fall down and land on the planet? ______________________

What would happen if an object went past a planet at a faster speed? Would it plummet straight down, or would it go into orbit? ______________________________What would happen if this orbit ever slowed down? __________________________

What if an object goes past a planet at a very high velocity. Might it escape being captured? _______

EXTENSION:
Is it likely that the moons around the planets started out as asterioids drifting slowly through space? ____
What would they have needed in order to begin orbiting? _____________________
What would happen if an orbiting moon suddenly encountered friction? ___________________________

6) Can a small planet have a large moon?

Place a marble in the center of the fabric. Roll a golf ball across so that it starts into orbit around the marble. How long does it stay in orbit? What happens in the end? Do this several times to confirm your results.

Try this again with a ping pong ball instead of a golf ball. Does the ping pong ball "stay in orbit" any longer than the golf ball did? _______ A ping pong ball and a golf ball are about the same size. Why, then, are the results so different? ____

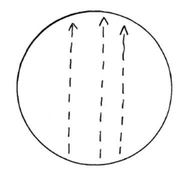
Try it one last time with two marbles, then with two golf balls. Does one end up orbiting the other, or do they orbit each other equally? _____________

Conclusion:
Can a small planet have a large (more massive) moon? _________ What would happen if a planet's moon was the same mass as the planet? ____

7) What does "perturbation" mean?

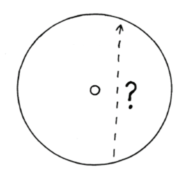
If you read about the discovery of Uranus, Neptune, and Pluto, you will almost certainly be introduced to the word "perturbation." In daily life, if you are "perturbed" about something it means you are bothered about it, or irritated by it. In astronomy, being perturbed means being gravitationally affected by something. A comet's orbit can be perturbed as it passes by a large planet like Jupiter. Jupiter gives the comet a tug and changes its orbit a bit. The orbit of a planet can be perturbed by the gravitational effects of other planets.

Astronomers use mathematics to determine the path that planets "should" follow assuming they are not bothered (perturbed) by anything. These calculations are very accurate and can predict where a planet "should" be at any given time. If a planet goes on a slightly different path than predicted, this means it is probably being affected by the gravitational pull of another planet or of a passing comet or asteroid. Often, astronomers can't even see this other object; they only observe its effects on the planet they are looking at. The existence of the outer planets was proposed even before they were actually seen in a telescope. Astronomers detected anomalies in the orbits of the known planets, so they guessed that there must be unknown planets out there tugging on the known ones. They were right.



Roll a marble in a straight line across the fabric. Roll it across again, several times. Make some rolls cross the middle and make other rolls away from the center. Does it generally roll straight across? _______

Now place a marble in the center of the fabric. Then try rolling another marble past it. Can you still make the marble travel to the other side in a straight line? If not, why not? ____



Roll the marble past again, this time watching the stationary marble in the center. Does that marble move at all—even a tiny bit? ________

Put a golf ball in the middle of the fabric and roll a marble past it. Is it easier or harder to get the marble to travel in a straight line? ________ Watch the golf ball as the marble rolls by. The golf ball is much bigger than the marble. You might think it would not be affected by the brief presence of a tiny marble. Is the golf ball perturbed as the marble passes by? ________

8) Preferential direction of orbiting bodies

Is the direction that moons travel about a planet just random? Watch this 9-minute video on YouTube to see an experiment about this question, using a stretchy fabric vortex similar to your, only much larger. If your stretched fabric is large enough perhaps you could try this yourself/

Search on YouTube using keywords: "Gravity Visualized."

9) What about two focal points of gravity?

What would happen if your piece of fabric was large enough to allow two balls to have their own sphere of influence. What would happen if you rolled marbles into this "binary system"? If you want to see this experiment, plus a few others, go to YouTube and search for "Operation Spandex."

ANSWERS:

1) Answers will vary. Probably a few centimeters or so.

2) Answers will vary.
A ping pong ball should have a smaller sphere of influence than an marble because it has less mass.
A golf ball will have a much larger sphere of influence than a ping pong ball because it is more massive.
A lead marble would have a greater sphere of influence.
Mass is what primarily determines how much gravity something has.

3) Individual particles can attract each other and form a clump. The only force holding them together will be their own gravity.

4) Objects traveling in space are much more likely to join together if they are traveling in the same direction and at the same speed. Otherwise, it is very difficult for particles to join together.

5) Marbles with very little kinetic energy will end up crashing into the golf ball, not going into orbit. Only marbles coming in with considerable velocity will be able to start orbiting. This is because an object in orbit has forward velocity. If the planet's gravity suddenly disappeared, the satellite would go flying off in a straight tangent line. The planet's gravity keeps it in a circular orbit.
If a passing object has enough velocity, it will not be captured.
If an orbiting object suddenly experienced friction, the friction would slow its speed and the result would be that it would lose altitude and go towards the planet.

6) A small planet cannot have a more massive moon. The less massive object always orbits the more massive one. Two objects of equal mass will orbit each other equally.

7) It should roll straight across at first. After placing a marble in the center, it will be difficult, if not impossible, for the rolling marble to roll straight across. The central marble, or golf ball, will wobble a bit as the rolling marble passes by. It will absorb a tiny bit of the energy of the passing marble.