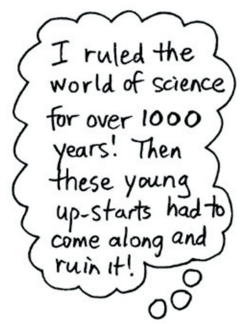
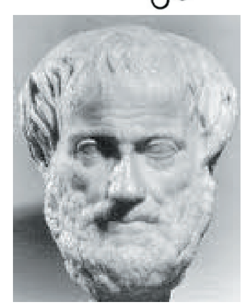
INERTIA AND MASS

What a strange word! How do you even pronounce it? Like this: “in-NER-sha.” The word “inertia” comes from the Latin word “inert,” which means “lazy.” If you’ve studied chemistry a bit, you may have come across this word when you learned about the noble gases (such as helium and neon). These gases are often described as “inert” because they don’t react with any other elements. They aren’t really lazy-- they are just incapable of sharing their electrons. Maybe those early chemists had a bit of a sense of humor when they decided to call atoms lazy.

In physics, inertia describes the natural “laziness” that all objects have. Objects that are sitting still want to keep sitting there and not move. (Sort of like a teenager in front of a computer or a TV.) However, once an object is put into motion, then it will want to keep on moving because stopping would involve more work than just keeping moving. If you’ve ever tried ice skating, you’ll know this to be true. It is easy to keep gliding along. Stopping yourself while on skates takes quite a bit of work!

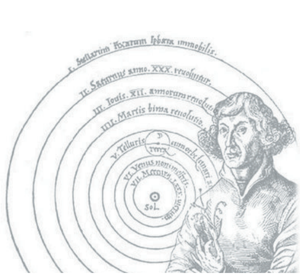
The scientist who officially gets credit for proposing this idea is Isaac Newton. The truth is, however, that Newton was not the first person ever to think about objects moving or sitting still. The idea that we now call inertia has been discussed for over 2,000 years. Aristotle [around 330 BC] said that all objects on Earth want to sit still and remain at rest. But his observations had also led him to conclude that objects in motion do not want to remain in motion, but want to go back to being at rest. Aristotle had seen rolling objects slow down and stop, and it seemed reasonable to assume that this was because the objects wanted to go back to sitting still. Other Greek philosophers thought about these ideas and proposed other theories, but Aristotle’s ideas won out and were generally accepted until the 1300s.





During the Renaissance period (the 1300s) a scientist named Jean Buridan got to thinking about objects and motion. He believed that objects didn’t slow down and stop because they wanted to, but because something was affecting them, causing them to slow down and stop whether they wanted to or not. He also proposed that air was one of the things that acted on objects to slow them down. Buridan brought us a step closer to understanding inertia (though he didn’t call it that). Buridan’s research was continued by several of his students, who refined his ideas and helped science take a few more steps towards modern physics.

In the 1500s, an Italian scientist named Benedetti began studying motion and came to the conclusion that Aristotle had been wrong about many things and that although Buridan was on the right track, he had not discovered one important truth about motion--that the forces that pushed on objects and caused them to move only did so in straight lines. He believed that “pushing forces” could only push in one direction. When we see what looks like curved motion, like a ball following a curved path through the air, it is the result of more than one force affecting the object. This was quite a revolutionary thought.


Copernicus

Also in the 1500s, Copernicus and Galileo added their insights to the study of motion. Copernicus, who was an astronomer, pointed out that objects at rest (as we see them sitting on a table) are not really at rest at all because the table is sitting on planet Earth which is traveling through space at a very high speed, orbiting the Sun. Galileo concluded (after doing many experiments) that “an object moving on a level surface will continue in the same direction at a constant speed unless disturbed.” Galileo later stated that he thought that motion is “relative”, meaning that whether something is in motion or not depends on your viewpoint. (This was an idea that Einstein would develop into his Theory of Relativity.)

Finally, along came Isaac Newton (in the 1600s). Many people don't realize that Newton wasn't the first person to think about objects moving or being at rest. He knew about all of these previous theories. It's a bit unfair to call the principles of motion "Newton's Laws." Newton didn't come up with these ideas completely on his own--and Newton himself knew this was true. He admitted that he was building on the work of scientists that had gone before him, and he once said, "If I have seen further, it is by standing on the shoulders of giants." Newton gets credit for the principle of inertia because he refined these previous ideas, and gave us our modern definition of it.

ACTIVITY #1 ***Watch the first "Eureka!" video (Episode 1: "Inertia")***

This video is a great way to review the idea of inertia. It's in the "Physical Science Stuff" playlist on the Basement Workshop YouTube channel: www.YouTube.com/eejm63. (This series of videos was made by "TV Ontario" in the early 1980s and stars funny little cartoon guys and features very easy-to-understand explanations of the principles of physics.) You can also find the Eureka" videos by searching YouTube, or by using Google search. There are a few websites other than YouTube that post these videos.

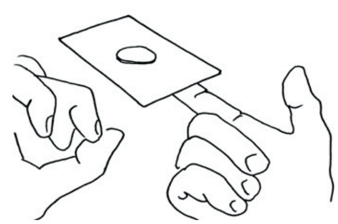
The concept of inertia is pretty simple--objects like to keep doing what they are doing. If they are sitting still, they want to keep sitting there. If they are moving, they want to keep moving. Force is required to get a stationary object to start moving. Force is required to get a moving object to slow down or stop. This concept has come to be known as "***Newton's First Law of Motion***" (often shortened to "***Newton's First Law***"). Yes, Newton gets official credit for this principle, even though Galileo said it first. (At least Galileo did get credit for lots of other discoveries. Poor Benedetti doesn't even get a mention in most physics books.)

However, as the video pointed out, not all objects have the same amount of inertia. The heavier the object, the more force it takes to get it going. And to make it slow down. An airplane is a very large, heavy object, and it takes jet engines running at full throttle to get it going fast enough for take off. Then, when the airplane needs to land, the pilots have to run the engines *backward* at full throttle, but with just as much force as during take off. It takes the same amount of energy to stop a plane as it does to put it in the air.

Here are a few fun activities that demonstrate how the inertia of an object can be used to perform entertaining tricks.

ACTIVITY #2 The coin and card trick

You will need a playing card and a medium-sized or large coin.



1) *Put the coin on the center of the card.*
2) *Balance this on the tip of one finger.*
3) *With your other hand, give the card a quick flick.*

The coin stays on your finger because of its inertia. It's at rest and wants to stay at rest. The motion of the card underneath it happens so fast that the energy is not transferred to the coin. This is a small version of the classic "pulling the tablecloth out from underneath the dishes" trick. If you want to see this tablecloth trick, go to YouTube.com/eejm63, click on the "Physical Science Stuff" playlist, then click on "Tablecloth Trick."

ACTIVITY #3 The old "drop the coin in the bottle" trick

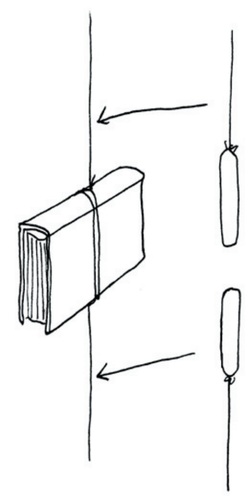
You will need a small coin (such as a US dime), a bottle that has a neck just slightly larger than the diameter of the coin, and a round hoop of some kind. For the hoop, you can use a roll of masking tape, an embroidery hoop, a circle cut from a large, round plastic jug, or even a strip of thin cardboard taped into a hoop. The larger the hoop, the more dramatic this trick looks.

1) Balance the coin on top of the hoop, then balance the hoop on top of the bottle, as shown.
2) Put your finger inside the hoop, then pull the hoop out moving your hand very quickly.
3) The coin should drop right through the neck of the bottle. If the neck of the bottle is just slightly bigger than the coin, this make the trick more amazing. The coins goes right down through the center of the neck!
4) Try the trick again, but this time put your hand outside the hoop instead of inside. Does it still work?

The fact that you had to balance the coin and the hoop ensured that the coin was directly over the neck of the bottle. Gravity is a great help for getting things vertically straight ("plumb"). It's perfect every time! When you pulled quickly on the hoop, the energy from the moving hoop did not have time to get transferred to the coin, so the coin was unaffected by the motion of the hoop. Thus, the coin stayed directly over the neck of the bottle. Then gravity pulled it straight down into the bottle. If you push the hoop from the outside, your finger bends the hoop inward (assuming you have a flexible hoop) and ruins the perfect circle shape. It was this perfect circle shape that helped to keep the coin lined up. The coin loses its perfect alignment and therefore drops slightly off center.

To see an elaborate version of this trick, check out www.YouTube.com/eejm63, playlist "Physical Science Stuff" then click on "Egg Drop Inertia Challenge." In this video, science presenter Steve Spangler drops eggs into glasses of water without breaking them.

ACTIVITY #4 "Hanging by a Thread"



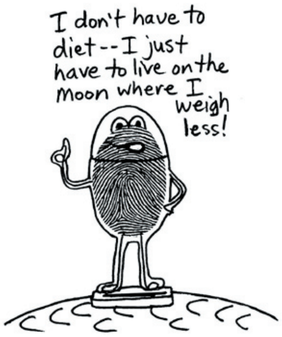
You will need two pieces of thread (each about a meter [yard] long) and a heavy book.

1) Tie the end of one piece of thread around the book. Adjust the loop of thread so the book hangs balanced.
2) Tie the end of the other piece of thread around the book, but so that it hangs off on the other side.
3) Hold one of the threads so that the book hangs in the air with the other thread dangling beneath it.
4) Predict which thread will break if you yank very hard on the bottom thread.
5) Yank! Which thread broke?

You would think the that top thread would break because it already has a lot of weight pulling down on it. It might not be able to take any more weight.

So are all objects equally lazy? Is a pebble as lazy as a boulder? How can you measure how lazy something is? The amount of laziness, or inertia, something has can be measured by finding its ***mass***.

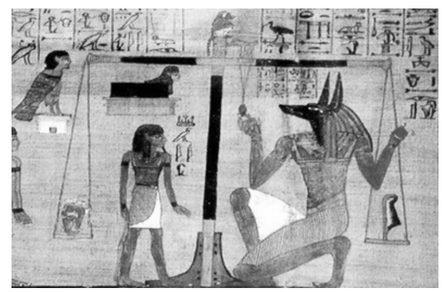
The word "mass" comes from Greek and means "a barley cake or a lump of dough." (If an English word had been chosen for this concept, they might have chosen the word "stuff." Apparently, the Greeks didn't have a word for "stuff.") Mass is usually measured with a scale, or ***balance***. If someone were to ask you what your mass is, your answer would probably be in pounds or kilograms. You would have measured your weight on a scale. The kind of scale you measured yourself on probably depended on gravity. Gravity pulls you down as you stand on the scale and the bigger you are (the more stuff there is for gravity to pull on) the larger the number you register on the scale. This works well as long as you are on planet Earth. Since most of us rarely leave planet Earth, this works out okay. All objects we come into contact with in our daily lives are being pulled down by the same gravitational force, so we can compare weights taken with scales. We can weigh a feather and find that it registers 2 grams on our scale, then we can weigh a small rock and find that it weighs 12 grams. The rock obviously has more mass than the feather. But what if we take our rock off planet Earth and weigh it somewhere else?



If we take our rock and our scale to the moon (leaving our feather behind on Earth) we will find that when we set our rock on the scale, it will weigh... 2 grams! But how can this be? Does this mean that our rock has changed in some way? Did it shrink? How can it weigh the same as the feather?

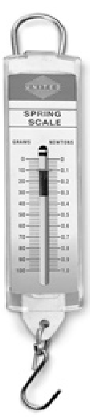
The moon is smaller than the Earth and therefore its gravity is less. The moon's gravity is about 1/6 the gravity of the Earth. If something weighs 6 kilograms on Earth, it will only weigh 1 kilogram on the moon. When we weighed our rock on Earth it weighed 12 grams. Predictably, when we weighed it on the moon, it was 2 grams. Our rock did not change in any way. Its mass stayed the same. Its weight changed because it went to a place with less gravity. Therefore, an object's weight depends on the gravity it is experiencing. Its mass stays the same no matter where it is.

To measure mass (not weight), scientists can use a modern version of a very ancient tool--a balancing scale, sometimes called a "pan balance" or a "hanging balance." You've seen pictures of these in books about life in ancient civilizations. They used them to weigh things like fresh produce or gold dust. This illustration shows the Egyptian god Anubis weighing a soul with a pan balance. The soul sits in one pan (in a little jar on the left) and an ostrich feather sits in the other pan. (The ostrich feather was symbolic of Ma'at, the goddess of truth and justice.) If the pan with the soul in it went down, this indicated that the soul had more mass than the feather, which was very bad news for owner of that soul, as this meant that his or her afterlife would not be pleasant.



Anubis has the head of a jackal (wild dog).

If we took a pan balance to the moon, and set a 12 gram weight in one pan and our little rock in the other, the pans would balance, telling us that the rock's mass was still equivalent to 12 "Earth grams." (You'll see an animation of this in the "Eureka!" episodes listed below.)



This difference between weight and mass can be very confusing. And to make matters worse, scientists also like to use a special unit of measure for weight-- a unit of measure the rest of us never use, and probably don't even know about! This unit of measure is called a ***Newton*** (after you know who) and is represented by the letter N. The type of scale on which you will find Newtons is called a ***spring scale***. It basically consists of a spring attached to a measuring rod. You hang something on the hook at the end of a spring and the weight of the object pulls the spring down. There's a little indicator that points to a number. One side is marked in Newtons. But since no one ever really uses Newtons that much, the other side is marked in grams--a unit we use all the time. So how much is a Newton? One Newton is equal to approximately 100 grams. How much is a gram? We'll discuss before we're done, but first, watch these "Eureka!" episodes. They animate all this information about the difference between mass and weight.

ACTIVITY #5 Watch "Eureka!" epidoses 2 and 7 ("Mass" and "Weight vs. Mass")

You can search for these videos, or you can use the "Eureka!" playlist on YouTube.com/eejm63.

So now we understand that weight is relative to what gravitational field you are in. You'd weigh different amounts on different planets. (On Jupiter you'd weigh so much that your bones and muscles would barely be able to keep you standing up!) The mass of an object does not change as it goes from planet to planet, but its weight changes due to the differing gravitational forces.

So you need gravity to measure how much something weighs. Most of the time we measure mass using grams or pounds because gravity is everywhere all the time--we take it for granted. But what if an astronaut in a weightless environment wanted to measure an object's mass? A regular scale would not work because it depends on gravity. Is there another way to measure mass?

ACTIVITY #6 Measure mass without using gravity (by using an <u>inertial balance</u>)

You will need: a hanger, a small plastic cup (or a sturdy paper one), several dozen coins (can substitute washers, nuts, marbles, or any other small, heavy objects), duct tape, and a watch that counts seconds.

(Note: An alternate way to make the arm of this balance is to use a hacksaw blade taped to a ruler. This method of construction will allow you to use heavier weights in your experiment because the wide, flat shape of both the blade and ruler will prevent the arm from bending down as much. But not everyone has access to hacksaw blades. If you decide to use a blade, you could nail it to a short, thick piece of wood, then stand on the wood to keep if from moving around.)

1) Unwrap the coiled part of the hanger near the hook. Straighten it out, then bend a long loop at then end opposite the hanger hook. Make the loop at a 90 degree angle from the hanger hook.
2) Tape the small cup into the hanger hook.
3) Duct tape this contraption to the edge of a table so that the cup end is dangling way out from the edge. Make sure the tape is very secure, You should be able to "twang" the cup back and forth without the base coming off the table.

What you have made is called an <u>inertial balance</u>. Yours isn't nearly as accurate as a real one, but it will be good enough for you to experiment with inertia.

5) Pull the cup back about 10 cm (5 inches) or so and then let go. Count how many seconds it takes for the balance to go back and forth 20 times.
6) Now put 5 coins (or their equivalent) into the cup. Pull the spring back the same distance you did before and let go again. Again, count how many seconds it takes for the cup to go back and forth 20 times. (If you have trouble estimating how far back to pull the spring each time, you can put the back of a chair right at that spot. Then you just pull the spring back until it touches the chair. This will ensure that you pull it the same distance every time.)
7) Add 5 more coins and count again. Then 5 more. Then 5 more.
8) Keep adding coins until the count gets noticeably longer.
9) If you want to use this as a math activity, you could make a graph of this experiment, with one axis being the number of coins and the other being the number of seconds.

If you did the lab on "Center of Mass," you will remember that we briefly mentioned the correct definition of mass. ***Mass is the measure of an object's resistance to a change in speed***. This definition makes no sense at all unless you have done a lab like this. Now that you have used an inertial balance, you can see how this definition is possible. When the cup contained very little mass, it was happy to change directions many times per second. The more mass we put in the cup, the less it wanted to change direction, and therefore the fewer number of swings back and forth it did. The force applied on the wire spring was the same each time. As mass increased, the force was able to accomplish less and less. If we put a bowling ball in the cup, the wire probably would not be able to move at all (maybe because the inertial balance would have crashed to the floor!). The reason that scientists use this definiton of mass is that it is independent of gravity. It works in any situation, anywhere in the universe. (No, we're not going to discuss black holes.)

Using a balance that moves side to side really helps us to understand the definition of mass as "the amount of resistance to a change in direction." However, except for the occasional mass measurement in space, scientists rarely use inertial balances. They use balances that weigh an object in grams or kilograms. The balance on the left is a bit old-fashioned but you might still find one in use somewhere. The other two balances are state-of-the-art, 21st-century pieces of equipment, and like everything else in our modern world, they are digital. The one on the right has a clear shield around it so that it can be used in high-tech labs where dust or air currents would affect the measurement of certain substances.

Scientific balances always measure using the metric system, based on grams. Some of them have alternate functions, too, so you can switch to ounces and pounds. The metric system is used in science because it is based on the number 10, and doing mathematical calulations based on the number 10 are much easier than on other numbers. The English system (ounces, pounds, and inches) is based on numbers like 4, 12 and 16. (Which would you rather multiply: 152x16 or 152x10?)

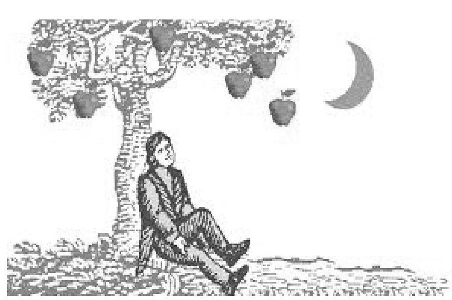
For those of you less familiar with the metric system, here are some aproximations of how much things weigh in grams and kilograms:

1 gram is about the weight of a paper clip.

10 grams is about the weight of a pencil.

100 grams is about the weight of a small apple.

1000 grams is called a ***kilogram***. A canteloupe weighs about a kilogram.



Remember that 100 grams is about the same as 1 Newton. It's easy to remember how much a Newton is if you think of an apple. You probably know the famous story about Newton watching an apple fall off a tree and from that observation deducing the theory of gravity. Some versions of the story have Newton getting hit on the head with an apple, but the man who recorded this story (as told to him by Newton), makes no mention of Newton getting hit on the head. Newton was simply sitting under an apple tree one autumn day, watching apples fall off the tree and hit the ground. How much did each apple weigh? About 1 Newton!