FORCE & MOTION 2

A comprehensive course that continues the science adventure in physics under Newton's work on the three laws of motion. Students get a crash-course in projectile motion as they build g-force accelerometers, float hovercraft on both land and water, build a rocket car, and measure the Earth's magnetic pulse.

Created by Aurora Lipper, Supercharged Science

www.SuperchargedScience.com

This curriculum is aligned with the National State Standards and STEM for Science.

© 2014 • Supercharged Science • P.O. Box 4418, San Luis Obispo, CA 93403 • (805) 617-1789

Lessons

Introduction

Greetings and welcome to the study of *Forces & Motion.* This unit was created by a mechanical engineer, university instructor, airplane pilot, astronomer, robot-builder and real rocket scientist… me! I have the happy opportunity to teach you everything I know about forces, acceleration, velocity, speed, friction, gravity and more over the next set of lessons. I promise to give you my best stuff so you can take it and run with it… or fly!

To get the most out of these labs, there are really only a couple of things to keep in mind. Since we are all here to have fun and learn something new, this shouldn't be too hard.

One of the best things you can do as the student is to cultivate your curiosity about things. *Why did that move? How did that spin? What's really going on here?*

This unit on *Forces & Motion* is chock full of demonstrations and experiments for two big reasons. First, they're fun. But more importantly, the reason we do experiments in science is to hone your observational skills. Science experiments really speak for themselves much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these science demonstrations and experiments to help you develop your observing techniques.

Scientists not only learn to observe what's going on in the experiment, but they also learn how to observe what their experiment is telling them, which is found by looking at your data. It's not enough to invent some new kind of experiment if you don't know how it will perform when the conditions change a bit, like on Mars. We're going to learn how to predict what we think will happen, design experiments that will test this idea, and look over the results we got to figure out where to go from there. Science is a process, it's a way of thinking, and we're going to get plenty of practice at it.

Good luck with this *Forces & Motion* unit!

For the Parent/Teacher:

Educational Goals for Force & Motion 2

We're going to study velocity, acceleration, forces, and Newton's three laws of motion in this section. You'll get to throw things, build g-force accelerometers, and much more as you uncover the basis of all physics in our crash-course in projectile motion. Build balloon racers, detect electric fields, construct a bridge that holds more than 400 times its own weight, float hovercraft on both land and water, create a rocket car, measure the Earth's magnetic pulse and so much more.

Here are the scientific concepts:

- An object's motion can be described by recording the change in its position over time.
- An object at rest usually has multiple forces on it, but they add up to give a net force sum of zero. Forces that don't sum to zero are imbalanced, and cause an object to change speed or direction of motion (or both). When the forces on an object are balanced, the motion of the object does not change.
- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's Third Law).
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.
- Electric and magnetic forces between a pair of objects do not require the objects be in contact. The size of the forces depends on the properties of the objects, their distance apart, and in the case of magnets, their orientation.
- Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.
- The velocity of an object is the rate of change of its position.
- To describe the velocity of an object, one must specify both direction and speed.
- Changes in velocity can be changes in speed, direction, or both, and this is called acceleration.

By the end of the labs in this unit, students will be able to:

- Design and build an experiment that shows how forces are balanced and unbalanced, and how unbalanced forces cause motion in an object.
- Make observations and measurements on an object's motion to figure out the predictable pattern of motion.
- Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.
- Design an experiment that shows when the arrangements of objects interacting at a distance changes, different amounts of potential energy are stored in the system.
- Show that when the motion energy of an object changes, energy is transferred to or from the object.
- How to solve problems involving distance, time, and average speed.
- How to interpret graphs of position versus time and speed versus time for motion in a single direction.

- Apply Newton's Third Law to design an experiment involving the motion of two colliding objects.
- Design and build an experiment that shows how the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
- Show that gravitational interactions are attractive and depend on the masses of the objects.
- Design and build an experiment that shows that fields exist between two objects that are not touching.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Measure and estimate the weight, length and volume of objects.
- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

Master Materials List for All Labs

This is a brief list of the materials that you will need to do *all* of the activities, experiments and projects in this unit. The set of materials listed below is just for one lab group. If you have a class of 10 lab groups, you'll need to get 10 sets of the materials listed below. Most materials are reusable.

Baking soda
Ball
Balloon
Bicycle wheel (detached from bicycle – the front wheel is pretty easy to detach)
Block or textbook
Board (12-inch square)
Bucket
Chicken broth (1 can)
Clam chowder (1 can)
Clean glass jar (pickle, jam, mayo, etc… any kind of jar that's heavy so it won't knock over easily)
Clear tubing (about 12-18″ long)
Container with a tight-fitting lid (I don't recommend glass containers… see if you can find a plastic one like a film canister or a mini-M&M container.)
Doughnut magnets (4)
Dowels (10) (or round pencils)
Fishing line
Food dye
Hardcover book
Hot glue gun, scissors and tape
Index card or scrap of cardboard
Laser pointer (any kind will work – even the cheap key-chain type)
Magnets (2, business-card sized)
Marbles (20)
Measuring tape or yard stick
Nylon filament (thin nylon thread works, too)
Nylon or metal barbed union that fits inside the tubing
Pencil
Pillow
Plastic cup
Protractor
Rare earth magnets (2)
Rocks
Rope (nylon, 10 feet or longer)
Shoes (about 5 different ones)
Skateboard
Small mirrors (2)
Soda bottle (empty)
Stopwatch
String
Tape
Toilet paper tube
Toy car
Vinegar
Wagon
Wall
Wine cork
Wooden spring-type clothespin
Yardstick (or tape measure)

Lab Safety

Goggles: These should be worn when working with chemicals, heat, fire, or projectiles. These protect your eyes from chemical splatter, explosions, and tiny fast-moving objects aimed at the eyes. If you wear glasses, you can find goggles that fit over them. Don't substitute eyeglasses for goggles, because of the lack of side protection. Eyeglasses don't provide this important side eye protection.

Clean up Messes: Your lab area should be neat, organized, and spotless before you start, during your experiment, and when you leave. Scientists waste more time hunting for lost papers, pieces of an experiment, and trying to reposition sensitive equipment… all of which could have easily been avoided had they been taught organizational skills from the start.

Dispose of Poisons: If a poisonous substance was used, created, or produced during your experiment, you must follow the proper handling procedures for disposal. You'll find details for this in the experiments as needed.

Special Notes on Batteries: Do not use alkaline batteries with your experiments. Find the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty") because these types of batteries have a carbon-zinc core, which does not contain the acid that alkaline batteries have. This means when you wire up circuits incorrectly (which you should expect to do because you are learning), the circuits will not overheat or leak. If you use alkaline batteries (like Energizer and Duracell) and your students short a circuit, their wires and components will get super-hot and leak acid, which is very dangerous.

No Eating or Drinking in the Lab: All foods and drinks are banned from your classroom during science experimentation. When you eat or drink, you run the very real risk of ingesting part of your experiment. For electricity and magnetism labs, always wash your hands after the lab is over to rinse off the lead from the electrical components.

No Horse Play: When you goof around, accidents happen, which means chemicals spill, circuits short, and all kinds of hazards can occur that you weren't expecting. Never throw anything to another person and be careful where you put your hands – it could be in the middle of a sensitive experiment, especially with magnetism and electricity. You don't want to run the risk of getting shocked or electrified when it's not part of your experiment.

Fire: If you think there's a fire in the room (even if you're not sure), let your teacher know right away. If they are not around (they always should be), smother the fire with a fire blanket or use a fire extinguisher and send someone to find an adult. Stop, drop, and roll!

Questions: If you're not sure about something stop and ask, no matter what it's about. If you don't know how to properly handle a chemical, do part of an experiment, ask! If you're not comfortable doing part of the experiment, then don't do it.

Lesson #1: Fast Ball

Overview: Gravity is an acceleration. That is, it affects all objects equally. Gravity accelerates objects at $9.8m/s^2$. Acceleration is a rate of change of speed or, in other words, how fast the speed is changing. We'll get some good practice with calculations and observations as we complete this lesson.

What to Learn: Students will learn that the velocity of an object is the rate of change of its position, and that acceleration is the rate of change of velocity. They will solve problems involving distance, time, speed and gravity.

Materials

- ball
- pencil
- stopwatch
- yardstick (or tape measure)

Lab Time

1. Go outside and pick one person to be the thrower and another to be the timer.
2. Have the timer say "Ready, Set, Go!" and at "Go," he or she should start the stopwatch.
3. When the timer says go, the thrower should toss the ball as high as he or she can.
4. The timer should stop the stopwatch when the ball hits the ground.
5. Write down the time that the ball was in the air using the data table.
6. Let each person take a couple of turns as timer and thrower.
7. Now, come back inside and do a bit of math (see below).

   Let's say you threw the ball into the air and it took 3 seconds to hit the ground. The first thing you have to do is divide 3 in half. Why? Because your ball traveled 1.5 seconds up and 1.5 seconds down! (By the way, this isn't completely accurate because of two things. One, air resistance and two, the ball falls a little farther than it rises because of the height of the thrower.) Now, take your formula and figure out the speed of the throw.

   $v=gt$, so $v=32\ ft/s^2 \times 1.5\ sec$ or $v = 48\ ft/s$.

   So, if that's how fast it left your hand, how fast was it going when it hit the ground? Yup, 48 ft/s. It has to be going the same speed because it had just as much time to speed up as it had to slow down, 1.5 seconds. Try that with your time and see how fast your throw was.

   OK, hold your breath, just a little deeper now. Let's talk about distance. If something starts from rest you can tell how far it drops by how long it has dropped. This formula is $d=\frac{1}{2}\,gt^2$ or distance equals one half the gravitational constant multiplied by time squared. Let's try it. If I drop a ball and it drops 3 seconds, how far has it dropped?

$D = ½ \times 32 ft/s^2 \times (3s)^2$ or $d = 16 ft/s \times 9s^2$ or $d=144$ ft

So it has dropped 144 ft.

Now try this with your time. What's the first thing you have to do? Divide your time in half again, right? It took your ball half the time to go up and half the time to come down. Now plug your numbers into $1/2gt^2$ and find out how high you threw your ball!

Fast Ball Data Table

Ball Time Aloft *(measure in seconds)*	**Speed:** $v=gt$ *(ft/sec or m/s)*	**Distance:** $d = ½ gt^2$ *(feet or meters)*

Reading

Gravity accelerates all things equally…what does that mean? All things accelerate at 32 feet per second squared due to gravity. In metric, that's 9.8 meters per second squared.

What that means is that every second something falls, its speed increases by 32 feet/second or 9.8 meters/second. Believe it or not, that's about 22 miles per hour!! Gravity will accelerate something from 0 to 60 mph in about 3 seconds. That's faster than all but the fastest sports cars!

So what is acceleration anyway? Well, speed is the amount of distance something travels in a certain amount of time. Five miles per hour, for example, tells you that something can travel five miles in an hour. Acceleration is how much the speed changes over time. So acceleration would be miles per hour per hour or feet per second per second.

Acceleration is a rate of change of speed or, in other words, how fast the speed is changing. Feet per second per second is the same as ft/s/s which is the same as ft/s^2. (I told you we were going deeper!) Let's say you're riding your bicycle at a positive acceleration (you're getting faster) of 5 ft/s^2.

That means in 1 second you're moving at a speed of 5 ft/s.

After 2 seconds you're moving at a speed of 10 ft/s.

After 3 seconds you're now clipping along at 15 ft/s (about 10 mph).

So you can see that as long as you accelerate, you will be getting faster and faster. The formula for this is $v=at$ where v is velocity, a is acceleration and t is time. (We will be doing more with acceleration in a future lesson.)

If we want to find out how fast something is going after it has been dropped, we use the formula $v=gt$. The letter "v" stands for velocity (which basically means speed.) "g" stands for the gravitational constant and "t" stands for time.

If we want to find out how fast a golf ball is dropping after it falls for 3 seconds we multiply 3 seconds by 32 feet/second squared and that equals 96 feet/second. So, if I dropped a golf ball off a building, it would be going 96 feet per second after 3 seconds of dropping.

The formula looks like this when we fill in the numbers:

$v=3s \text{ x } 32 \text{ ft/s}^2$

If we do more math, we'll see that after one second something will be going 32 ft/s, after 2 seconds it will be going 64 ft/s, after 3 seconds 96 ft/s, and after 4 seconds 128 ft/s. Get it? Anything dropped will be going that speed after that many seconds because gravity accelerates all things equally (air resistance will affect these numbers so you won't get exactly the numbers in practice that you will mathematically).

All right, let's go even deeper. We now know how to calculate how fast something will be going if it is dropped, but what happens if we throw it up? Well, which way does gravity go? Down, right? Gravity accelerates all things equally, so gravity will slow things down as they travel up by 32 ft/s^2. If a ball is thrown up at 64 ft/s, how long will it travel upwards? Well, since it is negatively accelerating (in physics there's no such thing as deceleration) after the first second the ball will be traveling at 32 ft/s and after 2 seconds the ball will come to a stop, turn around in midair, and begin to accelerate downwards at 32 ft/s^2. Using this, you can tell how fast you can throw by using nothing more than a timer. Let's try it – flip over to the experiment section now.

Exercises Answer the questions below:

1. Is gravity a speed, velocity, or acceleration?

2. Does gravity pull equally on all things?

3. Does gravity accelerate all objects equally?

4. How is acceleration different from speed and velocity?

Lesson #2: Tracking Treads

Overview: Now let's talk about the other ever-present force on this Earth, and that's friction. Friction is the force between one object rubbing against another object. Friction is what makes things slow down. Without friction things would just keep moving unless they hit something else. Without friction, you would not be able to walk. Your feet would have nothing to push against and they would just slide backward all the time like you're doing the moon walk.

What to Learn: Today you get to discover how friction is a complicated interaction between pressure and the type of materials that are touching one another.

Materials

- shoes (about 5 different ones)
- board, or a tray, or a large book at least 15 inches long and no more than 2 feet long.
- ruler or yardstick
- protractor
- pencil
- partner

Lab Time

1. Put the board (or whatever you're using) on the table.
2. Put the shoe on the board with the back of the shoe touching the back of the board.
3. Have a partner hold the ruler upright (so that the12-inch end is up and the 1-inch end is on the table) at the back of the board.
4. Slowly lift the back of the board, leaving the front of the board on the table. (You're making a ramp with the board). Eventually the shoe will begin to slide.
5. Stop moving the board when the shoe slides and measure the height that the back of the board was lifted to.
6. Test each shoe three times to verify your data.
7. Look at the 5 shoes you chose and test them. Before you do, make a hypothesis for which shoe will have the most friction.
8. On a scale from 1 to 5 (or however many shoes you're using) rate the shoes you picked. 1 is low friction and 5 would be high friction. Write the hypothesis next to a description of the shoes on a piece of paper. The greater the friction the higher the ramp has to be lifted. Test all of the shoes.
9. Analyze the shoes. Do the shoes with the most friction show any similarities? Are the bottoms made out of the same type of material? What about the shoes with very little friction?

Tracking Threads Data Table

Item/Object Description	**Guess First!** Rank each: 1 for lowest friction, 5 for most friction.	**Height of Board when Shoe Starts to Slide**

Reading

Since friction is all about two things rubbing together, the more surface that's rubbing, the more friction you get. Ever notice how the tire on a car has treads, but a race car tire will be absolutely flat with no treads at all?

The race car doesn't have to worry about rain or stuff on the road, so it gets every single bit of the tire to be touching the surface of the track. That way, there is as much friction as possible between the tire and the track. The tire on your car has treads to cut through mud and water to get to the nice firm road underneath. The treads actually give you less friction on a flat, dry road.

You can opt to use a skateboard shoe for this experiment. Notice that a skateboard shoe has very a flat bottom compared to most other shoes. This is because a skateboarder wants as much of his or her shoe to touch the board at all times, having as much contact friction as possible.

Exercises Answer the questions below:

1. What is friction?
2. What is static friction?
3. What is kinetic friction?

Lesson #3: Stick and Slip

Overview: Friction is everywhere! Imagine what the world would be like without friction! Everything you do, from catching baseballs to eating hamburgers, to putting on shoes, friction is a part of it. If you take a quick look at friction, it is quite a simple concept of two things rubbing together.

What to Learn: When you take a closer look at friction, it's really quite complex. What kind of surfaces are rubbing together? How much of the surfaces are touching? And what's the deal with this stick and slip thing anyway? Friction is a concept that many scientists are spending a lot of time on. Understanding friction is very important in making engines and machines run more efficiently and safely.

Materials

- magnets (2, business-card sized)
- fingers

Lab Time

1. Take two business card magnets and stick them together, black magnet side to black magnet side. They should be together so that the pictures are on the outside like two pieces of bread on a sandwich.
2. Now grab the sides of the magnets and drag one to the right and the other to the left so that they still are magnetically stuck together as they slide over one another.
3. Did you notice what happened as they slid across one another? They stuck and slipped didn't they? This is a bit like friction. As two surfaces slide across one another, they chemically bond and then break apart. Bond and break, bond and break as they slide. The magnets magnetically "bonded" together and then broke apart as you slid them across on another. The chemical bonds don't work quite like the magnetic "bonds" but it gives a decent model of what's happening.

Exercises Answer the questions below:

1. What is the difference between static and kinetic friction? Which one is always greater?

2. Design an experiment where you can observe and/or measure the difference between static and kinetic friction.

Lesson #4: Rocket Car

Overview: Let's take a good look at Newton's laws of motion while making something that flies off in both directions. This experiment will pop a cork out of a bottle and make the cork fly 20 to 30 feet, while the vehicle moves in the other direction! This is an outdoor experiment. Be careful with this, as the cork comes out with a good amount of force. (Don't point it at anyone or anything, even yourself!)

What to Learn: You'll learn how to solve problems involving distance, time, and average speed.

Materials

- toy car
- baking soda
- vinegar
- tape
- container with a tight-fitting lid (I don't recommend glass containers… see if you can find a plastic one like a film canister or a mini-M&M container.)
- measuring tape
- stopwatch

Lab Time

1. Strap the bottle to the top of the toy car or bus with the duct tape. You want the opening of the bottle to be at the back of the vehicle.
2. Put about one inch of vinegar into the bottle.
3. Shove a wad of paper towel as far into the neck of the bottle as you can. Make sure the wad is not too tight. It needs to stick into the neck of the bottle but not too tightly.
4. Pour baking soda into the neck of the bottle. Fill the bottle from the wad of paper all the way to the top of the bottle.
5. Now put the cork into the bottle fairly tightly. (Make sure the corkscrew didn't go all the way through the cork, or you'll have leakage issues.)
6. Now tap the whole contraption hard on the ground outside to force the wad of paper and the baking soda into the bottle.
7. Give the bottle a bit of a shake.
8. Set it down and watch. Do not stand behind the bus where the cork will shoot.
9. In 20 seconds or less, the cork should come popping off of the bottle.
10. After a few runs, it's time to do this experiment and take data as you go along. You'll need to measure how much vinegar and baking soda you use as well as how far it went using a ruler, and how long it traveled for using a stopwatch.
11. Complete the data table.

Rocket Car Data Table

How Much Baking Soda?	How Much Vinegar?	Travel Distance *(inches/feet or cm/m)*	Travel Time *(seconds)*	Average Speed *(v = d/t)*

Reading

There are two ways to do this experiment. You can either strap the bottle to the top of a toy car and use baking soda and vinegar, OR use effervescent tablets (like generic brands of Alka Seltzer) with a modified pop rocket (which you can strap to a toy car, or add wheels to the film canister itself by poking wooden skewers through milk jug lids for wheels and sliding the skewer through a straw to make the axle). Both work great, and you can even do both! This is an excellent demonstration of Newton's Third Law, inertia, and how stuff works differently here than in outer space.

What you should see is the cork firing off the bottle and going some 10 or 20 feet. The vehicle should also move forward a foot or two. This is Newton's Third Law in action. One force fired the cork in one direction. Another force, equal and opposite, moved the car in the other direction. Why did the car not go as far as the cork? The main reason is the car is far heavier than the cork. F=ma. The same force could accelerate the light cork a lot more than the heavier car.

Exercises Answer the questions below:

1. What is inertia?

2. What is Newton's First Law?

Lesson #5: Newton's Wagon

Overview: The natural state of objects is to follow a straight line. In fact, Newton's First Law of Motion states that objects in motion will tend to stay in motion unless they are acted upon by an external force. A force is a push or a pull, like pulling a wagon or pushing a car. Gravity is also a force, but it's a one-way force that attracts things to each another.

Newton's Second Law of Motion is for objects experiencing unbalanced forces. The first law, usually called the law of inertia, says that if all the forces acting on an object are balanced then the object is in equilibrium and does not accelerate. The object can either be at rest or in motion, but not accelerating (the object can be at a constant speed and traveling in a straight line). Objects not in equilibrium experience unbalanced forces, which causes them to accelerate. Acceleration is a change in speed, direction, or both.

Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction. This means that for every interaction, there's a pair of forces acting on the objects, which are equal in size and opposite in direction. (Want to know a secret? Forces *always* come in pairs!)

What to Learn The way to change how something is moving is to give it a push or a pull. The size of the change is related to the strength, or the amount of "force," of the push or pull.

Materials

- friends
- rocks
- wagon
- balloon
- fishing line
- tape
- stopwatch
- measuring tape

Lab Time Part 1

1. Let's really figure out what this "inertia" thing from Newton's First Law is all about using the wagon and friends. Pull the wagon down the sidewalk.
2. Try to stop as quickly as you can. Be careful. You could get run over by the wagon if you're not careful.
3. Put a friend in the wagon and repeat steps above.
4. Put another friend in the wagon and repeat again.

You may have noticed that the more friends (the more weight) you had in the wagon the harder it was to get moving and the harder it was to stop. This is inertia. The more weight something has the more inertia it has and the harder it is to get it to go and to stop!

Newton’s First Law of Motion Data Table

Number of Kids in Wagon	**Time to Stop** *(measure in seconds)*	**Distance to Stop** *(measure in feet or meters)*

Reading Part 1

What happens when you kick a soccer ball? The ”kick” is the external force that Newton was talking about in his first law of motion. What happens to the ball after you kick it? The ball continues in a straight line as long as it can, until air drag, rolling resistance, and gravity all cause it to stop.

If this seems overly simplistic, just stick with me for a minute. The reason we study motion is to get a basic understanding of scientific principles. In this experiment, the ball wants to continue in a straight line but due to external forces like gravity, friction, and so forth, the ball’s motion will change.

Newton’s First Law of Motion also says that objects at rest will tend to stay at rest and objects in motion tend to stay in motion unless acted upon by an external force. You’ve seen this before – a soccer ball doesn’t move unless you kick it. But what happens if you kick it in outer space, far from any other celestial objects? It would travel in a straight line! What if it wasn’t a soccer ball, but a rocketship? It would still travel in a straight line. What if the rocket was going to pass near a planet? Do you think you’d need more or less fuel to keep traveling on your straight path? Do you see how it’s useful to study things that seem simple at first so we can handle the harder stuff later on? Great – then let’s keep going.

Lab Time Part 2

1. Now we're going to experiment with Newton's Second Law, which deals with force, mass, and acceleration. Start with an empty wagon.
2. Pull it and try to get it to go as fast as it can, as fast as you can. In other words, get it to accelerate.
3. Now add weight. Put something in the wagon that weighs at least 50 lbs. or so (a nice, solid kid comes to mind)
4. Pull it again and get it to go as fast as it can as fast as you can.
5. Add more weight and do it again.
6. Keep adding weight until you have a very difficult time getting it to accelerate.

So what happened here? Force equals mass x acceleration. The mass was the wagon. The force was you pulling. The acceleration was how fast you could get it to speed up. The heavier you got the wagon (the more mass (m) there was) the harder (the more force (f)) you had to pull to get the wagon to move (to accelerate(a)), or $F = ma$.

An object that has a lot of momentum is going to take a lot of effort to stop. Momentum refers to the quantity of motion that an object has. It's defined as mass in motion. If an object is moving, then it has momentum. How much momentum it has is calculated by this equation: momentum (p) = mass (m) x velocity (v), or $p = m v$.

Note for the table below, try using the standard metric system. The conversion from the weight you measure on a scale (measured in pounds) to a quantity of mass in kg is this:

1 pound = 0.4365 kg
So a 100-lb kid has a mass of 45.36 kg.

7. Now let's fill out the data table. First, weigh the kids you are going to use as weight in the wagon. Record this in your data table.
8. With chalk or string, mark off three lines. The first is the start line where the wagon is going to start from rest. The second is about 2 meters (6 ½ feet) away, and when the wagon crosses this line it should be at constant speed. The third is the finish line, a distance of about 7 meters (about 23 feet) from the middle line. Make sure the course is on a long, straight-and-level path. We want the kids to be at the same speed when they cross the start and finish line.
9. Get out your timer. Load the wagon with kids.
10. Start pulling the wagon at the start line at the same time you start the timer.
11. Pull the kids and reach a constant speed when you cross the middle line. As you cross it, look at your timer (but don't stop timing). Record this time as your time to accelerate.
12. Continue timing until you cross the finish line. Stop timing and record the time.

Before you start filling out the table, let me show you how to use simple math to do some really cool stuff, like figure out how much force you pulled that wagon with! This is where math and science finally come together. It's really easy to do math-wise. See if you can follow these steps:

The second law defines a force to be equal to the change in momentum with a change in time. Momentum (p) is the mass (m) of an object multiplied by is velocity (v). If your mass is 100 kg, and you're travelling in a straight line at 10 m/s, then your momentum is 1,000 kg m/s.

If your speed changes over time, for example if it takes 10 seconds to go from 10 meters per second to 15 meters per second, then your momentum will also change from 1,000 to 1,500 kg m/sec. Since your momentum changed over time, we can do a little math to reduce the complicated equations down to get: $F = ma$

The force is equal to the change in momentum = 1,500-1,000 kg m/s = 500 kg m/s, which is then divided by 10 seconds to give a result of 50 N.

Note that this result is the same when you calculate it using $F = ma$.

Your acceleration is found by: a = (change in speed) / (time) = 5 m/s divided by 10 seconds = 0.5 m/s^2

So the net force = (100 kg) x (0.5 m/s^2) = 50 N!

For our experiments, the distance traveled at a constant speed is 7 meters (unless you changed this), so you can find your constant speed to be 7 meters divided by the *Time at Constant Speed*. Note that this isn't your *Total Time*. You have to subtract out the time it took you to get up to speed.

In our trials, we start at rest and travel to a constant speed. Let's say I recorded a *Time to Accelerate* of 4.2 seconds. This means that to get my acceleration, which is how much my velocity changed from start with no velocity to a constant velocity, I need to know what the constant velocity (or speed, as my direction is always in a straight line) is, so I first need to find my constant speed value. If my *Total Time* is 11.3 seconds, then I pulled the wagon at a constant speed for 11.3 - 4.2 = 7.1 seconds.

And I pulled them at a constant speed for 7 meters, which gives a constant speed of V_{const} = 0.986 m/s.

This means that for a 100-kg wagon, the finish line momentum is 98.6 kg m/s (we're assuming the wagon doesn't weigh that much compared to the kids inside, but if yours does, make sure to add it to your mass calculation).

How much did I accelerate? I didn't accelerate at all during the second and third line, which is what constant velocity means (no acceleration). But I had to accelerate some in order to go from zero to a speed of 0.986 m/s. Since it took me 4.2 seconds to get up to speed, my acceleration is (0.986 m/s) / (4.2 s) = 0.235 m/s^2.

So my net force is (100 kg) x (0.235 m/s^2) = 23.5 N! That's how much force I had to pull with to get that wagon to accelerate to my constant speed. Note that this is a *net* force, so I actually pulled with a force *greater* than this number, since I had to overcome air resistance and drag forces. Whew!

Now you give it a try:

Newton's Second Law of Momentum Data Table

Mass of Kids in Wagon *(kg)*	**Total Time** *(seconds)*	**Time to Accelerate** *(seconds)*	**Time at Constant Speed** *(seconds)*	**Constant Speed** *(meters/sec)*	**Momentum at Finish Line** *($p = mv$)*	**Acceleration from Rest to Top Speed** *(m/s^2)*	**Net Force** *(N)*
100 kg	*11.3*	*4.2*	*11.3-4.2 =7.1*	*7/7.1=0.986*	*100x0.986=98.6*	*0.986/4.2=0.235*	*23.5*

If you were able to do this lab, then you're ready for some pretty advanced stuff! If it didn't make a lot of sense, don't worry… there are a lot more labs for you try out that are not quite to math-intensive. I wanted to give those of you who crave to know when we use this "math stuff" in science, and I thought this would be a fun way to introduce these ideas to you.

Reading Part 2

Newton's Second Law is formally written like this: The acceleration (a) of an object as produced by the net force (F_{net}) is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass (m) of the object.

Whew – was that a lot to think about! Did you know that this next equation means exactly the same thing? Here it is: $a = F_{net} / m$

This equation (rewritten as $F = m\ a$) defines what we measure force in using the SI system:

1 Newton = (1 kg) x (1 m/s^2). For the standard metric unit of force, one Newton is defined to be the amount of force needed to give a 1 kilogram mass an acceleration of 1 m/s^2.

Newton's Second Law tells us what's going to happen when forces don't balance (and in the real world, they usually don't). This law states that unbalanced forces cause objects to accelerate directly proportional to the net force, and inversely proportional to the mass.

The second law is also referred to when discussing momentum. The second law defines a force to be equal to the change in momentum with a change in time. Momentum (p) is the mass (m) of an object multiplied by its velocity (v). If your mass is 100 kg, and you're travelling in a straight line at 10 m/s, then your momentum is 1,000 kg m/s.

If your speed changes over time, for example if it takes 10 seconds to go from 10 meters per second to 15 meters per second, then your momentum will also change from 1,000 to 1,500 kg m/sec. Since your momentum changed over time, we can do a little math to reduce the complicated equations down to get: F = ma (look familiar?)

The force is equal to the change in momentum = 1,500-1,000 kg m/s = 500 kg m/s which is then divided by 10 seconds to give a result of 50 N.

Note that this result is the same when you calculate it using F = ma.

Your acceleration is found by: a = (change in speed) / (time) = 5 m/s divided by 10 seconds = 0.5 m/s^2

So the net force = (100 kg) x (0.5 m/s^2) = 50 N!

Lab Time Part 3

1. Now let's work with Newton's Third Law: For every action, there is an equal and opposite reaction. If this next experiment doesn't work don't worry about it. You need a fairly low friction skateboard or wagon to make this work. If you're lucky enough to live where there's snow and ice, you might suit up the kids on skates and try this outdoors, because ice is very low friction.
2. Sit in the wagon or on the skateboard (please do not stand up).
3. Throw the heavy thing as hard as you can. (Please be careful not to hit anybody or anything!)
4. At this point, you should know what should happen, so what do you think? If you said that the throw forward would move you backward, you're right! Next time you're in a small canoe, toss the rock and see what happens to you and your boat. (Any guesses?)
5. Now tie a length of fishing line across the room about chest level for the kids. Thread a straw on the line before attaching the second end.
6. Blow up a balloon and pinch the end with your fingers (or use a clothespin to hold it shut).
7. Tape the balloon to the straw so when released, the balloon faces in a direction that will allow it to zip the furthest down the string.
8. After a few initial tests, get out your measuring tape and stopwatch. Record the distance and time for each balloon in the data table.

Newton's Third Law of Motion Data Table

Trial Number	**Time Traveled** *(feet or meters?)*	**Distance Traveled** *(feet or meters?)*	**Average Speed** *(units?)*

To find your average speed, divide the distance traveled by the time. For example, if it takes 3 seconds to travel 5.6 feet, then my average speed is 5.6 / 3 = 1.87 feet/second.

Reading Part 3

Forces come in pairs. When you stand up, your weight is pushing down on the floor as much as the floor is pushing back up on your feet. When you stretch out your arms and push the wall, the wall pushes back with the same amount of force every time. This is Newton's Third Law: For every action, there is an equal and opposite reaction.

A force is a push or a pull, like pulling a wagon or pushing a car. Forces come from interactions. Some forces come from contact interactions, like friction, tension in a spring, applied forces, and more. Other forces are "action at a distance" interactions, like gravitational, electrical and magnetic forces. When two objects interact with each other, whether or not they physically touch, they exert forces on each other. This holds true for rockets orbiting the moon, bugs that splat on the windshield, and kids on roller skates who crash into you.

Rifles “recoil” when fired, which is a classic example of action-reaction paired forces. The recoil happens when the gunpowder explosion creates hot gases that expand and push the bullet forward. The force that the rifle feels is equal to the force that the bullet feels, but since the bullet is tiny, it can move with a high acceleration. The rifle, which has a larger mass, doesn’t accelerate quite as quickly, but you can still feel it in your shoulder as the rifle recoils.

Exercises Answer the questions below:

1. What is inertia?
2. What is Newton’s First Law?
3. Will a lighter or heavier race car with the same engine win a short-distance race (like the quarter-mile)?
4. What concept does Newton’s Second Law of Motion deal with?
5. What is momentum?
6. What is the equation for Newton’s Second Law?
7. What is Newton’s Third law?
8. Give three examples of forces in pairs.
9. A rope is attached to a wall. You pick up the rope and pull with all you’ve got. A scientist walks by and adds a force meter to the rope and measures you’re pulling with 50 Newtons. How much force does the wall experience?
10. Can rockets travel in space if there’s nothing to push off of? Explain your answer.

Lesson #6: Ta-Daa!

Overview: Ever wonder how magicians work their magic? This experiment is worthy of the stage with a little bit of practice on your end. If you believe in the laws of physics, particularly Newton's laws, then this experiment will work every time.

Materials

- plastic cup
- hardcover book
- toilet paper tube
- several different objects like a ball that is smaller than the cup opening, but larger than the toilet paper tube

Lab Time

1. Put the cup on a table and put the book on top of the cup.
2. This is the tricky part. Put the toilet paper tube upright on the book, exactly over the cup.
3. Now put the ball on top of the toilet paper tube.
4. Check again to make sure the tube and the ball are exactly over the top of the cup.
5. Now, hit the book on the side so that it moves parallel to the table. You want the book to slide quickly between the cup and the tube.
6. If it works right, the book and the tube fly in the direction you hit the book. The ball however falls straight down and into the cup.
7. If it works say TAAA DAAA!
8. Draw a diagram of your experiment right before you hit the book. Label where you expect to see Newton's three different laws in action as soon as you set things in motion:

Reading

This experiment is all about inertia. The force of your hand got the book moving. The friction between the book and the tube (since the tube is light it has little inertia and moves easily) causes the tube to move. The ball, which has a decent amount of weight, and as such a decent amount of inertia, is not affected much by the moving tube. The ball, thanks to gravity, falls straight down and, hopefully, into the cup. Remember the old magician's trick of pulling the tablecloth and leaving everything on the table? Now you know how it's done. "Abra Inertia"!

Remember: inertia is how hard it is to get an object to change its motion, and Newton's First Law basically states that things don't want to change their motion. Once your students get good at this, invite them to try it with other objects, like unpeeled hardboiled eggs.

Exercises Answer the questions below:

1. What are two different pairs of forces in this experiment?

2. Explain where Newton's Three Laws of motion are observed in this experiment.

Lesson #7: Chicken and Clam

Overview: Next time you watch a car race, notice the wheels. Are they solid metal discs, or do they have holes drilled through the rims? I came up with this somewhat silly, but incredibly powerful quick science demonstration to show my university students how a good set of rims could really make a difference on the racetrack (with all other things being equal).

What to Learn: You're going to learn about inertia, what it is and how to measure it and its effects.

Materials

- clam chowder (1 can)
- chicken broth (1 can)
- long table
- books to prop up one end of the table so it becomes a long ramp
- optional: different kinds of cans of soup (note you must have the two mentioned above)

Lab Time

1. Prop up one end of a long table about 6-12″ (you can experiment with the height later).
2. You're going to roll both soup cans down the table at the same time.
3. Which do you expect to reach to bottom first – the chicken or the clam? Write down your guess in your data table.
4. Not only do my college students need to figure out which one will win, they also have to tell me *why*. The secret is in how you calculate the inertia of each. Take a guess, then do the activity.
5. Place the two cans together at the top of your ramp and release them at the same time so that they roll down together.
6. Do you think the can with more inertia will win or lose?
7. Try this experiment two more times in order to validate your results.
8. Try this with different kinds of soup cans. See if you can figure out a pattern and predict the results of more trial runs for this experiment.

Chicken and Clam Data Table

Soup Can #1	Soup Can #2	Guess: Who Will Win?	Who Won?

Reading

Inertia is a quality of an object that determines how difficult it is to get that object to move, to stop moving, or to change directions. Generally, the heavier an object is, the more inertia it has. An elephant has more inertia than a mushroom. A sumo wrestler has more inertia than a baby. Inertia is made from the Latin word "inert," which means "lacking the ability to move." Inertia isn't something people have a grasp of, though, as it's something you must mathematically calculate from an object's mass and size.

When riding in a wagon that suddenly stops, you go flying out. Why? Because an object in motion tends to stay in motion unless acted upon by an outside force (Newton's First Law). When you hit the pavement, your motion is stopped by the sidewalk (external force). Seat belts in a car are designed to keep you in place and counteract inertia if the car suddenly stops.

Did you know that Newton had help figuring out this First Law? Galileo rolled bronze balls down a wood ramp and recorded how far each rolled during a one-second interval to discover gravitational acceleration. And René Descartes (the great French philosopher) proposed three laws of nature, all of which Newton studied and used in his published work.

All of these men had to overcome the longstanding publicly accepted theories that stemmed from the Greek philosopher Aristotle (which was no small feat in those days). Aristotle had completely rejected the idea of inertia. He also had thought that weight affected falling objects, which we now know to be false. But remember that back then, people argued and talked about ideas rather than performing actual experiments to discover the truth about nature. They used words and reason to navigate through their world more than scientific experimentation.

In this experiment, the chicken soup wins for a very simple reason. Imagine that the cans are transparent, so you can see what goes on inside the cans as they roll down the ramp. Which one has just the can rolling down the ramp, and which has the entire contents locked together as it rolls? The can of the chicken soup will rotate around the soup itself, while the clam chowder acts as a solid cylinder and rotates together. So the inertial mass of the clam is much greater than the inertial mass of the soup, even though the cans weigh the same.

How do you calculate the inertia of the chicken soup and the clam? Here's the mathematical formulae from the back of a dynamics textbook (a typical course that all engineers take during their 2nd year of college).

Inertia of a solid cylinder = $1/2 * (mr^2)$
Inertia of a cylindrical shell = $1/12 * (mr^2)$

If the radius of the soup can is 6.5 cm and the mass for both is the same (345 grams, or 0.345kg), and the mass of an empty can is 45 grams, then:

(CLAM) Inertia of a solid cylinder = $1/2 * (mr^2) = 1/2 * (0.345\text{kg})*(6.5\text{cm})^2 = 7.29 \text{ kg cm}^2$
(CHICKEN) Inertia of a cylindrical shell = $1/12 * (mr^2) = 1/12 * (0.045\text{kg}) *(6.5\text{cm})^2 = 0.158 \text{ kg cm}^2$

The numerical value for the solid cylinder is larger than the shell, which tells us that it has a greater resistance to rolling and will start to rotate much slower than the shell. This makes logical sense, as it's easier to get the shell alone to rotate than move a solid cylinder. Remember, you must use the mass of the cylinder shell (empty can) when calculating the chicken's inertia, as the broth itself does not rotate and this does not have a "rolling resistance!"

Exercises Answer the questions below:

1. What is inertia (in your own words)?

2. Why does one soup can always win?

Lesson #8: Impulse and Momentum

Overview: Any object that is moving has momentum. Momentum is the product of the mass and the velocity. Larger and heavier objects will have a higher momentum than lighter and smaller objects.

What to Learn: You'll discover how to describe the velocity describe of an object by specifying both direction and speed as well as calculate momentum.

Materials

- handful of coins (at least two of each)
- pillow
- wall
- wagon
- skateboard

Lab Time

1. Find a wall.
2. Hit it with your bare fist. (Take it easy! Just hit it with enough force that you feel the impact *lightly*.)
3. Now put a pillow in front of the wall and hit it with about the same force as you hit it before.
4. With the pillow in front of the wall, you can hit it a little harder if you like, but again, don't go nuts!

What did the pillow do? It slowed the time of impact. Remember our formula Ft=mv. When the momentum of your moving fist struck the wall directly, the momentum was cut to zero instantly and so you felt enough force to hurt a bit. When the pillow was in the way, it took longer for your momentum to come to zero. So you could hit the pillow fairly hard without feeling much force. Basically a bike helmet is like a pillow for your head. It slows the time of impact, so when you fall off your bike, there is much less force on your head. Just be glad your mom doesn't make you wear a pillow on your head!

So let's go back to momentum for a minute. Momentum is inertia in motion. It is how much force it takes to get something to slow down or change direction. One more concept I'd like to give you is conservation of momentum. This is basically momentum equals momentum, or mathematically mv=mv. (Momentum is mass times velocity.) When objects collide, the momentum that both objects have after the collision is equal to the amount of momentum the objects had before the collision. Let's take a look at this with this next part of the experiment.

5. Put one penny on the table.
6. Put another penny on the table about 6 inches away from the first one.
7. Now, slide one penny fairly fast towards the first penny.
8. What you want to have happen, is that the moving penny strikes (or gives impulse to) the stationary penny head on. The moving penny should stop and the stationary penny will move.
9. Now, try that with other coins. Make big ones hit small ones and vice versa. It's also fun to put a line of 5 coins all touching one another. Then strike the end of the line with a moving penny.
10. Complete the data table for this part of the experiment after you read over the information below:

This is conservation of momentum. If you were able to strike the penny head on, you should have seen that the penny that was moving stopped, and the penny that was stationary moved with about the same speed of the original moving penny. Conservation of momentum is mv = mv. Once the moving penny struck the other, all the moving penny's momentum transferred to the second penny. Since the pennies weighed the same, the v (velocity) of the first penny is transferred to the second penny and the second penny moves with the same velocity as the first penny. What happens if you use a quarter and a penny? Make the quarter strike the penny. That penny should really zip! Again mv=mv. The mass of the quarter is much greater than the mass of the penny. So for momentum to be conserved, after impact, the penny had to have a much greater velocity to compensate for its lower mass.

Mathematically it would look like this (the masses are not accurate to make the math easier to see.) After collision Mass of Quarter x Velocity of Quarter = Mass of Penny x Velocity of Penny

5g x 10m/s = 1g x v

50 = 1 x v

50/1 = v

50m/s = v or 5g x 10m/s = 1g x 50 m/s

50 momentum = 50 momentum, or momentum (p) = 50 kg m/s, where *p* stands for momentum.

After the collision, the penny is moving at 50 m/s, 5 times faster than the quarter was moving because the penny is 5 times lighter than the quarter. (I know it's really only twice as light, but for this example let's pretend.)

11. Put the wagon and the skateboard close to one another.
12. Have one person sit on the skateboard while the other sits on the wagon.
13. Make sure the wheels are straight on the wagon and that the sidewalk is relatively free of stuff in the way.
14. Have one person give a good shove to the other person. Usually, it is easier for the person on the skateboard to push on the wagon. If this is true with your setup, then do it that way. Otherwise, do whatever is easiest.
15. Feel free to add more people or weight to the wagon and try it again.

Can you see how this and the one before it are really showing the same concept? Who went farther and faster? The lighter person on the lighter vehicle, right? The impulse of the push was the same for both vehicles, so both vehicles had the same momentum. Momentum is mass and velocity, so if the mass for both vehicles was the same, the speed would be the same. If the mass of one was more than the mass of the other, then the heavier one would move more slowly than the lighter one.

Impulse and Momentum Data Table

Weights of US coins: Penny= 2.5 g, Nickel = 5.0 g, Dime = 2.3 g, Quarter = 5.7 g, Half dollar = 11.3 g, Dollar = 8.1 g
Assume Velocity of Object 1 = 10 m/s

Mass 1 (m_1) *(kg)*	**Mass 2**(m_2) *(kg)*	**Momentum 1** (p_1) *(kg m/ s)*	**Velocity 2** (v_2) *(m/s)*

Reading

Momentum can be defined as inertia in motion. Something must be moving to have momentum. Momentum is how hard it is to get something to stop or to change directions. A moving train has a whole lot of momentum. A moving ping pong ball does not. You can easily stop a ping pong ball, even at high speeds. It is difficult, however, to stop a train even at low speeds.

Mathematically, momentum is mass times velocity, or Momentum = m x v.

The heavier something is and/or the faster it's moving the more momentum it has. The more momentum something has, the more force it takes to get it to change velocity and the more force it can apply if it hits something.

Now let's discuss impulse. Impulse is a measure of force and time. Remember, force is a push or a pull, right? Well, impulse is how much force is applied for how much time. Mathematically it's impulse equals force x time or Impulse = F x t.

Think about baseball. When you hit a baseball, do you just smack it with the bat or do you follow through with the swing? You follow through, right? Do you see how impulse relates to your baseball swing? If you follow through with your swing, the bat stays in contact with the ball for a longer period of time. This causes the ball to go farther. Follow-through is important in golf, bowling, tennis and many sports for the same reason. The longer the force is imparted, the farther and faster your ball will go.

Impulse changes momentum. If an object puts an impulse on another object, the momentum of both objects will change. If you continue to push on your stalled car, you will change the momentum of the car, right? If you are riding your bike while not paying any attention and crash into the back of a parked car, you will put an impulse on the car and you and the car's momentum will change. (As a kid, I did this pretty often. That's what you get when you ride and wonder at the same time. Believe me when I tell you that my momentum changed a lot more than the car's did!!)

In fact, there is a mathematical formula about this impulse and momentum thing. Impulse = change in momentum or Ft = change in mv. Force x time = mass x velocity. Does that sound familiar to anyone? It's awfully similar to Newton's Second Law (F=ma) isn't it? In fact it's the same thing.

F t = m v

Now if we divide both sides by "t" we get F=mv/t. Another way to say v is d/t (distance over time).

So now we have F=m(d/t)/t.

Those two "t's" together are the same as t^2 and d/t^2 is a (acceleration).

So what we have now is F=ma!

This Ft = mv is very important, in fact, it can save your life. Seat belts, air bags, crumple zones and other car safety features are based on this formula. When you want to shrink the force of impact, you want to increase the time the impact takes. This is called the collision time. The longer the collision time, the longer it takes your momentum to come to zero. Here's the math.

If you are in a 1000 kg vehicle moving at 30 km/h your momentum is 1000 x 30 or 30,000. Now, let's say you hit a brick wall so your momentum goes from 30,000 to 0 in .5 seconds.

Ft=mv so F(.5) = 30,000 so F= 60,000N! (N is for Newton which is a unit of force. It takes about 1 Newton to lift an apple so this car hits with the force of 60,000 apples! Talk about apple sauce!)

That's gonna leave a mark! Now let's say that instead of hitting a brick wall you hit a mound of hay and so the impact takes 3 seconds.

Now the formula looks like this: F(3)=30,000 or F= 10,000N.

See the difference, 60,000N versus 10,000N of force. All those safety features, seat belts, helmets, air bags, are designed to increase how long it takes your momentum to come to zero. Newton's laws to the rescue! Let's do a couple of experiments here to help this information have more impact (pun intended!).

Here are the highlights for this lab:

- Impulse is the amount of time a force is put on an object, how hard and how long something gets pushed or pulled.
- Ft = Impulse. Impulse affects the momentum of an object.
- Momentum is inertia in motion, how hard it is to get something to change directions or speed. Momentum = mv.
- Conservation of momentum; mv = mv. If something hits something else, the momentum of the objects before the collision will equal the momentum of the objects after the collision.

Exercises Answer the questions below:

1. What is momentum?

2. What is impulse?

3. What is the conservation of momentum?

Lesson #9: Driveway Races

Overview We know from earlier work that acceleration due to gravity is a uniform or constant rate of acceleration at 9.8 m/s^2, or 32 ft/s^2. However, if something is rolling down a ramp, it is still pulled by gravity, but at a portion of it, or not the full "strength."

What to Learn In this experiment, learn how changes in velocity can be changes in speed, direction, or both.

Materials

- ball (hard and smooth like a golf ball, racquetball, pool ball, soccer ball, etc.)
- tape or chalk
- driveway (slightly sloping – you can also use a board propped on one end as a ramp)
- timer or stopwatch
- pencil
- measuring tape or yard stick

Lab Time

1. Place the board on the books or whatever you use to make the board a slight ramp. You really don't want it to be slanted very high. An inch or less would be fine. If you wish, you can increase the slant later just to play with it.
2. Put a line across the board where you will always start the ball. Some folks call this the "starting line."
3. Start the timer and let the ball go from the starting line at the same exact time.
4. Now, this is the tricky part. When the timer hits one second, mark where the ball is at that point. Do this several times. It takes a while to get the hang of this. I find it easiest to have another person do the timing while I follow the ball with my finger. When the person says to stop, I stop my finger and mark the board at that point.
5. Do the exact same thing but this time, instead of marking the place where the ball is at one second, mark where it is at the end of two seconds.
6. Do it again but this time mark it at 3 seconds.
7. Continue marking until you run out of board or driveway.

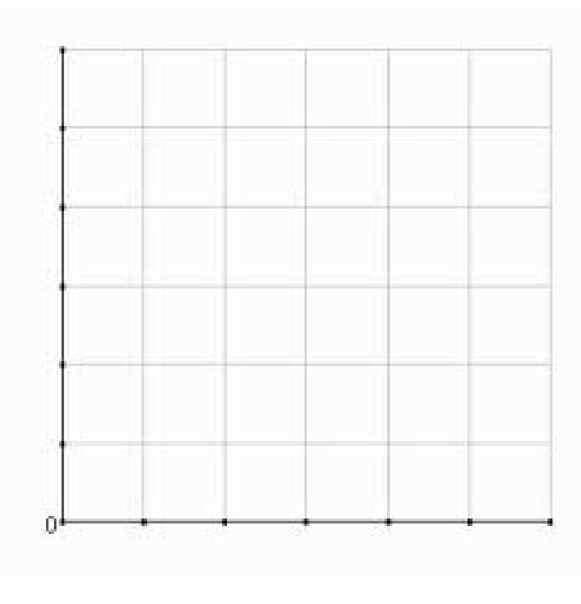
Driveway Races Data Table

Trial #	Trial 1 Distance	Trial 2 Distance	Trial 3 Distance	Average

You should have noticed that the distance didn't increase uniformly as it would when the velocity was constant. But the speed kept increasing, so the distance got larger each time. Use the following table, and we are going to determine the acceleration of your ramp by graphing it.

Using the equation $d = \frac{1}{2} at^2$. You can see that distance will be our y-axis and time will be our x-axis.

Using these variables, graph the results below. Be sure to label your axes!

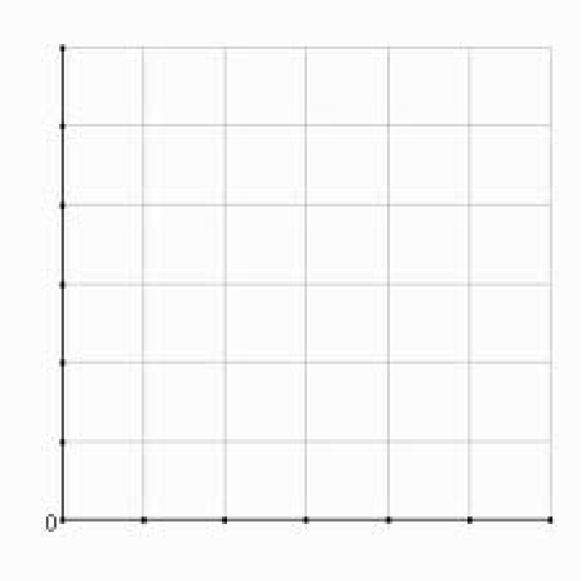


You should see that this does not create a straight line, so it can be difficult to try and determine the slope of the line.

This time, instead of graphing the time as is, square the time, then take half of it. So you have taken out ½ t^2.

That means what is left will be acceleration.

Now graph the results of the modified time.



Reading

You may notice that when things move, they rarely move at the same speed all the time. Especially when you drive, you can see right away that your speed is constantly changing. When your speed changes, you are accelerating. You can be either speeding up or slowing down. The type of acceleration we deal with, especially in introductory physics, is uniform acceleration, which means that it is accelerating at a constant rate.

Exercises Answer the questions below:

1. Was the line a straight line?
2. It should be close now, and the slope represents the acceleration it experienced going down the ramp. Calculate the slope of this line.
3. What do you think would happen if you increased the height of the ramp?
4. Knowing what you do about gravity, what is the highest acceleration it can reach?

Lesson #10: Gyro Wheel

Overview: Gyroscopes defy human intuition, common sense, and even appear to defy gravity. You'll find them in aircraft navigation instruments, games of Ultimate Frisbee, fast bicycles, street motorcycles, toy yo-yos, and the Hubble Space Telescope. Gyroscopes are used at the university level to demonstrate the principles of angular momentum, which is what we're going to learn about here.

What to Learn: You get to discover how velocity, acceleration, and momentum work together.

Materials

- bicycle wheel (detached from bicycle – the front wheel is pretty easy to detach)
- rope (about 2-3 feet)
- office chair

Lab Time

1. Carefully hold the bicycle wheel by the axle and give it a spin. Try to get it to spin as fast as you can but be VERY careful to hold onto it tightly and don't get your fingers in the spokes. It works well if someone else can spin it for you.
2. While it's spinning, try to move it around. You can try sitting in an office chair to see what happens! You'll find that the wheel does not want to be moved around and tries to do its own thing when you move it.
3. Take the rope and loop it around one side of the axle of the wheel. Spin the wheel fast and let go of the wheel while holding onto the rope. The wheel will stay spinning and defy gravity by staying straight up and down. Really! Try it, it's very cool!
4. Draw a diagram that shows the direction that the wheel spins, the direction of the force you apply when it's spinning, and the resulting force from the gyro when you apply the force. Do this for three different directions of applied force.
5. Draw a fourth of the wheel suspended from the rope. What direction of force does the gyro need to have in order for it to remain upright against the pull of gravity?

Reading

If you happen to have one of these toy gyroscopes, pull it out and play with it (although it's not essential to this experiment). Notice that you can do all sorts of things with it when you spin it up, such as balance it on one finger (or even on a tight string). Wrap one end with string and hold the string vertically and you'll find the gyro slowly rotates about the vertical string instead of flopping downward (as most objects do in Earth's gravitational field). But why? Here's the answer in plain English:

Imagine a spinning bicycle wheel hanging from a rope. Take a freeze-frame image of the wheel in your mind and imagine the top part of the wheel is at 12 o'clock, the left side at 9 o'clock, the bottom is 6 o'clock, and the center axle pointing toward you. And the wheel was rotating clockwise. Got it?

The 6 o'clock position wants to move to the left. When the 6 o'clock position gets to the 9 o'clock, it still wants to move left.

The original 9 o'clock position wants to move up. When the 9 o'clock position gets to 12 o'clock, it still wants to move up.

The 12 o'clock position wants to move to the right. When the 12 o'clock position moves to the 3 o'clock, it still wants to move right. See the pattern?

Okay, here's what you want to see now: As the top and bottom (12 and 6 o'clock) positions of the wheel rotate, the forces cancel each other out. Same with the 3 and 9 o'clock positions. And because the wheel is symmetrical, this occurs for every spot on the wheel. When this happens, the bicycle wheel turns (precesses), instead of falling. This is also why a spinning gyroscope will appear to float at the end of the string instead of dangling.

One more piece to the puzzle: The wheel itself is accelerating. Any object that swings in a circle is accelerating, because in order to move in a circle, you need to be constantly changing your direction (or else you'd be off in a straight line tangent to your circular path). When you swing a bag of oranges around your head, or a yo-yo on a string, or even take a turn in a car, acceleration is happening. We'll talk more about that when we do our g-force experiments. For right now, let's get our hands on a super-cool experiment that you usually only see at science museums or inside physics classrooms.

When you grab hold of the axle of a spinning bicycle wheel, you feel a "push" in an odd direction. This "push" is called precession, and is a wobble from the spin axis because you tried to move it in a direction it doesn't want to go.

Precession happens when you grab a spinning object at its rotating axis (like the ends of the gyroscope or the axle of a bicycle wheel) and try to move it about. You'll find a fierce resistance crop up. That's precession. The question is why. Why does the gyro act like this?

Normally, this area of scientific study is enough to make most third-year engineering students cry. The engineering required to model this system is complex, let alone finding the solution to the mathematical differential equations that make up the model itself. So we're not going to get into the nit-picky stuff, but instead talk about how it actually works using plain English. Here's what's going on:

Most gyroscopes are designed to have most of the rotating mass far away from the center axis (think of a thin disk with a heavy rim, like a bike wheel) so it can resist motion in certain directions. A spinning bike wheel stores large amounts of energy. Remember Newton's First Law of Motion? (An object in motion tends to stay in motion unless something else interferes.) Any time you try to torque the bike axle, the wheel will try to "compensate" for this and push in a different direction. (Parts of a car engine will also do this – think of the fast-spinning shaft or fan when you try to take a sharp turn.)

Who first thought up this stuff?

German scientist Johann Bohnenberger built the first gyroscope as a giant spinning ball near the start of the 1800s. About two decades later, Walter R. Johnson (an American) shifted the spinning solid sphere into a spinning disc, which was later upgraded to describing the Earth's rotation by a French mathematician Pierre-Simon Laplace. Léon Foucault attempted to use the gyroscope in experiments that could detect the earth's rotation (while still being on the planet itself), but his work lacked a frictionless mount (which was later developed), and now the famous Foucault Pendulum is in many science museums across the country. (It's the one with the 3-story tall, 300-pound brass plumb-bob that knocks over dominoes every 6-14 minutes.)

The first industrial application for the gyroscope was for the military (marine applications, then quickly followed for aircraft) in the early 1900s, followed shortly after by the toy industry. Today gyroscopes are used mostly in navigational systems and inertial guidance systems for ballistic missiles.

You can think of the Earth as a gyro as well. Precession is the "wobble" a spinning gyro makes when a force is applied (the force in this case is the pull mostly from the sun), then the Earth "wobbles" through one precession cycle about every 26,000 years. What does this mean? It means that the axial poles of the earth are scribing small, slow circles over time (the "wobble"). It also means that star positions will slowly change on our grid-marked area of the sky, so every so often we'll need to update our coordinate systems so we can accurately locate the positions of the stars. (But it's only a shift of about 1 degree very 70+ years.)

The interesting thing is that the Earth's precession was actually discovered ages ago by the ancient Greek astronomer Hipparchus (150 B.C.), but it couldn't be mathematically described until we had Newtonian physics to guide the way (and even then we had a few issues). For example, we had to figure out that the Earth is really not a sphere but more of a "squashed sphere" (imagine squashing a ball of clay slightly between your fingers so that the middle bulges out). And both the Sun and the Moon pull on the bulge (lunisolar precession), which adds more to the "wobble" of the Earth. And did I mention the Sun is not a perfect sphere, either? (It's actually kind of flat… so that had to be accounted for as well.)

All of this can be mathematically modeled in the world of engineering through a conservation law called Angular Momentum. For those of you who really want to learn more about angular momentum (which is purely your choice, but it is out of the scope of this program because it's a college-level topic), click here to download a chapter from an advanced textbook.

Exercises Answer the questions below:

1. What did it feel like when you tried to turn the wheel after it was spun?

2. What direction (orientation) does the wheel want to be in?

3. When you were on the spinning chair/platform, which way did you turn?

4. If you turned the wheel left, you should have spun the same way, where is the force coming from the pushed you in that direction?

5. What happened to the wheel while you held on to the string? Did it stay upright, or dangle?

6. Why do you think it stayed upright?

Lesson #11: Downhill Race

Overview: The force that is acting on an object is equal to its mass times the amount of acceleration acting on it at any given time. Now the thing to be careful of when trying to calculate this is that this force that is being used to calculate this is the net force. Remember from earlier lessons that net force is all of the forces being added together (in the same axis). When you add up the net force of you standing still, you would take the force of gravity (-490 N) and the normal force (490 N). Add them together and the net force is 0 N. If a = F/m, then a = 0 N/50 kg, and the acceleration = 0 m/s^2. So remember that F=ma works, but only when the F is actually F_{NET}.

What to Learn: You may notice that when things move they rarely move at the same speed all the time. Especially when you drive, you can see right away that your speed is constantly changing. When your speed changes, you are accelerating. You can be either speeding up or slowing down. The type of acceleration we deal with, especially in introductory physics, is uniform acceleration, which means that it is accelerating at a constant rate.

Materials

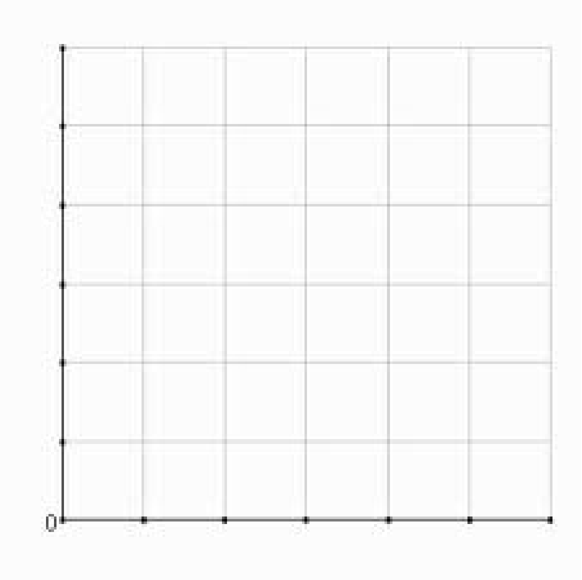
- sloping surface(such as a driveway, a board propped on one end as a ramp, or a table propped on one end)
- toy car or ball (to roll)
- stopwatch
- pen
- tape
- block or textbook

Lab Time

1. Raise the wooden ramp up, but not very tall, about 1-2 inches is fine.
2. Place the toy car at the top of the ramp and make a mark with a piece of tape (It doesn't matter if you place the mark at the front or back of the car, just be consistent. If you place the mark at the back, take the mark at the back at each set time interval)
3. Release the car and start the stopwatch. At the 1 second mark, note the location of the car and place a piece of tape or make a mark somehow.
4. Repeat this for 2 more trials to get a total of 3 trials at 1 second.
5. Continue this for up to time intervals up to 6 seconds

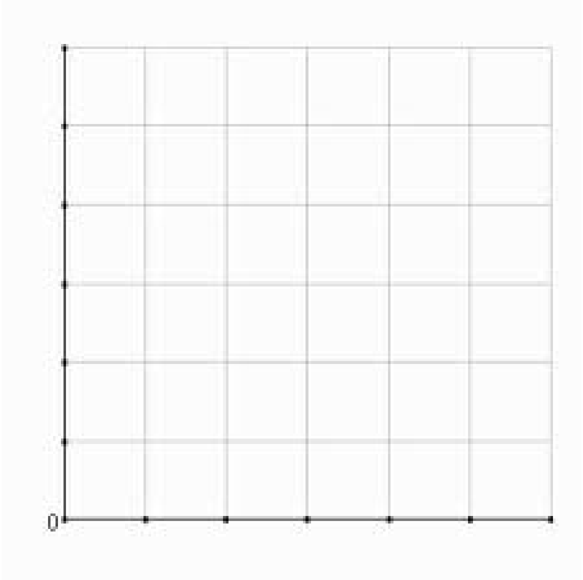
Downhill Races Data Table

Trial #	Trial 1 Distance	Trial 2 Distance	Trial 3 Distance	Average



Graph the results below with time on the x-axis and distance in the y-axis using the grid here.

Now graph the results with the distance on the y-axis and time on the x-axis, but square the time and take half of it.



Reading

What I'm hoping you will see here is that the car accelerates from zero to a certain velocity but then stays at that velocity as it continues down the driveway. In other words, it reaches its terminal velocity. If you timed and marked the distances, you should see that the car goes the same distance each second if it is indeed staying at a constant velocity. If the object you are using to roll down the slant continues to accelerate down the entire ramp, see if you can find something that has more friction to it (a toy car that doesn't roll quite to easily, for example).

Ok, so what's going on? F=ma right? Acceleration can't happen without force. What two forces are affecting the car? (Imagine the "Jeopardy" theme song here). If you said gravity and friction, give yourself a handshake. When the car is going at a constant velocity, is it accelerating? Nope, acceleration is a change in speed or direction.

"But you just said two forces are affecting my little car and that force causes acceleration and yet my car is not accelerating. Why not?"

Well, there's one little thing I haven't mentioned yet, which is why we did this experiment. In this case, the force of gravity pulling on the car and the force of friction pushing on the car are equal (remember, that's terminal velocity right?). So the net force on the car is zero. The pulling force is equal to the pushing force so there is zero force on the car. Force is measured in Newtons (name sounds familiar right?) so imagine that there are 3 Newtons of force pulling on the car due to gravity and 3 Newtons of force pushing on the car due to friction. 3 – 3 = 0. Zero force equals zero acceleration because you need force to have acceleration. By the way, 1 Newton is about the same amount of force that it takes to lift a full glass of milk.

Exercises Answer the questions below:

1. You should notice a difference between these graphs and the ones from the driveway races. What is it? (Hint: look to second half of the graph.)
2. The first graph doesn't continue to curve, but straightens out. What does this mean about the velocity?
3. in the second graph, the slope flattens out completely, what does this mean about the acceleration?
4. If the acceleration is zero, what does that mean about the net force?
5. What are the forces acting on the toy car as it is going down the ramp?
6. Name 3 other examples

Lesson #12: Net Forces

Overview: The net force (F_{net}) is when you add up all of the forces on something and see what direction the overall force pushes in. The word "net," in this case, is like net worth or net income. It's a mathematical concept of what is left after everything that applies is added and subtracted.

What to Learn: Today you get to learn how unbalanced forces cause changes in velocity.

Materials

- rope (about 3 feet long)
- friend
- sense of caution (Be careful with this. Don't pull too hard and please don't let go of the rope. This is fun but you can get hurt if you get silly.)

Lab Time

1. Both you and your friend grab either end of the rope. Pull it back just enough to get the rope off the ground. (scenario 1)
2. Have your friend pull harder than you are. (scenario 2)
3. You pull harder than your friend is. (scenario 3)
4. Both of you pull the rope, and try to pull with the same force. (scenario 4)
5. For scenario 1, draw a free body diagram below (the rope is your object, you are on the left, and your friend is on the right)

Reading

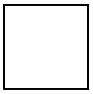
It is not very common for only one force to be acting on an object at one given time. In fact, at almost all times, there are two forces acting on you! We know that gravity is always acting on us, pulling us down towards the center of the Earth (the reason we don't fly off into space). But if gravity was the only force acting on us, we would be constantly falling towards the center of the Earth.

If we aren't always falling towards the center of the Earth, what is stopping us? Of course, it is the chair you are sitting on, or the ground you are standing on. The reason we know there is a force is, simply put: We are NOT falling towards the center of the Earth (I know, seems a little simple, right?). There is also a way to figure out exactly how much force the chair or ground exerts on us. We already know how to calculate to force of gravity ($F_G = mg$), If we are sitting or standing still, then we know the force the chair/ground exerts has to be the exact same amount as the gravity acting on us. The only difference is that gravity pulls us towards the center of the earth, while the force of the chair/ground pushes us away from the center of the earth.

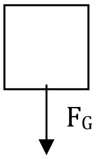
This is how we know Newton's Third Law of Motion. For every action, there is an ***equal*** and ***opposite*** reaction. In this case, for the force of gravity pulling us down there is an ***equal*** force pushing us in the ***opposite*** direction. This force is called a normal force, because it is the normal reaction to gravity.

What this leads us to is what is known as net force. Net is a term commonly used in mathematics and finance as a smart way to say "total." It is the total force acting on an object at any given point in time. Typically, you can draw the object and draw the forces pulling on the object at any given time. Don't worry, you don't have to be a great artist. In fact, to keep things simple and consistent, we always draw the object as a simple box. And we draw the forces acting on the box as an arrow, coming out from the object NOT into the object. If any forces push/pull the object down, we draw it coming out of the bottom of the box, anything pulling the object up coming out from the top of the box. The size of the arrow makes a difference, too. The bigger the force, the bigger the arrow. Let's look at how we would draw our example of you standing on the floor below.

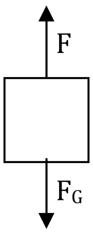
First, draw your object (remember, just a simple box)



Next, draw the first force (usually gravity, because it's always there!) Don't forget to label the force. When you get to 4 or 5 forces, labels help you remember what is what!



Now draw the second force (In this case our normal force). The magnitude of the force is the same, so the arrow should be the same size, but the direction is the opposite of the force of gravity



Our drawing makes it easy to see that there are 2 forces acting on the object, they are equal in magnitude and opposite in direction, so there is a net force of zero acting on our object. We know right away that our object is either not moving, or moving, but at a constant speed, so not accelerating.

We could add numbers to our diagram as well to mathematically calculate to Net Force acting on our object. To calculate the Net Force, we simply add up all of the forces (only add y-axis forces, or x-axis forces together, not an x force and a y force) or:

$F_{NET} = F_1 + F_2 + F_3$….

Let's say the force of gravity acting on our object is 100 N, and the normal force is also 100 N. If we add up our force to get our net force, we would get 200 N.

$F_{NET} = F_G + F_N$
$F_{NET} = 100\ N + 100\ N$
$F_{NET} = 200\ N$

That doesn't seem right, because we know the net force is 0 N. Because the forces are vectors, we have to consider direction. When they move in opposite directions, one of them has to be negative. Typically, the downward and leftward forces are negative, and the upward and rightward forces are positive. This isn't a rule, but an easy way to keep it consistent. So now if we add up the forces:

$F_{NET} = F_G + F_N$
$F_{NET} = -100\ N + 100\ N$
$F_{NET} = 0\ N$

We get zero for the net force, just like we already knew it should be.

Exercises:

1. For scenario 2, in which direction did you both move? Draw the free body diagram below
2. For scenario 3, in which direction did you both move? Draw the free body diagram below
3. For scenario 4, in which direction did the rope move? Draw the free body diagram below
4. What was the same about question 1 and question 4? What was different?
5. Even though the forces were less in question 1 than question 4, what was the net force for both?
6. There were always at least 3 forces acting on the rope, what were they? Did you include the third force in your free body diagram?

7. If the rope wasn't moving, but you had only one force moving down, what does that tell you about the force you and your friend exerted?

Net Forces Data Table

Calculations: Assume the light force (when you picked up the rope, or pulled less than your friend was 10 N. Assume the Stronger Force (when your friend pulled harder, or your pulled harder or you both pulled hard) was 75 N. If we ignore amount that counteracted gravity and assume they were both in the x-axis direction, fill in the table below. Don't forget to consider direction.

Scenario	**Your Force**	**Your friend's Force**	**Net Force**
1	*-10 N*	*10 N*	
2	*-10 N*	*75 N*	
3	*-75 N*	*10 N*	
4	*-75 N*	*75 N*	

Lesson #13: Exponential Friction

Overview: This is a classic experiment where a small kid can totally win a bet with the entire football team. When I demonstrate this activity, I'll pick the smallest kid and three of the largest to perform in front of the class. The small kid always wins, especially after a quick lesson in how you can get friction to grow exponentially.

What to Learn: Students will learn how friction can grow exponentially, and learn how to identify forces acting on a single static object.

Materials

- rope (nylon, 10 feet or longer)
- column or pillar
- people (two at least – more is better)

Lab Time

1. Stand by the column and put the rope around the pole (without looping it… have it make a U-turn around the pole for right now).
2. Have students pull on either end of the rope. Note that the friction is minimal.
3. Loop the rope around one time, so it's wrapped around one and a half times. What happens now when it's pulled on either end?
4. Try another loop (two and a half turns) and pull.
5. Note how the friction grows quickly!

Exponential Friction Data Table

Number of Turns Around the Pole	Number of Friends on the Other End of the Rope	What Happened?

Reading

For this experiment, you'll need to find a smooth, cylindrical support column, such as those used to support open-air roofs for breezeways and outdoor hallways. You'll be winding a length of rope around the column and pulling on one end while three friends pull on the other in a tug-of-war fashion, so make sure it's a sturdy pole you've selected.

This is a great demonstration of what "exponential growth" truly means. There is friction between the rope and the support column that you can feel as you tug on the rope. With every additional turn around the pole, the amount of friction increases exponentially until it skyrockets so much the rope feels as if it's welded to the pole. Experiment with the number of friends and the number of winds around the column. Can you hold your end with just two fingers against an entire team of football players? You bet!

Einstein himself stated that "exponential growth" was the eighth wonder of the world!

Exercises Answer the questions below:

1. How much money would you earn on Day 20 if I gave you one penny on Day 1, and doubled it every day after so Day 2 you received 2 pennies, and Day 3 you got 4 pennies?

2. Why do you think this experiment with friction works? Does it work with a flat surface the same way as a curved surface?

Lesson #14: Bearings

Overview: You're going to play with different kinds of bearings: Some only allow movement in one direction, like roller bearings, while others allow movement in two directions, like ball bearings.

What to Learn: Students will learn how scientists and engineers reduce friction in machines.

Materials

- 12-inch square board
- 10 dowels (You can also use or round, not hexagonal, pencils.)
- handful of marbles (at least 20)

Lab Time

1. Place one board on top of the other and push the top one. It moves relatively easily, right?
2. Sit on the top board and have someone try to push you gently across the floor. Is this easy or hard?
3. Now place the dowels parallel between the board and the floor. (Smooth wooden pencils can work in a pinch, as can the hard cardboard tubes from coat-hangers.)
4. Ask someone to push you.
5. Is there a direction you still can't travel easily? Now let's add another direction to your motion…
6. Replace the dowels with marbles. What happens?
7. Draw a diagram of the three different scenarios and indicate the direction of force applied to you, as well as the direction you traveled in. Label everything so it's obvious which experiment each drawing is representing.

Reading

Bearings are found everywhere something moves or rotates. You'll find bearings in your bike, in a car engine and wheel assemblies, at the tip of a ballpoint pen … anywhere you want to significantly reduce the friction of two surfaces so they slide against each other more easily. There are many different kinds of bearings as well as types of lubricants used to make them operate in different environments.

You can make your own low-friction ball bearings: Get two cans (with a deep groove in the rim, such as paint cans) and stack them. Turn one (still on top of the other) and notice the resistance (friction) you feel. Now sandwich a set of marbles along the rim between the cans. Place a heavy book on top and note how easily it turns around. You can add lubricant by adding a little vegetable oil to the marbles and you'll find it turns more easily yet.

Exercises Answer the questions below:

1. Why do the marbles make you go in all directions?

2. What direction(s) did the dowels roll you in?

Lesson #15: G-Force

Overview: Have you ever been riding in a really fast car and you almost feel "pushed" back into your seat because of how fast you start? Or been thrown forward when someone had to slam on the brakes? How about pushed to the side when the car took a fast turn? So … who pushed you? That's what this lab is all about.

What to Learn: You'll learn about centrifugal force, centripetal acceleration and g-force, and how to tell the difference between them.

Materials

- bucket
- water
- outdoor area
- clear tubing (about 12-18″ long)
- nylon or metal barbed union that fits inside the tubing
- soda bottle (empty)
- wine cork
- string

Lab Time

1. To make the cork accelerometer, fill an empty soda bottle to the top with water.
2. Modify the soda bottle cap as follows: attach a string 8-10″ long to a clean cork, like the kind from a wine bottle.
3. Hot glue the free end of the string to the inside of the cap.
4. Place the cork and string inside the bottle and screw on the top (try to eliminate the air bubbles). The cork should be free to bob around when you hold the bottle upside-down.
5. Now race around and see if you can predict where the cork is going to go. Complete the data table.

G-Force Data Table 1

Activity You Did	Which Way Do you Guess the Cork Will Move?	Cork Observations

Remember – it is measuring acceleration, which is the change in speed. It will only move when your speed ***changes***. The trouble with this accelerometer is that there are no measurements you can take – it's purely visual. This next activity in this lab is more accurate at measuring the number of g-s you pull in a sharp turn (whether in a vehicle or in a roller coaster!)

6. To make the g-force ring: (This quick homemade device roughly measures acceleration in "g's." We used it to measure the g-force on roller coasters at Six Flags Magic Mountain, and it worked just as well as the expensive ones you buy in scientific catalogs!)
7. Cut about a foot of tubing – the larger diameter tubing you can find, the easier it will be to read your measurements.
8. Fill your tube halfway with COLORED water (it's impossible to read when it's clear). Blue, green, red… your choice of food dye additive.
9. Make an O-shape using your barbed union to water-seal the junction.
10. Grab hold of one side and hold the circle vertical, with the barb-end pointing up.

11. Make sure there are equal amounts of water and air in your tube. Adjust if necessary.
12. Make a mark on the tube where the water meets the air with a black marker. This is your 0-g reading (relative, of course). No acceleration. Not a whole lot of fun.
13. Now, for your 1-g mark – measure up 45 degrees from the first mark. (If the top of the circle is 90 degrees, and the 0-g mark is zero degrees, find the halfway point and label it).
14. The 2-g mark is 22.5 degrees up from the 1-g mark.
15. 3-g mark is 11.25 degrees up from the last mark. And 4-g is 5.6 degrees up from the last mark. (See a pattern? You can prove this mathematically in college, and it's kind of fun to figure out!)
16. Now, if you have access to a car with a driver or a playground with swings and spinning things, hold the tube in your hand so that the water line starts at the zero mark. See how far it sloshes up when you accelerate and read how many g's you've pulled. We would have contests to see who could pull the most g's while spinning in a circle.

G-Force Data Table 2

Activity You Did	How Many g's Measured?	Observations

Reading

G-force is really just the force that you experience by being accelerated. Have you ever been riding in a really fast car and you almost feel "pushed" back into your seat because of how fast you start? Probably not, because most of us don't ride in cars that fast. More likely you've been "thrown" forward when someone had to slam on the brakes, or you feel pushed to the side whenever someone takes a fast turn. Whenever you feel these "pushes," that means you are accelerating or changing speeds.

The higher the acceleration, the harder the "push" feels. The reason I use quotation marks to describe the push is to describe the "push" you feel when you experience the g-force. This push you feel is actually just your own inertia wanting to maintain the motion (or rest) your body was already in. When you suddenly stop, your body wants to continue moving forward, but your sense of relative motion is set to the car as a stationary location.

When you feel yourself wanting to continue going forward, and the car is stopping you think of yourself as being "pushed" or "pulled" when you are really just trying to keep your original motion.

The same happens when you are turning, even when you are moving a constant speed. I know it seems confusing, but we need remember that velocity is a vector, meaning that it takes into account speed *and* direction. When you are turning at a constant speed, you are changing direction, and that directional change means your velocity changes, so you have an acceleration.

The concept of the "push" or "pull" is the same as braking: Your body wants to continue to move in a straight line. When the car is turning to the left, your body wants to go straight, but in relative motion to the car you appear to be moving to the right of the car, so you feel "pulled" to the right.

How does this all relate to "g-forces"? Well, like we learned before, the acceleration due to gravity is 9.8 m/s^2, or 32 ft/s^2. And the g-force that you experience is just a multiple of this number. For example, if you experience an acceleration of 19.6 m/s^2, you would divide this by 9.8 m/s^2 to get 2 g's. If you experience an acceleration of 48 ft/s^2, you divide this by 32 ft/s^2, and you get 1.5 g's. So it's just how many multiples of gravity's acceleration you experience.

How does acceleration relate to force? Through Newton's Second Law: F = ma! But there are different kinds of forces (and thus acceleration): centripetal and centrifugal. How can you tell the difference?

Centripetal (translation = "center-seeking"**)** is the force needed to keep an object following a curved path. Remember how objects will travel in a straight line unless they bump into something or have another force acting on them (gravity, drag force, etc.)? Well, to keep the bucket of water swinging in a curved arc, the centripetal force can be felt in the tension experienced by the handle (or your arm, in our case). Swinging an object around on a string will cause the rope to undergo tension (centripetal force), and if your rope isn't strong enough, it will snap and break, sending the mass flying off in a tangent (straight) line until gravity and drag force pull the object to a stop. This force is proportional to the square of the speed - the faster you swing the object, the higher the force.

Centrifugal (translation = "center-fleeing") force has two different definitions, which also causes confusion. The inertial centrifugal force is the most widely referred to, and is purely mathematical, having to do with calculating kinetic forces using reference frames, and is used with Newton's laws of motion. It's often referred to as the "fictitious force."

Reactive centrifugal force happens when objects move in a curved path. This force is actually the same magnitude as centripetal force, but in the opposite direction, and you can think of it as the reaction force to the centripetal force. Think of how you stand on the Earth … your weight pushes down on the Earth, and a reaction force (called the "normal" force) pushes up in reaction to your weight, keeping you from falling to the center of the Earth. A centrifugal governor (spinning masses that regulate the speed of an engine) and a centrifugal clutch (spinning disk with two masses separated by a spring inside) are examples of this kind of force in action.

Imagine driving a car along a banked turn. The road exerts a centripetal force on the car, keeping the car moving in a curved path (the "banked" turn). If you neglected to buckle your seat belt and the seats have a fresh coat of Armor-All (making them slippery), then as the car turns along the banked curve, you get "shoved" toward the door. But who pushed you? No one – your body wanted to continue in a straight line but the car keeps moving in your path, turning your body in a curve. The push of your weight on the door is the reactive centrifugal force, and the car pushing on you is the centripetal force.

What about the fictitious (inertial) centrifugal force? Well, if you imagine being inside the car as it is banking with the windows blacked out, you suddenly feel a magical ”push” toward the door away from the center of the bend. This “push” is the fictitious force invoked because the car’s motion and acceleration is hidden from you (the observer) in the reference frame moving within the car.

Exercises Answer the questions below:

1. Which accelerometer was better at giving a visual representation of accelerating?
2. Which one do you prefer? Why?
3. What activity did you do that created the most acceleration?
4. What does that tell you about acceleration?

Lesson #16: Detecting the Gravitational Field

Overview: Ok, sort of a silly experiment I admit. But here's what we're going for – there is an invisible force acting on you and the ball. Things don't change the way they are moving unless a force acts on them. When you jump, the force that we call gravity pulls you back to Earth. When you throw a ball, something invisible acts on the ball, forcing it to slow down, turn around, and come back down. Without that force field, you and your ball would be heading out to space right now!

What to Learn: Everywhere you go, the acceleration due to gravity will be the same. I mean that it will work the same on Earth, on the moon, on Jupiter, etc. For a long time, we knew there was something pulling us down (towards the center of the earth), but we didn't know all that much about how it worked. We thought it acted differently on different objects. For example, we thought it would make heavier objects fall at a faster rate than lighter objects (it would make a cannon ball fall faster than an apple). While we know that if we dropped a cannon ball on our foot and an apple on our foot, the cannon ball would definitely hurt more, it wouldn't necessarily fall faster!

Materials

- two different-sized objects
- tape measure or meter stick
- partner

Lab Time

1. Pick your two different-sized objects.
2. Hold them both at a height of 1 meter.
3. While your partner watches, drop both objects to see which one hits the ground first.
4. Repeat the experiment at least 2 more times.
5. Make an initial conclusion (was your hypothesis correct?)
6. Pick another item (larger or smaller) and repeat the experiment.
7. Does your initial conclusion hold true?
8. Change another variable about the experiment (change the height dropped from, change the weight of the object, or the volume of the object)

Detecting the Gravitational Field Data Table 1: Testing the Mass

Use objects of the same size but different weights.
(Ping pong ball, golf ball, foam ball, crumpled up wad of paper, tin foil ball, etc.)

Trial #	Mass/Weight	Guess First! Which Object Will Hit First?	Observations: Which Hit First?

Conclusion:

Detecting the Gravitational Field Data Table 1: Testing the Size

Use objects of the same mass but different surface areas.

Trial #	Diameter/Area	Guess First! Which Object Will Hit First?	Observations: Which Hit First?

Conclusion:

Detecting the Gravitational Field Data Table 1: Testing the Height

Use objects of the same size but different weights.
(Ping pong ball, golf ball, foam ball, crumpled up wad of paper, tin foil ball, etc.)

Trial #	Height	Guess First! Which Object Will Hit First?	Observations: Which Hit First?

Conclusion:

Reading

Gravity is probably the force field you are most familiar with. If you've ever dropped something on your foot you are painfully aware of this field! Even though we have known about this field for a looooong time, it still remains the most mysterious field of the four.

What we do know is that all bodies, from small atoms and molecules to gigantic stars, have a gravitational field. The more massive the body, the larger its gravitational field. As we said earlier, gravity is a very weak force, so a body really has to be quite massive (like moon or planet size) before it has much of a gravitational field. We also know that gravity fields are not choosy. They will attract anything to them.

All types of bodies, from poodles to Pluto, will attract and be attracted to any other type of body. One of the strangest things about gravity is that it is only an attractive force. Gravity, as far as we can tell, only pulls things towards it. It does not push things away. All the other forces are both attractive (pull things towards them) and repulsive (push things away).

Exercises Answer the questions below:

1. What did you determine about gravity and how it affects the rate of falling?
2. Did changing the object affect the rate of falling? Why or why not?
3. Did changing the variable affect the rate of falling? Why or why not?

Lesson #17: Hovercraft

This is a bonus lab for students who want to do an extra-special project.

Overview: Students will learn how to build a real model hovercraft! This is a great way to end the unit by making something they can see accelerate, defy gravity, and reduce friction by floating on a cushion of air.

What to Learn: Hovercraft transport people and their stuff across ice, grass, swamp, water, and land. Also known as the Air Cushioned Vehicle (ACV), these machines use air to greatly reduce the sliding friction between the bottom of the vehicle (the skirt) and the ground. This is a great example of how lubrication works – most people think of oil as the only way to reduce sliding friction, but gases work well if done right.

In this case, the readily available air is shoved downward by the hover motor and the skirt traps the air and keeps it inside, thus lifting the vehicle slightly. The thruster motor's job is to propel the craft forward. Most hovercraft use either two motors (one on each side) for steering, or just one with a rudder that can deflect the flow (as your project does).

The first hovercraft were thought about in the 1800s, but it wasn't until the 1950s that real ones were first tested. Today, the military uses them for patrolling hard-to-drive areas, scientists use them for swamp research studies, and businesses use them to transport toys and food across rough and icy areas. Scientists are already planning future ACVs to use magnetic levitation in addition to the air power… but it's still on the drawing board.

Materials

- skewer
- popsicle stick
- straw
- Styrofoam cup (16 oz. – note: waxed cups won't work)
- Styrofoam carryout container (The one in the video is 5.5" square and 3" high when closed)
- Styrofoam meat tray (The one in the video is 10" x 12" x 1" – but yours does not have to be this exact size – try different sizes by asking for clean ones from your butcher.)
- DC motors (two 3-volt – make sure they are high speed)
- propellers (2, in the video they are 3" in diameter – check with your local hobby store for a variety to test)
- 9V battery clip with wires
- 9V battery (a good brand like Duracell or Energizer)
- 9V battery holder (looks like a "C" – or you can use tape to attach the battery to your hovercraft)
- wires (a couple extras – like speaker wire, alligator clips, etc.)
- SPST switch
- ruler
- box cutter (with adult help)
- wire strippers (or scissors)
- tape
- pen
- string (small piece)
- hot glue gun
- glue sticks

Lab Time

1. First, we'll work to make the hovercraft hover. Start by finding the center of the Styrofoam meat tray. This will be your base.
2. Use the ruler to measure the diameter of your cup to make sure it's 3.5 inches. If it measures correctly, use the cup and pen to draw a circle in the middle of the tray
3. Carefully cut out the circle, supporting the bottom of the foam.
4. Cut your skewer into three pieces, making sure they are longer than the cut-out circle is wide.
5. Use the hot glue gun to attach the lip of the round motor onto the skewer pieces, keeping them as parallel as possible.
6. Gently attach the skewers onto the foam.
7. Attach a propeller onto the shaft of the motor which is now attached to the skewers and foam tray.
8. Now we will work with the takeout container. Open it and cut it in half and place one half to the side.
9. Check the diameter of the bottom of the foam cup to ensure it's about 2 ¼ inches. Then you can trace it with a pen on the top of the hamburger container half.
10. Cut out the circle and discard it.
11. Using the slide switch as a guide, cut out a small rectangle in the front for the switch. Reinforce it with hot glue, being careful to NOT get hot glue in the switch. Make sure it still slides back and forth.
12. Rest the hamburger half on top – we aren't going to attach it just yet.
13. Find the small motor and look for the small contacts (they are very small and fragile – they are copper and look a little like foil). Gently bend them up a little in the back.
14. Hot glue the motor onto the end of the popsicle stick with the shaft pointing away from the stick and the contacts pointing up.
15. Use hot glue to secure the stick across the top of the hole in the hamburger box.
16. Attach a propeller and give it a spin to make sure it will spin.
17. Find the 9-volt battery clip and hot glue the bottom of it onto the middle of the popsicle stick.
18. Cut your wire into two equal length pieces. Remove the insulation from the ends (about ¾ of an inch to an inch - get adult help if you need it). Twist the exposed wires together. Do this for both wires.
19. If you aren't going to solder the project, you'll need to cut off the metal ends of the 9 volt battery clip's wires and strip the wire insulation. Twist these wires together as well.
20. Now we'll work on wiring the inside motor. Take the end of one wire and put it halfway through one of the posts. Bend it up and twist it around itself very well to ensure it's connected well. Do this with the other wire and connection.
21. One of these wires will go to the switch. Thread the wire through a tab and twist it around itself.
22. Attach the black wire from your 9-volt battery clip to the other tab on the switch.
23. Thread your remaining wires (the red one from the battery clip and the remaining red wire from the first, hovering motor) up through the hamburger tray to attach them to the second motor. This is the thruster motor.
24. Now that everything is wired, glue the hamburger tray to the bottom tray by placing hot glue at each of the four corners and pressing down gently.
25. To test, grab your 9-volt battery. Check to make sure everything is wired correctly – the hovercraft should hover, not be sucked down to the table, and you should feel air blowing if you hold your hand in front of the thruster motor. Switch the appropriate wires if you note any issues during testing.
26. Now we'll build a shroud around the thruster motor. You'll need the cup, the last piece of wooden skewer, the straw, and the remaining big piece of foam. Measure about halfway down the cup and cut it all the way

around – essentially cutting it in half. You’ll be using the top of the cup – the cuff-like portion. It should fit around the propeller.

27. Starting on the cut side of the foam, cut out a rectangle to use as a shim. Hot glue the rectangle down to the hovercraft. Then hot glue the cup cuff down to the rectangle.
28. If the propeller is hitting the Styrofoam, you can move the cup around and hot glue as needed to make sure there is room for movement.
29. Make a vein from a rectangular piece of Styrofoam that fits inside the cup cuff.
30. Glue the straw onto the long end of this piece and trim the straw down. The wooden skewer should fit right through the straw.
31. Push the wooden skewer down through the top of the cup. Pierce the bottom of the cup but DO NOT pierce the bottom of the hovercraft.
32. Put the straw and Styrofoam piece in, and then thread the skewer back down through the straw.
33. Troubleshooting: make sure the bottom of the hovercraft – the tray’s lip – is as smooth as possible. You can sand it down lightly if you need to. You’ll need a clean, smooth, flat surface to hover on as well! You might also double check the motor directions. If necessary, you can lightly weigh down the front of the hovercraft to balance out the weight from the back.
34. Modification: Once the hovercraft is operational, you can hot glue foam tubing to the bottom to make a water hovercraft. However, it will no longer work on land!

Reading

The down-facing motor (the hover motor) is moving air which escapes out the bottom of the foam tray. Make sure your foam tray and table are both pretty flat, or you'll have drag issues and the hovercraft won't work. The air is a lubricating layer between the foam tray and table that allows the hovercraft to slide a lot easier by reducing the friction between the bottom of the hovercraft and the table.

Friction is the force between two objects in contact with one another. Friction is dependent on the materials that are in contact with one another: how much pressure is put on the materials, whether the materials are wet or dry, hot or cold. In other words, it's quite complicated! The friction between the puck and the street are a lot higher than with ice.

Friction happens due to the electromagnetic forces between two objects. Friction is not necessarily due to the roughness of the objects but rather to chemical bonds "sticking and slipping" over one another.

The first hovercraft was designed for military use in 1915, but was mostly operated over later. In the 1930s, inventors combined simple aircraft principles into their designs to produce the first vehicles that utilized ”ground effect” and could hover on land.

Lesson #18: The Electromagnetic Field

Overview: When you stare at a compass, the needle that indicates the magnetic field from the Earth appears to stand still, but we're going to find how it fluctuates and moves by creating a super-sensitive instrument using everyday materials (for comparison, you would spend over $100 for a scientific instrument that does the same thing).

What to Learn: Today you get to learn how to amplify tiny pulses in the Earth's magnetic field using a laser and a couple of magnets. It's a very cool experiment, but it does take patience to make it work right. Deep breath … are you ready?

Materials

- index card or scrap of cardboard
- 2 small mirrors
- 2 rare earth magnets
- nylon filament (thin nylon thread works, too)
- 4 doughnut magnets
- laser pointer (any kind will work – even the cheap key-chain type)
- clean glass jar (pickle, jam, mayo, etc… any kind of jar that's heavy so it won't knock over easily)
- wooden spring-type clothespin
- hot glue gun, scissors and tape

Lab Time

1. Sandwich the twine between the two rare earth magnets. These are the stronger magnets.
2. Use a tiny dab of glue on one of the magnets and attach a mirror to the magnet. Do this on the other side for the second magnet and mirror.
3. Lower the mirror-magnets into the container, leaving it hanging an inch above the bottom of the jar. Cut the twine at the mouth level of the container.
4. Glue the top of the twine to the bottom of the lid, right in the center.
5. When the glue has dried, place your mirror-magnets inside the jar and close the lid. Make sure that the mirror-magnets don't touch the side of the jar, and are free to rotate and move.
6. You've just built a compass! The small magnets will align with the earth's magnetic field. Slowly rotate the jar, and watch to see that the mirror-magnets inside always stay in the same configuration, just like the needle of a standard compass.
7. Set your new compass aside and don't touch it. You want the mirror-magnets to settle down and get very still.
8. You are going to build the magnet array now. Stack your four donut magnets together in a tall stack.
9. Fold your index card in half, and then open it back up. On one side of the crease you're going to glue your magnets. When the magnets are attached, you'll fold the card over so that it sits on the table like a greeting card with the magnets facing your glass jar.
10. Tape your index card down to the table as you build your magnet array. (Otherwise the paper will jump up mid-way through and ruin your gluing while you are working.)

11. Place a strip of glue on the bottom magnet of your stack and press it down onto the paper, gluing it into place.
12. Lift the stack off (the bottom magnet should stay put on the paper) and place glue on the bottom magnet. Glue this one next to the first.
13. Continue with the array so you have a rectangle (or square) arrangements of magnets with their poles oriented the same way. Don't flip the magnets as you glue them, or you'll have to start over to make sure they are lined up right.

Since we live in a gigantic magnetic field that is 10,000 times more powerful than what the instrument is designed to measure, we have to "zero out" the instrument. It's like using the "tare" or "zero" function on a scale. When you put a box on a scale and push "zero", then the scale reads zero so it only measures what you put in the box, not including the weight of the box, because it's subtracting the weight of the box out of the measurement. That's what we're going to do with our instrument: We need to subtract out the Earth's magnetic field so we just get the tiny fluctuations in the field.

14. Place your instrument away from anything that might affect it, like magnets or anything made from metal.
15. Fold the card back in half and stand it on the table. We're normally going to keep the array away from the jar, or the magnet array will influence the mirror-magnets just like bringing a magnet close to a compass does. But to zero out our instrument, we need to figure out what the distance is that the array needs to be in order to cancel out the Earth's field.
16. Bring the array close to your jar. You should see the mirror-magnets align with the array.
17. Slowly pull the magnet array away from the compass to a point where if it were any closer, the mirror-magnets would start to follow it, but any further away and nothing happens. It's about 12 inches away. Measure this for your experiment and write it on your array or jar so you can quickly realign if needed in the future.
18. Insert your laser pointer into the clothespin so that the jaws push the button and keep the laser on. Place it at least the same distance away as the array. You might have to prop the laser up on something to get the height just right so you can aim the laser so that it hits the mirror inside. (Note that you'll have a reflection from the glass as well, but it won't be nearly as bright.)
19. Find where the laser beam is reflected off the mirror and hits the wall in your room. Walk over and tape a sheet of paper so that the dot is in the middle of the paper. Use a pen and draw right on top of the dot, and mark it with today's date.
20. Do you notice if it moves or it is stays put? Sometimes the dot will move over time, and other times the dot will wiggle and move back and forth. The wiggles will last a couple of seconds to a couple of minutes, and those are the oscillations and fluctuations you are looking for!
21. Tape a ruler next to the dot so you can measure the amount of motion that the dot makes. Does it move a lot or a little when it wiggles? Two inches or six?

Reading

The reason this project works is because of tiny magnetic disturbances caused by the ripples in the ionosphere. Although these disturbances happen all the time and on a very small scale (usually only 1/10,000th of the Earth's magnetism strength), we'll be able to pick them up using this incredibly simple project. Your reflected laser beam acts like an amplifier and picks up the movement from the magnet in the glass.

Construction tip for experiment: You need to use a filament that doesn't care how hot or humid it is outside, so using one of the hairs from your head definitely won't work. Cotton tends to be too stretchy as well. Professionals use fine quartz fibers (which are amazingly strong and really don't care about temperature or humidity). Try extracting a single filament from a multi-stranded nylon twine length about 30″ long. If you happen to have a fine selection of nylon twine handy, grab the one that is about 25 microns (0.01″) thick. Otherwise, just get the thinnest one you can find.

Also note that big, powerful magnets will not respond quickly, so you need a lightweight, powerful magnet. Try finding a set of rare earth magnets from Radio Shack or the hardware store.

You can walk around with your new instrument and you'll find that it's as accurate as a compass and will indicate north. You probably won't see much oscillation as you do this. Because the Earth has a large magnetic field, you have to "tare" the instrument (set it to "zero") so it can show you the smaller stuff. Use the doughnut magnets about 30 centimeters away as shown in the video.**Exercises**

Answer the questions below:

1. Does the instrument work without the magnet array?

1. Why did we use the stronger magnets inside the instrument?
2. Which planet would this instrument probably not work on?

Forces & Motion Part 2 Evaluation

Teacher Section

Overview: Kids will demonstrate how well they understand important key concepts from this section.

Suggested Time: 45-60 minutes

Objectives: Students will be tested on the key concepts of Forces & Motion:

- An object's motion can be described by recording the change in its position over time.
- An object at rest usually has multiple forces on it, but they add up to give a net force sum of zero. Forces that don't sum to zero are imbalanced, and cause an object to change speed or direction of motion (or both). When the forces on an object are balanced, the motion of the object does not change.
- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's Third Law).
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.
- Electric and magnetic forces between a pair of objects do not require the objects be in contact. The size of the forces depends on the properties of the objects, their distance apart, and in the case of magnets, their orientation.
- Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.
- The velocity of an object is the rate of change of its position.
- To describe the velocity of an object, one must specify both direction and speed.
- Changes in velocity can be changes in speed, direction, or both, and this is called acceleration.

Students will also demonstrate these principles:

- Design and build an experiment that shows how forces are balanced and unbalanced, and how unbalanced forces cause motion in an object.
- Make observations and measurements on an object's motion to figure out the predictable pattern of motion.
- Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.
- Design an experiment that shows when the arrangements of objects interacting at a distance changes, different amounts of potential energy are stored in the system.
- Show that when the motion energy of an object changes, energy is transferred to or from the object.
- How to solve problems involving distance, time, and average speed.
- How to interpret graphs of position versus time and speed versus time for motion in a single direction.
- Apply Newton's Third Law to design an experiment involving the motion of two colliding objects.
- Design and build an experiment that shows how the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

- Show that gravitational interactions are attractive and depend on the masses of the objects.
- Design and build an experiment that shows that fields exist between two objects that are not touching.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Measure and estimate the weight, length and volume of objects.
- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

Materials (one set for entire class)

- a ball

Lab Preparation

1. Print out copies of the student worksheets, lap practical, and quiz.
2. Have a tub of the materials in front of you at your desk. Kids will come up when called and demonstrate their knowledge using these materials.

Lesson

The students are taking two tests today: the quiz and the lab practical. The quiz takes about 20 minutes, and you'll find the answer key to make it easy to grade.

Lab Practical

Students will demonstrate individually that they know how to demonstrate Newton's Three Laws of Motion. While other kids are waiting for their turn, they will get started on their homework assignment. You get to decide whether they do their assignment individually or as a group.

Forces & Motion Part 2 Evaluation

Student Worksheet

Overview: Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about forces and motion as we've studied it in these lessons. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to get started on your homework assignment. The assignment is due next week, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it. Choose one:
    a. Write a short story or skit about Newton's Laws of Motion from the perspective of the object (like a ball or a planet). You'll read this aloud to your class.
    b. Make a poster that teaches the main concepts of Newton's Three Laws of Motion. When you're finished, you'll use it to teach to a class in the younger grades and demonstrate each of the principles that you've learned.
    c. Write and perform a poem or song about velocity, acceleration, forces, friction and/or gravity. This will be performed for your class.

Forces & Motion Part 2 Quiz

Name____

1. What is Newton's Third Law of Motion?
2. What is velocity?
3. What are the forces acting on your body when you sit in a chair, and what is the net force?
4. Which forces can be attractive or repulsive? Do their sizes depend on the magnitudes of the charges? Give an example.
5. Do two objects interacting with each other electrically need to be in contact?
6. Gravitational forces are always: attractive, repulsive, or both?
7. True or false? Gravity pulls on all things equally.
8. True or false? Gravity accelerates all things equally.
9. How is acceleration different from speed and velocity?
10. What is friction?

11. What is inertia?

12. What is Newton’s First Law?

13. What concept does Newton’s Second Law of Motion deal with?

14. What is momentum?

15. What is the equation for Newton’s Second Law?

16. Give three examples of forces in pairs.

17. If the acceleration is zero, what does that mean about the net force?

Forces & Motion Lab Part 2 Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- A ball

Lab Practical:

- Students will demonstrate Newton's Three Laws of Motion. Hand the student a ball and ask them to teach you the three laws of motion.

Answers to Exercises

Lesson 1: Fast Ball

1. Is gravity a speed, velocity, or acceleration? (Gravity is an acceleration of 32.2 ft/s^2)
2. Does gravity pull equally on all things? (No.)
3. Does gravity accelerate all objects equally? (Yes.)
4. How is acceleration different from speed and velocity? (Speed is distance per unit time, velocity is speed and direction, and acceleration is the change in velocity, which means a change in the speed or a change in the direction.)

Lesson 2: Tracking Treads

1. What is friction? (the resistance that happens when two surfaces come into contact with each other)
2. What is static friction? (the resistance that must be overcome for an object to move)
3. What is kinetic friction? (the resistance that occurs when the objects are in motion, but still in contact)

Lesson 3: Stick and Slip

1. What is the difference between static and kinetic friction? Which one is always greater? (Static friction is always greater, since it takes more energy to start an object moving from rest. Static friction is the friction you need to overcome in order to start an object sliding. Kinetic friction is the friction after an object is in motion.)
2. Design an experiment where you can observe and/or measure the difference between static and kinetic friction. (Place an object on a ramp. Raise the ramp until the object starts to slide (static friction). Notice that you have to lower the incline just a bit to keep it sliding at a constant rate (kinetic friction). You can also take a rubber band and attach it to an object at rest on the ground. Measure the rubber band's length the moment the object starts to slide, and then also when it's sliding at a constant rate. You'll notice that the rubber band is longer when it's overcoming static friction and starting to slide.)

Lesson 4: Rocket Car

1. What is inertia? (The resistance something has to change its motion.)
2. What is Newton's First Law? (Objects at rest stay at rest, and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.)

Lesson 5: Newton's Wagon

1. What is inertia? (the resistance something has to change its motion)
2. What is Newton's First Law? (Objects at rest stay at rest, and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.)
3. Will a lighter or heavier race car with the same engine win a short-distance race (like the quarter-mile)?
4. What concept does Newton's Second Law of Motion deal with? (force, mass, and acceleration)
5. What is momentum? (mass times velocity, or mv)
6. What is the equation for Newton's Second Law? ($F_{net} = ma$)
7. What is Newton's Third law? (For every action, there is an equal and opposite reaction.)

8. Give three examples of forces in pairs. (You sitting in a chair: your weight is balanced by the chair pushing back on you; the chandelier hanging from the ceiling is balanced by the tension in the chain holding it up; your weight on quad roller skates is balanced by the ground pushing back with an eighth of your weight on each wheel).
9. A rope is attached to a wall. You pick up the rope and pull with all you've got. A scientist walks by and adds a force meter to the rope and measures you're pulling with 50 Newtons. How much force does the wall experience? (50 Newtons!)
10. Can rockets travel in space if there's nothing to push off of? Explain your answer. (This was a common misconception that rockets can't accelerate in space. If you've watched a rocket launch, then you've seen firsthand how rockets can and do accelerate in space. Rockets accelerate because they burn fuel and push the hot gases out the back end to propel themselves forward in the opposite

Lesson 6: Ta-Daa!

1. What are two different pairs of forces in this experiment? (the force made by the hand and the force of gravity on the ball)
2. Explain where Newton's Three Laws of motion are observed in this experiment. (This is fun to ask the students as you walk around observing their work. Have them point out different parts of their experiment in action.)

Lesson 7: Chicken and Clam

1. What is inertia (in your own words)? (The resistance something has to changing its motion.)
2. Why does one soup can always win? (The can of the chicken soup will rotate around the soup itself, while the clam chowder acts as a solid cylinder and rotates together. So the inertial mass of the clam is much greater than the inertial mass of the soup, even though the cans weigh the same. This means that the clam chowder has more rolling resistance than the chicken broth.)

Lesson 8: Impulse and Motion

1. What is momentum? (mass times velocity)
2. What is impulse? (forces times time)
3. What is the conservation of momentum? (this occurs when objects collide – their momentum before the collision will equal their momentum after the collision)
4. Was the line a straight line? (Yes.)

Lesson 9: Driveway Racers

1. It should be close now, and the slope represents the acceleration it experienced going down the ramp. Calculate the slope of this line. (Answers vary.)
2. What do you think would happen if you increased the height of the ramp? (Acceleration would increase.)
3. Knowing what you do about gravity, what is the highest acceleration it can reach? (9.8 m/s^2)

Lesson 10: Gyro Wheel

1. What did it feel like when you tried to turn the wheel after it was spun? (It resisted the movement.)
2. What direction (orientation) does the wheel want to be in? (upright)
3. When you were on the spinning chair/platform which way did you turn? (the same way you turned the wheel)
4. If you turned the wheel left, you should have spun the same way, where is the force coming from the pushed you in that direction? (It is the opposite of the force trying to upright the wheel.)
5. What happened to the wheel while you held on to the string? Did it stay upright, or dangle? (It stayed upright.)
6. Why do you think it stayed upright? (The momentum of the wheel is conserved when upright.)

Lesson 11: Downhill Races

1. You should notice a difference between these graphs and the ones from the driveway races. What is it? (Hint: look to second half of the graph. The graph stopped curving!)
2. The first graph doesn't continue to curve, but straightens out. What does this mean about the velocity? (It was a constant velocity after about 3 seconds.)
3. In the second graph, the slope flattens out completely, what does this mean about the acceleration? (The acceleration stopped.)
4. If the acceleration is zero, what does that mean about the net force? (The net force must be zero.)
5. What are the forces acting on the toy car as it is going down the ramp? (gravity and friction)
6. Name 3 other examples of an object that has reached a terminal velocity. (skydiver, racecar driver, bullet fired from a gun)

Lesson 12: Net Forces

1. For scenario 1, draw a free body diagram below (the rope is your object, you are on the left, and your friend is on the right)
2. For scenario 2, in which direction did you both move? Draw the free body diagram below (Right)
3. For scenario 3, in which direction did you both move? Draw the free body diagram below (left)
4. For scenario 4, in which direction did the rope move? Draw the free body diagram below (Didn't move)
5. What was the same about question 1 and question 4? What was different? (The rope didn't move. Question 1 had small forces, Question 4 had large forces)
6. Even though the forces were less in question 1 than question 4, what was the net force for both? (Net force was zero in both cases.)
7. There were always at least 3 forces acting on the rope, what were they? Did you include the third force in your free body diagram? (2 applied forces and gravity)
8. If the rope wasn't moving, but you had only one force moving down, what does that tell you about the force you and your friend exerted? (They had to have some portion of the force that was pulling up.)

Lesson 13: Exponential Friction

1. How much money would you earn on Day 20 if I gave you one penny on Day 1, and doubled it every day after so Day 2 you received 2 pennies, and Day 3 you got 4 pennies? (Day 20 = $5,242.88)
2. Why do you think this experiment with friction works? Does it work with a flat surface the same way as a curved surface? (There is friction between the rope and the support column that increases with every

additional turn around the pole, since there's more contact between the rope and the pole with every turn. Since the pole is curved, this adds to the friction exponentially.)

Lesson 14: Bearings

1. Why do the marbles make you go in all directions? (Due to their shape, they allow movement in two different directions (x-y plane).)
2. What direction(s) did the dowels roll you in? (only in the x-direction, or along a single line, due to their shape)

Lesson 15: G-Force

1. Which accelerometer was better at giving a visual representation of accelerating? (the liquid in the tube)
2. Which one do you prefer? Why? (The liquid in the tube actually gives a numerical measurement.)
3. What activity did you do that created the most acceleration? (spinning around in a circle)
4. What does that tell you about acceleration? (Centripetal acceleration is much higher and easier to achieve than linear acceleration.)

Lesson 16: Detecting the Gravitational Field

1. What did you determine about gravity and how it affects the rate of falling? (Gravity appears to affect all objects the same.)
2. Did changing the object affect the rate of falling? Why or why not? (No, it appears that gravity affects all objects the same.)
3. Did changing the variable affect the rate of falling? Why or why not? (No, it appears that gravity affects all objects the same.)

Lesson 18: The Electromagnetic Field

1. Does the instrument work without the magnet array? (Yes, but only as a compass.)
2. Why did we use the stronger magnets inside the instrument? (Small lightweight magnets are needed to be used to move the mirrors and detect the fluctuations.)
3. Which planet would this instrument probably not work on? (Venus and Mars)

Vocabulary for the Unit

Acceleration is the rate of change in velocity. In other words, how fast a change in speed and/or a change in direction is happening.

Force is a push or a pull, like pulling a wagon or pushing a car.

A **force field** is an invisible area around an object within which that object can cause other objects to move. A force field can be attractive (pull an object towards it) or repulsive (push an object away).

The four **force fields** are gravity, magnetic, electric, and electromagnetic.

Friction is the force between two objects in contact with one another, due to the electromagnetic forces between two objects. Friction is not necessarily due to the roughness of the objects but rather to chemical bonds "sticking and slipping" over one another.

Four **fundamental forces i**n order of relative strength are strong nuclear force, electromagnetism, weak nuclear force, and gravity.

Gravity is a force that attracts things to one another. Gravity accelerates all things equally, which means all things speed up the same amount as they fall.

All bodies (objects) have a **gravitational field**. The larger a body is, the greater the strength of the gravitational field.

The **inverse square law** states that the closer something gets to the object causing the force, the stronger the force gets on that object.

Kinetic friction is the friction between two objects where at least one of them is moving.

Mass is a measure of how much matter (how many atoms) make up an object.

The **net force** is the sum of all the forces on an object.

Static friction is the friction between two objects that are not moving.

Terminal velocity means something has speed but no acceleration. This is normally used when something falling cannot gain any more speed because the air resistance pushing against that something is equal to the force of gravity pulling down on that something.

Velocity has both a speed (like 55 mph) and a direction (northeast).

Weight is a measure of how much gravity is pulling on an object.