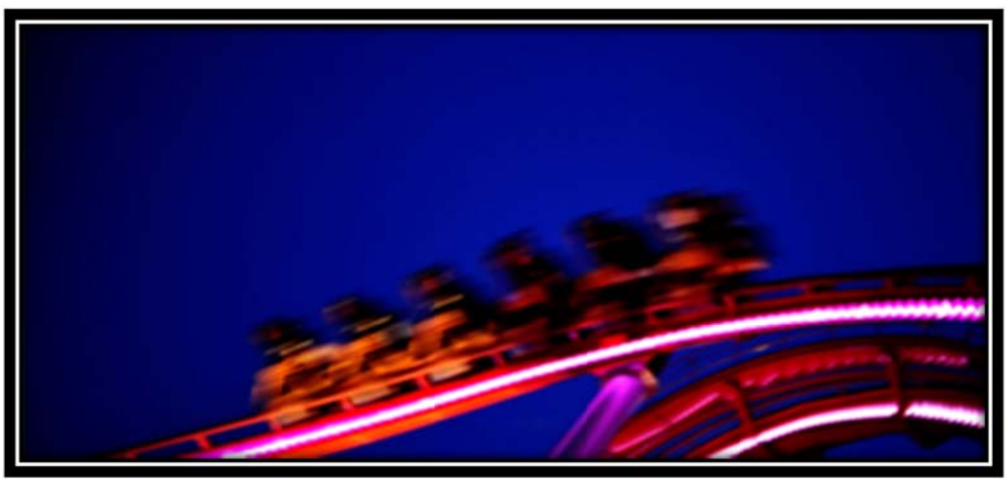
FORCE & MOTION 1

A comprehensive course that teaches the big ideas behind Galileo and Newton's ground-breaking work. Students study velocity, acceleration, forces, friction gravity and Newton's three laws of motion as they uncover the basis of all physics in our crash course in projectile motion. Zoom balloon racers, detect electric fields, construct a bridge that holds 400 times its own weight, and more.



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

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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 1

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.
- 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 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.

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

- Make observations and measurements on an object's motion to figure out the predictable pattern of motion.
- 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.
- Show that gravitational interactions are attractive and depend on the masses of the objects.
- 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 each section. 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. For 10 lab groups, an easy way to keep track of your materials is to fill each tub with the materials listed below, label the tubs with the section name, like *Forces & Motion Study Kit* and copy these lists and stick them in the bin for easy tracking. Feel free to reuse items between lessons and unit sections. Most materials are reusable year after year. (RS=Radio Shack)

- Audio plug (Radio Shack #42-2420)
- Balloon
- Blindfold
- Blocks
- Book or light clipboard
- Bouncy ball
- Bowl
- Business cards (3)
- Caps (4, like the tops of milk jugs)
- Cereal
- Clay
- Coins or poker chips (2)
- Compass
- Cotton string (3-4 feet)
- Cup (plastic disposable)
- Disc magnet (1" donut-shaped magnet) (Radio Shack #64-1888)
- Drill and drill bits
- Earplugs
- Eraser
- Feather
- Film canister or similar small plastic container
- Foam (small piece)
- Foam plate
- Golf ball
- Hex nut
- Hot glue gun
- Index cards
- Magnet (1, disk)
- Magnet (1, rectangular)
- Magnet wire AWG 30 (Radio Shack #278-1345)
- Magnets (4)
- Measuring tape
- Needle
- Neodymium magnets (4)
- Paper
- Paperclip
- Pencils (2)
- Ping pong ball
- Popsicle stick (tongue depressor-sized) (5)
- Rocks
- Rubber bands (10, one at least 1/4″ wide)
- Ruler
- Scissors
- Spoon
- Stopwatch
- Straws
- String
- Tape
- Thread
- Violin rosin (optional)
- Wagon
- Water bottle
- Wood skewer
- Wooden clothespin

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: Balloon Racers

Overview: We're going to experiment with Newton's Third Law by blowing up balloons and letting them rocket, race, and zoom all over the place. When you first blow up a balloon, you're pressurizing the inside of the balloon by adding more air from your lungs into the balloon. Because the balloon is made of stretchy rubber, like a rubber band, it wants to snap back into the smallest shape possible as soon as it gets the chance, which usually happens when the air escapes through the nozzle area. When this happens, the air inside the balloon flows in one direction while the balloon zips off in the other.

What to Learn: The motion of objects can be observed and measured.

Materials

- balloons
- string
- wood skewer
- two straws
- caps (4, like the tops of milk jugs, film canisters, or anything else round and plastic about the size of a quarter)
- wooden clothespin
- stiff cardboard (or four popsicle sticks)
- hot glue gun
- meter or yardstick
- stopwatch

Lab Time

1. Blow up the balloon (don't tie it), then let it go. Wheee! Okay, so that step was to get the balloon ready for the experiment. Now…
2. Tie one end of the string to a chair.
3. Blow up the balloon (don't tie it).
4. Tape a straw to it so that one end of the straw is at the front of the balloon and the other is at the nozzle of the balloon.
5. Thread the string through the straw and pull the string tight across your room.
6. Let go. With a little bit of work (unless you got it the first time) you should be able to get the balloon to shoot about ten feet along the string.

Balloon Racer Data Table

Trial	Number of Breaths to Blow Up Balloon	How Far Did It Go? *(measure in feet or meters)*	How Long Did It Take? *(measure in seconds)*

Reading

When you first blow up a balloon, you're pressurizing the inside of the balloon by adding more air from your lungs into the balloon. Because the balloon is made of stretchy rubber, like a rubber band, it wants to snap back into the smallest shape possible as soon as it gets the chance, which usually happens when the air escapes through the nozzle area. When this happens, the air inside the balloon flows in one direction while the balloon zips off in the other.

Have you ever noticed how the balloon crazily zips all over the place when you let go? Why is that?

The balloon zigzags all over because of something called "thrust vectoring," which means the direction of the balloon changes depending on the angle that the nozzle makes at the end (the part you blew into).

Think of a fire hose. There's a lot of water rushing out of the end of a fire hose, right? A fire hose not only has high-speed water rushing out, but there's also a lot of volume in a fire hose. How easy do you think it would be to try to change the direction of all that water? You'd actually feel a "kick" back from the water when you tried to angle around a fire hose operating at full blast. That "kick" is the same reaction force that propels both balloons and fighter aircraft into their aerobatic tricks.

Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction. These experiments are a great demonstration of Newton's Third Law. The air inside the balloon shoots off in one direction, and the balloon itself rockets in the opposite direction.

It's also a good opportunity to bring up some science history. Many folks used to believe that it would be impossible for something to go to the moon, because once something got into space there would be no air for the rocket engine to push against and so the rocket could not "push" itself forward.

In other words, those folks would have said that a balloon shoots along the string because the air coming out of the balloon pushes against the air in the room. The balloon gets pushed forward. You now know that that's silly! What makes the balloon move forward is the mere action of the air moving backward. Every action has an equal and opposite reaction.

Exercises Answer the questions below:

1. What is Newton's Third Law of Motion?

2. Why does the balloon stop along the string?

Lesson #2: Look Out Below

Overview: If you jump out of an airplane, how fast would you fall? What's the greatest speed you would reach? Let's practice figuring it out without jumping out of a plane.

This experiment will help you get the concept of velocity by allowing you to measure the rate of fall of several objects.

What to Learn: In this experiment, learn how an object's motion can be described by recording the change in its position over time. Changes in velocity can be changes in speed, direction, or both.

Materials

- stop watch
- feathers (or small pieces of paper, a plastic bag – anything light and fluffy)
- tape measure

Lab Time

1. Get five or so different light and fluffy objects. Feathers of different size, small strips of paper, parts of a plastic bag, cotton balls, whatever is handy.
2. Make a prediction by writing down the objects you chose in order of how fast you think they will fall.
3. Drop the different items and time them from the moment you let go to the moment they hit the ground. Be sure to drop each item from about the same height. The higher the better. Just be sure not to fall off anything! We don't want to measure your velocity!!
4. Drop individual items two or three times to get an average time.
5. Now compare the items. Which one fell the least amount of time (dropped the fastest)? Which one fell the most amount of time (dropped the slowest)? Record your results. By the way, did you find anything that dropped slower than a feather? I have seen very few things that take longer to fall straight down than a feather.

Look Out Below Data Table

Trial Number	Object	Time (seconds)

Reading

Speed tells us how fast an object is traveling, but velocity adds another variable. Velocity is the speed of an object AND the direction in which it's moving. For constant velocity, both the speed of an object and its direction must be constant. Acceleration occurs when velocity increases and deceleration is a decrease in velocity.

In this experiment, you will see how many of your objects stop accelerating very quickly. In other words, they reach their terminal velocity soon after you let them go and they will fall all the way to the ground at that same constant velocity. This is why a parachute is a skydiver's best friend! A human has a decent amount of air resistance, but he or she can reach a velocity of 120 mph if dropped from a great height. The parachute increases the air resistance so that the terminal velocity of that skydiver is quite a bit safer!

Exercises Answer the questions below:

1. What is velocity?

2. How do acceleration and deceleration relate to velocity?

3. How do we know when an object has reached terminal velocity?

Lesson #3: Detecting the Electric Field

Overview: You are actually fairly familiar with electric fields, too, but you may not know it. Have you ever rubbed your feet against the floor and then shocked your brother or sister? Have you ever zipped down a plastic slide and noticed that your hair is sticking straight up when you get to the bottom? Both of these phenomena are caused by electric fields and they are everywhere!

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

- head of hair
- balloon
- yardstick or meterstick
- spoon, large

Lab Time

1. Blow up a balloon and tie it off.
2. Put the spoon on the table and balance the yardstick on top of it, overhanging the edge of the table.
3. Charge the balloon by rubbing it on your hair.
4. Bring the charged balloon next to the ruler and use it to guide the stick around on the table. If the effect weakens, recharge the balloon on your hair.
5. This works really when you add more people and more balloons!

Detecting the Electrical Field Data Table

Item/Object	Did It Stick?	How Long Did It Stick? *(measure in seconds)*

Reading

Electric fields are extremely common. If you comb your hair with a plastic comb, you cause that comb to have a small electric field. When you take off a fleece jacket or a polyester sweat shirt, you create an electric field that may be thousands of volts! Don't worry, you can't get hurt. There may be lots of voltage but there will be very little amperage. It's the amperage that actually hurts you.

Different parts of the atom have different electrical charges. The proton has a positive charge, the neutron has no charge (neutron, neutral get it?) and the electron has a negative charge.

These charges repel and attract one another kind of like magnets repel or attract. Like charges repel (push away) one another and unlike charges attract one another.

So if two items that are both negatively charged get close to one another, the two items will try to get away from one another. If two items are both positively charged, they will try to get away from one another. If one item is positive and the other negative, they will try to come together.

How do things get charged? Generally things are neutrally charged. They aren't very positive or negative. However, occasionally (or on purpose as we'll see later) things can gain a charge.

Things get charged when electrons move. Electrons are negatively charged particles. So if an object has more electrons than it usually does, that object would have a negative charge.

If an object has less electrons than protons (positive charges), it would have a positive charge. How do electrons move? It turns out that electrons can be kind of loosey-goosey.

Depending on the type of atom they are a part of, they are quite willing to jump ship and go somewhere else. The way to get them to jump ship is to rub things together. Let's play with this a bit and see if we can make it more clear.

Remember, in static electricity, electrons are negatively charged and they can move from one object to another. This movement of electrons can create a positive charge (if something has too few electrons) or a negative charge (if something has too many electrons). It turns out that electrons will also move around inside an object without necessarily leaving the object. When this happens, the object is said to have a temporary charge.

Try this: Blow up a balloon. When you rub the balloon on your head, the balloon is filled up with extra electrons, and now has a negative charge. Now stick it to a wall— to create a temporary charge on the wall.

Opposite charges attract, right? So, is the entire wall now an opposite charge from the balloon? No. In fact, the wall is not charged at all. It is neutral. So why did the balloon stick to it?

The balloon is negatively charged. It created a temporary positive charge when it got close to the wall. As the balloon gets closer to the wall, it repels the electrons in the wall. The negatively charged electrons in the wall are repelled from the negatively charged electrons in the balloon.

Since the electrons are repelled, what is left behind? Positive charges. The section of wall that has had its electrons repelled is now left positively charged. The negatively charged balloon will now "stick" to the positively charged wall. The wall is temporarily charged because once you move the balloon away, the electrons will go back to where they were and there will no longer be a charge on that part of the wall.

This is why plastic wrap, Styrofoam packing popcorn, and socks right out of the dryer stick to things. All those things have charges and can create temporary charges on things they get close to.

Exercises Answer the questions below:

1. What happens if you rub the balloon on other things, like a wool sweater?
2. If you position other people with charged balloons around the table, can you keep the yardstick going?
3. Can we see electrons?
4. How do you get rid of extra electrons?
5. Does the shape of the balloon matter?
6. Does hair color matter?
7. Rub a balloon on your head, and then lift it up about 6”. Why is the hair attracted to the balloon?
8. Why does the hair continue to stand on end after the balloon is taken away?
9. What other things does the balloon stick to besides the wall?
10. Why do you think the yardstick moved?
11. What other things are attracted or repelled the same way by the balloon? (Hint: try a ping pong ball.)

Lesson #4: Newton's First Law of Motion

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.

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

- wagon
- rocks
- friends
- stopwatch
- meterstick or yardstick or measuring tape

Lab Time

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

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 of which 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?

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)?

Lesson #5: Newton's Second Law of Motion

Overview: 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.

What to Learn: Students will learn how to calculate the net force and acceleration of an object. They will learn that acceleration of an object produced by the net force (the vector sum of all forces) is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Materials

- friends
- wagon
- rocks
- stopwatch
- measuring tape

Lab Time

1. Now we're going to experiment with Newton's Second Law that 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.

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)*

Reading

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 in direct proportion 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 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.

Exercises Answer the questions below:

1. What concept does Newton's Second Law of Motion deal with?

2. What is momentum?

Lesson #6: Newton's Third Law of Motion

Overview: 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 action 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

Lab Time

1. Now let's work with Newton's Third Law: For every action, there is an equal and opposite reaction. If this first 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 a rock and see what happens to you and your boat. (Any guesses?)

Newton's Third Law of Motion Data Table

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

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

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 Newton's Third Law?
2. Give three examples of forces in pairs.
3. 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?
4. Can rockets travel in space if there's nothing to push off of? Explain your answer.

Lesson #7: Barrel Roof

Overview: This roof can support more than 400 times its own weight, and you don't need tape! One of the great things about net forces is that although the objects can be under tremendous force, nothing moves! For every push, there's an equal and opposite pull (or set of pulls) that cancel each other out, so all forces balance.

What to Learn: A force is a push or pull on a object that results from an interaction with another object. Forces always come in pairs.

Materials

- template print out (heavy weight paper works best)
- scissors
- pencils (2)
- thread
- book or light clipboard
- paper to load the roof

Lab Time

1. Trim each of the four corners from the paper.
2. You will fold the diagonals following one direction first. Flip the template over to the plain side, and then find the first diagonal line by curling the paper back until you see the diagonal. Fold and crease well on the diagonal, making sure the fold is straight.
3. Continue this process of locating and carefully creasing each diagonal in one direction. Then fold all of the diagonals which are oriented in the other direction. These are called mountain folds in origami, because they go up and down like the sides of a mountain.
4. The horizontal lines will be valley folds, which means they are folded on the inside and will be the opposite of the mountain folds. Crease the horizontal valley folds very well.
5. Once all the lines are folded, it's time to prepare the accordion shape which will be used in your roof. This will happen naturally as you push down on the valley (horizontal) folds and push up on the mountain (diagonal) folds. These works best if you start on the outside edges first and pinch the folds together, guiding the diagonals up and the horizontal folds down.
6. After it's all folded, fluff out the structure. Tie two pencils together with about ½ inch of space between them with a bit of string. The pencils make the barrel roof easier to load. Begin stacking on your book or clipboard, making sure that the bottom of the barrel structure is spread out at the bottom and supported. Also add about 50 sheets of paper to see how the structure does.
7. How many sheets can you pile on without collapsing your barrel roof?

Barrel Roof Data Table

You'll be making several different barrel roofs for this data table. You may change the type of paper it's made from, the size, or even the fold lines if you're feeling adventurous. Record your observations here.

Barrel Roof Description	How Many Sheets of Paper?	How Long Did It Stand?

Exercises Answer the questions below:

1. What is Newton's Third Law?

2. What kind of groups do forces come in?

3. What is another name for Newton's Third Law?

Lesson #8: Building Bridges

Overview: What keeps buildings from toppling over in the wind? Why are some earthquake-proof and others not? We're going to look at how engineers design buildings and bridges while making our own.

What to Learn: Objects near the Earth fall to the ground unless something holds them up.

Materials

- index cards
- blocks
- straws
- clay
- cups, disposable

Lab Time

1. Grab an index card and place it across two blocks.
2. Roll up a lump of clay and place it on the card. This represents your person on the bridge.
3. Try adding another lump of clay, representing another person. Does that work as well?
4. Now, put the card between the two blocks so that it forms an arch in the middle. What happens when you load this new bridge?
5. Spread out the arch a bit and add another index card on top. Test it with your clay again – how many clay lump "people" can you add to this bridge?
6. Make lengthwise accordion folds in an index card and place it on top of the blocks. Place another, unfolded card on top. How many clay lumps can you add now?
7. Use the straws and clay to make bridge supports for your pleated bridge.
8. Continue to experiment with your materials to perfect your bridge. Remember to simulate weather conditions and even earthquakes to test your structures.

Building Bridges Data Table

Draw a Picture of your Bridge Design and/or Describe it in Words	How Much Weight Did it Hold?

Reading

There are different kinds of forces, and they act in different ways on things like buildings, chairs, bridges, fences, frames, and more. We'll be dealing with a static load in this lab, which is like holding a stack of heavy books. You're not moving, but you're keeping the books from falling to the floor by holding them up. A stack of books on anything non-moving, like a chair, table, desk, or counter is a static load.

For comparison, I'll list a few more different kinds of forces so you can get a feel for how they differ from each other.

A dynamic load is when you're moving with the load. If you place the books on a skateboard, or walk with them across the room, now you're dealing with a dynamic load.

Tension is the pull an object feels when you try to pull it apart. Two kids playing tug-of-war puts tension in the rope. A chandelier hanging from the ceiling has tension in the cable. A kid on a swing puts tension on the chain. This stretching puts the object in tension.

Compression is what you feel if you lift a heavy weight over your head. You feel compressed as the weight pushes down on your arms. When you sit in a chair, you are compressing the chair's legs. If you sit on a balloon, you are compressing it into a smaller shape.

Torsion is the force an object feels when you twist it along its length. If you hold a ruler or stick at opposite ends and twist in opposite directions, the ruler feels a twist (torsion). Crankshafts use torsion to spin the wheels of your car from the engine.

Shear force happens when forces are applied in two different directions to an object. When you squeeze a pair of pliers, you are applying a shear force on the pin that holds the piers together. If you rub a piece of paper between your hands as you rub your hands together, you are applying a shear force to the paper.

How do you design something to be earthquake proof? In 1989, a massive earthquake caused structural engineers to redesign the Bay Bridge in San Francisco, California with three distinct elements: shear link beams, hinge pipe beams, and piles. The shear link beams are steel beams in the central tower designed to shear under excessive loads and will absorb the damage. The hinge pipe beams are 20 60-foot-long tubes that connect sections of the bridge's road. The soft centers of the tubes are like a fuse, and during an earthquake are designed to fail so they can easily be replaced. Part of the bridge sits on top of mud, which turns to liquid during an earthquake, so engineers drove 160 angled piles down 300 feet into the mud to get a more solid foundation for the bridge.

Exercises Answer the questions below:

1. What are three different kinds of forces?

2. Using only blocks, what kind of wall design is the weakest?

3. Why does the bridge seem stronger when a card is arched underneath?

Lesson #9: Weighty Issue

Overview: If I drop a ping pong ball and a golf ball from the same height, which one hits the ground first? How about a bowling ball and a marble?

What to Learn: Students will learn that gravity accelerates all things equally. Objects near the Earth fall to the ground unless something holds them up.

Materials (per lab group)

- ping pong ball
- golf ball
- feather
- balloon
- bouncy ball
- eraser
- pencil
- 2 sheets of paper (crumple one up to the size of a golf ball)
- paperclip
- empty water bottle

Lab Time

1. Take a careful look at both objects and make a prediction about which object will hit the ground first if they are dropped from the same height. Record your hypothesis.
2. Test your prediction. Hold both objects at the same height. Make sure the bottom of both objects is the same distance from the floor.
3. Let them go as close to the same time as possible. Sometimes it's helpful to roll them off a book.
4. Watch carefully. Which hits the ground first, the heavier one or the lighter one?
5. Try it three times and watch carefully. It will be a little easier for the person who isn't dropping them to see what happens.

Weighty Issue Data Table 1

Item/Object A	Item/Object B	Guess First: Which one will hit first?	Record Observation: Which one hit first?

Weighty Issue Data Table 2

To determine the mass in kg, use the following conversion: 1 pound = 0.4536 kg.
For calculating area of a 3D object, use the side that the oncoming air sees as it falls to the ground.
For a ball, it's $A_{sphere} = (\pi r^2) / 4$. *For a sheet of paper, it's (length) x (width). Don't forget to write your units!*

Object A	Mass A	Area A	Object B	Mass B	Area B	Which hit first?

Reading

For this experiment, you'll need two objects of different weights: a marble and a golf ball, or a tennis ball and a penny for example. You'll also need a sharp eye and a partner.

When dropped from the same distance, you should see that both objects hit the ground at the same time! Gravity accelerates both items equally and they hit the ground at the same time. Any two objects will do this, a brick and a Buick, a flower and a fish, a kumquat and a cow!

"But," I hear you saying, "If I drop a feather and a flounder, the flounder will hit first every time!" OK, you got me there. There is one thing that will change the results and that is air resistance.

The bigger, lighter and fluffier something is, the more air resistance can affect it and so it will fall more slowly. Air resistance is a type of friction which we will be talking about later. In fact, if you removed air resistance, a feather and a flounder would hit the ground at the same time!

Where can you remove air resistance? The moon! One of the Apollo missions actually did this (well, they didn't use a flounder, they used a hammer). An astronaut dropped a feather and a hammer at the same time and indeed, both fell at the same rate of speed and hit the surface of the moon at the same time.

Ask someone this question: Which will hit the ground first, if dropped from the same height, a bowling ball or a tennis ball? Most will say the bowling ball. In fact, if you asked yourself that question 5 minutes ago, would you have gotten it right? It's conventional wisdom to think that the heavier object falls faster. Unfortunately, conventional wisdom isn't always right. Gravity accelerates all things equally. In other words, gravity makes all things speed up or slow down at the same rate.

This is a great example of why the scientific method is such a cool thing. Many, many years ago, there was a man of great knowledge and wisdom named Aristotle. Most people believed whatever he said to be true. The trouble was he didn't test everything that he said. One of his statements was that objects with greater weight fall faster than objects with less weight. Everyone believed that this was true.

Hundreds of years later, Galileo came along and said, "Ya know…that doesn't seem to work that way. I'm going to test it." The story goes that Galileo grabbed a melon and an orange and went to the top of the Leaning Tower of Pisa. He said, "Look out below!" and dropped them! By doing that, he showed that objects fall at the same rate of speed no matter what their size.

It is true that it was Galileo who "proved" that gravity accelerates all things equally no matter what their weight, but there is no real evidence that he actually used the Leaning Tower of Pisa to do it.

Exercises Answer the questions below:

1. What did you notice from your data? Did heavier or lighter objects fall faster? Did more massive objects or smaller objects fall faster? What characteristic seemed to matter the most?
2. Is gravity a two-way force, like the attractive-repulsive forces of a magnet?
3. If I were to drop a bowling ball and a balloon filled with a gas six times heavier than air (sulfur hexafluoride SF_6) and inflated to the exact size of the bowling ball from my roof, which will strike the ground first?

Lesson #10: Forever Falling

Overview: If I toss a ball horizontally at the exact same instant that I drop another one from my other hand, which one reaches the ground first?

What to Learn: Gravity accelerates all things equally and objects near the Earth fall to the ground unless something holds them up.

Materials

- rulers or paint sticks (2, anything wide and flat)
- coins or poker chips (2)
- sharp eye and ear
- partner

Lab Time

1. Place one of the rulers flat so that it is diagonal across the edge of a table with half the ruler on the table and half sticking off.
2. Place one coin on the table, just in front of the ruler and just behind the edge of the table. Place the other coin on the ruler on the side that's hanging off the table.
3. Put your finger right in the middle of the ruler on the table so that you are holding it in such a way that it can spin a bit under your finger. Now, with the other ruler you are going to smack the end of the first ruler so that the first ruler pushes the coin off the desk and the coin that's resting on the ruler falls to the ground.
4. Now, before you smack the ruler, make a prediction. Will the coin that falls straight down or the coin that is flying forward hit the ground first?
5. Try it. Do the test and look and listen carefully to what happens. It's almost better to use your ears here than your eyes. Do it a couple of times in order to confirm your findings.

Forever Falling Data Table

Coin A	Coin B	What did you observe?

Reading

Did you read the first sentence at the top of this lab? What do you think will happen?

The balls will hit the ground at the exact SAME time.

Is that odd or what?

Gravity doesn't care if something is moving horizontally or not. Everything falls toward the center of the Earth at the same rate.

Let me give you a better example: A bullet fired parallel to the ground from a gun and a bullet dropped from the same height at the same time will both hit the ground at the same time, even though the one fired lands a mile away! It seems incredible, but it's true.

Gravity doesn't care what size something is or whether or not it is moving, Gravity treats all things equally and accelerates them the same.

Notice that I say gravity accelerates all things equally, not gravity *pulls* on all things equally. Gravity does pull harder on some things than on other things. This is why I weigh more than a dog. I am made of more stuff (I have more atoms) than the average dog, so gravity pulls on me more.

Weight is nothing more than a measure of how much gravity is pulling on you. This is why you can be "weightless" on a scale in space. You are still made of stuff, but there's a balance of the gravity that is pulling on you and the outward force due to the acceleration since you're moving in a circle (which you do in order to remain in orbit), so it looks like you have no weight.

The larger a body is, the more gravitational pull or the larger a gravitational field it will have.

The Moon has a fairly small gravitational field (if you weighed 100 pounds on Earth, you'd only be 17 pounds on the Moon), the Earth's field is fairly large and the Sun has a HUGE gravitational field (if you weighed 100 pounds on Earth, you'd weigh 2,500 pounds on the sun!).

As a matter of fact, both the dog and I both have gravitational fields! Since we are both bodies of mass ,we have a gravitational field which will pull things towards us. All bodies have a gravitational field. However, my mass is sooooo small that the gravitational field I have is miniscule. Something has to be very massive before it has a gravitational field that noticeably attracts another body.

So what's the measurement for how much stuff you're made of? Mass. Mass is basically a weightless measure of how much matter makes you, you. A hamster is made of a fairly small amount of stuff so she has a small mass. I am made of more stuff, so my mass is greater than the hamster's. Your house is made of even more stuff so its mass is greater still.

So, here's a question. If you are "weightless" in space, do you still have mass? Yes, the amount of stuff you're made of is the same on Earth as it is in your space ship. Mass does not change, but since weight is a measure of how much gravity is pulling on you, weight will change.

Did you notice that I put weightless in quotation marks? Wonder why?

Weightlessness is a myth! Believe it or not, one is never weightless. A person can be pretty close to weightless in very deep space but the astronauts in a space ship actually do have a bit of weight.

Think about it for a second. If a space ship is orbiting the Earth, what is it doing? It's constantly falling! If it wasn't moving forward at tens of thousands of miles an hour it would hit the Earth. It's moving fast enough to fall around the curvature of the Earth as it falls but, indeed, it's falling as the Earth's gravity is pulling it to us.

Otherwise the ship would float out to space. So what is the astronaut doing? She's falling, too! The astronaut and the space ship are both falling to the Earth at the same rate of speed and so the astronaut feels weightless in space. If you were in an elevator and the cable snapped, you and the elevator would fall to the Earth at the same rate of speed. You'd feel weightless! (Don't try this at home!)

Exercises Answer the questions below:

1. True or false? Gravity pulls on all things equally.

2. True or false? Gravity accelerates all things equally.

3. In your *own* words, why do the coins hit the ground at the same time? Is this what you'd expect to happen on Mars?

Lesson #11: Rocketball Launcher

Overview: One of the basic laws of the universe is the conservation of momentum. When objects smack into each other, the momentum that both objects have after the collision is equal to the amount of momentum the objects had before the impact.

What to Learn: Today you'll get introduced to the ideas about mass, velocity, impact, and momentum as well as see firsthand how momentum is conserved as it's transferred from one object to another.

Materials

- Two balls of very different sizes, like a bouncy ball and a tennis ball, or a tennis ball and a basketball

Lab Time

1. First, hold out the larger ball at arm's length in front of you. You'll want to do this over a flat surface – something without any rugs or carpet. Drop (don't throw and don't bounce) your larger ball on the floor. Do you see how high it bounces on its own?
2. Now drop your smaller ball (this can be a bouncy ball or a tennis ball if you're using a basketball) on the ground and notice how far it bounces back up.
3. Now place the smaller ball on top of the larger ball like it shows here in the picture and let them BOTH drop at the same time so that they fall together and hit the ground with the smaller ball still on top. You've got to make sure that the smaller ball stays on top when it hits the ground. If it falls off, you've got to do it again.
4. Try this with different-sized balls and record what you see.
5. What happens if you try THREE?

Rocketball Laucher Data Table

Top Ball (Smaller)	Bottom Ball (Larger)	Observations

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 (p) is mass (m) times velocity (v), or: $p=mv$

In today's experiment, we're going to have two balls, one much larger than the other, collide and transfer energy. Once the two balls hit the ground, all of the larger ball's momentum transferred to the smaller ball (plus the smaller ball had its own momentum, too!) and thus the smaller ball goes zooming to the sky.

Do you see how using a massive object as the lower ball works to your advantage here? What if you shrink the smaller ball even more, say to bouncy-ball size? Momentum is mass times by velocity, and since you aren't going to change the velocity much (unless you try this from the roof, which has its own issues), it's the mass that you can really play around with to get the biggest change in your results. So for momentum to be conserved, after impact, the top ball had to have a much greater velocity to compensate for the lower ball's velocity going to zero.

You can also try a small bouncy ball (about the size of a quarter) and a larger bouncy ball (tennis-ball size) and rest the small one on top of the large one. Hold upright as high as you can, then release. If the balls stay put (the small one stays on top of the larger) at impact, the energy transfer will create a SUPER high bounce for the small ball. (Note how high the larger ball bounces when dropped.)

Exercises Answer the questions below:

1. What is the mathematical formula for momentum?

2. Explain momentum in words.

3. What happens to the momentum of the bottom ball in this experiment?

Lesson #12: Detecting the Magnetic Field

Overview: Remember, there are four different kinds of forces: strong nuclear force, electromagnetism, weak nuclear force, and gravity. There are also four basic force fields that you come into contact with all the time. They are the gravitational field, the electric field, the magnetic field, and the electromagnetic field. Notice that those four force fields really only use two of the four different kinds of force: electromagnetism and gravity. Let's take a quick look at what causes these four fields and what kind of objects they can affect, starting with the magnetic field.

What to Learn: Magnets can be used to make some objects move without being touched.

Materials

- needle
- foam (small piece)
- magnet
- cup or bowl
- water
- compass

Lab Time

1. To make a compass, you need a needle and a compass.
2. Swipe the needle with the magnet – only in one direction – many, many times.
3. Stick the magnetized needle through a piece of foam so that it will float.
4. Place the foam and needle in a cup or small bowl of water.
5. You can check the needle with a compass to make sure they are pointing the same direction.
6. Look at the compass, but don't pick it up. Walk anywhere and keep your eye on the compass.
7. Turn in circles and keep your eye on the compass (don't get too dizzy).
8. The Earth's magnetic force field, one of those strange and mysterious force fields, always pushes that needle in the same direction. It's invisible and you can't feel it … but the needle can!

Detecting the Magnetic Field Data Table

To complete these trial runs with your compass, you'll need to calibrate your compass first. Find North by using a real compass, and then look at your compass. The needles should be facing the same direction (if not, re-magnetize your needle). Mark the side of your cup that the needle points to with a "N, just like the real compass has. Mark the other three directions (South, East, and West) based on your mark for North.

Now you're ready to do your experiments.

Location of Compass	Direction Indication?

Reading

You're probably fairly familiar with magnetic fields. If you've ever stuck a magnet to a refrigerator, you've taken advantage of magnetic fields. Sticking a magnet to a refrigerator is one of those everyday experiences that should just be absolutely flabbergasting. There you are holding an "I'd Rather be Relative" magnet and it sticks to the fridge! But wait a minute, if you put it on the wall … it falls off! How does it "know" what to stick to? Not only does it stick to the fridge, it also pushes some things away, attracts other things and couldn't care less about still other things. What's that all about?! We rarely think about what magnets do but, wow, the things they do are weird!

Magnetic fields come from objects that have a surplus of electrons all moving in the same direction. This can be an electric wire with current running through it or one of several special types of metals. Iron, nickel and cobalt are the most common metals that can be magnetic. Magnetic fields can only affect objects that can be magnetic themselves. That's why a magnet can attract an iron nail, but it can't attract an aluminum can. The iron nail can be magnetic, but the aluminum cannot. Magnets can also be attractive or repulsive. Two magnets with the same kind of poles facing one another will push themselves apart. Two magnets with opposite poles facing one another will pull themselves together.

Using a compass and the Earth, you can do a simple experiment to detect the magnetic field of our planet. (If you don't have a compass, just slide a magnet along the length of a needle several times (make sure you only swipe in one direction!) then stick it through a cork or bit of foam. Float the needle-foam thing in a cup of water.)

Again a very simple little activity, but I hope you can see the point. No matter where you went or what you did, that needle always pointed the same direction! The Earth's magnetic force field, another strange and mysterious force, always pushes that needle in the same direction. It's invisible and you can't feel it … but the needle can!

Exercises Answer the questions below:

1. Why does the needle need the foam?

2. Why do we use water?

3. What are the forces in a magnetic field?

Lesson #13: Flying Paperclip

Overview: In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse-square law.

What to Learn: The inverse-square law applies to quite a few phenomena in physics. When it comes to forces, it basically means that the closer an object comes to the source of a force, the stronger that force will be on that object. The farther that same object gets from the force's source, the weaker the effect of the force.

Materials

- magnets (4)
- paper clip
- string
- ruler
- tape

Lab Time

1. Tie the string to one of the paperclips.
2. Tape the end of the string to the table.
3. Bring your magnet close to the paperclip so the paperclip flies up to it.
4. Using a ruler, measure how far your magnet is when the paperclip falls back to the table. Which part of your magnet is it most attracted to? Which part of the magnet is the strongest? That's the side of the magnet we want to use when you record your data.
5. Repeat steps 3 and 4 with all of your different magnets.
6. Complete the data table. (Don't forget your units in column 3! Did you measure in inches, feet, centimeters…?)

Flying Paper Clip Data Table

Type/Shape of Magnet	Which part is the strongest?	How far before the paperclip falls?

Reading

The inverse square law states that the closer something gets to the object causing the force, the stronger the force gets on that object. The inverse square law applies when some force or energy is radiated outward from a point source. Imagine turning on a light in the middle of the room. The light bulb is your point source, and the light coming from the bulb will spread out the further it gets from the source. Since the surface area of a sphere is proportional to the square of the radius, the farther the light gets from the source, the more spread out it will be. The inverse square law is seen in gravitation problems between two point masses as they increase their distance apart from each other, in electrostatics between two electrically charged particles, in light (and other electromagnetic radiation) as the intensity radiates from a point source, and in acoustics as the sound pressure gets further from its source.

Exercises: Answer the questions below:

1. Circle one: The closer you get to the magnet, the (stronger | weaker) the force of the magnetic field is on the paper clip.

2. Why does it matter which way you orient the magnet in this experiment?

3. Which magnet has the strongest magnetic field?

4. Is the north or south pole stronger on a magnet?

Lesson #14: Force-full Cereal

Overview: Did you know that your cereal may be magnetic? Depending on the brand of cereal you enjoy in the morning, you'll be able to see the magnetic effects right in your bowl. You don't have to eat this experiment when you're done, but you may if you want to (this is one of the ONLY times I'm going to allow you to eat what you experiment with!) For a variation, pull out all the different boxes of cereal in your cupboard and see which has the greatest magnetic attraction.

What to Learn: Magnets can be used to make some objects move without being touched. Certain materials that contain iron are affected by magnets, like your breakfast!

Materials

- cereal
- bowl
- milk (or water)
- spoon
- magnet (1, rectangular)
- magnet (1, disk)

Lab Time

1. Fill the bowl with milk (or water).
2. Put about 20 pieces of cereal into the bowl. You want to make sure there's space for the experiment. What do you notice about the Os? Do they attract each other?
3. Stir up the bowl a little and note what happens.
4. Separate a single piece of cereal and get it a little close to a clump of cereal. What happens?
5. What happens if you bring a magnet close to the cereal? Do different magnets affect the cereal differently?

Reading

In this experiment, you'll see the cereal "O's" get close to one another as they attract each other. The closer they get, the stronger their attraction to each other and the faster they move towards each other. If you wait and watch long enough, you get a nice tight batch of cereal all clustered together in one or two big blobs. This activity is a great illustration of what is meant by the inverse square law because the attraction between "O's" was stronger the closer they got to each other.

I discovered this activity one morning as I was eating cereal. The same thing happens with bubbles when you're doing the dishes. Science is everywhere! Feel free to eat the cereal!

Exercises Answer the questions below:

1. Why do the pieces of cereal stick to each other?

2. Does the cereal move slower or faster the closer the pieces come in contact with each other?

3. What other cereals does it work for?

Lesson #15: Ear Tricks

Overview: Think of your ears as "sound antennas." There's a reason you have TWO of these – and that's what this experiment is all about.

What to Learn: Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- noisemaker
- partner
- blindfold
- earplugs

Lab Time

1. Sit or stand in the middle of a room.
2. Close your eyes or put on the blindfold.
3. Have your partner walk to another part of the room as quietly as possible.
4. Have your partner move the sound maker around the room, but also make sure your partner makes the sound directly in front of you, behind you and over your head as well.
5. With your eyes still closed, point to where you think the sound came from.
6. Try it several times and then let your partner have a turn.

Did you get fooled this time? This works sometimes, but not always. What I hope happened was when the noisemaker was above your head, directly in front of you or directly behind you, you had trouble determining where the sound was coming from. Can you guess why this might have happened? Your ears are placed directly across from one another. If a noise happens directly in front of you, it hits your both ears at the exact same time. Your brain has no clues as to where the sound is coming from if the sound hits both ears at the same time so it makes its best guess. In this case, its best guess may be wrong. Let's try one more thing here.

7. Close your eyes or put on the blindfold.
8. Put an ear plug in one of your ears. If you don't have one, use your finger to cover your ear. Be very careful not to put your finger into your ear. Just use your finger to cover the hole in your ear.
9. Have your partner walk to another part of the room as quietly as possible.
10. Have your partner make the noisemaker make a noise. This will work best if the noise is not too loud.
11. With your eyes still closed, point to where you think the sound came from.
12. Try it several times and then let your partner try to find the sound.

How did you do with just one ear? Did you get fooled a little more often this time? Your brain has fewer clues to work with so it does the best it can with what it has.

Reading

Your ears are very good at determining where sounds are coming from. The reason your ears are so good at detecting the direction of a sound is due to the fact that sound hits one ear slightly before it hits the other ear. You brain does an amazing bit of quick math to make its best guess as to where the sound is coming from and how far away it is. Let's do a little more with this.

Exercises Answer the questions below:

1. How do your two ears work together to determine the location of a sound?

2. Does it matter what frequency (how high or low) the sound is? Are some frequencies easier to detect than others with only one ear?

Lesson #16: Humming Balloon

Overview: You can easily make a humming, screeching balloon using just a little bit of physics knowledge about sonic vibrations.

What to Learn: Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- hex nut
- balloon
- optional: other small options (washer, various coins, marble, etc.)

Lab Time

1. Place a hex nut OR a small coin in a large balloon.
2. Inflate the balloon and tie it.
3. Swirl the balloon rapidly to cause the hex nut or coin to roll inside the balloon. The coin will roll for a very long time on the smooth balloon surface.
4. At high coin speeds, the frequency with which the coin circles the balloon may resonate with one of the balloon's "natural frequencies," and the balloon may hum loudly.

Humming Balloon Data Table

Object inserted into balloon	Did you swirl the balloon slow, medium, or fast?	Noise made? Volume?

Reading

Sound is a form of energy that our ears can hear when sound vibrations reach them. Sound's energy vibrations travel in waves to our ears.

The pitch tells us how high or low a sound is. Pitch represents the frequency of sound vibrations. High vibrations are high frequency and high pitch. Low vibrations are low frequency and low pitch.

In this experiment, students will be able to change the pitch depending on how fast the hex nut is spinning. They'll also be able to feel the vibrations which produce the sound.

Exercises Answer the questions below:

1. How does sound travel?

2. What is pitch?

3. How is frequency related to pitch?

Lesson #17: Harmonica

Overview: Sound is caused by something vibrating. If you can hear it, you can bet that somewhere, something is vibrating molecules and those molecules are vibrating your eardrums. The sound may be coming from a car, thunder, a balloon popping, clapping hands, or your goldfish blowing bubbles in her tank. However, no matter where it's coming from, what you are hearing is vibrating particles, usually vibrating air molecules.

What to Learn Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- tongue depressor popsicle sticks (2)
- rubber bands (3, one at least 1/4″ wide)
- paper
- tape
- ruler

Lab Time

1. Rip the piece of paper in half.
2. Stack popsicle sticks on top of each other and loosely wrap the paper around them. This is your first cuff, and it should be loose enough to slide off the sticks.
3. Secure the paper to itself with tape – don't tape it to the sticks.
4. Now follow steps 4 & 5 again to make one more cuff.
5. Put one rubber band along the length of one popsicle stick.
6. Put the cuffs on this stick with the rubber band on it, placing one on each end. Place the other popsicle stick on top of this one.
7. Secure the sticks together by wrapping the two remaining rubber bands around the ends.
8. To play the harmonica, put the sticks up to your mouth and blow. You can vary the sound by moving the cuffs.

Harmonica Data Table

Distance Between Cuffs *(measure in inches or cm)*	**Pitch Observed** *(high, medium, low)*

Reading

What happens if you place an alarm clock in outer space? Will you hear it ring?

When you put an alarm clock in a space without air, no sound can come from the clock. There's nothing to transfer the vibrational energy. It's like trying to grab hold of fog – there's nothing to hold on to.

Sound is a form of energy. Energy is the ability to move something over a distance against a force. What is moving to make sound energy?

Molecules. Molecules are vibrating back and forth at fairly high rates of speed, creating waves. Energy moves from place to place by waves. Sound energy moves by longitudinal waves (the waves that are like a slinky). The molecules vibrate back and forth, crashing into the molecules next to them, causing them to vibrate, and so on and so forth. All sounds come from vibrations.

In this project, the rubber band vibrates as you blow across it to get a sound. The pitch can change by sliding the cuffs (this does take practice). Remember that pitch represents the frequency of sound vibrations.

If you can't get a sound, you may have clamped down too hard on the ends. Release some of the pressure by untwisting the rubber bands on the ends and try again. Also – this one doesn't work well if you spit too much – wet surfaces keep the rubber band from vibrating.

Exercises Answer the questions below:

1. What is sound?

2. What is energy?

3. What is moving to make sound energy?

Lesson #18: Buzzing Hornets

Overview: When something vibrates, it pushes particles. These pushed particles create a longitudinal wave. If the longitudinal wave has the right frequency and enough energy, your eardrum antennas will pick it up and your brain will turn the energy into what we call sound.

What to Learn: Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- index cards (2)
- scissors
- popsicle stick (tongue depressor sized)
- rubber band (thick)
- cotton string (3-4 feet)
- hot glue gun
- ruler or tape measure

Lab Time

1. Cut two corners off one side of your index card.
2. Run a bead of glue down the length of the popsicle stick and quickly attach to the side with untrimmed corners. If your card is longer than the stick, trim it down with the scissors.
3. Cut the second index card in half. Fold each portion in half three times.
4. Put hot glue on both sides of the popsicle stick and attach one of the folded index cards to the end.
5. Take the second folded index card portion. Tie the string around the middle, then around the fold and attach it to the popsicle stick as you did the other portion of the index card.
6. When the glue dries, wrap the rubber band along the length of the popsicle stick. This is your completed hornet.
7. Now, grab the end of the string and whip the hornet around your head really fast until you hear the sound.
8. When you sling the hornet around, wind zips over the rubber band and causes it to vibrate like a guitar string… and the sound is focused (slightly) by the card. The card really helps keep the contraption at the correct angle to the wind so it continues to make the sound.
9. You can try this with different-sized rubber bands, multiple rubber bands, and without the index card attached.

Buzzing Hornets Data Table

String Length *(measure in inches or cm)*	**Pitch Observed** *(high, medium, low)*

Reading

Sound is made by things vibrating back and forth, whether it's a guitar string, drum head, or clarinet reed. The back and forth motion of an object (like the drum head) creates a sound wave in the air that looks a lot like a ripple in a pond after you throw a rock in. It radiates outward, vibrating its neighboring air molecules until they are moving around, too. This chain reaction keeps happening until it reaches your ears, where your "sound detectors" pick up the vibration and work with your brain to turn it into sound.

You can illustrate this principle using a guitar string – when you pluck the string, your ears pick up a sound. If you have extra rubber bands, wrap them around an open shoebox to make a shoebox guitar. You can also cut a hole in the lid (image left) and use wooden pencils to lift the rubber band off the surface of the shoebox.

Troubleshooting: Most kids forget to put on the rubber band, as they get so excited about finishing this project that they grab the string and start slinging it around… and wonder why it's so silent! Make sure they have a fat enough rubber band (about 3.5" x ¼" – or larger) or they won't get a sound.

Variations include: multiple rubber bands, different sizes of rubber bands, and trying it without the index card attached. The Buzzing Hornet works because air zips past the rubber band, making it vibrate, and the sound gets amplified just a bit by the index card.

Exercises Answer the questions below:

1. What effect does changing the length of the string have on the pitch?

2. What vibrates in this experiment to create sound?

3. Why do we use an index card?

Lesson #19: Air Horn

Overview: Sound can change according to the speed at which it travels. Another word for sound speed is pitch. When the sound speed slows, the pitch lowers. With clarinet reeds, it's high. Guitar strings can do both, as they are adjustable. If you look carefully, you can actually see the low pitch strings vibrate back and forth, but the high pitch strings move so quickly it's hard to see. But you can detect the effects of both with your ears.

What to Learn: Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- 7-9" balloon
- straw
- film canister or similar small plastic container
- drill and drill bits

Lab Time

NOTE: DO NOT place these anywhere near your ear… keep them straight out in front of you.

1. To make an air horn, poke a hole large enough to insert a straw into the bottom end of a black Kodak film canister. (We used the pointy tip of a wooden skewer, but a drill can work also.)
2. Before you insert the straw, poke a second hole in the side of the canister, about halfway up the side.
3. Grab an un-inflated balloon and place it on your table. See how there are two layers of rubber (the top surface and the bottom surface)? Cut the neck off a balloon and slice it along one of the folded edges (still un-inflated!) so that it now lays in a flat, rubber sheet on your table.
4. Drape the balloon sheet over the open end of the film canister and snap the lid on top, making sure there's a good seal (meaning that the balloon is stretched over the entire opening - no gaps). Insert the straw through the bottom end, and blow through the middle hole (in the side of the canister).
5. You'll need to play with this a bit to get it right, but it's worth it! The straw needs to *just* touch the balloon surface inside the canister and at the right angle, so take a deep breath and gently wiggle the straw around until you get a BIG sound. If you're good enough, you should be able to get two or three harmonics!

Reading

What is the sound barrier? It's when something travels faster than the speed of sound. When an object travels faster than the speed of sound, there's a loud crack or boom that happens.

There are lots of things on earth that break the sound barrier – bullets and bullwhips, for example. The loud crack from a whip is the tip zipping faster than the speed of sound.

So why do we hear a boom at all? Sonic booms are created when an object travels faster than sound waves. In order to do this, the object must push enough air out of its way as it tears through the atmosphere. The faster an object travels through the air, the more air pressure is built up in front of the object (think of how the water collects at the bow of a boat as it travels through the water). The object, like an airplane, pushes air molecules aside in such a way that they are compressed to the point where shock waves are formed. These shock waves form two cones, at the nose and tail of the plane. The shock waves move outward and rearward in all directions and usually extend to the ground.

Since the airplane is flying, the shock waves extend from the plane to the ground. The sharp release of pressure, after the buildup by the shock wave, is heard as the sonic boom.

This experiment is rather tricky. Instead of a rubber band vibrating to make sound, a rubber sheet vibrates, and the vibration (sound) shoots out the straw. It will take practice for your child to make a sound using this device. The straw needs to barely touch the inside surface of the balloon at just the right angle in order for the balloon to vibrate. Make sure you're blowing through the hole in the side, not through the straw.

Exercises Answer the questions below:

1. Why do we use a straw with this experiment?

2. Does the length of the straw matter? What will affect the pitch of this instrument?

Lesson #20: Best Parent-Annoyer

Overview: This is one of my absolute favorites, because it's so unexpected and unusual. The setup looks quite harmless, but it makes a sound worse than scratching your nails on a chalkboard. If you can't find the weird ingredient, just use water and you'll get nearly the same result (it just takes more practice to get it right). Ready?

NOTE: DO NOT place these anywhere near your ear… keep them straight out in front of you.

What to Learn: Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- water or violin rosin (this is the weird ingredient)
- string (a few feet)
- cup (disposable plastic)
- pokey-thing to make a hole in the cup

Lab Time

1. Poke a hole in the bottom of the cup that's large enough to thread the string through.
2. Thread the string through the hole and tie a knot in the other end of the string. Pull the string through the cup up to the knot.
3. Soak the string in water. Alternately, put a layer or two of violin rosin along the length of the string. Make sure you get all sides of the string coated with rosin.
4. Hold the cup in one hand while pinching the string with two fingers of the other hand so that your fingers are able to stick and slip down the string.
5. If done just right, you should be able to hear the annoying sound!

Best Parent-Annoyer Data Table

String Length *(measure in inches or cm)*	**Pitch Observed** *(high, medium, low)*

Reading

Sound travels in vibrating waves, like ripples in a pond moving outward from a dropped stone. There are three components to sound that we'll learn about today: Volume is how loud or soft a sound it, tone is the character of the sound, and pitch is how high or low the sound is.

Pitch is directly related to the vibrational frequency of a sound. Higher pitches have higher frequency and more vibration. Lower pitches are the opposite – with slower vibrations and lower pitch.

Exercises Answer the questions below:

1. What does the rosin (or water) do in this experiment?

2. What is vibrating in this experiment?

3. What is the cup for?

Lesson #21: Seeing Sound Waves

Overview: This section is actually a collection of the experiments that build on each other. We'll be playing with sound waves in many different forms, and you get to have fun making a loud mess.

What to Learn: Sound is made by vibrating objects and can be described by its pitch and volume.

Materials

- radio or some sort of music player
- balloon
- mixing bowl
- water
- spoon
- rubber bands

Lab Time

1. Turn on your music player and turn it up fairly loud.
2. Take a look at your speaker. You should be able to see it vibrating. If there's a song with a lot of bass, you should really be able to see it moving.
3. Put your hand on the speaker. Can you feel the vibrations?
4. <u>Teachers/Parents Only:</u> Carefully put a half-filled bowl of water on top of your speaker. You should be able to see the water vibrate. (Don't leave it there! Put it away as soon as you're done with this step.)
5. Inflate the balloon. (Get it fairly large. You want the membrane to be stretched fairly thin.)
6. Turn the music on loud (the more bass the better!).
7. Put both hands lightly on the balloon.
8. Walk around the room holding the balloon lightly between your hands. Try to feel the balloon vibrating.
9. Does the balloon vibrate more for low sounds or high sounds?
10. If you have a synthesizer (piano keyboard) you may want to try turning it up a bit and playing one note at a time. You should notice that the balloon vibrates more or less as you go up and down the musical scale. At very high notes, your balloon may not vibrate at all.
11. Now for the last part. Take the mixing bowl and put it on the table.
12. Smack it with the wooden spoon. Listen to the sound.
13. Put your ear next to the bowl and try to hear how long the sound continues.
14. Now hit the bowl again.
15. Touch the bowl with your hand a second or two after you hit it. You should hear the sound stop. This is called dampening.
16. Now, for fun, fill the bowl with water up to an inch or so from the top.
17. Smack the bowl again and look very carefully at where the bowl touches the water. (When you first hit the bowl, you should see very small waves in the water.)
18. Stretch a few rubber bands around the box or the bowl. If possible, use different thicknesses of rubber bands.
19. Strum the rubber bands.

20. Feel free to adjust how stretched the bands are. The more stretched, the higher the note.
21. Try plucking a rubber band softly.
22. Now pluck it fairly hard. The hard pluck should be louder.

Again, I'd like you to notice three things here. Just like the first part of the experiment, you should see that the sound is coming from the vibration. As long as the rubber band vibrates, you hear a sound. If you stop the rubber band from vibrating, you will stop the sound. Sound is vibration.

The second thing I'd like you to notice is that the rubber bands make different pitched sounds. The thinner the rubber band, or the tighter it's stretched, the faster it vibrates. Another way to say "vibrating faster" is to say higher frequency. In sound, the higher the frequency of vibration, the higher the pitch of the note. The lower the frequency, the lower the pitch of the note. The average human ear can hear sound at as high a frequency as 20,000 Hz, and as low as 20 Hz. Pianos, guitars, violins and other instruments have strings of various sizes so that they can vibrate at different frequencies and make different pitched sounds. When you talk or sing, you change the tension of your vocal cords to make different pitches.

One last thing to notice here is what happened when you plucked the rubber band hard or softly. The rubber band made a louder noise the harder you plucked it, right? Remember again that sound is energy. When you plucked that rubber band hard, you put more energy into it than when you plucked it softly. You gave energy (moved the band a distance against a force) to the rubber band. When you released the rubber band, it moved the air against a force which created sound energy. For sound, the more energy it has, the louder it is. Remember when we talked about amplitude a few lessons back? Amplitude is the size of the wave. The more energy a wave has the bigger it is. When it comes to sound, the larger the wave (the more energy it has) the louder it is. So when you plucked the rubber band hard (gave it lots of energy), you made a louder sound.

I said this in the beginning but I'll repeat it here, hoping that now it makes more sense: When something vibrates, it pushes particles against a force (creates energy). These pushed particles create longitudinal waves. If the longitudinal waves have the right frequency and enough energy (loudness), your ear drum antennas will pick it up and your brain will translate the energy into what we call sound.

Seeing Sound Waves Data Table

Rubber Band Size	Plucking Hard or Soft?	Pitch / Volume Observations

Reading

Sound is vibrating molecules. Speakers get air molecules to vibrate, creating waves that push the air. Eardrums vibrate just like speakers do when the sound waves hit the ears.

You'll be doing a couple of different experiments with this lab. First, you'll be feeling the vibrations from a speaker playing music. You'll also notice what happens when you place a bowl of water right on top of a speaker. Next, you'll use a balloon to detect treble and bass pitches of music, and finally you'll set up your own vibrations using a homemade guitar.

Sound waves don't just travel to your eardrum. They travel all over the room, bouncing into everything they can find, including windows, tables, chairs, and the balloon you're going to be using. What's causing the objects to vibrate?

Energy. Energy causes objects to move a distance against a force. The sound energy coming from the speakers is causing the objects to vibrate. Your eardrums move in a very similar way to a balloon, which is why we're going to use it in part of our experiment. Your eardrum is a very thin membrane (like the balloon) that is moved by the energy of the sound. Your eardrum, however, is even more sensitive to sounds than the balloon which is why you can hear sounds when the balloon is not vibrating. If your eardrum doesn't vibrate, you don't hear the sound.

I want you to notice two things here. Sound is vibration. When something is vibrating, it's making a sound. When you stop it from vibrating, it stops making sound. Any sound you ever hear comes from something that is vibrating. It may have vibrated once, like a balloon popping. Or it may be vibrating consistently, like a guitar string.

The other thing I want you to notice is that you can actually see the vibrations. If you put water in the bowl and set it on top of a speaker, the tiny waves that are formed when you first hit the bowl are caused by the vibrating sides of the bowl. Those same vibrations are causing the sound that you hear.

Exercises Answer the questions below:

1. What is sound?

2. How does the rubber band make different sounds?

3. What difference does it make how hard or soft you pluck the rubber bands?

Lesson #22: Building Speakers

Overview: We'll be making different kinds of speakers using household materials (like plastic cups, foam plates, and business cards!), but before we begin, we need to make sure you really understand a few basic principles.

What to Learn: An electrical signal (like music) zings through the coil (which is also allowed to move and attached to your speaker cone), which is attracted or repulsed by the permanent magnet. The coil vibrates, taking the cone with it. The cone vibrates the air around it and sends sounds waves to reach your ear.

Materials

- foam plate
- plastic cup
- copy paper (one sheet)
- business cards (3)
- magnet wire AWG 30 or 32 (RS#278-1345)
- neodymium magnets (2-4, use these from previous experiments)
- disc magnet (1" donut-shaped magnet) (RS#64-1888)
- index cards or stiff paper
- cup (plastic disposable)
- tape
- hot glue gun
- scissors
- audio plug (RS #42-2420) or other cable that fits into your stereo (iPods and other small devices are not recommended for this project – you need something with built-in amplifier like an old boombox)

Lab Time

1. Cut a business card in half lengthwise. Fold each strip in half, and then fold the lengths in half again so you have a W-shape.
2. Stack your magnets together and roll a small strip of copy paper around the magnets. Tape the paper into place. Do this one more time, so you now have two paper cylinder sleeves around your magnets.
3. Wrap the magnet wire 20-50 times around the paper tube (keep the magnets inside so this step is easier). Secure with tape.
4. Carefully remove only the *inside* paper sleeve and discard (you can take the magnets out when you do this).
5. Trim one side of the paper so one side of the coil is near the paper edge.
6. Hot glue the uncut side of the paper tube to the bottom of a foam plate.
7. Hot glue one side of the W-shape of the business card to the bottom of the foam place. You want a W-shape on either side of the paper tube, an inch or two away.
8. Hot glue your magnets to the center of a stiff piece of cardboard.
9. Place your paper tube over the magnets and glue the W-shapes to the cardboard. These are your "springs.".

10. Tap the plate lightly with your finger. Make sure the foam plate is free to bounce up and down.
11. Sand the ends of each magnet wire to strip away the insulation.
12. Unscrew the plastic insulation from the audio plug and wrap one wire around each terminal. Make sure the two contacts and wires don't touch each other, or your speaker won't work. You can secure each connection with tape.
13. Plug it into your boombox and play your music on the highest volume. You should hear the music coming from your speaker!

Reading

Let's talk about the telegraph. A telegraph is a small electromagnet that you can switch on and off. The electromagnet is a simple little thing made by wrapping insulated wire around a nail. An electromagnet is a magnet you can turn on and off with electricity, and it only works when you plug it into a battery.

Anytime you run electricity through a wire, you also get a magnetic field**.** You can amplify this effect by having lots of wire in a small space (hence wrapping the wire around a nail) to concentrate the magnetic effect. The opposite is true also – if you rub a permanent magnet along the length of the electromagnet, you'll get an electric current flowing through the wire. Magnetic fields cause electric fields, and electric fields cause magnetic fields. Got it?

A microphone has a small electromagnet next to a permanent magnet, separated by a thin space. The coil is allowed to move a bit (because it's lighter than the permanent magnet). When you speak into a microphone, your voice sends sound waves that vibrate the coil, and each time the coil moves, it causes an electrical signal to flow through the wires, which gets picked up by your recording system.

A loudspeaker works the opposite way. An electrical signal (like music) zings through the coil (which is also allowed to move and attached to your speaker cone), which is attracted or repulsed by the permanent magnet. The coil vibrates, taking the cone with it. The cone vibrates the air around it and sends sounds waves to reach your ear.

If you placed your hand over the speaker as it was booming out sound, you felt something against your hand, right? That's the sound waves being generated by the speaker cone. Each time the speaker cone moves around, it create a vibration in the air that you can detect with your ears. For deep notes, the cone moves the most, and a lot of air gets shoved at once, so you hear a low note. Which is why you can blow out your speakers if your bass is cranked up too much. Does that make sense?

Exercises Answer the questions below:

1. Does it matter how strong the magnets are?
2. What else can you use besides a foam plate?
3. Which works better: a larger or smaller magnet wire coil?
4. How can you detect magnetic fields?
5. How does an electromagnet work?
6. How does your speaker work?
7. Is a speaker the same as a microphone?
8. Does the shape and size of the plate matter? What if you use a plastic cup?

Forces & Motion Part 1 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 1 Quiz

Name____

1. What is Newton's Third Law of Motion?

2. What is velocity?

3. Which forces can be attractive or repulsive? Do their sizes depend on the magnitudes of the charges? Give an example.

4. Do two objects interacting with each other electrically need to be in contact?

5. Gravitational forces are always: attractive, repulsive, or both?

6. True or false? Gravity pulls on all things equally.

7. True or false? Gravity accelerates all things equally.

8. How is acceleration different from speed and velocity?

9. What is friction?

10. What is Newton's First Law?

Forces & Motion Part 1 Lab 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:

- Demonstrate Newton's Three Laws of Motion. Here's a ball for you to teach your parent the three laws of motion.

Answers to Exercises

Lesson 1: Balloon Racers

1. What is Newton's Third Law of Motion? (For every action, there is an equal and opposite reaction.)
2. Why does the balloon stop along the string? (Friction between the string and straw.)

Lesson 2: Look Out Below

1. What is velocity? (It's the measure of speed combined with the direction an object is traveling.)
2. How do acceleration and deceleration relate to velocity? (Acceleration is an increase in velocity; deceleration is a decrease in velocity.)
3. How do we know when an object has reached terminal velocity? (This occurs when an object has reached a constant velocity and is no longer accelerating or decelerating.)

Lesson 3: Detecting the Electric Field

1. What happens if you rub the balloon on other things, like a wool sweater? (You'll charge the balloon with a positive charge instead of a negative charge.)
2. If you position other people with charged balloons around the table, can you keep the yardstick going? (Yes!)
3. Can we see electrons? (Nope!)
4. How do you get rid of extra electrons? (Touch something that's grounded, like a metal pipe that's partly buried in the ground.)
5. Does the shape of the balloon matter? (Not really.)
6. Does hair color matter? (I've found that color and texture do!)
7. Rub a balloon on your head, and then lift it up about 6". Why is the hair attracted to the balloon? (The negative charge on the balloon is attracted to the positive charge on the hair.)
8. Why does the hair continue to stand on end after the balloon is taken away? (The balloon brought the positive charges to the surface, so now each hair has little positive charges all over the surface, making each hair strand repel each other.)
9. What other things does the balloon stick to besides the wall? (You, the wood desk, anything that is a good insulator.)
10. Why do you think the yardstick moved? (The negative charge on the balloon attracted the positive charge on the yardstick.)
11. What other things are attracted or repelled the same way by the balloon? (Hint: try a ping pong ball.)

Lesson 4: Newton's First Law of Motion

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)?

Lesson 5: Newton's Second Law of Motion

1. What concept does Newton's Second Law of Motion deal with? (force, mass, and acceleration)
2. What is momentum? (mass times velocity, or mv)

Lesson 6: Newton's Third Law of Motion

1. What is Newton's Third Law? (For every action, there is an equal and opposite reaction.)
2. Give three examples of forces in pairs. (You sitting in a chair, your weight 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).
3. 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!)
4. 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. Rockets accelerate because they burn fuel and push the hot gases out the back end to propel themselves forward in the opposite direction.)

Lesson 7: Barrel Roof

1. What is Newton's Third Law? (For every action, there is an equal, but opposite reaction.)
2. What kind of groups do forces come in? (pairs)
3. What is another name for Newton's Third law? (the action-reaction law)

Lesson 8: Building Bridges

1. What are three different kinds of forces? (Shear, static, and tension.)
2. Using only blocks, what kind of wall design is the weakest? (When you stack them in independent stacks and place them side by side.)
3. Why does the bridge seem stronger when a card is arched underneath? (The card provides additional support in the vertical direction.)

Lesson 9: Weighty Issue

1. What did you notice from your data? Did heavier or lighter objects fall faster? Did more massive objects or smaller objects fall faster? What characteristic seemed to matter the most? (see data tables)
2. Is gravity a two-way force, like the attractive-repulsive forces of a magnet? (No, only attractive.)
3. If I were to drop a bowling ball and a balloon filled with a gas six times heavier than air (sulfur hexafluoride SF_6) and inflated to the exact size of the bowling ball from my roof, which will strike the ground first? (Both, unless it's windy!)

Lesson 10: Forever Falling

1. True or false? Gravity pulls on all things equally. (False!)
2. True or false? Gravity accelerates all things equally. (True!)
3. In your *own* words, why do the coins hit the ground at the same time? Is this what you'd expect to happen on Mars? (Yes!)

Lesson 11: Rocketball Launcer

1. What is the mathematical formula for momentum? (momentum = mv)
2. Explain momentum in words (It's mass times velocity; it's inertia in motion.)
3. What happens to the momentum of the bottom ball in this experiment? (It's transferred to the small ball.)

Lesson 12: Detecting the Magnetic Field

1. Why does the needle need the foam? (So it can float and align with the magnetic field.)
2. Why do we use water? (Water is very low-friction, so it allows the needle to move and orient itself.)
3. What are the forces in a magnetic field? (attractive and repulsive)

Lesson 13: Flying Paperclip

1. Circle one: The closer you get to the magnet, the (**stronger** weaker) the force of the magnetic field is on the paper clip.
2. Why does it matter which way you orient the magnet in this experiment? (The magnetic force is strongest at the magnetic poles.)
3. Which magnet has the strongest magnetic field? (Refer to your data.)
4. Is the north or south pole stronger on a magnet? (Neither – they are identical in force.)

Lesson 14: Force-full Cereal

1. Why do the pieces of cereal stick to each other? (The iron in the cereal makes it act like a bunch of little magnets.)
2. Does the cereal move slower or faster the closer the pieces come in contact with each other? (Faster)
3. What other cereals does it work for? (Any cereal fortified with iron.)

Lesson 15: Ear Tricks

1. How do your two ears work together to determine the location of a sound? (Sound hits one ear slightly before it hits the other ear, and your brain makes a guess as to where the sound is coming from and how far away it is based on your experience.)
2. Does it matter what frequency (how high or low) the sound is? Are some frequencies easier to detect than others with only one ear? (answers will vary)

Lesson 16: Humming Balloon

1. How does sound travel? (via vibrating waves)
2. What is pitch? (how high or low a sound is)
3. How is frequency related to pitch? (High frequency means high pitch, low frequency means low pitch.)

Lesson 17: Harmonica

1. What is sound? (Sound is a form of energy.)
2. What is energy? (Energy is the ability to move something over a distance against a force.)
3. What is moving to make sound energy? (molecules)

Lesson 18: Buzzing Hornets

1. What effect does changing the length of the string have on the pitch? (Refer to data table)
2. What vibrates in this experiment to create sound? (the rubber band)
3. Why do we use an index card? (to amplify the vibrations so we can hear them)

Lesson 19: Air Horn

1. Why do we use a straw with this experiment? (To blow a continuous stream of air onto the rubber sheet to set up a vibration in the sheet, which allows air to escape out the side where the straw contacts the rubber sheet.)

2. Does the length of the straw matter? What will affect the pitch of this instrument? (Air flow, tightness of rubber sheet.)

Lesson 20: Best Parent-Annoyer

1. What does the rosin (or water) do in this experiment? (It creates a stick-and-slip surface that creates sound from friction.)
2. What is vibrating in this experiment? (The string.)
3. What is the cup for? (To amplify the sound)

Lesson 21: Seeing Sound Waves

1. What is sound? (Sound is vibrating air molecules.)
2. How does the rubber band make different sounds? (Thinner rubber bands are stretched more tightly, so it vibrates faster and makes a higher pitched sound.)
3. What difference does it make how hard or soft you pluck the rubber bands? (Since sound is energy, the harder you pluck, the more energy you give the rubber band, which means a larger amplitude sound wave and a higher volume or louder sound.)

Lesson 22: Building Speakers

1. Does it matter how strong the magnets are? (Yes, the stronger they are, the better the signal you hear from the speaker.)
2. What else can you use besides a foam plate? (plastic cups, paper plates…)
3. Which works better: a larger or smaller magnet wire coil? (larger)
4. How can you detect magnetic fields? (with a compass)
5. How does an electromagnet work? (When you put electricity through the wire, it turns it into a magnet.)
6. How does your speaker work? (Refer to the Background Reading Section.)
7. Is a speaker the same as a microphone? (No – they are opposite. Refer to the Background Reading Section.)
8. Does the shape and size of the plate matter? What if you use a plastic cup? (Yes – shape and size do matter!)

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.