Newton's Wagon

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

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

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

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

Materials

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

Lab Time Part 1

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

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

Newton’s First Law of Motion Data Table

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

Reading Part 1

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

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

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

Lab Time Part 2

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Now you give it a try:

Newton's Second Law of Momentum Data Table

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

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

Reading Part 2

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

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

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

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

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

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

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

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

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

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

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

Lab Time Part 3

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

Newton's Third Law of Motion Data Table

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

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

Reading Part 3

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

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

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

Exercises Answer the questions below:

1. What is inertia?

2. What is Newton's First Law?

3. Will a lighter or heavier race car with the same engine win a short-distance race (like the quarter-mile)?

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

5. What is momentum?

6. What is the equation for Newton's Second Law?

7. What is Newton's Third law?

8. Give three examples of forces in pairs.

9. A rope is attached to a wall. You pick up the rope and pull with all you've got. A scientist walks by and adds a force meter to the rope and measures you're pulling with 50 Newtons. How much force does the wall experience?

10. Can rockets travel in space if there's nothing to push off of? Explain your answer.

Answers to Exercises: Newton's Wagon

1. What is inertia? (the resistance something has to change its motion)
2. What is Newton's First Law? (Objects at rest stay at rest, and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.)
3. Will a lighter or heavier race car with the same engine win a short-distance race (like the quarter-mile)?
4. What concept does Newton's Second Law of Motion deal with? (force, mass, and acceleration)
5. What is momentum? (mass times velocity, or mv)
6. What is the equation for Newton's Second Law? ($F_{net} = ma$)
7. What is Newton's Third law? (For every action, there is an equal and opposite reaction.)
8. Give three examples of forces in pairs. (You sitting in a chair: your weight is balanced by the chair pushing back on you; the chandelier hanging from the ceiling is balanced by the tension in the chain holding it up; your weight on quad roller skates is balanced by the ground pushing back with an eighth of your weight on each wheel).
9. A rope is attached to a wall. You pick up the rope and pull with all you've got. A scientist walks by and adds a force meter to the rope and measures you're pulling with 50 Newtons. How much force does the wall experience? (50 Newtons!)
10. Can rockets travel in space if there's nothing to push off of? Explain your answer. (This was a common misconception that rockets can't accelerate in space. If you've watched a rocket launch, then you've seen firsthand how rockets can and do accelerate in space. Rockets accelerate because they burn fuel and push the hot gases out the back end to propel themselves forward in the opposite