Newton's Wagon - Newton's Laws

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? Great – then let's keep going.

Newton's 1st Law : An object at rest will stay at rest, or an object in motion will stay in motion unless acted on by an outside force. This means that an object will remain still or keep moving unless something (a force) acts on it. Also gives us the idea of inertia which relates the amount of mass to how much force is required to move it.

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 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 (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!

Newton's 2nd Law: The acceleration of an object is directly proportional to the net force, and inversely proportional to its mass. This law sounds confusing, but the equation is a lot simpler to remember: F_{net}=ma.

"F_{net}" stands for net force, and 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 that 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.

Newton's 3rd Law: For every action there is an equal and opposite reaction.

Newton's wagon – Activities

Objective: to see Newton's laws in action with simple demonstrations

Materials: Wagon
Rock (an actual rock, not Duane Johnson)
Friends

Procedure

1st Law:

1) Pull the empty wagon down the sidewalk.
2) Try to stop as quickly as you can. Be careful, you don't want to get run over by the wagon
3) Put a friend in the wagon and repeat steps 1 & 2
4) Put another friend in the wagon and repeat steps 1 & 2

Analysis:

1) Which was harder, pulling the empty wagon, the wagon with 1 friend, or 2 friends?

2) Which was the hardest to stop?

3) This is the first law of motion the more mass something has, the harder it is to start moving and stop moving. The word we use to describe this is called inertia. What are some other examples of inertia?

4) If there was a lighter car and a heavier car with the exact same engine, which would win a short (1/4 mile) race? Why?

2nd Law:

1) Start with an empty wagon
2) Pull it and try to get the wagon going as fast as it can, as quickly as you can. In other words, try to accelerate it.
3) Add weight (maybe a friend, with a helmet). Be careful even going fast, so the wagon doesn't tip over.
4) Repeat step 2

5) Add even more weight (another friend comes to mind)
6) Repeat Step 2
7) Keep adding weight until it becomes very difficult to pull the wagon and get it to top speed as quickly as you can.

Analysis:

1) Why did pulling the wagon get so hard?

2) Adding people adds more mass, so as you added more mass, were you able to accelerate the wagon faster or slower?

3) The equation associated with the second law of motion is F = ma. Above, as you added mass, the acceleration decreased, which means the force you used stayed relatively the same. What would you say the relationship is between mass and acceleration?

3rd Law: *For this activity, it may be hard to see results unless you have a very low friction wagon, or skateboard.*

1) Stand on you skateboard or sit in your wagon with a heavy object (The heaviest item you feel you can safely throw.
2) Throw the object as hard as you can in front of you.

Analysis:

1) What happened to you after you threw the object?

2) You had more mass than the object. Which traveled faster, you or the object?

3) So, the lower the mass, the higher the acceleration, which means the force that moved the object and you were about equal. What made them opposite?

This is also a good experiment to try if you are in a canoe, because there is relatively low friction between the boat and the water

Newton's Laws – Problems

1) Which of Newton's 3 Laws best applies?
   ____ A) In a car collision, a person without a seatbelt flies forward and hits the windshield.

   ____ B) Your foot pushes backwards on the ground and friction pushes you forward.

   ____ C) When you accelerate quickly in your car you have to use

   ____ D) A racing car needs to accelerate faster, so they make the car lighter.

   ____ E) You push your knuckles into a table and your knuckles start to hurt.

Use Newton's 2nd Law, F=ma, to solve the following problems

2) A 1500 kg car is accelerating at 2.5 m/s^2. What is the force applied by the engine to cause this acceleration?

Given:	Equation(s):	Solve:
	Substitute:	
Unknown:		

3) A rocket engine exerts a force of 12,000 N to accelerate the rocket to 1.5 m/s^2. What is the mass of the rocket?

Given:	Equation(s):	Solve:
	Substitute:	
Unknown:		

4) A boy accelerates a 250 kg box with 400 N of force. Calculate the acceleration.

Given:	Equation(s):	Solve:
	Substitute:	
Unknown:		

5) What is the force of a 2000 kg dragster accelerating at 3.5 m/s^2?

Given:	Equation(s):	Solve:
	Substitute:	
Unknown:		

6) Which requires more force: A 2500 kg elephant accelerating at 0.5 m/s^2, or a 40 kg cheetah accelerating from rest to 36 m/s in 1.2 seconds?

Given:	Equation(s):	Solve:
	Substitute:	
Unknown:		

Newton's Wagon - Newton's Laws

Analysis:

1) Which was harder, pulling the empty wagon, the wagon with 1 friend, or 2 friends?
   2 friends

2) Which was the hardest to stop?
   2 friends

3) This is the first law of motion the more mass something has, the harder it is to start moving and stop moving. The word we use to describe this is called inertia. What are some other examples of inertia?
   Trying to push a large car is hard, because it has a lot of mass. Trying to pull a wagon is easy, because it has a relatively low mass.

4) If there was a lighter car and a heavier car with the exact same engine, which would win a short (1/4 mile) race? Why?
   Lighter car, the same force would accelerate a lighter object faster

2nd Law:
Analysis:

1) Why did pulling the wagon get so hard?
   Added more people to it
2) Adding people adds more mass, so as you added more mass, were you able to accelerate the wagon faster or slower?
   slower
3) The equation associated with the second law of motion is $F = ma$. Above, as you added mass, the acceleration decreased, which means the force you used stayed relatively the same. What would you say the relationship is between mass and acceleration?
   They are inversely related

3rd Law:
Analysis:

1) What happened to you after you threw the object?
   I went backwards

2) You had more mass than the object. Which traveled faster, you or the object?
   The object moved faster

3) So, the lower the mass, the higher the acceleration, which means the force that moved the object and you were about equal. What made them opposite?
The object and I moved in opposite directions

Newton's Laws – Problems

1) Which of Newton's 3 Laws best applies?
__1__ A) In a car collision, a person without a seatbelt flies forward and hits the windshield.

__3__ B) Your foot pushes backwards on the ground and friction pushes you forward.

__2__ C) When you accelerate quickly in your car you have to use more force

__2__ D) A racing car needs to accelerate faster, so they make the car lighter.

__3__ E) You push your knuckles into a table and your knuckles start to hurt.

Use Newton's 2nd Law, F=ma, to solve the following problems

2) A 1500 kg car is accelerating at 2.5 m/s^2. What is the force applied by the engine to cause this acceleration?

Given:	Equation(s):	Solve: *3750 N*
	Substitute:	
Unknown:		

3) A rocket engine exerts a force of 12,000 N to accelerate the rocket to 1.5 m/s^2. What is the mass of the rocket?

Given:	Equation(s):	Solve: *8000 kg*
	Substitute:	
Unknown:		

4) A boy accelerates a 250 kg box with 400 N of force. Calculate the acceleration.

Given:	Equation(s):	Solve: *1.6 m/s²*
	Substitute:	
Unknown:		

5) What is the force of a 2000 kg dragster accelerating at 3.5 m/s^2?

Given:	Equation(s):	Solve: *7000 N*
	Substitute:	
Unknown:		

6) Which requires more force: A 2500 kg elephant accelerating at 0.5 m/s^2, or a 40 kg cheetah accelerating from rest to 36 m/s in 1.2 seconds?

Given:	Equation(s):	Solve: *1250 N – elephant* *1200 N - cheetah*
	Substitute:	
Unknown:		