Newton's First Law of Motion

> *Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.*
> - Newton's First Law of Motion, translated from the *Principia*'s Latin

Newton's Second Law of Motion

> *The acceleration produced by a particular force acting on a body is directly proportional to the magnitude of the force and inversely proportional to the mass of the body.*
> - Newton's Second Law of Motion, translated from the *Principia*'s Latin

Newton's Third Law of Motion

> *To every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.*
> - Newton's Third Law of Motion, translated from the *Principia*'s Latin

Newton's First Law of Motion

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This is sometimes called the Law of Inertia, or just inertia. Essentially, it makes the following two points:

- An object that is not moving will not move until a force acts upon it.
- An object that is in motion will not change velocity (including stopping) until a force acts upon it.

The first point seems relatively obvious to most people, but the second may take some thinking through, because everyone knows that things don't keep moving forever. If I slide a hockey puck along a table, it doesn't move forever, it slows and eventually comes to a stop. But according to Newton's laws, this is because a force is acting on the hockey puck and, sure enough, there is frictional force between the table and the puck, and that frictional force is in the direction opposite the movement. It's this force which causes the object to slow to a stop. In the absence (or virtual absence) of such a force, as on an air hockey table or ice rink, the puck's motion isn't hindered.

Here is another way of stating Newton's First Law:

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A body that is acted on by no net force moves at a constant
velocity (which may be zero) and zero acceleration.
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So with no net force, the object just keeps doing what it is doing. It is important to note the words *net force*. This means the total forces upon the object must add up to zero. An object sitting on my floor has a gravitational force pulling it downward, but there is also a *normal force* pushing upward from the floor, so the net force is zero - therefore it doesn’t move.

To return to the hockey puck example, consider two people hitting the hockey puck on *exactly* opposite sides at *exactly* the same time and with *exactly* identical force. In this rare case, the puck would not move.

Since both velocity and force are [vector quantities](), the directions are important to this process. If a force (such as gravity) acts downward on an object, and there's no upward force, the object will gain a vertical acceleration downward. The horizontal velocity will not change, however.

If I throw a ball off my balcony at a horizontal speed of 3 m/s, it will hit the ground with a horizontal speed of 3 m/s (ignoring the force of air resistance), even though gravity exerted a force (and therefore acceleration) in the vertical direction. If it weren't for gravity, though, the ball would have kept going in a straight line . .

. . . at least until it hit my neighbor's house.

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The mathematical formulation of the second law is shown to the right, with **F** representing the force, *m* representing the object's mass and **a** representing the object's acceleration.

This formula is extremely useful in classical mechanics, as it provides a means of translating directly between the acceleration of and force acting upon a given mass. A large portion of classical mechanics ultimately breaks down to applying this formula in different contexts.

The sigma symbol to the left of the force indicates that it is the net force, or the sum of all the forces, that we are interested in.

As [vector quantities](), the direction of the net force will also be the same direction as the acceleration. You can also break the equation down into *x* & *y* (and even *z*) coordinates, which can make many elaborate problems more manageable, especially if you orient your coordinate system properly.

You'll note that when the net forces on an object sum up to zero, we achieve the state defined in Newton's First Law - the net acceleration must be zero. We know this because all object have mass (in classical mechanics, at least). If the object is already moving it will continue to move at a constant velocity, but that velocity will not change until a net force is introduced. Obviously, an object at rest will not move at all without a net force.

The Second Law in Action

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A box with a mass of 40 kg sits at rest on a frictionless
tile floor. With your foot, you apply a 20 N force in a
horizontal direction. What is the acceleration of the box?
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The object is at rest, so there is no net force except for the force your foot is applying. Friction is eliminated. Also, there's only one direction of force to worry about. So this problem is very straightforward.

You begin the problem by defining your coordinate system. In this case, that's easy - the +*x* direction will be the direction of the force (and, therefore, the direction of the acceleration). The mathematics is similarly straightforward:

$$\boldsymbol{F} = m * \boldsymbol{a}$$

$$\boldsymbol{F} / m = \boldsymbol{a}$$

$$20 \text{ N} / 40 \text{ kg} = \boldsymbol{a} = 0.5 \text{ m} / \text{s}^2$$

The problems based on this law are literally endless, using the formula to determine any of the three values when you are given the other two. As systems become more complex, you will learn to apply frictional forces, gravity, electromagnetic forces, and other applicable forces to the same basic formula.

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We represent the Third Law by looking at two bodies *A* and *B* that are interacting. We define F_A as the force applied to body *A* by body *B* and F_A as the force applied to body *B* by body *A*. These forces will be equal in magnitude and opposite in direction. In mathematical terms, it is expressed as:

$$\boldsymbol{F_B} = - \boldsymbol{F_A}$$

or

$$\boldsymbol{F_A} + \boldsymbol{F_B} = 0$$

This is not the same thing as having a net force of zero, however.

If you apply a force to an empty shoebox sitting on a table, the shoebox applies an equal force back on you. This doesn't sound right at first - you're obviously pushing on the box, and it is obviously *not* pushing on you. But remember that, according to the Second Law, force and acceleration are related - but they aren't identical!

Because your mass is much larger than the mass of the shoebox, the force you exert causes it to accelerate away from you and the force it exerts on you wouldn't cause much acceleration at all.

Not only that, but while it's pushing on the tip of your finger, your finger in turn pushes back into your body, and the rest of your body pushes back against the finger, and your body in turn pushes on the chair or floor (or both), all of which keeps your body from moving and allows you to keep your finger moving to continue the force. There's nothing pushing back on the shoebox to stop it from moving.

If, however, the shoebox is sitting next to a wall and you push it toward the wall, the shoebox will push on the wall - and the wall will push back. The shoebox will, at this point, stop moving. You can try to push it harder, but the box will break before it goes through the wall because it isn't strong enough to handle that much force.

Tug of War: Newton's Laws in Action

Most people have played tug of war at some point. A person or group of people grab the ends of a rope and try to pull the person or group at the other end, usually past some marker (sometimes into a mud pit in really fun versions), thus proving that one of the groups is stronger. All three of Newton's Laws can be seen very obviously in tug of war.

There frequently comes a point in tug of war - sometimes right at the beginning but sometimes later - where neither side is moving. Both sides are pulling with the same force and therefore the rope does not accelerate in either direction. This is a classic example of Newton's First Law.

Once a net force is applied, such as when one group begins pulling a bit harder than the other, an acceleration begins, and this follows the Second Law. The group losing ground must then try to exert *more* force. When the net force begins going in their direction, the acceleration is in their direction. The movement of the rope slows down until it stops and, if they maintain a higher net force, it begins moving back in their direction.

The Third Law is a lot less visible, but it's still there. When you pull on that rope, you can feel that the rope is also pulling on you, trying to move you toward the other end. You plant your feet firmly in the ground, and the ground actually pushes back on you, helping you to resist the pull of the rope.

Next time you play or watch a game of tug of war - or any sport, for that matter - think about all the forces and accelerations at work. It's truly impressive to realize that you could, if you worked at it, understand the physical laws that are operating in your favorite sport.