Newton’s Laws of Motion

Physicists now realize that everything in the universe operates in a well ordered fashion, and it’s possible to discover mathematical laws to help describe the properties and behaviors of things.

Isaac Newton’s development of his Three Laws of Motion constituted a major step forward in the understanding of nature. We’ll go through them one by one.

Newton’s First Law of Motion

An object at rest will remain at rest, and an object in motion will remain in motion (moving at a constant speed & in a straight line) unless acted upon by a net outside force.

This means that nothing will change its speed and direction unless some other object forces it to. It’s a bit surprising to learn that when you slide a book across the table, it stops only because a force is exerted by the table (friction). Before Newton, people mostly thought that objects stop because it is in their nature to be at rest.

The phrase *net outside force* is important. *Outside* implies that an object cannot accelerate itself and the word *net* is there because objects can have more than one force on them. When a book sits on a table, there are two forces on it. Gravity pulls down and the table pushes up. The net force is zero and so the object remains at rest.

Newton’s Second Law of Motion

$$\vec{F} = m\vec{a}$$

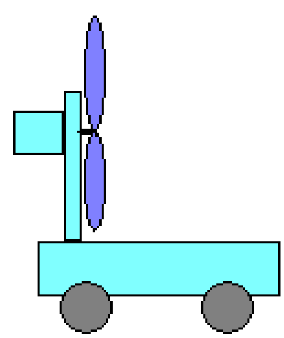
This law is the easiest of the three to state, and very useful. The first law says that nothing changes its speed and direction unless it’s acted upon, and this law describes the change when a force does act. In words, the law says when an object with mass m experiences a net force $\vec{F}$, it accelerates, and the acceleration is given by $\vec{a}$. The arrows over the F and the a indicate that these quantities, force and acceleration, have a particular direction in space. The acceleration, not surprisingly, will be in the same direction as the force.

Newton’s Third Law of Motion

If object A exerts a force on object B, then B simultaneously exerts an equal and opposite force on A.

By *opposite* we mean the opposite direction in space. This law is as important as the 2nd law, because it means that the both objects (the forced one & the forcing one) can accelerate.

Example 1



The figure shows a wheeled cart with a fan to drive it along. Newton’s 3rd Law tells us that the propeller pushing on the air will require that the air push back with an equal and opposite force, and so the cart accelerates as a result of this returned force.

Suppose that the cart has a mass of 500 grams (0.500 kg) and that the force is one third of a Newton. Newton's 2nd Law can be used to calculate the acceleration of the cart.

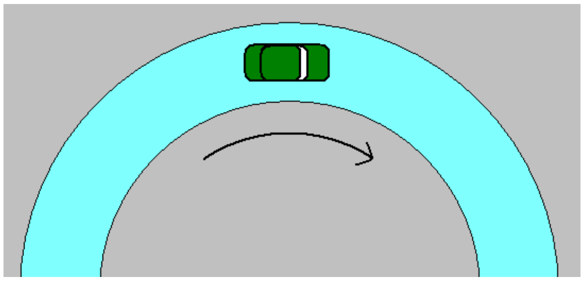
$$\vec{F} = m\vec{a}$$

$$⅓\, N\,\hat{\imath} = (0.500kg)\,\vec{a}$$

$$⅔\, m/s^2\ \hat{\imath} = \vec{a}$$

You might be wondering why the symbol î is in the expression. Remember that the arrows over the force and acceleration symbols indicate that there is a spatial direction associated with these quantities. The symbol î indicates a particular direction in space. It indicates the direction of a coordinate axis. When this kind of problem is done, one begins by defining a coordinate system in which to describe directions in space so that these directional quantities can be analyzed. So you can see that since the force was in this direction, so is the resulting acceleration.

Example 2



A car moves at 38 mph $(17\, m/s)$ around a circular curve whose radius is 105 ft $(32\, m)$. It weighs 1907 lbs $(865\, kg)$. Friction with the road must exert a sideways force to turn the car toward the center of the circle, because according to Newton's 1st Law, the car will naturally travel in a straight line unless acted upon by a net force. What's the magnitude of that force?

In order to use Newton's 2nd Law of motion, we need to know the acceleration of the car. It's not something we've covered, but physicists know that if an object is traveling in a circular path, then it's accelerating toward the center of the circle and the magnitude of the acceleration is given by:

$$a = \frac{v^2}{R}$$

a is the acceleration, v is the speed, and R is the radius of the curve. So the acceleration in this case is:

$$a = \frac{(17\, m/s)^2}{32m}$$

$$a = 9.03\, m/s^2$$

Now we can use Newton's 2nd Law to find the friction force exerted by the road to keep the car on its course.

$$\vec{F} = m\vec{a}$$

$$\vec{F} = (865\, kg)(-9.03\, m/s^2\ \hat{r})$$

$$\vec{F} = -7810\, N\,\hat{r}$$

The symbol $\hat{r}$ means that the direction of the force is in the radial direction with the center of the circle as the center, and the negative sign means that the force is toward the center instead of outward.