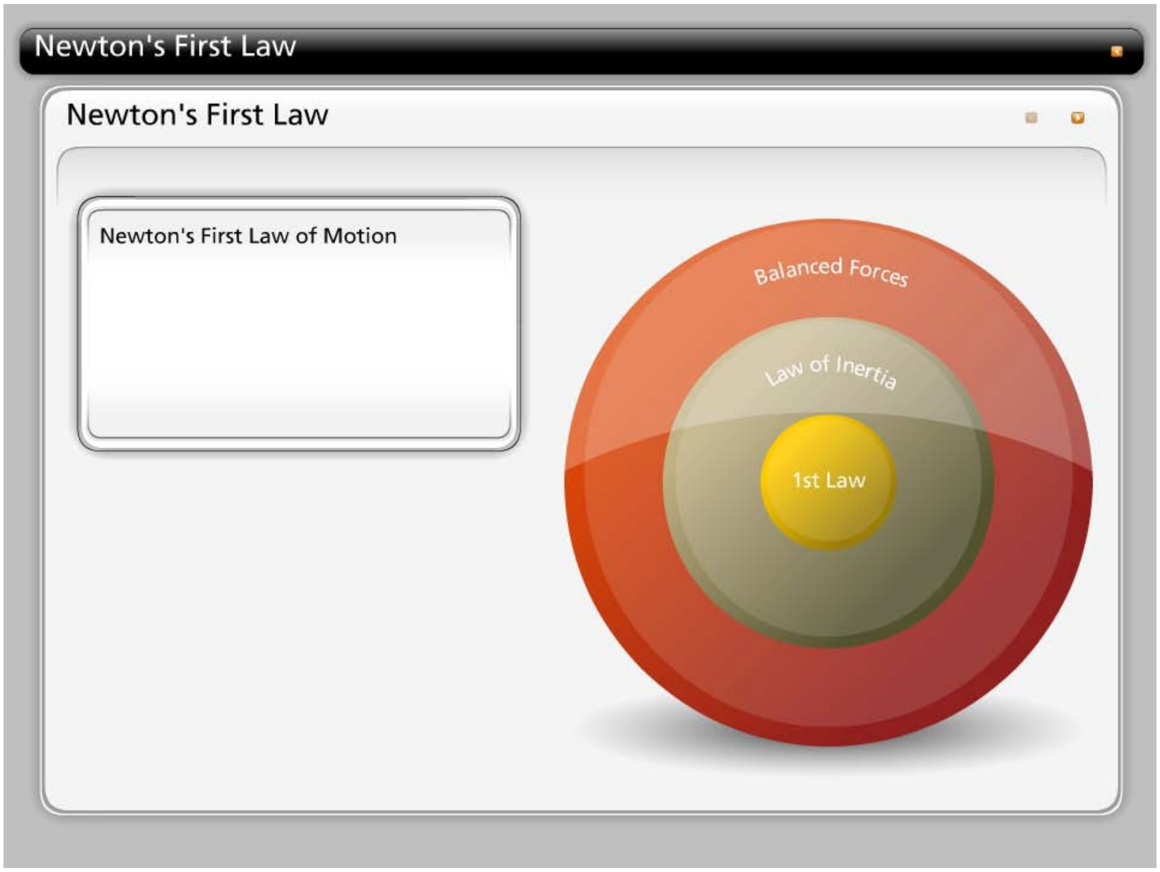
Module 2: Forces and Newton's Laws

Topic 2 Content: Newton's First Law Presentation Notes



Isaac Newton proposed several laws, among which are his famous laws of motion.

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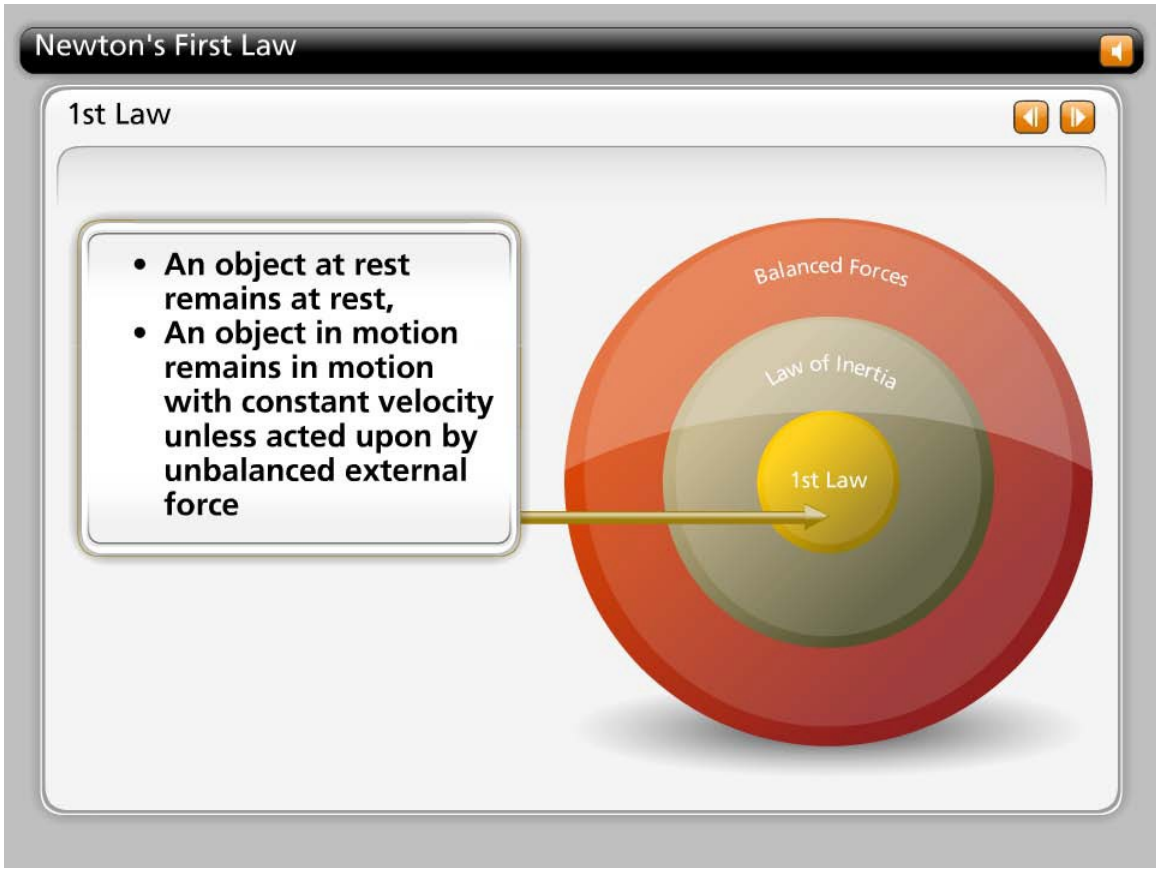

Newton's First Law has three parts to it. An object at rest will remain at rest, and an object in motion will remain in motion with constant velocity unless the object is acted upon by an unbalanced external force.

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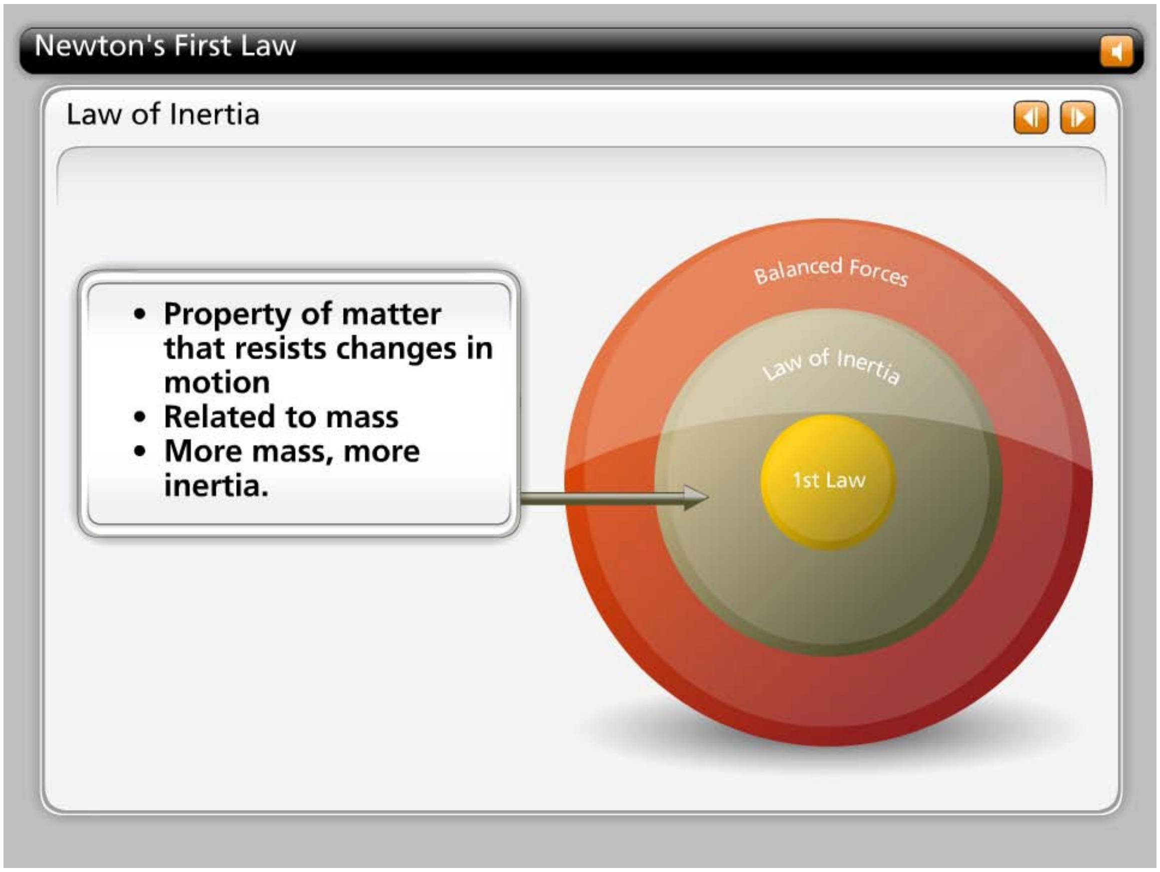

Notice that in this law, there is no concept about the natural state of an object being at rest. It is just as natural for an object in motion to remain in motion, as it is for objects at rest to remain at rest. What Newton set down in this law was the concept of objects changing motion due to unbalanced forces.

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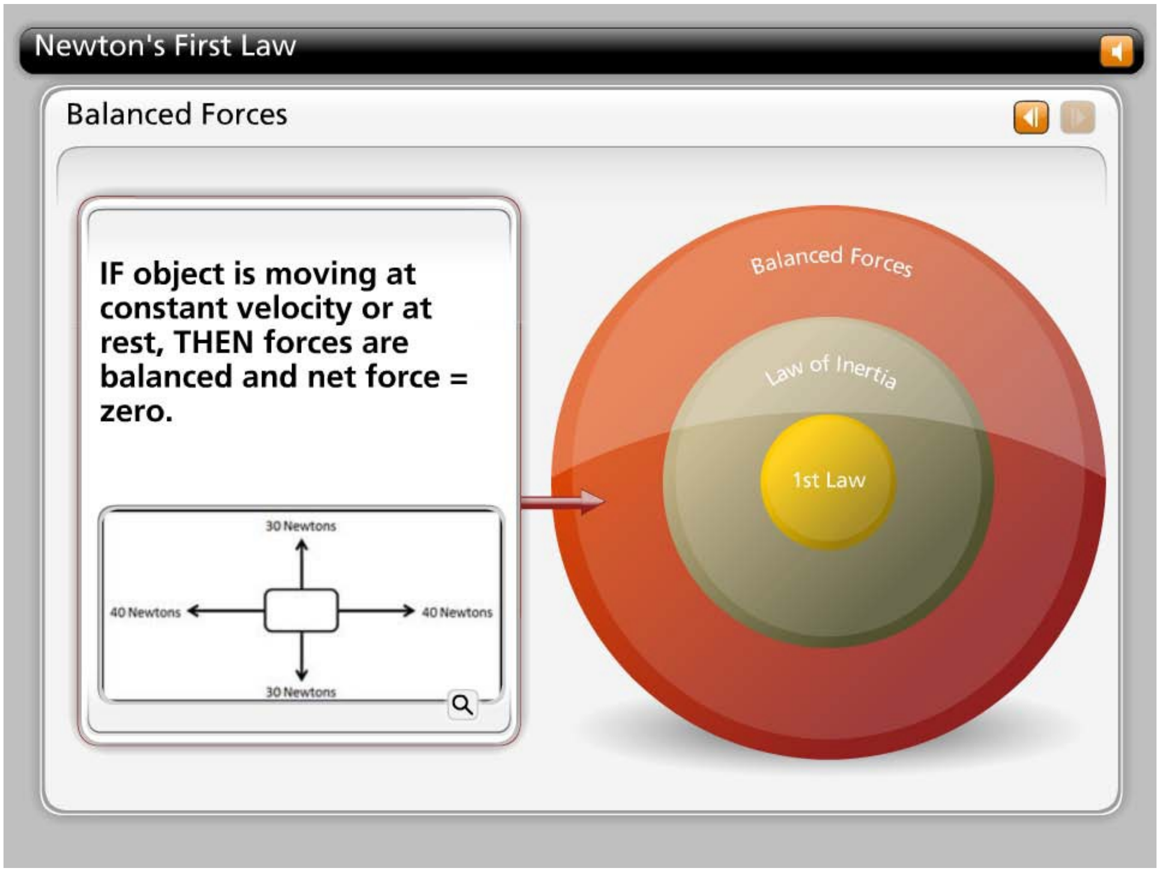

Earlier, you calculated the net force on objects in various situations. Newton's first law deals with situations in which the net force on the object is zero. When the net force is zero, we say that forces are balanced.

As you learned, the horizontal forces and the vertical forces must be considered separately, and each must balance out and net to zero in order to have zero net force overall.

It helps to think of Newton's first law in a different way. If an object is moving at a constant velocity or if an object is at rest, then we know the forces on the object must balance and the net force must be zero.

We can use this concept to solve a variety of problems in physics, when objects are either at rest or moving at a constant velocity.

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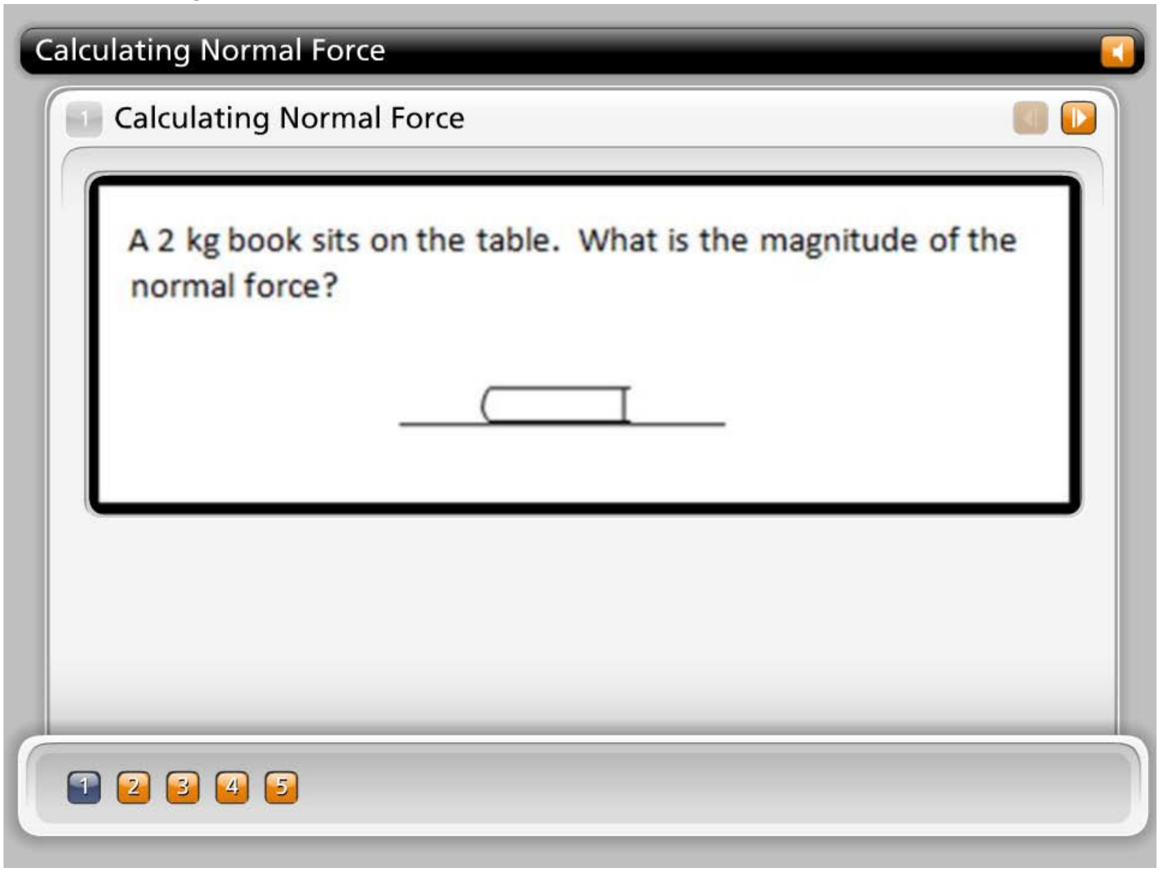

We can use Newton's first law to better understand the normal force, which we introduced in an earlier lesson.

To see how Newton's first law helps us, let's look at an example of a 2 kilogram book sitting on the table. How are we going to determine the magnitude of the normal force?

First, we have to recognize that the book is at rest. Newton's first law tells us that if the book is at rest, then all forces acting on the book must add to a net force of zero, both in the vertical and in the horizontal direction.

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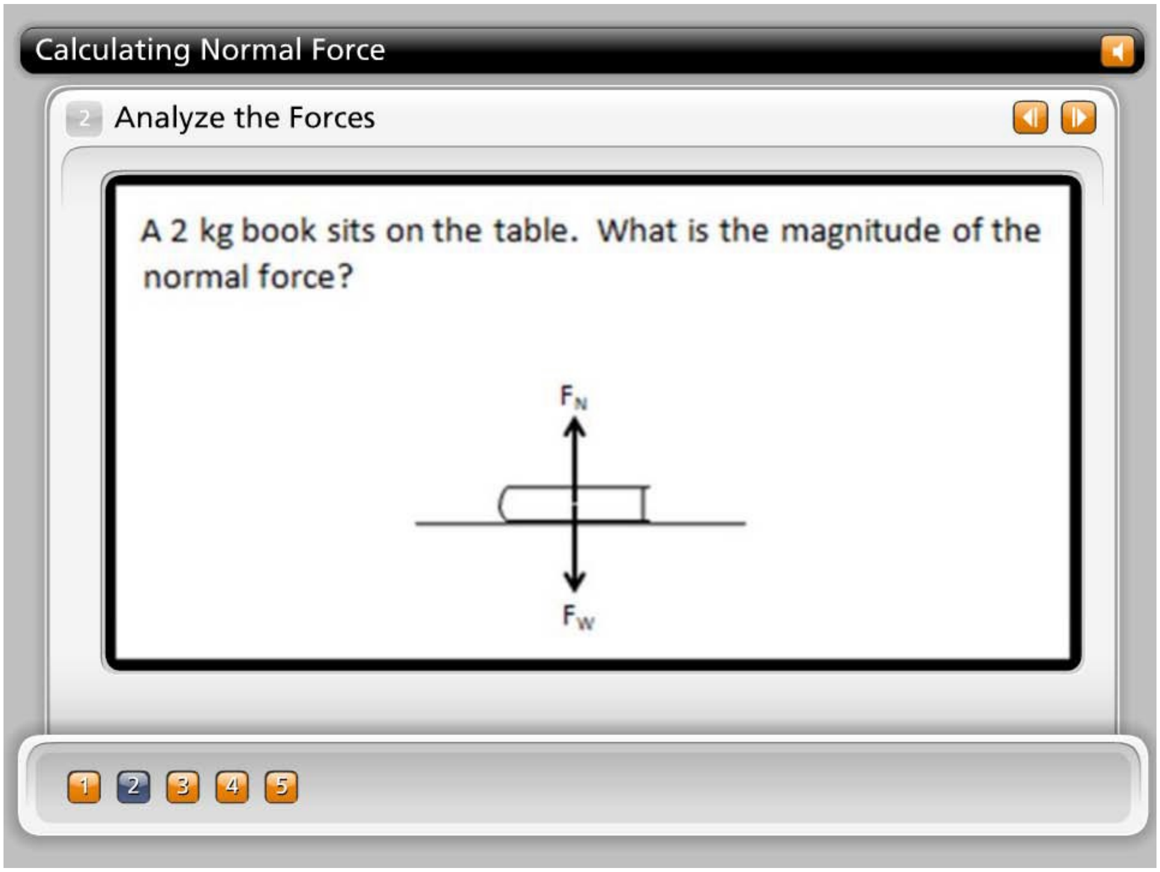
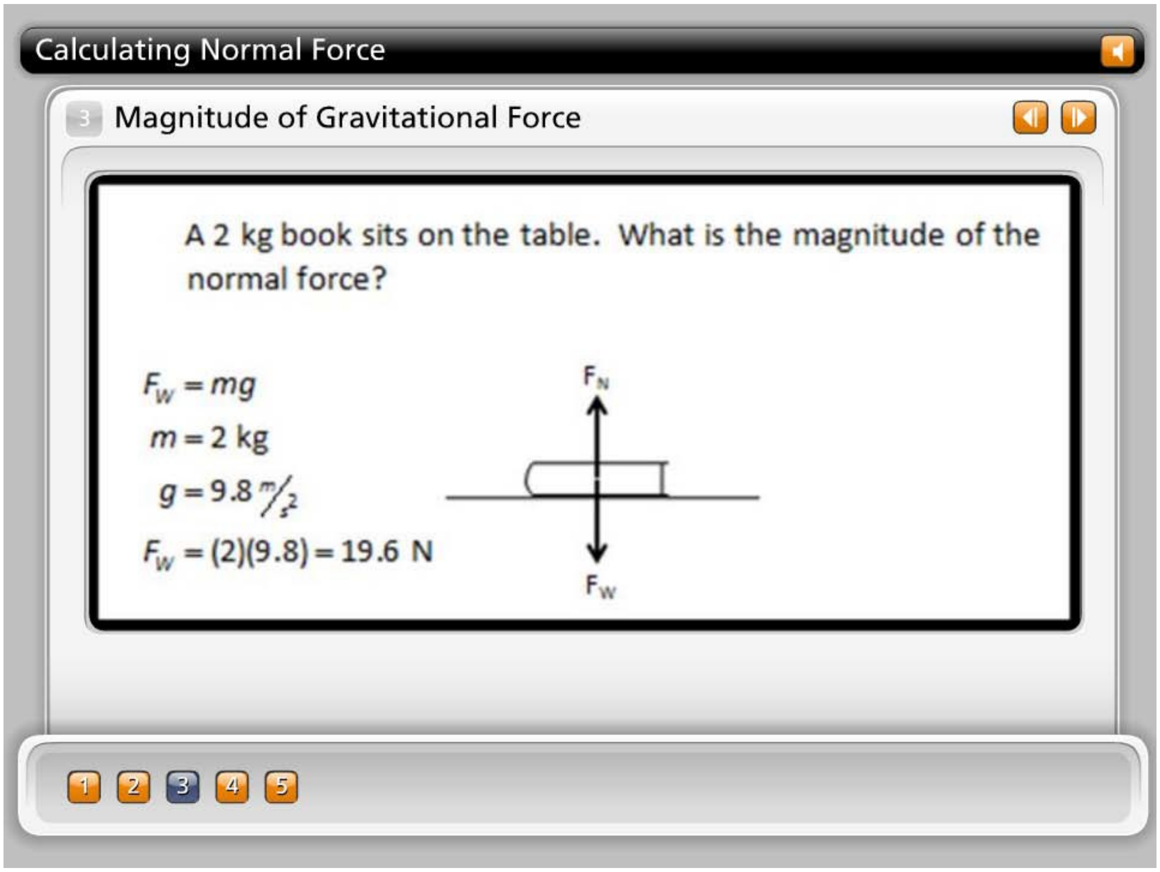


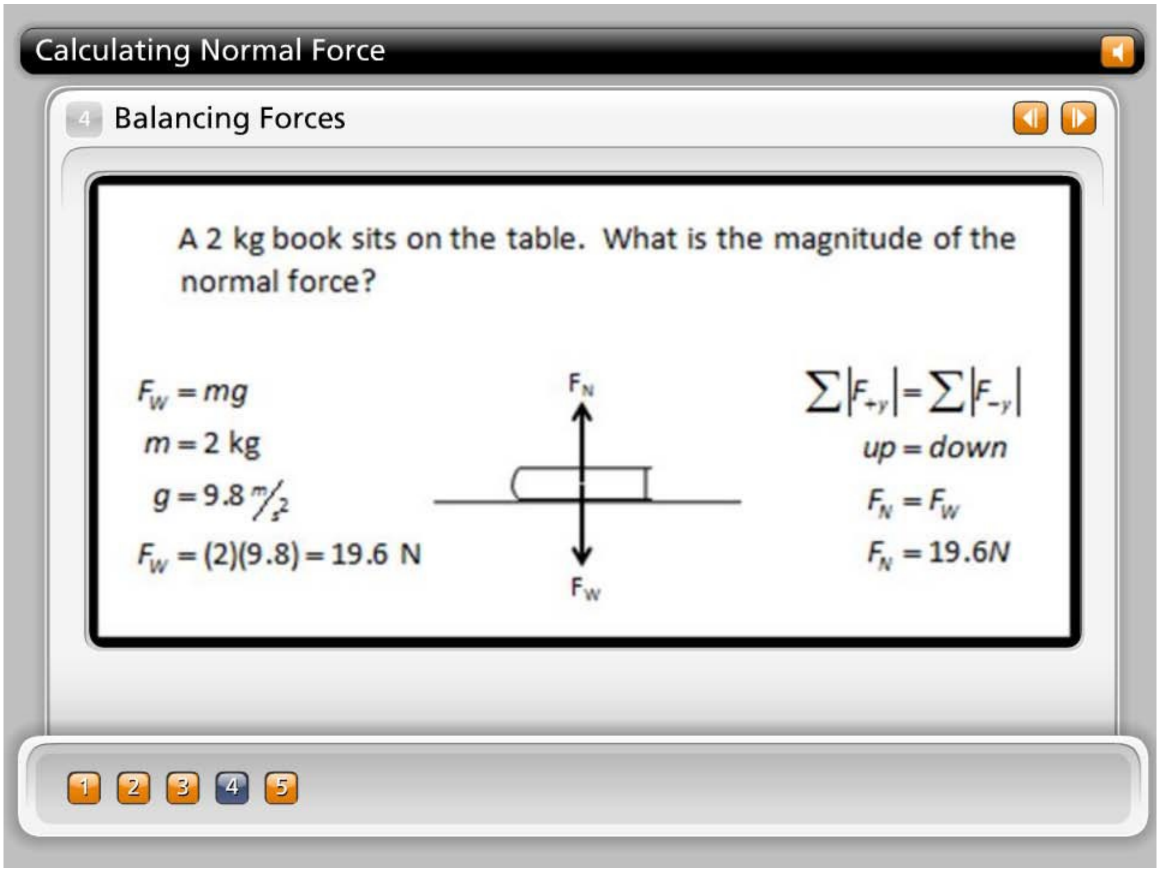
In order to properly analyze the forces, we should draw a free body diagram that includes all the forces that act on the book.

We know that the gravitational force will pull the book directly down toward the center of the earth, so we draw an arrow pointing down and label it F W. Since the object is resting on the surface of the table, there is also a normal force directed out of the table. We draw this arrow perpendicular to the table and label it F N.

There are no additional forces acting on the book so we have completed our free body diagram.



Now, we can begin to analyze the magnitudes of these forces. The magnitude of the gravitational force, F w, will be equal to the mass of the book times the acceleration of gravity. Two kilograms times nine point eight meters per second squared equals nineteen point six Newtons.



Since we only have two forces, directed in opposite directions, they must be of the same magnitude in order for the net force to be zero.

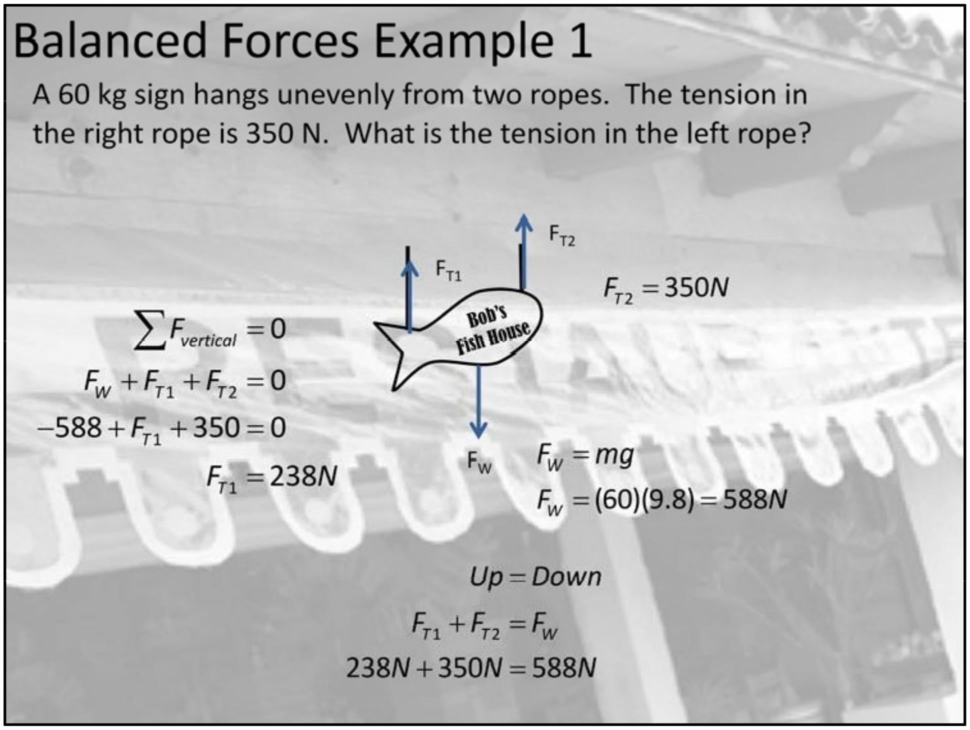
In general, when forces are balanced, the sum of the magnitudes of the forces in the positive y direction equals the sum of the magnitudes of the forces in the negative y direction. But it is easier to simply say "up equals down".

In the up direction, we have the normal force. In the down direction, we have the gravitational force. So we can write F N equals F W. Since we're considering only magnitudes, we plug in the absolute value of the gravitational force when we substitute.

So the normal force in this case must also be nineteen point six Newtons.

If we were paying attention to the direction of the forces and not just the magnitudes, we'd instead say F N plus F W equals zero, since the normal force would be in a positive direction and the gravitational force would be in a negative direction.

Another way to analyze this is by paying attention to the direction of the forces and not just the magnitudes. In this case, we'd say that the sum of the forces acting in the vertical direction equals zero, so F W plus F N equals zero. Here we'd have to include the negative sign to indicate that the gravitational force is directed down, and we'd see that the resulting normal force has a positive value, indicating that it is directed up.



As another example, let's consider a 60 kg sign hanging unevenly from two ropes. If the tension in the right rope is three hundred fifty Newtons, what is the tension in the left rope?

The first step is to draw a free body diagram to identify all the forces acting on the sign.

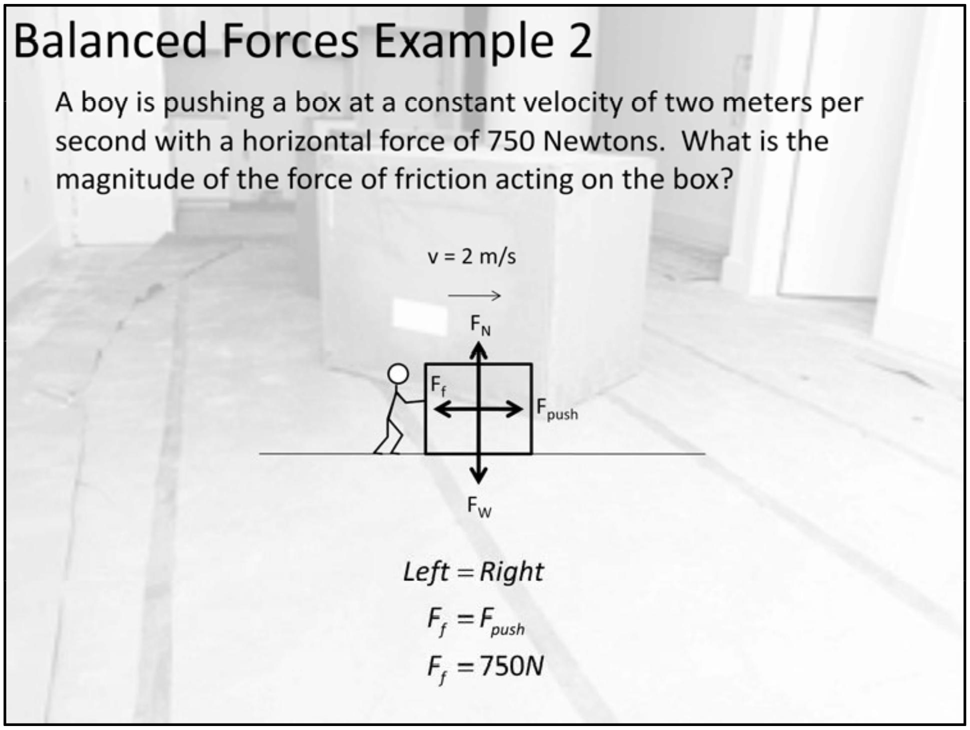
The force of gravity will be pulling straight down, so we draw an arrow down from the sign and label it F W.

There are two other forces acting on the sign. Each rope pulls up on the sign with a force of tension. So we will draw two arrows pointing upward and label them F T one and F T two.

We know the magnitude of the tension in the right rope, F T two, is equal to 350 Newtons. We also can easily calculate the gravitational force, knowing that the weight of the sign is its mass times the acceleration of gravity. The force of gravity on the sign is equal to five hundred eighty eight Newtons directed in a negative direction.

Since the sign is at rest, we can apply Newton's first law and state that the net force on the sign, or the sum of the forces acting on the sign, must equal zero.

All of our forces are in a vertical direction, up or down, so we can write that the sum of the forces in the vertical direction equals zero.



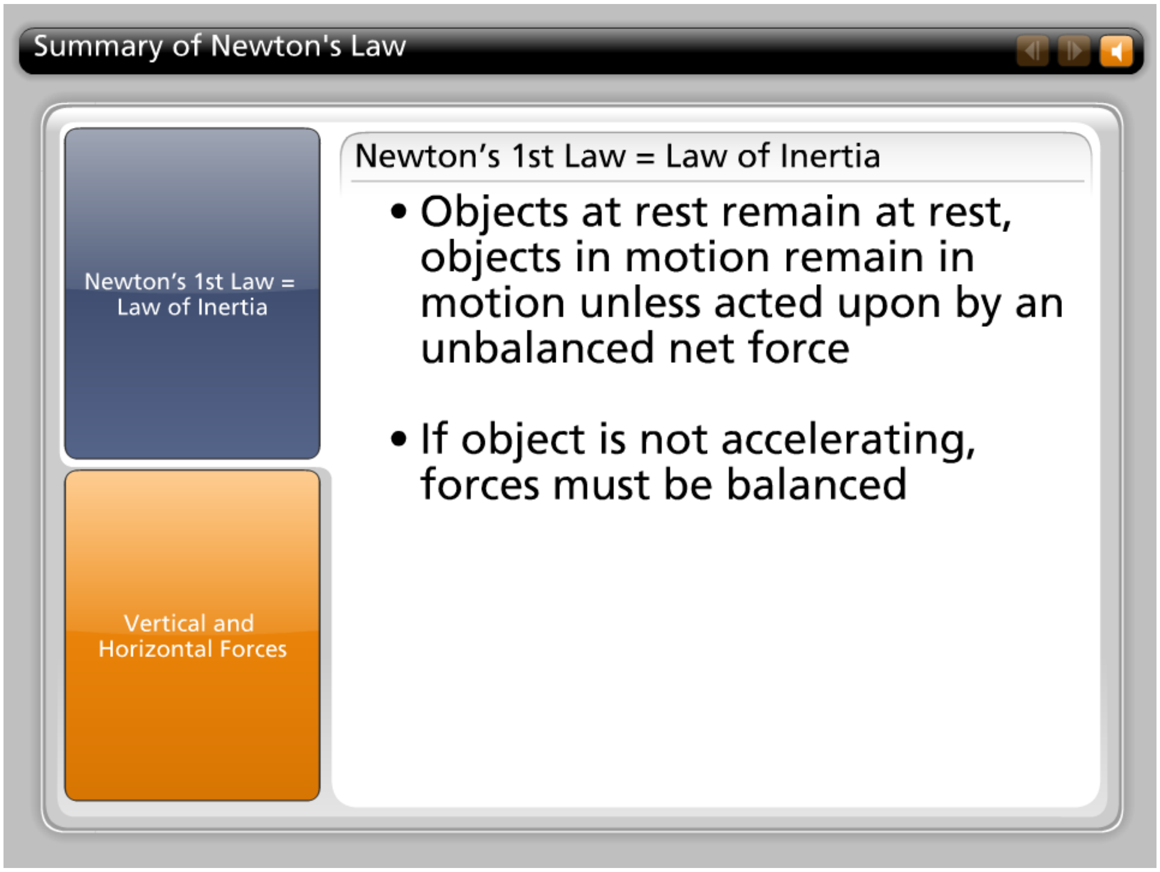
Now let's take a look at an object in motion. A boy is pushing a box at a constant velocity of two meters per second while applying a horizontal force of seven hundred fifty Newtons. What is the magnitude of the force of friction acting on the box?

As usual, our first step is to draw a free body diagram so that we can identify the forces acting on the box. In this case, we have gravity acting down and the normal force acting perpendicular to the surface. We also have the boy pushing with an applied force, which we write as F push and draw with an arrow to the right. Since the box is sliding to the right, the force of friction is directed to the left, which we label with F f.

Since the box is moving with a constant velocity, the net force on the box must be zero. This means that the vertical forces must add to zero and the horizontal forces must also add to zero.

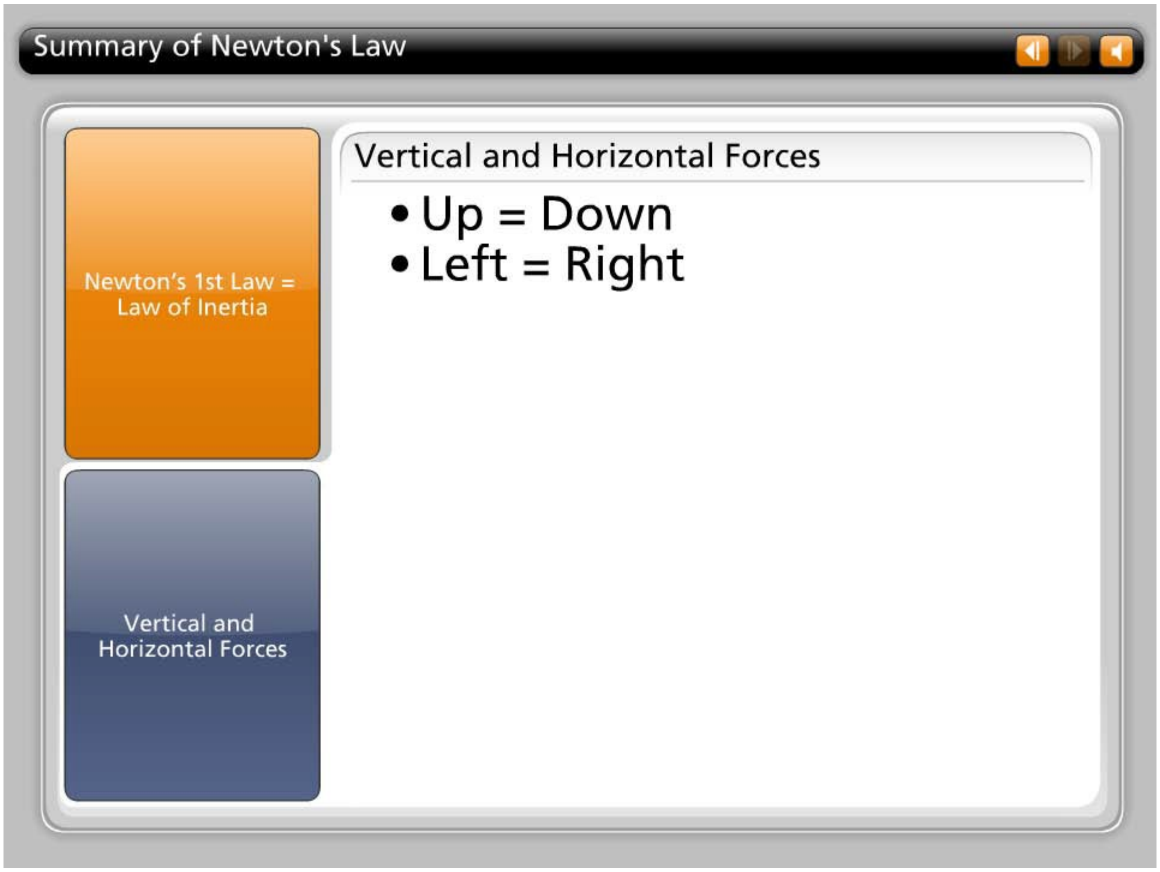
In the vertical direction, we have the gravitational force and the normal force. In the horizontal direction, we've got the applied force and the force of friction. Since we're interested in the force of friction, we'll only look at the horizontal forces.

To the left, we have the force of friction, and to the right is the applied force, or the push force. The magnitudes of these two must be equal. So the force of friction must be seven hundred fifty Newtons.



In summary, Newton's First Law, also known as the law of inertia states that objects at rest will remain at rest, and objects in motion will remain in motion unless acted upon by an unbalanced net force.

We may restate this to say that if an object is not accelerating, meaning it is at rest or moving with a constant velocity, then we know that the forces on the object must be balanced and the net force is zero.



When we have an equilibrium situation of balanced forces, we know that the magnitude of the sum of the forces up equals the magnitude of the sum of the forces down, or "up equals down"and the magnitude of the sum of the forces left equals the magnitude of the sum of the forces right, or "left equals right". The whole UP=DOWN and LEFT=RIGHT is more aptly equal and opposite - only the absolute values of the magnitudes are mathematically equal.

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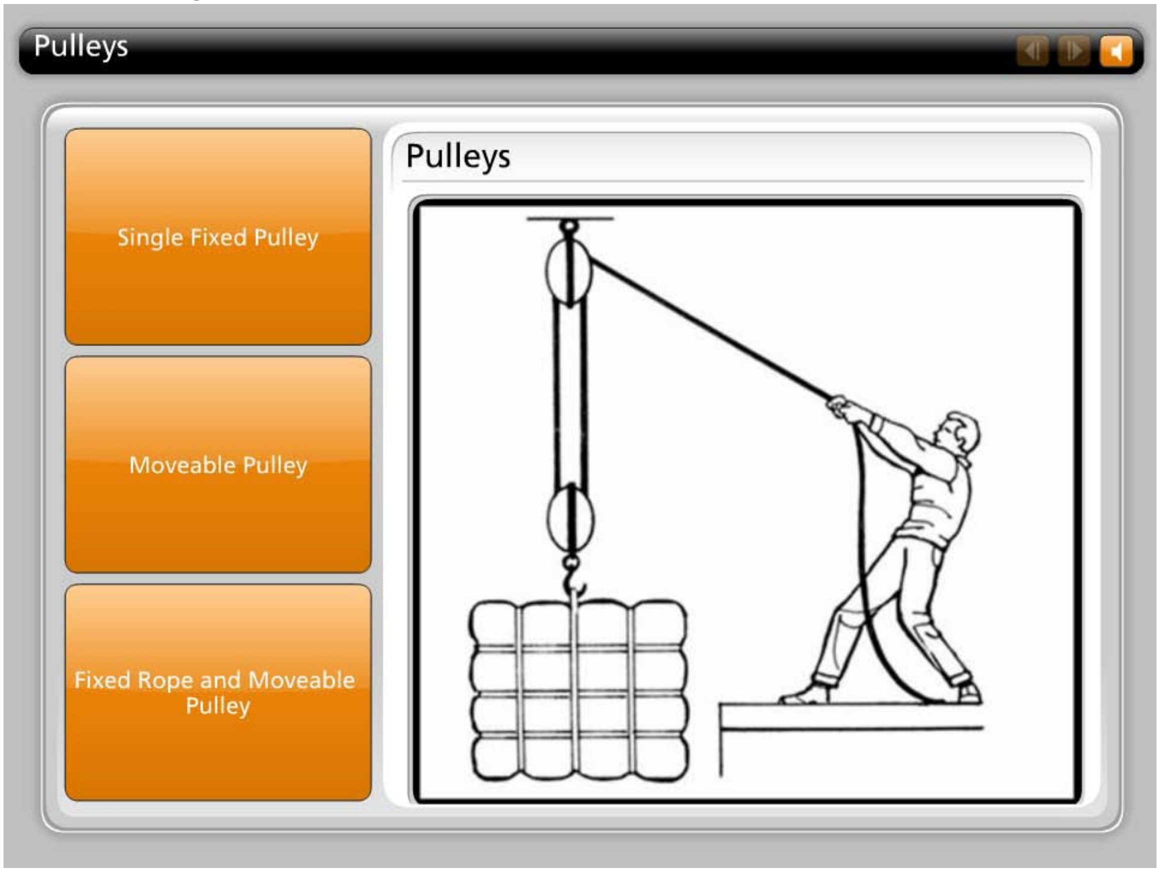

One application of Newton's First Law is in helping us to understand the workings of pulleys. We have all either used pulleys or seen them being put to use. But what makes pulleys so useful? In order to analyze pulleys using Newton's First Law, we first have to remember that ideal pulleys change the direction of the tension in a rope, without changing the magnitude. So the tension in a single rope is the same everywhere.

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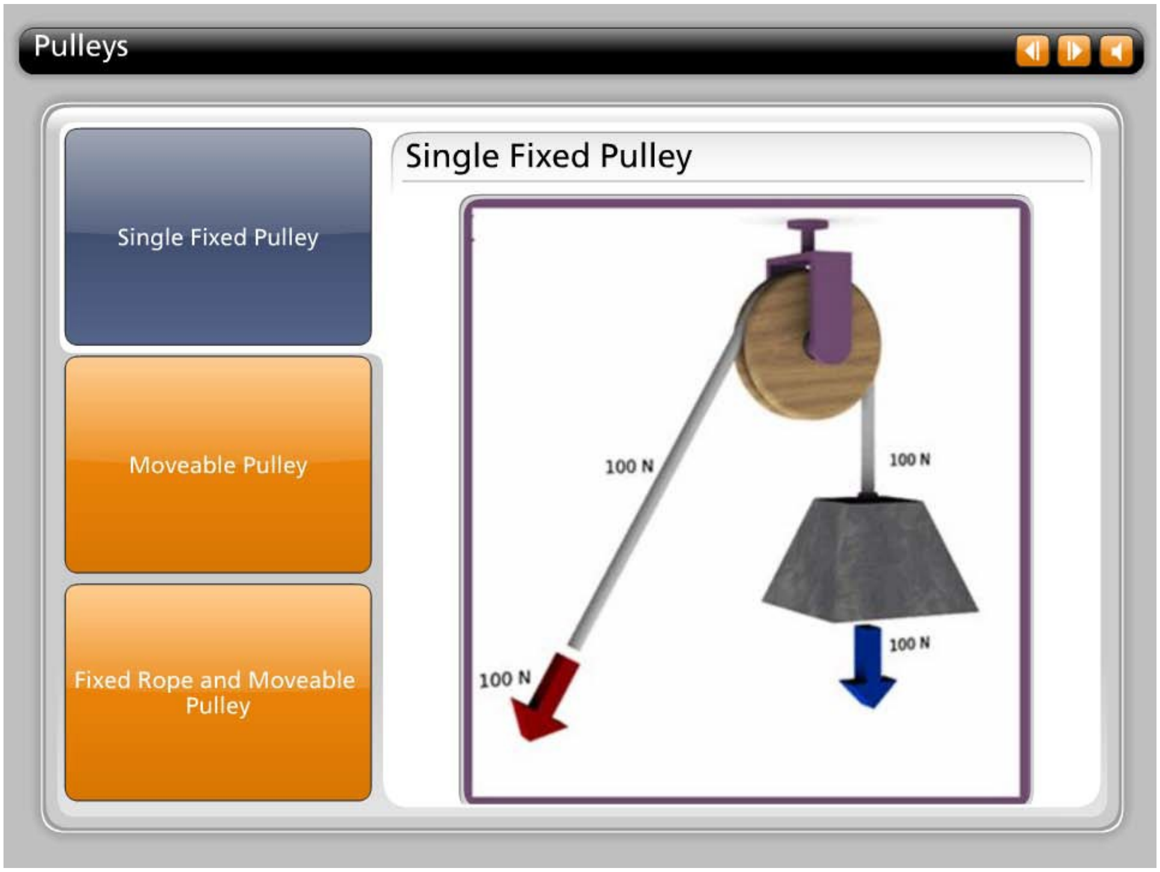

Let's start with a single, fixed pulley hanging from the ceiling. One end of the rope supports a mass weighing one hundred Newtons. How much force must be exerted on the end of the rope to keep the mass at rest?

Since the mass is at rest, we know that the forces on it are balanced. The only forces acting on the mass are the gravitational force down and the tension in the rope pulling upwards. Since forces are balanced, we can say the phrase "up equals down" and determine that the force of tension must also equal one hundred Newtons.

Now, we come to the pulley. Since the pulley merely changes the direction of the tension in the rope, we know that on the other side of the pulley, there must also be a tension of one hundred Newtons.

So, the force applied to the end of the rope in order to keep the mass in place must also be one hundred Newtons.

You should recognize that the analysis would be exactly the same if the mass had been being pulled up at a constant velocity, as forces would also be balanced in that case.

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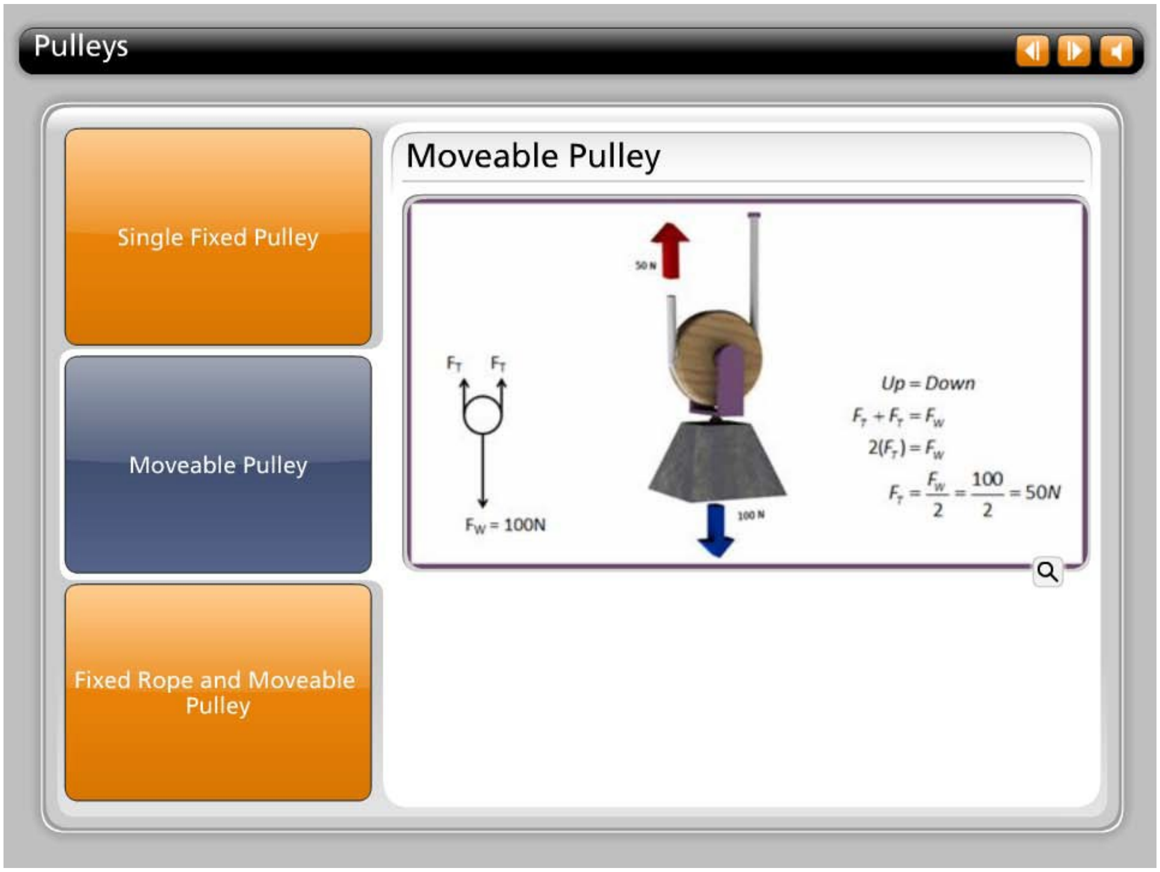

Next we will look at a moveable pulley. Here, one end of the rope is attached to the ceiling. The rope continues around a pulley attached to the top of a mass with a weight of one hundred Newtons. What force must be applied to the end of the rope to maintain the system at equilibrium?

In this example, to simplify our analysis, we will assume that the pulley's mass is small enough that it doesn't need to be included in the calculations. Often in physics we will make use of ideal frictionless, massless ropes and pulleys to make the analysis easier and focus on learning the concepts.

Here, it will be helpful to draw a free body diagram of the pulley. Beneath the pulley is a downward gravitational force of 100 Newtons. Pulling up on the pulley are two sections of rope, so we can add two upward tension forces to our free body diagram.

Now, we can apply Newton's first law by stating "up equals down" and writing an equation that applies this relationship.

In the up direction, we have the tension in the left rope and the tension in the right rope. In the down direction, we have the gravitational force. So we write F T plus F T equals F W. But we know that the tension in a rope is the same everywhere, so the tension in the left section equals the tension in the right section.

This leads us to conclude that two times the tension equals the gravitational force, or the tension equals half the gravitational force.

When we substitute and solve, we se that the tension in the rope is fifty Newtons.

As a general rule, when a weight is hanging from multiple strands of rope, the tension is divided evenly between the strands.

So if there were a set of pulleys arranged so that the string looped around such that five strands supported the one hundred Newtons, then the tension throughout the rope would be twenty Newtons.

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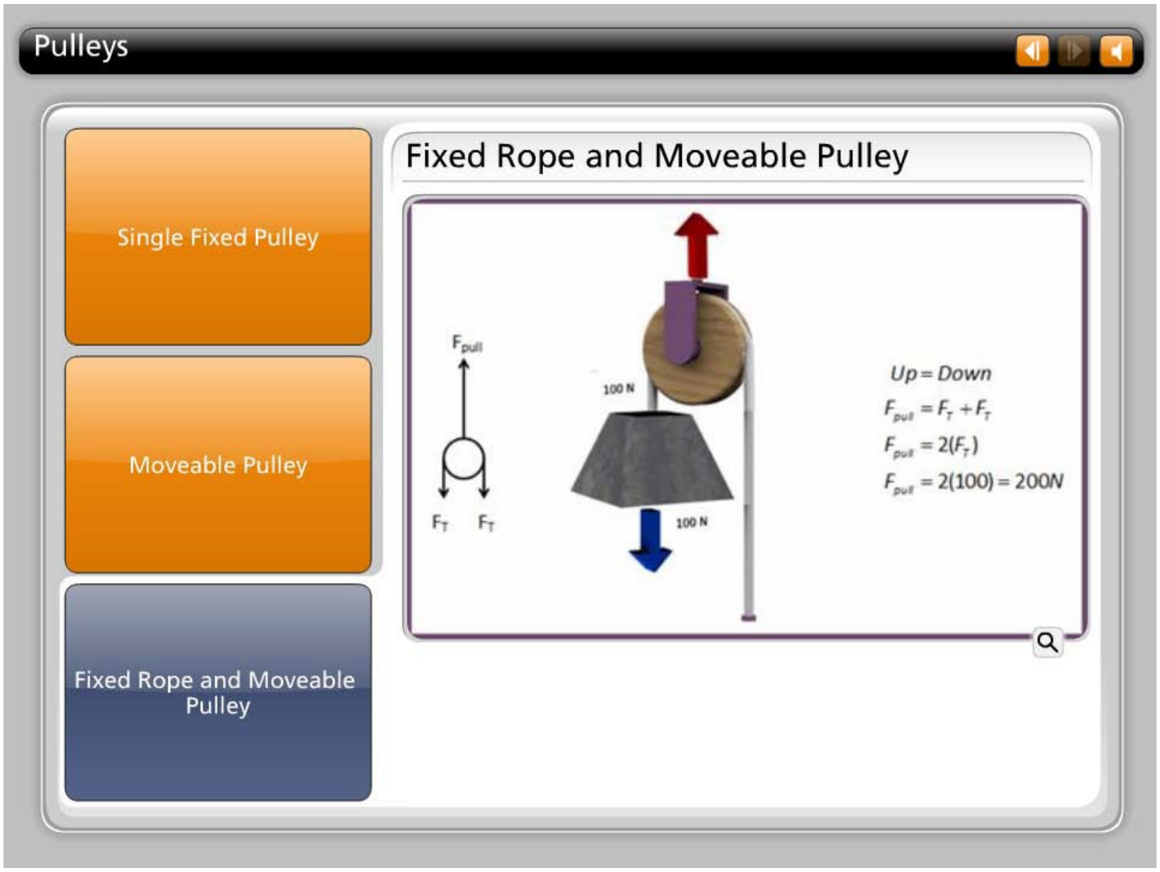

In this final example, we'll look at a situation where a rope is fixed to the floor, goes over a pulley and then attaches to a mass that again weighs one hundred Newtons. What force is required to lift the pulley?

We'll start by looking at the rope where it connects to the mass. A free body diagram would show two forces on the mass, the gravitational force down and the tension in the rope up. Newton's first law tells us that these are balanced, so the tension in the rope is also one hundred Newtons.

At this point, a free body diagram of the pulley would again be useful. In this case, there are two strands of rope extending down from the pulley, each with a tension, F T. Pulling up on the pulley is a single applied force.

Applying Newton's First Law again, we see that Up equals Down, so the applied force, F pull, is equal to the sum of the two tensions.

Since the tension in the rope is the same everywhere, it must be the case that each strand on the pulley pulls down with a force of one hundred Newtons. Therefore, the applied force must equal two hundred Newtons.