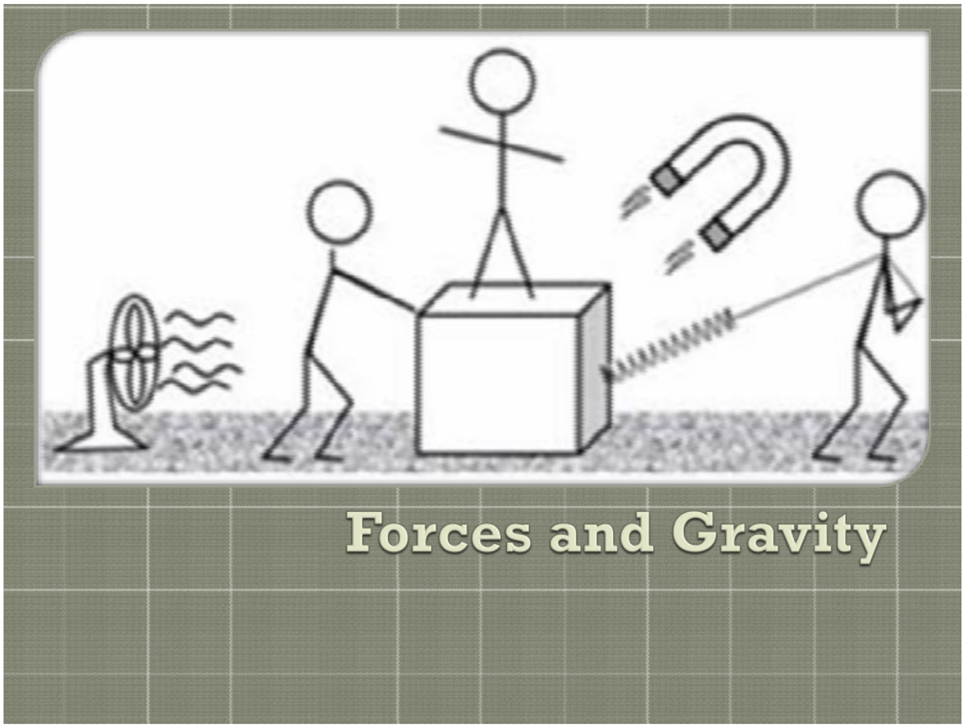
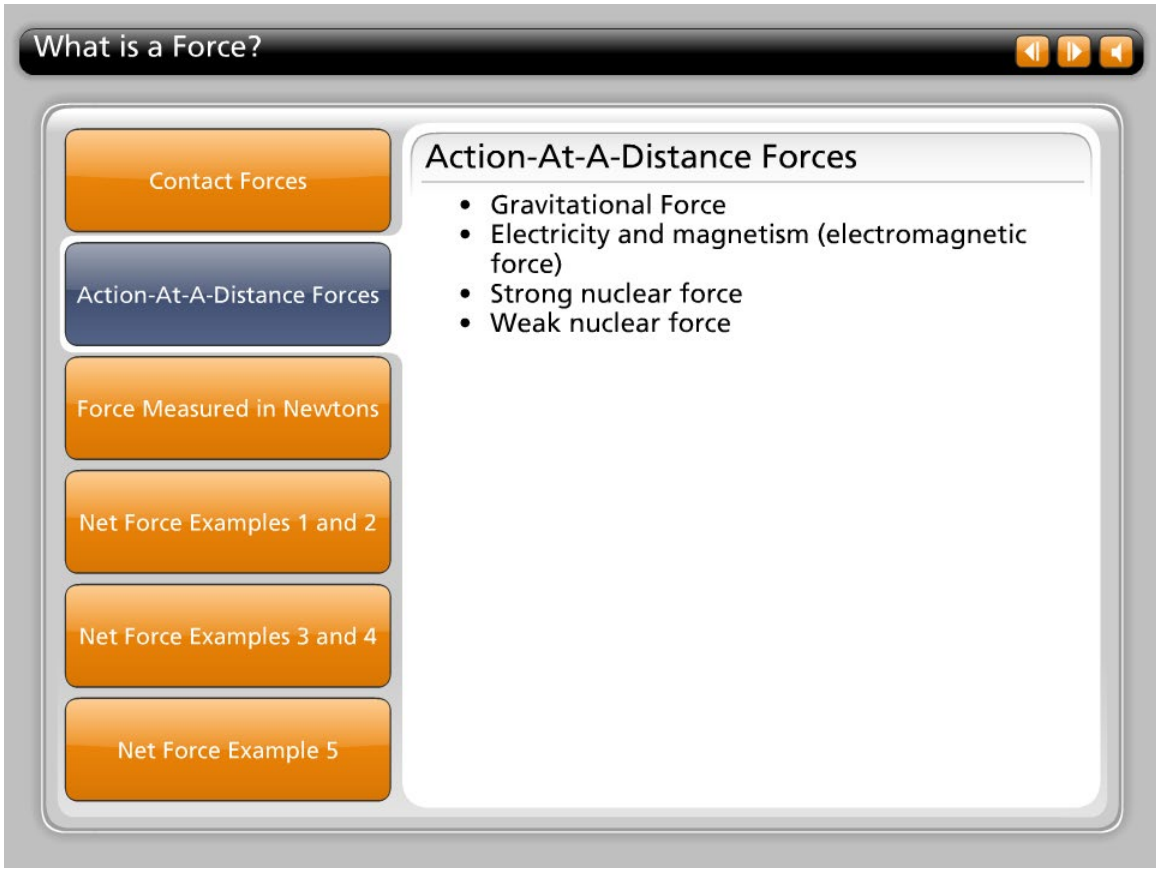
Module 2: Forces and Newton's Laws
Topic 1 Content: Forces and Gravity

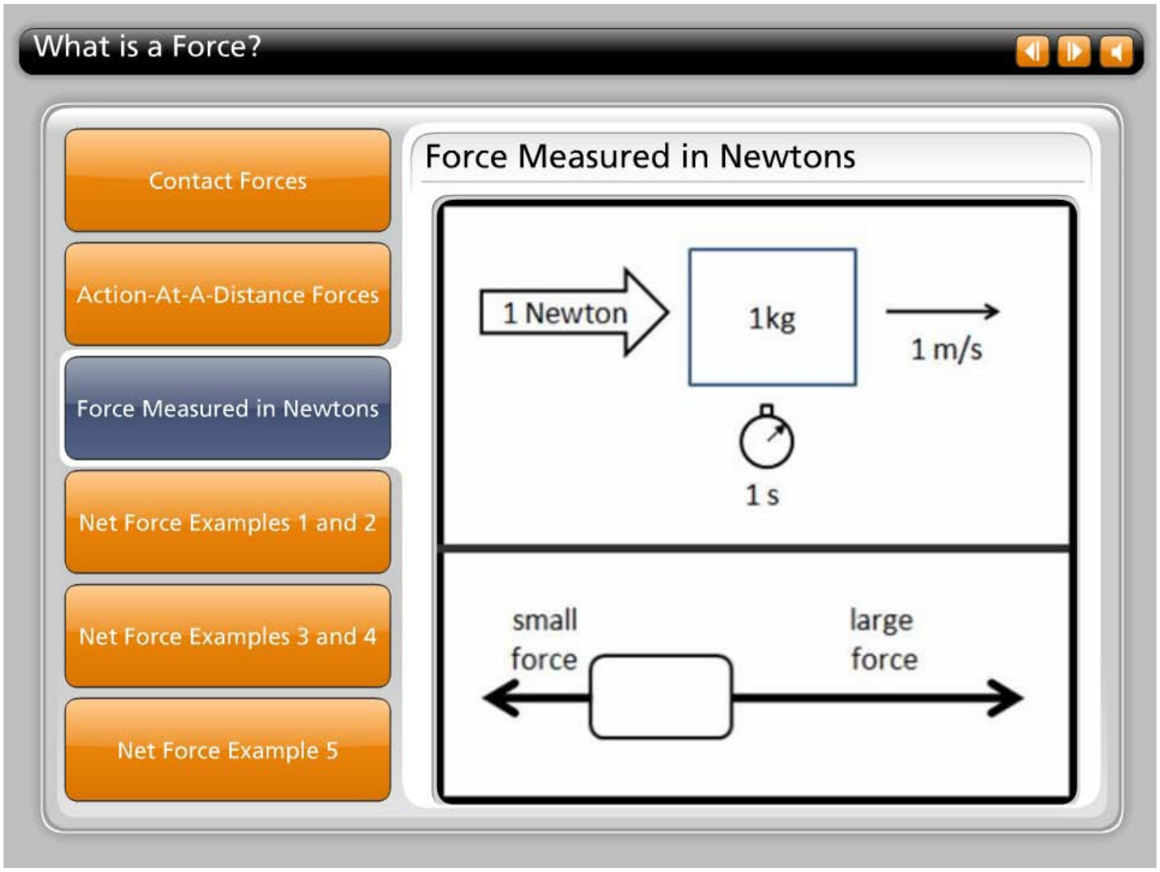


Have you ever heard anybody say that they were being pulled in several directions at the same time? If they said this in physics class, we'd immediately start thinking about forces. You've learned about describing motion in earlier lessons, but here we're going to focus on understanding why objects start in motion, remain in motion, accelerate and turn, and come to a stop. You'll discover that it's all due to the action of various types of forces. So what is a force? A force is anything that can push or pull - anything that can cause an object to change its motion. Forces come in two general categories, those that involve contact with the object, and those that can act at a distance.

Contact forces include actual pushes and pulls, which we call applied force. Examples of applied forces include tension in a rope, chain or cable; forces from surfaces in contact, such as friction and the normal force; the resistive forces that arise from moving through a medium such as air or water, and forces of stretching and compression. All of these only act while the object is in contact with whatever is supplying the force. As soon as contact stops, the force stops.



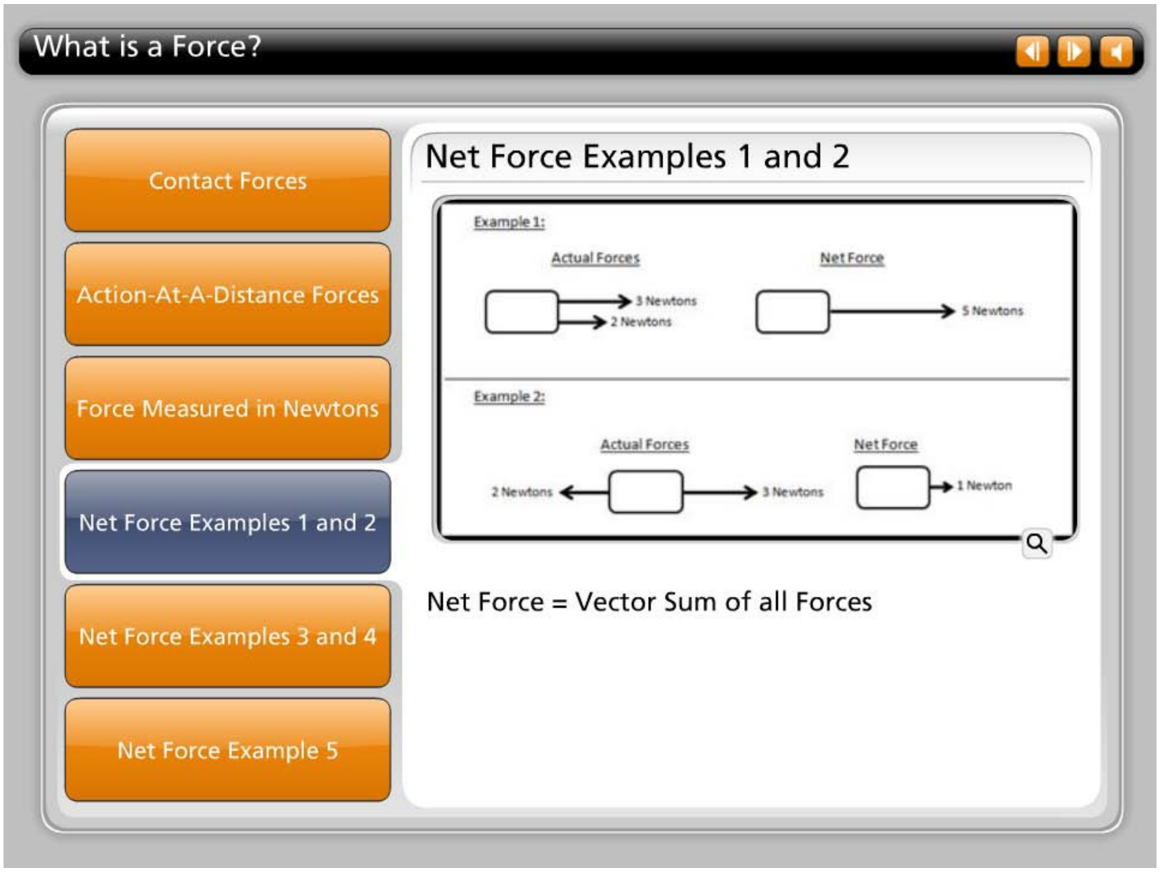
Such at-a-distance forces are gravity, with which we are already familiar; electricity and magnetism, which are actually two aspects of the same electromagnetic force; and two other forces that only act on the scale of the atomic nucleus. These two forces are the strong nuclear force and the weak nuclear force. In addition to gravity, these four forces comprise the fundamental forces of the standard model of physics. While this course defines the fundamental forces-at-a-distance, further study of this topic is beyond the scope of our introductory course.



The unit of force is the newton, named for Sir Isaac Newton. Newton's Principa, published in 1687, is considered by many to be the foundation of the study of physics.

If you apply a force of one Newton to a mass of one kilogram for one second, the mass will accelerate from rest to a speed of one meter per second.

Force is a vector quantity. We draw arrows representing forces pointing in the direction the force acts on the object. Generally, we try to draw longer arrows for larger forces and shorter arrows for smaller forces so that we can intuitively see what the effect of the force on the object may be.



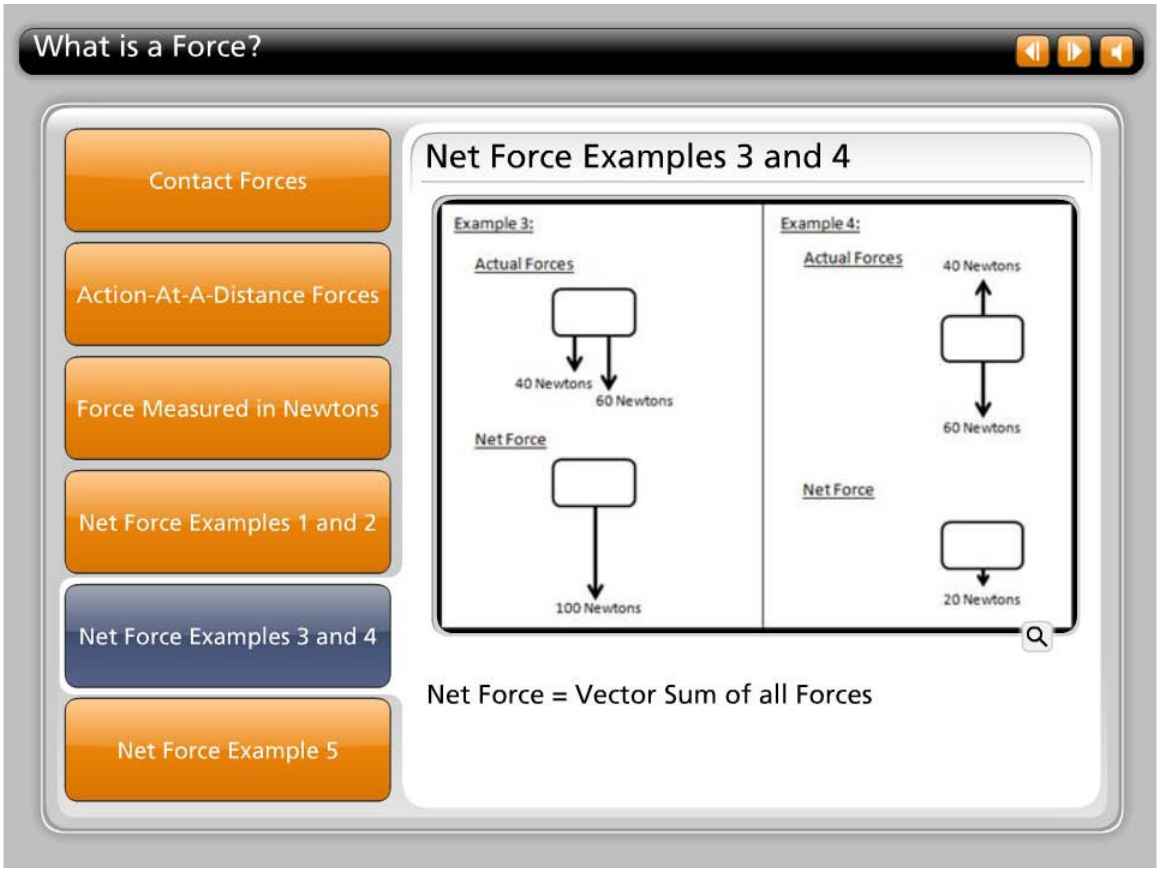
Just like other vector quantities, forces pointing in the same direction will add together, and those that point in opposite directions will subtract or even cancel out.

When all the forces acting on an object have been taken into account, the resulting force is called the net force on the object.

For example, if we had an object that had only two forces acting on it, the first being three Newtons and the second being two Newtons, both pulling it to the right, the net force would be three plus two or five Newtons to the right.

If, instead we had an object with three Newtons pulling it to the right, and two Newtons pulling it to the left, the net force would be three minus two or one Newton pulling to the right.

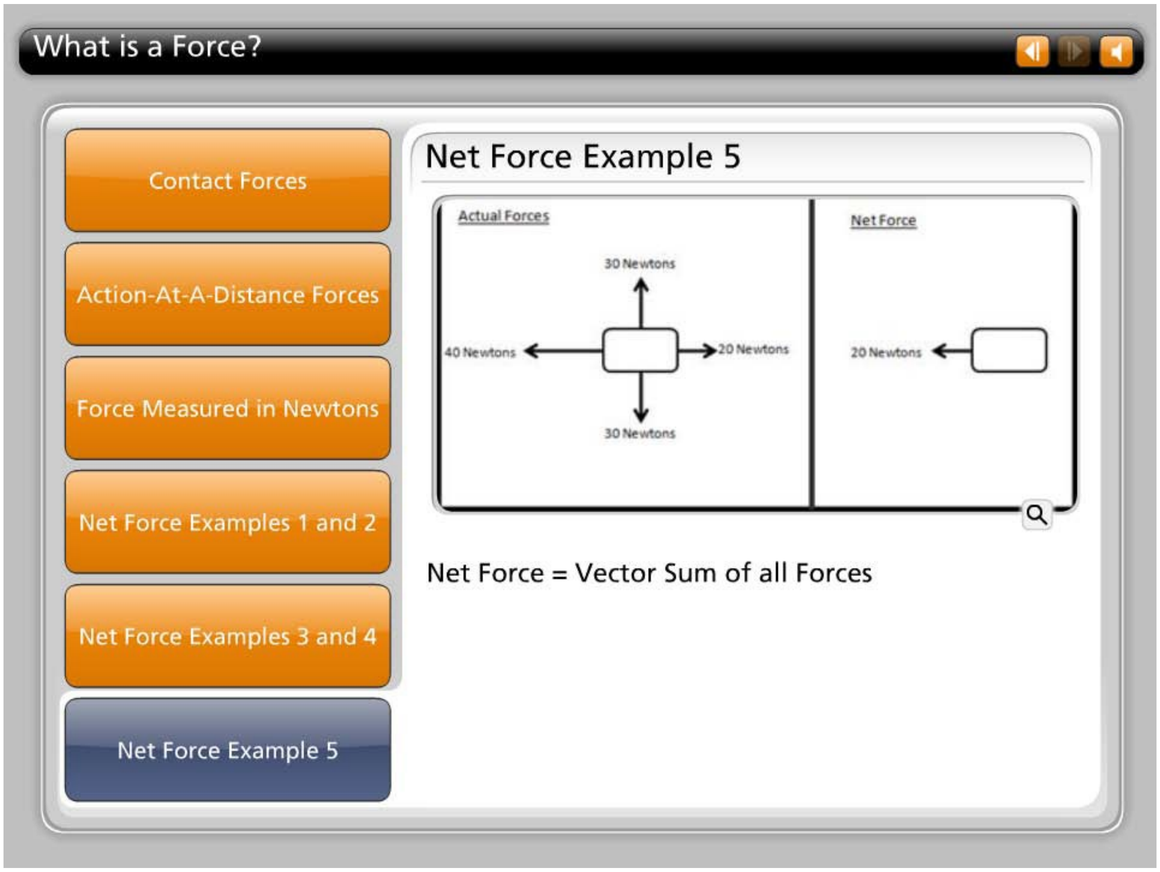
We use the same convention of direction with right as positive and left as negative.



The same is true if we're dealing with forces in the vertical direction.

If we had an object with two forces acting on it, one of forty Newtons and the other of sixty Newtons, both pointing down, the net force would be one hundred Newtons down.

If , however, the forces were pointing in opposite directions, with forty Newtons up and sixty Newtons down, then the net force would be twenty Newtons down.



What if there are forces acting in both the horizontal and vertical directions?

In this case, you deal with the horizontal direction independent from the vertical direction.

Vertically, the forces are thirty Newtons up and thirty Newtons down, which add to a net vertical force of zero Newtons.

The net force in the horizontal direction is twenty Newtons to the left. This ends up being the net force on the object.

When there is a net force in both the horizontal and vertical directions, or if there are forces that originate at an angle, then the problems become somewhat more complicated. We will deal with these situations later in the course, after you have mastered the basic concepts.

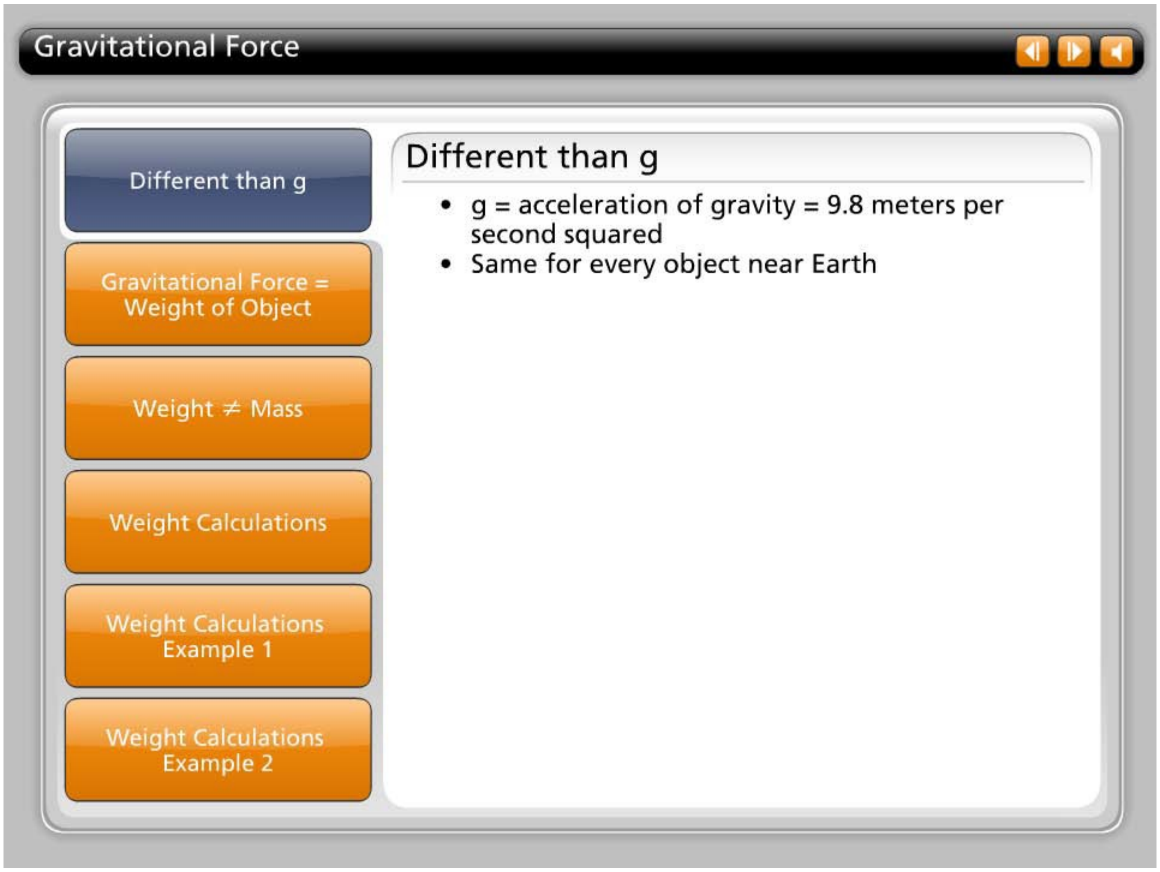
One of the forces that we must consider in almost every situation is gravitational force.

The gravitational force is an attractive force that acts between any two objects that have mass. The amount of force depends on product of the masses of the objects, so that if you increase the mass of either object, you increase the gravitational force between them. The reason you can feel yourself being pulled down towards the earth, and you can't feel yourself being pulled by gravity to the person next to you, is because the earth is so massive that it produces a measurable force, but the attractive force between you and your neighbor does exist, it is just immeasurably small.

Gravitational force also decreases with distance, which is why you feel the pull of Earth, but not the pull of the much more massive planet Jupiter.

The gravitational force can be said to act on the center of the objects in question, which is where the term center of mass comes in. So the center of mass of an object is attracted to the center of the earth.

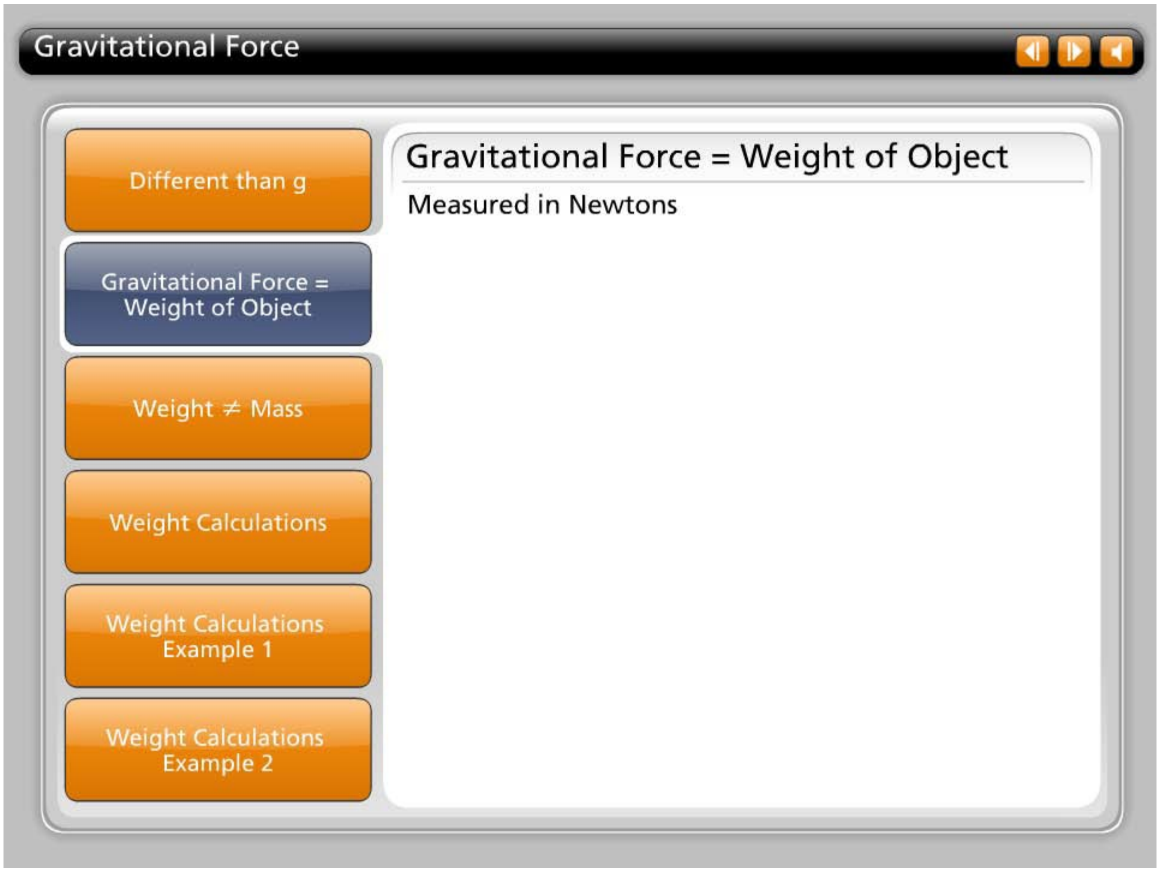
Gravitational force is an action-at-a-distance force that acts even when the objects are not in physical contact.



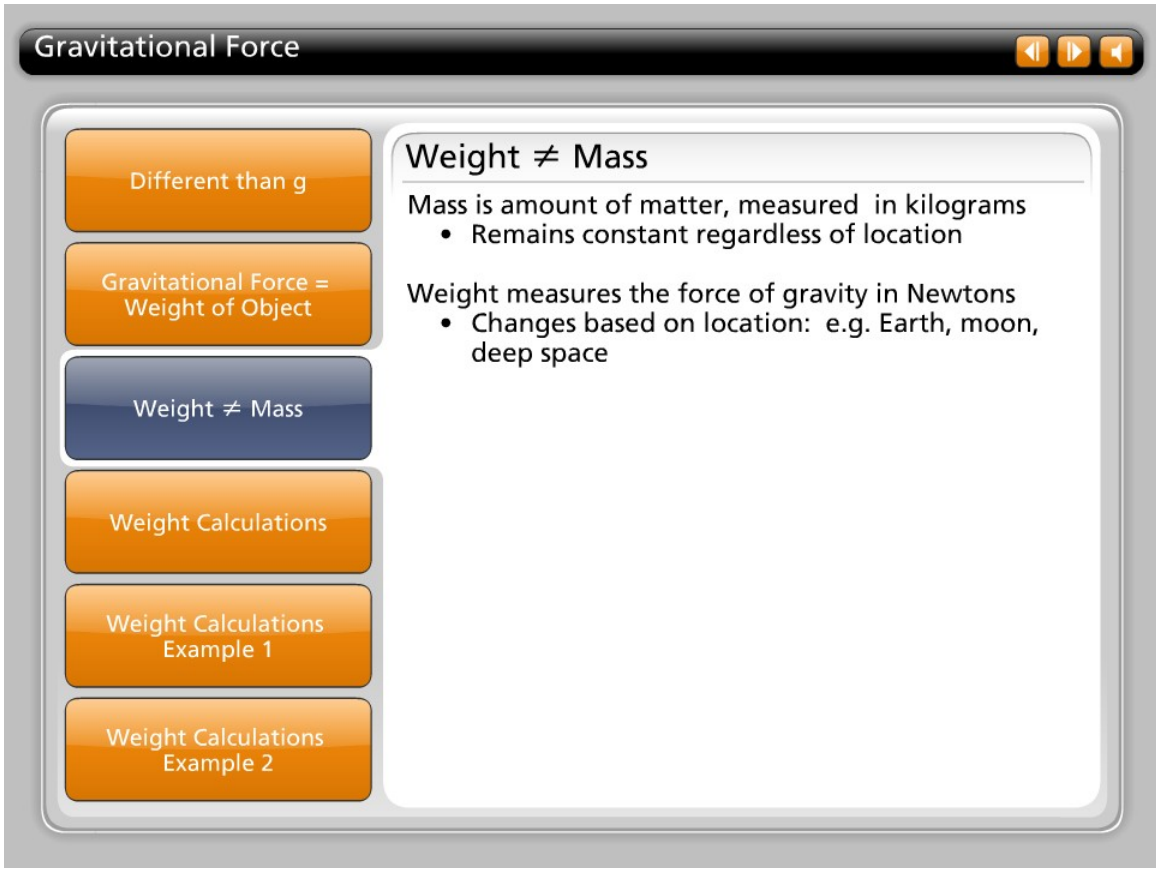
Earlier in this course, when calculating freefall, we used g for the acceleration of gravity. Although related, g is the acceleration of gravity, not the gravitational force.

Near the surface of the earth, all objects will accelerate downwards towards the center of the earth at an acceleration of nine point eight meters per second per second, or nine point eight meters per second squared. This is gravitational acceleration, and not gravitational force (remember that the unit of force is the Newton).

Weight, on the other hand, is a measure of the gravitational force on the object. If the object is on the earth, it will weigh a certain amount, and if it is on the moon, it will weigh substantially less, because the moon, with its smaller mass, will have less of an attraction for the object. If the same object was floating in deep space, far away from planets, stars or other large objects, it would be effectively weightless, as there would not be a substantial amount of gravitational force on it.



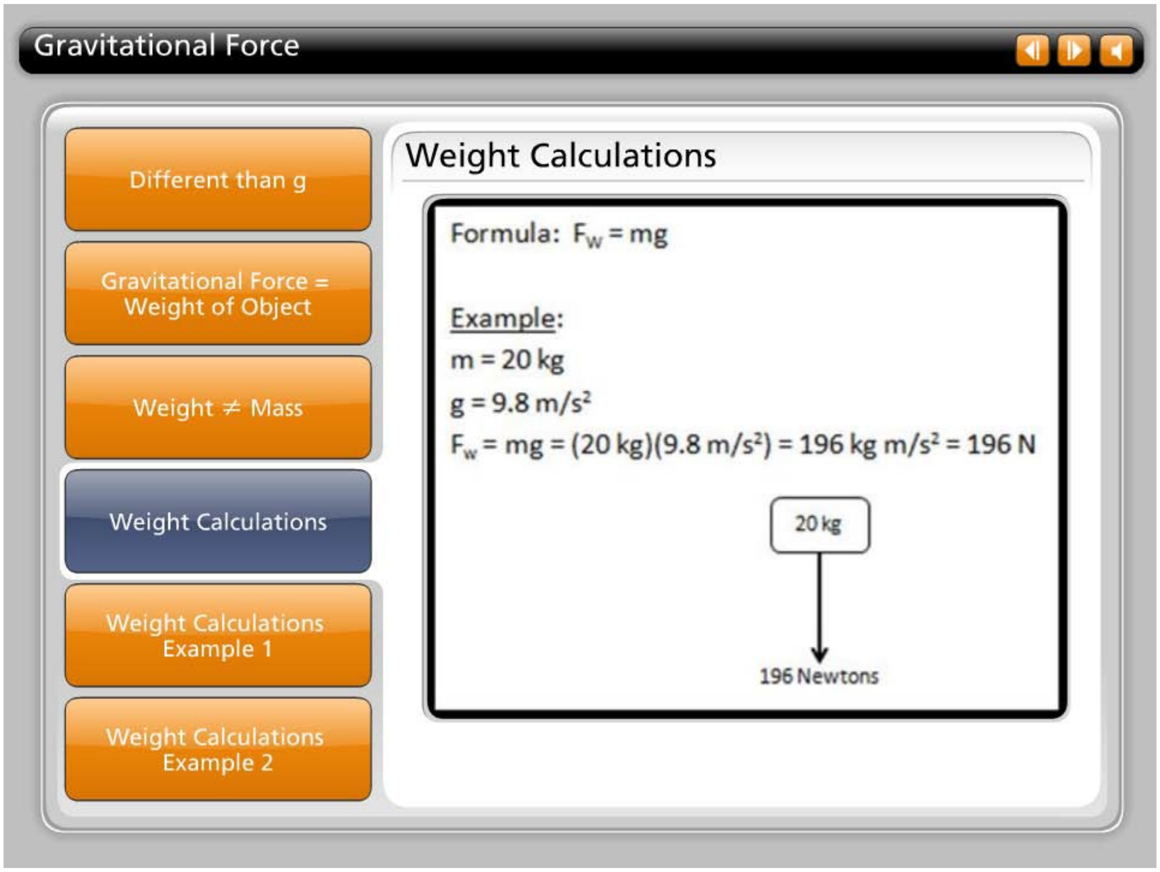
The gravitational force on an object is the same as the weight of the object, as it is a force measured in Newtons that depends on the local gravitational field.



It is common for students to mistake the words "weight" and "mass". In the study of physics, it is quite important to differentiate between the two terms in both definition and unit of measurement.

Mass is the amount of matter that makes up an object, measured in kilograms. This amount remains precisely the same regardless of if the object is on Earth, on the Moon or floating in deep space.

Weight, on the other hand, is a measure of the gravitational force on the object. If the object is on the earth, it will weigh a certain amount, and if it is on the moon, it will weigh substantially less, because the moon, with its smaller mass, will have less of an attraction for the object. If the same object was floating in deep space, far away from planets, stars or other large objects, it would be effectively weightless, as there would not be a substantial amount of gravitational force on it. Mass is the measure of the inertia of an object.



To calculate the weight of the object you need to know the mass of the object and the acceleration of gravity.

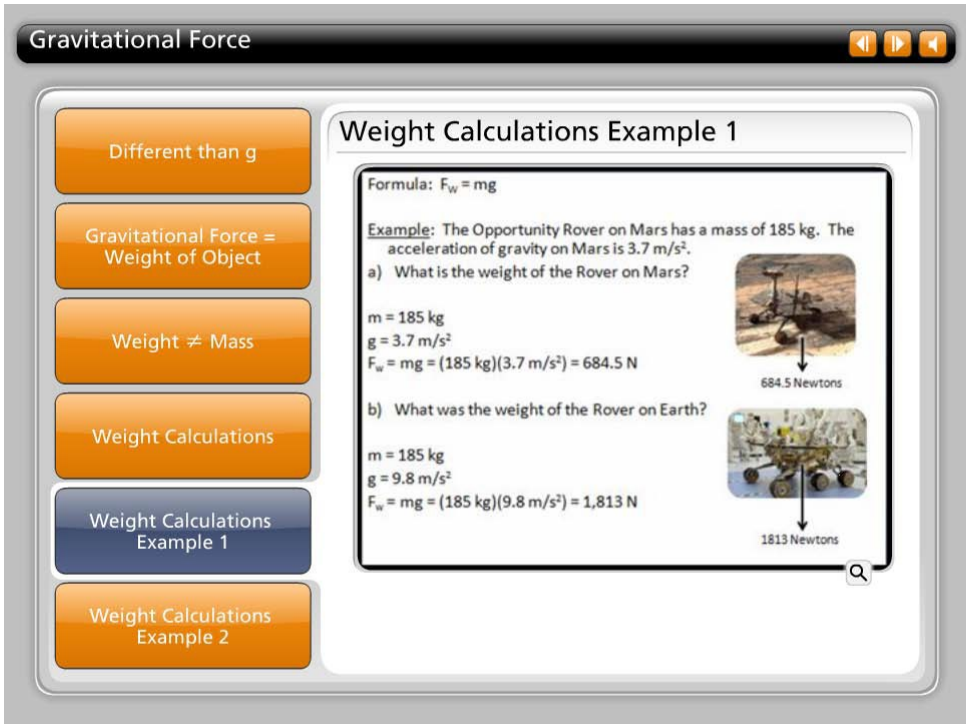
The weight of the object is equal to mass times acceleration of gravity, or F w equals m times g. On the surface of the earth

What is the weight of a twenty kilogram object on the surface of the earth?

Kilograms measures mass, so the mass is twenty kilograms. The acceleration of gravity, g, equals nine point eight meters per second squared.

So a twenty kilogram object would weigh twenty times nine point eight, or 196 Newtons. This means that the gravitational force on the object would pull it with a force of 196 Newtons towards the center of the earth.

Remember that a Newton is defined as a kilogram meter per second squared.



For our next example, let's look at the Opportunity Rover, which began its mission on Mars in July of 2003 and has a mass of 185 kilograms. If the acceleration of gravity on Mars is three point seven meters per second squared, what was the weight of the rover when on Mars?

The mass of the rover is 185 kilograms, so we write m equals 185 kilograms. The acceleration of gravity on Mars is not nine point eight meters per second squared, but since Mars is smaller than Earth, the acceleration of gravity is only three point seven meters per second squared. So we write g equals three point seven meters per second squared.

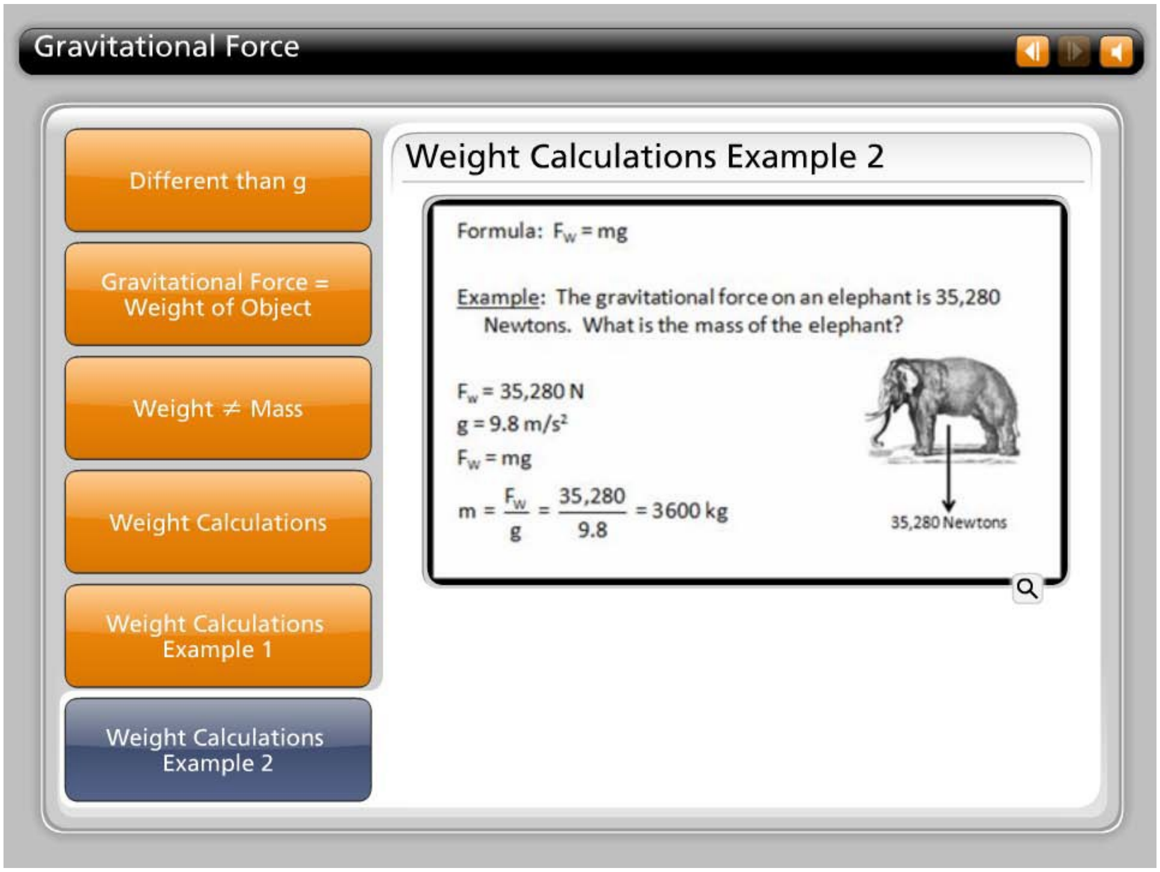
The equation we use is f w equals m times g. When we substitute and solve, we find that opportunity weighs six hundred eighty four point five Newtons on Mars.

What was the weight of the Opportunity rover when it was on Earth? This is the same rover that we sent to Mars, but we put it together here on Earth.

The mass is still 185 kilograms, but on earth, the acceleration of gravity is nine point eight meters per second squared.

When we substitute and solve, we get a weight of one thousand eight hundred thirteen Newtons.

The very same rover weighs less on Mars than it did on Earth, not because it lost parts along the way, but because the gravitational force on Mars is less than the gravitational force on Earth due to the smaller mass of Mars.



Sometimes we have the force of gravity on an object in Newtons and need to determine its mass in kilograms.

If the gravitational force on an elephant is thirty five thousand two hundred eighty Newtons, what is its mass?

The gravitational force on an object is its weight, so we can write F w equals thirty five thousand two hundred eighty Newtons. The acceleration of gravity is nine point eight meters per second squared.

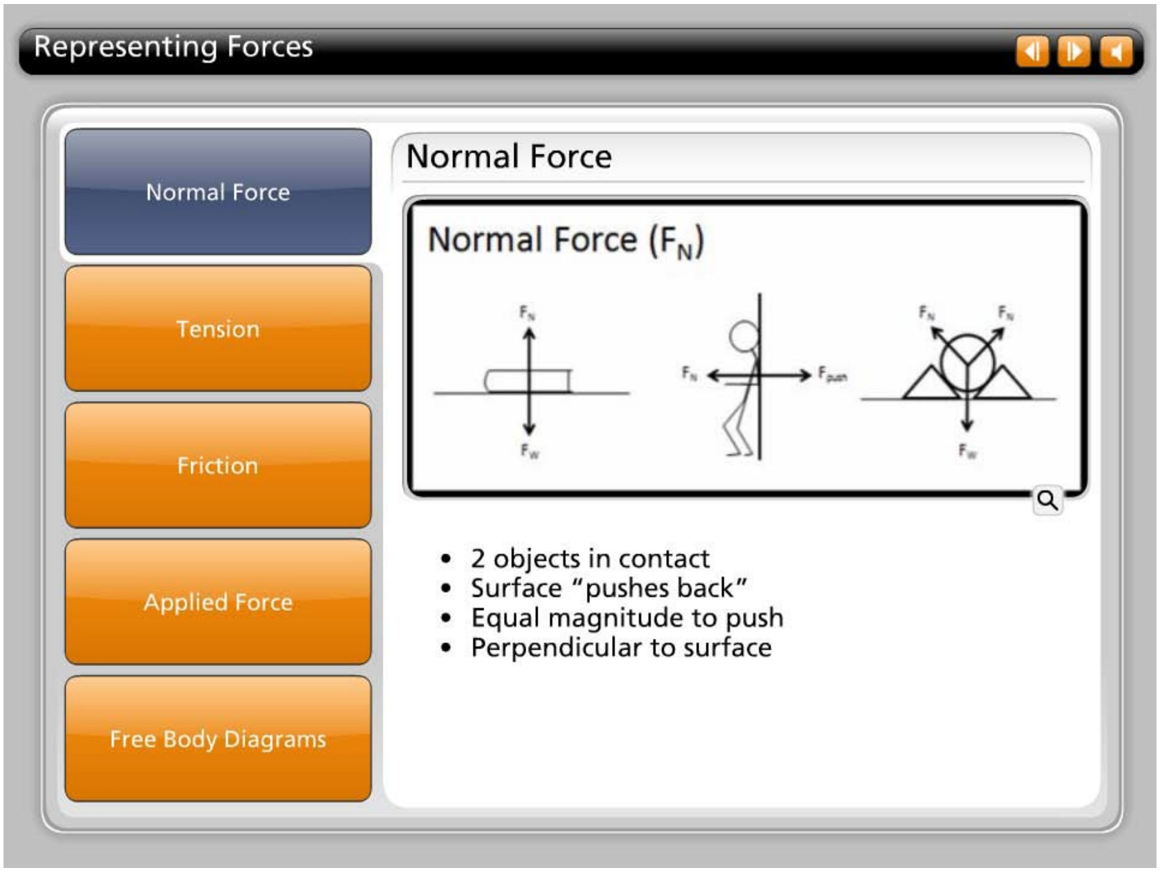
Our equation is F w equals m times g, so m equals f w divided by g.

Substituting, we get a mass of thirty six hundred kilograms.

Now that you know about the ever-present gravitational force, it is time to look at additional common forces, and how we represent them to help us with our analysis of physics.

While the gravitational force is quite important, and will have to be considered in nearly all of our examples, there are additional forces that are quite common and which you will need to consider throughout this course.

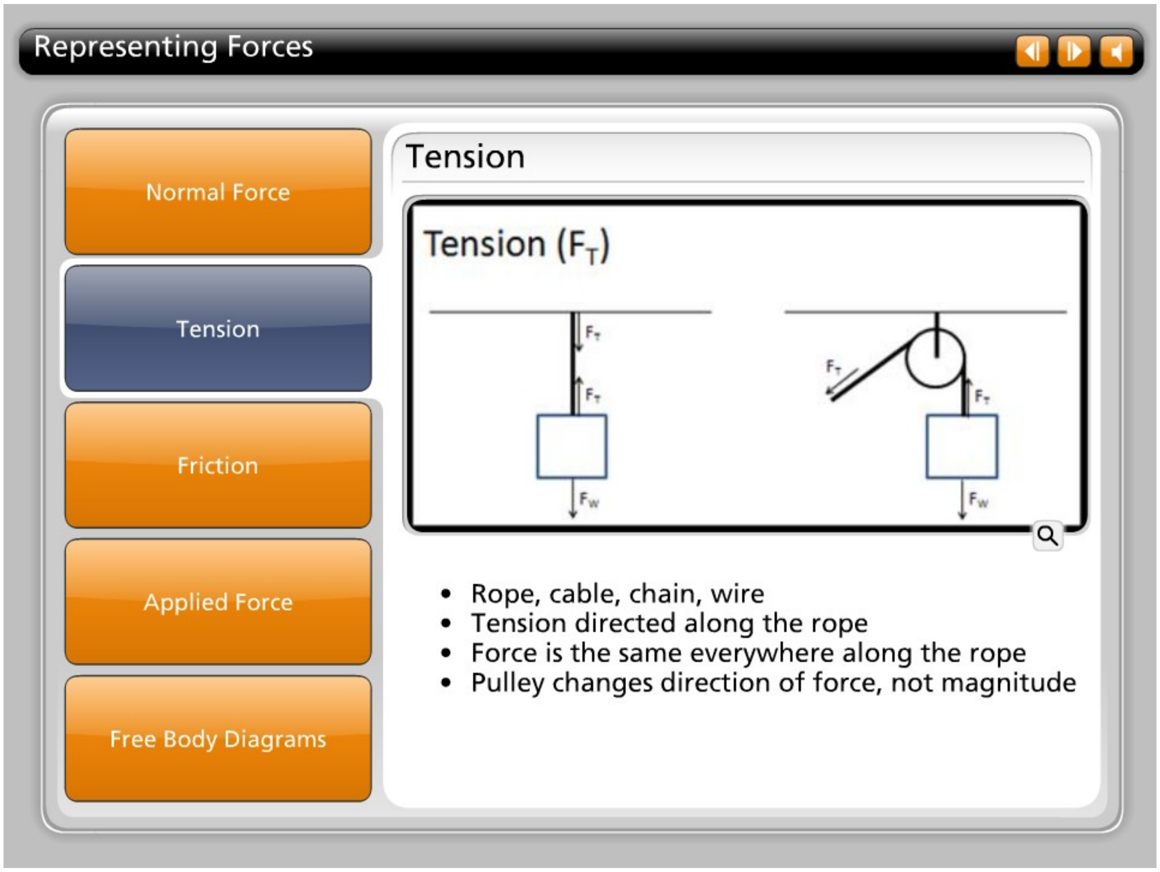
Among these are the normal force, the force of tension, the force of friction, and an applied force.



The normal force is the force that keeps you from falling through the floor.

When one object rests on a surface, such as a book sitting on a table, or is pushed into a surface, such as a person leaning on a wall, the surface responds with a force that pushes back. This is called the normal force. The magnitude of this force is equal to the magnitude of the force pushing into the surface, and the normal force is directed out, perpendicular to the surface. If an object is in contact with more than one surface, then a normal force exists perpendicular to each surface.

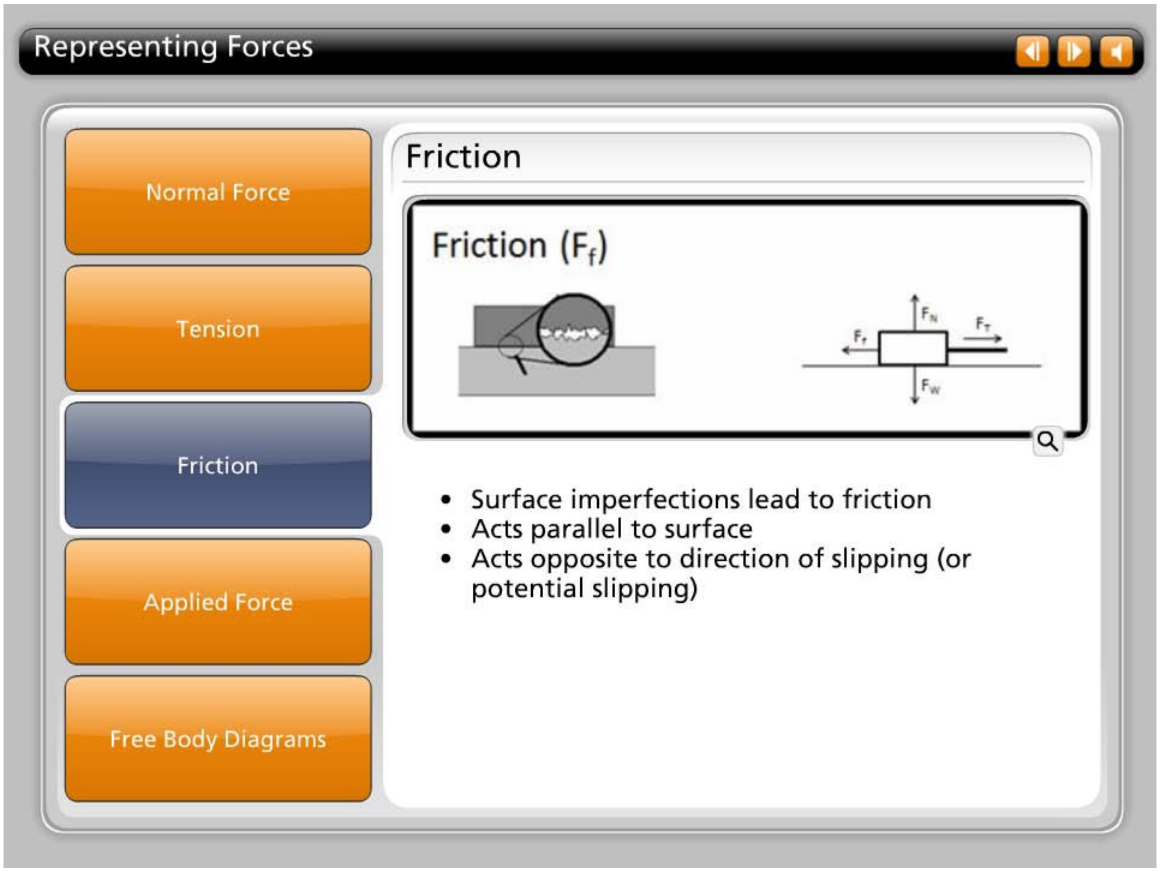
The word "normal" originally meant "perpendicular", since a "norma" was a carpenters square, used to make right angles. When building a house, you hoped to have all your door frames and walls be "normal" to the floors and ceilings. The common modern usage of the word is adapted from this original meaning.



When a rope, cable, chain, wire or similar object is involved, we will utilize the force of tension.

When a rope is under tension, the force pulls from the point of contact directly along the rope, and the amount of tension will be the same anywhere along the rope. This means that if you were to cut the rope at any point and put in a spring scale or force sensor, you would register the same pull in each direction no matter where you were to measure.

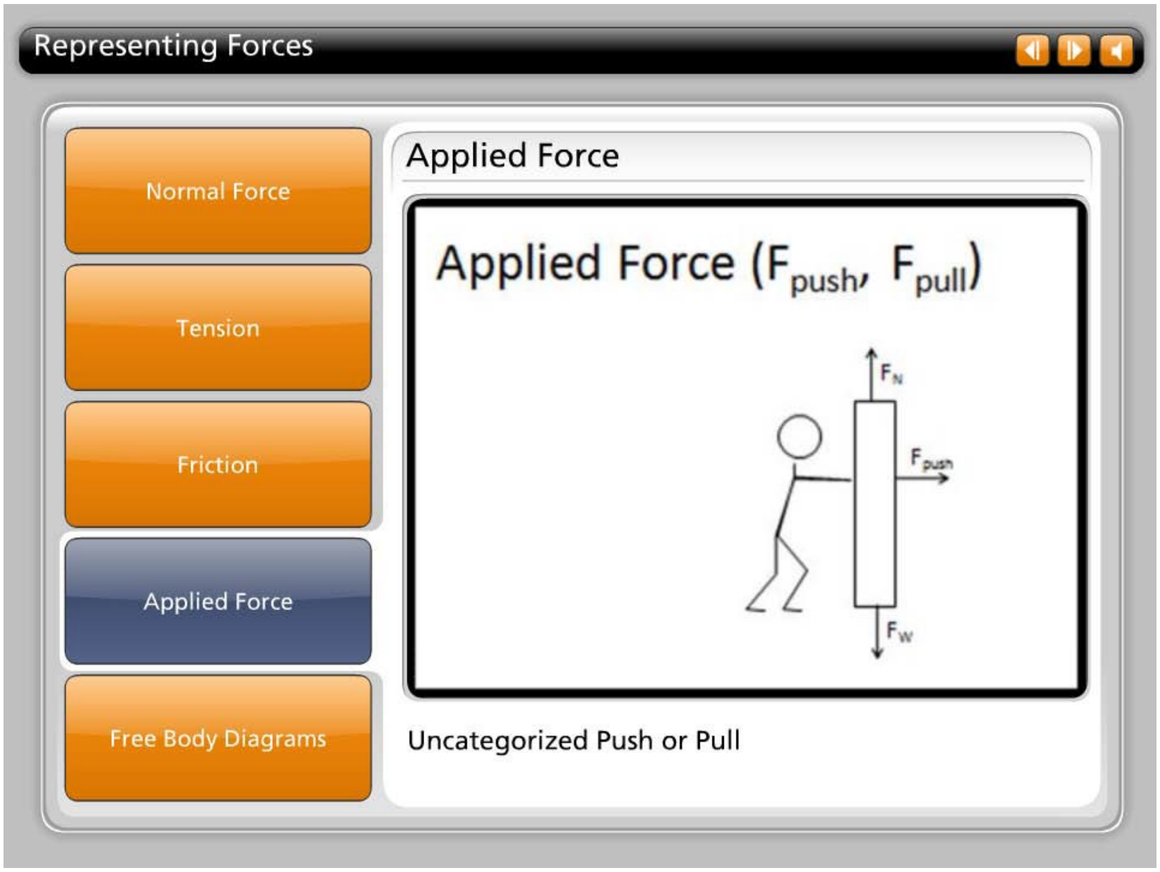
If a pulley is involved, it only changes the direction of the force, not the magnitude. The tension anywhere in the rope is the same.



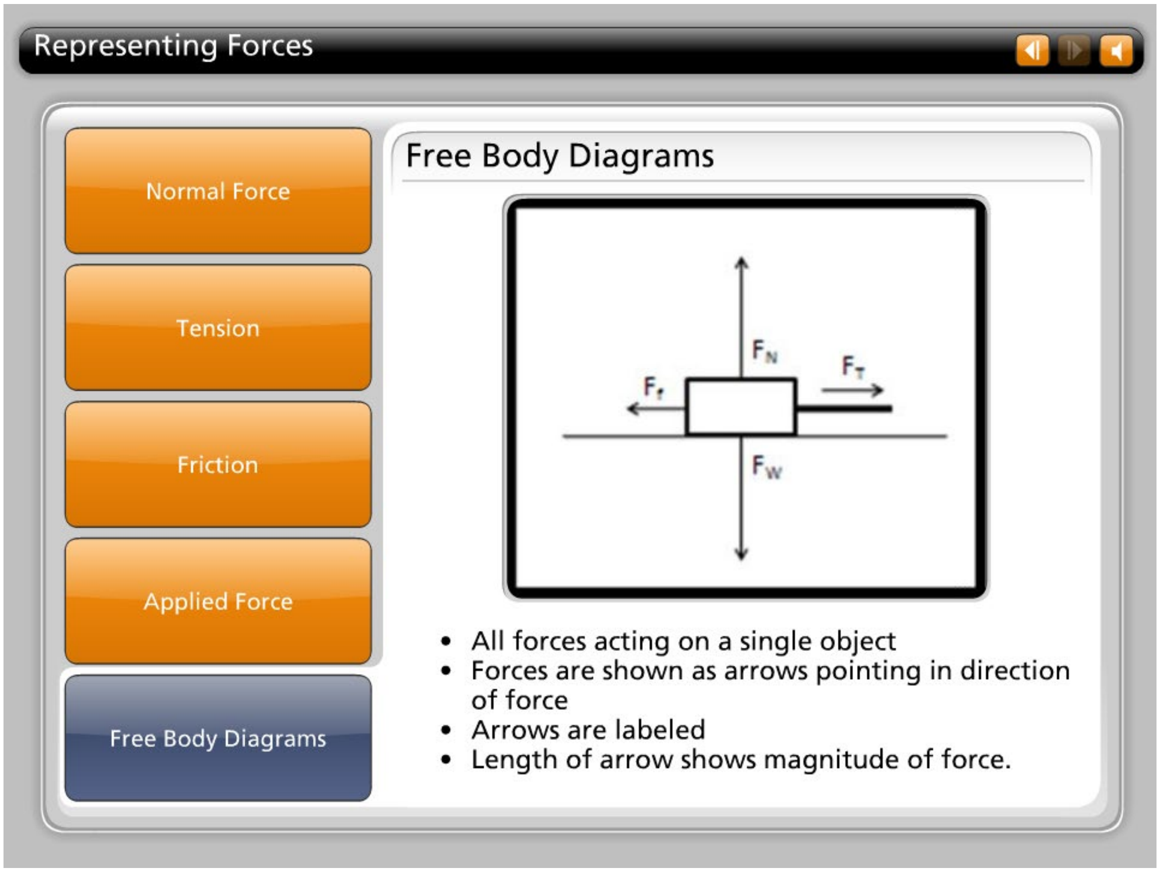
When two objects are in contact and there is some force directed parallel to the surface, there is likely friction involved. If we could look with great magnification at even surfaces that appear smooth, we would see that these are actually quite jagged at the microscopic level. When we try to slide these objects past one another, the collisions of these jagged surfaces result in a force that resists the motion. We call this force friction.

The normal force acts when the object is pushed into the surface and is always perpendicular to the surface. Friction acts when the object is pushed parallel to the surface, and the force of friction responds parallel to the surface. It is quite common for both of these forces to be included, and you will learn how the increased normal force leads to an increased force of friction.

The frictional force is directed opposite the direction of motion of a slipping object, or opposite the direction of potential slipping for surfaces that are not moving with respect to each other.



The term "applied force" is a generic term used for forces that are either unspecified or which don't neatly fit into other categories.



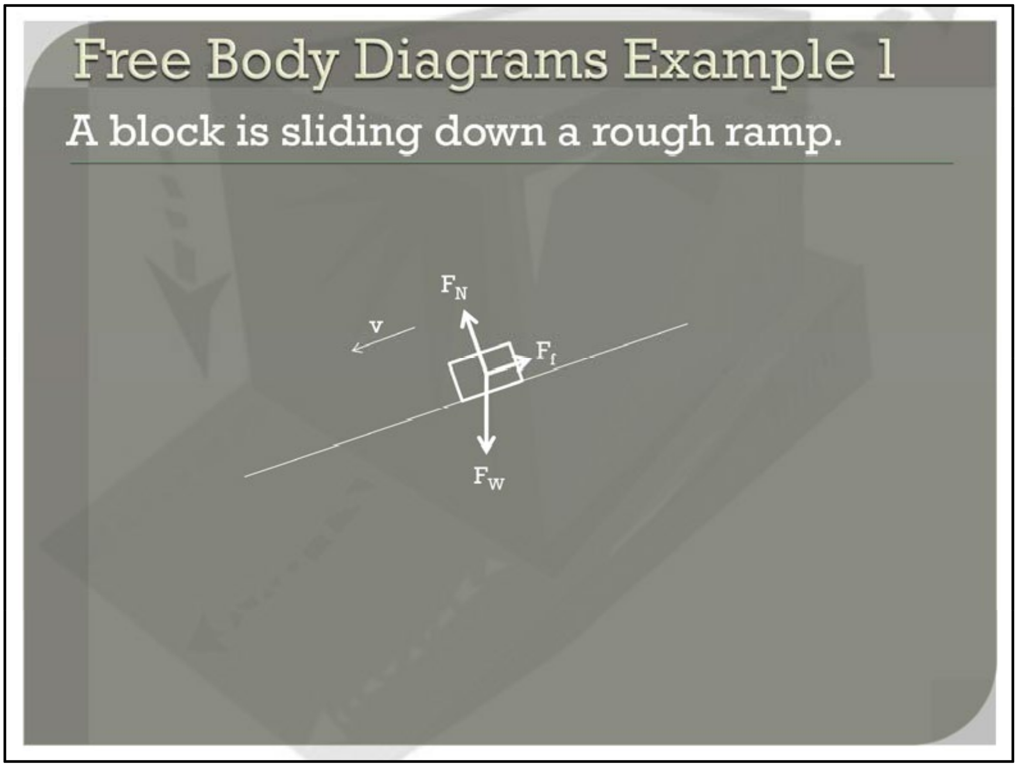
In order to effectively organize the varied forces that may be affecting an object, so that we can analyze and determine the net force, we will use something called a free body diagram.

A free body diagram includes all forces acting on a single object. Each force is represented by an arrow pointing in the direction of the force, and each arrow must include a label to indicate the type of force it represents.

An attempt should be made to make the length of each arrow represent the relative magnitude of the force. Longer arrows represent stronger forces and shorter arrows represent weaker forces.

You may have noticed that the examples used in this lesson made some use of free body diagrams. Several of the drawings with labeled arrows pointing in various directions were free body diagrams.

Now let's look at some examples of free body diagrams.

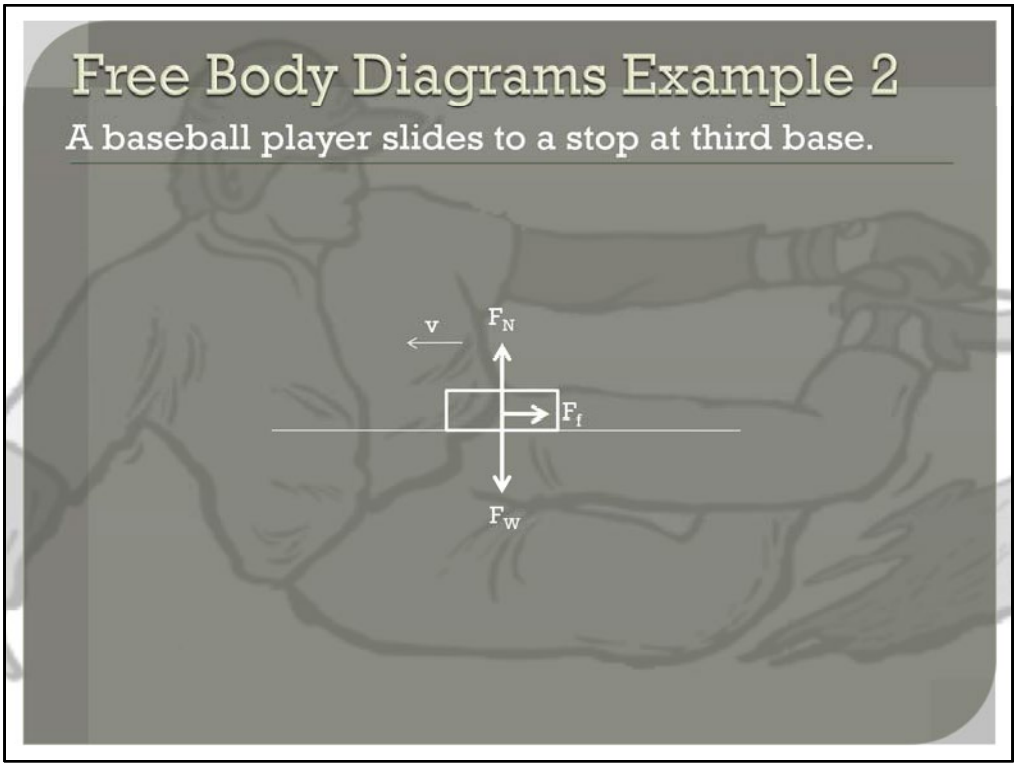


Let's look at an example. Here, let's draw a free body diagram of a block that is sliding down a rough ramp. The direction of the velocity is indicated, but is not part of the free body diagram.

To draw a free body diagram, we need to identify the forces involved and determine their direction. Then we must estimate the relative strengths of these forces and draw labeled arrows to represent them.

In this case, as in most cases, we have the gravitational force. This force is always directed straight down. Next, since we have two objects in contact, we have a normal force that keeps the block from falling through the ramp. The normal force is always directed perpendicular to the surface. A third force in this situation is the force of friction, because it was stated that this was a rough surface. In general you should assume there is friction unless otherwise directed. The block is sliding down the ramp, so friction opposes the motion and points up the ramp, opposite the direction the object is moving and is directed parallel to the surface.

As we draw these three arrows, we also have to label them. We draw the gravitational force with an arrow straight down and label it F W. We draw an arrow for the normal force perpendicular to the surface and label it F N. Finally we draw an arrow for the frictional force directed up the ramp and label it F F.

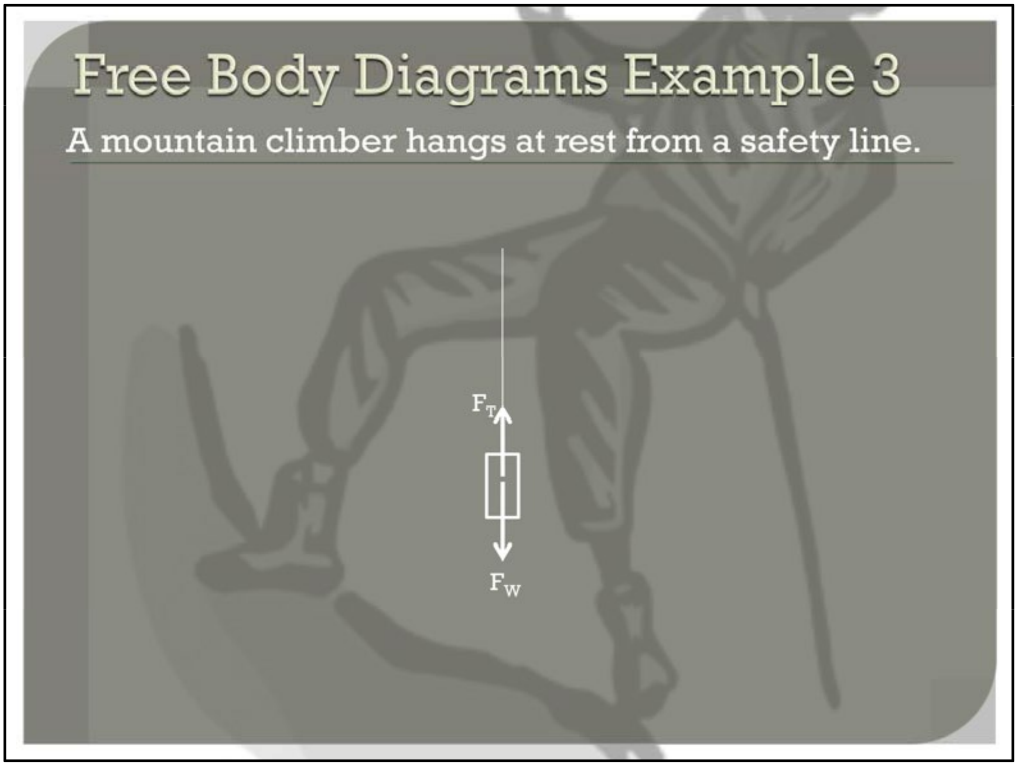


Here's another example. What would the free body diagram of a baseball player sliding into third base look like?

Of course, the picture looks nothing like a baseball player, but that is intentional. You don't have to spend time drawing a baseball player when you only want to analyze the forces. So we'll just draw the baseball player as a box. Again, the direction of the velocity is indicated, but is not part of the free body diagram.

There are several forces acting on the baseball player at this point.

The first is the gravitational force, or weight of the player, which is directed straight down. We represent this with an arrow pointing down and labeled F W. Opposing the gravitational force is a normal force, since he's in contact with the surface. The normal force is drawn perpendicular to the surface, in this case straight up, and is labeled F N. Finally, since the player is sliding to the left, there is a frictional force directed to the right, opposite the direction of sliding. We label this F f.

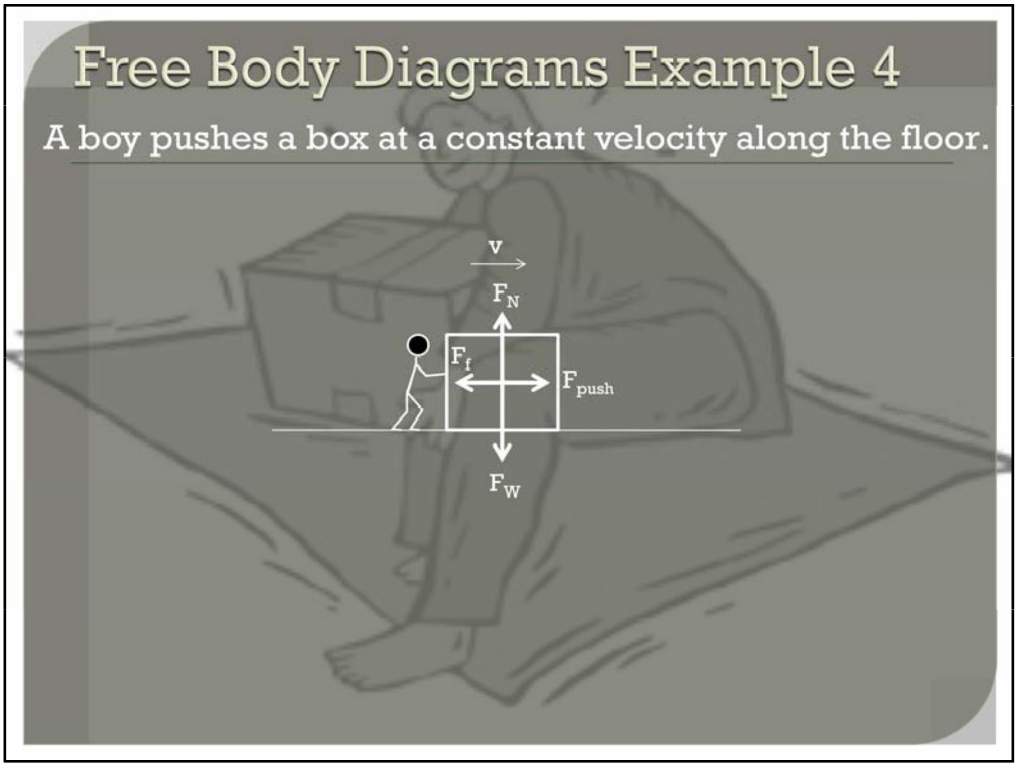


In this example, a mountain climber hangs at rest from a safety line.

As is typical, we have the gravitational force pulling down on the mountain climber. We draw this arrow directed downward and label it F W.

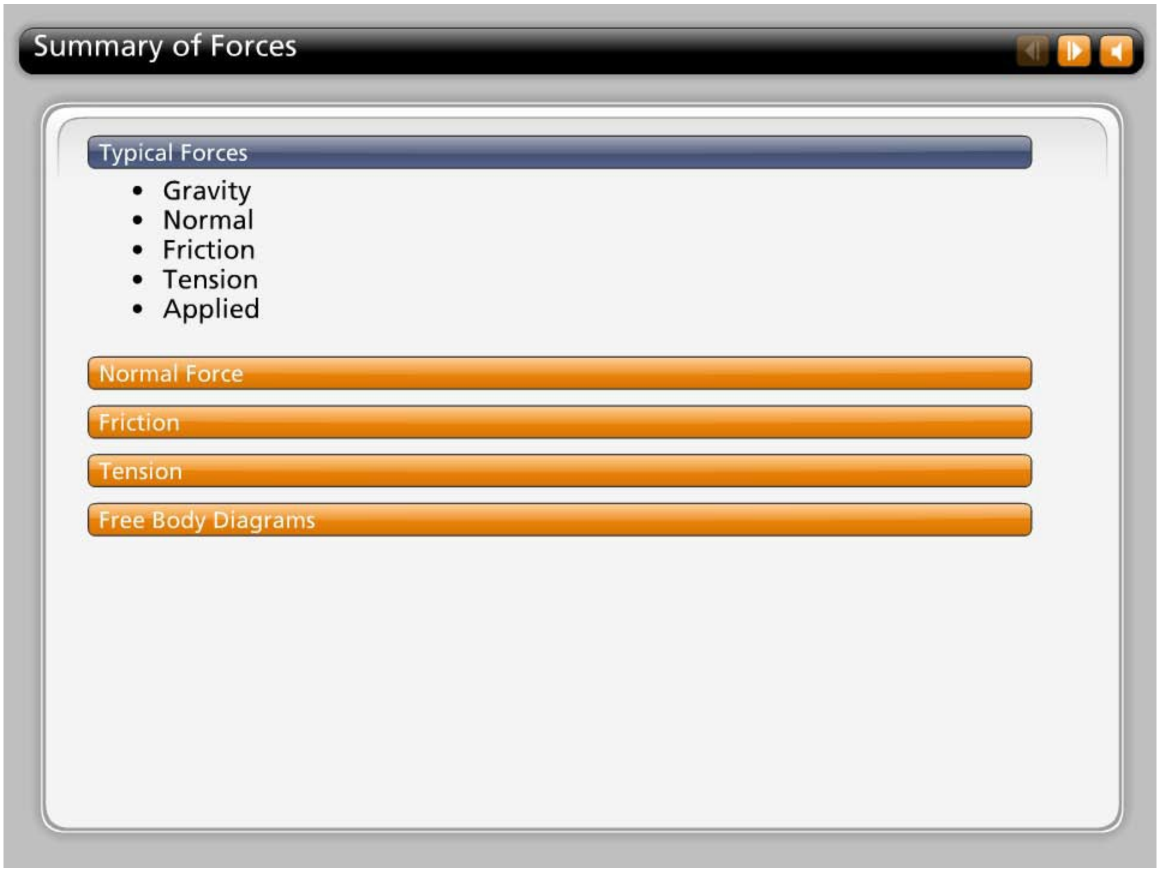
Since the mountain climber is not in contact with a surface, there is no normal force, nor is there a frictional force.

There is a rope involved, so we must include the force of tension, pulling up on the climber. We label this with F T.

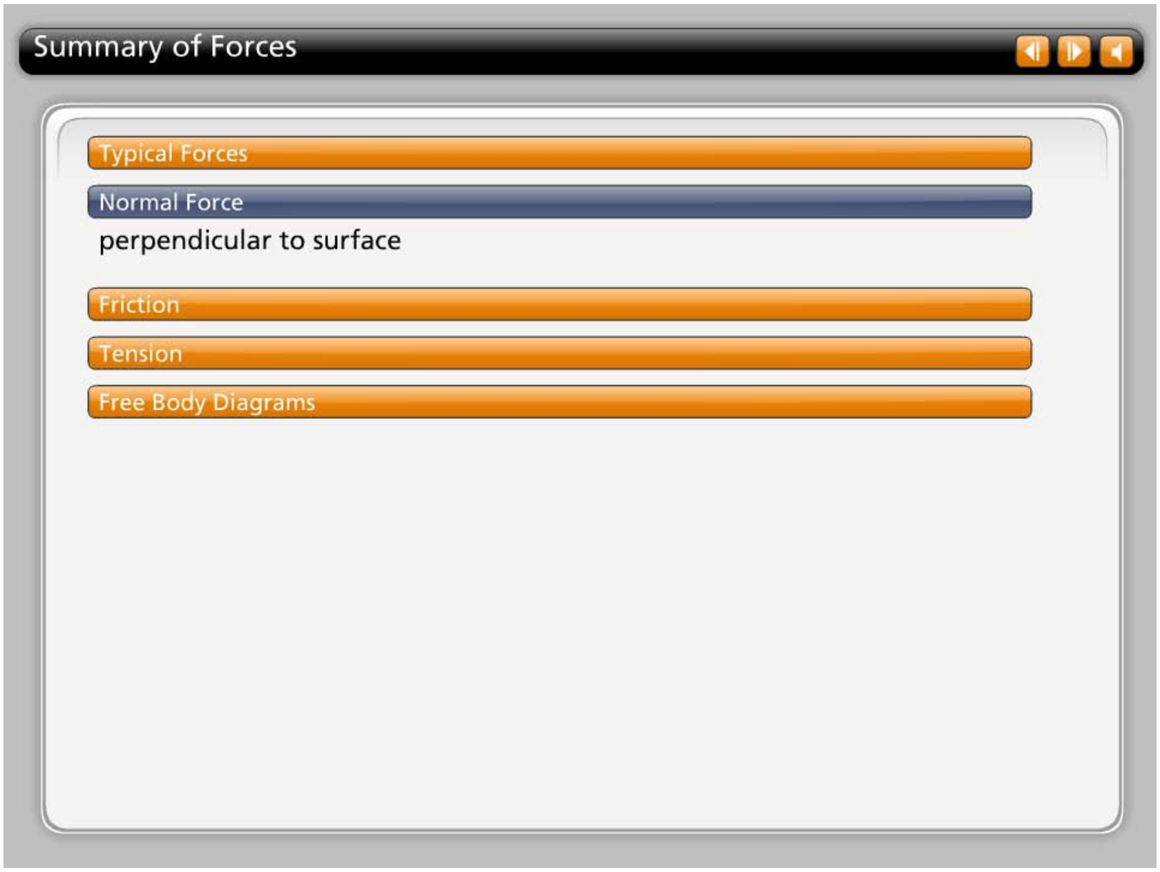


In our final example, we will draw a free body diagram of a boy pushing a box at a constant velocity along the floor.

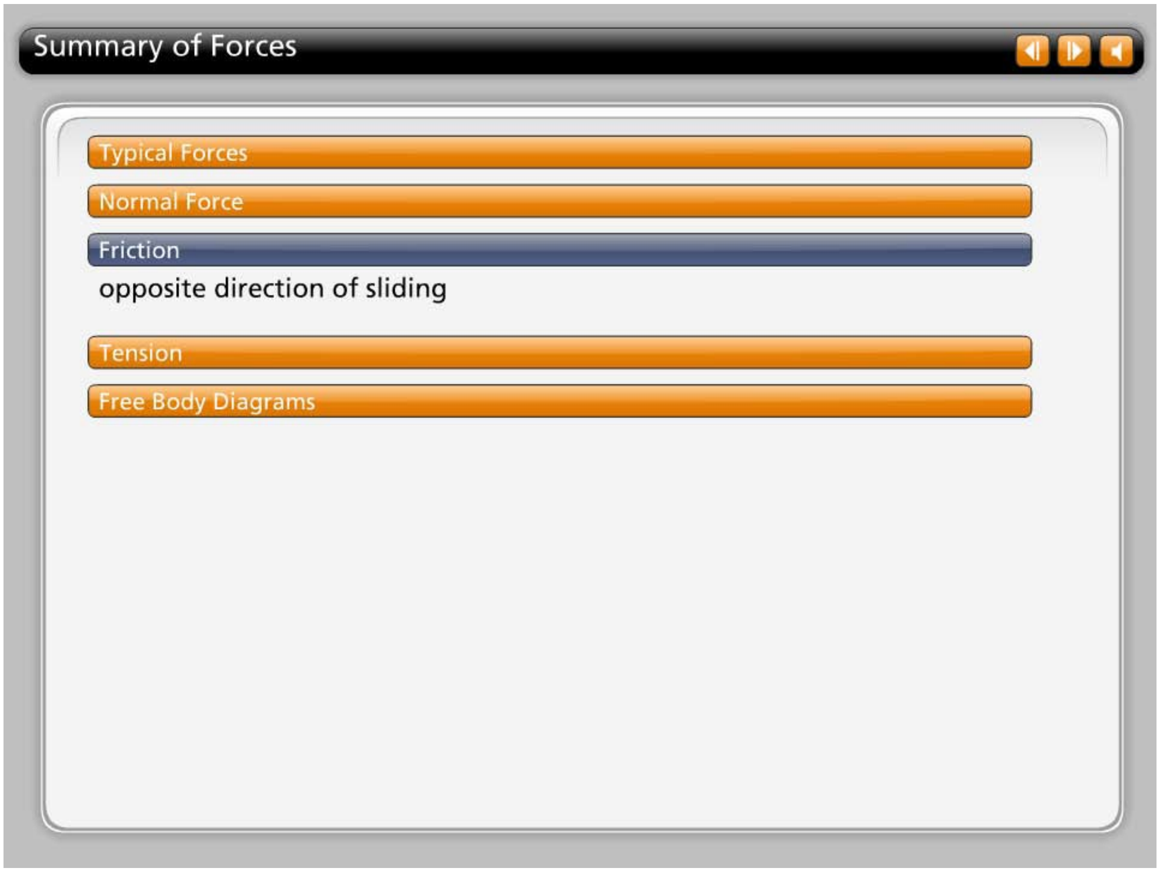
Again, we will include the gravitation force on the box, or the weight of the box, pushing straight down. Since the box is in contact with the floor, the floor provides a normal force perpendicular to the floor, in this case, straight up. The surface also provides a frictional force pushing opposite the direction of sliding, in this case to the left. And the boy is providing an applied force to the right, which we will label F push.



In this topic, we have learned that in addition to the gravitational force, the typical forces we will consider are the normal force, the force of friction, the force of tension and applied forces.



Normal Force - perpendicular to surface



Friction - opposite direction of sliding

Tension - the same everywhere in a rope

- Include all forces acting on a single object
- Arrows point in the direction of forces