Lecture 6 Force and Motion

Identifying Forces
Free-body Diagram
Newton's Second Law

We are now moving on from the study of motion to studying what causes motion. Forces are what cause motion. Forces are something you already know a lot about.

Let's have a volunteer: I can exert a force on someone else as a push or pull. Do you agree? I can also exert the same force on an inanimate object. Yes?

What if we add a rope into the equation. I can pull on a rope that someone holds onto. Let's ask the volunteer, what do you feel?
I exert a force on the rope. This creates a tension force in the rope and the tension force is what pulls on the volunteer.

There are many objects that exert forces, like springs. If we get a volunteer to hold one end of a spring and I pull on the other – the spring stretches. We can also ask our volunteer what they experience.
The spring will pull on the person just as the person pulls on the spring. Now let's hang the spring up and attach a mass. The spring stretches, so we can see that the spring is exerting a force up on the mass. If we hang the same mass by a string, what can we say about the forces in this situation. The string doesn't appear to stretch, but if we took a microscope and looked at the rope, we could see that there are actually spring-like bonds holding the atoms in their places. So the spring stretches on a macroscopic level this is where the force comes from, but the string stretches on a microscopic/atomic level and that is where the force comes from in that situation.

Now we'll talk about something in physics called the normal force. [Place a block in the center of the lecture table] Let's identify the forces on this block. Gravity…normal force. Now some of you may know that the normal force in this case is the force of the table acting up on the block, but do you actually have any proof that this so called "normal force" exists? [pass around stiff spring, pen spring?]

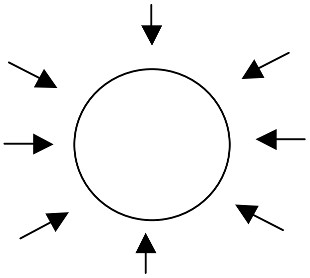
We can all agree that when a spring compresses, a force is exerted. So if we were to take a block and put in on a spring on this table, we could agree that the compressed spring is exerting a force up on the block. So if we could show that the table compressed when we put a mass on it, we would have proof that it was exerting a force on the object.
[set up laser on table with shallow angle, have student mark reflected laser point.] Now when I get up on the table, the mark moves because the table has compressed a little! We've proven that the table compresses, so there is a force up….the normal force actually exists!!! It's really the compression of the molecular bonds again (just like in the string) that matters.

<u>So to recap</u>:

- push or pull
- occurs at a point of contact between the object and some identifiable agent that exerts the force
- exerted by animate or inanimate object

There's another force we haven't talked about yet. Slide your hand across the top of the table, what do you feel? There is a force against the motion of your hand. So friction acts parallel to the surface of contact and it acts against the direction of motion.

Another force we have a lot of experience with is the force of gravity. I drop something it falls. But where's the contact in that situation? With a push or pull, we require contact to transmit the force. In the case of gravity we have a long-range force. The earth has a lot of mass, because of this it pulls on everything around it. That means that everything close to the earth feels a force pulling toward the center of the earth, hence everything dropped falls down.



For your purposes, gravity will be the only long range force to worry about. All other forces you'll deal with this semester will require contact. Now that we've spent a lot of time identifying forces, let's analyze a situation. If I throw a ball up into the air what forces are involved after the ball leaves my hand?

Force of the hand on the ball? Doesn't that require contact? But if there's no upward force how is it moving up? We'll leave this question for a later answer.

So now that we've worked on identifying forces, we should think about the laws of physics that govern those laws.
If I take a smooth ball and roll it along the track (the closest we'll get to frictionless motion), what would we expect to happen? It should roll forever in the absence of friction. What would we have to do to change its motion? Exert a force on it somehow. So in the absence of a force, the motion of something at rest stays at rest, and the motion of something in motion stays in motion. If the ball was stopped, I would have to exert a force on it or it would stay at rest.

We are going to split the class in two groups and have you discover one of these laws. You have a cart hooked to a pull scale. [Demonstrate pulling of the cart.]
What kind of motion will keep the reading on the pull scale constant (non-zero)?

- motion with acceleration (constant velocity)
- motion without acceleration (increasing velocity)

As a group write your conclusion with a brief explanation on a separate sheet of paper.
Then use the cart to try both types of motion.
After the experiment, write your conclusion on the paper. Did the experiment confirm or dispel your initial conjecture? Explain.

What happened when you moved at constant velocity? The reading on the scale should have dropped to zero. So our conclusions are:

- when you were accelerating the force was constant
- at constant velocity, zero acceleration, force is zero

At this point we should have discovered that forces are essential to motion. We've uncovered the most important of newton's laws of motion, Newton's Second Law.

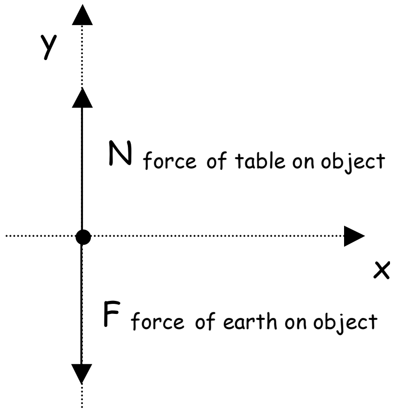
The net force on an object is proportional to its acceleration.
We can write this in several different ways:

$\Sigma F \propto a$, $F_{net} \propto a$.

There's actually one more factor to complete this relationship to change the proportional sign to an equal sign, we have to include mass. So the relationship is $a = F_{net}/m$. More force = more acceleration, but more mass means less acceleration. This makes sense that to get the same acceleration for a heavier object you have to exert more force. [add mass to cart, have student pull it]

What do we mean by net force? This is where free-body diagrams are valuable. Let's draw a free-body diagram for an object sitting stationary on this table.

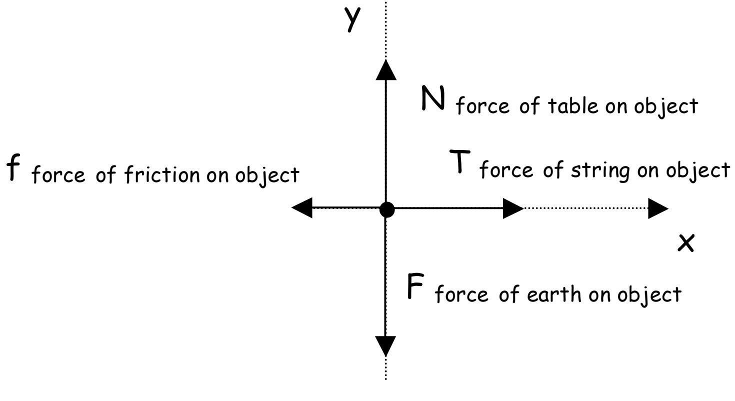
First, we represent the object as a dot. Then draw a coordinate system. Finally we can draw the forces as vectors, because a force has a magnitude and direction. We only draw forces that act on the object. From this diagram we can develop an equation reflecting Newton's Second Law.



$F_{net} = N - F = ma$

since $a = 0$, $F_{net} = 0$, so $N = F$

So net force means you take all the forces in the x-direction or y-direction and add them up. Now let's try a more complicated diagram. What if we pull the box across the table. Now we have forces in the x and y direction:



So now we have the same equation as before in the y-direction:

$(F_{net})_y = N - F = ma_y$
since $a_y = 0$, $(F_{net})_y = 0$, so $N = F$

But now we have an equation to describe the x-direction:
$(F_{net})_x = T - f = ma_x$
but in this case $a_x \neq 0$
$a_x = (T - f)/m$

If we knew the value of the tension and friction as well as the mass, we would know what kind of acceleration to expect. But let's check the limiting cases. What if the tension was equal to the friction, there would be no acceleration...does that mean that the object is sitting still?
What if the mass was really big...the acceleration would be really small!

So now that we know Newton's Second Law, we can figure out how to solve for the force of gravity. We already know the acceleration of gravity (9.8 m/s^2), so if we know $F = ma$, $F_g = mg$. Let's figure out the units of force.

$$mg = kg \bullet \frac{m}{s^2} = N$$

$$N - Newton$$

So instead of saying "kilogram times meter per second squared" we just say Newton, of course named in honor of Issac Newton who defined all these laws of motion.

So, while we're at it we should talk about mass. Mass is measured in kilograms typically. It is an inherent property of matter, which means it does not change if we change gravity. If I have a 10kg block and I take it to the moon (where gravity is different), it would still be 10kg! But if I take it to the moon and figure out it's weight (the force of gravity on it, it would be different). Let's try the calculation.
First, does anyone know how the acceleration of gravity on the moon compares to the acceleration of gravity on earth?
$g_{moon} = g_{earth}/5 = 9.8/5 = 2.0\ m/s^2$

$F_{\text{earth on object}} = (10\text{kg})(9.8\text{m/s}^2) = 98.0\text{kg*m/s}^2 = 98\text{N}$
$F_{\text{moon on object}} = (10\text{kg})(2.0\text{m/s}^2) = 20.0\text{N}$

So again, the weight of the object will change (force of gravity on object), but the mass which is an intrinsic property of the object does not change because it depends on the object, not on the pull of the earth or moon.

Let's do an example:
An elevator is going up at a steady speed. Draw a free body diagram and write a statement of Newton's Second law. Is the tension force greater than equal to or less than the weight? Explain.