Friction: Crash Course Physics #6

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If you watched our episode on Newton's laws of motion, then you're practically an expert on forces, and the way they make things accelerate. But there's something we left out -- something important when you're trying to describe how things move in real life: friction. It stops a baseball player sliding into home plate. And it's the reason I can pick up this cup without it slipping through my fingers. Without friction, it would be tough to do... almost anything. But it also makes doing other things pretty hard. Anyone who has moved furniture knows that. Luckily, friction is also a force, so, as physicists, we know what to do with it. [Theme Music] You're moving into a new house, and you ask a friend to come help out, which he does, because he's just nice like that. And you really do need his help, because you'll have to move giant bookcases and a desk, and you can't do all of that on your own. And about halfway through the move-in, you're rearranging the furniture in your new bedroom when you run into a problem:

You're pushing and pushing on your bookcase, but it just not sliding across the floor. So you call your friend over from the other room, and with both of you pushing, the bookcase finally starts to slide. But it was really hard to get it moving -- and stay moving -- because there's a force working against you - stopping the bookcase from sliding: friction. And there are actually two kinds of friction.

First, there's kinetic friction -- that's the force that slows the bookcase down as it slides. And there's also static friction — the force you had to overcome to get it moving in the first place. So let's talk about kinetic friction first. It's a resistive force, which just means that no matter what, it'll act to resist you. In other words, if you push the bookcase so it slides to the left, then the force of kinetic friction is acting to the right. But if you move the bookcase to the right, then the friction will resist to the left. Kinetic friction will also often generate heat or sound or both.

So, what causes it? The bookcase and the wood floor might look smooth, but if you looked at their surfaces under a microscope, you'd see that they're covered in tiny bumps and grooves. As the bookcase slides across the floor, the surfaces catch on each other, and might even start to form weak intermolecular bonds. That pulls on the bookcase, slowing it down. But as the bookcase continues to slide, it breaks those bonds and moves past whatever bumps it was stuck on. The newly-freed molecules start to spring back, and the movement produces heat and sound. Then the cycle continues with the next patch of floor.

You end up with a force that resists any kind of sliding movement, and its strength depends partly on what materials are sliding against each other. Rougher materials have more surfaces to catch on each other, which is why the bookcase will be easier to slide on the wood floor than if you'd tried it on carpet. And the way in which this roughness affects kinetic friction is called the coefficient of kinetic friction, and it's different for pretty much every combination of materials.

But there's another factor at work in friction: How hard the materials are pressed together puts more of their surfaces in contact with each other. And that's where the normal force, or F_N, comes in. You might remember from our last episode, that when a force pushes a bookcase against the floor, the floor pushes right back. That's Newton's third law, and we call the force from the floor on the bookcase the normal force. In this case, the force from the bookcase on the floor is just its weight, mg. So the normal force would be equal to mg, but pointing up -- equal and opposite.

So - Now we know about the two main factors that affect the strength of kinetic friction: the coefficient of kinetic friction -- written as mu_k -- and the normal force, F_N. It shouldn't be too surprising, then, that the equation for kinetic friction is just... the coefficient times the normal force. But that's only half the picture. What about static friction?

When you weren't able to move the bookcase to begin with, that was because of the static friction between the bookcase and the floor. Like kinetic friction, it's also a resistive force. But not only can its direction change -- its strength can change, too. Say you push on the bookcase lightly, with just one hand, and it doesn't move. Since it doesn't have any acceleration, the bookcase must be in equilibrium -- meaning that the forces on it balance out. So the force from static friction must be exactly equal to the force from your hand, but in the opposite direction -- because of that equilibrium.

It's not the same as the normal force, and it has nothing to do with Newton's third law. But say you really put your back into it, pushing as hard as you can. The bookcase still doesn't move, so static friction must still be pushing back with the same amount of force you are. However, the static friction between two objects can change: Once your friend starts pushing too, the bookcase starts to slide, because the force from your teamwork is greater than the maximum amount of static friction -- which we write like this. And the relationship between the maximum static friction and the normal force is similar to the relationship between kinetic friction and the normal force.

There's even a coefficient of static friction, which measures the roughness between any two objects -- and we just write it as mu_s. And the maximum force of static friction is just equal to the coefficient of static friction times the normal force. So now we know the equations for both kinds of friction and where they come from. Which means we can use that information to figure out how to solve problems involving friction.

Just like with the other force-related problems, we start with a free body diagram. That helps sort out what's pushing where, so we can get an overview of the situation. Next, we decide on some axes: where are x and y? And which way is positive? That'll be useful when ramps come up, because if we want, we can just decide that x points down the ramp and y points straight into it. The next thing we'll need to do is separate vectors into components along our new x and y axis because strange things happen to the normal force when you have something (like that bookcase) sitting on a ramp.

The normal force is pointing out of the ramp, because it's perpendicular to the surface, but it's not equal and opposite to the force of gravity, because that's pointing straight down. Instead, we'll have to use trigonometry to separate the force of gravity into two perpendicular components: one pointing down along the ramp, and one pointing into it. Then, the normal force will just be equal and opposite to the part of the gravitational force that's pointing into the ramp.

So, here's how to separate and diagram everything that's going on: The angle between the force of gravity and the component pointing into the ramp is called theta. And it's the same as the incline of the ramp. Those make two sides of a right triangle. And since the component pointing into the ramp is adjacent to the angle, we know that it's equal to (mg) x (the cosine of that angle) -- and so is the normal force. The other component, pointing alongside the ramp, is opposite the angle. So, again using trigonometry, we know that it's equal to (mg) x (the sine of the angle).

So! You've drawn your free-body diagram, you've decided on axes, and separated the force of gravity into two useful components. Now, we can finally set up our equations! That's where Newton's second law -- F(net) = ma -- comes in handy.

There'll actually be two of these -- one for the x direction, down the ramp, and one for the y direction, into the ramp.

So let's say you've got the bookcase where it needs to go, and now you're ready to get something else out of the moving van -- this time, a 40-kilogram box with a very fragile vase inside it. It's heavy, so let's say you put it down on the ramp leading from the back of the truck to the ground -- which happens to be angled at 30 degrees -- and then walk away to get a drink of water. You also happen to know that the coefficient of static friction between the box and the ramp is 0.50.

What is the box's acceleration? If it's zero, it'll stay put and your vase should be okay when you walk away from it. If not, that means the box will start sliding down the ramp, and you may have a problem. The first thing we need to do is draw a free-body diagram of this box. For our coordinate system, we'll have x along the ramp, with the positive side at the bottom, and y perpendicular to the surface of the ramp, with the positive side also toward the bottom.

And we have a whole bunch of forces here: The normal force is pointing out of the ramp. There's also the force of static friction, which, right now is pointing up the ramp - since it's resisting the part of the gravitational force pulling the box down. Speaking of which: the force of gravity is pointing straight down -- not along either of our axes, so we separate it into components: (mg)(cos)(theta) pointing into the ramp, and (mg)(sin)(theta) pointing down along the ramp.

Now we set up our net force equations along each axis: The box isn't going anywhere along the y axis -- nothing's going to make it start rising above the surface of the ramp, right? So we know that all the forces acting along the y axis should add up to zero, since they're all balanced out. But the forces along the x axis, along the ramp, are a different story. If the box has no acceleration (it's standing still, or moving at a constant velocity) they'll also add up to zero. But if it does have acceleration along the ramp, then the forces will add up to its mass, times that acceleration.

So, to figure out if the box slides, all we need to do is find out if the part of the gravitational force pushing it down the ramp, (mg)(sin)(theta), is greater than the maximum static friction resisting it. In other words: if down the ramp is the positive direction, is the net force positive or zero? The forces here are the gravitational force pushing the box down the ramp, (mg)(sin)(theta), and the maximum static friction. But we write the maximum static friction as negative, because it's pointing in the negative direction on our x-axis -- up the ramp.

So, adding them together, we get this equation. Multiplying together the different values that make up (mg)(sin)(theta), we find that it's equal to 196.20 Newtons. And the maximum static friction is just equal to the (coefficient of static friction) x (the normal force) -- so, plugging in the numbers, we find that it's 169.91 Newtons. Which means that the net force is 26.29 Newtons.

So, yes, there's a net force pushing the box down the ramp, and it's going to slide. Which means I have some bad news for you about that vase...

But today, you learned about the two types of friction: kinetic friction and static friction, and how they act to resist applied forces. We also talked about how to use friction to describe an object's motion, including how to calculate the normal force when that object's on a ramp. Finally, we calculated whether a box on a ramp would start sliding down. This episode of Crash Course Physics is supported by Audible.com Right now, Audible is offering viewers a 30-day trial period. Just go to audible.com/crashcourse. You can access their audio programs and titles, like this book - The Tao of Physics by Fritjof Capra. My plan is to listen to this on my flight back home this week... it's a long flight. Go to audible.com/crashcourse – and make sure you use that link to help us out, and to get your membership trial.

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