Newton's Laws: Crash Course Physics #5

Crash Course: Physics
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===== Introduction (00:00)=====
We've been talking a lot about the science of how things move, You throw a ball in the air and there are ways to predict exactly how it will fall.

But there's something we've been leaving out: Forces and why they make things accelerate. And for that we're going to turn to a physicist you've probably heard of: Isaac Newton.

With his three laws published in 1687 in his book Principia, Newton outlined his understanding of motion and a lot of his ideas were totally new. Today, more than 300 years later, if you're trying to describe the effects of forces on just about any everyday object , a box on the ground, a reindeer pulling a sleigh or an elevator taking you up to your apartment, then you're going to want to use Newton's laws. And yes, I'll explain the reindeer thing later.

[Crash Course Intro plays]

===== Newton's First Law (0:53) =====

Newton's first law is all about Inertia, which is basically an object's tendency to keep doing what it's doing. It's often stated as:
"An object in motion will remain in motion, and an object at rest will remain at rest, unless acted upon by a force." Which is just another way of saying that to change the way something moves, to give it acceleration, you need a net force. So how do we measure inertia?

Well, the most important thing to know is mass. Say you have two balls, that are the same size, but one is an inflatable beach ball and the other is a balling ball. The balling ball is going to be harder to move and harder to stop once it's moving, it has more inertia because it has more mass. Makes sense, right? more mass means more stuff with a tendency to keep doing what it was doing before your force came along and interrupted it.

===== Newton's Second Law (1:36) =====

And this idea connects nicely to Newton's second law: "Net force is equal to mass times acceleration."

Or as an equation: (Fnet = ma). It's important to remember that we're talking about net force here, the amount of force left over once you've added together all the forces that might cancel each other out.

Let's say you have a hooky puck sitting on a perfectly friction-less ice rink. And I know they're not usually perfectly friction-less but stick with it. If you're pushing the puck along with a stick, that's a force on it that isn't being canceled out by anything else. So the puck is experiencing acceleration.

But when the puck is just sitting still, even when it's sliding across the ice after you've pushed it, then all the forces are balanced out. That's what's known as equilibrium. An object that's in equilibrium can still be moving, like the sliding puck, but its velocity won't be changing. It's when the forces get unbalanced, that you start to see the exciting stuff happen.

And probably the most common case of a net force making something move is the gravitational force. Say you throw a 5 kg ball straight up in the air - and then, you know, get out of the way because that would really hurt if it hits you. But the force of gravity is pulling down on the ball, which is accelerating downward at a rate of 9.81 m/s^2. So the net force is equal to m*a, but the only force acting here is gravity. This means that, if we could measure the acceleration of the ball, we'd be able to calculate the force of gravity. And we can measure the acceleration- it's 9.81 m/s^2, the value we've been calling small g. So the force of gravity on the ball must be: 5 kg (which is the mass of the ball) times g. Which comes to 49.05 kg(m)/s^2.

We use this equation for gravity so much that it's often just written as F(g) = mg. that's how you determine the force of gravity, otherwise known as weight.

Now those units can be a bit of a mouthful, so we just call them Newtons. That's right we measure weight in Newtons, in honor of Sir Isaac, and NOT in kilograms! Kilograms are a measure of mass.

But gravity often isn't the only force acting on the object. So when we're trying to calculate the net force, we usually have to take into account more than just gravity. This is where we get into one of the forces that tends to show up a lot, which is explained by Newton's third law.

===== Newton's Third Law (3:45) =====

You probably know this law as "for every action, there's an equal but opposite reaction." Which just means that if you exert force on an object, it exerts an equal force back on you. And that's what we call: a normal force "normal" in this instance
means perpendicular and the normal force is always perpendicular to whatever surface your object is resting on. At least, it is when you're pushing on something big, and macroscopic, like a table.

If you put a book down on a table, the normal force is pushing -and therefore pointing- up. But if you put it on a ramp, then the normal force is pointing perpendicular to the ramp.

Now the normal force isn't like most other forces, it's special, because it changes its magnitude. Say you have a piece of aluminum foil stretched tightly across the top of a bowl, and then you put one lonely grape on top of it. Because of gravity, that grape is exerting a little bit of force on the foil, and the normal force pushes right back with the same amount. But then you add another grape, which doubles the force on the foil, in that case the normal force doubles too. That will keep happening until eventually you add enough grapes that they break through the foil. That's what happens when the normal force can't match the force pushing against it.

But, what does Newton's famous third law really mean, though? When I push on this desk with my finger right now, I'm applying a force to it, and it's applying an equal force right back on my finger - one that I can actually feel.

But if that's true - and it is - then why are we able to move things? How can I pick up this mug? Or how can a reindeer pull a sleigh? Basically, things can move because there's more going on than just the action and reaction forces.

For example, when a reindeer pulls on a sleigh, Newton's third law tells us that the sleigh is pulling back on it with an equal force. But the reindeer can still move the sleigh forward, because it's standing on the ground. When it takes a step, it's pushing backward on the ground with its foot, and the ground is pushing it forward. Meanwhile, the reindeer is also pulling on the sleigh, while the sleigh is pulling right back. But the force from the ground pushing the reindeer forward is stronger than the force from the sleigh pulling it back. So the animal accelerates forward, and so does the sleigh.

So, one take away here is that: there would be no Christmas without physics!

===== Applications to Newton's three laws of motion (5:53) =====

But now we have an idea of some of the forces we might encounter, let's describe what's happening when a box is sitting on the ground.

The first thing to do, which is the first thing you should always do when you're solving a problem like this, is draw what's known as a free body diagram. Basically you draw a rough outline of the object, put a dot in the middle and then draw and label arrows to represent all the forces. We also have to decide which direction is positive, in this case we'll choose up to be positive.

For our box the free body diagram is pretty simple. There's an arrow pointing down representing the force of gravity, and an arrow pointing up representing the force of the ground pushing back on the box. Since the box is staying still, we know that it's not accelerating, which tells us that those forces are equal, so the net force is equal to 0. But what if you attach a rope to the top of the box, then connect it to the ceiling so the box is suspended in the air? Your net force is still 0, because there's no acceleration on the box. And gravity is still pulling down in the same way it was before. But now, the counteracting upward force comes from the rope acting on the box, in what we call the tension force.

To make our examples simpler, we almost always assume that ropes have no mass and are completely unbreakable -- no matter how much you pull on them, they'll pull right back. Which means that the tension force isn't fixed. If the box weighs 5 Newtons, then the tension in the rope is also 5 Newtons. But if we add another 5 Newtons of weight, the tension in the rope will become 10 Newtons. Kind of like how the normal force changes, with the grapes on the foil. But in this case, it's in response to a pulling force instead of a push. The key is that no matter what, you can add the forces together to give you a particular net force -- even though that net force might NOT always be 0, like in an elevator.

So let's say you're in an elevator -- or as I call them, a lift. The total mass of the lift, including you, is 1000 kg. And its movement is controlled by a counterweight, attached to a pulley. The plan is to set up a counterweight of 850kg, and then let the lift go. Once you let go, the lift is going to start accelerating downward - because it's HEAVIER than the counterweight. And the hope is that the counterweight will keep it from accelerating TOO much. But how will we know if it's safe? How quickly is the lift going to accelerate downward?

To find out, first let's draw a free body diagram for the lift, making UP the positive direction. The force of gravity on the lift is pulling it down, and it's equal to the mass of the lift x small g -- 810 Newtons of force, in the negative direction. And the force of tension is pulling the lift UP, in the positive direction. Which means that for the lift, the net force is equal to the tension force, minus the mass of the lift x small g.

Now! Since Newton's first law tells us that F(net) = ma, we can set all of that to be equal to the lift's mass, times some downward acceleration, -a. That's what we're trying to solve for. So, let's do the same thing for the counterweight. Gravity is pulling it down with 8338.5 N of force in the negative direction. And again, the force of tension is pulling it up, so that the net force is equal to the tension force, minus the mass of the counterweight times small g.

And again, because of Newton's second law, we know that all of that is equal to the mass of the counterweight, times that same acceleration, "a" -- which is positive this time since the counterweight is moving upward. So! Putting that all together, we end up with two equations -- and two unknowns. We don't have a value for the tension force, and we don't have a value for acceleration. But what we're trying to solve for is the acceleration. So we use algebra to do that.

When you have a system of equations like this, you can add or subtract all the terms on each side of the equals sign, to turn them into one equation. For example, if you know that 1 + 2 = 3 and that 4 + 2 = 6, you can subtract the first equation from the second to get 3 = 3. And in our case, with the lift, subtracting the first equation from the second gets rid of the term that represents the tension force. We now just have to solve for acceleration -- meaning, we need to rearrange the equation to set everything equal to "a."

We end up with an equation that really just says that "a" is equal to the difference between the weights -- or the net force on the system -- divided by the total mass. Essentially, this is just a fancier version of F(net) = ma. And we can solve that for "a", which turns out to be 0.795 m/s^2. Which is not that much acceleration at all! So, as long as you aren't dropping too far down, you should be fine. Even if the landing is a little bumpy.

In this episode, you learned about Newton's three laws of motion: how inertia works, that net force is equal to mass x acceleration, how physicists define equilibrium, and all about the "normal" force and the "tension" force.

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