

RES.TLL-004 STEM Concept Videos, Fall 2013

Transcript – Newton’s Laws

The motion of objects we’re familiar with –things like a football traveling toward the goal; a figure skater being tossed in the air; two cars colliding – the motion of these objects is governed by Newton’s Three Laws. In this video we’ll use the laws to describe a few complex physical situations in detail, so that you can appreciate the universal nature and broad applicability of these laws.

“Hello. My name is Deepto Chakrabarty. I am a professor in the EECS department at MIT, and today I’ll be talking with you about Newton’s Laws. You’re probably already familiar with Isaac Newton’s three laws from your previous courses – the Law of Inertia, $F = ma$, and the law of equal and opposite reactions – but you may not have seen them used to describe real-world phenomena. This is a shame, as these three laws and their rotational equivalents govern every interaction we see around us. They’re really quite pervasive.

“Here are the particular situations that we’re investigating today.

“This is a crash test of the Volvo C30.”

“And this is a head-on crash test between a 2009 Chevy Malibu and a 1959 Chevy Bel Air.”

“And this is a 2010 Ford Ranger colliding with a 2008 Changan Tiger Star.”

“For contrast, we have a video of a pairs figure-skating championship.”

“We’ll be investigating these videos from several different angles. As we go along, see if you can spot some good places to illustrate Newton’s Laws.”

“Newton’s First Law states that objects in straight-line motion will remain in that same straight-line motion until a force acts on them. Likewise, objects at rest will remain at rest in the absence of an outside force. Let’s look in our videos for places where we can see Newton’s First Law at work.”

“The most obvious place to see this is as the cars come in before the crash. Only the force from the crash stops them from continuing their initial straight-line motion. However, there are many other places where we can see the law of inertia at work.”

“Here we see the Volvo C30 in mid-crash.”

“We can see these objects here, which have exited the vehicle and continued their forward motion. Not enough backwards force was exerted to keep them in the car.”

“Similarly, in the Chevy crash, we can see the headlight from the Malibu exiting the vehicle entirely. It continues more or less straight forward as the cars rotate around each other. Its motion is clear in several different clips, such as this one... and this one. Interestingly, the Bel Air also loses its headlight, here.”

“In figure skating, the First Law has an important effect: the woman is tossed upward and comes right back down into the man’s arms despite the fact that both are moving forward. The low friction on the

ice allows the man to move forward without slowing, and the up-and-down forces from the throw have no effect on the skaters' forward velocity."

"In this view of the Volvo we can see a vertical spray of liquid. What does the direction of the spray tell us about the car?"

"Because the liquid is moving generally upwards (rather than forward), we can guess that it was ejected once the part of the car it came from had already come to a halt."

"A particularly subtle instance of the First Law can be seen here, on the bottom mirror of the Volvo. You can see it bend forward as the car comes to a halt. We'll come back to this again when we discuss the Second Law and rotation."

"You can see that even something as simple as the First Law has many applications."

Chapter Break

"Now let's look at Newton's Second Law. The Second Law defines force as a change in momentum. We often simplify it by assuming our object's mass will stay the same and talking about only the change in velocity."

"With the skaters we can see a simple application of the Second Law: one force pushes them upwards into their jumps, and another pulls them back down to the ice."

"The change in velocity created by a force can be in any direction, positive or negative; x, y, or z. We'll set the forward direction for the Volvo as our positive x direction here.

"If the car is moving in the +x direction, its acceleration during the crash must be in the -x direction. Remember that we still call it "acceleration" even if, outside of class, we might think of it as deceleration."

"Because the acceleration is in the negative x direction, the force is too."

"While we're used to thinking of force as starting an object's motion, it works just as well to stop it."

"We can see this on the Chevy crash too."

"The force, acting against the direction of motion, slows the vehicles so that they make much less forward progress."

"It's important to remember that force in one direction doesn't change your velocity in another direction. You can see this during this lift in the skating video. The skaters continue forward at the same rate even though there are clearly forces acting in the vertical direction."

"We can also find applications for the rotational version of Newton's Second Law. It's on the screen to refresh your memory."

(pause)

"A subtle place to see this law at work is on the driver's side mirror for the Volvo. What makes this mirror rotate?"

"The mirror moves forward due to the law of inertia, but it rotates in the process because of a force applied on it by the hinge where it is attached. As you can see, the force is off-center on the mirror, which causes it to acquire an angular velocity."

"A not-so-subtle place to see this at work is in the Chevy crash."

"Each car feels a force from the other. Since the collision happens somewhat off-center, the cars are rotated by the force. Inertia allows them to continue forward during this process."

"We can see in this series of diagrams that the force is applied only when the cars are in contact with each other."

“We’ll come back to this situation when we talk about Newton’s Third Law.”

Chapter Break

“Newton’s Third Law is all about interactions between objects. It states that when one object exerts a force on another, the second object exerts the same strength of force back on the first. You can imagine that it will be very important when it comes to car crashes. Despite that, it’s not always easy to see that the third law is in effect, especially when the objects have different masses. Let’s take a look at some examples.”

“We can see the third law most clearly in the Chevy crash. Each vehicle is slowed; each one is deformed and damaged by the crash. We can see the dramatic effects of the forces on both objects, and because the cars had comparable velocity and mass, we have an instinctual feel that the forces on the two cars are equal.”

“Watch the velocity of the skaters carefully during this throw. The man slows down as he throws the woman, and she moves forward more quickly. You can see that the forces on them must be acting in opposite directions.”

“If we compare this to the previous throw, we can see that the direction of the force makes all the difference in the vertical versus the horizontal movement of the skaters.”

“We can also understand the effects of the third law in the truck crash. The Changan is lighter, and because the forces are the same, it ends up moving backward.”

“In the Volvo crash, the third law is more difficult to see at work. We can see the “action” as the C30 crumples around the pole, but where is the “reaction?” The pole doesn’t move; in the top view we can detect only a slight wobble. Where is that reaction force?”

“You can see here that the pole is braced by hefty steel struts. Those struts are themselves braced against a reinforced wall, and that wall is anchored to the floor. The force involved, while clearly high enough to demolish a car, isn’t enough to break the wall off the building’s foundation. Just because we can’t see the reaction force’s effect doesn’t mean that it wasn’t there.”

“Newton’s Laws are over 400 years old. It is a tribute to their effectiveness and universal nature that we still use them today. While there are limits to their usefulness in discussing electromagnetism, quantum-scale objects, or relativistic situations, they remain vitally important tools for examining and describing the day-to-day world. I hope that this video has helped you appreciate how effective they can be in the right context.”

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