Physics of Ice Skating: The Joy Of Physics

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1 Slipperiness

1.1 Intro.

We're going to start our talk tonight with a question we'd like you to consider: Why is ice slippery? Now that I've given you a couple seconds to think about that, could I get a brave volunteer to share what came to your mind? Anyone? I knew it would be a bad idea to start the talk with a rhetorical question, I'm just going to start over from the beginning. (pause, turn and face away from audience for 3 seconds, turn back around, smiling) Fat penguin. Sorry, I just wanted to break the ice.

Seriously though, any volunteers for why ice is slippery? Well, I'll volunteer a reason. And please just play along with me for a little bit. I think Ice is slippery because it is cold. This is what scientists do in general, we ask questions, come up with a plausible answer, then test whether that answer is correct.

1.2 Poking the Universe

We're going to do some science right now and test: if something is colder, is it more slippery? We've brought with us some liquid nitrogen.What we are actually wondering when we ask if something slippery is what the coefficient of friction is. So when I say the word "coefficient of friction" just think "slipperiness" We test it by putting an object on top of an angled surface so that it just barely starts moving. Using the angle the surface is tilted, we can calculate what the coefficient of friction is. What we've done here is fixed the angle so that a metal block will just *barely* start moving if we place it on the ramp. Now if we cool it down and the coefficient of friction (slipperiness) changes, then it will either not slide down the ramp, or slide down a lot more quickly. Let's see what happens. We can also try it with another material, wood, and see if the results are consistent.

So we find out that coldness does not determine, or even increase slipperiness. We, of course, could have arrived at this solution simply by observing that concrete doesn't become more slippery when it's 90 degrees out versus 20 degrees.

This is at the heart of what physicist, and in general scientists, do. We ask a question come up with a possible answer, and then test whether that answer is correct. As an experimental physicist, I actually get to poke the universe and see what happens, while Andrew does the same thing but there isn't actually physical poking, he writes computer code to simulate the poking.

1.3 The real answer

So what is the real answer though? Why *is* ice is slippery? It turns out that this is a more difficult question than you would think, and it wasn't until the year 2000 that we obtained experimental evidence for our current best explanation of Ice's slidiness. The best explanation that scientists have so far is that the surface of ice is not as smooth as it seems and has ragged protrusions on the surface. When you step on the surface these break off and form a small layer of liquid, similar in consistency to slush. When I say slush, I'm of course referring to a liquid with the same consistency as a certain popular cold beverage commonly sold in convenience stores.

When you step on the ice, this quasi-liquid layer is created, and the ice particles act like little roller-balls underneath your feet, causing you to slip and fall. If you're thinking like a physicist now, you'll ask yourself, "Wait, would having little roller-balls underneath my feet really be *that* slippery." A comprehensive search of the literature (in this case, when I say literature, what I actually mean is YouTube) provided no experimental evidence for this claim, but we were able to find a close approximation to the rollerballs that gives this claim some credibility (* video of Home-Alone car slipping scene. *)

In addition, the scientists that experimentally discovered why ice was slippery also discovered that if ice didn't have this quasi-liquid layer, it would be just as slippery as wet concrete, which isn't that slippery!

2 Controlling Slippery/ Skate Design

If ice is really so slippery, how are we able to move around on ice skates? This is of course because of the skate blade's design. When we skate across the ice, the metal blade points in the direction of our motion and allows us to easily travel. If it allows us to easily travel forward, the same has to also be true for backward, which leaves us with a problem. How can we move forward if when we try to push off our skate slips on the ice? The answer is that we must use the sides of the blade to push off. (* Diagram of angling skates versus direction*)

If you look at the bottom of a skate, you might be surprised to see that it looks relatively flat, rather than being sharpened to a point. If you look still closer, you'll see that though it looks flat from afar, it actually is concave, a word which here means that the edges of the blade go down further than the center of the blade, giving in effect, two small edges that are skated upon. These edges dig in to the ice when they are pushed from side to side (rather than forward and backward) and prevent the skate from slipping in that direction. If this concavity were absent, ice skates would be just about as effective as skating on ice as tennis shoes- or as effective as, say, the hooves of a pig. (show video of pig slipping all over ice). When the surface is completely flat, You lose the ability of the skate to dig in and they just slide every which-way across the ice.

3 Linear Motion

As physicists, we love ice because it gives us a frictionless surface on which to play on. We hate friction, because it causes energy to magically disappear from where we can measure it, into pesky things like heat and sound. One of a physicists favorite things is conservation laws. Energy is always conserved. Momentum is also always conserved. Momentum is something that people are often familiar with, but in physics it has a very specfic definition- an object's mass multiplied by its velocity. Here's a beautiful example of momentum being conserved. If we have two people standing next to each other on an ice rink one is a football player, the other a cheerleader. The two people aren't moving, so each of their velocities is zero. If the velocities are zero, then the momentum is also zero, and the total momentum of the system is- you guessed it, zero. What do you think happens if they push off of one another?

Because we know that the total momentum is conserved, we know that it will still be zero. But we also know that they'll move away from each other! How can the total momentum be zero if they're both moving? Direction matters! One is a positive value, and the other is negative, and their numbers exactly match each other. Negative numbers to the rescue! But the cheerleader will move much more quickly than the football player because he or she has a smaller mass. In fact, the veolcity of the cheerleader will be inversely proportional to their own mass, and directly proportional to the mass of the football player and the football player's velocity.

There's a side point that I'd like to make here. As you can already tell, describing how the world behaves with words starts to get really cumbersome. It's no secret that we physicists love equations, and now you can hopefully understand why. I find that many times people say they enjoy learning about physics, but don't like the math and equation part of it. If I don't use math and equations, then to explain what happens I have to say this: (show slide with all the words that I used to describe the problem earlier) But if I use equations, I can just say this: (Show slide with momentum equation). They communicate a wealth of information in a very small space.

Conservation laws are one of the foundations of physics, and they also help to explain one of the most interesting phenomena in Ice skating: how the people can manage to spin around in circles so quickly.

4 Circular Motion/Angular motion

(* Show video of ice skater spinning very quickly *) You see, what is true about things moving in a straight line- momentum being conserved. Is also true about things that are rotating about a point. We call it conservation of angular momentum, and it has a couple of key differences from the linear case. Just like linear momentum, angular momentum depends on the velocity of the object, this time the angular velocity, or how fast it is spinning. Now instead of multiplying the velocity by mass, it's multiplied by something called a moment of inertia. The moment of inertia is something that you usually use calculus to calculate, so we're not going to talk about it too much. What's important for this discussion is that the moment of inertia depends on the shape of the thing that's spinning. If more stuff is further away from the center of the spin, then it will have a large moment of inertia. If the same stuff is closer to the center of the spin, it will have a smaller moment of inertia. We multiply the moment of inertia by the angular velocity and we angular momentum, which is always conserved.

We have an excellent way to show this here. This is called a Haberman's sphere. It's a cool toy that can expand or contract to many times its original size. We just learned about moment of inertia, if we were to spin this on the string its hanging on while its expanded, does it have a small, or large moment of inertia? Yes, Large. And then we pull the string, what happens to the moment of inertia? Correct again, it gets smaller. Let's see conservation of momentum in action: (* Do demo of haberman's sphere *)

So now we start the sphere turning while its expanded, and since we know it has a moment of inertia, and now an angular velocity, the angular momentum, L, also has a value that's fixed in size. If I were then to pull the string, we change the moment of inertia, but since angular momentum is *conserved* the L value has to stay the same size, that means that what has to happen to the angular velocity? Right, I gets smaller, but L has to be the same size, so it spins faster.

Since neither Andrew or I are trained Ice Skating professionals, we can't demo this for you on ice, but we have a close approximation with this rotating disc. (Depending on time, either one of us can do it or we can call up a volunteer). You begin a spin with your arms extended out away from you. Once the spin has begun, you bring your arms closer to your body, the spinning center. This reduces your moment of inertia, but your total angular momentum has to say the same, so you start spinning faster.