The Physics of Donkey Carts (English)

Have you ever had a bad morning? The bicycle chain came off the sprocket on the way to school. Or the car ran out of gas and wouldn't start. We understand and we can fix these problems. But what happens when our donkey won't start?

Hello. My name is Naveed Malik, and I'm associated with the Virtual University of Pakistan. In today's Blossoms module, we are going to talk about physics, and the everyday things that we observe and happen all around us. And we have chosen an interesting topic for you. It is the physics of donkey carts.

But before we get to the physics of donkey carts, we have to understand, basically, what are the laws that govern the world around us. You know when we pick up a thing and place it another place, at another point, we are talking about laws of physics. When we see a crane in operation, some other set of laws is working. We pick up a heavy weight, the whole body acts as a complicated machine, all governed by laws of mechanics and physics.

One thing, of course, we must understand that it is not that physics or the world around us is governed by these laws. It is as human beings we find simple ways to explain the phenomenon that we observe. And these other laws that we devise to explain these phenomena.

Now, probably the most well known set of laws that explain the mechanical things that we observe Newton's Laws of Motion, which he stated in 1687 or thereabouts. Now, these laws are very simple and straightforward, but sometimes there is a problem in understanding their implications. Let us look at the First Law. The First Law states every body remains in a state of rest or uniform motion-- that is constant velocity-- unless it is acted upon by an external force.

Now take a look at this keyboard. It is lying on the desk, and it is not moving. It seems that the First Law seems to be working. There is no external force on it, so it is sitting at rest. Of course, there's no net external force on it. All forces on this keyboard are actually balanced. When we think in terms of the second half of the law, it is slightly difficult to come up with a thought experiment that explains it, which is that if a body is moving, it will continue with constant velocity, which means with a constant speed, in a straight line, in a given direction, unless it is acted upon by some other external force.

When we talk about the Second Law, Newton's Second Law says that when a force acts on a body, then it creates an acceleration in that body which is proportional to the mass and proportional to the force. Now, force and acceleration, as you understand, are both vectors and mass is the constant that relates them.

The Third Law is very, very interesting. The Third Law states, and again, I quote, and this is from Wikipedia, "the mutual forces of action and reaction between two bodies are equal, opposite, and collinear." In simple words, "this means that whenever a first body exerts a force F on a second body, the second body exerts a force -F on the first body. F and -F are equal in magnitude and opposite in direction." Sometimes the interpretation of the Third Law leads to complications. However, before we get there, let us take a look back at our keyboard.

Now this keyboard is actually exerting a force downward due to gravity, which is equal to its weight. Now when I place it back on the table, according to the Third Law, the table exerts exactly an equal and opposite force upwards onto this keyboard. If you consider the keyboard alone, it has a force downwards due to its weight, and an exactly balancing force upward due to the force exerted on it by the tabletop. And basically the forces are balanced, and the keyboard stays where it is.

Let us see if we can prove this through a very simple experiment. It's actually going to use some very simple apparatus like kitchen scales, but it's a little delicate to set up. So let us see what happens.

Let us see if we can look at the Third Law through a simple but very interesting experiment. What I have in front of me are two kitchen scales. A little space age-y, but they're regular kitchen scales that you might find in your mom's kitchen.

Now the interesting thing with these scales, and I had to look around for them, is that they're based on load cell, which means they have no moving parts whatsoever. And whatever load we place on the glass surface, the weight is reflected in the digital display over here. Now we've got two scales. What I'm going to do is turn both of them on, set the units to grams, and I have a reading of zero grams. I pick up one scale, and I put it on top of the other.

Any guesses as to what the readings are? What would be the reading on the upper scale? Simply zero. There is no load on the glass at this time, so the upper scale reads zero. As far as the lower scale is concerned, it reflects the weight of the upper scale. And that is reading at this time 500 grams, exactly. So interestingly, the upper scale reads nothing. The lower scale reads 500 grams.

Just as an aside, let's do something interesting. I take my cell phone and I put it on top of the upper scale. What do I see? I see a reading of 188 grams on top, and 688 grams on the bottom scale, which is as it should be. The bottom scale is reading the weight of the upper scale plus the weight of the cell phone, while the upper scale is only reading the weight of the cell phone. Anyway, that was just an aside.

Since there is no load on the upper glass, the reading on the upper scale is zero. But what happens if I turn it upside down? Now, if Newton's Third Law is correct, whatever load the upper scale exerts on the glass off the lower scale, it will be reciprocated by an equal and opposite force upwards onto the glass of the upper scale. So if I were to do this. there should be an equal and opposite force on this glass, and we should be able to see the reading here.

So first of all, let me zero it out. And we have it zeroed out while in inverted position. Now very gently, I'm going to lower it onto the scale on the table. And let us see what the readings are. OK? The lower scale reading has already stabilized to exactly 500 grams, which is what it was earlier. It doesn't matter whether I placed it right side up or upside down, the reading should be the same.

Let us see if I can take a peek at the reading on the upper scale. So I go down, do some acrobatics, and guess what? What I see is 499 grams, which is well within the error limits of these two scales. Maybe there was a just slight misadjustment in the tear setting, but a 1-gram difference? I see 500 grams here. Essentially, I see 500 grams on the upper scale. Equal and opposite forces. The Third Law works.

I think we've seen that Newton's Third Law works, but coming back to our donkey-- remember? We can't forget him. He wouldn't start-- it seems he has acquired a shallow understanding of the Third Law. Let us see what he did.

Basically, our donkey puts forward this argument. He says, according to the Third Law, when I try to pull the cart forward, with a certain force F, the cart actually exerts a force backwards exactly equal to that F. In other words, it exerts a force -F on me. Since the forces are equal and opposite, this cart and myself, we're not going anywhere. So why even bother pulling the cart? Now the interesting question is do you agree with the donkey's understanding of the Third Law?

Now we've all seen donkey carts moving on their own. Well, at least I have. I hope you've seen some kind of animal-drawn vehicles on the road or somewhere. In a movie perhaps? So you would understand that these vehicles do move. So there must be something wrong in the donkey's understanding of the Third Law. What I want you to do now is to debate and discuss the issue in the class, and try to gain an understanding where is the fallacy in the donkey's reasoning. And I will see you in about five minutes.

Welcome back. I sincerely hope none of you agreed with the donkey. See, the trick in understanding the Third Law is to understand that the donkey and the cart are two different physical entities. When we are talking about forces and the action on the bodies, we have to consider them separately.

For example, if we consider just the donkey. Yes, the donkey exerts a force on the cart, and there is a -F force coming from the cart onto the donkey. But what we have not considered, or what the donkey didn't consider, was the fact that his hooves were pushing against the road. So there was a net forward force onto the donkey, and he would have moved forward if he had chosen to apply his mind and do so.

The situation with the cart is actually much simpler. The card has a load which is pointing downwards due to gravity. It doesn't affect the forward motion of the cart. And the net force exerted in the forward motion by the donkey only has to counter the forces of friction in the axle off the carts wheel.

So in fact, the donkey cart would move. The donkey should have worked and should have applied himself, and pulled the cart along the road. Now this point is quite subtle. And you have to understand that whereas the forces may be equal and opposite, the effect of these forces may be quite different.

If you consider the fact that a moth fluttering in the air meets the windscreen of your vehicle as you're driving down the highway, the force exerted by the moth on the windscreen is exactly equal and opposite to the force exerted by the windscreen on the moth. Unfortunately, the situation is quite desperate for the moth, because he explodes into a million pieces. And of course the windscreen doesn't even know what happened.

Same thing you can think in terms of dropping an egg onto the floor. The egg and the floor would exert equal and opposite forces on each other, except that the egg would smash, and there would be nothing wrong with the floor other than it getting dirty.

Let's continue and take a look at this desk. For example, if I were to try and push it, there would be a certain amount of force that I would exert on the desk, and according to the Third Law, an equal and opposite force would be exerted on me. So let's see if we can do that. So I do this, and it's OK. Notice I haven't fallen over. Although my center of gravity is about here, and it's pulling me downwards. I can't lean over infinitely, but I lean against the desk.

In fact, I'm pushing against the desk, but I don't fall over, because the desk is pushing backward towards me. But if that was the only force on me, I should have fallen over backwards. There is a second force, and that is the force of friction of my feet on the ground. So the two forces balance and I stay in the same position.

Now if we change the object against which I push or lean, the situation changes dramatically. For example, I try to do the same thing with the chair. What happens? If I were to let myself go, we would both go crashing onto the floor. And I'm sure you don't want me to do that. The reason is whereas the force exerted by my hand on the chair is exactly equal and opposite as the force being exerted by the chair on the hand, now the masses are different. So it does depend on which body is exerting how much force on which other body.

As far as the action of the body itself is concerned, you have to treat it as an independent entity. You have to look at all of the forces on the chair and not worry about me. Or if you're worried about me, you have to only consider the forces acting on my body and not worry about the chair or the desk. I would now like you to do some experiments in your class with your teacher, and try to understand the implications of all of these forces and the equal and opposite reactions that we've been talking about. And I will see you in a few minutes.

Welcome back. Continuing with our saga of a bad morning, you could have put the chain back onto the sprocket, and ridden your bike off merrily to school. You could've sent somebody off and got a tankful of gas, put it in the car, started the engine. But what do we do with a donkey that doesn't start? Well, what we did was we changed the donkey. And for good measure, we changed the cart as well. And since the owner might also have had some part in educating the donkey incorrectly about the Third Law, we changed the donkey cart owner as well. Let us see what happened.

What we saw was the cart proceeding merrily on the road, until they came to an intersection, and there was a red light, and the cart had to stop. The donkey tried to get the car to stop, couldn't really manage it, and therefore the cart owner had to jump off and assist the donkey and bring the cart to a halt.

Now here's the challenge for you. What I want you to do is to discuss amongst yourselves, and try to discover exactly what were the forces acting on the cart. What was required to make it stop? Why did the cart owner jump off and try to stop the cart and assist the donkey? And how was he able to do so? Look at each and every aspect, and look at it from a perspective of physics. OK? Let me give you a broad hint. It has to do with friction and surface areas. And I'll see you in just a few minutes.

Now what you would have seen is the donkey trying to stop the cart. And you must have wondered why he was not able to do so. For those of you who've actually seen an animal-drawn vehicle, like a donkey cart or a bullock cart, or seen movies, you will realize that these carts do not have any brakes. It is the poor animal in front who has actually got to apply the braking force. How can they do that? They can only do that, by trying to put their hooves and their muscles to work along the road surface and try to pull the cart, in a way, get the cart to stop.

In this case, the donkey has these little tiny hooves. He's got a big load at the back of bricks and cement and whatever else, including the donkey cart owner. And he's simply not able to bring the cart to a stop. So the owner jumps off, and holds one side of the cart, and plants his big feet on the ground, and assists the donkey. Now again, it's the force of friction of the cart owner's shoes against the road, in combination with the friction of the donkey's little hooves on the road, that eventually brings the cart to a stop.

Now friction and surface areas are a whole another topic, and we could actually get into a sideline discussion, but I would like you to observe a few things around yourself. Look at the sizes of the brakes on the vehicles that you see around you. If you look at your bicycle, you'll notice that there are these little tiny caliper brakes around the rim that causes the wheel to stop. On a motorcar, you will see disk brakes in front. Most of the time now, there are disk brakes at the back as well. Or they might be drum brakes. And they're about eight inches, ten inches in diameter. If you look at the same brakes on a bus or truck, they're quite big.

In fact, if you're waiting at the train station, try to look down at the wheels and see what are the size of the brakes on a train's wheels. And you'll realize that the calipers are on the outside of the wheel, so there's a huge radius and big huge calipers that are squeezing the wheels and getting it to stop. So it has to do with friction. It has to do with surface area, or the area of the two surfaces that rub against each other. And in a way, you come back to the donkey cart, you realize that the poor donkey's little feet were simply not able to bring the cart to a stop.

Well, the cart did come to a stop. But let's see what happened next.

Now that wasn't too much fun for the poor little donkey, was it? The cart did come to a stop, but he went airborne. I'm sure you might have experienced something like that, if your bicycle had a little carrier seat at the back, and you were sitting in front, and one of your fat friends came and jumped on to the back. The front wheel probably went up into the air. So, again, there's a very simple principle of physics that's at work here.

And your next challenge is to try and discover what is the principle under which this poor donkey went up into the air, what other laws that govern this behavior, and how we could come to these laws. So there you are. You discuss this. And try to discover in your classroom with your teacher what happened and how we could eliminate this effect. And I'll see you in a few minutes.

I think you know what principle we are talking about. It was the principal of levers that went to work here. The whole cart was a lever. The axle of the cart acted as the fulcrum. The bricks and the cement on one side were the load. And the donkey and perhaps the cart owner sitting on the side of the cart were the effort.

So the principle of levers, which basically states that the load into the load arm, which is the distance measured from where the load is applied to the fulcrum, is equal to the effort, the force that is being applied, times the effort arm, which is the distance from the fulcrum to the point where the effort is being applied. If they are equal, the lever will balance. If these forces are not equal, as was the case is for the donkey cart when they came to a stop at the red light. The donkey goes up into the air.

This, in fact, is exactly the same as something that you might have done when you were little children. In the playground, we have a device called a see-saw. Let's take a look at a couple of kids playing on a see-saw.

I really love this video. What we saw was that the girl was a little heavier than the boy. And if they sat at equal distances from the fulcrum, she could actually stay on the ground and keep the little boy up in the air for as long as she wanted. The lever was not balanced. The load into the load arm times the effort into the effort arm were not balanced.

When she took pity on the boy and essentially moved forward a little bit, the law didn't change but the load arm did. She reduced the load arm, so that the product of the load and load arm became equal to the product of the effort and the effort arm, if you call the little boy's weight the effort. And once the seesaw became balanced, they could actually play around, and one would go up and then the other would go up.

Tackling this problem through simple arithmetic, we didn't actually go out and weigh the kids, but we know that the see-saw was approximately six feet long on either sides of the spectrum. The girl's weight would be about 25 kilograms and the boy would be about 20 kilograms. And we know that 25 into six feet-- different units, but doesn't matter-- is not equal to 20 times six feet. In fact, the load and the load arm is much more than the boy's weight times the effort arm. And then the lever would always tilt in favor of the girl.

When she decided to move forward, we did do a measurement there. We discovered that she sat down at a place that's approximately 4.8 eight feet from the fulcrum. If you do the arithmetic and you can see this, we notice that 25 times 4.8 is exactly equal to 20 times 6. The lever equation is balanced, and they would then play merrily with each other on the see-saw.

There's some experiments planned for you in the classroom. I want you to play with the equipment-- it's very simple, a meter rule, some pencils, some weights-- and understand the principal of levers thoroughly. When we come back we will look at a practical real world device that uses this very principle and it's very interesting to understand it. So I'll see you in a few minutes.

OK, as promised, we have a new toy to play with. Interestingly, you remember we looked at some kitchen scales earlier on? There was a little bit of magic about them. They were digital. So There were no moving parts. They used a load cell which was not visible. We placed a load on top and magically some numbers appeared, which showed us what the weight of the thing was. There's nothing like that.

It's a very simple down to earth industrial scale, works on the basic principle of levers that we've been talking about. So let's just look at this machine and investigate it a little further. This big thing down here, this is the platform on which we place the load. Anything that we wish to weigh we would be putting it up here. I have with me some approximate weights-- a 20 kg block, a 5 kg block. Connected from this platform right up through this central channel is a rod, a lever, that comes up to this point over here.

Now so, if you think about it, the actual principle of levers is happening here. This is a lever. It has a fulcrum right in the middle here, behind this orange spot. This point over here is the rod coming up from the load platform and it is hooked up to the lever. So if you think about the load being there, then this over here is the load arm.

On the other hand, we would have an effort over here on this platform, so from the fulcrum to this point, this whole thing would be the effort arm. Now at the moment, there's no load on the platform, so if I were to relieve the lever, let us see what happens. And lo and behold, if you look at the close up here, you notice that this lever is floating. The whole system at the moment shows a state of balance, load into load arm is equal to effort into effort arm.

Now, how about putting some load on the scale itself? I hope I don't break my back. It's fragile. But let us move 20 kg block, and put it on top of the scale. OK. I think it's almost 20 kg. And I unlock this. It goes all the way up to the top. Why? Because the 20 kg load is pulling the lever down at this end from the fulcrum.

What should I hang over here so that we can balance this 20 kg block? Well, here are these little weights that one can put up there. Maybe this is too small. Perhaps this is tiny as well. That's very interesting. It has the number 20 written on it. I don't know if the camera can pick it up, but this has a number 20 written on it.

Let's see what happens if I put it down here. OK. Nothing moved. But are we close? Let's see. I think we are very, very, very close.

Let's do some trivial addition of a weight from here. And guess what? We have a lever that is floating once again. And that means load into load arm is equal to effort into effort arm. And that means that this little tiny piece of iron is able to counterbalance the 20 kilograms weight that we had in the form of probably bricks inside that brown paper bag. Can we really agree that there is a ratio of-- I don't know-- maybe 1 is to 100 for this scale?

Let's take a look at what the load arm and the effort arm look like. I have a simple measuring tape over here. The distance from the effort to the fulcrum over here, if you can pick it up, is almost 13 inches. So from here, all the way to the fulcrum, which is hidden behind this orange line, is 13 inches. On the other end, if I were to look at from the fulcrum to the load point, it is 1.3 inches, which is in fact exactly 1/10 of this length.

There is a similar factor of 10 which is actually built in to the base of this device. And therefore we actually get 10 times 10, a factor of 100, going from there to here. So this is not 2 kilograms. This is 0.2 kilograms. And this is able to counterbalance the weight of 20 kilograms. And notice that the lever is floating.

If I were to weigh myself-- I don't want to reveal my exact weight, that's for sure-- but I'm pretty certain that this is pretty close, and this is way too heavy. This little piece of counterweight is too heavy to weigh me. So it would probably sink the lever onto to the far side.

So very interesting. A very simple device that uses plain, simple physics, load into load arm equal to effort into effort arm. And we can weigh some really heavy weights. Much nicer, and it basically just doesn't fail. It's based on some very simple basic physics principles.

In this Blossoms module, we used some basic laws of physics to try and understand the things that we see happening around us. We started with Newton's Laws of Motion, and then using our donkey cart as a vehicle, we went all the way to the principle of levers. We also saw how a misinterpretation of the Third Law could lead to complications. I hope you gained some insight into basic physics from this module.

There are many other Blossoms modules, very exciting ones, that I hope that you will look at and make full use of. For the moment, I will beg leave, and let our donkey cart trot away merrily into the proverbial sunset. Bye-bye.