How the things work

Module 4 (RAMP)

Ramp I

Ramp introduction

Whenever something is too heavy to lift straight up, the simplest solution is often a ramp. As long as the slope of the ramp is gentle enough, and you have something like wheels to keep friction at bay, you can lift almost anything from here to there. You use ramps without even thinking about it. Whenever you drive or bicycle up a hill, you're using a ramp to lift yourself to that hilltop. Consider the alternative. Travelling straight up a cliff face to that hilltop. Not for everyone. Ramps are just as useful for lowering things as they are for lifting them. Suppose, for example, that you have a piano on a ledge and you want to lower it to the ground. Well, you can push the piano off the ledge and it will arrive at the ground, but don't expect it to be in tune when it gets there. You do a lot better to lower that piano. Much more delicately, more carefully, by taking it down a ramp. Ramps, also known as inclined planes, are one of the six simple machines. Doing something is of special significance in physics because it often involves the transfer of an important physical quantity, energy. The term energy is familiar, but people use that term to describe a broad range of concepts, only some of which are the physical quantity. One of my goals for this episode, then, is to explain what physicists mean when they talk about energy. For now, you can think of energy as the capacity to do things. As background, ramps come in all shapes and sizes. There are ramps that are long, and there are ramps that are short.

Why doesn't a wagon fall through a sidewalk?

The sidewalk pushes up on the wagon to prevent the two objects from occupying the same space at the same time. The sidewalk exerts what's known as a support force on the wagon. Support forces appear whenever two surfaces try to occupy the same space. My hands, for example. As I push them together, trying to make them overlap, the atoms, molecules, and materials that are my hands begin to push apart. Well, support forces act perpendicular to surfaces. Perpendicular is the ex-, sort of universal right angle. This stick is perpendicular to the surface of this book, meaning it is at right angles in every respect. And the stick actually is experiencing a support force when I push it against the book. Again, I am trying to make the two of them occupy the same space and they do not like that. The book pushes. Away, with a support force on the stick. And the stick is showing you the direction of the book's support force. There's another kind of force that acts along surfaces. That type of force is known as a frictional force. And we're going to leave frictional forces for the episode on wheels. For now, we're going to ignore friction and look only at support forces. And so, if we go back to the wagon, the sidewalk is pushing perpendicular to its surface on the wagon. And since the surface on the sidewalk is horizontal, its support force on the wagon is straight up. That upward force cancels the wagon's downward weight leaving the wagon here inertial and motionless. Evidently, the wagon and sidewalk push equally hard on one another. The sidewalk exerts an upward support force on the wagon, and the wagon pushes back exactly as hard on the sidewalk with a downward support force. Well, the wagon is motionless here, which means that it's inertial. It's not accelerating at all. So the net force on it must be zero. We know it has a weight, and yet it's not falling. So the support force from the wag, from the sidewalk on the wagon must exactly cancel the wagon's weight. And so it does. The sidewalk is perfectly supporting the wagon's weight. Well, before we go on to look at why the sidewalk chooses exactly that amount of force to exert on the wagon, let's take a look at Newton's Third Law, one last look at it, and recognize that so far I've only talked about three forces. The wagon's downward force on the sidewalk, the sidewalk's upward force on the wagon, and the wagon's downward weight. That's three forces, that's an odd number. And Newton's third law says that for every one force, there's an equal but opposite force around. We'll deal with this in the next section. We'll We're missing a force. The missing force is the gravitational attraction of the wagon on the earth. The one pair is the wagon's force on the sidewalk and the sidewalk's force on the wagon. The other pair is the earth's gravitational force on the wagon and the wagon's gravitational force on the earth.

Why does a sidewalk perfectly support a wagon?

We know that the wagon is perfectly supported because it's not accelerating. Its weight downward must be perfectly cancelled by the upward support force that the sidewalk is exerting on the wagon. But how does a sidewalk know how to exert that amount of force on the wagon? The answer to the question is, the wagon and sidewalk negotiate until the sidewalk perfectly supports the wagon's weight. That negotiation is real and it actually takes some time. Underlying it is the fact that there's no such thing as a truly rigid object. Everything dents slightly when you push on it and when it's pushing back on you. So when I push on the sidewalk, it dents a little as it pushes on my hands. The more I push on it the more it dents. But it's a lot easier if I pick a softer object like this spring scale that not only moves downward noticeable when it's pushing, when I'm pushing on it and it's pushing on me but there's the needle that shows you how much it is dented downward. So if I push gently on it it dents a little. If I push hard on it it dents a lot.

The same negotiation that occurs between the wagon and the spring scale also occurs between the wagon and the sidewalk. They negotiate briefly and, when the dust settles, the sidewalk is perfectly supporting the wagon's weight and the wagon is therefore inertial and motionless.

For example if I push on this wagon one of the forces acts on the wagon and causes it to accelerate. The other force in that Newton's third law pair, namely the, the, force that wagon exerts on my finger acts on me. And in principle it would cause me to accelerate. In fact, if I were on slippery ice, I would accelerate. Off I'd go in that direction, the wagon would go off to the right. Well, that's it for wagons on sidewalks. Now it's time to tip the sidewalk up to make it a ramp.

Ramps II

How Does a Wagon Move as You Let it Roll Freely on a Ramp?

The wagon accelerates downhill. Now, it's tempting to think that the wagon moves downhill. But that's not necessarily true. If I start the wagon heading uphill watch what happens to it. It initially is moving uphill. It comes to a stop and then it rolls downhill. So it's not necessarily moving downhill. While it's rolling freely. What you can say, though, is that it's always accelerating downhill. So if I let go of it from rest it starts from rest and develops more and more downhill speech, Why does a wagon on a ramp accelerate in that particular direction? And the answer to that, is, the net force on the wagon, once I let go of it, is downhill. And it's accelerating in the direction of the net force on it.

Why is it More Exhausting to Lift a Wagon Up Than to Lower a Wagon Down?

You transfer energy to the wagon as you lift it and you receive energy from the wagon as you lower it. Energy is an intangible physical quantity that can move from object to object. And people generally find it more exhausting to give energy away than to receive it. Energy is what's known as a conserved physical quantity. Meaning, that you can't create it or destroy it. You can only move it from object to object. Energy is the conserved quantity of doing. The more energy you have, the more you can do. The doing that I have in mind is what physicists call work. Work is a common word that has many meanings, only one of which is what physicists refer to as work. That, physicist work is the mechanical means of transferring energy. Doing work is analogous to spending money. When you spend money, you're transferring money from you to someone else. For example, if I put my hand under the wagon, push up on it, and cause it to move upward, I'm doing work on the wagon. I'm following the rules. I'm exerting an upward force on the wagon, you know this from experience, and you saw that the wagon moved a distance in the direction of my force. Therefore, I did work on the wagon and that means I transferred my energy to the wagon. The total amount of energy around in the world didn't change, but it did move in part from me to the wagon.

Why is it Easier to Pull a Wagon Up a Ramp Than to Lift it Up a Ladder?

The ramp allows you to lift the wagon using a smaller force exerted over a longer distance. Regardless of how you lift the wagon you have to do work on it, to raise its altitude from this to this. That increase in altitude comes with an increase in gravitational potential energy in the wagon. So you have to transfer a specific amount of energy to the wagon. To pay for that increase in altitude and therefore increase in gravitational potential energy. Suppose I want to lift this wagon from ground level to building entry level. I have two options. On the right I can go up to that ledge and lift the wagon straight up. In a very short distance I can manage to elevate the wagon from ground level to entry level. On the left I can go up the ramp. It's a much longer trip. I'll be pulling the wagon up, up the ramp, but I can still do the job of lifting the wagon from ground level to entry level.

Summary of Ramp

Ramps are simple machines that allow you to use gentle forces to lift and lower heavy loads. You exert those forces uphill as the, as the heavy loads move long distances along the ramp. The story of ramps is also the story of energy and work. It's the story of energy because energy is a conserved quantity that depends only on the situation. So, in this case, the wagon has a certain amount of energy. And now, The story of ramps is also a story of work because in going from this position to this position, you have to do a certain amount of work on the wagon to increase its gravitational potential energy from its low value to its high value.

Module 5 (Seesaw)

Seesaw I

Seesaw Introduction

Seesaws are a simple toy that consists of a long board mounted on a central pivot. Two riders get on opposite ends of that board, and adjust their positions until the seesaw balances. At that point then, they can begin to make the seesaw rock back and forth. Either by leaning toward or away from the pivot, or by pushing on the ground with their feet. When I was a kid, seesaws were everywhere. Nowadays, seesaws are becoming rarer and rarer. It seems that either they're risky, or perhaps modern children don't enjoy that sort of activity as much. Whatever the reason, they're missing an opportunity to experiment with rotational motion, balance, levers, and mechanical advantage. If you don't have a see-saw, well, you can make one yourself. All you need is some object to serve as a central pivot and a board to balance on that pivot. You adjust the spacings just so and. Voila, a seesaw. You can have it rock back and forth,

How does a balanced seesaw move? Why does a seesaw need a pivot? Why does a lone seesaw rider plummet to the ground? Why do the riders' weights and positions affect the seesaw's motion? Why do the riders' distances from the pivot affect the seesaw's responsiveness? How do the seesaw's riders affect one another?

How does a balanced seesaw move?

A balanced seesaw rotates steadily about a fixed axis. Now it's tempting to think that a balanced seesaw doesn't move at all. In fact, it's horizontal and motionless.Yes, a balanced seesaw can be horizontal, and it can be motionless. But it doesn't have to be. What a balanced seesaw does exhibit, however, is rotational inertia. If I set it spinning, it rotates steadily about a fixed axis. Up until now, we're looking at objects that can exhibit rotational inertia. When they're at rest, they stay at rest. When they're rotating, they continue to rotate. A torque is the influence that causes rotational inertia. And therefore, violates Newton's first law of rotational measure. we'll look more at torques. when I exert a torque on this seesaw. To do it, I twist the see-saw. So I'll grab the see-saw from the front, and I will twist. And suddenly, it changed it's angular velocity. It started with an angular velocity of z, of zero. That's rotational inertia. So in a normal see-saw that perpetual rotation isn't possible, because during the rotation. Even when it's balanced initially. It eventually touches the ground. And at those moments when it touches the ground, the ground exerts torques on the seesaw. It twists the seesaw and therefore takes it out of the, out of Newton's First Law of Rotational Motion, violates Newton's First Law of Rotational Motion, and new things happen. And those new things, basically the consequences of torques.

Why does a seesaw need a pivot?

The pivot prevents the seesaw from undergoing translational motion, while leaving it free to undergo rotational motion. Without a pivot to support its weight and that of its riders, the seesaw would fall. And while two children might find it exciting to jump out of an aeroplane seated at opposite ends of unsupported seesaw, that idea is unlikely to be popular with their parents. I'm going to leave that for children who enjoy extreme recess. Instead, I'm going to show you how an unsupported and riderless seesaw moves. Basically, I'm going to throw the seesaw through the air and we'll watch its motion.

How do we make sense of the seesaw's motion? It turns out that he seesaw is doing two things at once, it's translating and it's rotating. Translational motion. Well, it's centre of mass is travelling in the arc of a falling object as though it were a tiny ball located at the centre of mass, that's travelling in the arc that we're familiar with for falling balls. At the same time, The seesaw, which is an extended object, is rotating about its centre of mass, its natural pivot. And, it's doing these two things at once: the translation motion of a falling object located right at its centre of mass, and the rotational object. Motion of an extended object rotating about its natural pivot. Its centre of mass. A seesaw has its centre of mass located pretty much in its geometrical centre. So, the motion we saw had the centre of the board travelling in the arc of a falling object as the rest of the board rotated about its geometrical centre.
The object's natural pivot. So the object is doing two things at once. It's translating in the arc of a falling object as it's rotating in the manner of an object that's just simply free to rotate about its own natural pivot. Its centre of mass.

Why does a Lone seesaw rider plummet to the ground?

The lone rider produces a torque on the seesaw and causes it to undergo angular acceleration. The seesaw rotates such that the rider descends toward the ground. And hit it. There are several ways of examining this situation. So I'm going to follow the path that I think is most straightforward. The rider's weight gives rise to a torque on the seesaw. And since the seesaw is no longer rotationally inertial, its angular velocity is no longer constant. Instead, that angular velocity changes with time, and the rider soon plummets to the ground. But those observations give rise to two more questions. How does the seesaw respond to torques, and what is the origin of this particular torque? So let me start by looking at the seesaws' response to torques. When the seesaw is experiencing no outside torques it's covered by Newton's first law of rotational motion. So it rotates at constant angular velocity, like this. But once there is a torque acting on the seesaw, the seesaw is no longer covered by angu-, by Newton's First Law of Rotational Motion. And its angular velocity is no longer constant. Instead, its angular velocity begins to change with time. The seesaw undergoes angular acceleration. Angular acceleration is another vector physical quantity of rotational motion, and it is the rate at which angular velocity is changing with time.

Seesaw II

Why do the Rider’s Weights and Positions Affect the Seesaw's Motion?

Why do the rider's weights and positions affect the seesaw's motion? The short answer to that question is that they affect the net torque on the seesaw, and therefore the seesaw's angular acceleration. In most cases, the riders of a seesaw position themselves so the net torque on the seesaw is 0 or very nearly 0. As a result, the angular acceleration of the seesaw is either 0. That is, its coasting rotationally. Or it's just got the smallest amount of angular acceleration. That's to the lever arm from the pivot. It produces a torque and boom, the seesaw undergoes rapid angular acceleration such that the rider drops to the ground. But what if we put two riders on the seesaw simultaneously? And what I'm going to do is I'm going to position them very carefully. And look. The seesaw is experiencing very little angular acceleration, so the net torque on it is either zero or very near zero.

Why Do the Riders' Distances from the Pivot Affect the Seesaw's Responsiveness?

The rider's masses are from the pivot, the greater the seesaw's overall rotational mass and the slower its angular accelerations. Two riders can balance the seesaw in a variety of ways. To begin with, they can go to the ends of the board and adjust their distances from the pivot carefully until it balances. That is, until it experiences zero overall torque due to gravity. I mean I'm pretty much there. Balanced seesaw. But they can also come in close to the pivot and sit like this, with much smaller lever arms to work with now. So that they're producing much smaller torques as individuals.

How Do the Seesaw's Riders Affect One Another?

They support one another and they exchange energy as the seesaw rotates back and forth. Let's start with the support issue. And to do this, I'm going to treat the seesaw as a facilitator rather than the object of our main attention. I'm going to define the centre of rotation as lying in the middle of the pivot. So the axle rotation for this entire story is right here at the pivot of the seesaw. But, otherwise, the seesaw is just helping the red rider exert a torque on the purple rider about the pivot. And the purple rider exerted a torque on the red rider about the pivot. Well, you might wonder why the red rider should ever care about exerting a torque on the purple rider. That's because the purple rider is already experiencing a second torque, a torque due to gravity. Gravity is pulling downward on that purple rider, at a level arm from the pivot, the axle rotation. So gravity by itself is exerting a torque on the purple rider, and that torque is towards me, that is away from you. To keep that purple rider from undergoing angle acceleration and plummeting toward the ground, the red rider comes to the rescue. Okay? The red rider is exerting a second torque on the purple rider, and that torque is toward you. So the second torque acting on the purple rider cancels gravity's torque on the purple rider. This is all about that, that pivot, and prevents the purple rider from undergoing angle acceleration.The red rider really is supporting the purple rider. How about the other way around? Well, the red rider is also experiencing a gravitational torque, forces down, lever arm is toward your left. So, the gravitational torque on the red rider is toward you. By itself, that would cause the poor red rider to undergo angle acceleration, boom, and drop toward the ground. But once again, the purple rider comes to the rescue. And now, the purple rider is exerting a torque on the red rider, that is this way, toward me it cancels the gravitational torque on the red rider and saves the red rider. So the long and short of it is, the red rider is keeping gravity from twisting the poor purple rider to the ground and the purple rider is stopping gravity from twisting the poor red rider to the ground. They really are supporting one another.

Seesaw summary

A seesaw is a pretty amazing toy and a beautiful example of rotational motion. It rotates about its own centre of mass, its own natural pivot so that the only reason I need this physical pivot passing through it is to prevent the seesaw from falling. If I could turn off gravity, I wouldn't need that physical pivot to make the seesaw do exactly what it's doing. Well, there is gravity so you need the central pivot. And the pivot also constrains the seesaw so it can't do rotations that we don't want. It can only do what you see it doing at the moment. Although it can also do that in the, in the other direction. The seesaw is balanced as well, meaning that it's experiencing no torque due to gravity. That's because the centre of gravity of the seesaw is located right at the pivot as well. Basically vertically in line with the pivot. In fact it's on the pivot. And as a result, the force of gravity produces no torque on the seesaw about its pivot. No torques. So, the seesaw is turning according to Newton's First Law of Rotational Motion. It's a rigid object that is not wobbling. And it's not experiencing any external torques. So, it rotates at constant angular velocity. Well, when you put riders on the seesaw, life can get more complicated, which we've seen. Those riders produce their own torques on the seesaw, and they move in various interesting ways. If they're not balanced, the seesaw undergoes angular acceleration in various ways. But once they are balanced, and again there is no gravitational torque on the seesaw and its riders, the seesaw is once again rotationally inertial. It turns according to Newton's first law of rotational motion. If they come out of balance, and the seesaw undergoes angular acceleration, it does so according to Newton's second law of rotational motion. The angular acceleration of the seesaw is equal to the net torque acting on the seesaw divided by its rotational mass. And depending on where the riders sit on the seesaw, they can go from making the, giving the seesaw a small rotational mass to giving it a large rotational mass. Lots of flexibility. And as they're tipping back and forth, they're exerting torques on one another, these two riders. And that's according to Newton's Third Law of Rotational Motion. If the red rider exerts a torque on the purple rider, the purple rider has to exert an equal but oppositely directed torque back on the red rider, every time. And as they tip up and down, they do work on each other. They transfer energy to each other with the help of the seesaw board. So there's really a lot going on here in the seesaw. And we'll use many of these same concepts later on as we continue to look at how things work. .

Module 6 (Wheels)

Wheels I

Wheels introduction

When they're used to propel a bicycle or car. Wheels serve as yet another simple machine. Without powered wheels, you'd have to imitate a cartoon character by churning your feet directly on the ground. But, wheels are far more than simple machines. They also save us from the limitations of friction. Without wheels nothing would just roll along. There would be no free-wheeling adventures and the wheels of industry would grind to a halt. In fact, wheels are so inextricably linked to friction that the story of wheels is also the story of friction.

It's also the story of energy, but in a different way from ramps and seesaws. Ramps transformed energy from one form to another. Seesaws transfer energy from one person to another, but wheels prevent friction from wasting energy. That is, from grinding up useful energy into countless tiny, random fragments, that are then very difficult to use. We'll examine friction and wasted energy here in the context of wheels, and then use our new found understanding as we continue to look at how things work.

Suppose you're riding a bicycle or a car and you are stopped waiting for something. And then it's time to accelerate forward. Will you accelerate forward fastest if you twist your wheels so hard that they begin to skid across the ground, that is slide on the ground, or if you twist them somewhat less hard so that they just barely avoid skidding? Why does a wagon need wheels?

Why is sliding a box across the floor usually hardest at the start? How is energy wasted as a box skids to a stop? How do wheels help a wagon coast? How do powered wheels propel a bicycle or car forward? How is energy present in a wheel?

Why does a wagon need wheels?

A wheel-less wagon would struggle against friction whenever it moved, or tried to move. The motion of an ordinary wagon that is one with wheels resembles that of a skater. When you leave them alone, they're inertial and they move according to Newton's First Law of Motion. If they're at rest, they remain at rest. If they're in motion, they continue in motion at constant velocity. Remove it's wheels, however, and the wagon exhibits entirely different behaviour. If you push it, it moves. If you stop pushing it, it stops. The moving wheel-less wagon doesn't slow to a stop because it lacks inertia. It slows to a stop because it's experiencing a non zero net force. And it, therefore, accelerates in accordance with Newton's second law, rather than coasting according to Newton's first law. For a wagon to move according to Newton's first law, it has to be free of net force. And thus, free of the slowing effects of friction, that's why a wagon needs wheels. Frictional forces are exerted by surfaces on one another and like all forces, Since wagons move on stationary sidewalks, a wheel-less wagon is going to have serious problems with friction. You'll have to push it hard to overcome the opposition of friction in getting the wagon started. And once it is started, you'll still have to push it, every step of the way.

Why is sliding a box across the floor usually hardest at the start?

The surfaces of the box and floor settle into one another while they're at rest, so they're particularly resistant to the start of sliding. Friction originates in the microscopic interactions between two surfaces, and those interactions depend on several things. On the type of surfaces involved, on how hard those surfaces are pressed against one another. And on whether or not the surfaces are actively sliding across each other. For the purposes of this story, I'm going to talk about a box on the floor, and, they're two types of forces to, to separate, distinguish between the box and floor. First, is old news, support forces. When I push the box against the floor, and try to make those two surfaces occupy the same space at the same time, they respond by developing support forces. And like all support forces, those forces, act perpendicular to the surfaces involved. So, the floor's support force on the box is straight up. The box's support force on the floor is straight down. So far, so good. The frictional forces are all horizontal. All like this, these directions. And they're caused, they basically originate in the tiny structures that make up the floor's top surface, and the tiny structures that make up the box's bottom surface.

How is Energy Wasted as a Box Skids to a Stop?

Sliding friction transforms the box's kinetic energy into thermal energy. When I slide a box across the floor, something strange happens to its energy. I do work on the box, pushing it, and it moves in the direction of my push, so I'm transferring energy to it. It leaves my hand with that energy mostly in kinetic form, the energy of motion. But then, it encounters the floor. Moments after hitting the floor and sliding across it, the box is motionless. When a box slides to a stop on a motionless floor, which object does work on the other? The floor does negative work on the box, and that's it. the floor pushes the box in the direction opposite the box's velocity. And so the box, in this case, is moving to your left as the floor is pushing the box to your right, so the floor is pushing in the direction opposite the box's motion, so the floor does negative work on the box. At the same time, the box is pushing on the floor but the floor doesn't move. So, the box does not work, there is zero work on the floor. The energy is still conserved and we have to look for where that energy goes. Sliding friction can't violate the conservation of energy.

Wheels II

How Do Wheels Help a Wagon Coast?

Wheels eliminate only sliding friction. And even then, they only eliminate sliding friction between the wagon and the ground. Those details are important, and my goal for this video is to explain why. When you're trying to move a wagon down the sidewalk you want it to be able to coast indefinitely. In other words, you want to avoid wasting any energy, and you want to avoid wearing out the wagon on the sidewalk. So those two problems are associated only with sliding friction, that's what you want to avoid, sliding friction. Static friction isn't necessarily a problem. So long as it doesn't prevent the wagon from moving on the sidewalk. One solution to this problem, that is one way to get rid of sliding friction between the wagon and the sidewalk. Allowing the wagon to coast and not waste any energy or wear anything out, is to use rollers.

Metal on ruby or, or sapphire has a small coefficient of friction. Finally, the two polished surfaces, the jewel and this polished piece of metal, they're so smooth that they don't have serious collision problems as they slide across each other. And they experience almost zero wear. Therefore, this wheel-like component can go round and round and round for years, decades, or even centuries, with almost zero wear. And that's why one of these clocks or watches can keep on ticking for a very long time. But there's actually a better solution to this friction problem in the hub axle system. The solution is to insert a bearing between the axle and the hub. And that bearing is our old friend, the roller. Instead of loose rollers, It consists of a bunch of rollers very loosely held in a frame, known as a cage, and we insert this.

How do Powered Wheels Propel a Bicycle or Car Forward?

The ground exerts a forward static frictional force on each powered wheel and thereby pushes the entire bicycle or car forward.

In the previous notes, however, I pointed out that the ground exerts static frictional forces on free wheels as well. So, what could be different between free wheels and powered wheels? To explain that, let me start by re-examining free wheels. When you pull a wagon forward so that it accelerates forward. The bottoms of its wheels are threatening to slide forward relative to the ground. And so static friction acts to prevent that sliding. It pushes the bottoms of the wheels backward, and that backwards force of static friction, the bottoms of the wheels, has two effects First, it produces torques on the wheels that cause those wheels to begin their spin, to roll. And so when I pull the wagon forward and its wheels roll, that's because of static friction with the ground. But second, those backward frictional forces on the bottoms of the wheels affect the entire wagon. And, you have to pull a little extra hard, and do a little extra work to get the wagon up to speed. Because its spinning wheels are carrying extra kinetic energy. Something we'll explain in the next video. The key point here is that the ground pushes free wheels backward as their vehicle accelerates forward.

How is Energy Present in a Wheel?

The wheel has kinetic energy in both its translational and rotational motions. It can have other forms of energy. Such as gravitational potential energy if it's high in the air. Or nuclear energy if it's made out of uranium, but the energy I have in mind here is kinetic energy, energy of motion. And, as I'm about to explain, a spinning wheel on a vehicle carries an especially large amount of kinetic energy.

A physical quantity officially known as momentum. Since momentum is all about moving. Going somewhere in a particular direction. It does depend on the direction. But energy has no direction, and no dependence on the direction of motion. So far we know that the kinetic energy of a wheel depends on its speed. The second important observation is that the kinetic energy of a wheel is proportional to its mass.

Compare the kinetic energies in two pitches. The faster moving baseball is carrying four times as much kinetic energy with it. Even though it's only travelling twice as fast.

The kinetic energy in a wheel's rotational motion turns out to be equal to one half the wheel's rotational mass times the square of its angular speed. Fast-spinning wheels can therefore carry enormous kinetic energies, even when they're rotating in place. The wheels on a moving vehicle however are translating and rotating at the same time. When your bicycle is moving forward, each wheel has translational kinetic energy associated with the velocity of its centre of mass. And rotational kinetic energy associated with its angular velocity about its centre of mass.

That double dose of kinetic energy distinguishes the wheels from the rest of the bicycle. Bicycle wheels carry more kinetic energy per kilogram than any other part of the bicycle. Since you have to provide that energy as work when you peddle the bicycle forward from rest. The wheels make your job more difficult. Similarly, the bicycle's brakes have to get rid of that extra energy when they slow the bicycle to a stop, because of these effects, extra energy in, extra energy out, in the wheels. Those wheels are generally designed very carefully to reduce both their masses, and their rotational masses. Replacing a solid rubber tire with an air filled pneumatic one, not only reduces the wheel's weight, so it's easier to lift and carry uphill. It also reduces the wheel's mass and rotational mass and thus reduces the kinetic energy that the wheel carries as it moves.

Wheels summary

Without wheels, a wagon would experience sliding friction as it moved across the sidewalk. That sliding friction would grind up the wagon's ordered energy into thermal energy. And wear out both the bottom of the wagon and the top of the sidewalk. Adding wheels doesn't eliminate all friction. But it does eliminate sliding friction between the wagon and the sidewalk. In normal situations, the wagon's wheels and the sidewalk experience only static friction, this touch and release stuff. And static friction doesn't waste energy. Although sliding friction still occurs between each wheel's hub and axle. They don't waste much energy. Because the hub and axle don't move very far relative to one another. And so the work is done against sliding friction in that hub and axle. Even that, sliding friction, can be eliminated by inserting roller bearings or ball bearings between the hub and axle. When you pull a wagon forward, the sidewalk exerts static frictional forces on the wagon's free wheels. And those static frictional forces produce torques of the wheels that cause them to undergo angular acceleration and begin to turn. When you pedal a bicycle, you are exerting a torque on that powered rear wheel. In causing the sidewalk to exert a forward static frictional force on that powered wheel that propels the entire bicycle forward. Once the wagon or bicycle is moving and its wheels are rotating and translating. Those wheels have kinetic energy in both their translational motion. And in their rotational motion. So, they have more than their fair share of kinetic energy. Frictional forces and their effects on motion. Energy can be ground into thermal energy. And we've developed strategies to minimise the waste of energy by way of static friction. We'll use those concepts often now as we continue to study how things work.

Module 7
Bumper car

Bumper cars introduction

Like many amusement park rides, bumper cars involve almost as much physics as they involve fun. A bumper car is a small electric vehicle that is surrounded on all sides by rubber bumpers. Those bumpers are essential because collisions are unavoidable in bumper cars. In fact, the whole point of driving a bumper car is to crash into as many other cars as possible. If you've never seen bumper cars, picture a rectangular or oval floor surrounded on all sides by a wall, a padded wall with bumpers on it. that arena for bumper cars. And driving around this arena are about 20 little electric cars, each just big enough to hold one or maybe two people. Every car has a steering wheel and a motor that's controlled by a pedal. So, it resembles a little car, or more like a golf cart or something. And the drivers drive around that arena wildly and smash into one another frequently.

When two bumper cars collide, they typically exchange some energy. So, that's what we've seen. But they also exchange two other conserved physical quantities, momentum and angular momentum. Those conserved quantities are new to us and they are so important in bumper cars.

Does a Moving Bumper Car Carry a Force?

The moving bumper car carries momentum, but it cannot carry a force. A force is exerted by one object on another object. So a single object can't carry a force. But we intuit that a moving bumper car carries some physical quantity of motion with it, some capacity to make other objects move in the direction of its motion. That physical quantity of motion does exist. And the bumper car is deep carrying it as it moves. That physical quantity is called momentum and momentum is the conserved quality of moving. As required by conserved quality momentum can not be created or destroyed but it can be transferred between objects. So when I bump these two bumper cars into one another, they transfer some of their momentum,

A negative amount of momentum to the right is momentum to the left. And so when I encounter that wall on the right I can do it again. I can do this over and over as long as I don't get injured when I go. I'm going to give it my rightward momentum and extra rightward momentum. I gave it more rightward momentum than I had. And I ended up with a deficit of rightward momentum, less than zero rightward momentum. Which is to say leftward momentum. So when you bounce, you might want to bounce something other than yourself, off of a wall. Unless you're a small child, having a lot of fun. and our bouncing off walls.

How is Momentum Transferred From One Bumper Car to Another?

The first bumper car does an impulse on the second bumper car. Just as you can transfer energy by doing work. You can transfer momentum by doing an impulse. Impulse is a force exerted for a time. For example, I do an impulse on this bumper car by pushing on it as time passes. The product of my force on the bumper car. Times the duration of that force. Is the impulse. And correspondence to the amount of momentum I transfer to the bumper car. Since an impulse transfers a vector quantity.

The original bumper car basically has lost its rightward momentum, and the second bumper car carries it away. You can see, this one almost stops, and the second bumper car carries away the rightward momentum that had started in the first bumper car. The transfers of momentum that are occurring as these two bumper cars collide have to be perfect, because momentum is a conserved quantity. Whatever momentum the second bumper car receives, the first bumper car has to lose. Well, an impulse is proportional to both the force that, that's responsible for it and the time of which it adds. I can increase the amount of momentum I transfer into that bumper car. Either by pushing harder or by pushing for a longer duration, I can transfer the same amount of momentum to the bumper car with different pairings of my force and its duration. As long as the product of my force times the duration doesn't change, I'd do the same impulse and transfer the same amount of momentum to the bumper car. For example, I can start by exerting a medium force for a medium amount of time. Here we go. I pushed it medium hard for a medium amount of time and off it went. But I can do the same impulse by pushing hard for a short amount of time.

Same thing, or I can go back and transfer the same amount of momentum by using a gentler force for a longer duration. I have some choices here. Are there any consequences to changing those pairings of force and duration? Oh, yeah. The faster the momentum transfer occurs, the shorter its duration and the larger the force must be. Big forces can break things. For example, here is a hammer.

The impulse that it's experiencing as it picks up speed involves a relatively weak frictional force from the floor exerted for a long period of time. During collisions however, things happen so fast that there's very little momentum transfer to the floor. The frictional force between the wheels and the floor are just too weak. And there isn't enough time for any significant impulses. So, when two bumper cars collide, they're pretty much on their own during that collision.

Bumper car II

Does a Spinning Bumper Car Carry a Torque?

The spinning bumper car carries angular momentum, but it can't carry a torque. As you've probably guessed, Like a force, a torque is exerted by 1 object on another object. So a single object can't carry a torque. But there is a physical quality of rotational motion that a spinning bumper car does carry. A capacity to make other things turn in the direction the bumper car is turning. That physical quantity of rotational motion is called angular momentum. And angular momentum is the conserved quantity of turning. As required of any conserved quantity angular momentum can't be created or destroyed. It can only be transferred between objects. So, one bumper car can transfer angular momentum to a second bumper car. So skaters do this trick that they start spinning with their arms out and then they pull in tight and they spin faster as their angular momentum stays constant, but their rotational mass shrinks and their angular velocity increases.

How is Angular Momentum Transferred From One Bumper Car to Another?

The first bumper car does an angular impulse on the second bumper car. Just as you can transfer energy by doing work and linear momentum by doing an impulse, you can transfer angular momentum by doing an angular impulse. So, what exactly is an angular impulse? An angular impulse is a torque exerted for time, for example, I can do an angular impulse on this bumper car by twisting it, that's the torque, as time passes, here we go. Okay, I did an angular impulse on that bumper car and I transferred momentum to it. So, that product, my torque times the time over which it acted in the angular impulse, and therefore, the amount of angular momentum that I transfer to the bumper car. And angular impulse transfers a vector quantity, angular momentum, so that angular impulse itself is a vector quantity. It points in the direction of the torque that's responsible for it. So, for example, if I twist the bumper car downward, I transfer downward angular momentum to the, to the bumper car. So I did a downward angular impulse. On the other hand, if I twist it upward, that upward torque produces an upward angular impulse that results in an upward transfer of angular momentum to the bumper car. And also like impulses.

How Does a Bumper Car Move on an Uneven Floor?

The bumper car accelerates in the direction that reduces its total potential energy as quickly as possible. I hope you're thinking, wait a second. A bumper car accelerates in the direction of a net force acting on it. That's part of Newton's second law. Why is Lou talking about potential energy? Your observation about bumper car's acceleration is exactly right. It does accelerate in the direction of the net force acting on it. But my observation is also right. It does accelerate in the direction that reduces its total potential energy as quickly as possible. This is another big picture moment. Forces and potential energies are intimately related. After all, potential energy is energy stored in forces. When I lift this ball upward, I'm doing work against the gravitational forces it experiences. It's downward weight, and it stores my work as gravitational potential energy. So I'm doing work against the same force that stores that work as potential energy. When I let go of the ball, and it becomes a falling ball, it accelerates downward.

Bumper cars summary

While riding in bumper cars are heavily influenced by three conserved quantities: energy, momentum and angular momentum. Energy, we've seen before, and we know that it's transferred by doing work. So, when two cars collide with one another, one of them may well do work on the other and, therefore, give the other car some of its energy. Now, the bumpers in bumper cars aren't perfectly elastic. They don't restore and return all the energy that goes into them during the collision. And they turn some of that into thermal energy. They grind it up and degrade it. And that actually helps to keep the motion on the bumper car arena a little under control. The cars don't get more and more energetic, as the game goes on and they use more and more electric energy to get themselves moving. Momentum is new in this episode and you can see how influential it is in the game bumper cars. When two cars collide they transfer momentum by way of impulses. Force times time and that, that can always occur, so they're always, whenever there's a collision, there's always a transfer of momentum. And depending on the masses of the cars involved, those transfers of momentum can have different effects. For example, two cars of the same mass colliding tend to exchange their motions. If it's a head-on collision, one of them tends to resume motion as though it were the other car. But if two cars of different masses collide, you know, this green one and that red one, the lighter the low mass car tends to bounce off the high mass car. And the high mass car tends to swat the low mass car kind of almost off the arena field.