**Momentum**

**Section 1**

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| 00:00:01 | TEACHER: We just reviewed Newton's third law of motion, and here's an example. A vehicle that's driving on a road exerts a force on the road, and the road exerts a force back up on the vehicle. That is an action/reaction pair that allows the car to move. What other forces are working on the car as it moves? Have you ever noticed that large trucks, like semi-trucks, |
| 00:00:25 | can get moving very quickly as they move downhill? Sometimes they end up moving so quickly that their brakes actually burn out. And that's when they use something like this, a runaway truck ramp. So if they can't depend on their brakes, then the vehicle will pull up the hill in order to stop. And there's a reason that semi-trucks and large vehicles |
| 00:00:47 | aren't able to slow down or stop very easily when they get going downhill. The reason has to do with momentum. So let's take a closer look at what momentum is. |

**Section 2**

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| 00:00:01 | TEACHER: Let's take a look at momentum. Momentum is the measure of the motion of an object found by multiplying the object's mass and velocity. And it's represented using this equation right here, where the symbol p-- this is a lowercase p, used to represent momentum-- equals mass times velocity, or mv. Now, momentum does include direction, so it is a vector. And the units that we use to measure momentum |
| 00:00:31 | are the product of the mass, which is kilograms, and velocity, which is meters per second. Let's take a look at how to solve a problem for momentum. Let's read this together. What is the momentum of a 2 kilogram hammer swung at 0.8 meters per second? Well, what information are we already given? We already know that the mass of the hammer is 2 kilograms. |
| 00:00:57 | So we have a mass of 2 kilograms. And we know the velocity. It was swung at 0.8 meters per second. So velocity is 0.8 meters per second. What is it that we're trying to find? Recall that we want to know what the momentum is. And momentum is represented with the lowercase p. So our unknown is p for momentum. |
| 00:01:19 | And now we can use our equation, p equals mv. So let's write p equals. And now we can simply fill in the numbers for the variables. So we have 2 kilograms, that's our mass, times our velocity, which is 0.8 meters per second. And our momentum equals 1.6 kilograms meters per second. Now you'll have an opportunity to try to calculate momentum on your own. |

**Section 4**

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| 00:00:01 | TEACHER: Let's take a look at momentum a little more closely. So we know that momentum depends on two things. It depends on mass and velocity. And we know that momentum is represented with a lowercase p. And momentum equals the mass times the velocity. Now, if we have two objects that have the same mass, then the object with the greater velocity will have greater momentum. |
| 00:00:26 | Also, if we have two objects that have the same velocity, then the object with the greater mass will have greater momentum. That's because we're simply multiplying mass times velocity, and that will affect our momentum. For example, take a look at these two horses. Let's imagine that they're running with the same velocity. Which horse has more momentum? |
| 00:00:49 | Well, the larger horse has a greater mass and therefore has a greater momentum. So this horse will have greater momentum. Now, we know that two objects that have the same mass or the same velocity might have the same momentum. But what if we have two objects that have different mass and different velocity? |
| 00:01:11 | Can they still have the same momentum? The answer is actually yes. So let's take a look at how this can occur. Let's calculate the momentum for the car and then for the truck and compare the two. So in order to find the momentum, we know that p equals m times v. So the mass for the car down here is 1,000. |
| 00:01:34 | p equals 1,000 kilograms. And the velocity-- we'll multiply down here. The velocity is 25 meters per second. So we know that the momentum for the car equals 25,000 kilogram meters per second. Now we have the momentum for the car. Let's look at the momentum for the truck. The mass for the truck is right here. |
| 00:02:02 | So p equals the mass of 5,000 kilograms multiplied times its velocity, which is 5 meters per second. And again, the momentum equals 25,000 kilogram meters per second. Let's take a closer look at the momentum for each of these. We know that they're equal to each other. So let's look at each piece individually. Let's look at the mass. |
| 00:02:34 | So the mass for the car-- let's compare that to the mass of the truck. What do you notice? The mass of the truck is much greater. Now let's take a look at the velocity, the velocity of the car compared to the velocity of the truck. And what do you notice? The velocity for the car is much faster. |
| 00:02:55 | So what we can tell from this is that in order for the car and the truck to have the same momentum, the car, which has much less mass, must be much faster, have a faster velocity, than the truck. So let's write that down right here. The car will have a lower mass and a faster velocity. And the truck must have a higher mass and a slower velocity in order for these two to have the same momentum. |
| 00:03:33 | Next, why don't you try applying this information to a problem on your own? Good luck. |

**Section 6**

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| 00:00:01 | TEACHER: You just learned what momentum is and how to calculate it. Anything that has movement actually has momentum. And the greater mass that an object has, the more momentum it has. Take, for example, these train cars-- an engine or a fully loaded train car can have a mass of several tons, which |
| 00:00:20 | means that even at relatively slow speeds, those train cars have great amounts of momentum. Train engineers will actually crash two train cars into each other in order to join them and get them attached to each other. When they crash or collide into each other, something called a coupling joint hooks together. But if this coupling joint does not engage, |
| 00:00:46 | then the trains have something called buffers attached to them. And the buffers will push the train cars back away from each other. During this collision of train cars, the momentum of individual cars might change. But the momentum of all of the cars together remains the same. How? |
| 00:01:08 | Well, next we're going to take a look at how the total momentum can stay the same when there is a collision. |

**Section 7**

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| 00:00:01 | TEACHER: The law of conservation of momentum states that the total momentum of interacting objects does not change. So this means that the total momentum of interacting objects before an event-- like a collision or an explosion-- will be the same as after the event. This holds true as long as no outside forces are working on any of the objects, forces like friction. |
| 00:00:25 | For example, here you see a pool table. And before the break shot, all of the pool balls are put into a triangular pattern. And they're sitting motionless in this triangular pattern. Since none of the balls are moving, we could say that the momentum is at 0. But after the break shot when the cue ball hits all of these balls, all of the balls |
| 00:00:50 | go scattering in different directions at different velocities. And since momentum is a vector, there is going to be some positive momentum and some negative momentum. If we add up the momentum of all of the balls after the break shot, what we'll find is that the total amount of momentum |
| 00:01:12 | for all of the balls after the break shot still remains 0. So we can sum up the law of conservation of momentum with this equation, where Pi equals Pf. And that's the initial momentum equals the final momentum. Take this information and see if you can do a problem using it. |

**Section 9**

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| 00:00:01 | Let's take a look at how momentum is conserved during different types of collisions. In some collisions the two objects will join together and become one. When this happens, the masses join together to form one larger mass. And the velocity after the collision-- there's only one velocity because the object |
| 00:00:20 | is moving as one unit. Let's take a look at an example of where this happens. Here we have a green train car moving to the right with a mass of 600 kilograms at a velocity of 10 meters per second. Coming at it from an opposite direction before the collision is this purple train car with a mass of 400 kilograms and a velocity of negative 5 meters per second. |
| 00:00:43 | Now the negative in front of the 5 indicates that this purple train car is moving to the left. In order to find out what the momentum is before the collision, we need to find the momentum of the first car and the momentum of the second car. So if we multiply the mass times the velocity, we will end up with the momentum. |
| 00:01:04 | So 600 kilograms times 10 meters per second, gives us 6,000 kilogram meters per second. And for the purple car-- we have a momentum of 400 kilograms times negative 5 meters per second, which gives us negative 2000 kilogram meters per second. Now in order to find out what the total momentum is for both of these, we will need to add the two moments |
| 00:01:35 | together. So we have 6,000 kilogram meters per second plus a negative 2000 kilogram meters per second, which equals a total of 4,000 kilogram meters per second. Now after the collision, these two trains have come together, which means the mass is going to be the first mass plus the second mass, |
| 00:02:02 | and that was 600 kilograms and 400 kilograms. So we now have the total mass of 1,000 kilograms. And the velocity has also changed. The velocity is now only 4 meters per second. So let's see if the Law of Conservation of Momentum holds true. Let's see what the momentum is after the collision. Let's take the meters, the mass, excuse |
| 00:02:29 | me, times the velocity-- so that's 1,000 kilograms times 4 meters per second. And that gives us 4,000 kilogram meters per second. So we have a total momentum before the collision of 4,000 kilogram meters per second, and a total momentum after the collision of 4,000 kilogram meters per second. So momentum was indeed conserved. |
| 00:02:58 | Now let's take a look at what happens when a collision causes two objects, instead of joining, to bounce off of each other. Here we have again is same green car-- train car-- moving to the right. This time it has a mass of 600 kilograms and velocity of 2 meters per second. Heading towards it from the opposite direction-- so to the left-- is the purple train car |
| 00:03:20 | with a mass of 400 kilograms and a velocity of negative 4 meters per second. Again the negative indicates that this purple train car is moving to the left. After the collision, these two objects aren't going to stay together. So they're going to maintain their mass, so mass should be the same. |
| 00:03:39 | Before the collision the green car was 600 kilograms-- after the collision the mass of the green car is still 600 kilograms. The mass of the purple car was 400 kilograms, and after the collision-- still 400 kilograms, because they haven't joined together. Now the velocity is changing. These train cars have changed directions. |
| 00:04:01 | The green car that was headed to the right is now headed to the left. So the velocity of the green car is now a negative 2 meters per second, and the velocity the purple train car has changed-- it's changed directions-- it was negative heading to the left, now it's positive heading to the right. So the purple train part is now negative-- I'm sorry-- is now 2 meters per second, no longer negative. |
| 00:04:26 | Let's see if we can identify whether or not the Law of Conservation has held true. Is the total momentum before the collision the same as after the collision? Well if we multiply the mass times the velocity of the first car before the collision, we will find that we have a momentum of 1,200 kilogram meters per second, and the momentum of the second car |
| 00:04:55 | before the collision is negative 1,600 kilogram meters per second. In order to find out what the total momentum before the collision was, we'll just add those two together. So we have 1,200 kilogram meters per second plus a negative 1,600 kilogram meters per second, and that gives us a total momentum of negative 400 kilogram meters per second. |
| 00:05:30 | Let's find out what the momentum after the collision was. So again we will find the momentum of the green car by multiplying the mass times velocity which equals a negative-- this time it's negative because it's moving back to the left-- so a negative 1,200 kilogram meters per second. And for the purple train car-- we have a momentum of 400 times 2, which |
| 00:05:58 | is 800 kilogram meters per second. So to find the total momentum after the collision-- again we will need to add the two elements together. So that would be a negative 1,200 kilogram meters per second plus the 800 kilogram meters per second and we get, when we add those two together, a negative 400 kilogram meters per second. So as you can see before the collision |
| 00:06:31 | the momentum was negative 400 kilogram meters per second. And after the collision-- again we have negative 400 kilogram meters per second. So we know that the Law of Conservation of Momentum is holding true. Now it's important to remember that not all collisions are coming from opposite directions and either attaching to things, or making them bounce off of each other. |
| 00:06:54 | If we stick with the train example, then you could have an example where a train might be holding still, so its momentum is at 0 and the second train comes and hits it and then makes it move. Or you may have two objects that are moving in the same direction-- so they're both having a negative or a positive value, and after they hit they continue to both have a positive or negative value. |
| 00:07:20 | That's an awful lot of information. See if you can do some problems on your own using all of this information. |

**Section 11**

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| 00:00:00 | TEACHER: You just learned that momentum is always conserved. And you saw the law of conservation of momentum as it applies to collisions. But what about other events, like explosions like you see here, with this cannon and cannonball? When a cannonball is sitting in a cannon, it's not moving. So it has a momentum of 0. And you know that momentum is the product of mass times |
| 00:00:24 | velocity. So if neither the cannonball nor the cannon are moving, then there is no momentum for each individually or as a whole system. But when a cannon fires a cannonball, it has a lot of momentum as it comes out. The cannonball has momentum now. But did it just violate the law of conservation of momentum? |
| 00:00:47 | In order to address situations like this, what we need to do is take a closer look at Newton's third law of motion. |

**Section 12**

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| 00:00:01 | TEACHER: Newton's Third Law of Motion can be applied to the conservation of momentum. In this diagram, here we have an action-reaction force pair. The cannon pushes the cannonball, and the cannonball pushes back on the cannon. Before the cannon fires, the total momentum of this system is 0. So we can say momentum, represented by the lowercase p, |
| 00:00:26 | is equal to 0 kilograms/ meters per second. After the cannon fires, each part has momentum, and that's indicated here with these velocity arrows. So the cannonball has this large arrow, and we can say this is the velocity of the cannonball. While the cannon has this small velocity arrow pointing to the left, so it's going to be negative. So we'll have a negative for the velocity for the cannon. |
| 00:00:55 | But when considered all together, the total momentum of this system is still 0. Now why is this? That's because of Newton's Third Law. Newton's Third Law describes these action-reaction force pairs. And since there's momentum of the cannon, cannonball, there's equal and opposite motion or momentum |
| 00:01:19 | of the cannon. And we can see this illustrated here in a nice equation, where the left side of the equation represents or is equal to the momentum of the cannon. And that's going to be equal to the momentum, p, of the cannonball. And since there's an equal sign between these, we know the momentum is equal. |
| 00:01:45 | Since the momentum is equal, the different variables must be quite different. That's because we know that the mass of the cannon is much greater than the mass of the cannonball, and the velocity of the cannonball is much greater than the velocity of the cannon. If we write that and just change the size of our writing in the equation, you can actually see it. |
| 00:02:07 | It's a nice way to visualize it. So let's write a large mass of the cannon, and this is going to be equal to the small mass of the cannonball. And then we're going to multiply it by the velocity. And the velocity, remember, of the cannon is quite small. So we'll put in a small velocity. That's also a negative. |
| 00:02:27 | Multiplied on the other side, the velocity is going to be, for the cannonball, quite large. So we end up with a large mass times a small velocity, which is then equal to a small mass times a large velocity. And this ends up equal and opposite, thus, conserving momentum and holding true to Newton's Third Law of Motion. |

**Section 14**

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| 00:00:01 | TEACHER: If you are walking and happen to trip, would you rather land on the grass or on cement? It's a pretty easy question, right? Of course, if you land on grass, it will hurt much less. But why is that? Your body is falling with the same momentum whether it hits grass or the cement. So why is it that it hurts less to fall on grass? |
| 00:00:20 | Well, the grass has a little bit of give. And so it lengthens the time that it takes your body to stop from falling, to stop that momentum. Even if it's only by a few fractions of a second, that's still enough for your body to feel less pain and sustain fewer injuries. Car manufacturers have used this idea as they design cars to help protect people in collisions. |
| 00:00:43 | Here you see a crash test dummy. And when the crash test dummy hits the steering wheel in a collision, this takes a lot of force to stop the crash test dummy very quickly. And that force can cause a lot of injuries. That's why car manufacturers have required manufacturers to put something called airbags in the cars. This lengthens the time that it takes |
| 00:01:10 | for the momentum of the crash test dummy to stop. And that, by lengthening the time, creates fewer injuries because the force of the dummy stopping is a little bit longer. Any change or transferring of momentum requires a force. Recall that momentum is calculated by mass and velocity. So the faster an object travels, the more momentum there is. |
| 00:01:37 | And faster objects require greater changes in momentum in order to stop. In order to minimize the force that's exerted on action-reaction force pairs, that reduces the damage caused. So we will highlight "minimizing force" and "reduces damage." The way that we reduce the force that's exerted by action-reaction force pairs |
| 00:02:05 | is done by extending the time of the collision. So whether it's the give in the grass or the give in an airbag in a car, that will reduce the force and the impact and |