

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Momentum

Momentum Calculation

Newton's 2nd Law

Direction

The diagram illustrates the vector nature of momentum. It shows the equation $\vec{p} = m \vec{v}$, where \vec{p} is the momentum vector, m is mass, and \vec{v} is the velocity vector. Below this, three vector addition scenarios are shown:

- Two vectors pointing in the same direction (both labeled $\vec{1}$) are added to result in a single vector of length 2, also pointing in the same direction.
- Two vectors of length 1 are added: one pointing right and one pointing up. The resultant vector is the hypotenuse of a right-angled triangle with legs of length 1, labeled with the value 1.41.
- Two vectors of length 1 pointing in opposite directions (one right, one left) are added to result in a zero vector.

Momentum is a vector, so the direction matters. The momentum vector points in the same direction as the velocity vector. Also, since it is a vector, we will need to be careful later about how we add momentum because one plus one could be any value between zero and two depending on the direction of each vector.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

The screenshot shows a presentation window titled "Momentum" with navigation buttons in the top right. On the left, there are two vertical buttons: a blue one labeled "Momentum Calculation" and an orange one labeled "Newton's 2nd Law". The main content area is titled "Momentum Calculation" and contains a blue-bordered box with the following text:

$$p = mv$$
$$p = (65 \text{ kg})(8 \text{ m/s}) = 520 \text{ kg m/s}$$

$$p = mv$$
$$v = \frac{p}{m} = \frac{520}{85} = 6.11 \frac{\text{m}}{\text{s}}$$

Below the box are two numbered questions:

1. What is the momentum of a 65 kg football player running at 8 m/s?
2. How fast would an 85 kg player have to be moving in order to have the same momentum?

Let's take a look at a momentum calculation. What is the momentum of a sixty five kilogram football player running at eight meters per second?

Using our equation for momentum, we see that the momentum is equal to sixty five times eight or five hundred twenty kilogram meters per second.

How fast would an eighty five kilogram player have to be moving in order to have the same momentum?

We can rearrange our equation to see that v equals p over m . Substituting the momentum and the mass, we see that the eighty five kilogram player would have to run at a speed of only six point one one meters per second to have the same momentum.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

The image shows a presentation slide titled "Momentum" with a navigation bar at the top. On the left side, there are two buttons: "Momentum Calculation" (orange) and "Newton's 2nd Law" (blue). The main content area is titled "Newton's 2nd Law" and contains a blue-bordered box with the following equations:

$$F = ma$$
$$a = \frac{\Delta v}{t}$$
$$F = \frac{m\Delta v}{t}$$
$$Ft = m\Delta v$$
$$m\Delta v = \Delta mv = \Delta p$$

By itself, momentum isn't very useful. However, if we remind ourselves of Newton's Second Law, momentum starts to be quite useful.

Newton's second law was expressed in equation form as force equals mass times acceleration. Remembering that acceleration is change in velocity divided by time, we see that force equals mass times change in velocity divided by time. If we multiply both sides by time, we now see that force times time equals mass times change in velocity.

In other words, if you apply a force for a period of time, it will cause a mass to change velocity. And when a mass changes velocity, its momentum changes.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

The image shows a presentation slide titled "Impulse". On the left side, there is a vertical menu with four orange buttons: "Newton's 2nd Law", "Graph", "Impulse Calculation", and "More Time = Less Force". The main content area on the right is titled "Impulse" and contains a blue-bordered box with the following text:

Impulse = Force \times time

Impulse = J

J=Ft

(N)(s)=Ns

The product of force and the elapsed time is impulse. You use the capital letter J as the variable for impulse. Again, you have a letter with no direct relationship to the quantity it represents, but it is the letter that is commonly used in physics for impulse. So you write J equals F t.

Since force is in Newtons and time is in seconds, the units for impulse are Newtons times seconds or Newton seconds.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

The screenshot shows a presentation window titled "Impulse" with navigation controls. On the left is a vertical menu with four buttons: "Newton's 2nd Law" (highlighted in blue), "Graph", "Impulse Calculation", and "More Time = Less Force". The main content area is titled "Newton's 2nd Law" and contains the following text and equations:

$$J = Ft = m\Delta v = \Delta mv = \Delta p$$
$$Ns = kg \text{ m/s}$$
$$N = kg \text{ m/s}^2$$
$$Ns = (kg \text{ m/s}^2)(s) = kg \text{ m/s}$$

Now, back to your rearrangement of Newton's Second Law. Force times time, or impulse, equals mass times change in velocity, or change in momentum. In other words, when you apply an impulse to an object you change its momentum.

The units for impulse are Newton seconds, while the units for momentum are kilogram meters per second. How can this be?

If you remember that a Newton is a kilogram meter per second squared and multiply this by seconds, you see that you wind up with kilogram meters per second, the same as momentum. So your units match.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse

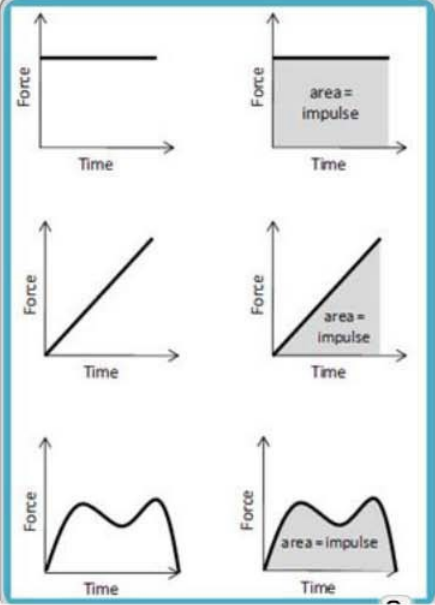
Newton's 2nd Law

Graph

Impulse Calculation

More Time = Less Force

Graph



If you look at a graph of a constant force applied over a period of time, you should recognize that the area under the graph is calculated by multiplying force times time.

Since the product of force and time is impulse, the area under the force time graph is equal to the impulse.

It can be shown that this works with a constant force, but also works with a force that varies over time, so that the area under any force versus time graph is equal to the impulse.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse

Newton's 2nd Law

Graph

Impulse Calculation

More Time = Less Force

Impulse Calculation

Force	Time	Impulse
-25,000 N	1 s	-25,000 N s
-2,500 N	10 s	-25,000 N s
-25 N	1000 s	-25,000 N s

$Ft = Ft = J$

If a one thousand kilogram car is moving at twenty five meters per second, it has twenty five thousand kilogram meters per second of momentum. In order to stop it, we need to apply an impulse of negative twenty five thousand Newton seconds.

If a one thousand kilogram car is moving at twenty five meters per second, it has twenty five thousand kilogram meters per second of momentum. In order to stop it, we need to apply an impulse of negative twenty five thousand Newton seconds.

But this impulse can be accomplished in many ways. You could apply a force of twenty five thousand Newtons for one second, a force of two thousand five hundred Newtons for ten seconds, or a force of twenty five Newtons for a thousand seconds. Each would be the same amount of impulse, and each would bring the car from twenty five meters per second to a stop.

Of course, each of these would feel very different. When driving, you can stop by slamming on the brakes, or panic braking, or you can gently press on the brakes allowing the car to come to a stop over a longer period of time. Both would accomplish the same change in momentum, but one would be a large force over a small time and the other would be a small force over a large time.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse

More Time = Less Force

Newton's 2nd Law

Graph

Impulse Calculation

More Time = Less Force



The image shows a large yellow hard hat. On the front of the hard hat, there is a smaller, square inset image. This inset image shows a person wearing a pink and white helmet, likely a motorcycle helmet, with a visor. The yellow hard hat has two yellow chin straps visible at the bottom.

This is the concept behind many safety devices including air bags, padded dashboards, bike helmets and crash barriers.

Each of these devices increases the amount of time to bring a moving object to rest. If you increase the amount of time to accomplish the same change in momentum, you necessarily will be applying a smaller force.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse and Momentum Examples

$J=350 \text{ N s}$	$J=350 \text{ N s}$
$m = 75 \text{ kg}$	$m=150 \text{ kg}$
$\Delta p=?$	$\Delta p=?$

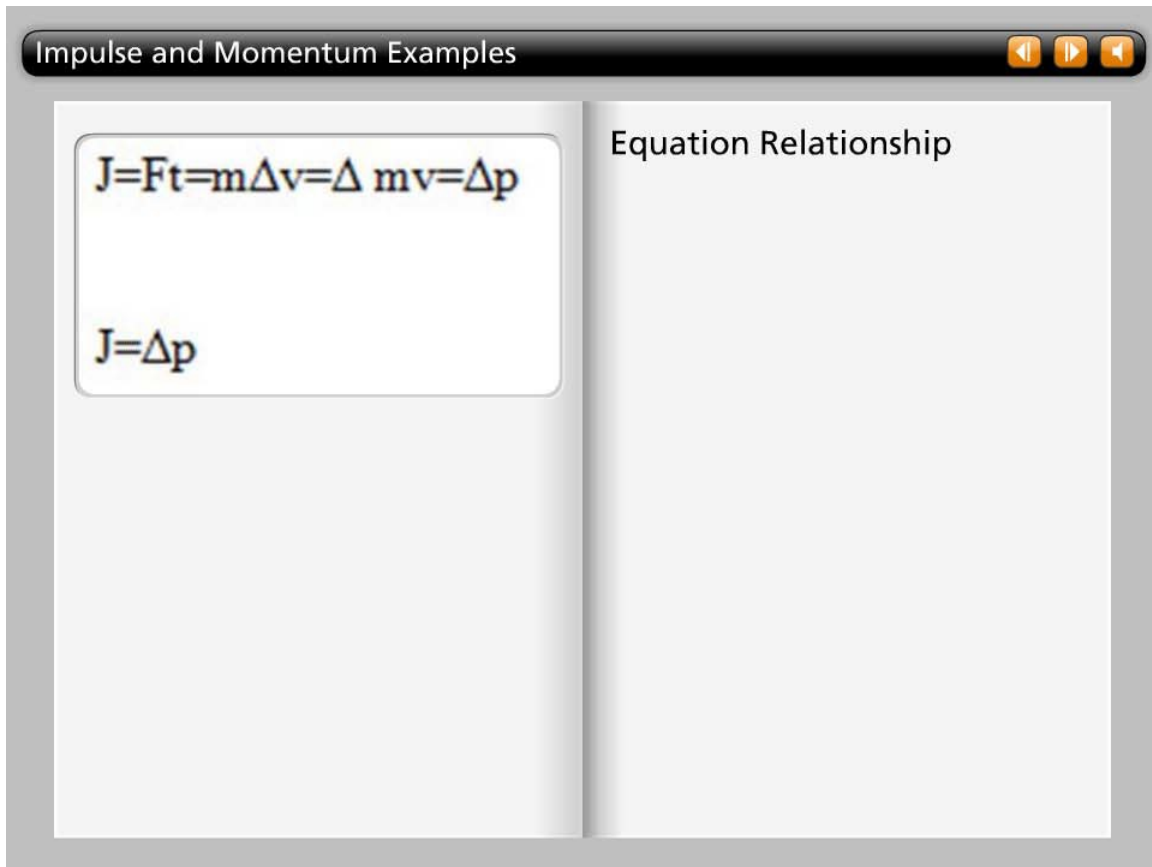
Example 1
An impulse of 350 Newton seconds is applied to a mass of 75 kg. If the same impulse is applied to a mass of 150 kg, which would undergo the greater change in momentum?

Let's look at a few examples of impulse and momentum calculations to better understand how these concepts work together.

An impulse of three hundred fifty Newton seconds is applied to a mass of seventy five kilograms. If the same impulse is applied to a mass of one hundred fifty kilograms, which would undergo the greater change in momentum?

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes



The screenshot shows a presentation window with the title "Impulse and Momentum Examples" and navigation buttons. The main content is split into two columns. The left column contains two equations: $J = Ft = m\Delta v = \Delta mv = \Delta p$ and $J = \Delta p$. The right column is titled "Equation Relationship" and is currently blank.

You have one equation that relates impulse and momentum in all its different forms. You can say that impulse equals force times time equals mass times change in velocity, which equals change in mass times velocity, which equals change in momentum.

This relationship, that impulse equals change in momentum, is known as the impulse momentum theorem.

From this overall equation, you can pull out any pair of equalities that best apply to the current situation.

Since impulse is equal to change in momentum, the mass doesn't matter in this situation. Each mass would experience the same change in momentum.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse and Momentum Examples

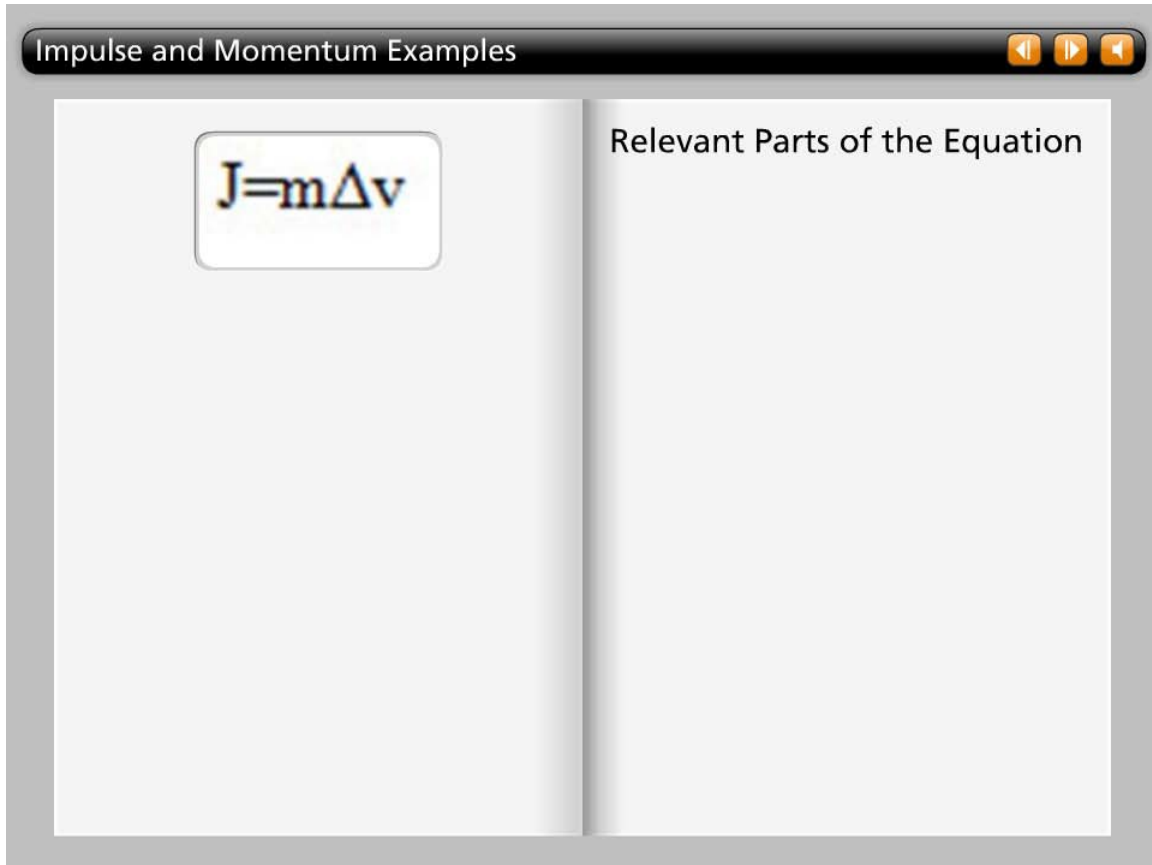
$J=350 \text{ N s}$	$J=350 \text{ N s}$
$m = 75 \text{ kg}$	$m=150 \text{ kg}$
$\Delta v=?$	$\Delta v=?$

Change in Velocity

What would be the change in velocity of each mass?

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes



Impulse and Momentum Examples

$$J = m\Delta v$$

Relevant Parts of the Equation

Now that you're looking for the change in velocity, you can pick the relevant parts of the equation and write impulse equals mass times change in velocity, or J equals m delta v .

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse and Momentum Examples

$J=m\Delta v$	$J=m\Delta v$
$350=(75)\Delta v$	$350=(150)\Delta v$
$\Delta v=4.67 \text{ m/s}$	$\Delta v=2.33 \text{ m/s}$

First and Second Mass

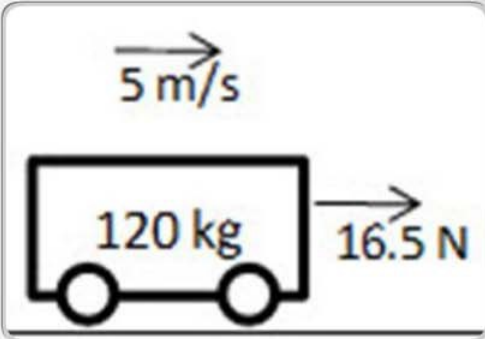
For the first mass, you see that the change in velocity will be four point six seven meters per second.

For the second mass, you see that the change in velocity would be only two point three three meters per second.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse and Momentum Examples



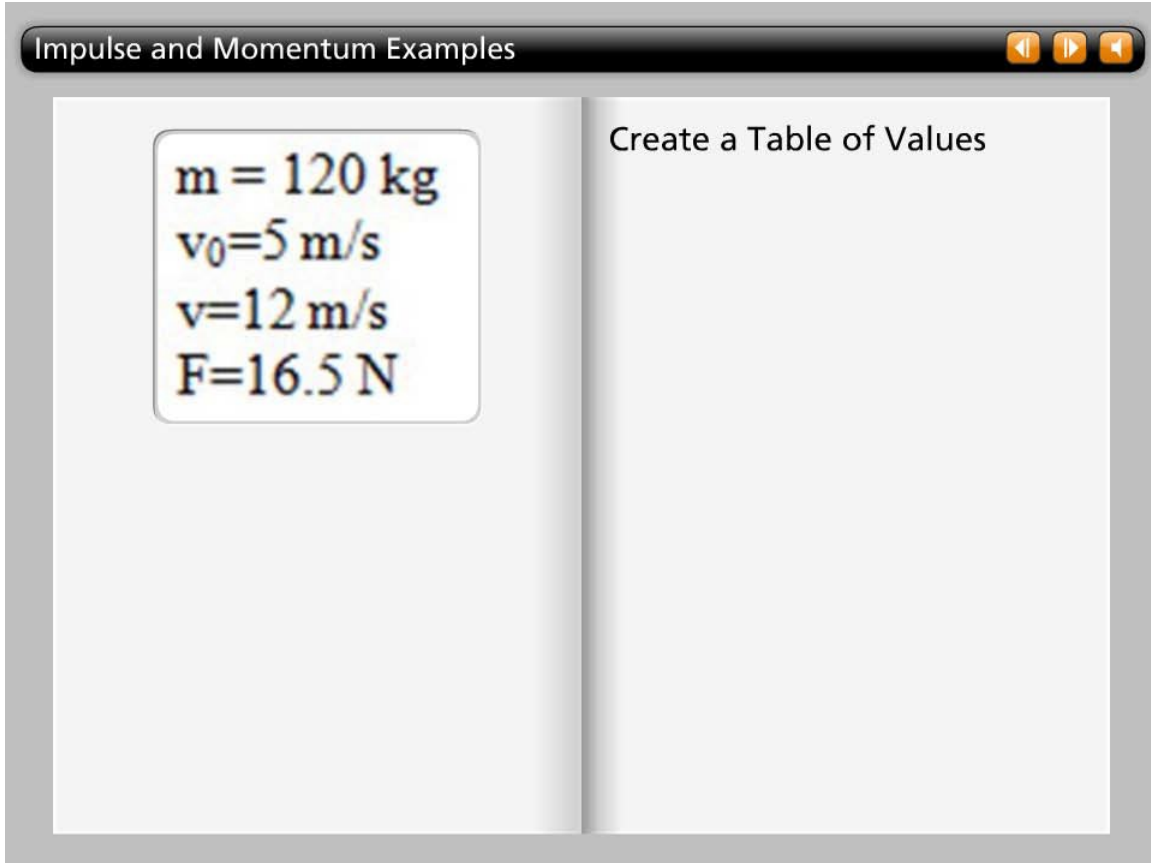
The diagram shows a rectangular wagon with two wheels. Inside the wagon, the text "120 kg" is written. Above the wagon, there is a right-pointing arrow with "5 m/s" written below it. To the right of the wagon, there is another right-pointing arrow with "16.5 N" written below it.

Example 2
How much time would be required for a constant force of 16.5 Newtons to increase the speed of a 120 kg wagon from 5 m/s to 12m/s?

How much time would be required for a constant force of sixteen point five Newtons to increase the speed of a hundred twenty kilogram wagon from five meters per second to twelve meters per second?

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes



The screenshot shows a presentation window with a title bar that reads "Impulse and Momentum Examples". The window is divided into two panes. The left pane contains a list of variables: $m = 120 \text{ kg}$, $v_0 = 5 \text{ m/s}$, $v = 12 \text{ m/s}$, and $F = 16.5 \text{ N}$. The right pane is titled "Create a Table of Values" and is currently empty.

You should first create a table of values. The mass is one hundred twenty kilograms. The initial speed is five meters per second. The final speed is twelve meters per second and the force is sixteen point five Newtons.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse and Momentum Examples

$J = Ft = m\Delta v = \Delta mv = \Delta p$

$Ft = m\Delta v$

Looking for Time

Looking at the same combined equation, in this case, you know the force and the mass. You can easily calculate the change in velocity and you are looking for time. So you can write $Ft = m\Delta v$.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes

Impulse and Momentum Examples

$\Delta v = v - v_0 = 12 - 5 = 7 \text{ m/s}$

Table of Values:
 $m = 120 \text{ kg}$
 $v_0 = 5 \text{ m/s}$
 $v = 12 \text{ m/s}$
 $F = 16.5 \text{ N}$

$Ft = m\Delta v$
 $(16.5)(t) = (120)(7)$
 $t = 50.9 \text{ s}$

Change in Velocity

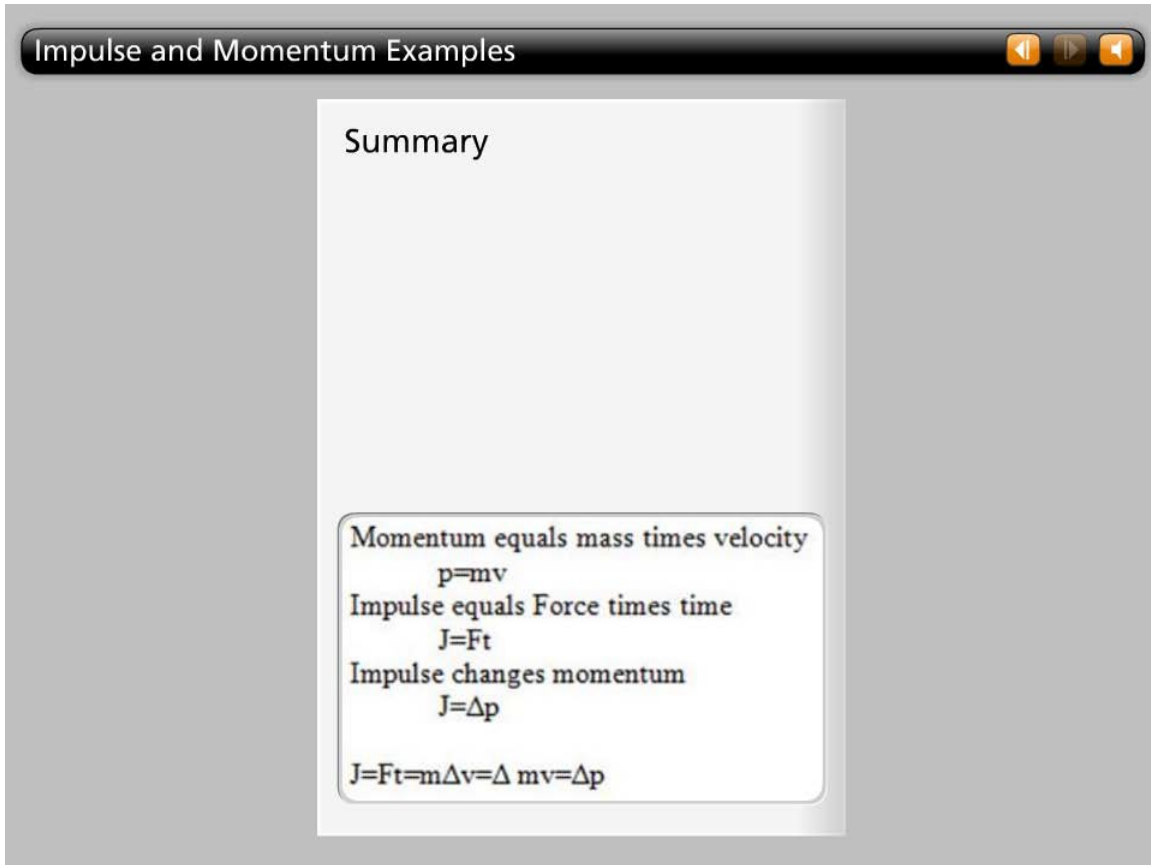
The change in velocity is the final velocity minus the initial velocity. Twelve minus five equals seven meters per second.

Now you can substitute the values into our equation.

You can now calculate the time. Rearranging and solving, you see that the time is equal to fifty point nine seconds.

Module 5: Impulse and Momentum

Topic 1 Content: Impulse and Momentum Presentation Notes



Impulse and Momentum Examples

Summary

Momentum equals mass times velocity
 $p=mv$
Impulse equals Force times time
 $J=Ft$
Impulse changes momentum
 $J=\Delta p$
 $J=Ft=m\Delta v=\Delta mv=\Delta p$

You can see that impulse and momentum give you a valuable new way of looking at objects in motion.

Momentum is the vector product of mass times velocity. Impulse is the vector product of force times time.

Impulse changes momentum.

And you can relate these three concepts with a single expanded equation.