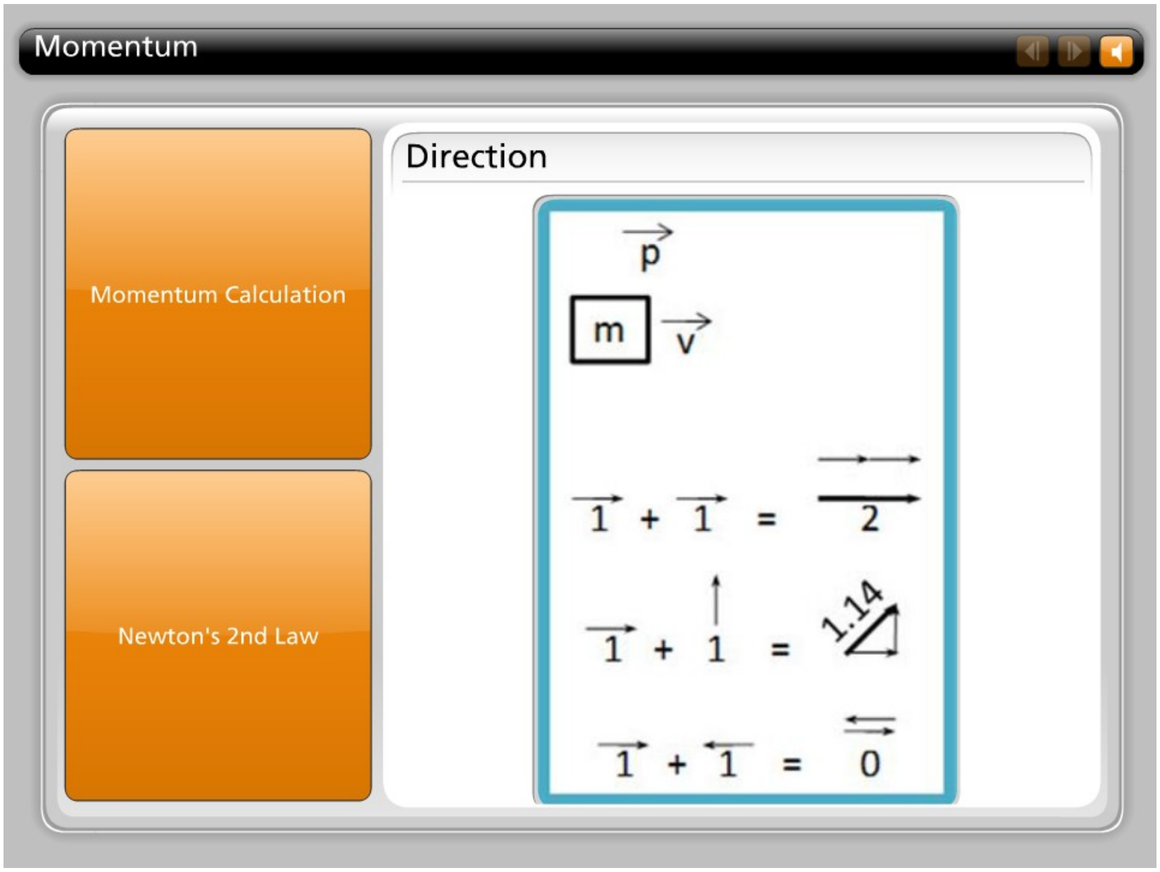
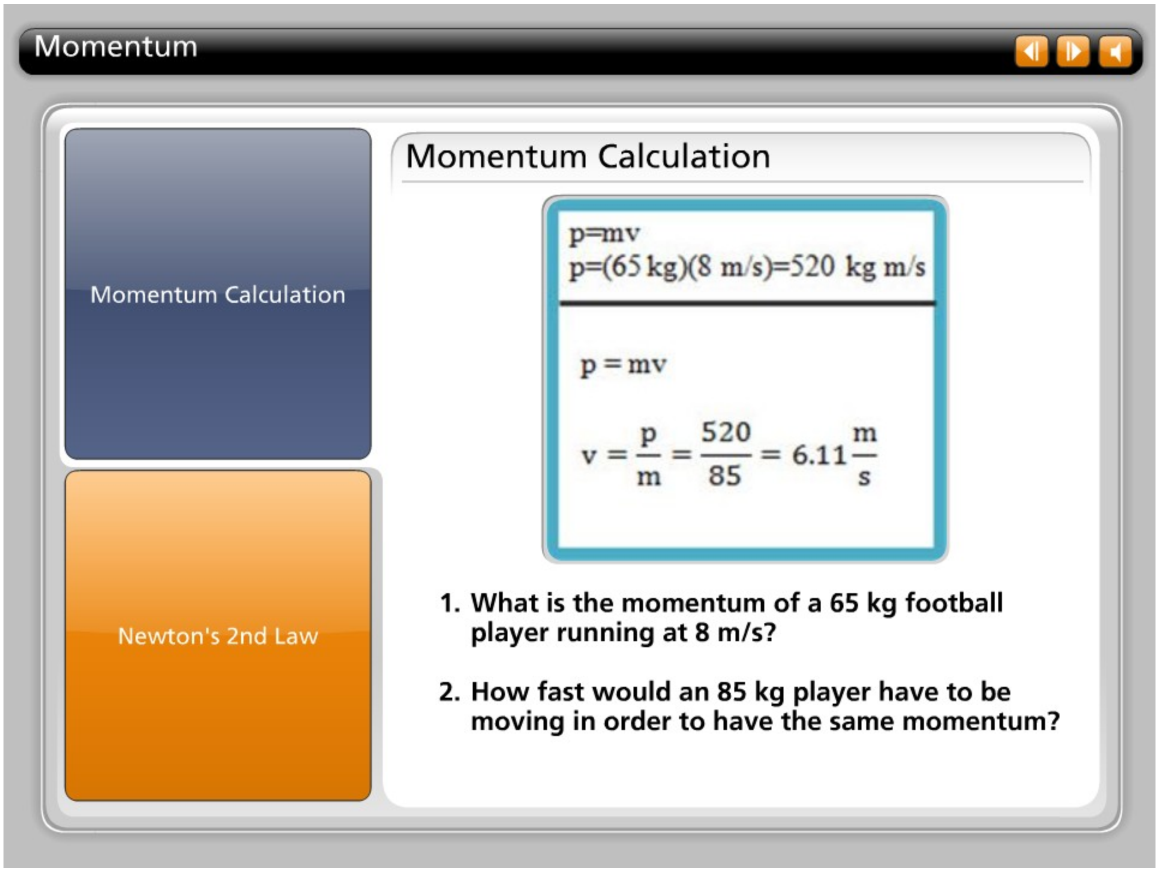
Module 5: Impulse and Momentum
Topic 1 Content: Impulse and Momentum Presentation Notes



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.

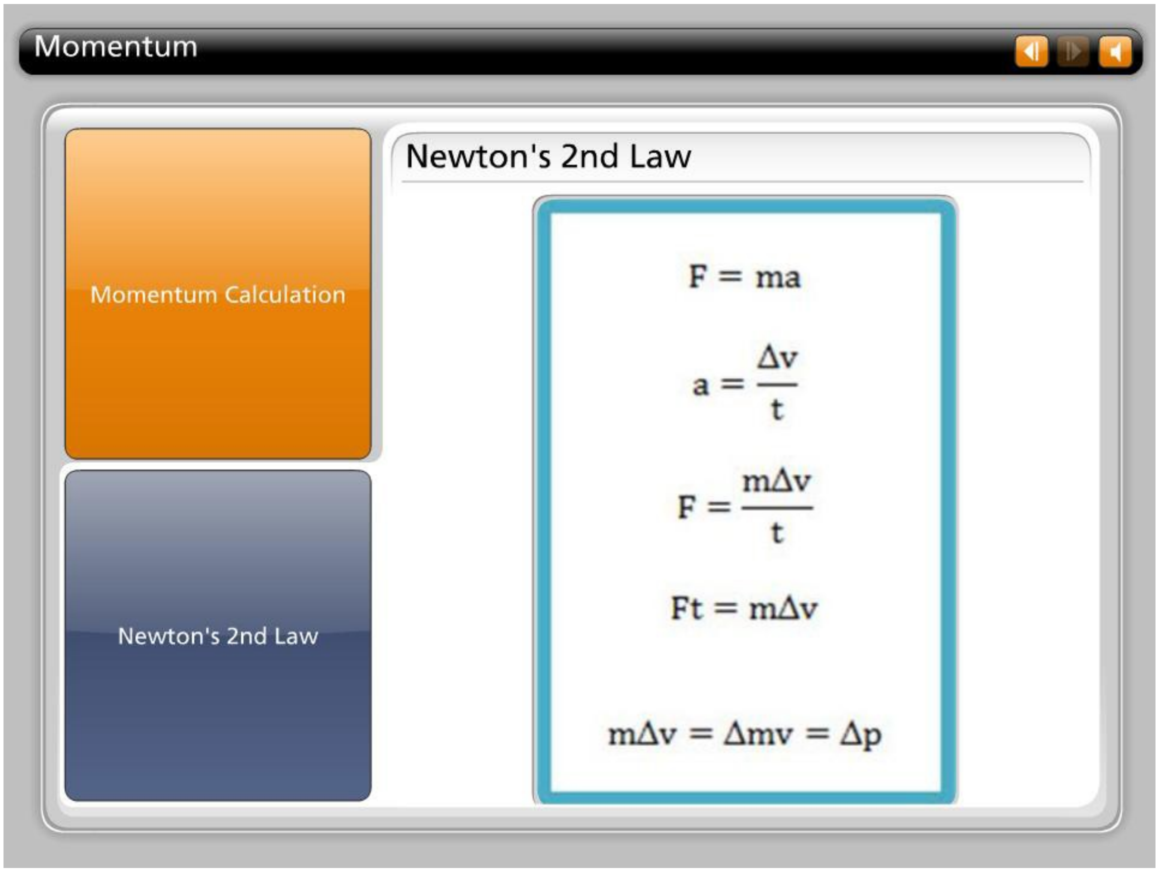


Let's take a look at a momentum calculation. What is the momentum of a sixty five kilogram football player running at eight meters per second?

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.



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.

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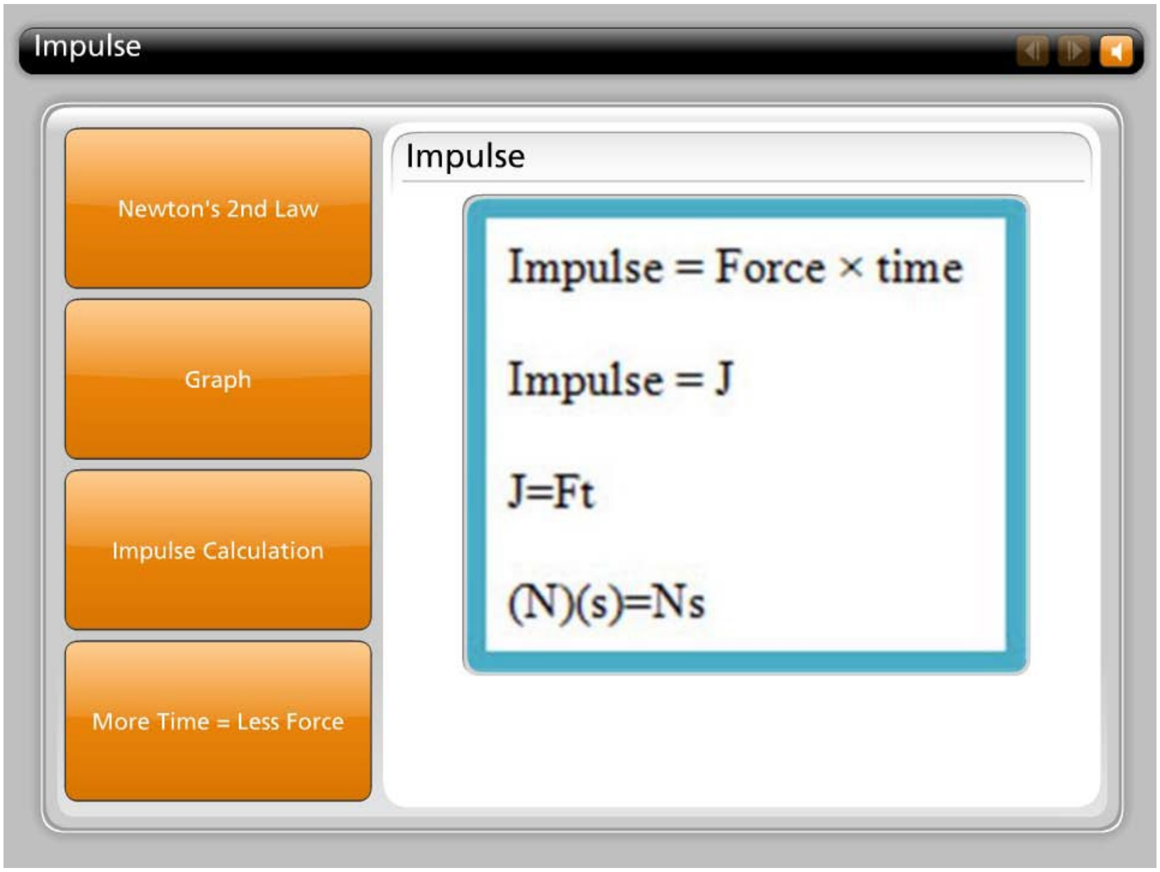
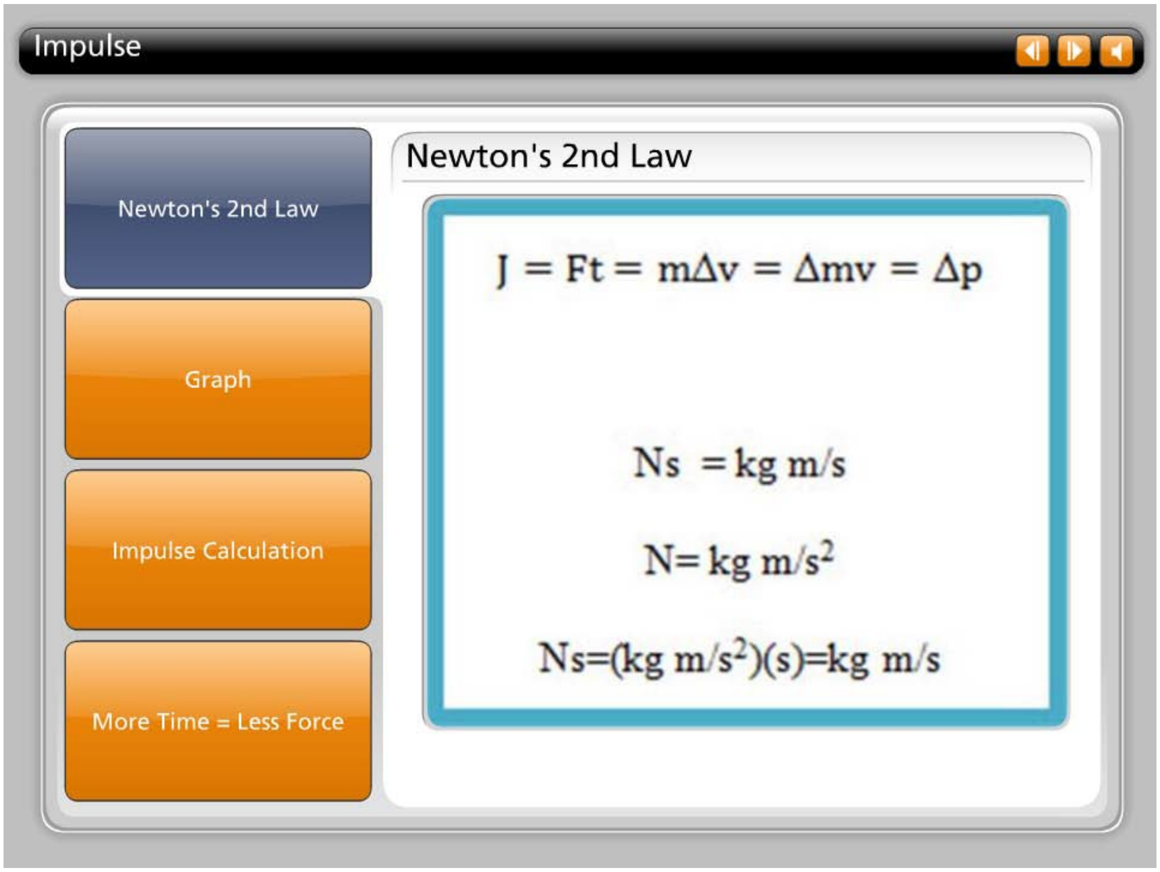


The product of force and the elapsed time is impulse. You use the capital letter J as the variable for impulse. Again, you have a letter with no direct relationship to the quantity it represents, but it is the letter that is commonly used in physics for impulse. So you write J equals F t.

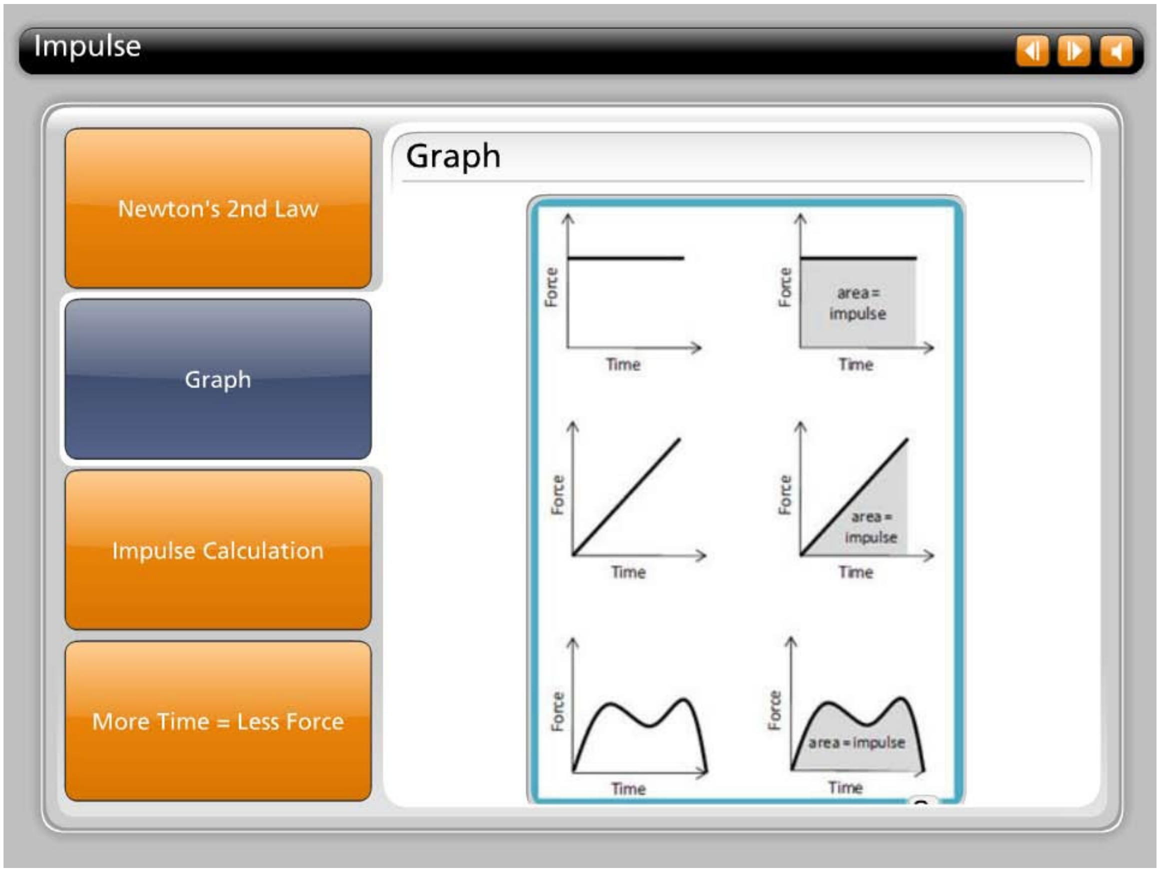
Since force is in Newtons and time is in seconds, the units for impulse are Newtons times seconds or Newton seconds.



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?

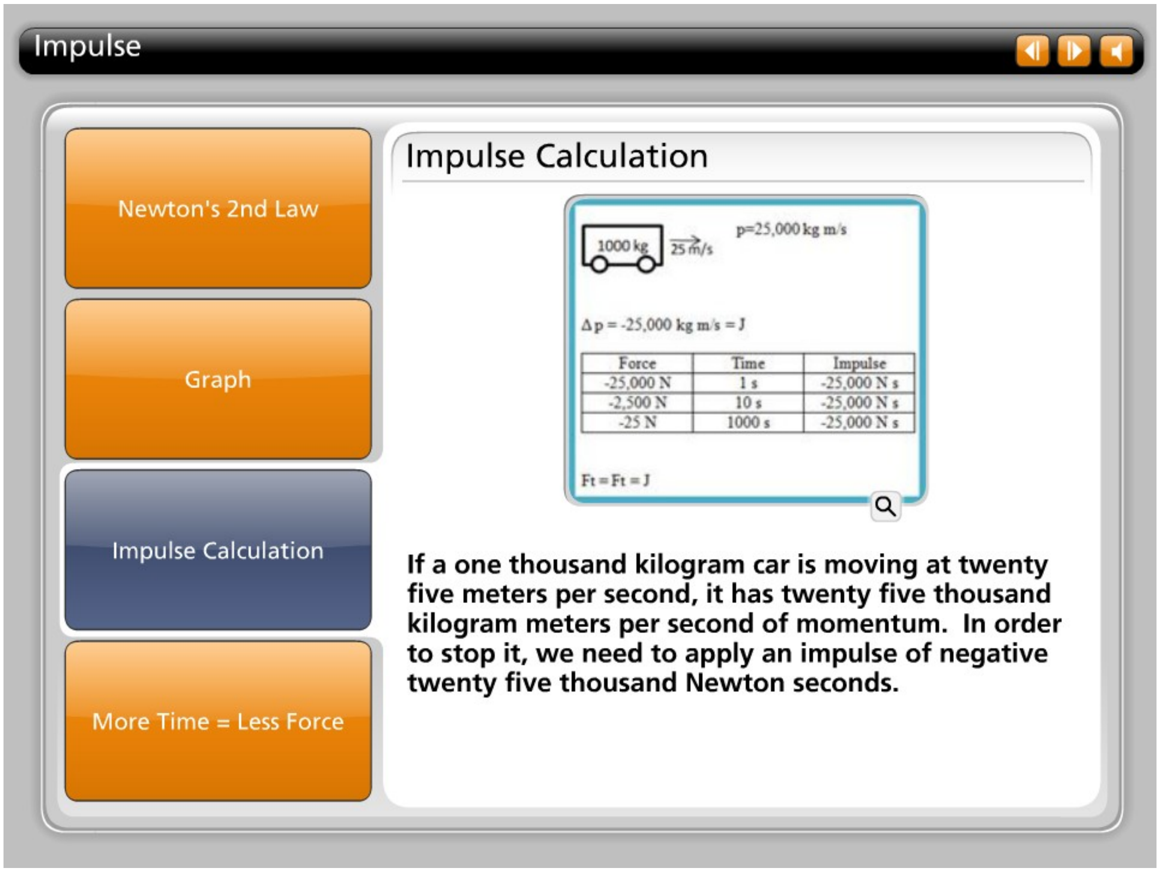
If you remember that a Newton is a kilogram meter per second squared and multiply this by seconds, you see that you wind up with kilogram meters per second, the same as momentum. So your units match.



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.



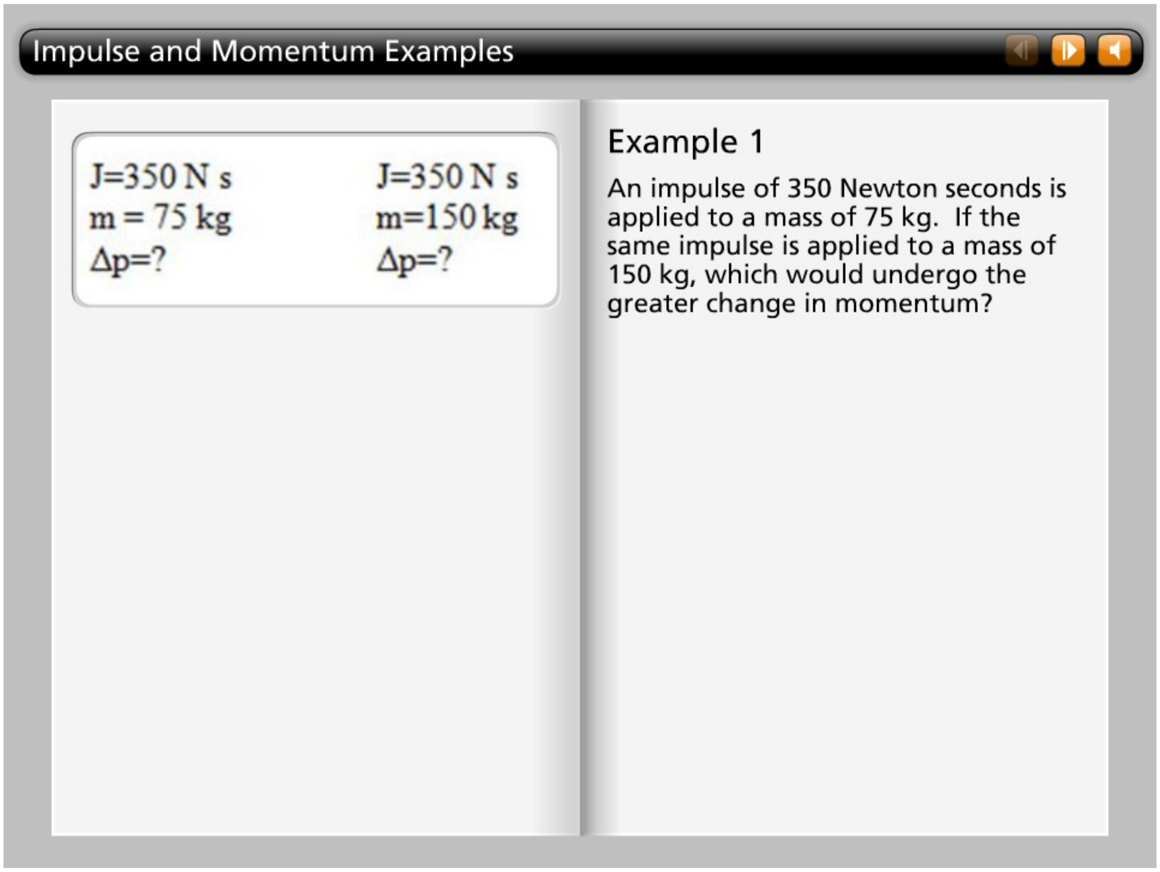
If a one thousand kilogram car is moving at twenty five meters per second, it has twenty five thousand kilogram meters per second of momentum. In order to stop it, we need to apply an impulse of negative twenty five thousand Newton seconds.

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.

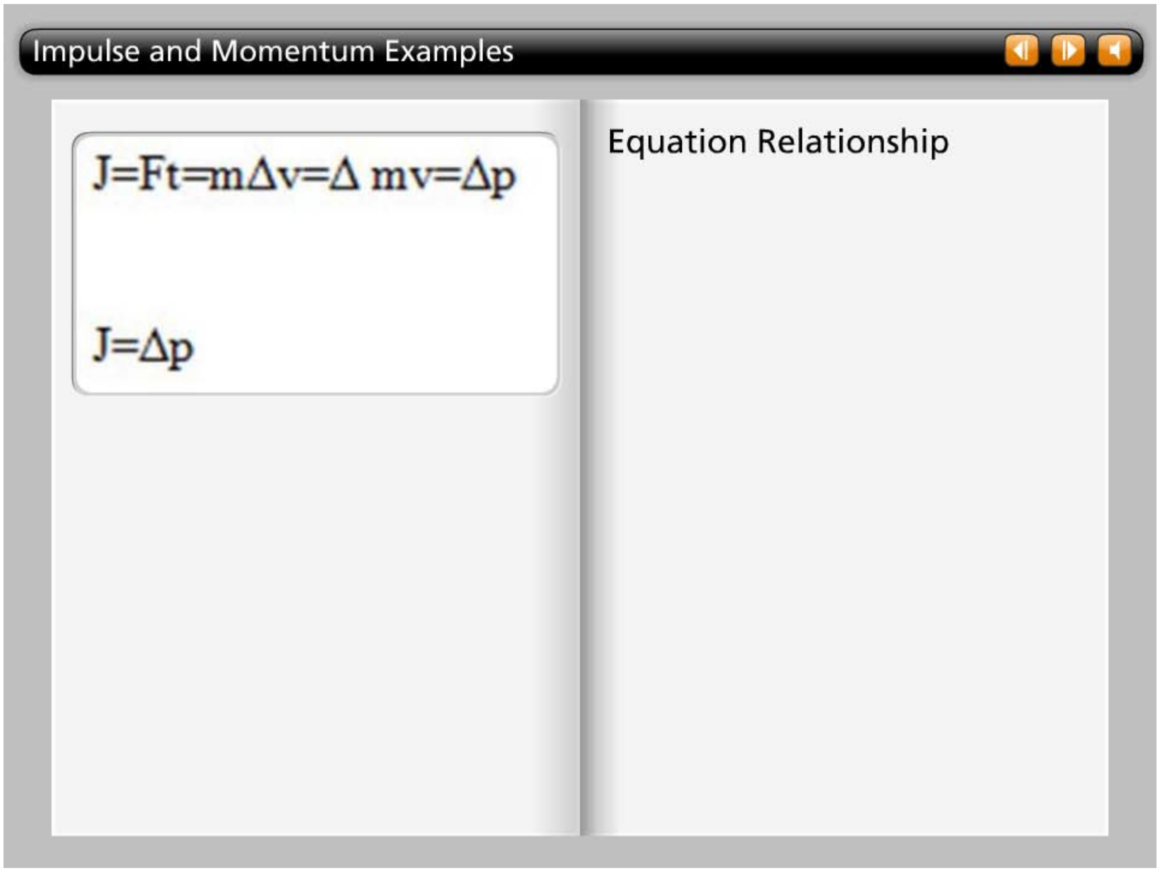
This is the concept behind many safety devices including air bags, padded dashboards, bike helmets and crash barriers.

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.



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?

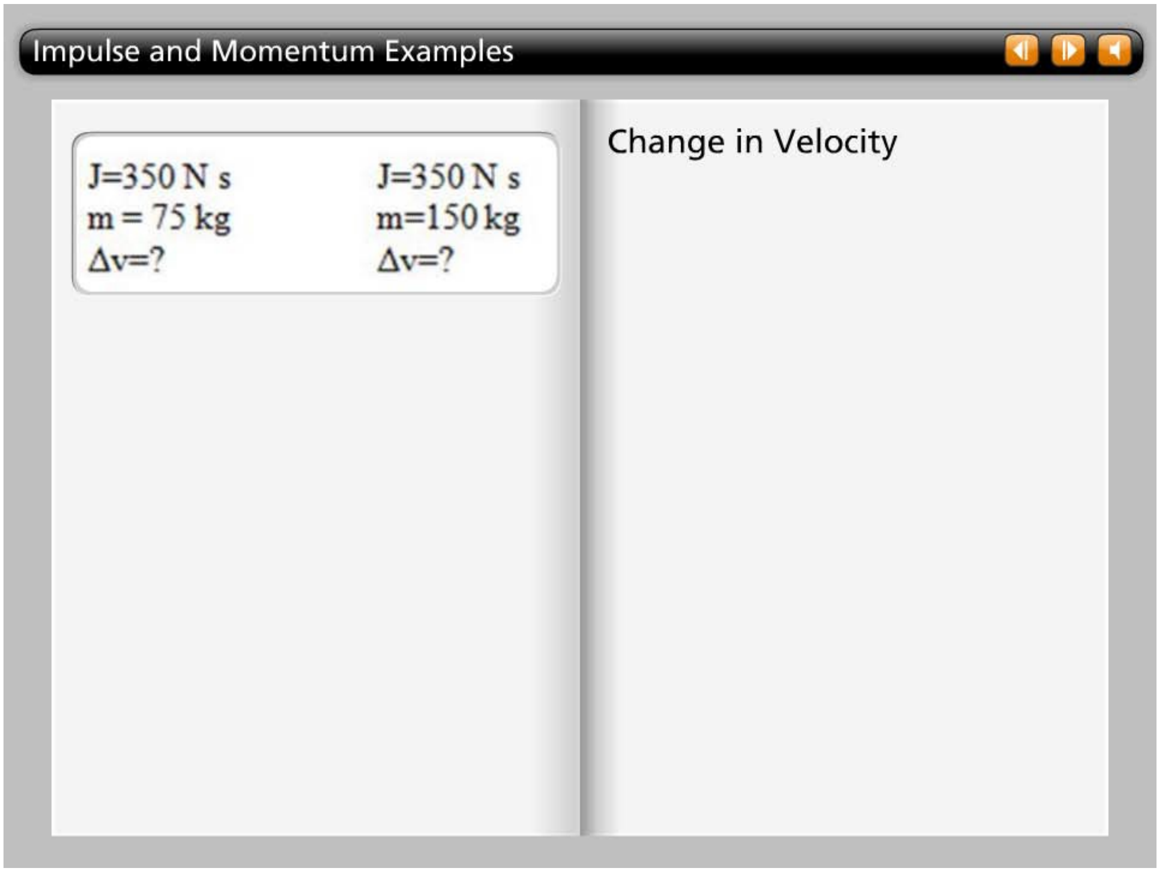


You have one equation that relates impulse and momentum in all its different forms. You can say that impulse equals force times time equals mass times change in velocity, which equals change in mass times velocity, which equals change in momentum.

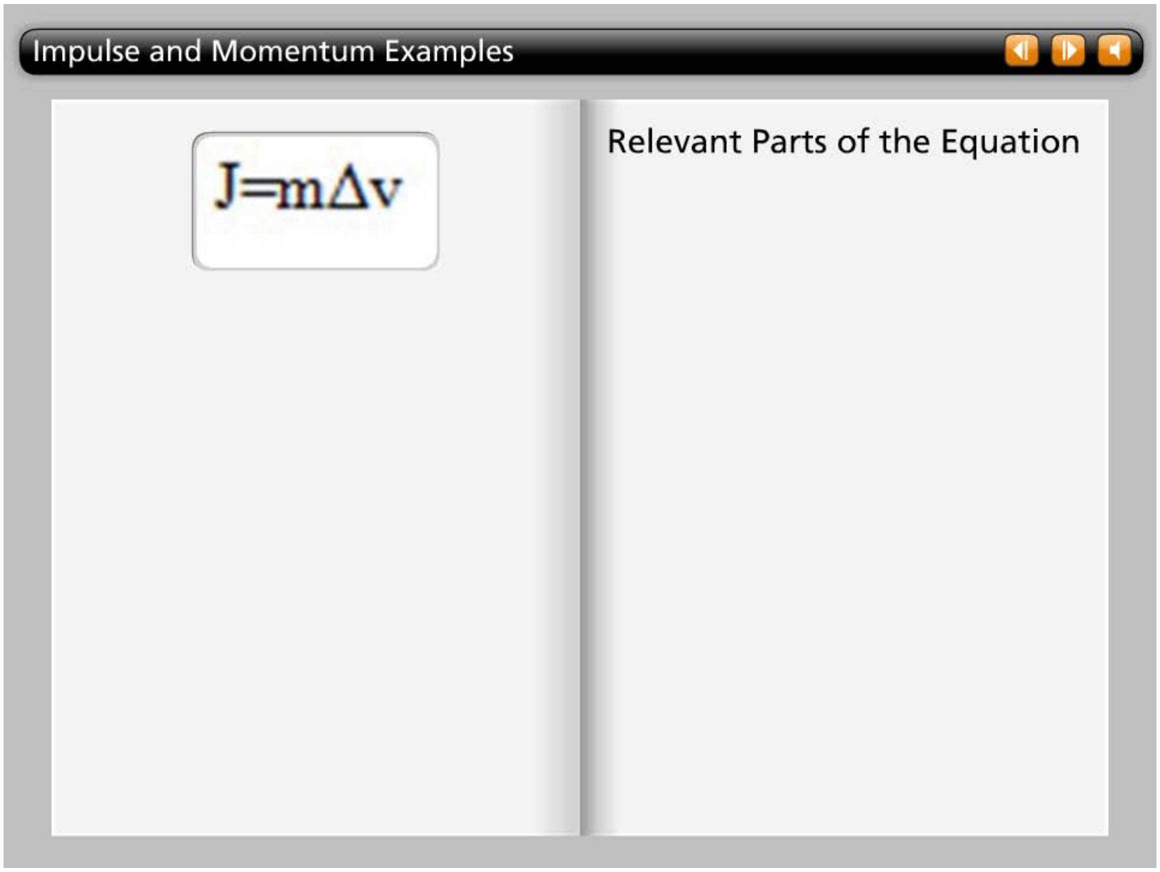
This relationship, that impulse equals change in momentum, is known as the impulse momentum theorem.

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

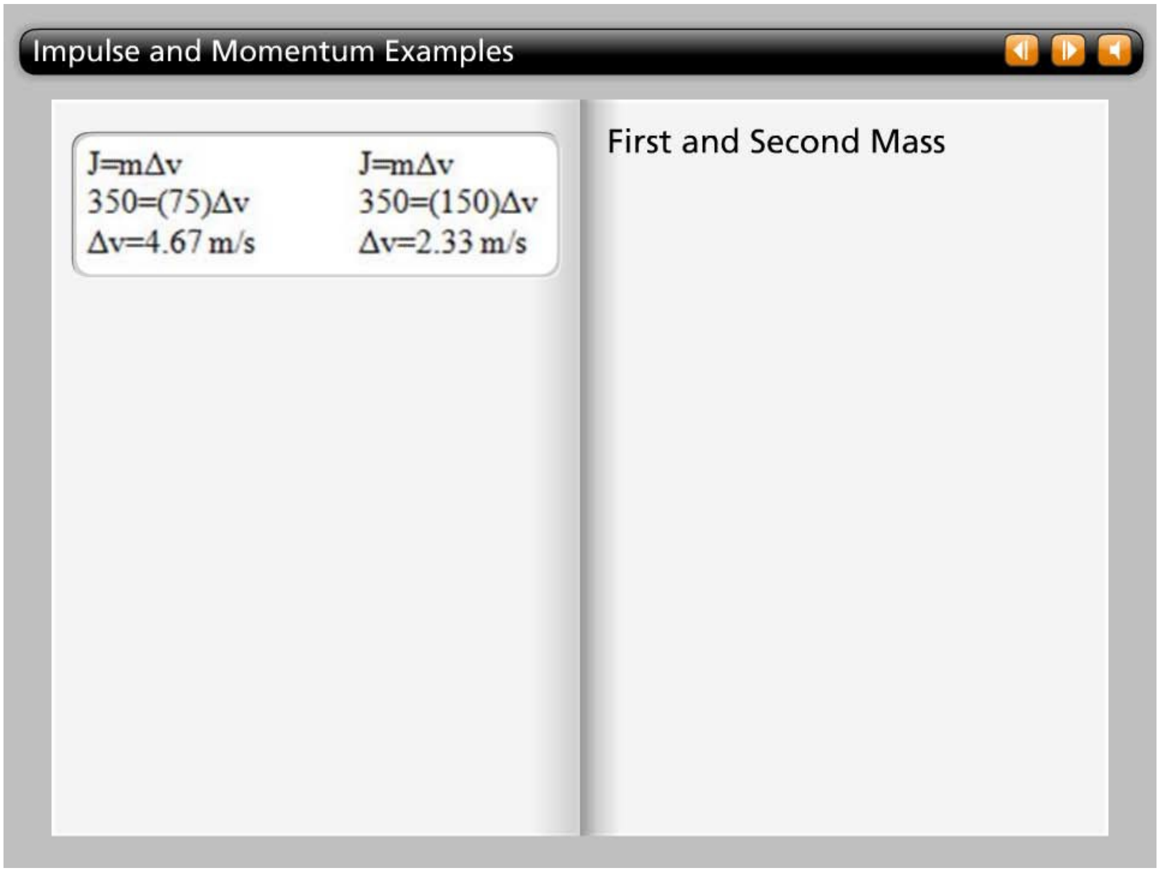
Since impulse is equal to change in momentum, the mass doesn't matter in this situation. Each mass would experience the same change in momentum.



What would be the change in velocity of each mass?

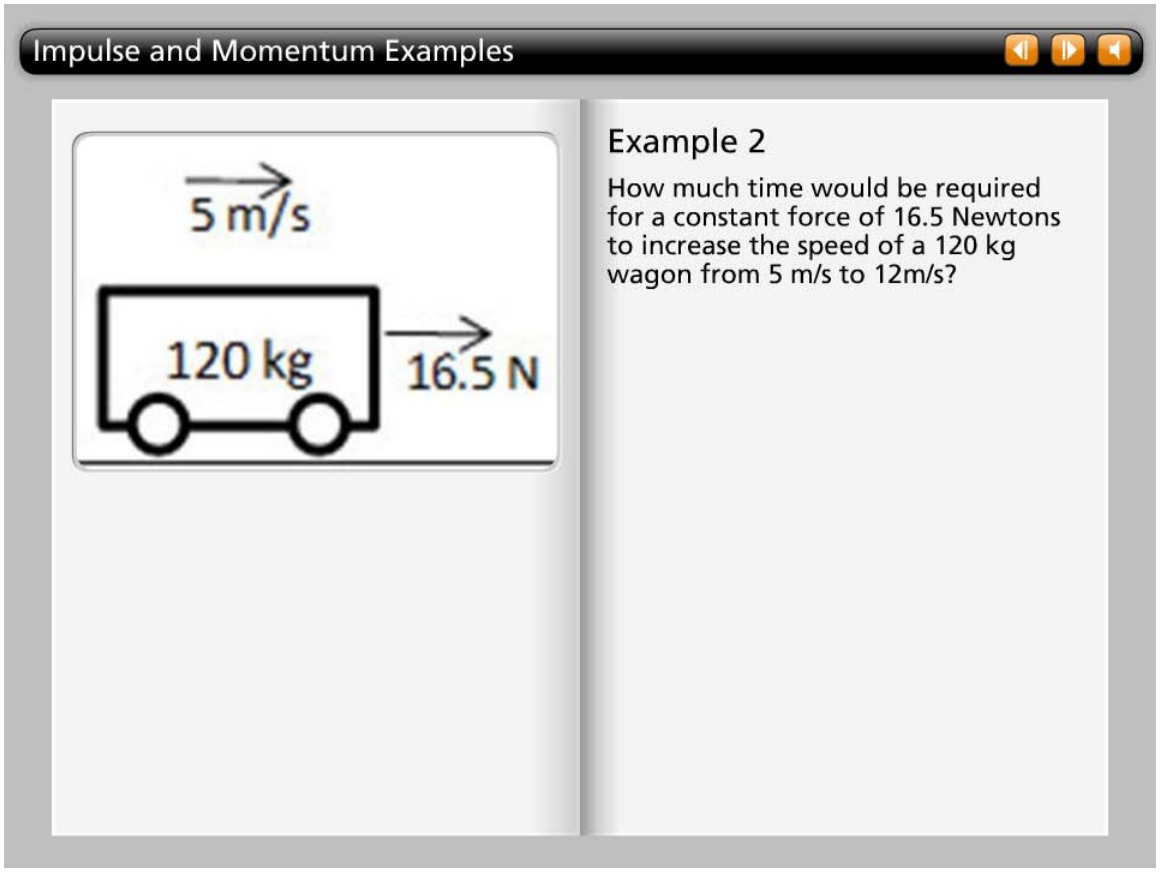


Now that you're looking for the change in velocity, you can pick the relevant parts of the equation and write impulse equals mass times change in velocity, or J equals m delta v.

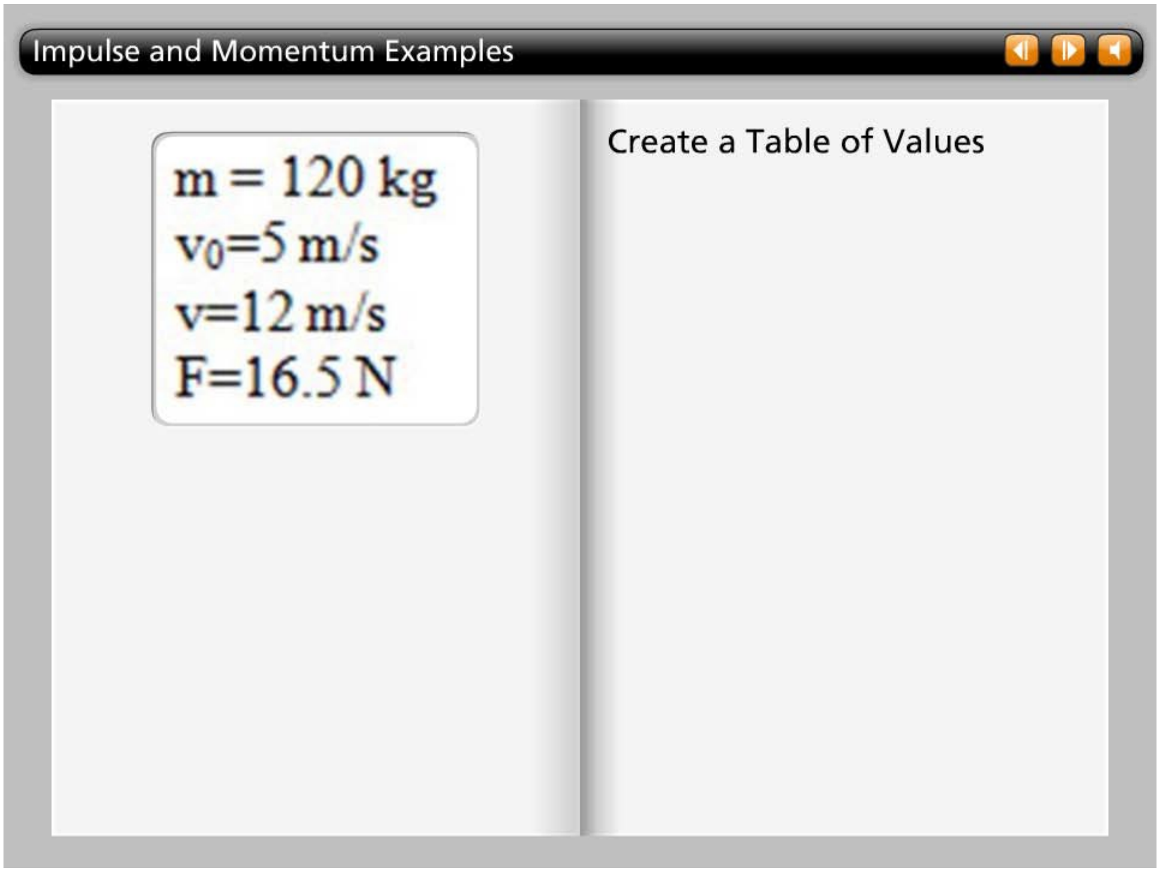


For the first mass, you see that the change in velocity will be four point six seven meters per second.

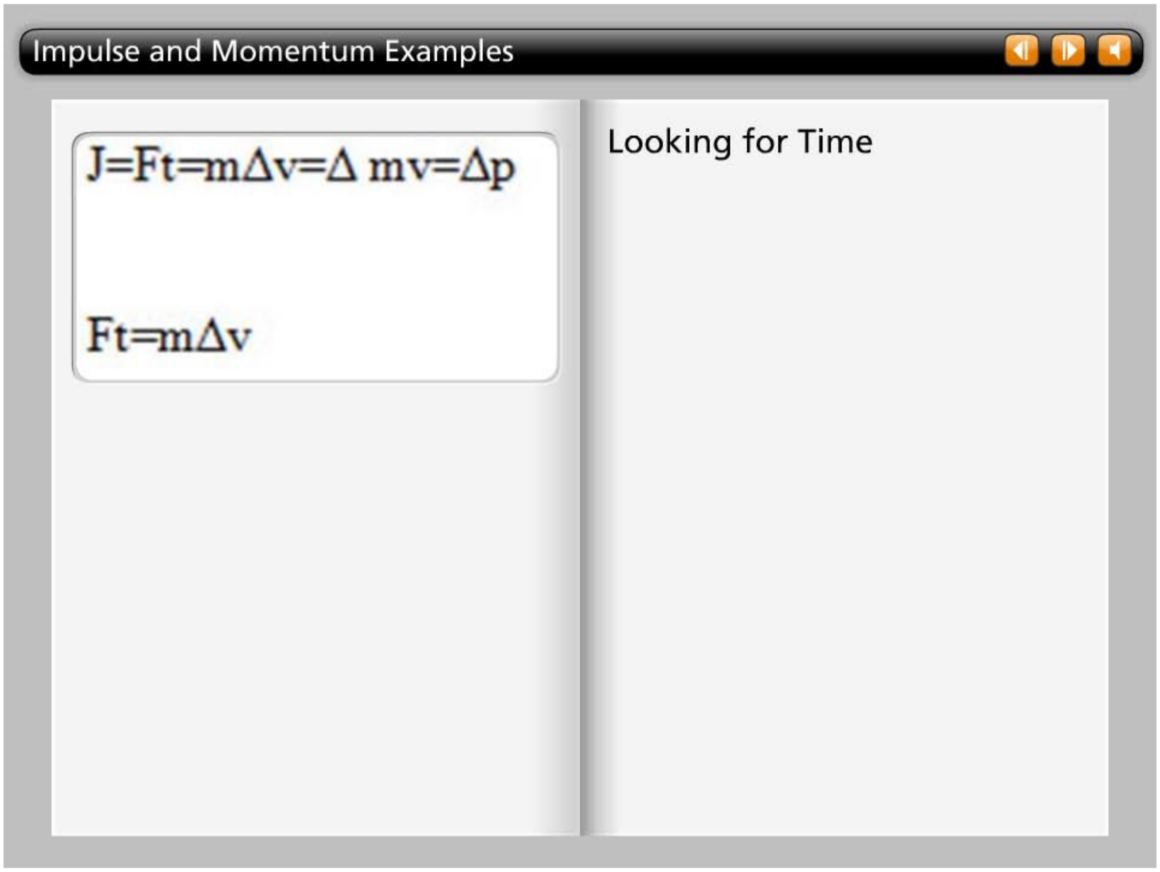
For the second mass, you see that the change in velocity would be only two point three three meters per second.



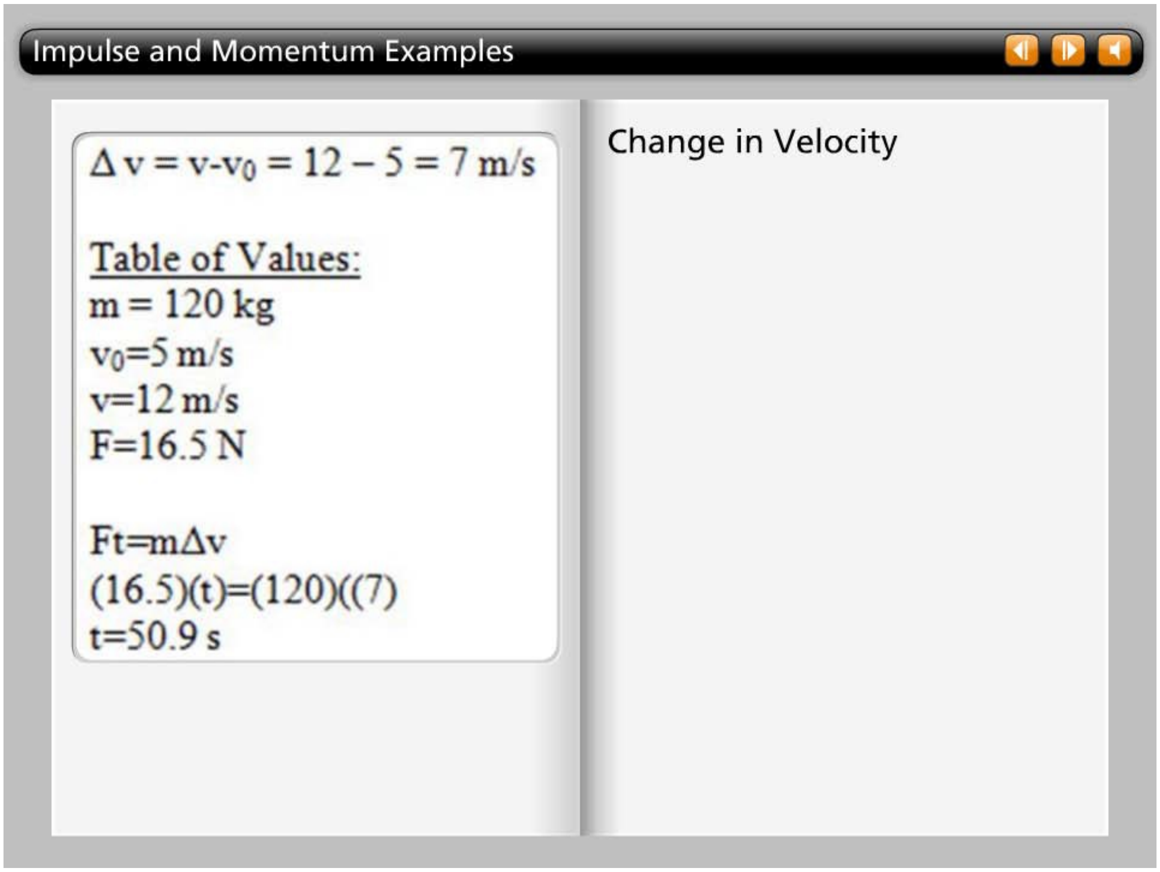
How much time would be required for a constant force of sixteen point five Newtons to increase the speed of a hundred twenty kilogram wagon from five meters per second to twelve meters per second?



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.



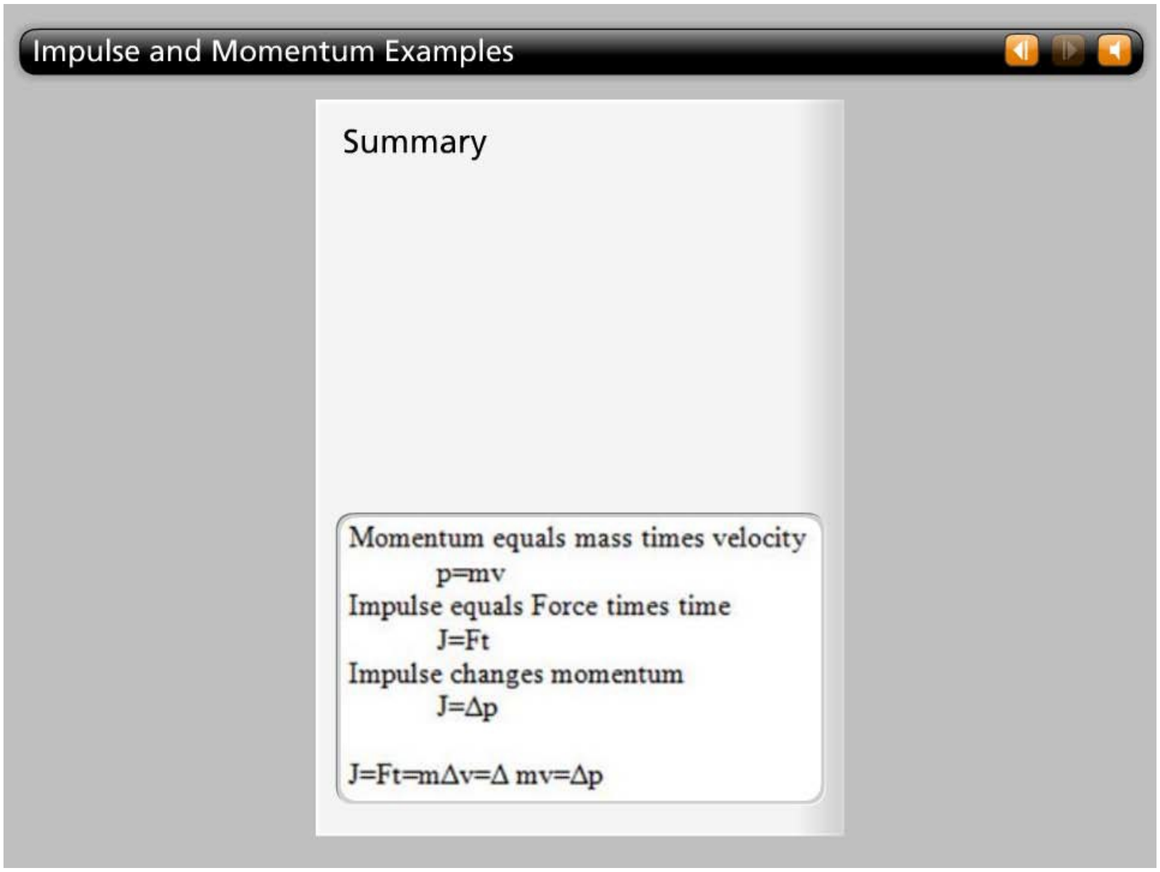
Looking at the same combined equation, in this case, you know the force and the mass. You can easily calculate the change in velocity and you are looking for time. So you can write F t equals m delta v.



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.



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.