4.6.1 Force and change of momentum

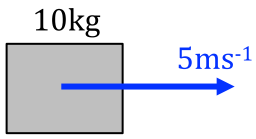
Linear momentum (p) is defined as the product of an objects mass (m) and velocity (v):

$$p = mv$$

videos

As velocity is a vector quantity, so is momentum (it has a direction and size).

On this course, we only deal with momentum in one dimension. We usually take momentum to the right to be positive and momentum to the left to be negative.



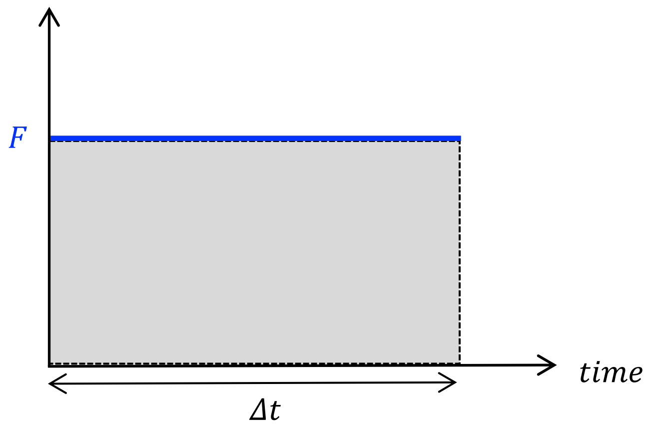
(1) What is the momentum of the block, above? What are the units?

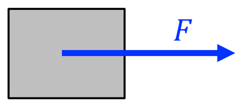
If an object has momentum, a force is required to change its momentum. The length of time (Δt) the force (F) acts on the object the bigger the change in momentum (Δp). We can write the following expression:

$$\Delta p = F\Delta t$$

(2) From this equation, what is an alternative unit for momentum?

The product $F\Delta t$ is called impulse. Consider the graph below:





We can see that a force F acts on an object for a time Δt. The area under this graph $F\Delta t$ represents the change of momentum of the object. For example, if the object was initially at rest, and a force is applied to the right (for a time Δt) it would gain momentum ($F\Delta t$) to the right.

(3) What would the change in momentum be for an object experiencing a force to the left of 20N for 0.1s?

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The simplified version of Newton's 2nd law is $F = ma$, where m is the mass of an object and a is its acceleration. Lets see if this law is consistent with the equation for change of momentum, above. (Remember momentum $p = mv$).

$$\Delta p = m\Delta v = F\Delta t$$

$$\therefore F = m\frac{\Delta v}{\Delta t} = ma$$

So, yes! In fact the more general description of Newton's 2nd law is:

$$F = \frac{\Delta p}{\Delta t}$$

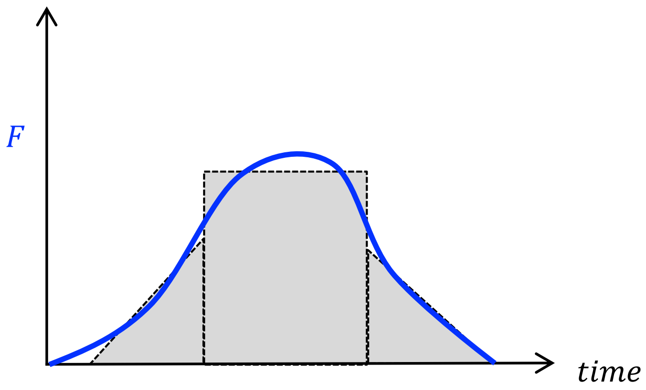
"The rate of change of momentum is equal to the unbalanced force applied."

It is more general because it takes into account that the mass of an object may change during the application of a force. For example, consider a rocket. The propulsion is provided by the ejection of a lot of fuel (which has mass). Therefore the mass of the rocket will decrease over time.

(4)✐A rocket with an initial mass of 2000kg is launched from rest and reaches a velocity of 11000ms^{-1} after 3000s. It burns (and ejects) 1000kg of fuel in the process. What is its change of momentum?

(5)✐What is the average force from the rocket engines?

Now consider the following force-time graph:



In this case we can see that the force acting on an object is not constant over time, but is changing. We can work out the impulse (=change of momentum) by working out the area under the graph, as before. However, in this case we will need to approximate the area using rectangles and triangles and adding up the areas, as shown in the diagram.

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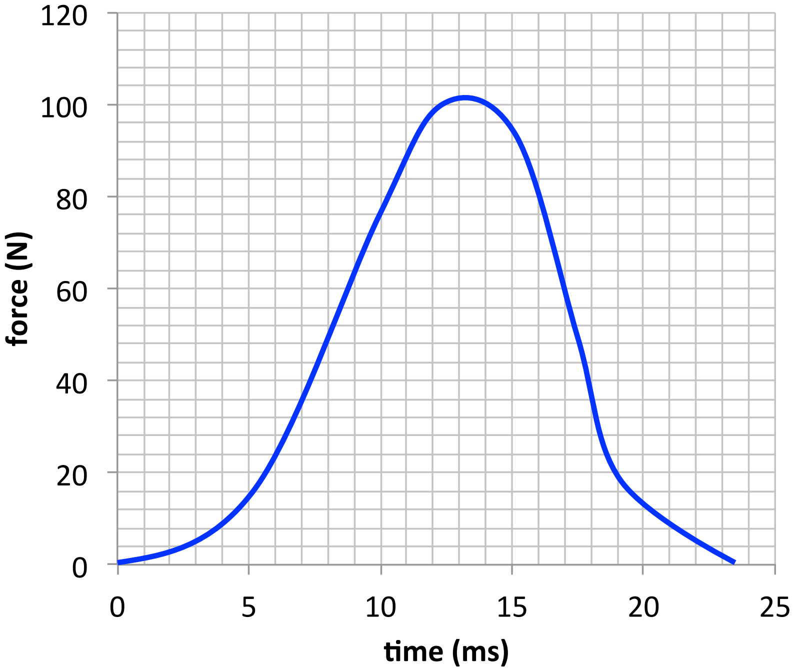
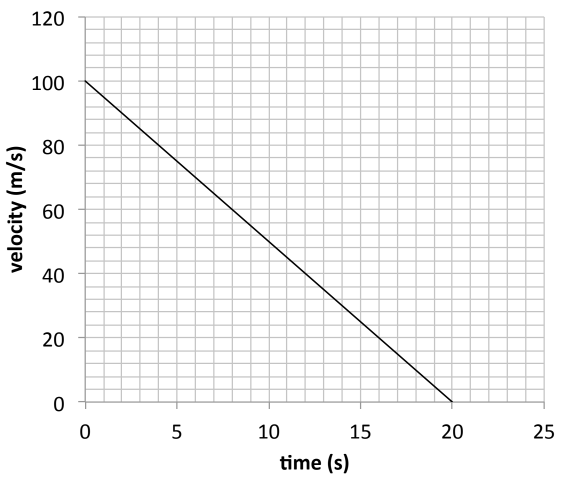
(6)✐ *The following force-time graph shows the force felt by a golf ball whilst being struck by a golf club. Use the approximation technique, above, to work out the change in momentum of the golf ball. (Note: time in x10^{-3} seconds)*



(7)✐ *Given that the golf ball has a mass of 0.04kg, and is initially at rest, work out its final velocity.*

Vehicles braking

When vehicles brake, the brakes provide (along with the friction between the tyres and the road) a force which opposes motion and slows the vehicle down. In problems involving braking, we often assume that the braking force is a constant. In this case deceleration (-acceleration) is a constant. Consider the velocity-time graph:



(8)✐ *What is the deceleration?*

(9)✐ *Given that the vehicle is 1000kg, what is the braking force?*

(10)✐ *What is the change of momentum?*

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