WOW sheet

Newton's second law

The second of Sir Isaac Newton's three laws of motion, Newton's second law says:

> Force is equal to the product of mass and acceleration.

This law is usually written as a mathematical formula:

$$\mathbf{F}=m\boldsymbol{a}$$

In other words, this is really just a simple multiplication formula: **F**orce = *m*ass × ***a***cceleration. As long as you know the values for two of those three things, you can calculate the third!

But what does this equation mean? And how does it relate to motion?

F=*ma* and motion

Newton's first law explains that in order to overcome inertia, you need an outside force. Newton's second law builds on this idea. This law explains *how* an outside force will affect an object's motion.

Newton's second law (**F**=*m****a***) tells us that force, mass and acceleration are interconnected. This relationship determines the motion of an object.

So, what are force, mass and acceleration?

- **Force** is a push or a pull exerted on one object by another object. The unit that force (**F**) is measured in is newtons (N).
- **Mass** is the amount of matter there is in something. The unit that mass (*m*) is measured in is kilograms (kg).
- **Acceleration** is the change in the velocity of an object over time. The unit that acceleration (***a***) is measured in is meters per second squared ($\frac{m}{s^2}$).

You can see that there's actually a lot of information packed into the simple formula (**F**=*m****a***). You don't need to understand all of it in order to understand what it tells us about the relationship between force, mass and acceleration, however.

Look at the equation again:

F=*m****a***

Because this is a mathematical formula, we can determine a few things about the relationship between force, mass and acceleration just by looking at the structure of the formula.

For example, this equation tells us that the more mass an object has, the more force it will take in order to get that object to accelerate.

In other words, the greater the *m*ass of an object, the greater the **f**orce you need to get it to ***a***ccelerate.

Here's an example

Think about bowling balls at a bowling alley. Different bowling balls have different masses. Let's say there are three bowling balls you can choose between: a 3kg ball, a 5kg ball or an 8kg ball. No matter which ball you choose, you want to get the ball to accelerate at a rate of $2\frac{m}{s^2}$ down the lane. To make it simple, let's ignore the units and just look at the values.

Newton's second law says that $\mathbf{F}=m\boldsymbol{a}$. That means that for the three bowling balls:

$\mathbf{F}= 3\times2$

$\mathbf{F}= 5\times2$

$\mathbf{F}= 8\times2$

You can see that the more mass the bowling ball has, the more force you will need to use to get it to accelerate down the lane.

Curious about the answers? Remember, force is measured in newtons (N). So, for our bowling balls, here's the force you would need:

$(3\text{kg})\times(2\frac{m}{s^2}) = 6\text{N}$

$(5\text{kg})\times(2\frac{m}{s^2}) = 10\text{N}$

$(8\text{kg})\times(2\frac{m}{s^2}) = 16\text{N}$

You can also think about this the other way. The same size **f**orce will cause an object with greater *m*ass to ***a***ccelerate less. This is sometimes described by saying force is inversely proportional to the mass of the object.

Another thing this equation tells us is that the more force you apply to an object, the more that object will accelerate. In fact, the magnitude (size) of the acceleration will be directly proportional to the magnitude of the force. In other words, the greater the **f**orce you apply to an object, the greater the ***a***cceleration will be.

Here's an example

Back to the bowling alley! Let's say you choose the 5kg ball.

Newton's second law says that $\mathbf{F}=m\boldsymbol{a}$. The equals sign tells us that the two sides of the equation have the same value. The mass of your bowling ball is 5kg, so that won't change no matter how much force you apply to the ball. That means the acceleration must increase the harder you throw the ball!

Want to see the maths? Here's what increasing the force on your 5kg bowling ball does to its acceleration:

$5N=(5kg)\times(1\frac{m}{s^2})$ → 5N of force = $1\frac{m}{s^2}$ acceleration

$10N=(5kg)\times(2\frac{m}{s^2})$ → 10N of force = $2\frac{m}{s^2}$ acceleration

$15N=(5kg)\times(3\frac{m}{s^2})$ → 15N of force = $3\frac{m}{s^2}$ acceleration

*a*cceleration = Force ÷ *m*ass

Newton's second law is usually written as a mathematical formula:

$$\mathbf{F}=m\boldsymbol{a}$$

However, you can rearrange the law using algebra and show the same idea with a different formula:

$$\boldsymbol{a}=\frac{\mathbf{F}}{m}$$

In other words, ***a***cceleration = **F**orce ÷ *m*ass.

Here's an example

Back to the bowling alley!

What will the acceleration be if you apply a force of 25 newtons to your 5kg bowling ball? We can use the rearranged version of Newton's second law to work it out:

$$\boldsymbol{a}=\frac{\mathbf{F}}{m}$$

Let's ignore the units to keep it simple:

$$\boldsymbol{a}=\frac{\mathbf{25}}{5}$$

Which means that acceleration is $5\frac{m}{s^2}$!

Bonus! Here's the units: $\boldsymbol{a}=\frac{25\left(\frac{kg*m}{s^2}\right)}{5kg}$

The kg units cancel each other out which leaves $\frac{m}{s^2}$ → $5\frac{m}{s^2}$!

Force and acceleration are both vectors

If you look at the equation again, you will see that both force and acceleration are written in bold letters.

$$\mathbf{F}=m\mathbf{a}$$

Why? This is to show that these are both **vectors**.

A **vector** is a quantity that has both a direction and a magnitude (a size).

Here's an example

Speed is a measurement that tells you how fast something is going, but not what direction it is going. Velocity is a different measurement that tells you both how fast something is going AND what direction it is going. Velocity has both direction and magnitude (in this case, speed) so it's a vector.

Both force and acceleration are vectors, which means they both have a direction. In fact, they have the same direction! Think of it like this: if you kick (apply force) a ball towards a goal, it will accelerate towards the goal. Whatever direction a force is in, that's the direction the acceleration it causes will be in too.