# 2 Newton's laws, forces and momentum

This unit will help you to learn more about how forces cause acceleration and changes to the movement of objects. These forces also cause changes to the momentum of objects during impacts.

In the exam, you will be asked to answer questions such as the one below.

**Exam-style question**

1 Figure 1 shows a golf ball of mass 45 g resting on a golf tee. A golfer will shortly hit it with a golf club.

(a) Give the momentum of the golf ball before the club hits it. (1 mark)

.....

After the club has hit the golf ball, the ball moves away with a velocity of 80 m/s.

(b) Calculate the momentum of the golf ball immediately after it has been hit. Include the correct unit for momentum. (2 marks)

Figure 1

.....

(c) Give the change in momentum for the golf club during the impact. (1 mark)

.....

The impact between the club and the ball lasts for 0.02 s.

(d) Calculate the average acceleration of the ball during the impact. (2 marks)

.....

(e) Use your answer to part (d) to calculate the average force acting on the ball during the impact. (1 mark)

.....

You will already have done some work on forces and changes in velocity. Before starting the **skills boosts**, rate your confidence in each area. Colour in the bars.

1 **How do I explain acceleration using Newton's laws?**

2 **How do I find the size of the forces causing objects to accelerate?**

3 **How can I describe the momentum of objects?**

## Get started

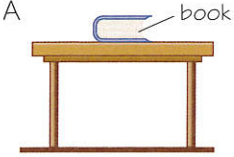
Resultant forces (sometimes called unbalanced forces) cause changes to the movement of objects. This change in movement is called acceleration. An object that is not accelerating can be at rest (stationary) or it can move at a constant speed in a straight line (a constant velocity).

**1** There are many words used to describe motion. Draw a line to connect each key word to its correct definition. One has been done for you.

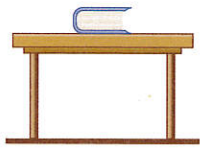
| Key word | Definition |
|---|---|
| A momentum | a the rate of change of displacement |
| B acceleration | b a vector that tells you how far you are from a starting position and in what direction |
| C velocity | c the distance travelled each second |
| D gradient | d not moving |
| E stationary | e the product of the mass and velocity of an object |
| F kinetic | f the rate of change of velocity |
| G speed | g the slope on a graph |
| H displacement | h the energy store associated with movement |

**2** The diagrams below show a book at rest on a table. Label the diagrams, selecting words from the box for the labels. Each word can be used once, more than once or not at all.

A




B



drag friction weight compression tension buoyancy support force

**Remember** You are only drawing the forces acting on the book. The book isn't moving so there must be balanced forces acting on it.

a On diagram A, draw and label arrows to show the forces acting **only on the book**.

b On diagram B, draw and label arrows showing the forces acting **only on the table**.

Be careful with your force arrows. They should start where the force acts and point in the direction of the force. The length (*not* thickness) of the arrows should represent the size of the force.

**3** The diagram on the right shows a football moving through the air after it has been kicked.


a Draw force arrows to show the forces acting on the ball as it moves through the air.

b How would these forces be different if the ball was moving faster?

There are two forces here: a non-contact force that does not change and a contact force that acts to slow the ball down.

Make sure you understand what each force does to the ball as it moves. Is the force slowing the object down or speeding it up and in what direction?

## 1 How do I explain acceleration using Newton's laws?

Newton gave three laws of motion which describe how forces cause objects to move (or stay stationary). Newton realised that all acceleration (change in velocity) is caused by unbalanced forces acting on objects. His laws link the **resultant** force on the object to the acceleration that takes place.

**1** Newton's Second Law allows us to perform calculations linking mass, acceleration and force. The relationship is usually written as $F = m \times a$.

Draw lines to link each quantity with its symbol and unit.

| Quantity | Symbol | Unit |
|---|---|---|
| force | $a$ | newton, N |
| mass | $F$ | metre per second squared, $m/s^2$ |
| acceleration | $m$ | kilogram, kg |

**2** The diagrams in the table below show the forces acting on an object.

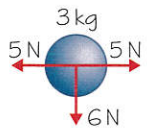
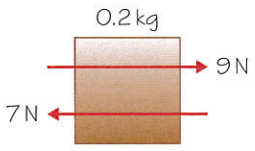
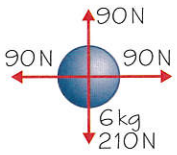
**a** Draw an arrow to represent the resultant force acting on each object. Write the size of the force. One arrow has been drawn for you.

It is important to remember that it is the resultant force which causes acceleration.

To find a resultant force add all the forces acting in one direction and subtract the forces acting in the opposite direction.

**b** Calculate the acceleration that each object would be experiencing. Write your calculation in the table.

To do this you could rearrange equation $F = m \times a$. This equation can be rearranged to $a = \frac{F}{m}$ and $m = \frac{F}{a}$.

| | A | B | C |
|---|---|---|---|
| Object |   |   |   |
| Resultant force |  ..... | ..... | ..... |
| Acceleration | $a = \frac{F}{m}$ $= \frac{.....}{3.0}$ $a =$ ..... $m/s^2$ | $a = \frac{F}{m}$ $= \frac{.....}{.....}$ $a =$ ..... | |

## 2 How do I find the size of the forces causing objects to accelerate?

It is important to be able to find the sizes of the forces causing acceleration, particularly for vehicles. For this you need to be able to use two relationships, one after the other, as described here.

Velocity is a vector quantity. This means that it has a size and a direction. When we are finding changes in velocity we need to take into account the direction the object is moving at the start and at the end. To do this we can follow a rule like this one:

- Take movement to the right to be a positive velocity and movement to the left to be a negative velocity. For example, 6 m/s to the right is +6 m/s while 6 m/s to the left is –6 m/s.

We can do similar things with other opposite directions, such as taking movement to the north as positive velocity and movement to the south as negative velocity.

(1) Complete this table to calculate the changes in velocity being described.

Use the rule that velocity to the right is positive and velocity to the left is negative.

| Description of change in velocity | Identifying velocities | Calculation of change in velocity |
|---|---|---|
| 4 m/s to the right then 8 m/s to the right | start velocity ($u$) = +4<br>end velocity ($v$) = +8 | change in velocity = $v - u$<br>change in velocity = 8 − 4<br>change in velocity = ..... |
| 9 m/s to the right then 3 m/s to the left | start velocity ($u$) = +9<br>end velocity ($v$) = ..... | change in velocity = $v - u$<br>change in velocity = −3 .....<br>change in velocity = ..... |

To find the forces involved when a vehicle changes velocity we need to use $F = m \times a$. Often the acceleration, $a$, is not provided, so you need to go through several stages to reach the answer.

(2) Follow these stages to complete the table below. The first example has been done for you.

| Stage | Example | Your try |
|---|---|---|
| Scenario<br>a Underline (A) the information you need to calculate the acceleration. | A motorcycle has a mass of 500 kg. Calculate the force needed to accelerate it from 0 m/s to 10 m/s in 5.0 s. | A car has a mass of 1200 kg. Calculate the force needed to accelerate it from 0 m/s to 5.0 m/s in 5.0 s. |
| b Find the change in velocity | 0 to 10 m/s<br>change in velocity = 10 − 0 = 10 m/s | 0 to 5.0 m/s<br>..... |
| c Find the acceleration<br>$a = \frac{\text{change in velocity}}{t}$ | $a = \frac{\text{change in velocity}}{t} = \frac{10}{5.0}$<br>$a$ = 2.0 m/s | $a = \frac{\text{change in velocity}}{t} = \frac{.....}{.....}$<br>$a$ = ..... |
| d Find the size of the forces involved<br>$F = m \times a$ | $F = m \times a$<br>$F = 500 \times 2.0$<br>$F = 1000$ N | $F = m \times a$<br>.....<br>..... |

## 3 How can I describe the momentum of objects?

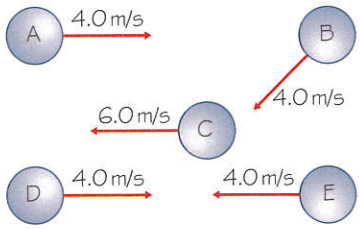
The momentum of an object is a measurement of its 'movement'. Large fast-moving objects have high momentum while small slow-moving objects have low momentum. Momentum is calculated using the expression:

momentum (kg m/s) = mass (kg) × velocity (m/s)

In symbols, this can be written as $p = m \times v$.

Momentum is a vector quantity. This means that it has both magnitude (size) and direction.

**1** The diagram below shows five balls, each with the same mass, moving in a variety of directions.




a Which balls have the same speed? .....

b Which two balls have the same velocity? .....

c Which balls have the same momentum? .....

To find the magnitude of the momentum we need to use the relationship $p = m \times v$. We also need to remember to describe the direction.

**2** Calculate the momentum, $p = m \times v$, of the objects below. The first one has been done for you.

Example


$p = m \times v$

$p = 10 \times 2.0$

$p = 20$ kg m/s to the left


.....

.....

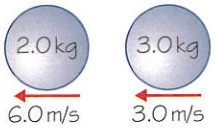
.....

**Remember** to give the direction of the momentum by saying whether the object is moving left or right.

The total momentum of a **system** is the sum of the momentum of each individual object taking into account the direction.

**3** Two systems with momentum are shown below. For each system calculate the momentum of each object by adding the momentums together. One has been done for you.

Example

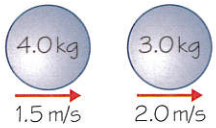



$p = m \times v$

$2.0 \times -6.0 = -12.0$ (to the left)

$3.0 \times -3.0 = -9.0$ (to the left)

$-12.0 - 9.0 = -21.0$ kg m/s (to the left)




$p = m \times v$

.....

.....

.....

**Remember** Take movement to the right to be a positive velocity and movement to the left to be a negative velocity. For example, 6 m/s to the right is +6 m/s while 6 m/s to the left is −6 m/s.

# Sample response

Here are some exam-style questions. Use the student answers to these questions to improve your understanding of how forces cause acceleration and changes in momentum.

**Exam-style question**

1 A snooker ball has a momentum of 0.30 kg m/s and is travelling at 2.50 m/s.

(a) Calculate the mass of the ball. (3 marks)

(a) $m = \frac{v}{p} = \frac{2.50}{0.30} = 8.3333333\,kg$

(b) The ball hits the cushion of the table and bounces off in the opposite direction with a velocity of 2.0 m/s. Calculate the change in momentum for the ball. (2 marks)

(b) *Change in momentum = change in velocity × mass = 0.5 × 8.333 = 4.17 kg m/s*

1 a Look at the student's answer to part (a). They have used an incorrect version of the equation linking momentum, mass and velocity. Write the correct version of this equation.

**Remember** the definition of momentum is from momentum = mass × velocity

b Calculate the correct value.

c What other mistake has the student made in part (a) so they would not gain full marks?

d What has the student done correctly in part (b)?

e What mistake have they made in part (b)?

**Remember** Momentum is a vector quantity so take a close look at the velocities.

f What is the correct answer to part (b)?

# Your turn!

It is now time to use what you have learned to answer the exam-style question from page 121. Remember to read the question thoroughly, looking for information that may help you. Make good use of your knowledge from other areas of physics.

**Exam-style question**

1 Figure 1 shows a golf ball of mass 45 g resting on a golf tee. A golfer will shortly hit it with a golf club.


Figure 1

(a) Give the momentum of the golf ball before the club hits it. (1 mark)

.....

After the club has hit the golf ball, the ball moves away with a velocity of 80 m/s.

(b) Calculate the momentum of the golf ball immediately after it has been hit. Include the correct unit for momentum. (2 marks)

.....

.....

(c) Give the change in momentum for the golf club during the impact. (1 mark)

If you make a mistake calculating the momentum in part (b) this won't affect your marks for your answer to part (c) as you have already been penalised. This is known as 'carrying the error forwards'.

.....

The impact between the club and the ball lasts for 0.02 s.

(d) Calculate the average acceleration of the ball during the impact. (2 marks)

Use the start and end velocities and the time of impact. Don't forget to give the correct unit for acceleration.

.....

.....

(e) Use your answer to part (d) to calculate the average force acting on the ball during the impact. (1 mark)

Use Newton's Second Law here.

.....

.....

# Need more practice?

Exam questions may ask about different parts of a topic, or parts of more than one topic. Questions about momentum could occur as:

- questions about that topic only
- part of a question on how objects move or how forces change the velocity or momentum of objects
- part of a question about an experiment or investigation.

Have a go at this exam-style question.

## Exam-style question

1 A cyclist in a race is travelling at 11.0 m/s along a straight section of road. The cyclist sees a crash ahead and brakes suddenly to a speed of 5.0 m/s in a time of 1.5 s.

(a) Calculate the average acceleration of the cyclist during braking. (2 marks)

Look back at the equation linking acceleration, change in velocity and time.

.....

.....

The total mass of the cyclist and the bicycle is 60.0 kg.

(b) Calculate the average braking force the two tyres exerted on the road during the braking. (1 mark)

This is where you should use Newton's Second Law.

.....

.....

(c) Give the size of the force the road exerts on the tyres during the braking. (1 mark)

This question involves Newton's Third Law.

.....

The cyclist is unable to stop in time and crashes at a speed of 5.0 m/s.

(d) Calculate the momentum of the cyclist and bicycle just before they crash. (1 mark)

.....

.....

## Boost your grade

To boost your grade, make sure that you know how to break down calculations into stages. Acceleration is the factor that links movement and forces so practise using all the equations that involve it.

How confident do you feel about each of these **skills**? Colour in the bars.

1. How do I explain acceleration using Newton's laws?
2. How do I find the size of the forces causing objects to accelerate?
3. How can I describe the momentum of objects?