Forces
Speed *and* Gravity

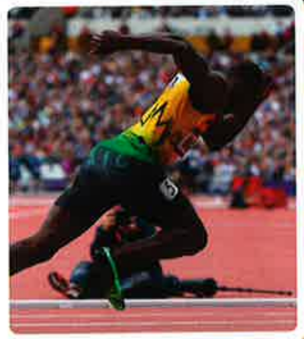
Ideas you have met before

Movement

Speed is a measurement of how quickly distance is being covered.

The speed of an object can be calculated by dividing the distance travelled by the time taken.

Speed is measured in units such as metres per second (m/s) and kilometres per hour (km/h).



Force

Forces can be pushes, pulls or turning forces. They can be 'contact' forces – when objects are touching – or 'non-contact' forces – when the forces act at a distance.

Force arrows drawn to scale show the size and direction of forces.

A newton-meter allows us to measure the size of a force.

Force is measured in newtons.

Gravity

Gravity is a non-contact force.

Large objects, like planets, exert strong gravitational forces on other objects. These objects are attracted towards the planet.

Gravity pulls objects towards the Earth.

Gravity keeps the Moon in orbit around the Earth and the Earth in orbit around the Sun.

Gravity affects objects such as people and rockets that are exploring space.

In this chapter you will find out

Speed and acceleration

- The greater the speed, the shorter the time taken to cover a certain distance.
- An object's motion can be represented on a distance–time graph, which can be analysed to find out more about the motion.
- A straight line on a distance–time graph shows constant speed and a curved line shows acceleration.
- The motion of two objects can be compared and their relative speeds calculated.

Resultant force

- All the forces acting on an object can be combined to find the resultant – a single force which has the same effect.
- If the resultant force is not zero, the object will speed up, slow down or change direction.

Gravity

- Mass and weight are different, but related.
- Gravity is a non-contact force that acts between all masses.
- Every object exerts a gravitational pull on every other object.
- A planet, like the Earth, has a gravitational field.
- The gravitational fields of the Earth and other objects in the solar system affect space travel.

Understanding speed

We are learning how to:

- List the factors involved in defining speed.
- Describe a simple method to measure speed.
- Use the speed formula.

On Britain's busy roads, there are speed limits to make them safer. Driving too fast is one of the factors that causes accidents. Cameras that measure the speed of vehicles were introduced in the 1960s. In 2013 the number of deaths on Britain's roads was the lowest it had been since records began.

FIGURE 1.1.1a: Safety cameras and speed limit signs help to keep the number of deaths on British roads to a low level.

Distance and speed

When you travel on a journey, it takes a certain amount of time to travel the **distance**. The **speed** of a vehicle is worked out from how far a journey is and how long it takes. The **units** used for measuring speed are metres per second (m/s).

When travelling fast your speed is high. You cover a longer distance in a certain time – you travel more metres in each second, compared with travelling slower.

1. What does speed measure?
2. Which two quantities are needed to work out the speed at which something is travelling?
3. If car A travels 2 metres in one second and car B travels 2.5 metres in two seconds, which has the higher speed?
4. Motorbikes C and D both travel 100 metres. C takes 4 seconds and D takes 5. Calculate the speed of each motorbike.

FIGURE 1.1.1b: A car's speedometer shows the car's speed at each instant.

Calculating speed

We use a **formula** to calculate speed:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

The units of speed depend on which units were used for measuring the distance and the time.

Example calculation:
Usain Bolt from Jamaica won the 2016 Olympic 100-metre final in a time of 9.81 seconds.

speed = distance travelled ÷ time taken

Usain's speed = 100 ÷ 9.81 = 10.19 m/s
This is equivalent to about 37 km/h or about 23 mph.

5. Use the speed formula to calculate the speed of a cross-country runner who runs steadily for an hour and a half and covers 15 km. Show your working.
6. A mouse runs 2 metres in 4 seconds. What is its speed?

Did you know...?

A formula is a way of showing the relationship between quantities, using words or symbols.

Did you know...?

Some scientists have measured the force that an athlete's legs can produce, and how quickly the force can be transferred. From this they have worked out that it might be physically possible for the best athletes to run at over 60 km/h. We do not know if this will ever be achieved.

Average speed

When Usain Bolt won the Olympics sprint in 2016, his speed varied during the race. At the start it took a while to get up to full speed. The speed of 10.19 m/s that we calculated is his **average speed** over 100 metres. His top speed was over 12 m/s.

Some speed cameras work out a car's average speed over a distance of a kilometre or so, while other types work out speed almost in an instant. A car's speedometer displays the exact speed at any moment.

7. Explain why your average speed and your top speed over a car journey will be different.
8. What benefit to road safety may there be when cameras work out average speed over a distance, rather than in one spot?

FIGURE 1.1.1c: For an Olympic sprinter the distance is measured in metres (m) and the time is measured in seconds (s), so the speed is calculated in metres per second (m/s).

Know this vocabulary

distance
speed
unit
formula
average speed

Describing journeys with distance–time graphs

We are learning how to:

- Gather relevant data to describe a journey.
- Use the conventions of a distance–time graph.
- Display the data on a distance–time graph.

Science provides explanations for how the world works and gathers data to test the explanations. Graphs are a useful way of displaying data and can help you to understand the story behind the data.

FIGURE 1.1.2a: Travelling at a steady speed.

Looking at distance–time graphs

The cyclists in Figure 1.1.2a are travelling at a steady speed along the path. This means that they cover the same distance every second.

The cyclists' journey can be represented on a **distance–time graph**, as shown in Figure 1.1.2b. For every second that passes, the cyclists travel 5 m. After 10 s they are 50 m from the starting point.

You can use information from the graph to find how much distance has been covered at different times, how long it takes to travel different distances, and the cyclists' speed.

1. What unit should be used to measure the cyclists' speed in Figure 1.1.2b?
2. How far did the cyclists travel in the first 6 seconds of their journey?
3. What was the cyclists' speed?
4. Describe or sketch a line graph to show another cyclist who is travelling at half the speed. How does it differ from Figure 1.1.2b?

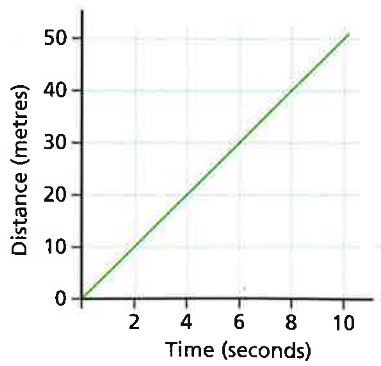


FIGURE 1.1.2b: Distance–time graph for constant speed.

Changing speed

In the distance–time graph in Figure 1.1.2c, the cyclist does not travel the same distance every second. For the first 10 s they travel at a slow speed and cover little distance. However, they gradually **accelerate** (speed up).

The speed between 30 s and 45 s is faster than before because the cyclist covers more distance every second. The steeper line of the graph indicates that the speed has increased. Subsequently the cyclist stops and then remains **stationary**. The flat part of the graph shows that no more distance is covered.

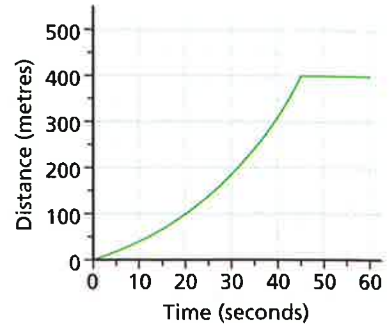


FIGURE 1.1.2c: A distance–time graph for a cyclist who changes speed.

5. On a distance–time graph, what does it mean when:
   a) the graph is a horizontal line?
   b) the graph is a straight upward-sloping line?
   c) the graph is an upward-sloping curve?
6. Looking at Figure 1.1.2c, how long was the cyclist stationary for?

Complex journeys

Figure 1.1.2d shows a distance–time graph for a student's journey to school which includes walking (1), waiting for a friend (2), walking with their friend (3), waiting for a bus (4) and riding on the bus (5). Their speed varies during different sections of the journey – at certain times no distance is covered.

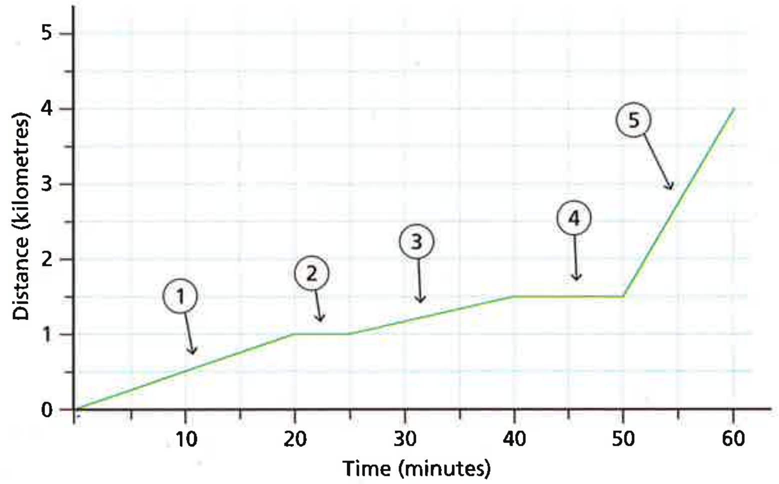


FIGURE 1.1.2d: A distance–time graph for a student's journey to school.

7. Looking at Figure 1.1.2d, what is the evidence that the students travelled faster on the bus than at other times during the journey?
8. Compare sections 1 and 3 on the graph. How are they different? Suggest a possible reason for the difference.
9. Imagine a journey where you travel from your home to an overseas holiday destination. Sketch a line graph to represent the journey. Label each part of the graph to explain what is happening.

Did you know...?

From a distance–time graph you can work out the average speed for a whole journey during which the speed varies at different times. You can also work out the speed at different parts of the journey.

Know this vocabulary

distance–time graph
accelerate
stationary

Exploring journeys on distance–time graphs

We are learning how to:

- Interpret distance–time graphs to learn about the journeys represented.
- Relate distance–time graphs to different situations and describe what they show.

A speeding motorist sees a speed camera and slows down. The car then accelerates and is again breaking the speed limit. Further along the road a second camera comes into view and, again, the driver slows. A few days later a letter from the police arrives in the post...

FIGURE 1.1.3a: A speed camera.

Speed cameras and distance–time graphs

Speed measurement on roads is often done by cameras that record the position of a car at the start and at the end of a period of time. The further the distance the car moved during that time, the faster it was going. It is then simple to use the speed formula to calculate the car's speed.

Motorists who realise they are speeding may suddenly slow down when they see a camera. Figure 1.1.3b shows what a distance–time graph might look like in such a situation.

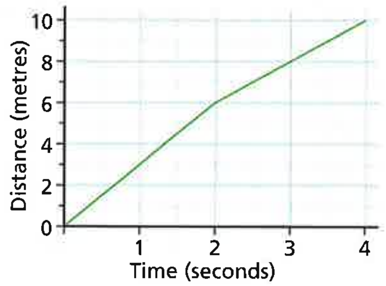


FIGURE 1.1.3b: A distance–time graph for a car approaching a speed camera.

1. What is the formula for calculating speed?
2. Looking at Figure 1.1.3b, how can you tell that the car's speed has changed?
3. Calculate the speed of the car in both sections of the graph. Show your working.

Using a time-lapse sequence

Figure 1.1.3c shows a **time-lapse sequence** taken as a candle burned. The photographs were taken at five-minute intervals. The candle burned at a steady rate so it got shorter by a similar amount every five minutes.

The same process of time-lapse photography can be used to record the motion of objects, such as cars. The longer the distance between a car's position in successive photographs, the faster it must have been travelling. For example, if photographs are taken at one-second intervals and a car moves 12 m between each photograph, then the speed of the car is 12 m/s.

Did you know...?

A time-lapse sequence is a series of images showing the same object or scene at different points in time.

FIGURE 1.1.3c: Time-lapse photography of a burning candle – images were taken every 5 minutes.

4. Look at Figure 1.1.3c. How long did the candle take to burn?
5. Read the final paragraph on the opposite page. What is the speed of the car in km/h?
6. Assuming the car in question 5 is travelling at a steady speed, draw a distance–time graph to show its motion.

Acceleration

If you consider all the forces acting on an object and they don't cancel each other out then the object will accelerate (increase in speed). Later on in this chapter we'll be finding out more about force and acceleration.

On a distance–time graph, a steep slope shows that an object is travelling faster than an object with a shallow slope. If the object rapidly accelerates, the slope of the line will change rapidly. However, if the change in speed is more gradual, the gradient will change more gradually.

Figure 1.1.3d shows three different journeys. The change in each slope shows how quickly the speed of each object changes. How quickly speed changes is called **acceleration**.

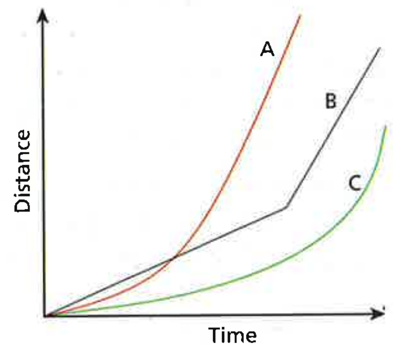


FIGURE 1.1.3d: Looking at acceleration on a distance–time graph.

7. Looking at Figure 1.1.3d, which object has:
   a) the fastest speed at the start?
   b) the fastest final speed?
8. If speed is measured in m/s, what unit is used for acceleration?
9. Sketch the graph in Figure 1.1.3d and extend the lines to show:
   a) object A continuing at the same speed for a while and then stopping abruptly;
   b) object B coming to a gradual halt having travelled a shorter total distance than object A;
   c) object C slowing down and then travelling at a steady speed.

Did you know...?

Drag race cars can accelerate from a standstill to cover a 300 m straight-line race track in less than 4 s, reaching speeds of over 500 km/h.

Know this vocabulary

time-lapse sequence
acceleration

Investigating the motion of a car on a ramp

We are learning how to:

- Describe the motion of an object whose speed is changing.
- Devise questions that can be explored scientifically.
- Present data so that it can be analysed to answer questions.

A toy car released at the top of a ramp will accelerate. We can explore what will make it go faster and whether a steeper ramp necessarily means a longer journey.

Thinking about the journey

If we put a toy car at the top of a ramp and release it, it will accelerate down the ramp. When it reaches the end of the ramp it will continue moving but slow down. The acceleration at the start of the journey is caused by forces acting on the car. It eventually stops because of forces too.

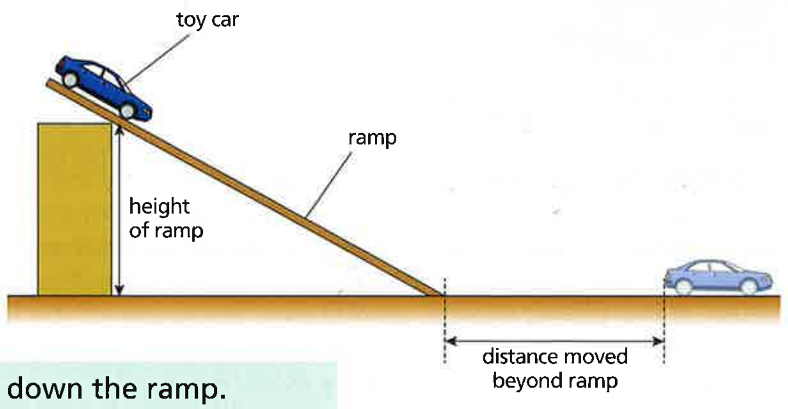


FIGURE 1.1.4a: The car's journey.

1. Explain why the car accelerates down the ramp.
2. Explain why the car decelerates once it reaches the ground.
3. Suggest why the forces in the first part of the journey make it accelerate and those in the second part make it decelerate.

Planning the investigation

When we plan an investigation like this, we need to think about the things we could alter that might affect the motion. It will be important to identify these because these are factors we might want to investigate. We might want to find out what happens if we change them. Alternatively, we might want to identify them so that we can keep them the same. If the motion changes, we will want to know what we've done to cause that. If we've changed several things, we won't know which of them has made a difference.

Things we could change are called **independent variables**. Altering these could make a difference to other things, which are called **dependent variables**. Some of the independent variables will be kept the same; these are then called **control variables**. If we alter one independent variable and see how a dependent variable changes we can look for a **correlation**.

4. a) If you are setting up a toy car to roll down a ramp, what are the independent variables?
   b) What might change as a result? (These are the dependent variables.)
5. a) Select one independent variable to alter and a dependent variable to measure. Use these to write an enquiry question in the form 'How does … affect …?'
   b) In this case, what will the control variables be?

Presenting data

Altering the independent variable means selecting values. If you changed the height of the ramp, for example, you need to decide which heights to use. When you have these values you can set up a table showing this data and also the dependent variable, which changed as a result.

Some data is continuous, because it can take any value. Changing the mass of the car by adding modelling clay gives continuous data, because any amount can be added. Other data is discrete because it can only have certain values. Swapping the red car for a blue car gives discrete data. From your table of data you can draw a graph. You will need to decide what kind of graph is appropriate.

If the independent variable is discrete, you should use a bar chart. If it is continuous, use a line graph.

6. What headings would your table need?
7. Would you need to repeat any of the readings?
8. What conclusion could you draw from your graph?
9. Ali and Dave decided to explore the relationship between the height of the ramp and the distance travelled by the car after it reached the end of the ramp. Sketch the graph they might have got.

Know this vocabulary

independent variable
dependent variable
control variable
correlation

Understanding relative motion

We are learning how to:

- Describe the motion of objects in relation to each other.
- Explain the concept of relative motion.
- Apply the concept of relative motion to various situations.

Imagine driving along a motorway. Alongside your car is another car travelling at exactly the same speed. Both cars' speedometers could be reading over 100 km/h, but compared to each other the cars are not moving at all.

Relative motion

When scientists compare the movement of two objects, they talk about **relative motion**. For example, if a car is travelling at 50 km/h and is being caught by a car doing 55 km/h, the speed of the second car relative to the first – its **relative speed** – is 5 km/h.

If you compare a cyclist doing 20 km/h and a car doing 60 km/h, the car is travelling at 40 km/h relative to the cyclist. After 1 hour the car has travelled 40 km further than the cyclist.

FIGURE 1.1.5a: The car travels faster in relation to the bicycle.

1. A person sets off jogging along a canal path at 12 km/h at the same time as a boat sets off at 10 km/h.
   a) How far will each one travel in half an hour?
   b) What is their relative speed?
   c) To the jogger, how would the boat appear to be moving as they travel along the canal?

Journeys and collisions

Figure 1.1.5b shows the distance–time graphs for two cars on a motorway. Car B set off later than car A. You can see when each will have completed their journey and the distance between them.

If the cars were in the same lane, car B would crash into the back of car A. It is the relative speed of two cars in a collision that is important rather than the actual speed of one car alone.

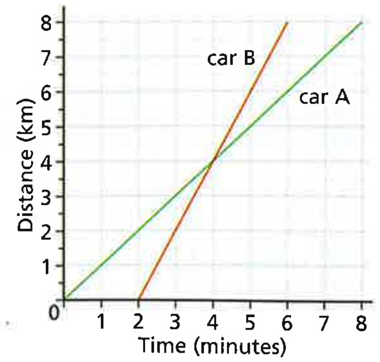


FIGURE 1.1.5b: Two cars travelling at different speeds.

Two cars travelling at 40 km/h towards each other have a relative speed of 80 km/h. This is equivalent to a moving car approaching a stationary car at 80 km/h.

2. Look at Figure 1.1.5b. What are the speeds of the two cars in km/h? What is their relative speed?
3. What is the relative position of the two cars:
   a) 2 minutes after car A sets off?
   b) 1 minute later?
4. Explain why head-on collisions are so dangerous.

Looking at events differently

If you look at the sky from a moving car it can be very difficult to tell which way the clouds are moving. They can appear to be stationary if the car is travelling at the same speed as the clouds. If the car speeds up, the clouds may appear to the passengers to be travelling in the opposite direction to the car.

FIGURE 1.1.5d: The relative motion depends on the speed and direction of the car and clouds.

5. Explain why in some situations it is hard to tell whether or not you are moving. How could your other senses help your judgement?
6. Explain the similarities and differences between these situations:
   a) a car travelling at 10 km/h and colliding with a parked car;
   b) a car travelling at 70 km/h and colliding with a car doing 60 km/h in the same direction;
   c) a car travelling at 70 km/h and colliding with a car doing 60 km/h in the opposite direction.

FIGURE 1.1.5c: Two cars travelling at different speeds.

Did you know...?

If you travel away from a loud noise faster than 344 m/s, you will never hear the sound. Sound travels through air at just over 343 m/s, so it would never catch you up.

Know this vocabulary

relative motion
relative speed

Understanding forces

We are learning how to:

- Recognise different examples of forces.
- List the main types of force.
- Represent forces using arrows.

All forces try to pull, push, twist or break objects but some are contact forces and some are non-contact forces. Gravity, like magnetism, is a non-contact force. It can have a spectacular effect though.

Types of force

A **force** can be a pushing force, a pulling force or a turning force. There is a pulling force from the Earth on this bungee jumper. Once he steps off the platform, the pulling force makes him fall. The arrow shows the pulling force making him move downwards. Without the pulling force of the Earth, he would not fall. The pulling force of the Earth on objects is called **gravity**.

1. How would you describe the type of force that the Earth produces on the bungee jumper?

2. What is the name given to this force?

FIGURE 1.1.6a: The downward force acting on a bungee jumper.

Multiple forces

A number of forces can be acting on something at the same time. The aeroplane in Figure 1.1.6b has four main forces acting on it:

- the downward pull of gravity;
- the forward push from the engines;
- the upward pull provided by the lift from the wings;
- the pushing force of the air which resists the plane as it moves.

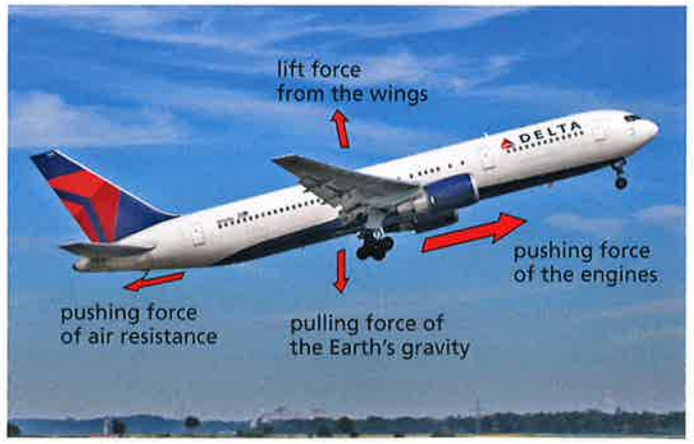


FIGURE 1.1.6b: These forces act on an aeroplane as it takes off.

The direction of a force can be shown by an arrow. We can show how strong one force is compared to another by using different-sized arrows.

3. Which forces are helping the plane in Figure 1.1.6b to fly?

4. Which forces are working against the plane when it flies?

5. Draw and label a force diagram showing the aircraft in horizontal flight.

Forces in balance

The two tug-of-war teams in Figure 1.1.6c are pulling equally and no one is moving. All the forces are in **balance**, which means each force is perfectly balanced by an equal force in the opposite direction. If we combine all the forces acting in a situation we can find the resultant force. Think of this as a single force which could replace all the others and have the same effect. In this situation the resultant force is zero.

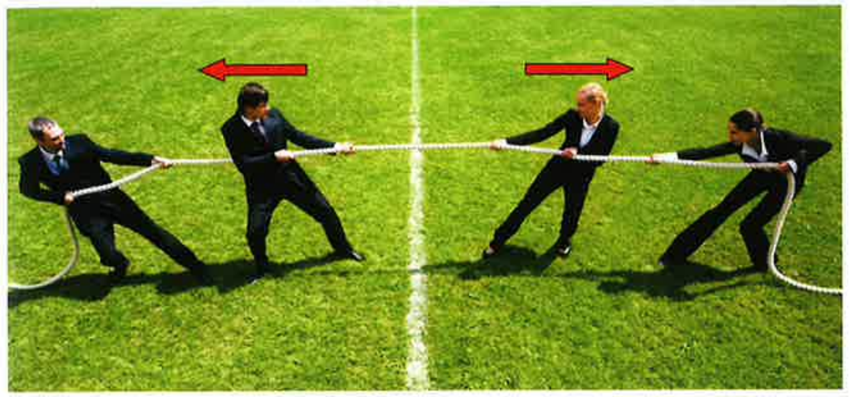


FIGURE 1.1.6c: Forces are present, but there is no movement.

6. What would happen to the size and direction of the resultant force if an extra person were added to the left-hand team in Fig 1.1.6c?

7. Sketch a car that is starting to move away from a set of traffic lights. Draw arrows to show the forces at work and comment on the direction of the resultant force.

8. Draw force diagrams and calculate the size and direction of the resultant force if:

a) a boat has a force of 500 N from the wind pushing it forwards and the water resistance is 200 N;

b) a sledge is being pulled with a force of 250 N and acted on by friction (100 N) and air resistance (50 N).

Did you know...?

When forces are balanced their size and direction cancel each other out.

Did you know...?

When you see films of astronauts inside a space station **orbiting** the Earth, the astronauts appear to be weightless. But they, and the space station and everything in it, are actually still being attracted by the Earth's gravity. If there were no pulling force of gravity from the Earth, the space station would fly off into space.

Know this vocabulary

force
gravity
balance
orbit

Understanding gravitational fields

We are learning how to:

- Describe gravity as a non-contact force.
- Explore the concepts of gravitational field and weight.
- Explain how weight is related to mass.

The Earth's gravitational field

The region around the Earth affected by its gravity is its **gravitational field**. A **field** is an area in which an object feels a force.

Within the Earth's gravitational field objects are pulled towards the Earth. This pull is a **non-contact force** because it acts at a distance – objects do not have to be on a planet's surface to be affected.

1. In what direction does Earth's gravitational force act?
2. Describe what is meant by a gravitational field.

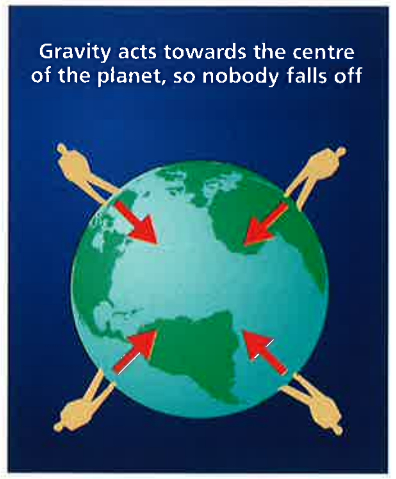


FIGURE 1.1.7a: Gravity acts all over the Earth towards its centre.

Gravitational field strength and weight

The Earth's **gravitational field strength** gets weaker the further you move from the Earth's surface. It also varies slightly in strength across the surface. Other planets and moons have similar gravitational fields.

Gravitational fields can extend over long distances. Even though the Moon is over 350 000 km from Earth, they are affected by each other's gravitational fields.

Gravity does not stop at the Earth's surface. If you descend into a deep mine you are still pulled towards the middle of the Earth.

The **weight** of an object depends on the mass of the object and the strength of the gravitational field acting on it. The formula used to calculate weight is:

weight of object (W) = mass (m) of object × gravitational field strength (g)

Weight is measured in newtons (N) and mass is measured in kilograms (kg), so the gravitational field strength is measured in newtons per kilogram (N/kg).

On the surface of the Earth the gravitational field strength (symbol g) is about 10 N/kg. To calculate how much a bag of fruit with a mass of 2 kg would weigh on the Earth's surface:

$W = m \times g = 2 \times 10 = 20\,\text{N}$

FIGURE 1.1.7b: The rise and fall of the tide is largely due to the Moon's gravitational field.

3. What evidence exists that the Moon's gravitational field affects the Earth?
4. List the main differences between the pulling force due to gravity and the pulling force from a rope in a tug-of-war.
5. Which quantities determine the weight of an object?
6. Calculate, if g = 10 N/kg:
   - **a)** the weight of a 25 kg mass;
   - **b)** the mass of a 1000 N weight.
7. Explain why the weight of an object can vary, but the mass always stays the same.

Acceleration in gravitational fields

The pulling force on an object in a gravitational field causes it to accelerate in the direction of the force. The stronger the field, the bigger the acceleration – they have the same numerical value. For example, on the Earth's surface the field strength of 10 N/kg causes an unsupported object to accelerate towards the Earth at 10 m/s^2. The acceleration depends on the gravitational field strength but not on weight or mass.

When investigating acceleration in the Earth's gravitational field, other factors such as air resistance can affect the results.

FIGURE 1.1.7d: Do different masses really fall at the same rate?

8. Draw force diagrams showing:
   - **a)** an apple suspended by a balance;
   - **b)** an apple in free fall.
9. Different masses fall towards the Earth at the same rate if air resistance is not a factor – explain why.
10. Design an activity to find out if air resistance affects the rate at which objects fall.

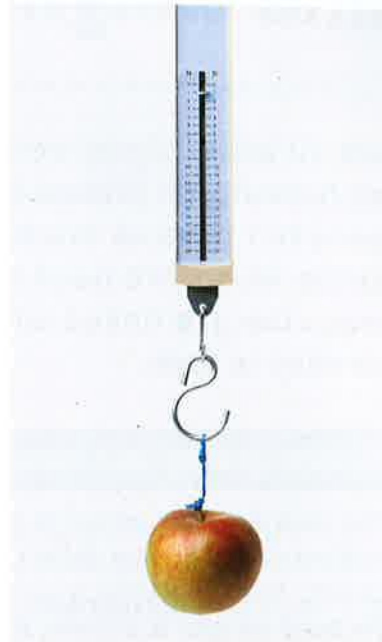


FIGURE 1.1.7c: All masses close to the Earth's surface are pulled by the gravitational field strength of 10 N/kg.

Did you know...?

The 'rule' about all objects falling at the same rate applies when there is no air resistance. Air resistance has a different effect on objects of different mass and different shape.

Know this vocabulary

gravitational field
field
non-contact force
gravitational field strength
weight

Understanding mass and weight

We are learning how to:

- Explain the difference between mass and weight.
- Apply ideas of weight to space travel.

We all know about weight because we all have it. It's caused by gravity, so we wouldn't have as much weight if we went to the Moon. We need to understand about mass too. It's linked with weight but isn't so easy to lose.

FIGURE 1.1.8a: Someone 'weighing' themselves with bathroom scales.

Weight, gravity and mass

The **weight** of an object is the force of **gravity** pulling down on the object. If there were no gravity then everything would be weightless. Because weight is a force, it should be measured in newtons. We can measure the weight of an object using instruments such as newton-meters and bathroom scales. Both measure how much the object is pulled down by gravity.

Mass is a measure of the amount of material in an object – the number of particles and type of particles it is composed of. Mass does not depend on the force of gravity, so it does not change if you take it somewhere where the gravitational field is not as strong, such as the Moon. Mass is measured in kilograms. The mass of an object can be measured using a balance that compares the object with a known mass.

FIGURE 1.1.8b: Using a balance to find the mass of an object.

Sometimes people mix up 'mass' and 'weight', so scientists need to be careful to choose which term to use.

1. Why do you think that some people confuse weight and mass?
2. If you measured the mass and the weight of an object on two planets of different sizes, what differences would you notice? Explain your answer.

Gravity in space

The force of gravity on you (your weight) depends on your distance from a planet. The further away you are from the Earth, the weaker the gravitational field strength, so the weaker the force pulling you back. In outer space, the distance to the nearest planets and stars could be so big that there would be no noticeable force of gravity – you would be weightless.

3. In much of outer space there is little or no gravity. Why is this?
4. Think of a spacecraft setting off from Earth and travelling directly to the Moon. Describe the changes in gravity you expect the spacecraft to experience during the journey.

Gravity in orbit

In videos of the astronauts in the International Space Station, in **orbit** around the Earth, the astronauts look as if they have no weight. However, the Earth's gravitational field is pulling on them and also on the space station and everything in it. They fall at the same rate so inside the station the astronauts float about. They appear to be – and feel – weightless.

FIGURE 1.1.8c: These astronauts in the space station are falling at the same rate as the space station.

5. Compared to standing on Earth, what would your weight be on a high-flying plane?
   a) Stronger **b)** The same **c)** Weaker **d)** Zero
6. Explain your answer to question 5.

Did you know...?

An object in orbit, such as a space station, is not in zero gravity. It is still being attracted by the Earth's gravity. If there were no pulling force of gravity from the Earth, the space station would fly off into space.

Know this vocabulary

weight
gravity
mass
orbit

Understanding gravity

We are learning how to:

- Understand that gravity varies according to where you are in the solar system.
- Apply ideas about gravity to various situations.

We are all experts in coping with gravity. We've dealt with it all our lives. We've made use of it as children on swings and slides. We know the problems it causes when we drop glass or china on a hard floor. But what is it?

FIGURE 1.1.9a: The Earth and the Moon. The bigger the **mass** of a planet or moon, the stronger its force of gravity.

Gravity and space exploration

When people explore space, one of the problems they face is coping with the way **gravity** varies. Astronauts visiting the Moon weighed much less than on Earth and in deep space they would be weightless. **Weight** depends on the force of gravity from massive objects such as stars, planets and moons.

1. Why, when travelling from the Earth to the Moon, did the weight of the astronauts become less the further they got from the Earth?
2. How did their weight change when they got nearer to the Moon?
3. Why do you think they weighed less on the Moon?

Understanding gravity

Gravity is a force that pulls pairs of objects together. For example, your body is pulled towards the Earth, and the Earth and other planets are held in orbit around the Sun.

Gravity actually exists between *all* objects, but the force is only large enough to be noticeable when a massive object, such as a planet or a star, is involved.

4. Look at Table 1.1.9. Where is gravity greatest?
5. Using information from the table, write the planets and the Moon in order of increasing gravitational field strength, if you were standing on the surface.

Did you know…?

Trying to stay fit is a real challenge in a location where gravity is less. If your muscles don't have to work to support you, you soon become unfit. The International Space Station has exercise machines which astronauts use regularly.

6. The table shows how high you could jump, in each of these places, using the same amount of force. Use the idea of opposing forces to explain why it varies so much.

TABLE 1.1.9: The effects of different values of gravity on the Moon and on other planets in the solar system.

	Earth	Moon	Mercury	Venus	Mars
Surface gravity (compared with the Earth's)	1.00	0.17	0.38	0.90	0.38
Your mass (compared with your mass on Earth)	1	1	1	1	1
How much you can lift (kg)	10	60	30	10	30
How high you can jump (cm)	20	120	53	22	53
How long it takes to fall back to the ground (s)	0.4	2.4	1.1	0.4	1.1

A gravity puzzle

Gravity is an attractive (pulling) force between masses. What gravity would you experience if you tunnelled towards the centre of the Earth?

Under the surface there would be a force of gravity from the mass of the Earth above you as well as from that below you. Because these forces are in opposite directions, the overall force of gravity would be lower than on the Earth's surface.

7. Imagine it was possible to build a tower on Earth to the height of an orbiting space station.
   a) What force(s) would you experience if you stepped off the tower?
   b) What movement would you expect?
8. Explain what would happen if you tried to weigh yourself in these situations:
   a) outer space;
   b) in a tunnel, halfway to the Earth's centre;
   c) on top of a tower at space station level.

Know this vocabulary

gravity
weight
mass

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills

Explain how to find the speed of an object.	Explain the concept of speed and how the formula for speed is derived.	Apply understanding of the speed formula to explain how speed cameras work.
Collect data about distance travelled and time taken for different journeys.	Present data collected or given as distance–time graphs.	Construct distance–time graphs for complex journeys.
Describe features of distance–time graphs.	Analyse distance–time graphs to describe an object's movement at different stages in a journey.	Explain distance–time graphs for complex journeys, including where an object travels at different speeds and accelerates at different rates.
Describe a situation where objects are travelling at different speeds.	Apply the idea of relative speed to two objects involved in overtaking or collision.	Apply the concept of relative motion to several moving objects in a variety of situations.
Identify different forces acting upon an object.	Calculate the resultant force of several forces acting in the same dimension.	Relate the resultant force to the motion of the object.
Identify the direction that a force is acting in.	Represent the direction of forces in a diagram.	Use a force diagram to identify a resultant.
Identify gravity as a pulling force and recognise that mass and weight are not the same.	Describe what is meant by mass, explain how gravity forces affect weight, explain why weight varies from planet to planet and explain the term 'weightless'.	Explain weight as a gravitational attraction between masses which decreases with distance; explain the difference between mass and weight.

Identify gravity as a non-contact force	Explain the difference between contact and non-contact forces.	Compare gravity with other forces.
Recall the units of mass and force.	Recall the units of gravitational field strength.	Explain why gravitational field strength has those units.
Explain how mass affects weight.	Use the formula weight = mass × gravitational field strength to determine weight.	Use the formula weight = mass × gravitational field strength to determine mass.
Explain what causes an object to have weight.	Describe how gravity affects the weight of an object.	Explain the relationship between gravitational field and the weight of an object.
Describe how an object's weight can vary.	Predict how an object's weight would vary depending on its position in relation to large bodies such as planets.	Use the concept of a gravitational field to explain various phenomena, including the orbits of planets around stars.

Questions

KNOW. Questions 1–5

See how well you have understood the ideas in this chapter.

1. What is the speed of a cyclist who covers 7 m in 1 second? [1]

a) 70 km/h **b)** 7 km/h **c)** 7 m/s **d)** 700 m/s

2. Which one of these units is *not* used for speed? [1]

a) km/h **b)** m/s **c)** N/kg **d)** mph

3. Which row of the table shows the correct units? [1]

TABLE 1.1.11

	Mass is measured in …	Weight is measured in …
A	N	N
B	N	kg
C	kg	N
D	kg	kg

4. Which of these is true about gravity on the Moon? [1]

a) There is no gravity on the Moon.
b) There is gravity on the Moon but it's less than on the Earth.
c) Gravity is the same strength everywhere – it's universal.
d) Gravity is greater on the Moon than on the Earth.

5. Which of these statements about weight is *not* true? [1]

a) Weight is affected by the gravitational field strength in the area.
b) Weight is affected by the mass of an object.
c) Weight increases at greater distances from massive objects.
d) Weight is affected by where an object is.

APPLY. Questions 6–10

See how well you can apply the ideas in this chapter to new situations.

6. A van takes 1 hour to travel along a 60 km stretch of road. A car takes 45 minutes to do the same journey. Which of these statements is true about their relative speeds? [1]

a) The van is 15 km/h faster. **b)** The van is 15 km/h slower.
c) The car is 20 km/h faster. **d)** The car is 20 km/h slower.

7. Sketch a distance–time graph for two horses moving across a 500 m field. One horse trots steadily across the field in 4 minutes. The other accelerates to a gallop, stops for 1 minute to eat grass and then gallops the rest of the way, reaching the far side after 3 minutes. [4]

8. Which of these statements is true about your weight and mass on a planet that has twice the gravitational field strength of Earth? [1]

a) Weight is the same, mass is double. **b)** Weight and mass are both the same.
c) Weight and mass are both double. **d)** Weight is double, mass is the same.

9. In which of these locations would the gravitational field be the strongest? [1]

a) On the surface of a red giant star.
b) On the Moon as it orbits the Earth's surface.
c) At the edge of the Earth's atmosphere.
d) On the Earth's surface.

10. Which of these statements would be true for a rocket taking off from a launch pad and accelerating towards space? [1]

a) The forces on it are balanced.
b) There will be a resultant force acting upwards.
c) Whilst it's travelling vertically upwards it will not experience air resistance.
d) Once it gets into orbit around the Earth, gravity will no longer act on it.

EXTEND. Questions 11–13

See how well you can understand and explain new ideas and evidence.

11. Which of these defines what the strength of the gravitational field on the surface of a planet depends on? [1]

a) The mass and radius of the planet.
b) The mass of the planet and its distance from the Sun.
c) The shape and radius of the planet.
d) The rotation speed of the planet.

12. Draw a diagram to show what would happen to a satellite if the Earth's gravity were suddenly turned off. [1]

13. Scientists believe that there is a massive black hole at the centre of our galaxy, with a mass 30 billion times that of the Sun. Explain what evidence could suggest its existence.

If a spacecraft set off in a straight line at a constant speed towards the black hole, what additional evidence would indicate the presence of the black hole?

What challenges would the spacecraft face? [4]