1.1 Introduction to forces

Learning objectives

After this topic you will be able to:

- explain what forces do
- describe what is meant by an interaction pair.

What does a rocket have in common with you? There are forces acting on you and on the rocket.

▲ This rocket took a rover to Mars.

What do forces do?

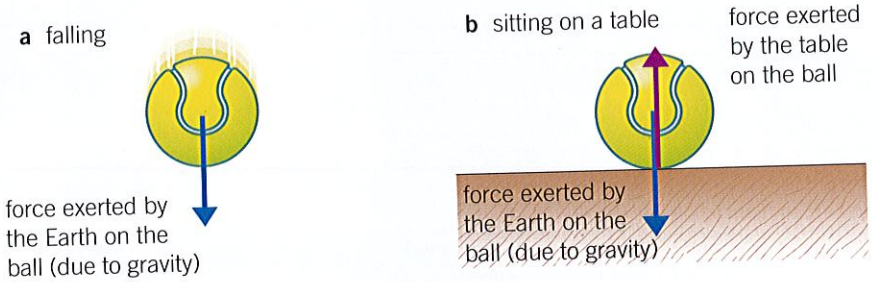
A rocket going to Mars moves away from the surface of the Earth very quickly. There is a force pushing the rocket up and forces pulling it down. A force can be a **push** or a **pull**.

Forces explain *why* objects move in the way that they do, or why they don't move at all. That's not all. Forces can change the direction that objects are moving in, and change their shape.

A List three things that forces do.

Describing forces

You can't see forces but you can see the effect of them. When you draw a diagram you add arrows to show the forces that are acting. 'Force arrows' show the direction *and* the size of the force. Forces act on objects so the arrow must touch the object in the diagram.



▲ These force arrows show the forces acting on a tennis ball.

Different types of force

Some forces act when you are touching something. This is a **contact force**. **Friction** and **air resistance** are contact forces. Support forces, like upthrust, are also contact forces.

The force of **gravity** acts on a tennis ball travelling through the air. The Earth pulls the ball down even though it is not touching it. Gravity is a **non-contact force**. The force between magnets is another non-contact force.

B Describe the difference between a contact force and a non-contact force.

Foul Fact!

Astronauts on the International Space Station cannot burp. The gas and liquid does not separate in their stomachs while they are in orbit.

Pairing up

A girl and her sister are hanging from a bar in a playground. Think about the forces acting on the girls.

▲ Forces act on the girls hanging from a bar.

- Gravity pulls the girls down. *This is the force of the Earth on the girls.*
- The girls pull the Earth up. *This is the force of the girls on the Earth.*

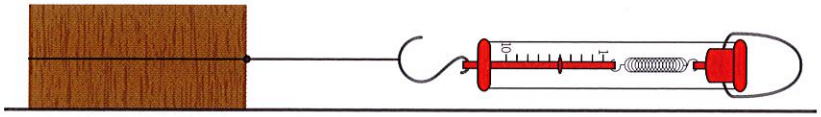
Forces always come in pairs. The pairs are called **interaction pairs**.

There is another interaction pair of forces acting on the girls.

- The bar supports the girls. *This is the force of the bar on the girls.*
- The girls pull on the bar. *This is the force of the girls on the bar.*

How do you measure forces?

You can measure force with a **newtonmeter** (sometimes called a spring balance). All forces are measured in **newtons** (N).



▲ A student is pulling the block with a force of 5 N.

C State the unit of force.

Newton predicts...

In the 1600s, Isaac Newton first explained how gravity affects objects. Scientists later used his ideas to predict that there was a planet beyond Uranus. In 1846 they discovered Neptune. A good explanation means that you can make predictions and test them.

▲ Upthrust supports you when you float.

Link

You can learn more about non-contact forces in P1 1.4 Forces at a distance

Key Words

push, pull, contact force, friction, air resistance, gravity, non-contact force, interaction pair, newtonmeter, newton (N)

Summary Questions

1 Copy and complete the sentences below.

A force is a _____ or a _____. We can show the forces acting on an object using force _____. Forces come in pairs, called _____ pairs. To measure forces you use a _____.

(5 marks)

2 Describe one of the interaction pairs for an apple hanging from the branch of a tree.

(2 marks)

3 You are probably sitting on a chair as you read this book. Explain in detail why the two forces acting on you are not two forces in the same interaction pair.

(6 marks QWC)

1.2 Squashing and stretching

Learning objectives

After this topic you will be able to:

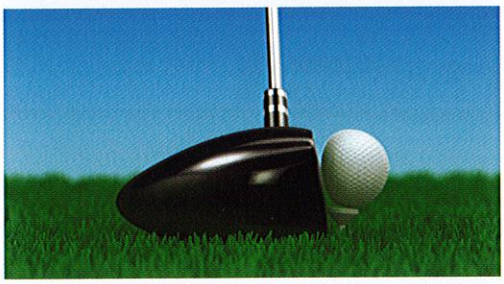
- describe how forces deform objects
- explain how solid surfaces provide a support force
- use Hooke's Law.

Why don't you fall through the chair you're sitting on? The chair changes shape, or deforms, when you sit on it. This produces the force that pushes you up.

Changing shape

When a ball hits the floor the ball **deforms**. Forces can **compress** (squash) or **stretch** objects. When you exert a force you can deform an object. You can compress it or you can stretch it.

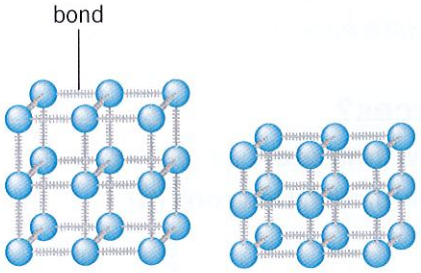
A Describe what happens to a tennis ball when it hits the ground.



▲ Even a solid golf ball changes shape when you hit it.

How can the floor push you up?

The floor pushes up on you when you stand on it. It seems strange to talk about the floor exerting a force on you. You can't see anything happening.



◀ These diagrams show what happens when you exert a force on a solid object.

You compress the bonds when you exert a force.

The floor is a solid; solids are made up of particles arranged in a regular pattern. The particles are joined strongly together by bonds. This is what happens when you stand on the floor:

- Your weight pushes the particles together.
- The bonds are compressed.
- They push back and support you.

Solid materials are only compressed a very small amount when you apply a force to them. A support force from a chair or the floor is called the **reaction** force.

Stretching

Bungee cords, springs, and even lift cables all stretch when you exert a force on them. The amount that they stretch is called the **extension**.

Foul Fact!

When a footballer heads a ball the forces deform both the ball and the footballer's head.

Link

You can learn more about particles in solids, liquids, and gases in C1 1.1 The particle model

Key Words

deform, compress, stretch, reaction, extension, tension, elastic limit, Hooke's Law, linear

A bungee cord stretches as the jumper falls. When the bungee cord has stretched as far as it will go, it pulls her back up. This force is called **tension**.

What happens when you stretch a spring?

Springs are special. If you *double* the force on the spring the extension will *double*. You can use the length of the spring to measure the size of a force. When you remove the force the spring goes back to its original length.

What's the limit?

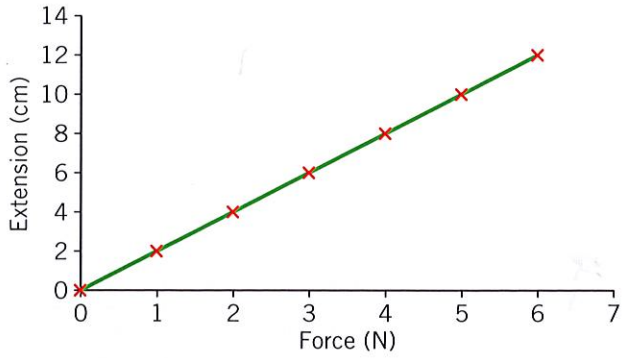
At some point the spring will not go back to its original length when you remove the force. This is the **elastic limit**. Trampoline springs are designed to never go past their elastic limit.

◀ The shape of a bungee cord changes when you stretch it.

Hooke's Law

If the extension doubles when you double the force then the object obeys **Hooke's Law**. The graph of force against extension is a straight line, or **linear**. Hooke's Law is a special case. Not everything behaves like a spring when you stretch it. If you double the force on an elastic band the extension may not double.

B State Hooke's Law.



▲ This graph shows how the extension of a spring changes as you pull it.

A straight-line graph

Using the graph below, find the extension when the force is 3 N and again when it is 6 N. Does this spring obey Hooke's Law? Explain your answer.

How long?

You have a spring that is 4 cm long. When you exert a force of 3 N it stretches to a length of 6 cm. What is the extension? What would the extension be if you doubled the force?

Summary Questions

1 Copy and complete the sentences below.

Forces can change the shape of objects or _____ them. Solid surfaces are made of _____. The bonds between particles are compressed when you apply a force. They _____ back on you. This provides a _____ force called the _____ force.

(5 marks)

2 Describe how your chair pushes you up.

(2 marks)

3 Design a new style of trampoline that would make trampolining more fun. Use the ideas on this page to explain how it works.

(6 marks)

1.3 Drag forces and friction

Learning objectives

After this topic you will be able to:

- describe the effect of drag forces and friction
- explain why drag forces and friction arise.

Slide your finger along the desk. Does the surface feel smooth or rough? Even really smooth surfaces exert a force.

What is friction?

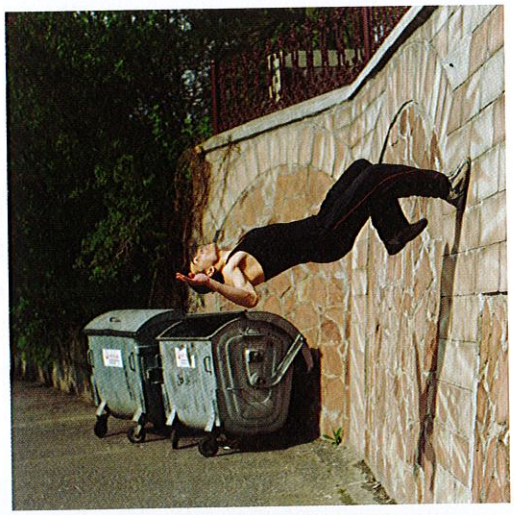
A surface such as a metal slide in a playground looks and feels really smooth. Now imagine zooming in on it; you will see that it is actually rough.

When a book is resting on the table you can push on it but it may not move. **Friction** grips objects. As you increase the force by pushing harder the book will start to move. If you remove the force the book slows down and stops. This is because the rough surfaces can no longer move past each other.

A State two things that friction does.

Fantastic Fact!

Which material has the lowest friction? BAM is a material that contains aluminium, magnesium, and boron. It is twice as slippery as ice.



▲ You need friction to move across surfaces.

Is friction useful?

Friction can be a good thing. You need friction to walk, as the friction between your foot and the road produces the force to move you forward. The brakes on your bike and in a car work because of friction.

B Describe how friction helps you to walk.

How can you reduce friction?

One way to reduce friction is by using oil or grease. This is called **lubrication**. When you oil the chain of your bike the surfaces move past each other more easily. Snowboarders wax their boards to reduce the friction between the board and the snow.

C Suggest why the hinges of a door need to be lubricated.

Fantastic Fact!

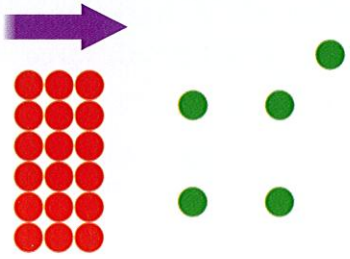
In 1995 Fred Rompelberg travelled at 167 mph.... on a bicycle! He did it by cycling behind a lorry where there was very little air resistance.

What are drag forces?

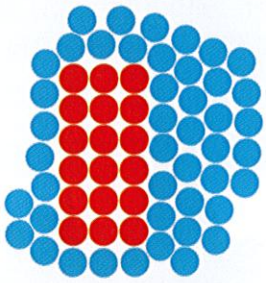
A dolphin swimming through the water and a surfer paddling through water will both experience **water resistance**. As a snowboarder jumps through the air he will experience **air resistance**. Water resistance and air resistance are **drag forces**.

▲ When you move through water you experience water resistance.

To understand drag forces you need to think about the particles in the air and the water.



A solid moves through a gas.



A solid moves through a liquid.

▲ A moving object is in contact with air or water particles.

As a dolphin moves through the water it pushes the water particles out of the way. This produces a drag force, which slows it down.

D Name the drag force acting on an aeroplane in flight.

How can you use drag forces?

Parachutes are used to slow down drag-racing cars and skydivers. The contact with the air produces a drag force.

How can you reduce drag forces?

An Olympic cyclist will tuck her arms in close to her body as she cycles. She will even make sure that her thumbs are as close to the handlebars as possible. This makes her more **streamlined**, which reduces the force of air resistance.

Testing a parachute

A company wants to compare different materials for making parachutes. Name **three** ways that they could make it a fair test.

Key Words

friction, lubrication, water resistance, air resistance, drag force, streamlined

Summary Questions

1 Copy and complete the sentences below.

The force of _____ acts between two solid surfaces in contact that are sliding across each other. The surfaces are _____ and will grip each other. This is why you need to exert a _____ to make something move. There are two drag forces: _____ and _____. When a moving object is in contact with _____ or _____ particles it has to push them out of the way.

(7 marks)

2 Describe the effect of water resistance acting on a bird diving into a lake to catch a fish.

(1 mark)

3 Suggest and explain a reason why the brake blocks on a bicycle need to be replaced from time to time.

(2 marks)

4 A dragster is a car that uses a parachute as a brake. Use the ideas on this page to compare the drag force due to the parachute acting on cars travelling at different speeds, or using parachutes of different sizes.

(6 marks QWC)

1.4 Forces at a distance

Learning objectives

After this topic you will be able to:

- describe the effects of a field
- describe the effect of gravitational forces on Earth and in space.

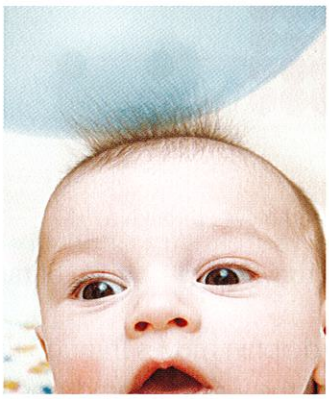
If you let go of your pen and it moved upwards you'd be very surprised. We are so familiar with the force of gravity that sometimes we don't even think of it as a force.

Gravitational forces

A gravitational force acts on a diver jumping off a diving board. It is a non-contact force. There are other types of non-contact force.

Magnets exert a **magnetic force** on magnetic materials or other magnets without touching them. If you rub a balloon you can pick up bits of paper with it. This is an electric or **electrostatic force**. Magnetic and electrostatic forces are non-contact forces.

▲ A magnet picks up filings.



▲ A balloon rubbed on your jumper attracts a baby's hair.

A Identify three forces that act at a distance.

Force fields

In physics a **field** is a special region where something experiences a force. There is a magnetic field around a magnet where magnetic materials experience a force. There are gravitational fields where things with mass experience a force.

Gravitational, magnetic, and electrostatic fields have something in common. As you get further away from the mass, magnet, or charge, the field gets weaker. Contact forces only act when the objects are touching each other. Non-contact forces act at any distance, even if the objects are not touching.

B Describe what is meant by a field.

Link

You can learn more about electrostatic forces in P2 1.1 Charging up

Foul Fact!

The strongest gravitational field in the Universe is made by a black hole. It is called a 'black' hole because even light cannot escape from its gravitational field. If you stood close to a black hole, the force of gravity on your feet would be much bigger than the force of gravity on your head. You'd be stretched. This is called 'spaghettification'.

Key Words

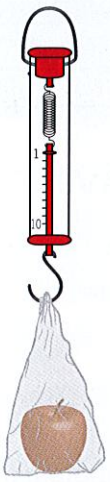
magnetic force, electrostatic force, field, weight, mass, kilogram (kg), gravitational field strength

What do I weigh?

You can use a newtonmeter to find the **weight** of an apple. The Earth pulls the apple downwards. Measuring the weight of the apple means measuring the force of the Earth on it.

What is the difference between weight and mass?

Weight is a force so it is measured in newtons (N). **Mass** is the amount of 'stuff' something is made up of. It is a measure of how hard it is to get something to move. Mass is measured in **kilograms** (kg).



An apple has a weight of about 1 N.

Units of mass

Smaller masses are measured in grams (g).
There are 1000 g in 1 kilogram (kg).
Convert these masses into grams: **a** 2 kg **b** 3.5 kg **c** 0.4 kg
Convert these masses into kilograms: **d** 4700 g **e** 250 g

You can calculate weight using an equation.

weight (N) = mass (kg) x **gravitational field strength**, *g* (N/kg)

On Earth gravitational field strength is about 10 N/kg.

This means that, if your mass is 50 kg, for example, then your weight on Earth is:

weight = 50 kg × 10 N/kg
= 500 N

Gravitational field strength is different on other planets and stars. Your weight would be different on different planets because *g* would be different.

The Apollo astronauts could jump much higher on the Moon because *g* on the Moon is about one sixth of *g* on Earth.

C State the unit of mass and the unit of weight.

What would happen to my weight in space?

Imagine blasting off from the Earth in a spacecraft. As you move away from the Earth the gravitational field gets weaker. If you stood on scales in the spacecraft the reading would be less than it would be on Earth.

The amount of 'you' would not change. Your mass stays the same. It is the force of the Earth on you, your weight, that is less.

Summary Questions

1 Copy and complete the sentences below.

Some forces act a distance. The force of gravity acts on things that have _____. A balloon has an _____ force when you rub it. You can feel a _____ force between two magnets. Your weight is a _____ and is measured in _____. Your _____ is the amount of stuff you are made up of and is measured in _____.

(7 marks)

2 Explain one reason why your weight on Jupiter is 2.7 times your weight on Earth.

(3 marks)

3 Describe what happens to the force of gravity as you move away from the Earth.

(1 mark)

4 Imagine the first Olympic Games conducted on the Moon in a specially designed dome. Use the ideas on this page to state and explain which sports would produce new records, and which would not.

(6 marks)

1.5 Balanced and unbalanced

Learning objectives

After this topic you will be able to:

- describe the difference between balanced and unbalanced forces
- describe situations that are in equilibrium
- explain why the speed or direction of motion of objects can change.

To get out of bed in the morning you need a force to get you moving.

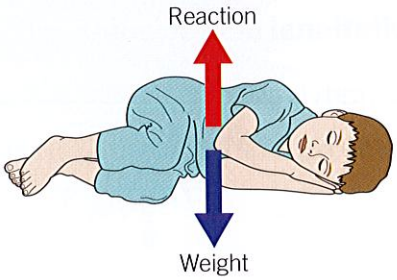
What are balanced forces?

When the forces acting on an object are the same size but in opposite directions we say that they are **balanced**. You can think of balanced forces like two teams in a tug of war. If each team pulls with the same force the rope doesn't move. The forces cancel out. The object is in **equilibrium**.

A State what equilibrium means.

▲ When the teams pull with the same force the forces are balanced.

All stationary objects are in equilibrium. There has to be a support force acting on them to balance out their weight.



◀ You are in equilibrium when lying in bed.

B Draw a diagram showing the forces acting on a stationary mass hanging on a spring.

Equal and opposite...?

Isaac Newton said, 'For every action there is an equal and opposite reaction'. The forces in an interaction pair are equal and opposite. Is lying in bed an example of this law? No, it is not. Each of the forces acting on you comes from a *different* interaction pair.

What are unbalanced forces?

The forces acting on this rocket-powered car are **unbalanced**. They are not the same size so they do not cancel out.

The **driving force** from the engine is much, much bigger than the **resistive forces** from air resistance and friction.

▲ The Thrust SSC was the first car to travel faster than sound.

Key Words

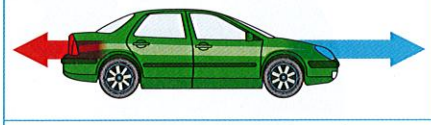
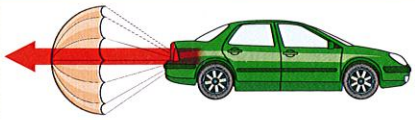
balanced, equilibrium, unbalanced, driving force, resistive force

C State the difference between balanced forces and unbalanced forces.

How do unbalanced forces change speed?

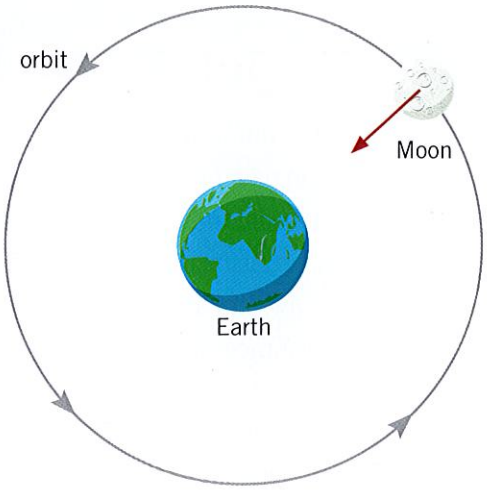
When the car's rocket-powered engine starts up the driving force will become very big very quickly. When the driver wants to stop he will fire a parachute to slow the car down. In both cases the forces on the car are unbalanced.

The driver uses a parachute because this gives a much bigger resistive force on the car than just using the brakes. The speed of the car will change much more quickly. The car will stop in a much shorter time.

	
The driving force is bigger than the resistive forces acting on the car.	The only forces acting on the car are resistive forces.
The speed of the car increases.	The speed of the car decreases.

How do unbalanced forces change direction?

Isaac Newton worked out that the Earth exerts a force on the Moon. The force of gravity acting on the Moon keeps the Moon in orbit around the Earth. It is this same force that acts on an apple and pulls it to the ground. It changes the *direction* of motion, not the speed.



◀ The force of gravity keeps the Moon in orbit.

Every time you go around a corner in a car the friction between the tyres and the road changes the direction of the car.

Link

You can learn more about speed in P2 3.1 Speed

▲ Friction changes the direction of a motorbike.

Summary Questions

1 Copy and complete the sentences below.

If the forces on an object are the same_____ but act in _____ directions they are balanced. This is called _____. The forces acting on any stationary object are _____. If the forces on an object are unbalanced the _____ will change. If the _____ force is bigger than the _____ force it speeds up. If the _____ force is bigger than the _____ force it slows down.

(9 marks)

2 A cyclist is slowing down as she is cycling along a road.

a Draw a diagram to show the forces acting on the cyclist. *(1 mark)*

b Label the forces using the words 'resistive' and 'driving'. *(1 mark)*

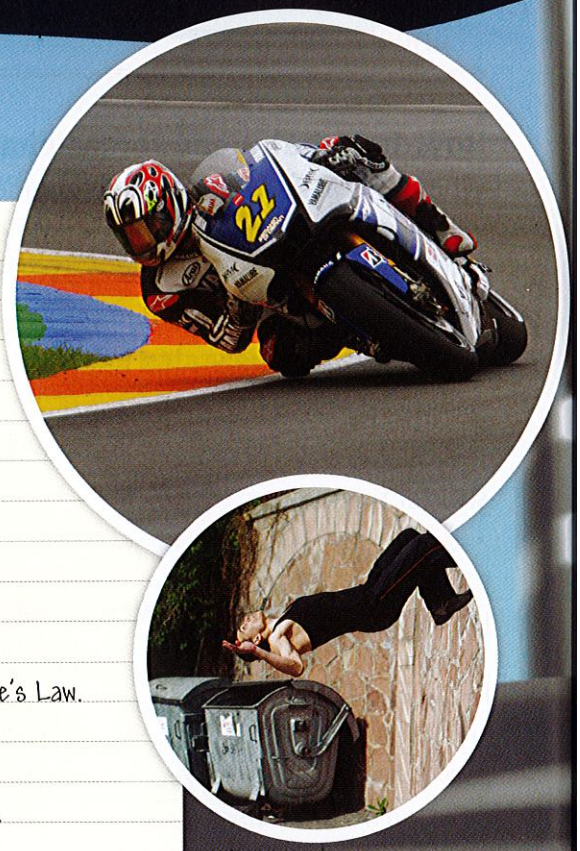
c Explain why her speed is decreasing. *(1 mark)*

3 Design a new ride for a theme park. Describe and explain the motion of people who go on the ride using the ideas on this page. *(6 marks)*

P1 Chapter 1 Summary

Key Points

- Forces are pushes or pulls, measured in newtons (N) using a newtonmeter.
- Forces exist when objects interact – this produces an interaction pair.
- Forces can deform objects, change their speed, or the direction of motion.
- Contact forces occur when objects are touching.
- Friction, air resistance, and water resistance are contact forces.
- Friction can be reduced by lubrication. Air resistance and water resistance can be reduced by streamlining.
- Non-contact forces occur when objects are not touching.
- Gravitational, electrostatic, and magnetic forces are non-contact forces.
- Solid surfaces provide a support force when they are compressed.
- Springs or ropes extend when you apply a force.
- For some objects if you double the force the extension doubles. This is Hooke's Law.
- A field is a region where something feels a force, for example, a mass in a gravitational field.
- Mass is the amount of stuff an object is made up of, measured in kilograms.
- Weight is the force of the Earth on an object, measured in newtons.
  Weight (N) = mass (kg) x g (N/kg)
- When the forces acting on an object are equal in size and acting in opposite directions they are balanced. The object is in equilibrium.
- If the forces are not balanced the object will speed up, slow down, or change direction.



BIG Write

Mission to Mars

NASA's Curiosity rover landed on Mars in August 2012. Imagine that the first astronauts have just returned from Mars in the year 2034.

Task

You were one of the astronauts on the mission. Write a blog that covers the whole mission. Start from when you take off from the Earth and finish with splash down when you return home.

Tips

- Explain the motion of the rocket during each stage of the journey to and from Mars.
- Use what you have learnt about where forces come from and how they affect motion.

Key Words

push, pull, contact, non-contact, interaction pair, newtonmeter, weight, newton (N), deform, compress, stretch, reaction, extension, tension, elastic limit, Hooke's Law, linear, friction, lubrication, water resistance, air resistance, drag forces, streamlined, gravity, magnetic, electrostatic, field, mass, weight, kilograms (kg), gravitational field strength, balanced, equilibrium, unbalanced, driving force, resistive force

End-of-chapter questions

1 State which of the forces below are contact forces and which are non-contact forces.

magnetic force, friction, air resistance, gravitational force, electrostatic force, upthrust

(6 marks)

2 For each object below state whether the forces on it are balanced or unbalanced.

a a boat that is speeding up *(1 mark)*

b a boy who is floating in a swimming pool *(1 mark)*

c a cyclist who is slowing down *(1 mark)*

(3 marks)

3 A student is investigating friction. She puts a block of wood on a ramp and lifts the ramp until the block starts to move. She repeats the experiment with different types of surface on the ramp.

a State the variable that she is changing (the independent variable). *(1 mark)*

b State the variable that she is measuring (the dependent variable). *(1 mark)*

c State the variable or variables that she should control. *(1 mark)*

d Explain why she will need to plot a bar chart in this investigation. *(2 marks)*

(5 marks)

4 A cyclist is sitting on her bicycle at the start of a race.

a Draw a diagram of the cyclist and label the forces acting on her. *(2 marks)*

b Explain how the bicycle seat exerts a force on the cyclist. *(2 marks)*

c The race begins. State whether the forces on her when she goes around a corner are balanced or unbalanced. *(1 mark)*

(5 marks)

5 A student wants to make a newtonmeter. He coils a piece of wire around his pencil to make a spring. He puts a 100 g mass on the spring. A 100 g mass has a weight of 1 N. He measures the extension.

a Describe how to measure the extension of a spring. *(3 marks)*

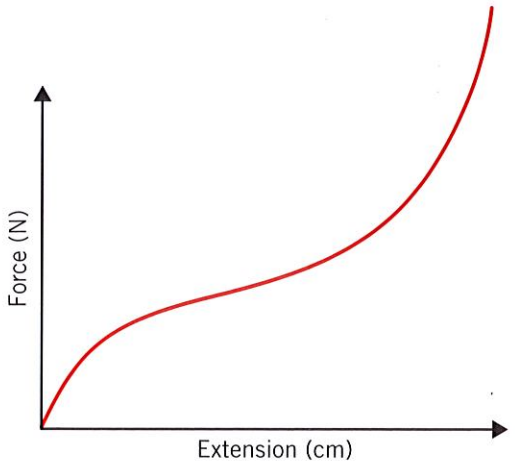
b Explain the difference between a mass of 100 g and a weight of 1 N. *(2 marks)*

The student measures the extension for different forces and plots his results on a graph. The line on the graph is a straight line.

c Use the shape of the graph to explain why the spring obeys Hooke's Law. *(2 marks)*

(7 marks)

6 Another student decides to use an elastic band as a newtonmeter and plots these results.



Explain in detail why the elastic band cannot be used as a newtonmeter but a spring can.

(6 marks QWC)