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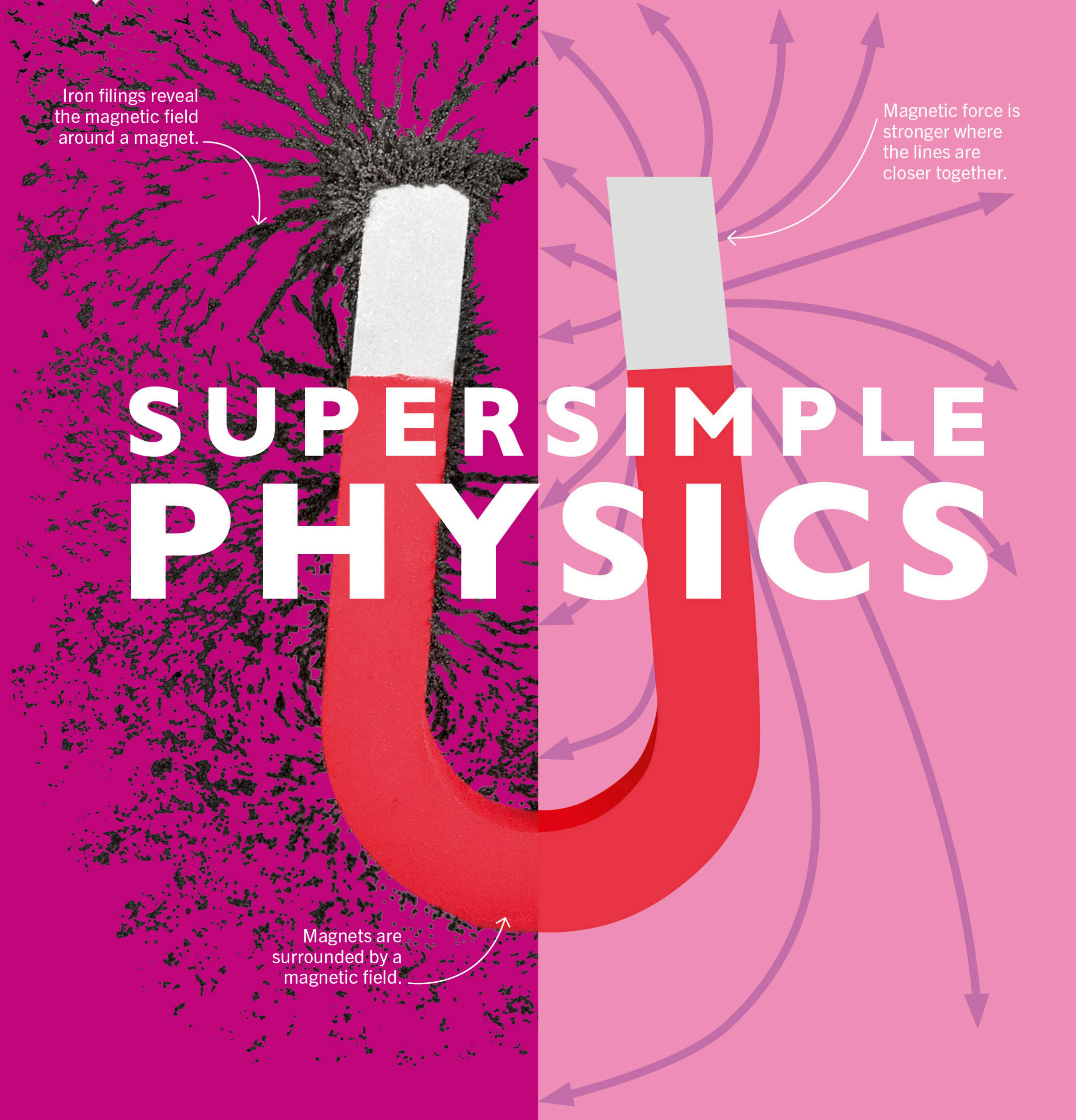
SUPERSIMPLE PHYSICS



THE ULTIMATE BITE-SIZE STUDY GUIDE

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For the curious

www.dk.com

Smithsonian

Established in 1846, the Smithsonian is the world's largest museum and research complex, dedicated to public education, national service, and scholarship in the arts, sciences, and history. It includes 19 museums and galleries and the National Zoological Park. The total number of artifacts, works of art, and specimens in the Smithsonian's collection is estimated at 156 million.

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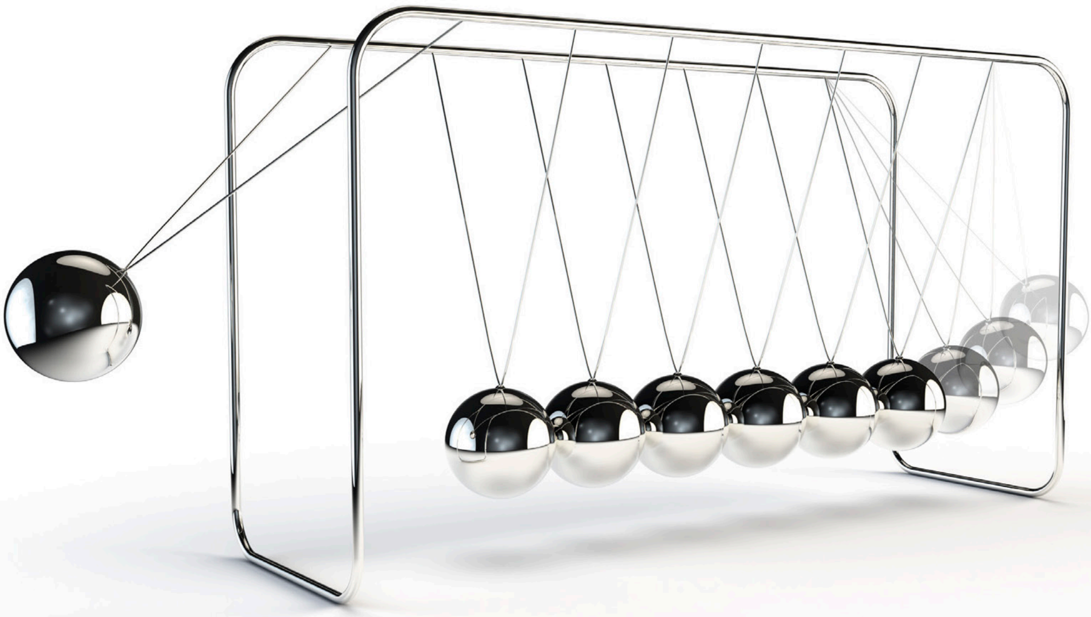

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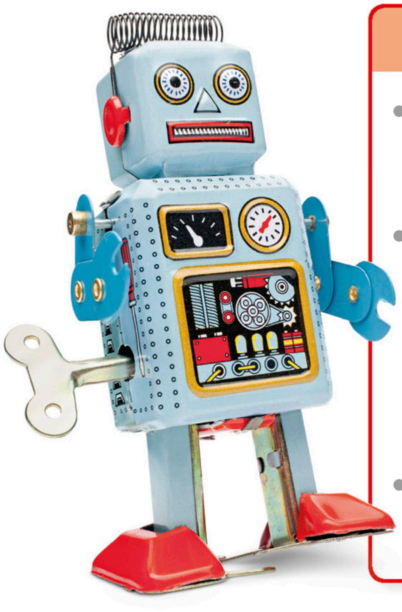

Safety and teacher supervision

- **The experiments outlined in this book describe the experiments required for the experiments set in the UK Physics GCSE curriculum. In undertaking these experiments, you must follow the instructions on each page, as well as the general instructions on "Working safely" on page 17.**
- **Some of the experiments require the additional supervision of a physics teacher, and they should therefore only be undertaken at school under such supervision. The experiments requiring teacher supervision are marked with this symbol:**

Teacher supervision required

- DISCLAIMER: The publisher cannot accept any liability for any injury or losses arising from experiments where such instructions were not followed and/or that were undertaken without appropriate supervision.

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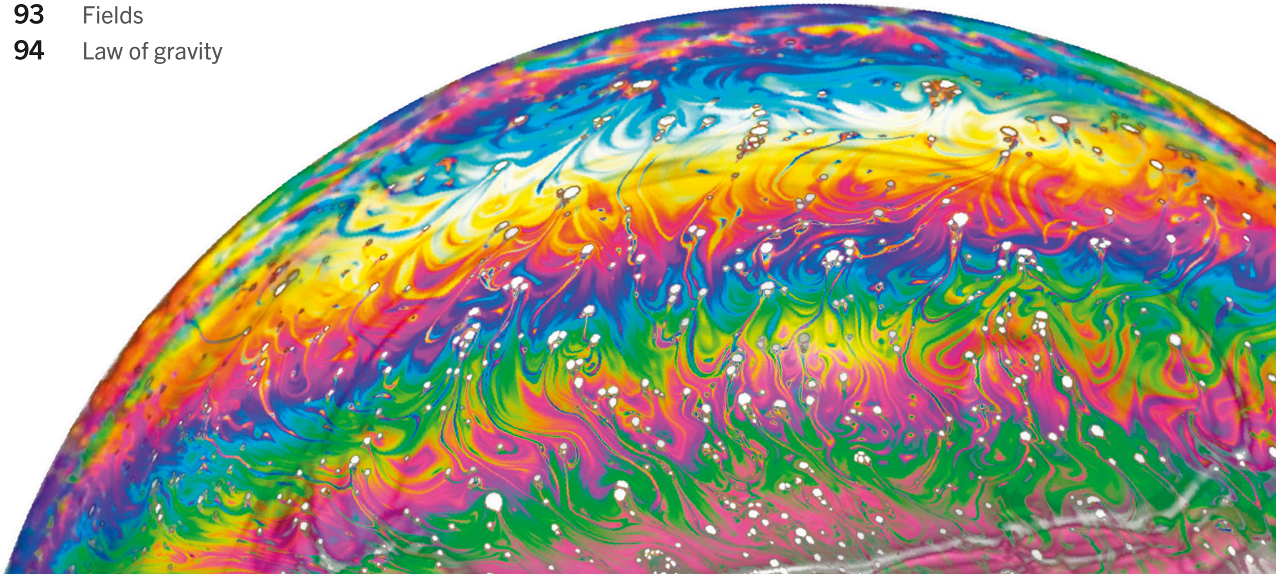

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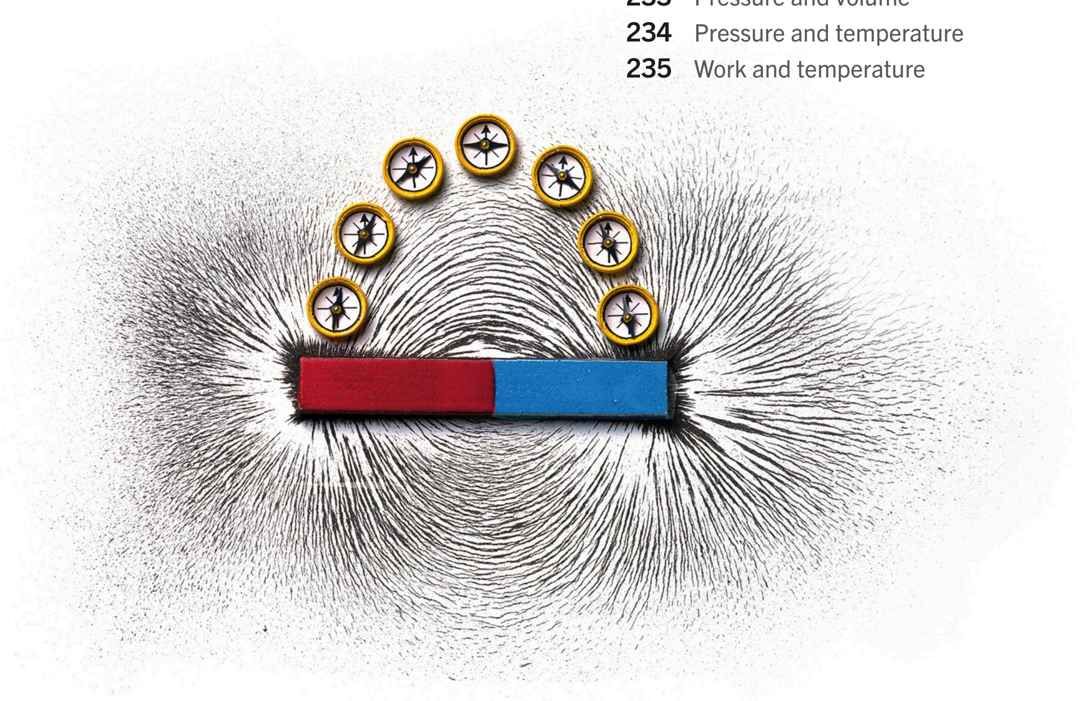


Atoms and radioactivity

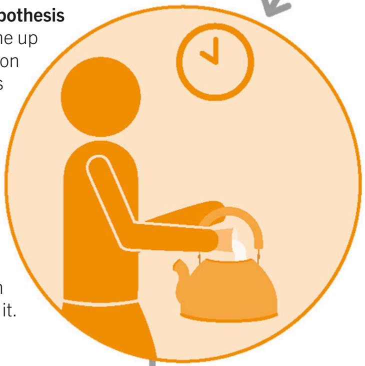
Space

Working scientifically

The scientific method

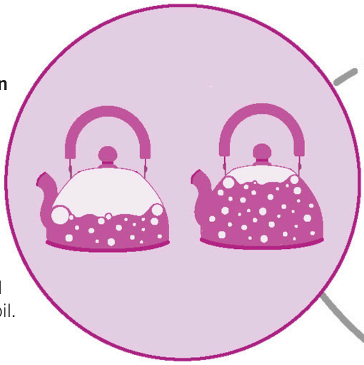
As scientists, we want to explain how and why things happen—such as what happens when a current flows through a wire or when stars or planets form. We do this by thinking logically in a step-by-step process. The steps on this page are used in all fields of science.

1. Ask a scientific question
Scientists are curious and often ask questions about how things work. For instance, why does a tea kettle sometimes take longer to boil? A scientific question is one that can be answered by collecting data (information). A question such as "Which kind of hot drink is nicest?" is not a scientific question.

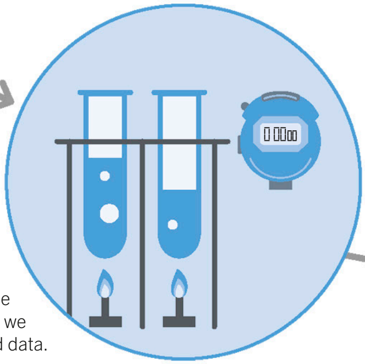


2. Make a hypothesis
The next step is to come up with a possible explanation that can be tested. This is called a hypothesis. We can often write a hypothesis using the words "depends on." For instance, our hypothesis might be: the length of time the tea kettle takes to boil depends on how much water is in it.

Collect data
Some scientific questions can't be tested by experiments. Astronomers can't experiment with planets and stars, for instance. However, they can still make hypotheses and predictions and then test the predictions by making observations to collect data.



3. Make a prediction
To test a hypothesis, we use it to make a prediction. A prediction can often be written as "If . . . then . . . ." For example: I predict that if I double the amount of water, it will take twice as long to boil.



4. Collect data
Hypotheses are usually tested by experiments. In this case, we might heat measured volumes of water and time how long each volume takes to boil. An experiment must be a fair test, which means the only variable we change is the one we're investigating (the volume of water, in this case). The information we collect in an experiment is called data.

7. Theory
If the hypothesis is tested many times and never fails, it might eventually become accepted as a scientific theory.

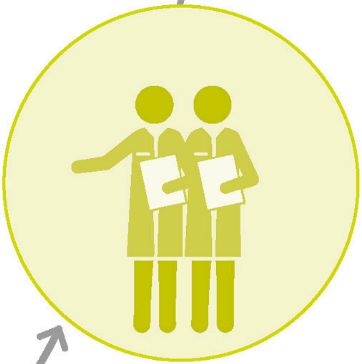
Key facts

- ✓ A hypothesis is a scientific idea that can be tested.
- ✓ A hypothesis is used to predict what may happen in an experiment.
- ✓ If a hypothesis is supported by an experiment, it may become part of a theory.
- ✓ Scientists present their discoveries to be checked by other scientists.

Refine hypothesis or experiment
If the prediction was wrong, the hypothesis might be wrong, too, or the experiment might not have worked properly. Failed experiments are not a waste of time—they sometimes lead to new discoveries.

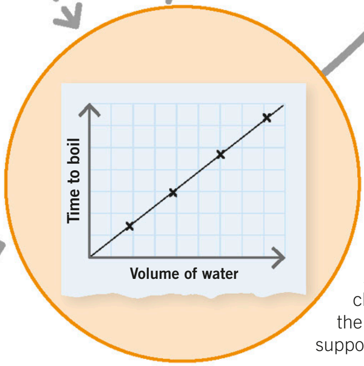
Many scientists repeat the experiment.

The conclusion does not support the hypothesis.



The conclusion supports the hypothesis.

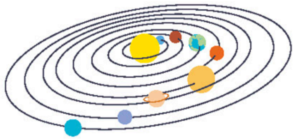
6. Peer review
After a successful experiment, a scientist may write a report (called a paper) so that other scientists can find out about the experiment and check the details. The paper may be published in a scientific journal for all scientists to read.



5. Analysis and conclusion
After collecting data, we analyze it carefully to check for errors and look for patterns. We use the analysis to decide whether the experiment supports the hypothesis. This forms our conclusion.

Scientific theories

People sometimes say “it’s just a theory” when they don’t believe something. However, in science, a scientific theory is an explanation that has been tested many times and become widely accepted as true. For example, the idea that Earth and other planets of the solar system orbit the Sun is a scientific theory based on many careful observations and predictions. If it weren’t for science, we’d probably believe that the movement of the Sun across the sky meant that it was orbiting Earth rather than vice versa.



Solar system

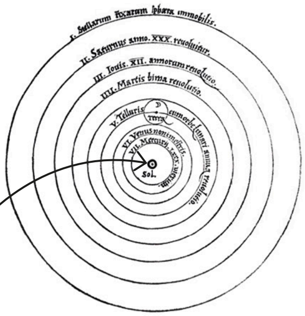
Scientific progress

Scientific methods and theories change over time. For example, the invention of the telescope changed the way people thought about the solar system. As telescopes became more powerful, new ideas about the stars and the Universe became accepted, too.

Key facts

- ✓ Scientific theories and methods change over time.
- ✓ The invention of the telescope led to new discoveries about the planets, moon, and stars.
- ✓ As telescope technology improved, new discoveries changed our understanding of the Universe.

Quadrant

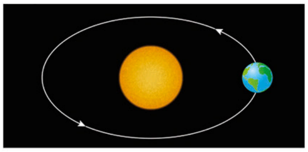


Sun

Observing the skies
The first people known to study the night sky were the people of Mesopotamia (now Iraq), around 5,000 years ago. Ancient astronomers used simple instruments like a quadrant to measure the angle stars or planets made with the horizon and to predict when the Sun or Moon would rise and set.

Heliocentric model
Using observations made with the naked eye, the Polish astronomer Nicolaus Copernicus devised a new model. This had the Sun at the center (heliocentric) and planets traveling around it in circular orbits. At first, it wasn't accepted because it didn't match observations perfectly.

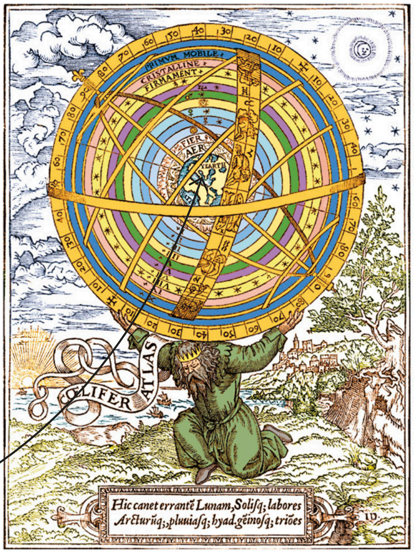
Elliptical orbits
About 80 years after Copernicus died, a German astronomer named Johannes Kepler proposed a heliocentric model with elliptical (oval) orbits instead of circular ones. This matched the movements of the planets much better than older models.



140 CE | 1543 | 1609 | 1610

Earth in the middle
The people of the ancient world thought that the Sun moved around Earth and that Earth was the center of the Universe. The Greek astronomer Ptolemy based his "geocentric model" of the solar system on this idea. Geocentric means Earth is in the middle. To make this model fit with the observation that planets sometimes appeared to move backward through the sky, Ptolemy gave each planet a complex system of orbits within orbits (epicycles).

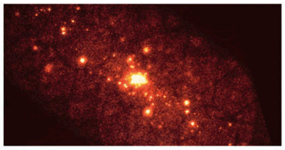
Ptolemy's model is called geocentric because it puts Earth in the center.

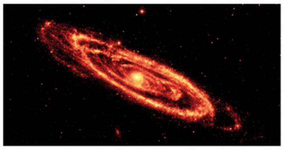


Telescopes
After the telescope was invented in the early 1600s, the Italian scientist Galileo Galilei discovered mountains and craters on the Moon and four moons orbiting Jupiter. His observations supported the heliocentric model.

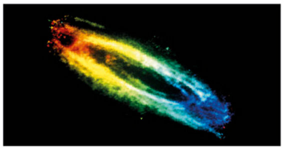
In a different light

Visible light is just one part of the electromagnetic spectrum. Astronomers can learn more about stars and galaxies by observing the other kinds of electromagnetic wave that they emit. Some of these waves are absorbed by Earth's atmosphere, so X-ray, ultraviolet, and infrared telescopes have to be launched into space. Radio telescopes can be built on the ground. The images here show what the Andromeda Galaxy looks like at different wavelengths.


X-ray


Infrared


Ultraviolet


Radio

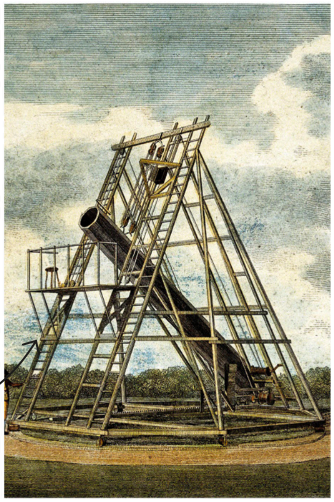
1687

Theory of gravity
Inspired in part by Kepler's elliptical orbits, the English scientist Isaac Newton published a book that included his laws of gravity and motion. These mathematical models help explain how the planets orbit the Sun and how moons orbit planets.


Newton also invented the reflecting telescope, which uses a curved mirror instead of lenses.

1781

Better telescopes
As telescopes got bigger and better, astronomers discovered more distant objects. The German-born astronomer William Herschel discovered Uranus using a telescope 39 feet (12 meters) long. He also identified lots of nebulas—clouds of glowing material among the stars.


William Herschel constructed his giant telescope with his sister Caroline Herschel.

1908


Andromeda Galaxy

Discovering galaxies
In 1912, the American astronomer Henrietta Swan Leavitt worked out a way of calculating the distance from Earth to variable stars—stars whose brightness varies. In 1923, another American, Edwin Hubble, used her idea to demonstrate the existence of other galaxies beyond our own, revealing that the Universe was far bigger than anyone had realized.

Present day

Modern observation methods
Today, astronomers can launch telescopes into space or build telescopes that detect radio waves or other forms of electromagnetic radiation instead of visible light. The information gathered has helped us explain how stars form and die, how gravity holds them together in galaxies, and how the Universe might have begun.


Radio telescope

Science and society

Scientific developments sometimes raise ethical questions that can't be answered by experiments, though gathering data can help people make informed decisions. The answers to questions such as the examples below depend on people's opinions, not on science.

Key facts

- ✓ Some scientific developments raise ethical questions.
- ✓ Questions about what is right or wrong cannot be answered by experiments and depend on people's opinions.

Cheap meat
Selective breeding can be used to produce farm animals that give better meat, cows that produce more milk, or hens that lay more eggs. However, changes that cut costs for farmers may be harmful to the animals. Chickens bred to grow very fast, for example, may be too heavy to walk. Are cheap meat and higher profits more important than animal welfare?

Clean energy
Climate change is happening because humans are adding too much carbon dioxide to the atmosphere. Tidal power generates electricity without producing carbon dioxide, but this sometimes involves building a barrage dam across a river estuary, preventing fish from migrating and changing natural habitats. Is clean energy more important than preserving wildlife habitats?

This golden rice is genetically engineered to produce extra vitamins.

Normal white rice

Genetic engineering
Genetic engineering can provide cures for diseases or alter crops to provide additional nutrients. These bring benefits to many people's lives, but genetically modified organisms are not natural. Is it wrong to modify life in this way?

Biofuel power station

Biofuels
Biofuels are fuels made from crops. Burning these fuels reduces carbon dioxide emissions compared to burning fossil fuels, as the crops absorb carbon dioxide as they grow. However, growing them uses land that could be used for food. Is clean energy more important than food supplies?

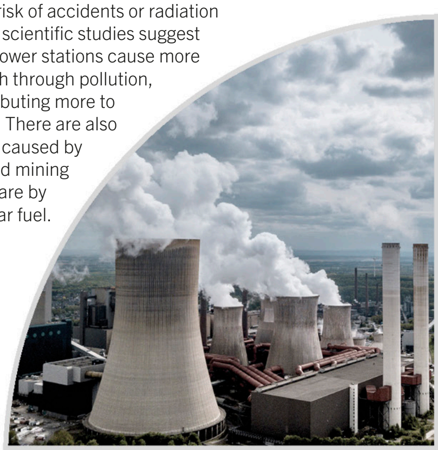
Risks and benefits

Science and technology can produce inventions that improve people's lives, but some technologies bring risks, too. Benefits and risks need to be weighed up, taking all the evidence into account. Often the option that we think is more dangerous turns out not to be.

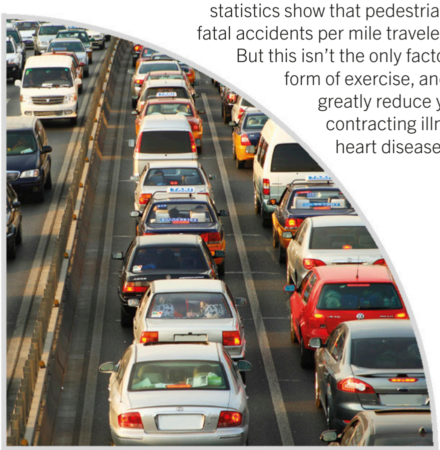
Key facts

- ✓ **Modern technology can have great benefits, but some technologies can also cause harm.**
- ✓ **The risks and benefits of different technologies need to be assessed before deciding whether or not to use them.**

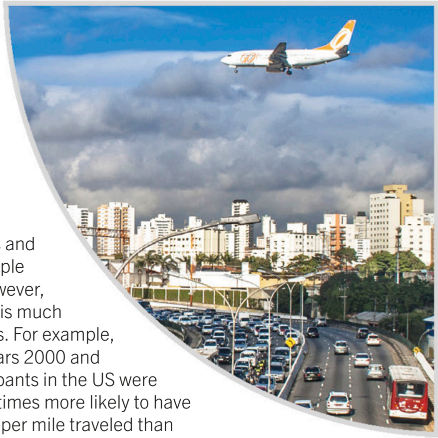
Nuclear power or fossil fuels
Many people think nuclear power is dangerous because of the risk of accidents or radiation leaks. However, scientific studies suggest that fossil fuel power stations cause more illness and death through pollution, as well as contributing more to climate change. There are also more accidents caused by drilling for oil and mining coal than there are by obtaining nuclear fuel.

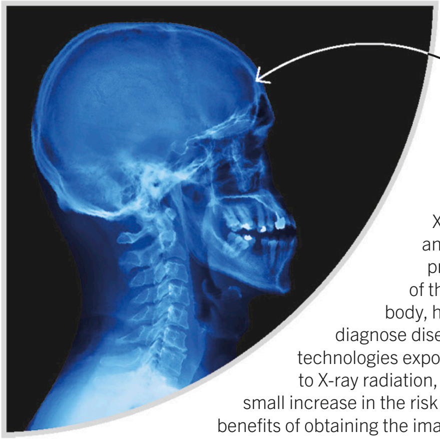


Walk or drive?
Which is safer—walking or driving? Accident statistics show that pedestrians suffer more fatal accidents per mile traveled than drivers. But this isn't the only factor. Walking is a form of exercise, and exercise can greatly reduce your chance of contracting illnesses such as heart disease and diabetes.



Flight safety
Air crashes are always big news and make some people afraid to fly. However, traveling by car is much more dangerous. For example, between the years 2000 and 2009, car occupants in the US were more than 100 times more likely to have a fatal accident per mile traveled than passengers on commercial airliners.





X-rays
X-ray machines and CT scanners produce images of the inside of the body, helping doctors diagnose disease, but these technologies expose living tissue to X-ray radiation, causing a very small increase in the risk of cancer. The benefits of obtaining the images in order to treat the condition usually outweigh the risks.

Scientific models

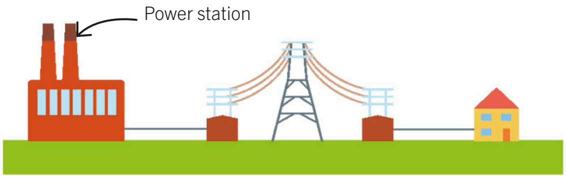
We often use models to help us understand scientific ideas. Like hypotheses, models can be tested by experiments. There are five main types of scientific model: descriptive, computational, mathematical, spatial, and representational.

Key facts

- ✓ Models help us understand or describe a scientific idea.
- ✓ Models can be used to make predictions, which can then be tested by experiments.
- ✓ Types of model used in physics include descriptive, computational, mathematical, spatial, and representational.

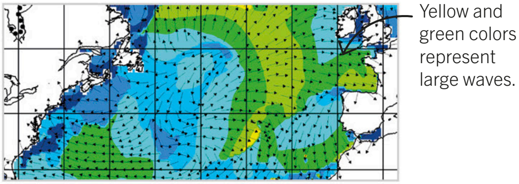
Descriptive models

These models use words and sometimes diagrams to describe something. This diagram showing how electricity travels from power stations to our homes is a descriptive model.



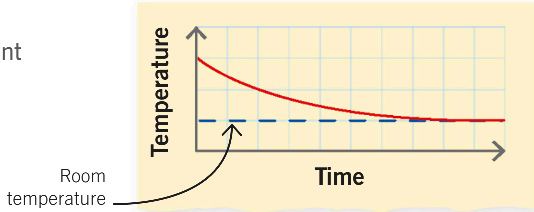
Computational models

Computational models use computers to simulate complex processes. Weather forecasts are made using computational models of the atmosphere. The image shown here is a forecast for the waves in the Atlantic Ocean.



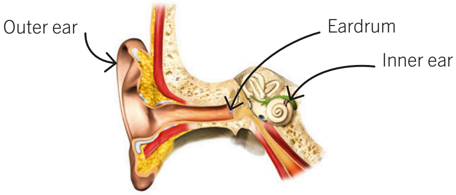
Mathematical models

These are models that use equations to represent what happens in the real world. For example, a mathematical equation can model the fall in temperature as a hot object transfers heat to its surroundings. The results of mathematical models can be shown on graphs.



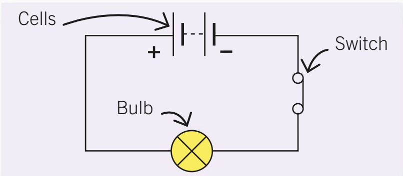
Spatial models

A spatial model shows how things are arranged in three-dimensional space, such as the way the parts of our ears fit together. This scale model is not the same size as a real human ear, but all the parts are the correct sizes relative to each other.



Representational models

These models use simplified shapes and symbols to represent more complex objects in the real world. For example, this circuit diagram helps us understand how the electrical circuit in a flashlight works.



Working safely

Physics experiments can involve electricity, moving objects, and heat, so there's a risk of being injured. It's important to conduct investigations safely, so be sure to follow these guidelines.

Protecting your eyes
Safety glasses or goggles protect your eyes against splashes of liquids or small particles such as iron filings. They should also be used if you are stretching wires or springs, in case the wire breaks and flies at your face.

Heating water
When heating water, take care to avoid splashing it on your skin. If scalded, run cold water over your skin as soon as possible.

Protecting your feet
Some physics experiments use weights that could fall on your feet and injure them. A cardboard box full of crumpled newspaper will catch a falling weight and stop you from putting your feet in the wrong place.

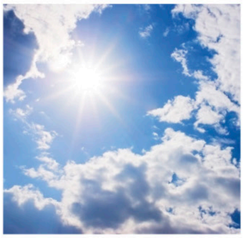
Slips and spills
If you spill water on the floor, clean it up right away in case someone slips on it.

Working with electricity
When working with electricity, always turn off or disconnect the power supply or battery before making changes to a circuit. Ask your teacher to check the circuit before you switch it on.

Dangerous substances
Some science experiments involve radioactive materials or dangerous chemicals. These substances should only be handled by specially trained people wearing appropriate safety equipment. Experiments involving dangerous substances should not be carried out at home.

Bunsen burners
When using a Bunsen burner, keep the area around it clear. Tie back loose hair and clothing to keep them from getting near the flame. Allow hot equipment to cool before handling, or use heat-resistant gloves.

Beware of the Sun
When doing experiments with light, never look directly at the Sun—it can permanently damage your eyes. The danger is even greater if using binoculars or a telescope.

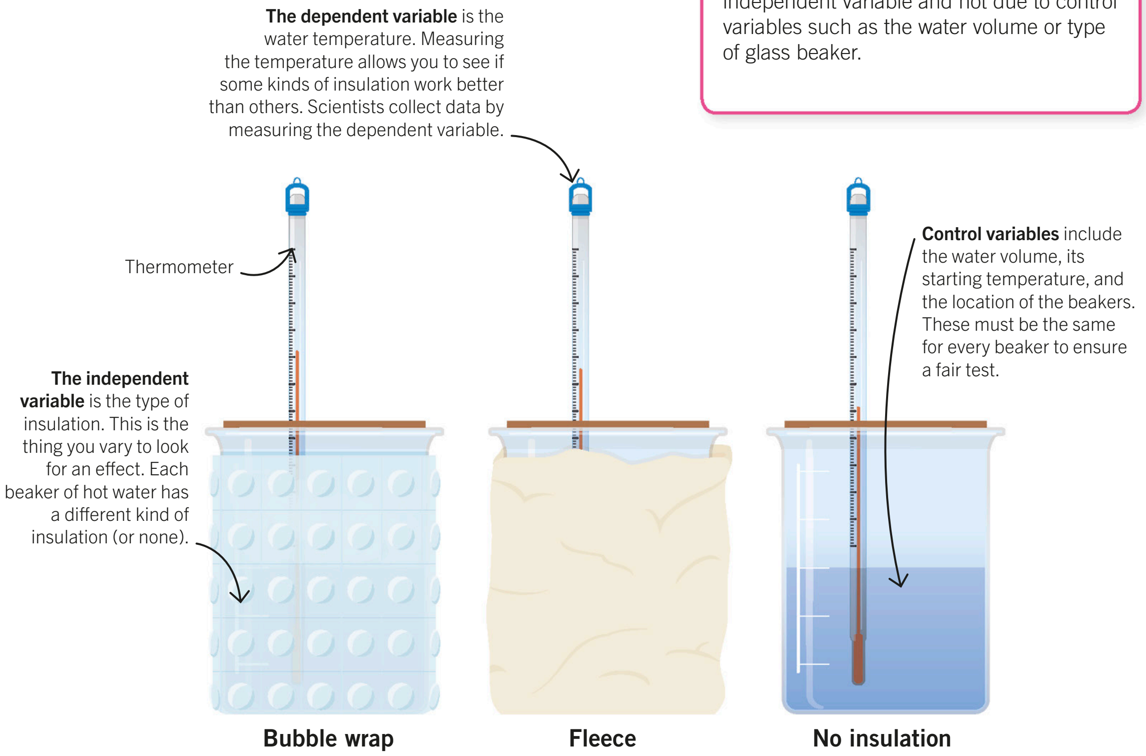


Planning an experiment

To be a fair test, a scientific experiment should vary only one thing at a time to see what effect it has on something else. We call the thing you deliberately vary the independent variable. The thing it affects is the dependent variable, and things you need to keep constant are control variables.

Investigating insulation

In the scientific method, you test a hypothesis (an idea) by carrying out an experiment. Air is a poor conductor of heat, so you might form a hypothesis that materials containing lots of trapped air will be good insulators. To test this hypothesis, you could carry out an experiment like the one shown here. Three beakers of hot water are given different types of insulation, and the water temperature is measured regularly as the beakers cool down.



Key facts

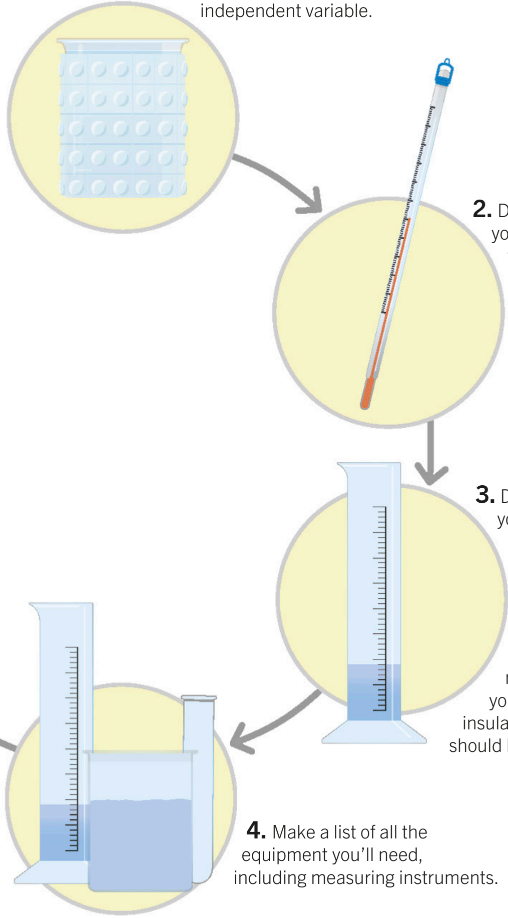
- ✓ Experiments must be carefully planned to ensure a fair test.
- ✓ Things that change in experiments are called variables.
- ✓ The independent variable is the thing you change.
- ✓ The dependent variable is the thing you measure.
- ✓ Control variables are the things you keep the same to ensure a fair test.

Experimental controls

The uninsulated beaker is an experimental control. It allows you to compare the temperature change with insulation to how it would change if no insulation had been used. Any differences must be due to the independent variable and not due to control variables such as the water volume or type of glass beaker.

The planning process

Experiments should always be carefully planned in advance. The most important part of the planning process is to decide what the independent and dependent variables are. It's also important to work out what equipment you need and ensure the experiment can be conducted safely.



1. First, decide which variable you will deliberately change. This is the independent variable. In the insulation experiment, the type of insulation is the independent variable.

2. Decide which variable you'll measure to look for an effect. In the insulation experiment, the temperature of the water is the dependent variable.

3. Decide which variables you need to keep constant to ensure the test is fair. These are your control variables. For example, the volume of water in each beaker and the starting temperature must be the same. If you compare different insulation materials, they should be equally thick.

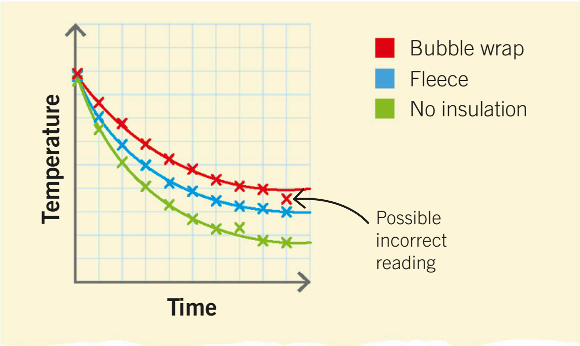
4. Make a list of all the equipment you'll need, including measuring instruments.

5. Plan the steps you'll take during the experiment in detail. How often will you take the temperature? How long will you leave the beakers standing? What volume of water will you use, and what should the starting temperature be?

6. Decide what safety precautions you need to take and write them down. For this investigation, be careful with the hot water, and make sure you wipe up any spills right away in case someone slips.

Collecting data

All experiments involve collecting data, which we use to see if a hypothesis is supported or not. Planning how and when to collect data is important. For this experiment, taking the temperature regularly allows you to create a graph of your results. The graph helps you spot possible errors in the measurements, and it helps you reach a conclusion.



Measuring

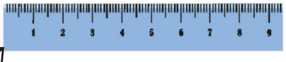
Most experiments involve taking measurements of physical quantities, such as temperature, volume, mass, or time. To obtain accurate data, you need to use an instrument suited to the size of the quantity you are measuring.

Key facts

- ✓ **Most experiments involve measurements of physical quantities, such as temperature, volume, mass, or time.**
- ✓ **Instruments that can measure large quantities are usually not accurate when measuring small quantities.**

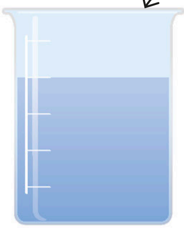
Length and distance

Use a tape measure to measure longer distances, such as when finding your walking speed over 10 meters.

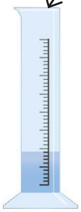


Use a ruler to measure the length of a small object.

Volume



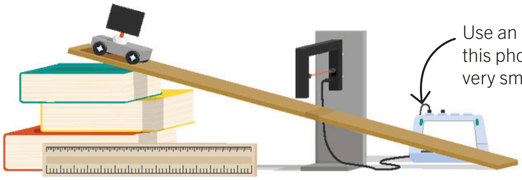
Use a beaker or large measuring cylinder for measuring large volumes of liquid.



Use a small measuring cylinder for small volumes of liquid.

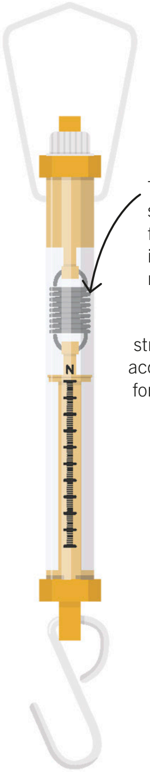
Time

Use a stopwatch to measure periods of time greater than 10 seconds.

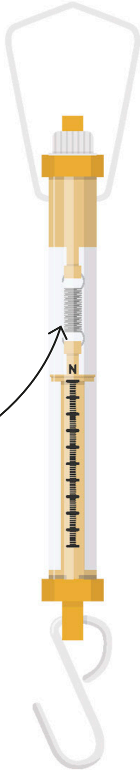


Use an electronic timer, like this photogate, to measure very small time intervals.

Force



This force meter has a stiff spring and can measure forces up to 50 N, but it is not very accurate for measuring very small forces.



This force meter has a stretchier spring and can accurately measure small forces. You will damage it if you try to measure a large force with it.

Electronic instruments

Electronic instruments are often more accurate than manual versions. However, this doesn't always make them the best choice. They are more expensive and easier to damage, so they should only be used in experiments where greater accuracy is necessary.

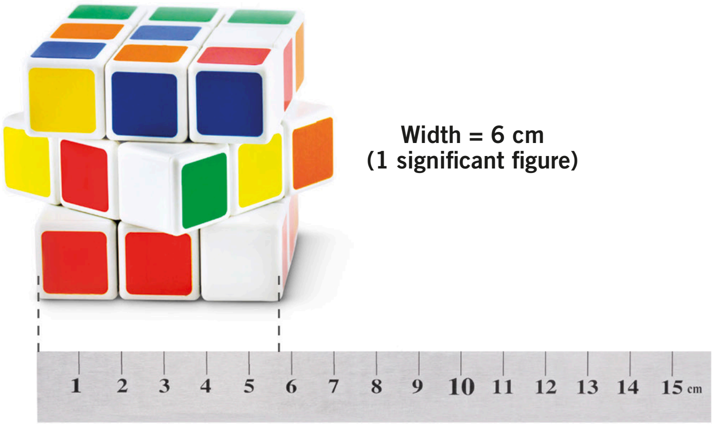
A digital multimeter can measure voltage, current, and resistance.

Test leads are connected to circuits.

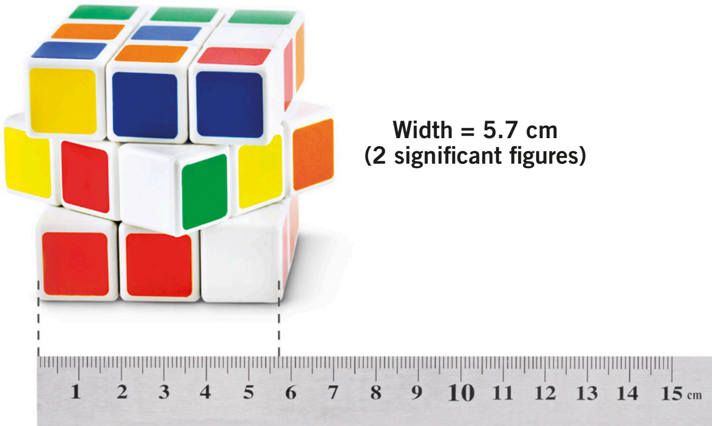
Significant figures

The significant figures in a number are the digits that have meaningful information. More accurate measuring devices produce values with more significant figures. When collecting data or doing calculations, we often need to round numbers up or down to just a few significant figures.

Recording data
The number of significant figures depends on the measuring instruments you use. For instance, a ruler with a scale divided into centimeters gives fewer significant figures than a ruler with a scale divided into millimeters. Digital instruments often give more significant figures than traditional ones (but this doesn't necessarily mean they are more accurate).



**Width = 6 cm
(1 significant figure)**



**Width = 5.7 cm
(2 significant figures)**

Key facts

- ✓ **More accurate measuring instruments produce values with more significant figures.**
- ✓ **When multiplying or dividing, round answers to the same number of significant figures as the least accurate starting value.**
- ✓ **When adding or subtracting, round answers to the same number of decimal places as the least accurate starting value.**

Using calculators

Sums done on calculators may give you more significant figures than you need. Suppose you calculate the resistance of a light bulb using the formula below. You use readings from a voltmeter and an ammeter that each show values to three significant figures.

$$R = \frac{8.12\ \text{V}}{1.04\ \text{A}}$$

The answer on a calculator is 7.8076923.

Writing your answer like this implies you know the resistance to 8 significant figures, but the measuring instruments were only accurate to 3 significant figures, so your answer should be too:

$R = 7.81\ \Omega$ (3 s.f.)

When multiplying or dividing, round your answer to the same number of significant figures as the least accurate starting value. When adding or subtracting, round your answer to the same number of decimal places as the least accurate starting value.

Presenting data

Data is the information you collect from experiments. It often consists of numbers such as measurements. Organizing data into tables, charts, or graphs helps you make sense of it and spot patterns. The kind of chart or graph you use depends on the kind of data you collect.

Tables

Tables are useful for organizing data and for doing simple calculations, such as working out mean (average) values. This table shows results from an experiment investigating how mass added to a cart affects its acceleration.

Independent variable

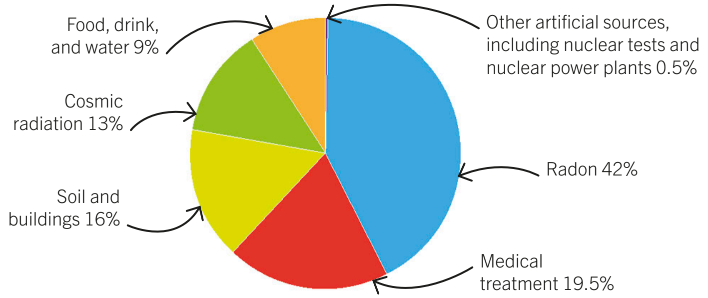
Dependent variable

Mass added to cart (kg)	Acceleration (m/s^2)			
	1st run	2nd run	3rd run	Mean
0.5	9.9	10.2	10.1	10.1
1.0	6.8	8.8	6.6	6.7
1.5	5.2	4.8	5.1	5.0

Tables help us spot "outliers." These are very different from the other values and may be mistakes. This value was ignored when calculating the mean.

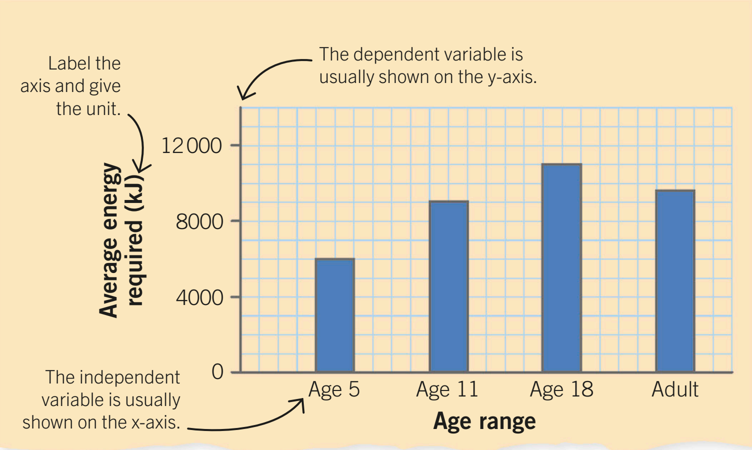
Pie charts

Use a pie chart to show percentages or relative amounts. For example, this pie chart shows estimates of different sources of background radiation that people are exposed to worldwide.



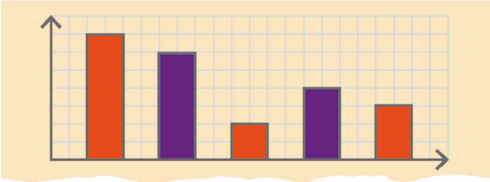
Bar charts

Use a bar chart when the independent variable is made up of discrete (separate) categories. For example, this bar chart shows how much energy different groups of people need each day. You should also use a bar chart when the independent variable consists of discrete values, such as numbers of people or numbers of objects (which are always counted in whole numbers).



Continuous and discrete variables

Discrete variables are variables that can only have certain values. For example, the number of passengers on a plane can only be a whole number, and the insulation around a container of hot water can only consist of certain materials. A continuous variable, however, can take any value and may not be a whole number. Length and weight, for example, are continuous variables.

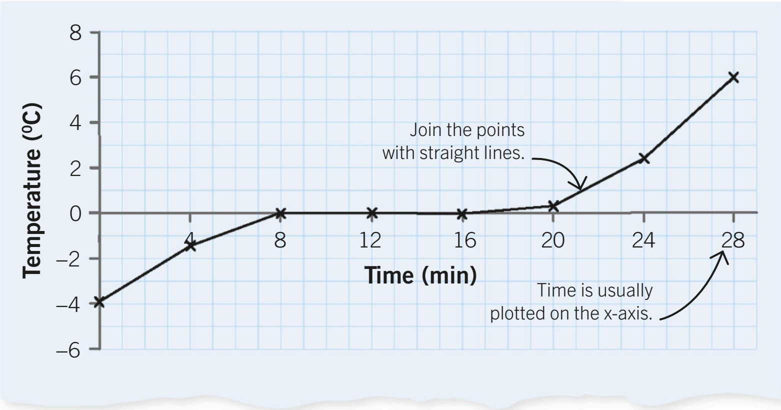


Discrete variable

Continuous variable

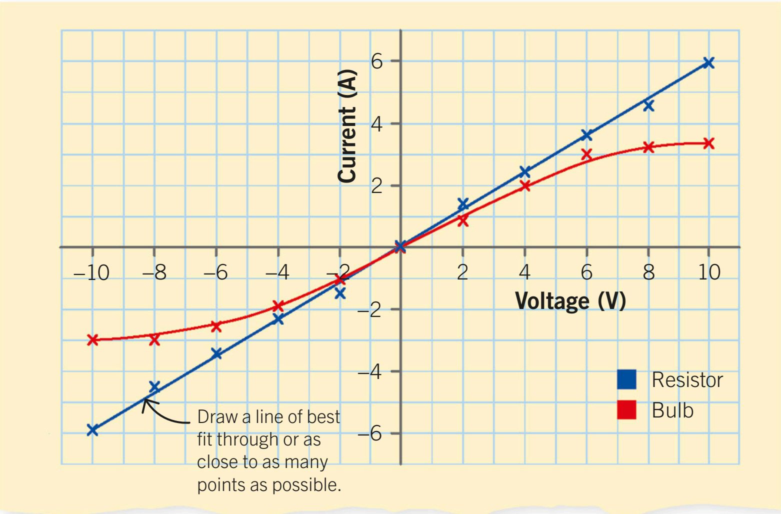
Line graphs

Use a line graph when both axes show numerical values that vary continuously rather than dividing into discrete (separate) categories. Line graphs are often used when one of your variables is time. This graph shows how the temperature of ice changes as it is heated.



Scatter graphs

Use a scatter graph to investigate a relationship between two variables. This graph shows how the current through a resistor and through a bulb varies when the voltage is changed. If the data points form a clear pattern when plotted on the graph, such as a line, we say the variables are correlated. When this is the case, draw a straight "line of best fit" or "curve of best fit" through the points.



Patterns in data

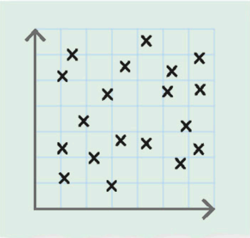
In some experiments, you might look to see if there is a relationship between two variables. In other words, if you change one variable, how does it affect the other?

Key facts

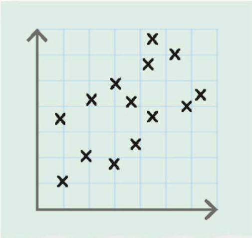
- ✓ A correlation is when one variable changes as the other variable does.
- ✓ A correlation does not show that one change causes the other.
- ✓ A relationship between two variables is linear if the points form a straight line when plotted on a graph.
- ✓ A relationship is proportional if a straight line goes through the origin.

Correlation

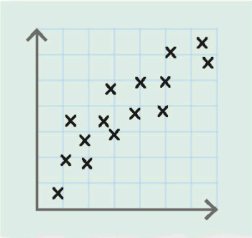
When two variables appear to be linked, we say they are correlated. Plotting a scatter graph of your data is a good way to spot correlations. A correlation between two variables doesn't show that one causes the other. For example, ice cream sales and swimming accidents are positively correlated, but this is because ice cream and swimming are both more popular in hot weather and not because ice cream causes swimming accidents.



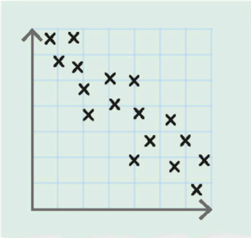
No correlation
The data points are scattered around randomly and show no pattern. There is no correlation between the variables.



Weak correlation
The points look as if they might be grouped around a diagonal line. The large scatter means this is only a weak relationship.



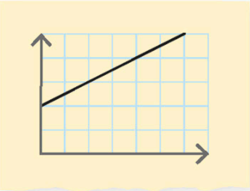
Strong positive correlation
The points form a diagonal line, showing that one variable increases as the other one does.



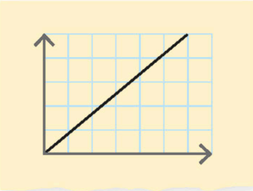
Strong negative correlation
The line formed by these points shows that one variable decreases as the other increases. This is a negative correlation.

Linear and proportional relationships

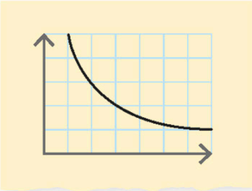
Graphs showing correlation can reveal other interesting patterns in a relationship, depending on their shape.



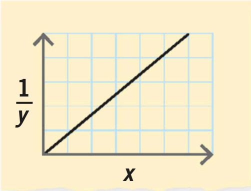
Linear
A correlation where the points form a straight line is described as linear.



Proportional
If the points form a straight line through the origin (where *x* and *y* both equal zero), the relationship is described as proportional. This means that if one variable doubles, so does the other.



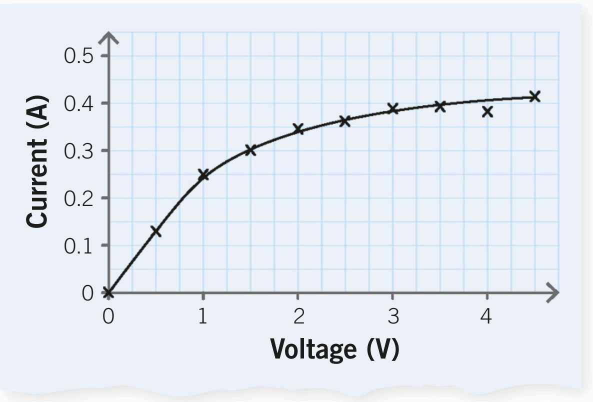
Inversely proportional
In an inversely proportional relationship, one variable halves when the other doubles. This forms a curved line.



Checking
To check whether a relationship is inversely proportional, plot one variable against the inverse of the other (1 divided by the value). The graph should be a straight line through the origin.

Conclusions

The conclusion of an experiment describes what you found out, interprets the results, and says whether the experiment agrees with the prediction you made.



An electricity experiment
Three students carried out an experiment to test the prediction that the current flowing through a bulb is proportional to the voltage across it. By using an ammeter to measure current in the circuit and a voltmeter to measure voltage across the bulb, they obtained the results shown in the graph. Their conclusions are shown below.

Conclusion 1
"The current does go up when the voltage goes up, so the prediction was correct."

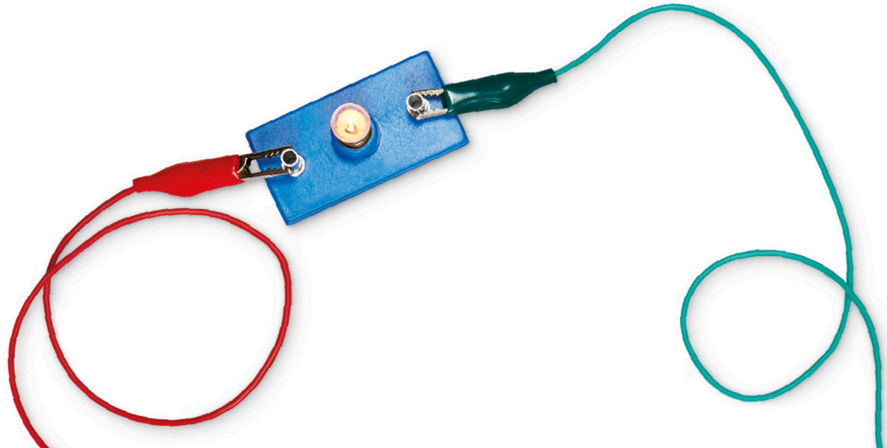
An incorrect conclusion
The description is not detailed, and the graph does not show a proportional relationship, which would produce a straight line.

Conclusion 2
"The current increases as voltage increases, but the graph is a curve. A proportional relationship would produce a straight line, so the prediction was not correct."

A better conclusion
The description has more detail and the final conclusion is correct.

Conclusion 3
"The graph shows that the current increases as the voltage increases. At lower voltages, the relationship could be proportional, as the first few points fall on a straight line. However, at higher voltages, there is a smaller increase in current for every increase in voltage. This shows that the resistance is increasing. The prediction was partially correct, as the current does increase with voltage, but the relationship is not proportional."

An excellent conclusion
The description is much more detailed. The student has used their knowledge of the link between current, resistance, and voltage to suggest what may be causing the change in shape of the graph.



Accuracy and precision

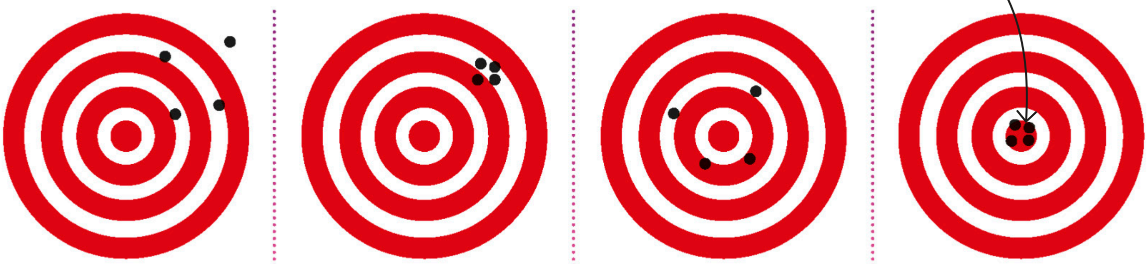
When planning and evaluating an experiment, you need to think about the accuracy and precision of your measurements. The words accurate and precise have specific meanings in science.

Key facts

- ✓ **Accurate measurements are ones that are close to the true value being measured.**
- ✓ **Precise measurements are those that give the same (or similar) values when the measurement is repeated.**
- ✓ **Errors in measurements can be random or systematic.**

Accurate or precise?

A measurement is considered more accurate if it is closer than other measurements to the true value being measured. It is precise if repeating the measurement several times produces values that are the same or very close to each other. To understand the difference, it helps to think of measurements as trying to hit a target.



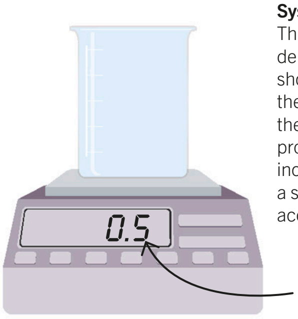
Inaccurate and imprecise
The measurements are inaccurate, as they are not near the center of the target, and imprecise, as they are not close to each other.

Precise but inaccurate
These measurements are precise because they are all nearly the same value, but they are inaccurate because they aren't close to the center.

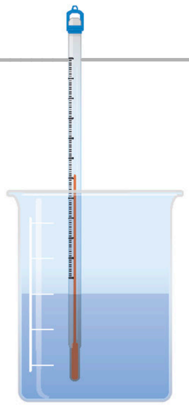
Accurate but imprecise
These are close to the center but not to each other, so they are accurate but imprecise.

Accurate and precise
These measurements are both accurate and precise.

Types of error



Systematic errors
The accuracy of some instruments depends on how they're used. Balances should be set to zero with a container on them so you only measure the mass of the contents. If a balance is not zeroed properly, all the measurements will be incorrect by the same amount. This is a systematic error and reduces the accuracy of the measurements.



Random errors
Random errors are different for every reading. For example, if you take the temperature of water in a beaker, the thermometer might return a slightly different reading each time it dips into a different part of the water. This reduces the precision of your measurements.

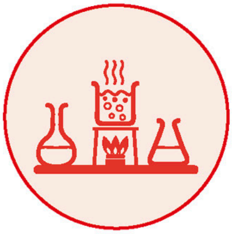
Evaluations

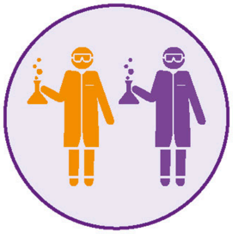
We often evaluate our experiments to decide how much we can trust the results. An experiment has to be valid and fair, and the conclusions must be based on high-quality data. An evaluation may also suggest how the method could be improved.

Is the experiment valid?

An experiment is valid if you can answer "yes" to all of these questions.

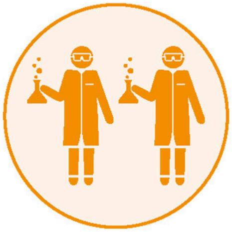
Was it a fair test?
Did you control all the variables apart from the independent variable you were testing?





Is it reproducible?
If a different person carries out the experiment using different equipment, do they get the same results?

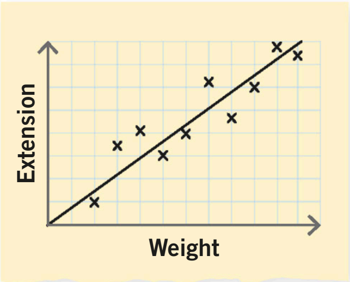
Is it repeatable?
If you repeat the experiment using the same equipment, do you get the same results?



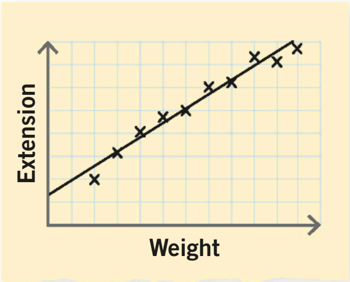
Did it test the hypothesis?
Did you make a prediction from your hypothesis? Was the experiment a good test of the hypothesis?

Data quality

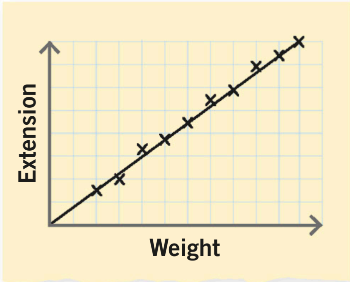
Good data is accurate and precise. You can assess the quality of your data by repeating an experiment, but sometimes you can also tell by looking carefully at the results. The graphs below are from an experiment measuring the extension of a spring holding different weights.



The data points are scattered around the line of best fit. The data is imprecise.



The points are closer to the line, so the data is precise. However, extension should be zero for zero weight, so it's odd that the line does not pass through the origin. There may be a systematic error (see page 26) causing inaccurate data.



This data is very close to the line of best fit, and the line goes through the origin, as we expect. This data is both accurate and precise.

Using mathematical models

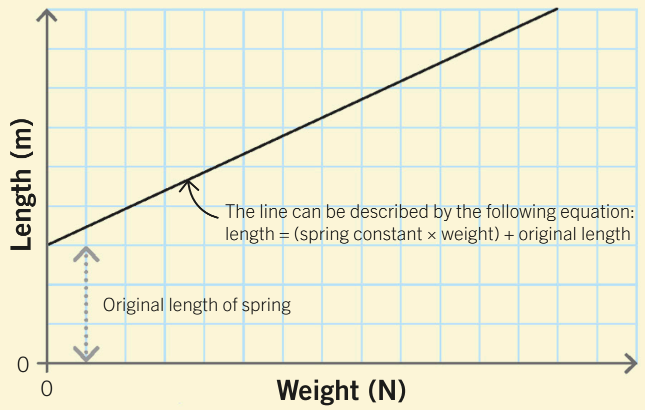
Mathematical models use equations to represent what happens in the real world. Sometimes we can work out a mathematical model from a graph of results. At other times, we might use an equation to predict a result.

Key facts

- ✓ Mathematical models use equations to represent what happens in the real world.
- ✓ Mathematical models can be used to describe graphs of results.
- ✓ We can rearrange equations to calculate particular quantities.

Linear equations

If a relationship between two variables produces a straight line on a graph, we call the relationship linear. Linear relationships can be described by equations written like this: $y = mx + b$. For instance, this graph shows how the length of a spring changes when different weights are hung on it. If you know the original length of the spring and the slope of the line, you can use the graph or the equation to work out the spring's length for any weight.

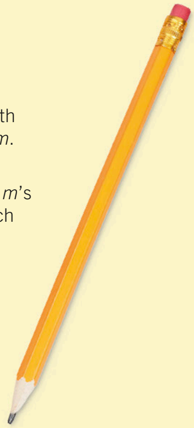


Rearranging equations

Sometimes you need to rearrange an equation before doing a calculation. For example, the equation $F = m \times a$ tells you how to calculate force if you know mass and acceleration, but what if you're told the force and asked to calculate acceleration? You need to rearrange the formula so that a is the subject. You can do it by dividing each side by m. Remember that equations have to stay balanced, so the same operation must be carried out on both sides.

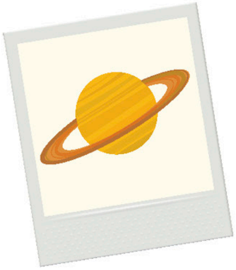
$$F = m \times a$$

1. $F = m \times a$
2. $\dfrac{F}{m} = \dfrac{m \times a}{m}$ Divide both sides by m.
3. $\dfrac{F}{m} = \dfrac{\cancel{m} \times a}{\cancel{m}}$ These two m's cancel each other out.
4. $\dfrac{F}{m} = a$
5. $a = \dfrac{F}{m}$



Standard form

Saturn is about 1 400 000 000 000 meters from the Sun. A bacterium is about 0.000 001 meters wide. It's easy to make mistakes in calculations when numbers have lots of zeros, so we simplify them by writing them in "standard form." This shows a long number as a much shorter number (from 1 to under 10) multiplied by a power of 10. To work out the power of 10, count how many times the decimal point has to move.



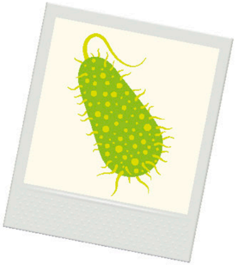
This shows how many places the decimal point has moved.

12 11 10 9 8 7 6 5 4 3 2 1

The second part is a power of 10.

$$1.400\,000\,000\,000 \text{ m} = 1.4 \times 10^{12} \text{ m}$$

The first part is a number with only one digit in front of the decimal point.



The minus sign shows the decimal point has been moved to the right.

1 2 3 4 5 6

$$0.000\,001 \text{ m} = 1.0 \times 10^{-6} \text{ m}$$

Calculating percentages

A percentage is a number shown as a fraction of 100. To turn any fraction into a percentage, work out the fraction on a calculator, multiply the answer by 100, and add a percentage symbol. For example, a 30-watt light bulb transfers 18 watts of power to light and wastes the other 12 watts as heat. What's its efficiency as a percentage?

$$\text{efficiency (\%)} = \frac{\text{useful power output (W)}}{\text{total power input (W)}} \times 100$$

$$= \frac{18 \text{ W}}{30 \text{ W}} \times 100$$

$$= 0.6 \times 100$$

$$= 60\%$$

SI units

Science is an international activity. Scientists from different countries work together on the same problems, so it helps if everyone uses the same units for measurements. Scientists around the world use the *Système International* (SI) system of units.

Base units

All SI units are based on a small number of base units. The five base units in the table below are used in this book.

Quantity	SI base unit	Symbol
time	second	s
length	meter	m
mass	kilogram	kg
current	ampere (amp)	A
temperature	kelvin	K

One unit on the Kelvin temperature scale is the same size as 1 degree on the Celsius scale, but the scales start at different points.

Derived units

Most SI units are derived from base units. For example, the unit for area (m^2) is based on the meter.

Quantity	SI unit
area	square meter (m^2)
volume	cubic meter (m^3)
speed and velocity	meters per second (m/s)
acceleration	meters per second squared (m/s^2)
frequency	hertz (Hz)
force	newton (N)
momentum	kilogram meters per second (kg m/s)
pressure	pascal (Pa)
energy	joule (J)
power	watt (W)
charge	coulomb (C)
potential difference (voltage)	volt (V)
resistance	ohm (Ω)

1 Hz =1 per second

1 Pa = 1 N/m^2

1 W = 1 J/s

SI prefixes

A meter isn't a very useful unit for measuring the size of an atom or the distance to Mars, so we add prefixes to standard units to make bigger or smaller versions.

Prefix	Multiplies by	Example
nano (n)	10^{-9}	1 nanometer (nm) = 0.000 000 001 m
micro (μ)	10^{-6}	1 microsecond (μs) = 0.000 001 s
milli (m)	10^{-3}	1 milligram (mg) = 0.001 g
centi (c)	10^{-2}	1 centimeter (cm) = 0.01 m
kilo (k)	10^{3}	1 kilogram (kg) = 1000 g
mega (M)	10^{6}	1 megahertz (MHz) = 1 000 000 Hz
giga (G)	10^{9}	1 gigawatt (GW) = 1 000 000 000 W
tera (T)	10^{12}	1 terawatt (TW) = 1 000 000 000 000 W

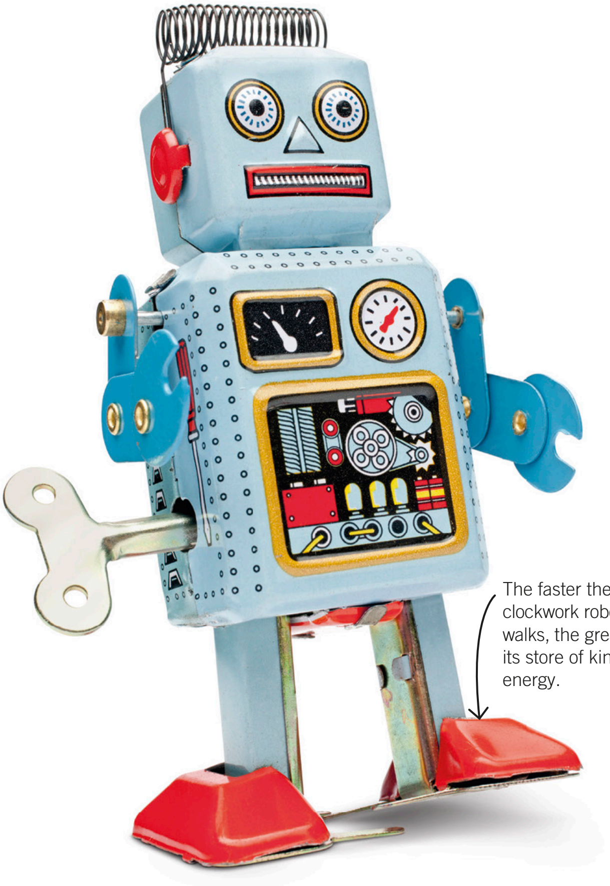
Energy

Energy

Energy is the ability to make something happen. It moves your arms and legs, charges your phone, powers your TV, and makes the Sun shine. Energy can be stored in different ways or transferred from one store to another, but it can never be destroyed.

Key facts

- ✓ **Energy can be stored in many different ways.**
- ✓ **Energy can be transferred from one energy store to another.**
- ✓ **Energy cannot be destroyed.**
- ✓ **Movement energy is also called kinetic energy.**



The faster the clockwork robot walks, the greater its store of kinetic energy.

Energy stores

Energy can be stored in different ways. The energy stored by a moving object is called kinetic energy. The faster an object is moving, the greater its kinetic energy.

Light transfers energy from a bulb to its surroundings.

Energy transfers

Energy can be transferred from one energy store to another. When you turn on a lamp, the bulb transfers energy to the surroundings by light and heating.

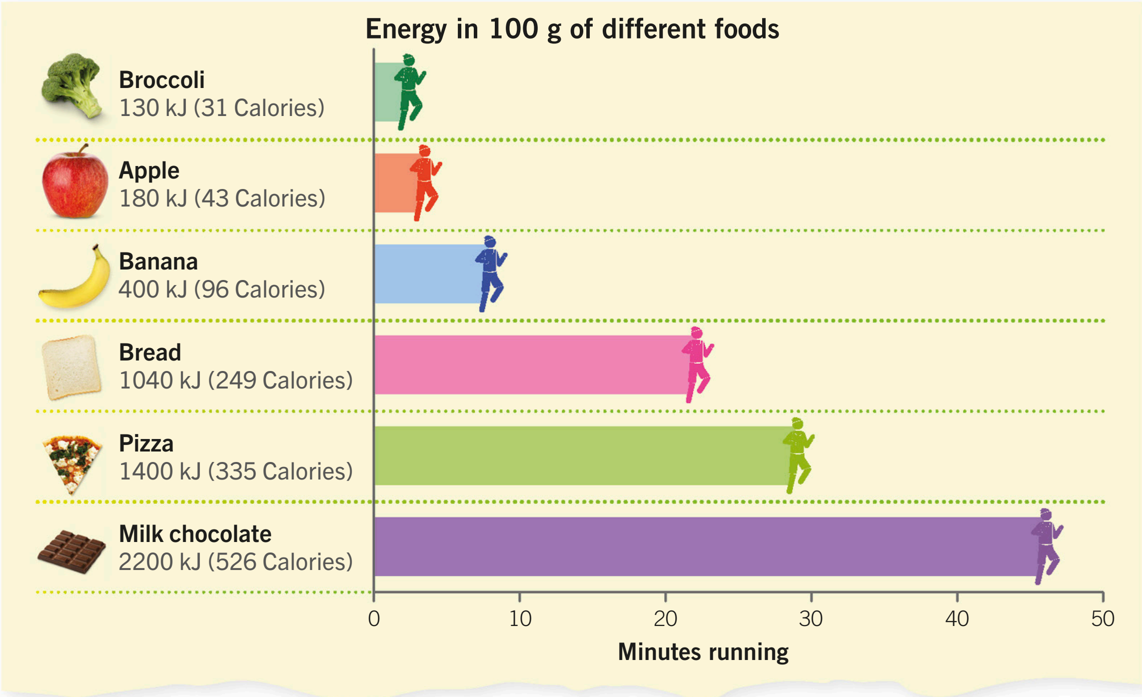
Energy and food

The food we eat supplies our bodies with energy. We measure the amount of energy in food using units called kilojoules.

Key facts

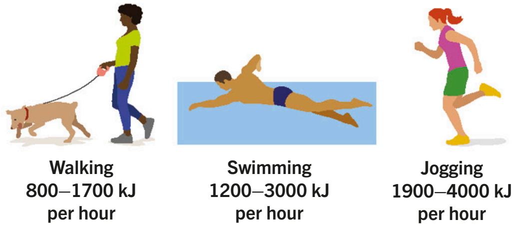
- ✓ The scientific unit for energy is the joule (J).
- ✓ The energy in food is often shown in kilojoules (1 kJ = 1000 J).
- ✓ A person's daily energy requirement depends on their age, size, and level of physical activity.

Energy in different foods
Different foods store different amounts of energy. We sometimes measure food energy in Calories, but the scientific unit for energy is the joule. Food contains thousands of joules, so we use units called kilojoules (1 kJ = 1000 J). The chart here shows how long you would have to run for to use up the energy in different foods.



Energy and exercise

The average adult needs around 10000 kJ of energy a day, but the figure varies from person to person and from day to day. In general, the greater a person's mass, the more energy they need—so adults use more energy than children. How physically active you are also affects how much energy your body uses.



Energy stores

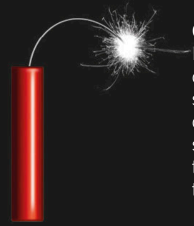
Energy isn't just stored in batteries—it can be stored in many different ways, from the kinetic energy stored in a moving car to the potential energy of a diver on a high diving board. When energy moves from one store to another, we say the energy is transferred.

Key facts

- ✓ Energy can be stored in many different ways, including thermal energy, chemical energy, gravitational potential energy, kinetic energy, elastic energy, and nuclear energy.
- ✓ An energy transfer is the movement of energy from one store to another.

Thermal energy
When energy is stored in hot objects, we call it heat energy or thermal energy. When you heat water to make tea or coffee, its store of thermal energy increases.

Kinetic energy
A moving object has kinetic energy. The faster it moves or the greater its mass, the greater its store of kinetic energy.



Chemical energy
Energy stored in chemical bonds is called chemical energy. The energy stored in batteries and food is stored as chemical energy. Explosives and fuels store large amounts of chemical energy that transfers to thermal energy when they burn.

Elastic potential energy
Stretch a rubber band or squeeze a spring and it will store elastic potential energy until you release it. Elastic potential energy can also be stored in objects when they're squashed or twisted.

Nuclear energy
The energy stored inside atoms is called nuclear energy or atomic energy. This store of energy powers nuclear reactors, nuclear bombs, and the Sun.

Gravitational potential energy
An object or a person raised to a high position stores gravitational potential energy (GPE). When a diver falls, their GPE is transferred to kinetic energy.

Hydroelectric power

Hydroelectric power stations use gravitational potential energy to make electricity. A dam is built to hold back a river in a valley, forming a deep artificial lake. Water from the lake flows downhill through pipes inside the dam, turning machines called turbines, which drive electricity generators. Gravitational potential energy transfers to kinetic energy in the turbines and ultimately to electrical energy, which is used to power homes.

Energy transfers

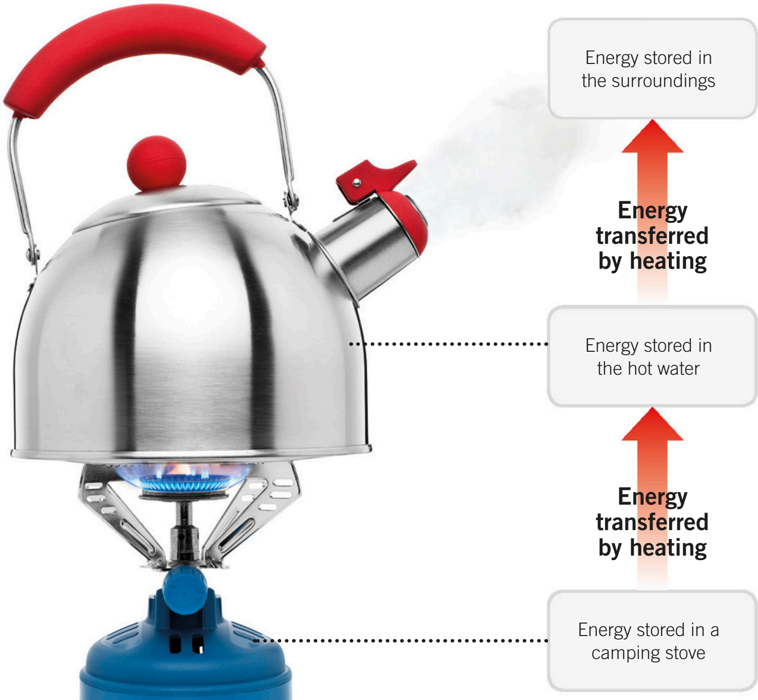
When you turn on a light, ride a bike, cook a meal, or do anything at all, you transfer energy from one energy store to another. Energy transfers make everything happen.

Key facts

- ✓ Energy can be transferred from one energy store to another.
- ✓ The total amount of energy in an isolated system is not changed by an energy transfer. This is known as the law of conservation of energy.
- ✓ Energy can be transferred in many ways: by heat, forces, electricity, radiation, and sound.

Energy transfer by heating

Heating an object transfers energy to its thermal energy store. This either makes the object warmer or causes a change of state to happen. Here, chemical energy stored in fuel is transferred by heating to water in a tea kettle. The hot water will eventually cool down as energy escapes, but the total amount of energy shared by the fuel, stove, tea kettle, water, and their surroundings remains constant. This is called the law of conservation of energy.



Energy diagrams

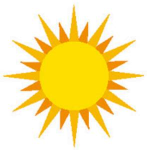
We can show energy transfers in simple diagrams like this one. The stove, tea kettle, and their surroundings together make up what we call an isolated system—a set of objects that don't exchange matter or energy with anything outside.

Other energy transfers

Heating isn't the only way to transfer energy. Energy can also be transferred by forces, electricity, radiation, and sound.

By forces
If a force acts on an object—for example, by moving it—it transfers energy to the object. We call the energy transferred in this way work.

By electricity
Whenever you turn on an electric device, energy is transferred along the wires by electricity.



By radiation
Different forms of radiation—such as visible light, X-rays, and microwaves—transfer energy at incredible speeds. Our planet gets most of its energy in this way from the Sun.

By sound
Like all types of wave, sound waves transfer energy as they travel. When sound waves reach your ears, the energy is transferred to your eardrums, which vibrate.

Renewable energy resources

Sources of energy that will never run out are called renewable energy resources. These energy resources are becoming more widely used because they contribute far less to climate change than fossil fuels. All sources of renewable energy have advantages and disadvantages.

Key facts

- ✓ Sources of energy that will never run out are called renewable.
- ✓ Renewable energy resources contribute far less to climate change than fossil fuels.
- ✓ Sources of renewable energy include solar, biofuels, wind, hydroelectric, tidal, wave, and geothermal.

Solar energy

A solar power station uses the Sun's energy to generate electricity. At a concentrated solar power plant, mirrors arranged in circles focus sunlight onto a central receiver, where the heat is used to boil water and make steam, which drives a generator. Electricity can also be produced directly using solar cells (photovoltaic cells). Solar power plants and solar cells work best in sunny climates and can't generate electricity at night.

Biofuels

In some parts of the world, biofuels are used to power cars rather than gasoline or diesel. Biofuels can be made from fast-growing crops like sugar cane. The sugar is fermented to make ethanol, which can be burned in car engines. Although biofuels contribute less to global warming than fossil fuels, their production takes up land that could be used to grow food and has led to deforestation in tropical areas.

Wind energy

Warmed by the Sun, the air in Earth's atmosphere is continually moving, and this kinetic energy can be captured by wind turbines and used to generate electricity. Wind turbines require suitable weather and must be high above the ground or ocean to work well. Many wind farms are built offshore (in the ocean), where they don't spoil the appearance of natural landscapes.

Hydroelectricity

Hydroelectric dams hold back rivers to form artificial lakes. Water from the lake flows through pipes to turbines at the bottom of the dam. The turbines drive generators, which produce electricity. One disadvantage of hydroelectricity is that the natural habitat of the valley is lost when it's flooded to make the lake.

Wave and tidal energy

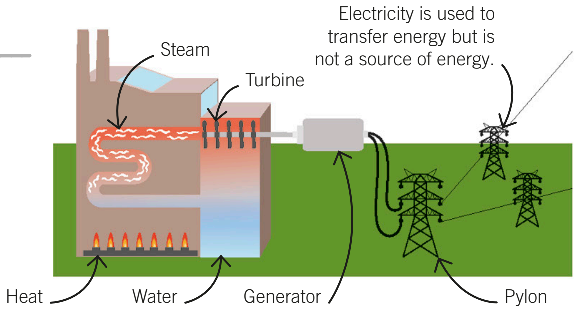
Wave and tidal power stations use the motion of sea water to drive turbines placed in water. Wave power is still experimental. Tidal power stations are difficult and expensive to build but can produce large amounts of electricity at predictable times, though not constantly. One disadvantage is that they can change tidal patterns upstream, affecting the wildlife there.

Geothermal energy

At a geothermal power station, cold water is pumped deep underground, where it is heated to make steam by energy from Earth's interior. The steam is then used to drive electricity generators. Geothermal power stations produce very little pollution but work best in volcanically active places.

Power stations

Most power stations use the same system to generate electricity. Energy from fuels or from the Sun is used to turn water into steam, which flows through pipes and turns spinning fans called turbines. The turbines drive generators, which create electricity. In wind farms, hydroelectric power stations, and wave or tidal power stations, moving water or air turns the turbines directly.



Nonrenewable energy

The modern world uses a lot of energy to power everything from cars and planes to the gadgets in our homes. Most of our energy comes from nonrenewable resources (resources that will run out one day), such as fossil fuels.

Key facts

- Nonrenewable energy comes from energy resources that will run out.
- Most of our energy comes from nonrenewable sources.
- Burning fossil fuels pollutes the atmosphere and causes climate change.

Fossil fuels

Fossil fuels formed from the remains of plants and algae that lived in the distant past. For millions of years, these organisms transferred energy from sunlight to stored chemical energy. These fuels are very useful because a small mass of fossil fuel stores a large quantity of energy. However, burning fossil fuels pollutes the atmosphere with carbon dioxide and is the main cause of climate change.

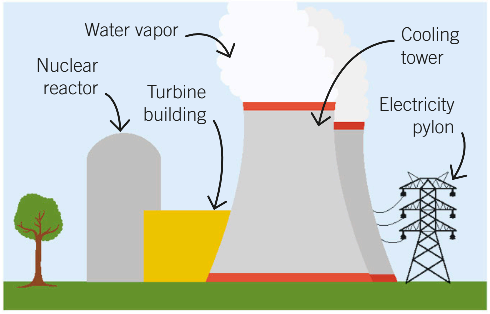
Oil
Oil (petroleum) comes from tiny fossilized sea organisms. Crude oil obtained from underground is used to make gasoline, diesel, and kerosene (a liquid fuel used to power jet engines in aircraft). These fuels are very convenient to store, transport, refill tanks, and burn in engines.

Coal
This solid fuel formed from the fossilized remains of trees and other plants. Coal is burned in power stations and generates much of the world's electricity. As well as producing carbon dioxide when it burns, it produces a pollutant called sulfur dioxide, which causes acid rain.

Natural gas
Natural gas is burned in power stations to make electricity and in homes to power central heating systems or cook food. It transfers about twice as much energy per kilogram as coal, which means it releases only half as much carbon dioxide when burned, causing less pollution.

Nuclear power

Nuclear power stations use the energy stored in the atomic nuclei of radioactive elements such as uranium. Nuclear fuels are nonrenewable, but they store huge amounts of energy and do not emit greenhouse gases such as carbon dioxide. Disadvantages of nuclear power include the production of radioactive waste that remains harmful for thousands of years and requires burial deep underground and the risk of widespread contamination of the environment if there is an accident.



Climate change

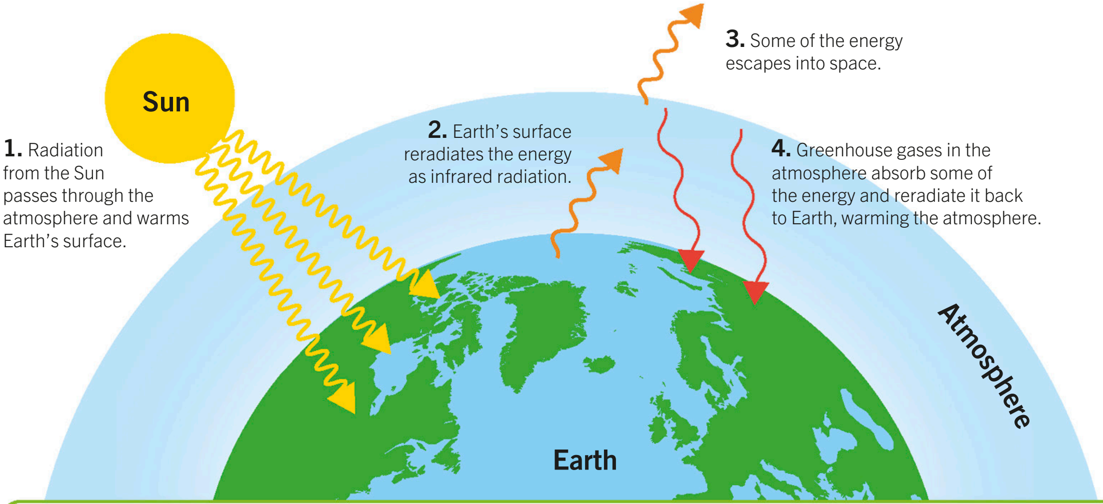
Much of the energy we use comes from fossil fuels, which release carbon dioxide gas (CO_2) when we burn them. CO_2 is a greenhouse gas—it traps heat in Earth's atmosphere. As atmospheric levels of CO_2 have risen, the planet's climate has changed.

Key facts

- ✓ The use of fossil fuels as an energy resource releases carbon dioxide (CO_2) into the atmosphere.
- ✓ Rising levels of atmospheric CO_2 and other greenhouse gases cause climate change through the greenhouse effect.

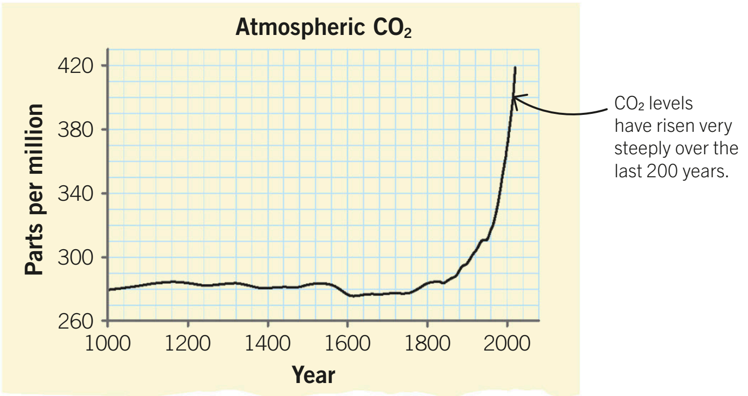
The greenhouse effect

The main cause of climate change is pollution of the atmosphere with greenhouse gases, such as CO_2 from fossil fuels and methane from agriculture. These gases absorb heat radiated from Earth's surface and reradiate it into the air, making the atmosphere warmer (much as glass traps warmth in a greenhouse). Without any greenhouse effect, Earth would be too cold for most life. However, human activity is making the effect too strong.



Atmospheric CO_2

Measurements of CO_2 levels in the atmosphere show they are currently rising steeply. Levels of CO_2 in the distant past can also be measured by sampling bubbles of air trapped in ancient ice sheets. These studies show that CO_2 levels were stable until about 200 years ago, when the use of fossil fuels began rising rapidly.



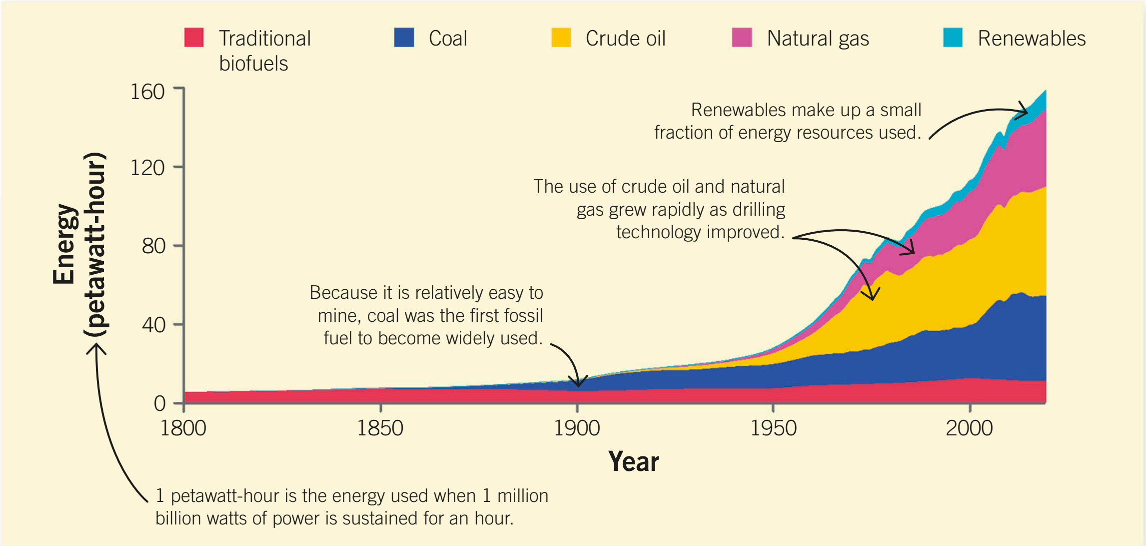
Trends in energy use

Our consumption of energy resources—especially fossil fuels—has increased dramatically in the last 200 years. Because fossil fuels are nonrenewable and harm the environment, many countries are now trying to increase their use of renewable energy instead.

Key facts

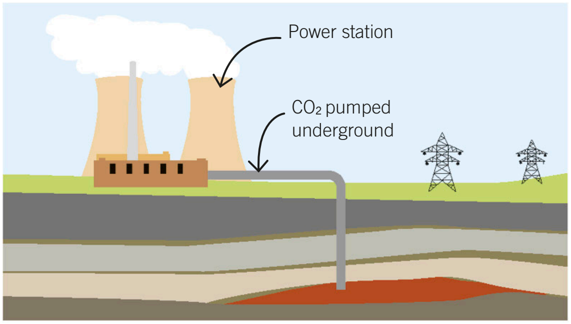
- ✓ The use of fossil fuels has increased dramatically in the last 200 years.
- ✓ The use of fossil fuels is one of the causes of climate change.
- ✓ Many countries are now trying to reduce their use of fossil fuels and increase their use of renewable energy.

Energy consumption
The graph shows how consumption of different energy resources has grown since the year 1800, when the world was starting to industrialize. The rise in the use of fossil fuels has caused a rise in the level of carbon dioxide in the atmosphere—the main cause of climate change.



Carbon capture and storage

Carbon dioxide released when fossil fuels are burned is the main cause of climate change. One idea proposed to reduce emissions is carbon capture. The carbon dioxide in waste gases from power stations is made to react with chemicals called amines to form a liquid that can be stored underground. Power stations could cut emissions by 90 percent this way, but the electricity they produce would be more expensive.



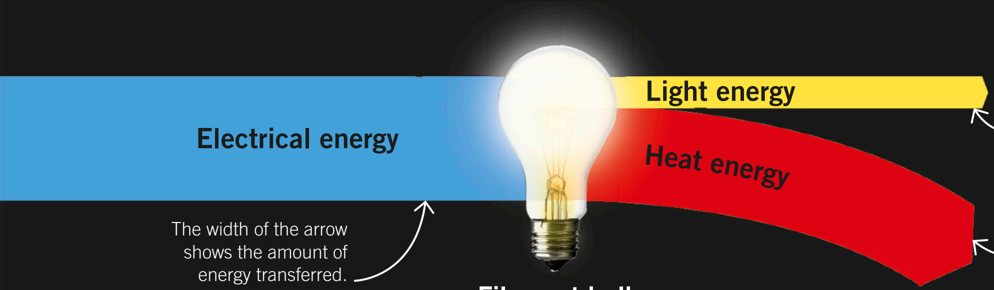
Efficiency

When you turn on a light, not all the energy is transferred to the surroundings by light—some of it is transferred to the air by heating. This is wasted energy. An efficient device is one that wastes only a small percentage of the energy it transfers.

Key facts

- ✓ An efficient device wastes only a small percentage of the energy it transfers usefully.
- ✓ Sankey diagrams show efficiency.
- ✓ Energy-efficient devices help reduce our consumption of energy.

Sankey diagrams
We can show how efficient a device is with a Sankey diagram. The diagrams here show that old-fashioned filament light bulbs have very low efficiency because most of the energy is transferred to the surroundings as heat. In contrast, an LED light bulb transfers most of its electrical energy to light and wastes only a small amount as heat.



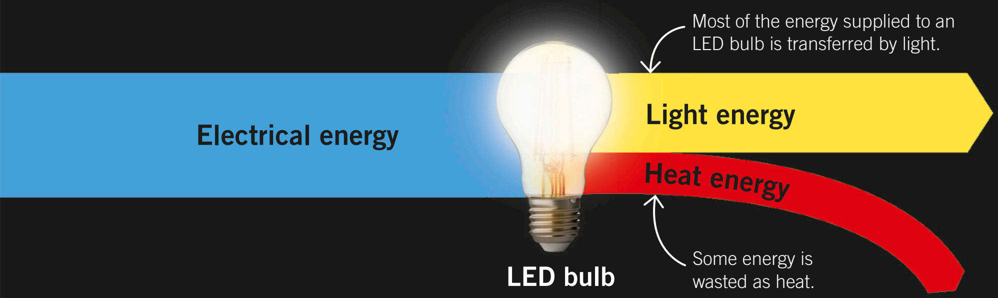
The width of the arrow shows the amount of energy transferred.

This thin arrow shows that only a small amount of energy is transferred by light.

The large arrow shows that most of the energy is wasted as heat.

Filament bulb

Most of the energy supplied to an LED bulb is transferred by light.



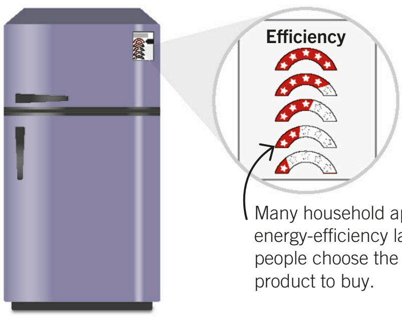
LED bulb

Some energy is wasted as heat.

The total amount of energy transferred away from the bulb is the same as the amount transferred to it.

Improving efficiency

All machines and devices waste energy, and that wasted energy ultimately escapes to the surroundings as heat. For example, bicycles waste energy through friction between moving parts. This can be reduced by keeping the chain and other moving parts lubricated. By using energy-efficient electrical devices in our homes, we can reduce how much energy we waste and so reduce our consumption of fossil fuels, which is good for the environment.



Many household appliances have energy-efficiency labels that help people choose the most efficient product to buy.

Heat transfers

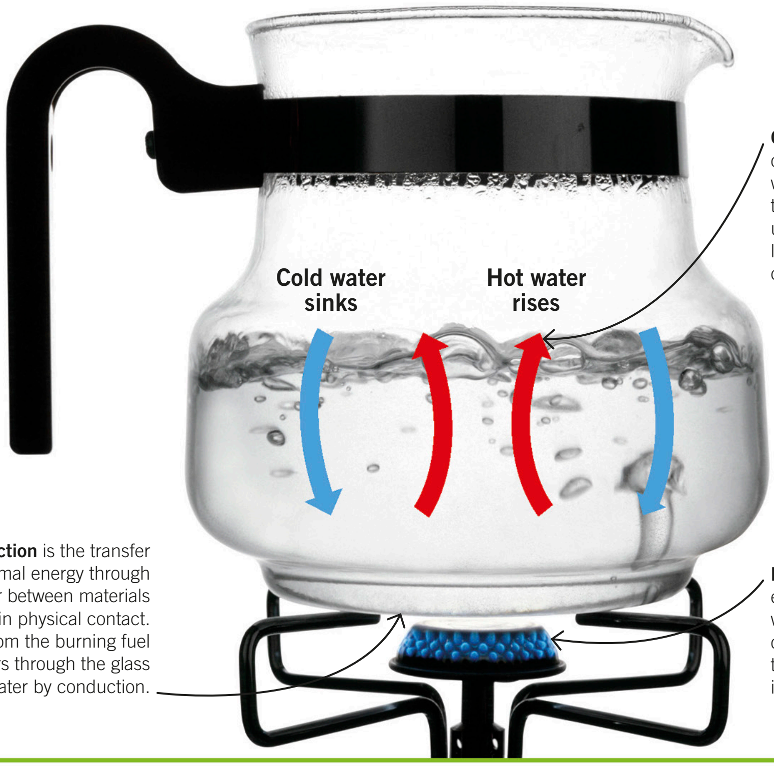
Why do hot drinks cool down? Stores of thermal energy (heat) never stay in one place—the energy always transfers from hot things to colder things. These transfers can happen in different ways.

Key facts

- ✓ Heat always transfers from hot objects to colder objects until they are at the same temperature (thermal equilibrium).
- ✓ Thermal energy is transferred in three ways: by conduction, convection, and radiation.

Heating water

When water is heated on a gas stove, energy is transferred in three ways: by conduction, convection, and radiation.



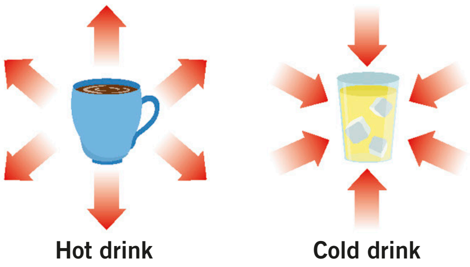
Convection is the transfer of heat by currents moving within a fluid. As water in the bottom of the pitcher heats up, it expands and becomes less dense. This makes it rise, creating convection currents.

Conduction is the transfer of thermal energy through solids or between materials that are in physical contact. Heat from the burning fuel transfers through the glass to the water by conduction.

Radiation is the transfer of energy by electromagnetic waves, which travel at the speed of light. As well as emitting light that we can see, the flames emit infrared radiation.

Thermal equilibrium

If you leave a hot drink standing, it will cool down until it's the same temperature as its surroundings. Similarly, a cold drink will warm up. This is because energy continually transfers from hotter objects to colder objects until they are at the same temperature as each other. When that happens, we say that they are in thermal equilibrium.



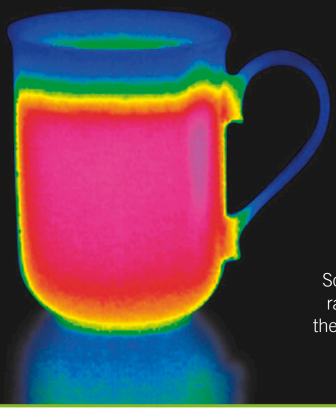
Radiation

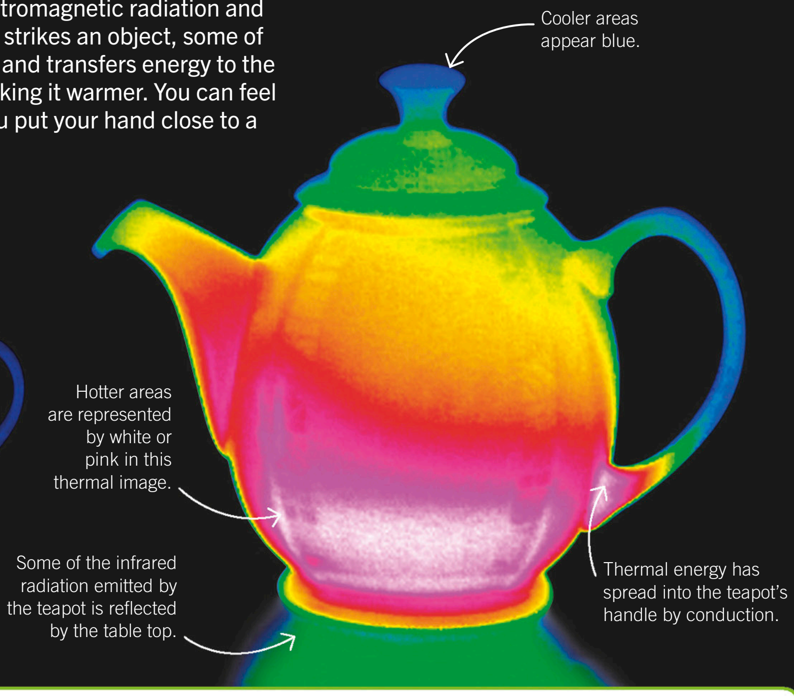
When you put your hand near a hot teapot, you can feel its heat warm your skin. That's because your skin can sense something your eyes can't see: infrared radiation. All objects emit infrared radiation, but the hotter an object is, the more radiation it gives out.

Key facts

- ✓ Hotter objects emit more infrared radiation than cooler objects.
- ✓ When infrared radiation strikes an object, it transfers energy to its thermal energy store.
- ✓ Matte black surfaces are better at absorbing and emitting infrared radiation than shiny or white surfaces.

Thermal images
Although infrared radiation is invisible to our eyes, thermal cameras can detect it. This thermal image shows the radiation emitted by hot tea in a cup and a teapot. Like visible light, infrared radiation is a form of electromagnetic radiation and can travel through space. When it strikes an object, some of the infrared radiation is absorbed and transfers energy to the object's thermal energy store, making it warmer. You can feel this warmth on your skin when you put your hand close to a hot cup without touching it.

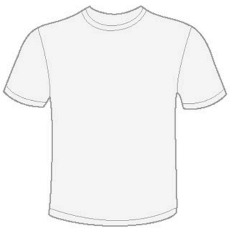




Absorbers and reflectors

The amount of energy an object absorbs from infrared radiation depends on the color and texture of its surface. Matte (nonshiny) and black surfaces are good at absorbing and emitting infrared radiation. White or shiny objects, however, reflect radiation, so they absorb relatively little thermal energy.

Black absorbs and emits infrared radiation well



White reflects infrared radiation well

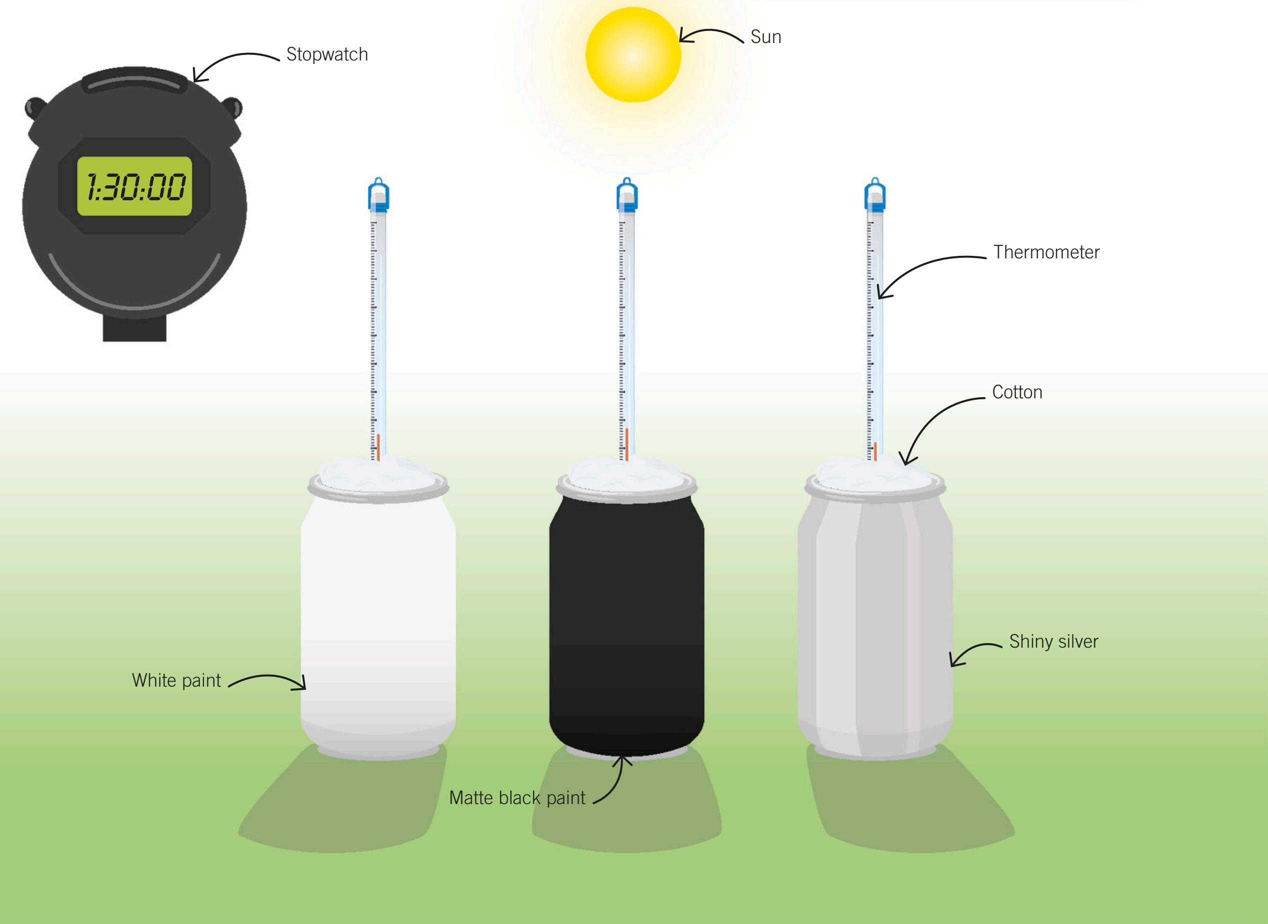
Investigating radiation

This experiment allows you to compare the rates at which black, white, and shiny surfaces absorb infrared radiation. You can also use the same equipment to investigate how different surfaces emit radiation.

Absorbing radiation
Infrared radiation from the Sun transfers energy to the cans, heating the water inside them. Matte black surfaces absorb more infrared radiation than white or shiny surfaces, so the water in the black can should heat up the fastest.

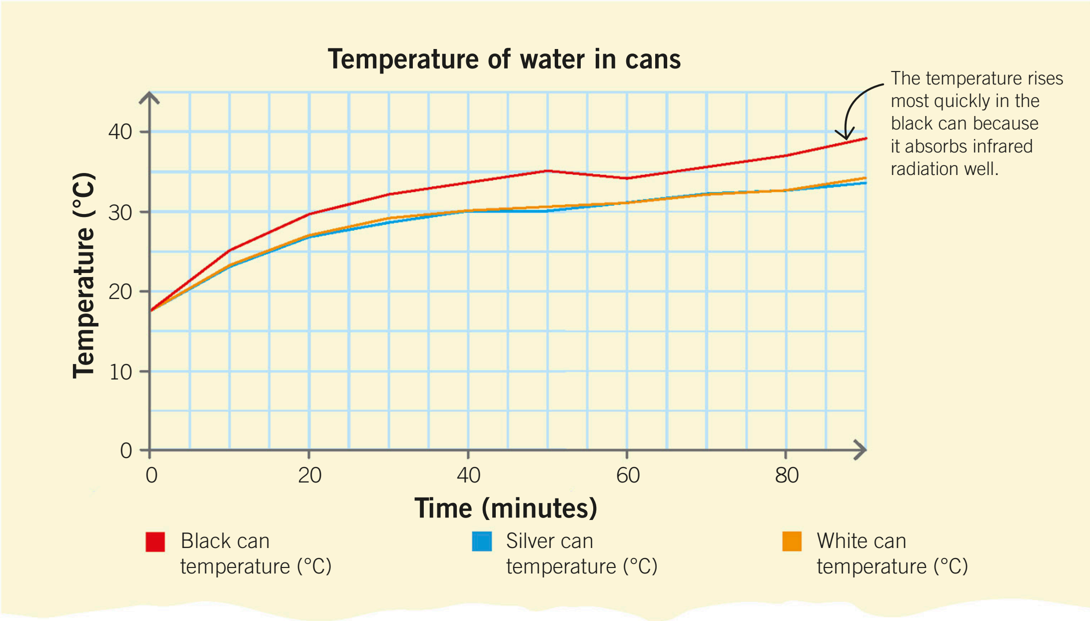
Method

1. Empty and rinse three drink cans or food cans. Paint one can matte black, another white, and the third shiny silver. The color of the can is the independent variable in this experiment.
2. Pour an equal amount of cold water into each can. Insert a thermometer and put some cotton around it to reduce loss of heat.
3. Place the cans outside on a sunny day. The quantity of water in the cans and the amount of heat they receive from the Sun are both control variables.
4. Note the temperature of the water in each can. Temperature is the dependent variable in the experiment.
5. Leave the cans in the Sun for 90 minutes, and record the temperature of the water every 10 minutes.



Results

Record your data in a table and then plot the results on a graph. The graph shows that the temperature rises quickly in all three cans but climbs fastest and highest in the black can. The silver and white cans show similar results.

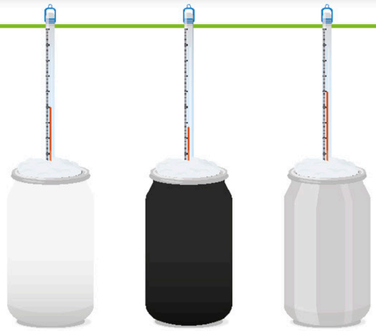


Conclusion

The black can absorbed more radiation than the silver and white ones. The only difference between the cans was color, so this means black absorbs radiation more easily than white or silver. The temperature of the water in the cans did not rise steadily. This might be because there was a breeze or a cloud passing in front of the Sun. The temperature and radiation reaching the cans could be controlled more easily indoors by using a heat lamp instead of the Sun.

Emitting radiation

You can use the same equipment to investigate how hot objects lose energy by radiation to their surroundings. This experiment is much quicker, so use one can at a time. Fill the first can with exactly 300 ml of water heated to 50°C, insert a thermometer, and put some cotton around it. Wait for the temperature to reach 45°C, then record the temperature every 30 seconds for 10 minutes. Repeat with the other two cans, making sure the room temperature stays the same, and show your results on a graph.



Conduction

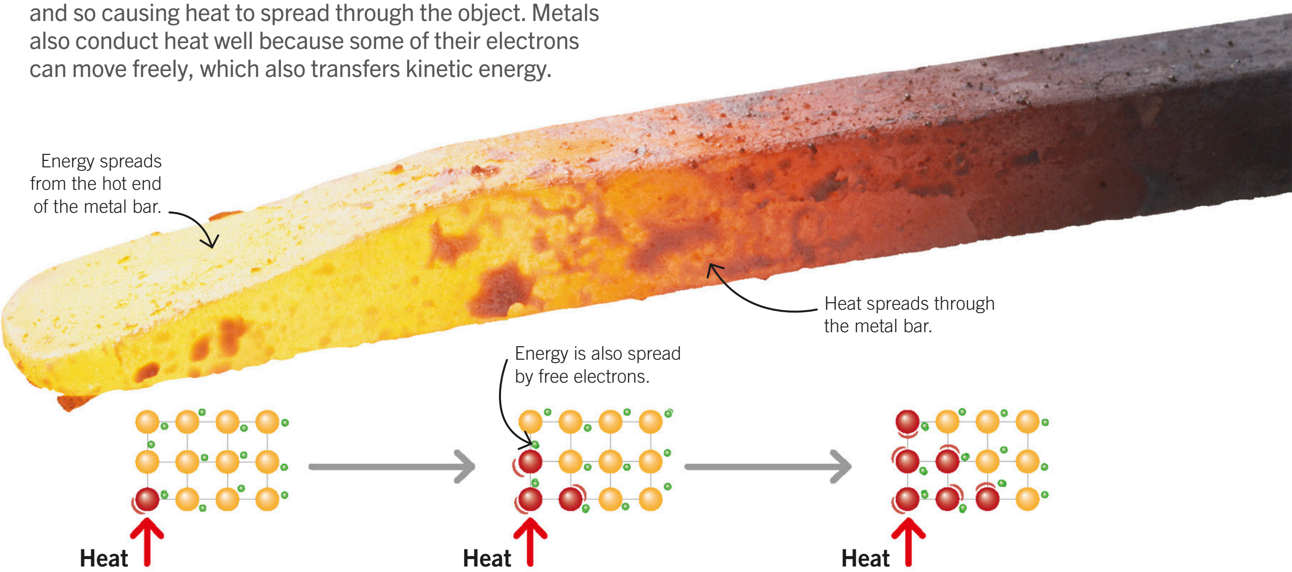
Metal objects often feel cold to the touch because metals are good at transferring energy away from your body. The spread of thermal energy through physical contact is called conduction.

Key facts

- ✓ Conduction is the transfer of energy by touch.
- ✓ Metals are good thermal conductors because the particles are arranged in a lattice and because electrons can move freely.
- ✓ Materials that are poor thermal conductors are called insulators.

Conduction in metals

When a metal bar is heated, the extra energy makes the particles vibrate more. Because the particles in metals are arranged in a tight lattice, vibrations spread from particles to their neighbors, transferring kinetic energy and so causing heat to spread through the object. Metals also conduct heat well because some of their electrons can move freely, which also transfers kinetic energy.



1. Heating transfers energy to the particles' kinetic energy stores.

2. The particles vibrate, which causes neighboring particles to vibrate, too.

3. Energy continues to spread along the metal bar.

Conductors and insulators

Solids that are dense and crystalline, such as metals, are good thermal conductors because the particles are packed tightly and locked in a lattice, which helps them transfer energy to their neighbors. In contrast, air is a very poor thermal conductor because the particles are far apart. Materials that contain trapped air, such as wool sweaters and foam coffee cups, are also poor conductors. We call these materials insulators and use them to slow the transfer of thermal energy. One of the best insulators is aerogel, a silicon-based insulator that is more than 99 percent air.

Aerogel blocks heat from a flame

Investigating insulators

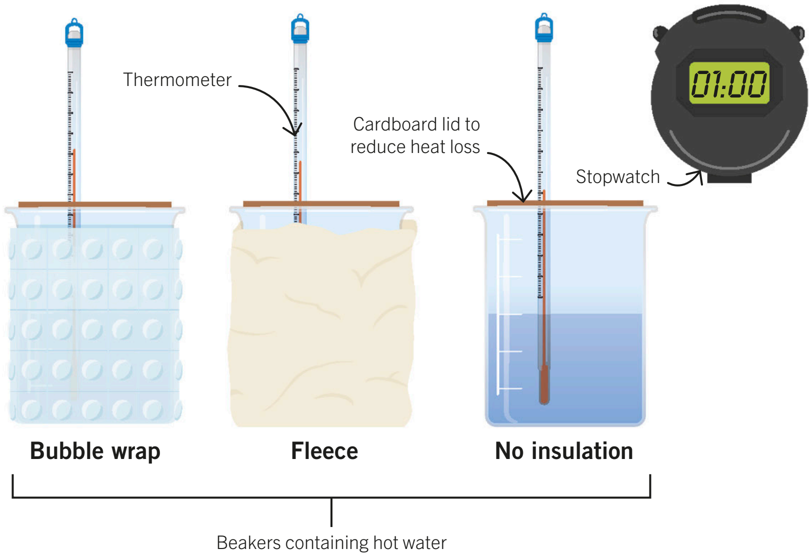
Some materials, like metals, conduct thermal energy well. Other materials are poor conductors (good insulators). These materials can be used to reduce the energy transferred from a hot object to its surroundings or to keep something cool by reducing the transfer of energy into it.

Method

1. Set up the apparatus as shown below. All the beakers must be the same size, and you should try to keep the thickness of the insulation the same.
2. When you're ready to start, pour the same volume of hot water from a tea kettle into each beaker. Put the thermometers in and start the stopwatch.
3. Write down the starting temperatures, then record the temperature of the water in each beaker every minute for 10 minutes.

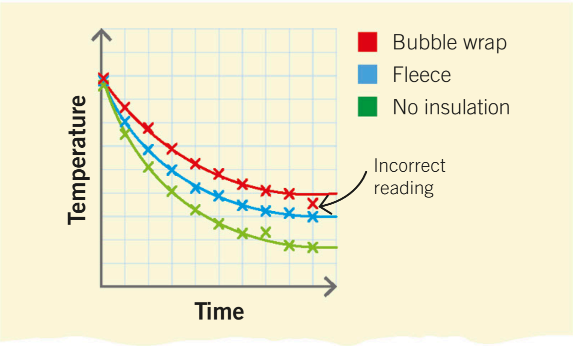
Investigating insulation
You can test the insulating properties of different materials by using them to insulate beakers of hot water. The best insulator is the one that keeps the water warm the longest. You also need to measure how quickly the temperature falls with no insulation.

Teacher supervision required



Results

Plot the data for all three beakers on the same graph. Draw a smooth curve through the points for each beaker. The graph should show that both the bubble wrap and the fleece kept the water warmer than having no insulation and that bubble wrap was best at keeping the water hot. You could have carried out this investigation more simply by recording just the start and end temperatures. However, if you'd also made an incorrect final reading like the one in this graph, you might then have wrongly concluded that bubble wrap has the same insulating properties as fleece.



Convection

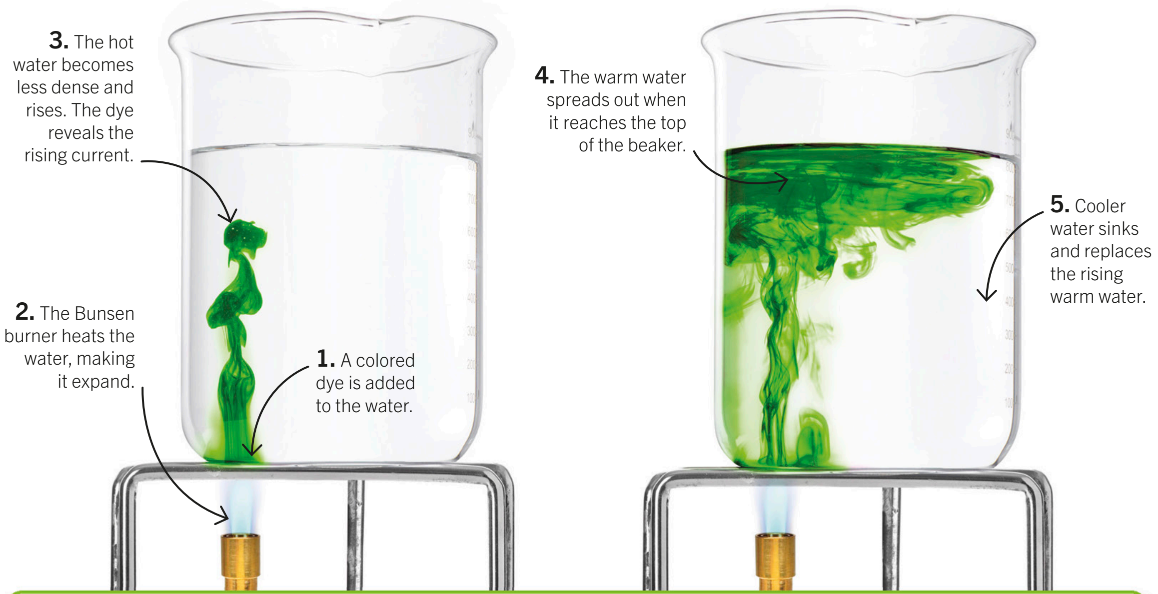
Convection is the transfer of thermal energy by currents moving in a fluid (a liquid or a gas). When a region of air or water is heated, it becomes less dense than the surrounding fluid and rises, creating a convection current.

Key facts

- ✓ Convection is the transfer of heat by currents moving in a fluid.
- ✓ Convection occurs because heating makes parts of a fluid less dense than the surrounding fluid.
- ✓ Thermals are rising columns of warm air produced by convection.

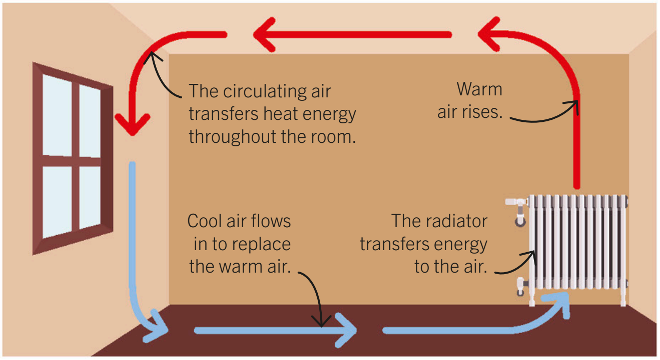
Convection in water

We can watch convection happen by adding a colored dye to water before heating it. In the experiment shown here, the dye is placed at the bottom of the beaker and gradually dissolves. When the water over the flame is heated, it becomes less dense than the surrounding water and rises.



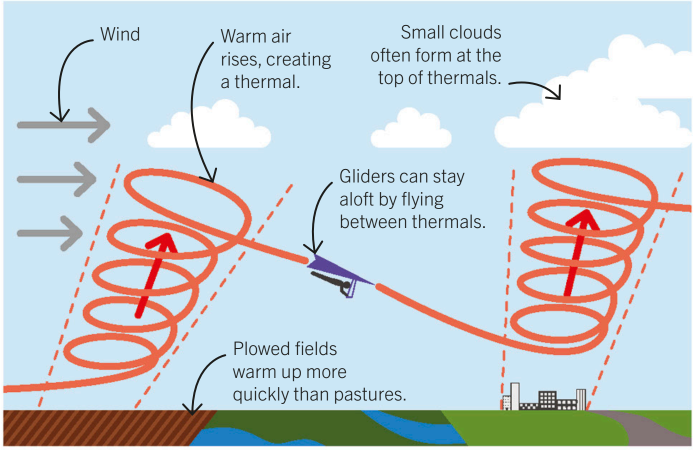
How radiators work

Modern central heating systems use convection to heat the air inside houses. Hot water in radiators transfers energy to the air, which warms and becomes less dense. The warm air rises and cooler air replaces it. Eventually, the warm air cools and sinks back down, completing the cycle. This circulation of air is a convection current.



How thermals work

Roads, buildings, and areas of darker ground (such as plowed fields) heat up more quickly in the Sun than areas of vegetation. They transfer energy to the air above them, creating rising columns of warm air called thermals, which are often topped by fluffy white cumulus clouds. Gliders can stay airborne for long periods by circling in a thermal to climb and then following the clouds to find another thermal.



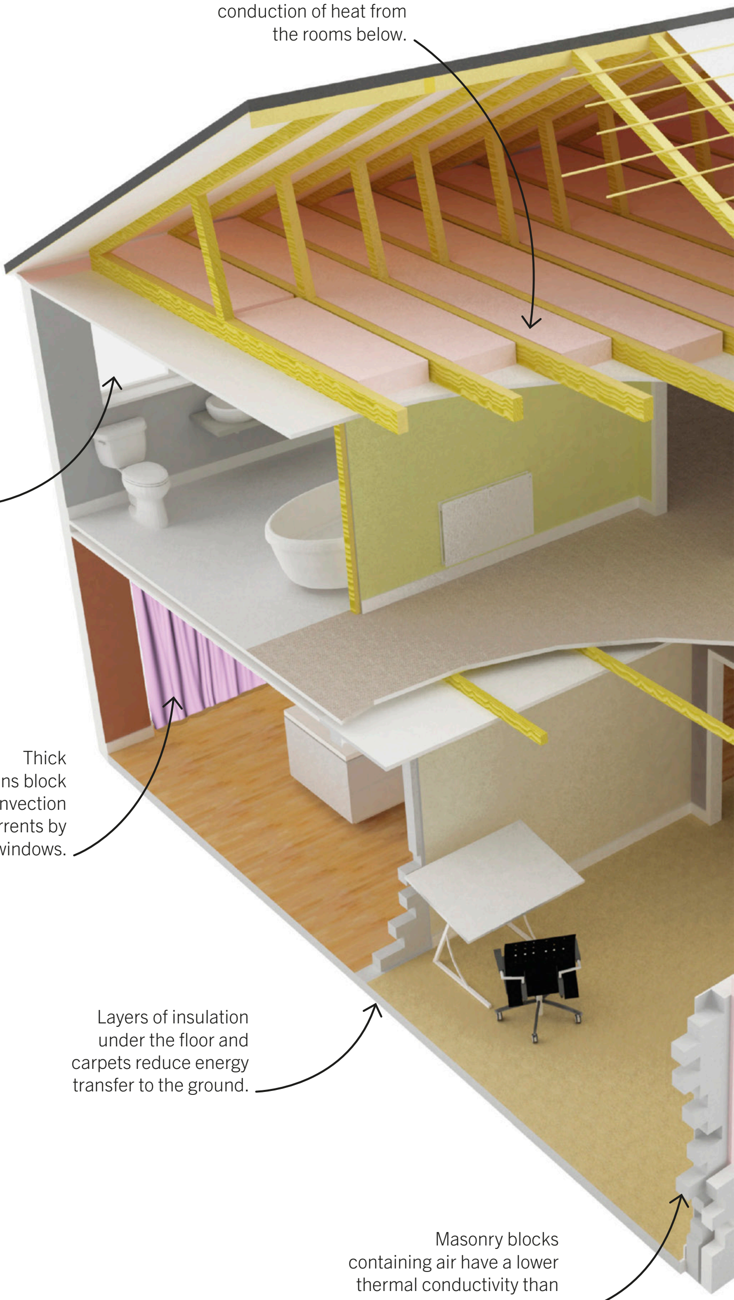
Thermals
This hang-glider needs no engine to stay airborne. It gets all the lift it needs from thermals—convection currents rising from the sun-warmed ground.

Reducing energy transfers

Heating a house can be expensive, so modern buildings are designed to minimize the transfer of energy to their surroundings. Well-insulated buildings also reduce our need for fossil fuels to supply energy for heating.

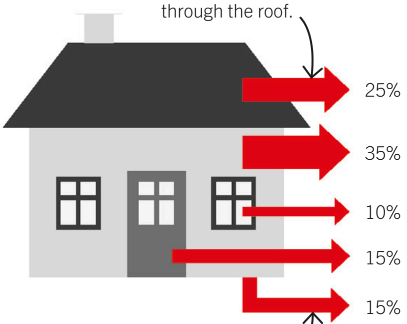
Insulating houses

Houses can transfer heat to the environment by conduction, convection, and radiation, so designers of modern buildings aim to reduce all three. Good insulation not only helps keep houses warm in winter, but keeps them cooler in summer, making them more comfortable.



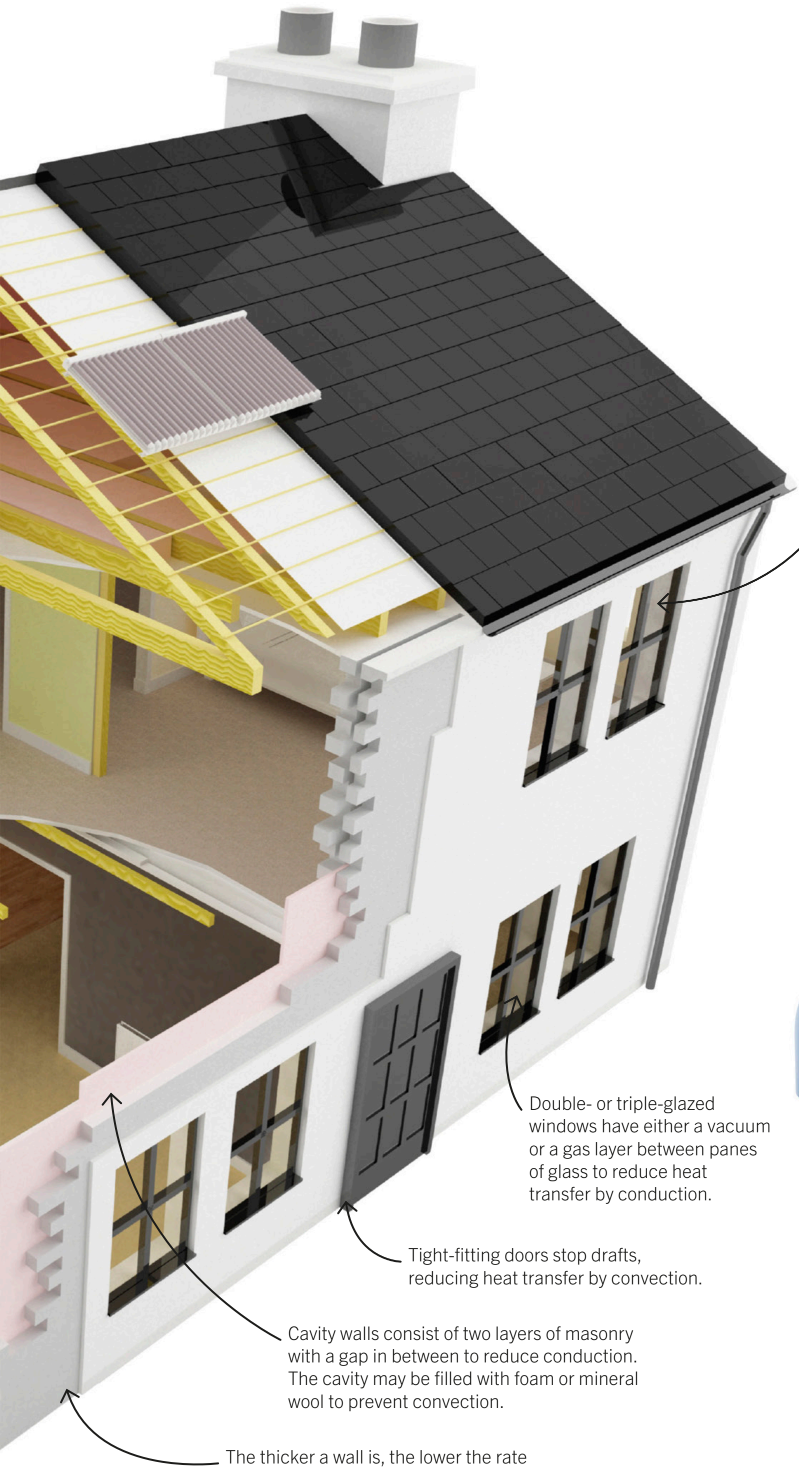
Heat loss

A house usually loses most of its energy through the roof and walls, but heat is also lost through windows, doors, and the ground. The greater the difference in temperature between the inside and outside of the house, the faster the rate of energy loss.



Key facts

- ✓ **Energy can be transferred from the inside of a house to its surroundings by conduction, convection, and radiation.**
- ✓ **Good insulation reduces heating bills and reduces the use of fossil fuels.**



Vacuum flask

Vacuum flasks were invented by Scottish chemist James Dewar in 1892 to keep chemicals cold, but today we use them more often to keep hot drinks hot. The inner flask has a double wall made of glass or aluminum with a vacuum between the two walls, which reduces transfer of energy by conduction or convection. The silvery inner surface also reflects radiation.

Kinetic and potential energy

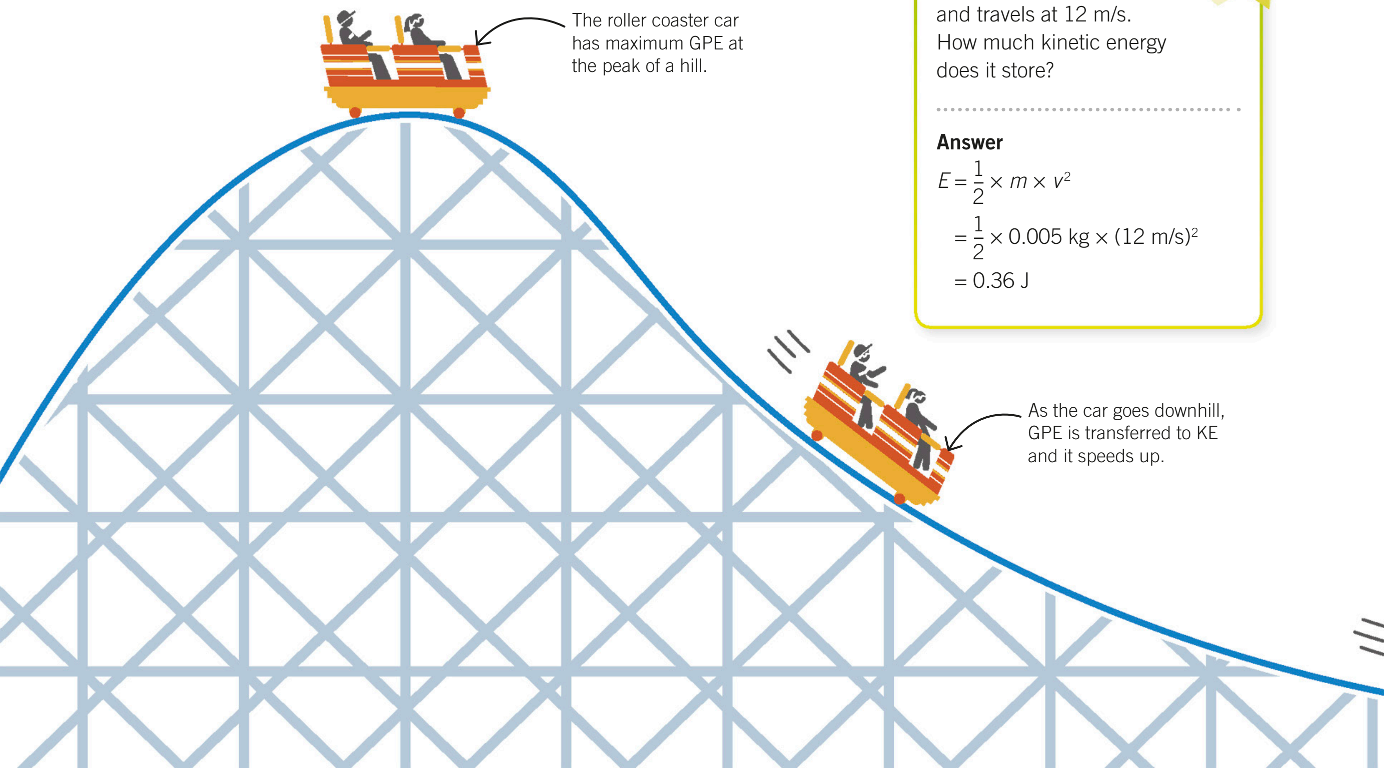
As a roller coaster races up and down, energy is transferred back and forth between its stores of kinetic energy (KE) and gravitational potential energy (GPE). The equations on these pages show you how to calculate both quantities.

Kinetic energy

A moving object stores kinetic energy. When it speeds up, energy is transferred to this store, and when it slows down, energy is transferred away. The faster the object moves, or the greater its mass, the greater its store of kinetic energy. The equation here shows how to calculate kinetic energy.

$$\text{kinetic energy (J)} = \frac{1}{2} \times \text{mass (kg)} \times \text{speed}^2\ (\text{m/s})^2$$

$$E_k = \frac{1}{2} \times m \times v^2$$



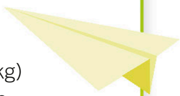
Key facts

- ✓ The faster an object moves, or the greater its mass, the greater its store of kinetic energy (KE).
- ✓ The higher an object is, or the greater its mass, the greater its store of gravitational potential energy (GPE).
- ✓ When a roller coaster accelerates downhill, energy is transferred from its store of GPE to its store of KE.

Calculating kinetic energy

Question

A paper plane has a mass of 5 g (0.005 kg) and travels at 12 m/s. How much kinetic energy does it store?



Answer

$$E = \frac{1}{2} \times m \times v^2$$

$$= \frac{1}{2} \times 0.005 \text{ kg} \times (12 \text{ m/s})^2$$

$$= 0.36 \text{ J}$$

Gravitational potential energy

When you raise an object, the lifting force does work and transfers energy to the object's store of gravitational potential energy (GPE). The higher an object is or the greater its mass, the greater its store of GPE. This equation shows how to calculate the change in an object's GPE from a change in its height.

On Earth, this figure is approximately 10 N/kg. On the Moon, it would be about a sixth of this figure.

$$\text{change in GPE (J)} = \text{mass (kg)} \times \text{gravitational field strength (N/kg)} \times \text{change in height (m)}$$

$$\Delta GPE = m \times g \times \Delta h$$

The Greek letter delta means "change in."

Calculating GPE

Question

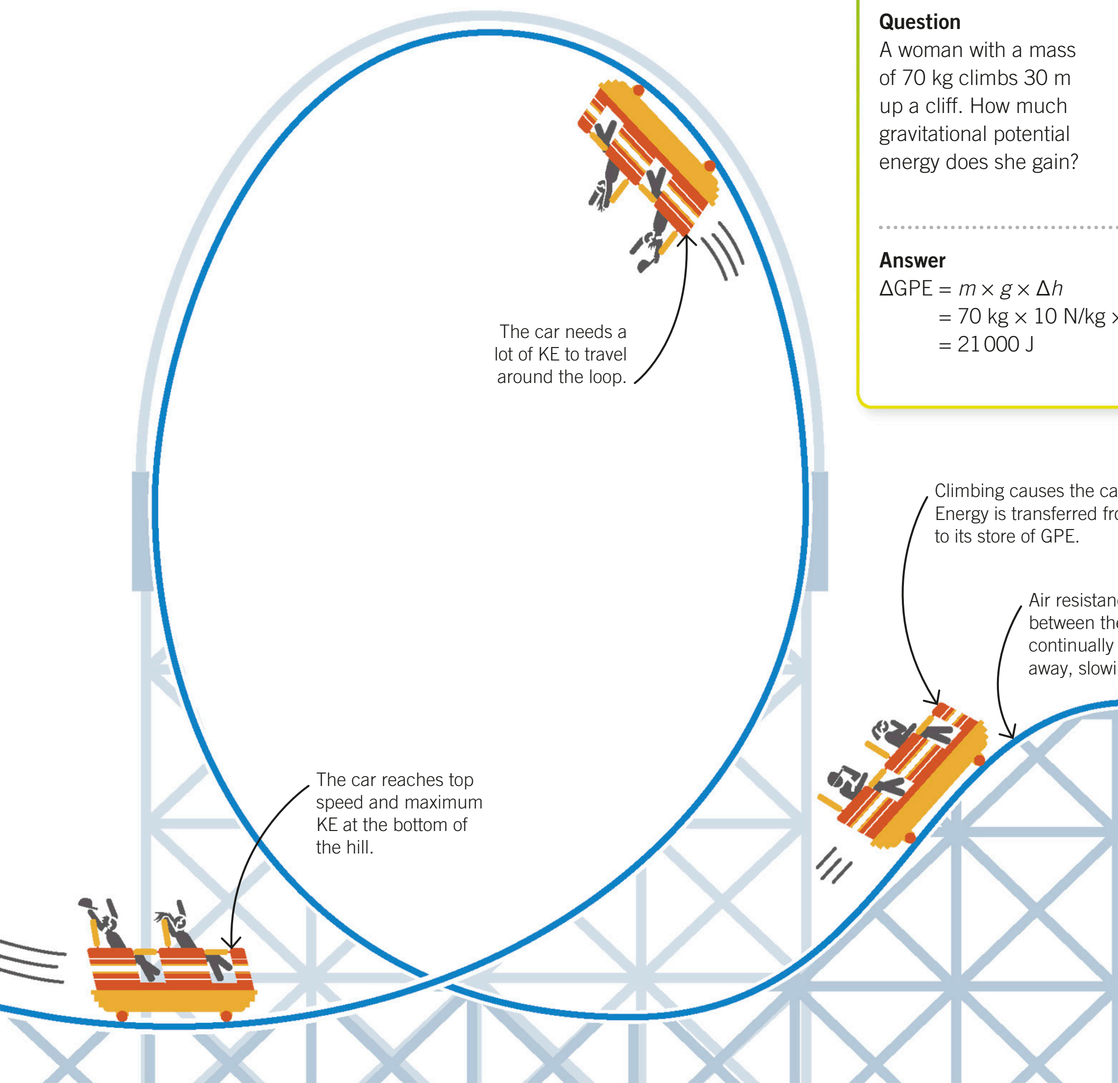
A woman with a mass of 70 kg climbs 30 m up a cliff. How much gravitational potential energy does she gain?

Answer

$\Delta GPE = m \times g \times \Delta h$

$= 70 \text{ kg} \times 10 \text{ N/kg} \times 30 \text{ m}$

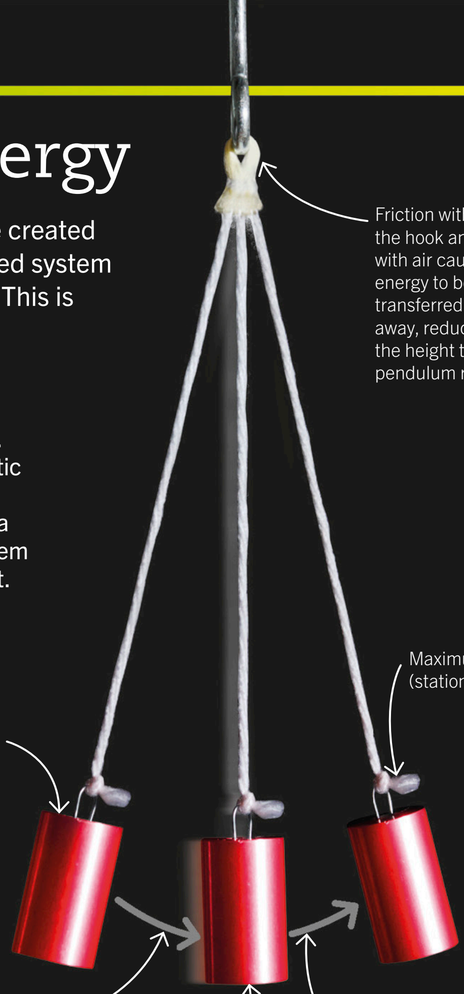
$= 21\,000 \text{ J}$



Conservation of energy

Energy can be transferred or stored, but it cannot be created or destroyed. The total amount of energy in an isolated system remains the same before and after energy transfers. This is known as the law of conservation of energy.

Energy transfers in a pendulum
A pendulum is a mass suspended freely from a fixed point. Energy is transferred between the pendulum's store of kinetic energy (KE) and its store of gravitational potential energy (GPE). The pendulum, hook, and air make up what we call a system. The total amount of energy within an isolated system (one that energy does not enter or leave) remains constant.

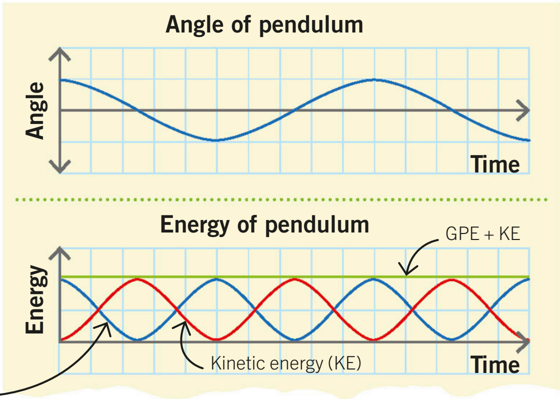


Key facts

- ✓ Energy can be transferred or stored, but it cannot be created or destroyed.
- ✓ The total amount of energy within an isolated system remains the same before and after energy transfers.
- ✓ As a pendulum swings, energy is transferred between its stores of kinetic energy and gravitational potential energy.

Harmonic motion

The pendulum's repetitive, back-and-forth movement is known as simple harmonic motion. Each swing takes exactly the same length of time, which is why pendulums are used as timekeepers in mechanical clocks. When the pendulum's angle of swing is plotted on the y-axis of a graph against time, it shows a pattern called a sine wave. Plotting GPE and KE on a graph also produces sine waves. When added, these form a straight line, showing that energy is transferred between them but conserved.



Transferring energy by forces

It takes energy to power a car, make a plane fly, or ride a bike. The energy transferred when a force moves an object is called work.

Key facts

- ✓ The energy transferred when a force moves an object is called work.
- ✓ As work done is a measure of energy, the units are joules (J).
- ✓ Work done equals force multiplied by distance moved in the direction of the force.

Work done

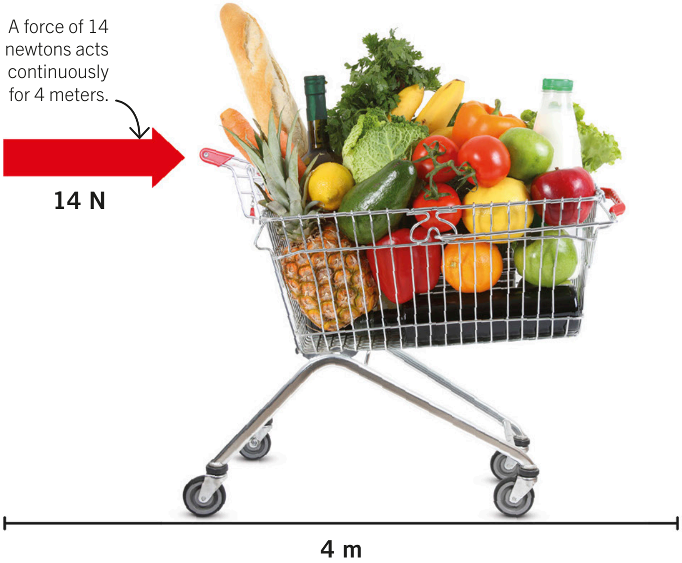
The scientific meaning of "work" is different from its everyday meaning. When you push an object, the force does work to move it and transfers energy from your body to the object's kinetic energy store. As work done is a measure of energy, the units are joules (J). You can work out the total energy transferred by multiplying the force by the distance moved in the direction of the force.

$$\text{work (J)} = \text{force (N)} \times \text{distance (m)}$$

$$W = F \times d$$

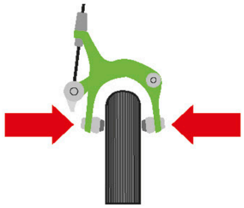
For instance, if you push a loaded shopping cart for 4 m with a continuous force of 14 N, you've done 56 J of work.

$$\begin{aligned} W &= F \times d \\ &= 14\ \text{N} \times 4\ \text{m} \\ &= 56\ \text{J} \end{aligned}$$



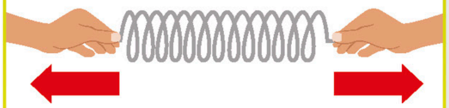
Examples of work

Work is done whenever energy is transferred.



When you pull the brakes on a bike, the force of friction between the brakes and wheel does negative work. Friction transfers energy from the bike's kinetic energy store to thermal energy, making the bike slow down.

When you drop a ball, the force of gravity does work and energy is transferred to the ball's kinetic energy store, making it accelerate.



When you stretch a spring, the force transfers energy to the spring's store of elastic potential energy. The force needed increases as the spring gets harder to stretch (see page 82).

Energy and power

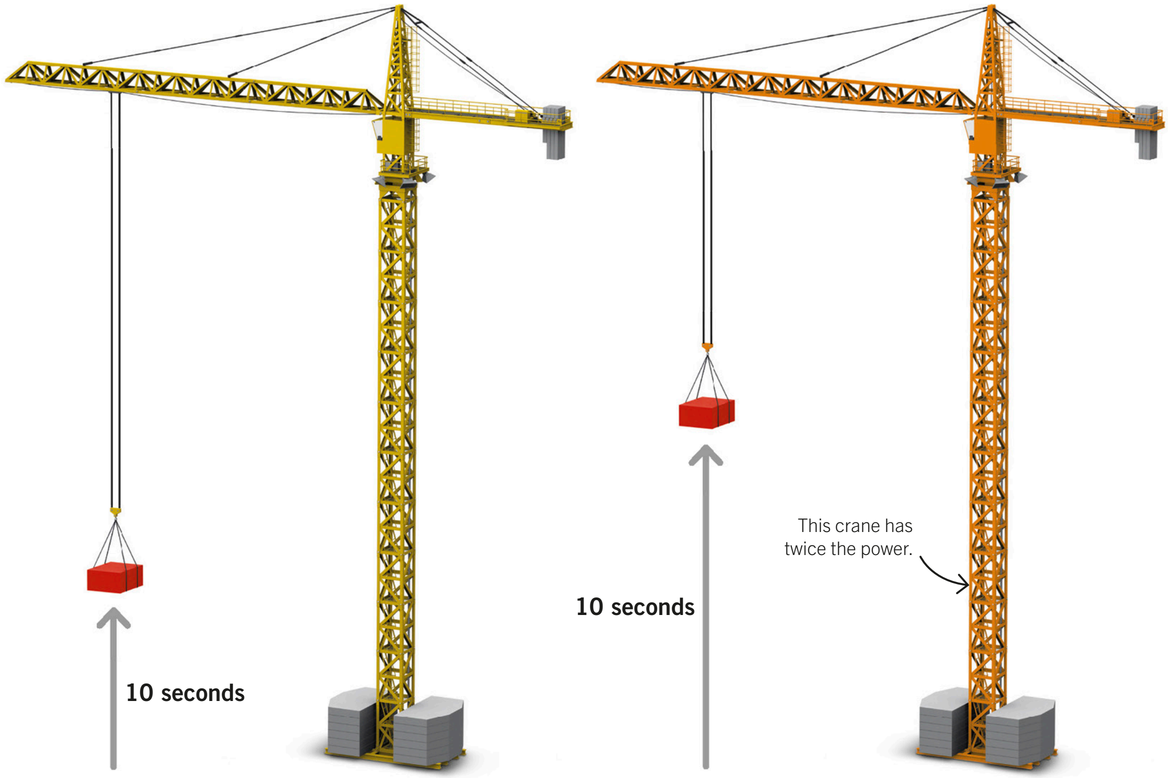
Power is a measure of how quickly energy is transferred (how quickly work is done). The more energy transferred per second, the greater the power.

Key facts

- ✓ Power is a measure of how quickly energy is transferred (how quickly work is done).
- ✓ Power = energy transferred ÷ time taken.
- ✓ We measure power in watts (W). 1 W = 1 J/s.

Lifting power

Two cranes use motorized pulleys to lift heavy loads from a ship. Both loads have the same mass, so the same energy is needed to lift them a certain distance. However, the orange crane lifts the cargo to twice the height of the yellow crane in the same time. Its motor has twice the power.



Power equation

The equation here shows how to calculate power. We measure power in units called watts (W). A power of 1 watt means 1 joule of energy is transferred in 1 second.

$$\text{power (W)} = \frac{\text{energy transferred (J)}}{\text{time (s)}}$$

$$P = \frac{E}{t}$$

Calculating power

Question
A boy weighing 400 newtons climbs 2.6 m up a ladder in 4 seconds. Use the formula work = force × distance to calculate how much energy was transferred. What was the boy's power?

Answer
First, calculate energy transferred (work done).

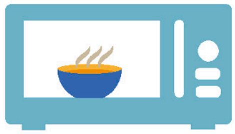
$$E = f \times d$$
$$= 400 \text{ N} \times 2.6 \text{ m}$$
$$= 1040 \text{ J}$$

Then use the power formula to calculate his power.

$$P = \frac{E}{t}$$
$$= \frac{1040 \text{ J}}{4 \text{ s}}$$
$$= 260 \text{ W}$$

Calculating energy

Question
A microwave oven with a power rating of 800 W heats a bowl of soup for 3 minutes. How much energy does it use?



Answer
First, rearrange the power equation to make energy the subject, then put in the numbers. Don't forget to convert minutes to seconds (3 minutes = 180 s).

$$P = \frac{E}{t}$$
$$E = P \times t$$
$$= 800 \text{ W} \times 180 \text{ s}$$
$$= 144\,000 \text{ J}$$

Rocket power
To escape the pull of gravity and reach orbit, massive rockets require engines with up to 60 gigawatts (60 billion watts) of power.

Calculating energy efficiency

Efficient devices are good at transferring energy to useful energy stores. An efficient light bulb, for instance, transfers energy mostly as light rather than wasting it as heat. The efficiency of a device is the percentage of energy transferred usefully.

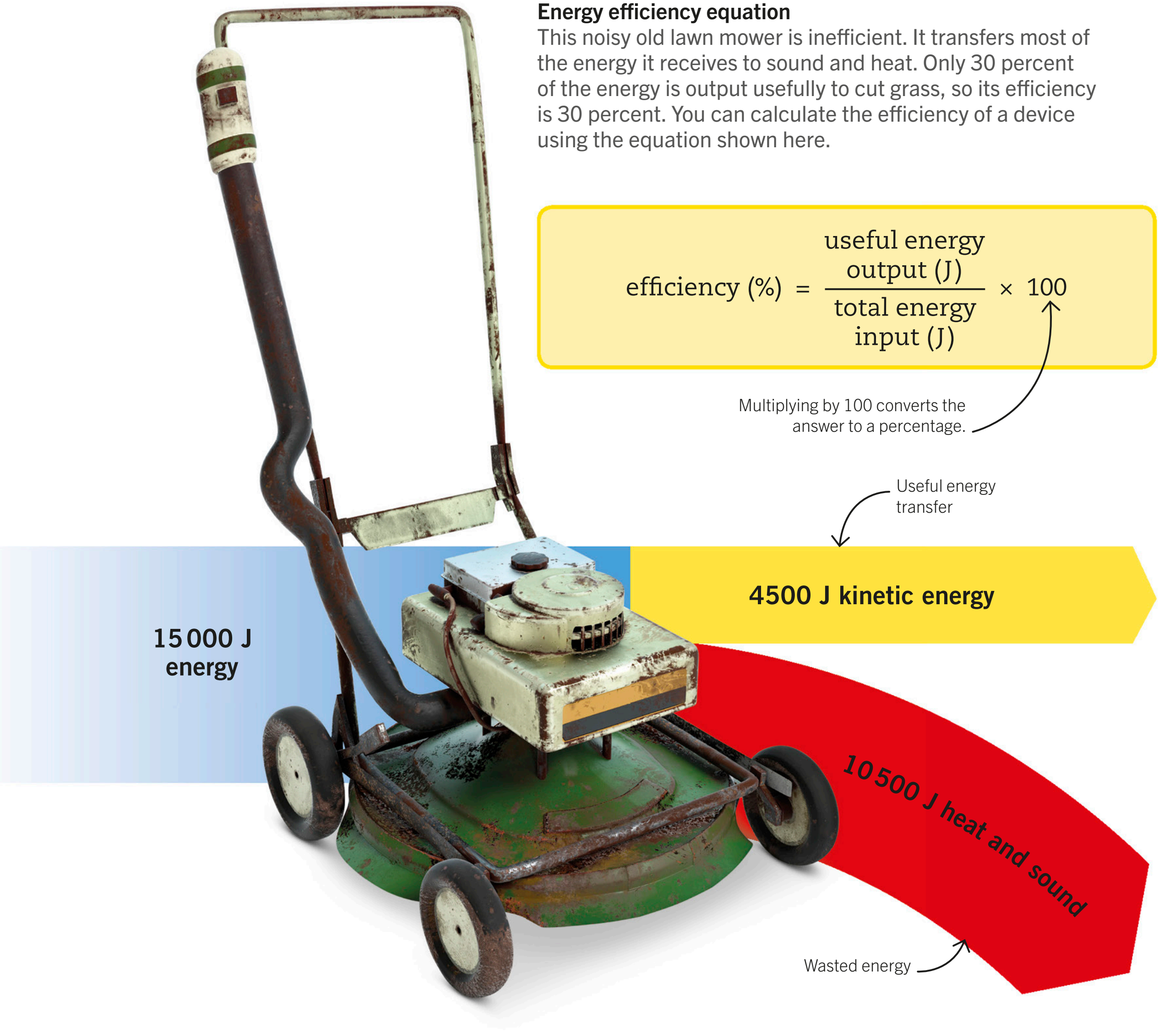
Key facts

- ✓ The efficiency of a device is the percentage of energy transferred usefully.
- ✓ Efficiency can be calculated from either energy or power.

Energy efficiency equation
This noisy old lawn mower is inefficient. It transfers most of the energy it receives to sound and heat. Only 30 percent of the energy is output usefully to cut grass, so its efficiency is 30 percent. You can calculate the efficiency of a device using the equation shown here.

$$\text{efficiency (\%)} = \frac{\text{useful energy output (J)}}{\text{total energy input (J)}} \times 100$$

Multiplying by 100 converts the answer to a percentage.



Efficiency and power

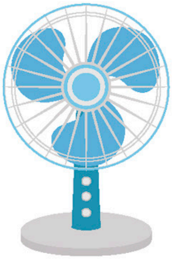
You can also calculate efficiency if you know the total power input and useful power output of a device. Use this equation instead.

$$\text{efficiency (\%)} = \frac{\text{useful power output (W)}}{\text{total power input (W)}} \times 100$$

Efficiency calculations

Question 1

A 75-watt fan runs for 1 minute, transferring 4500 joules of energy. 200 joules is transferred to thermal energy stores, 700 joules is transferred through sound waves, and the rest is transferred to useful kinetic energy stores. What is the efficiency of the fan?



Answer 1

$$\text{Useful energy transfer} = 4500\text{ J} - \underbrace{(200\text{ J} + 700\text{ J})}_{\text{Wasted energy}}$$
$$= 3600\text{ J}$$

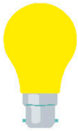
$$\text{Efficiency} = \frac{3600\text{ J}}{4500\text{ J}} \times 100$$
$$= 80\%$$

Total energy transferred

Check your answer makes sense. Nothing can be more than 100% efficient, so your answer must be less than 100.

Question 2

A 5-watt light bulb has an efficiency rating of 60%. What is its useful power output?



Answer 2

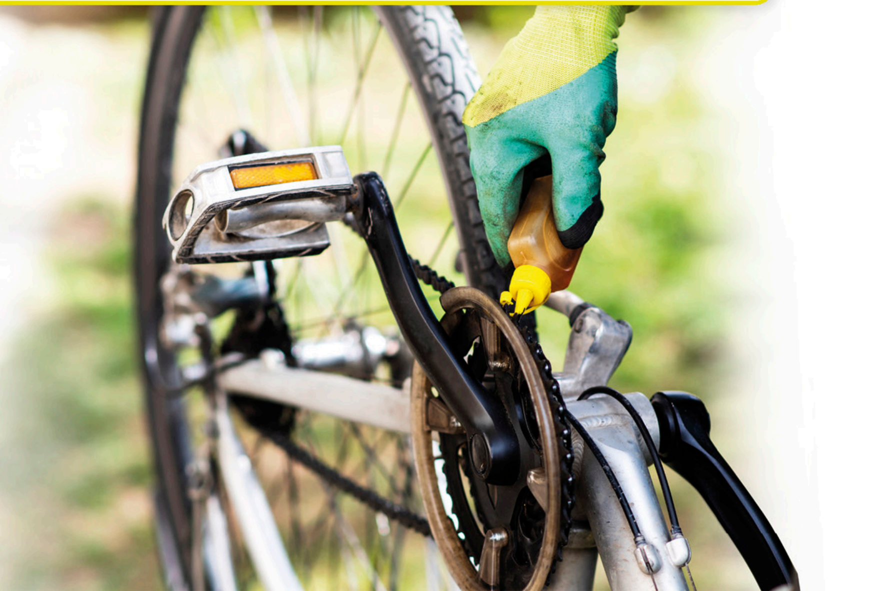
Rearrange the second efficiency equation to make useful power output the subject.

Useful power output = efficiency × total power input

$$= \frac{60}{100} \times 5\text{ W}$$
$$= 3\text{ W}$$

Improving efficiency

Machines with moving parts generate frictional forces that transfer energy to useless energy stores, such as sound and heat. Adding lubricants like oil reduces friction and so improves efficiency. No devices are 100 percent efficient, as some energy is always lost through heating, light, sound, or other energy transfers.



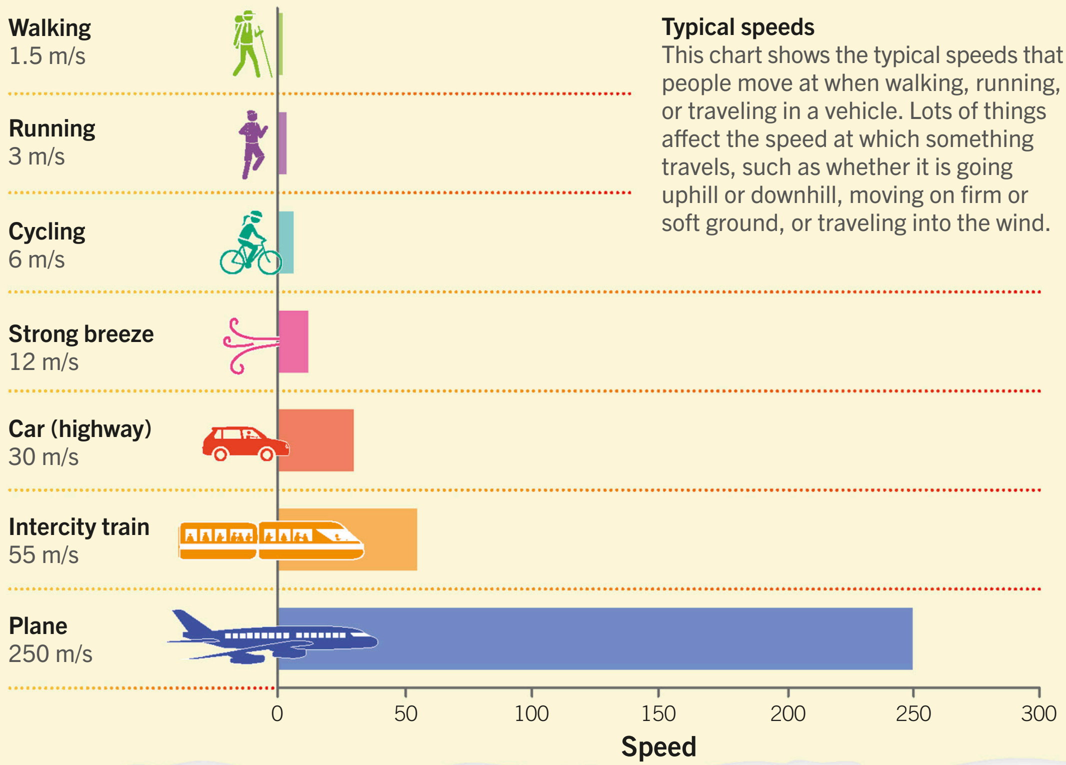
Describing motion

Speed

Speed is a measure of how fast something is moving. It describes distance traveled over a certain amount of time. It is usually measured in meters per second (m/s), miles per hour (mph), or kilometers per hour (km/h). Unlike velocity, which tells you how fast something is moving in a particular direction, speed has no direction—it is a scalar quantity rather than a vector (see page 66).

Key facts

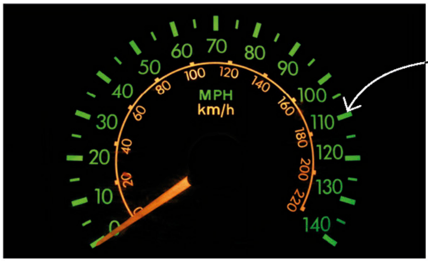
- ✓ Speed describes how far something travels in a given amount of time.
- ✓ Speed is a scalar quantity rather than a vector, so it has no direction.



Typical speeds
This chart shows the typical speeds that people move at when walking, running, or traveling in a vehicle. Lots of things affect the speed at which something travels, such as whether it is going uphill or downhill, moving on firm or soft ground, or traveling into the wind.

Measuring speed

Scientists usually measure speed in meters per second, but the speedometers in vehicles display speed in other units. Cars use miles per hour or kilometers per hour, and ships and planes usually use knots (nautical miles per hour).



This car speedometer shows speed in both miles per hour (green) and kilometers per hour (orange).

Calculating speed

To calculate the speed of a moving object, you divide the distance it travels by the time it takes to travel that distance. Average speed is the total distance divided by the total time taken, but instantaneous speed tells you how fast something is moving at a particular moment.

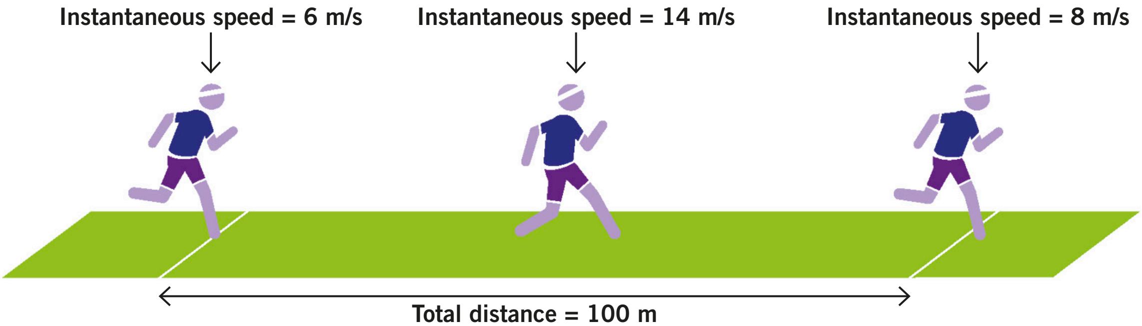
Key facts

- ✓ Average speed is equal to the total distance traveled divided by the total time taken.
- ✓ Instantaneous speed is how quickly something is moving at a specific point in time.

Average and instantaneous speed

Imagine a sprinter running a 100 m race. At the very start, she moves slowly, but she soon speeds up. Toward the end, she might get tired and slow down a little. Her instantaneous speed has changed throughout the race, but we can calculate her average speed using the formula below.

$$\text{average speed (m/s)} = \frac{\text{total distance (m)}}{\text{total time (s)}}$$



Calculating speed

Question
A sprinter completes a 100 m race in 12.5 seconds. What is her average speed?

Answer

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}}$$
$$= \frac{100\text{ m}}{12.5\text{ s}}$$
$$= 8\text{ m/s}$$

Calculating distance

Question
A cyclist in a race rides for 25 seconds with an average speed of 12 m/s. How far does he cycle?

Answer
Rearrange the equation to work out distance rather than speed:

Total distance = average speed × total time
= 12 m/s × 25 s
= 300 m

Measuring speed

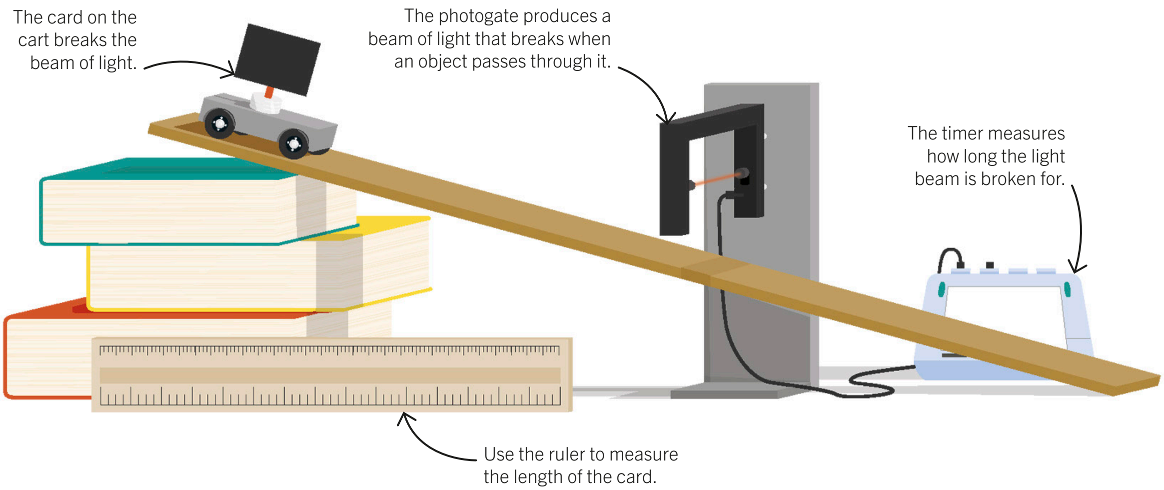
To measure speed, you have to measure the distance an object travels and the time it takes to travel that distance. Instruments used to measure distance include rulers and tape measures. Instruments used to measure time include stopwatches and photogates.

Key facts

- ✓ Instruments used to measure distance include rulers and tape measures.
- ✓ Instruments used to measure time include stopwatches and photogates.
- ✓ Photogates use a beam of light to measure time very accurately.

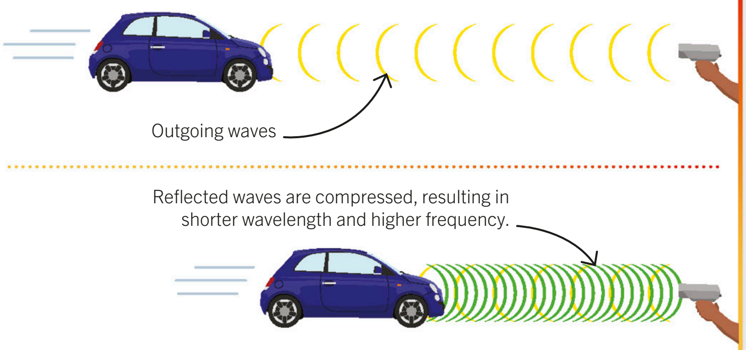
Photogates

A photogate is used to calculate the speed of fast-moving objects. It measures very brief time intervals much more accurately than a person can do with a stopwatch. In the experiment shown here, a cart carrying a card breaks the light beam for a fraction of a second. To find the cart's speed at that point, divide the length of the card by the time interval recorded.



Speed guns

The radar speed guns used by police to check if drivers are speeding use radio waves. When the outgoing radio waves reflect off an approaching car, their frequency and wavelength change. The faster the car, the higher the frequency of the reflected waves. The speed gun detects the returning echoes and uses their frequency to calculate the car's speed.



Position–time graphs

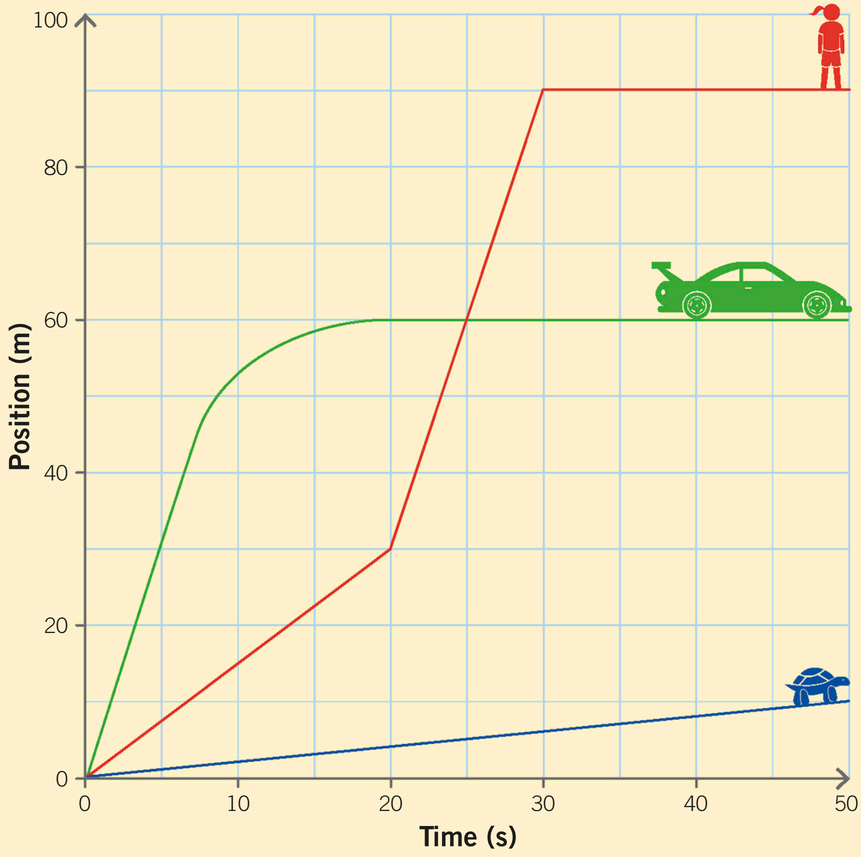
A position–time graph shows the journey of an object traveling in a straight line. The slope (gradient) of the line reveals how fast it's moving and when it speeds up, slows down, or stands still.

Key facts

- ✓ A position–time graph shows how far and how fast an object has traveled at different times in its journey.
- ✓ The gradient shows the speed of an object—the steeper the gradient, the faster the speed.
- ✓ You can use a position–time graph to calculate an object's speed at any point in the journey.

Understanding position–time graphs

Each of the lines on this position–time graph shows a different journey. The steeper the line, the faster an object is moving. A curved line has a changing gradient, which means an object is changing speed. A flat horizontal line means an object is stationary.



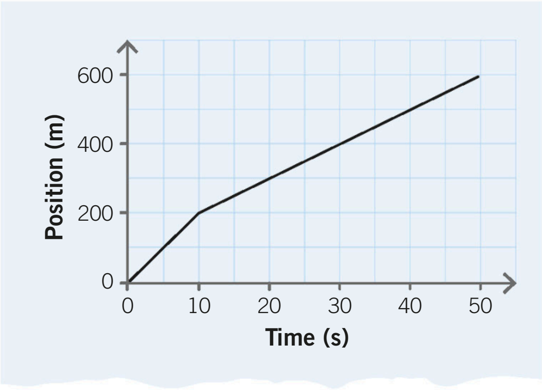
This person starts walking at a constant speed, but after 20 seconds, she suddenly speeds up—she must be running. After 10 seconds of running, she comes to a stop and the line remains horizontal.

At first, the car travels quickly at a constant speed, but then it gradually slows. When it reaches a position of 60 m, its distance traveled stops changing, so the car must have stopped.

The low gradient of the tortoise's line shows that it walks slowly. The line is perfectly straight, which means that its speed is not changing.

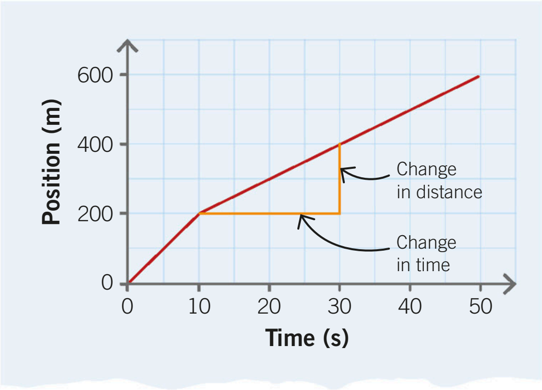
Calculating speed from a gradient

Question
This graph shows the position–time journey for a car. At what speed was the car traveling during the last 40 seconds of the journey?



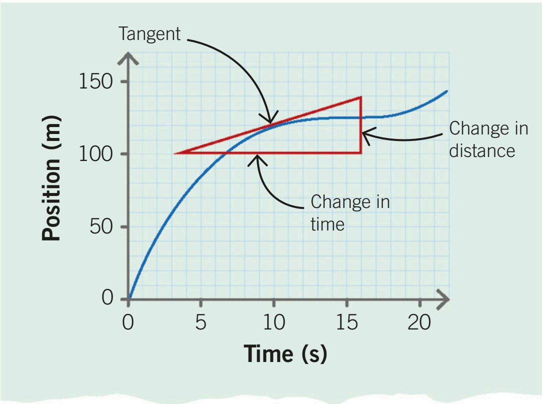
Answer
1. To find the speed, you need to calculate the gradient of the straight line. Draw a right-angled triangle under any part of the line. The triangle's vertical side is the change in distance. The horizontal side is the change in time.
2. Work out both values.
   Change in distance = 400 m – 200 m = 200 m
   Change in time = 30 s – 10 s = 20 s
3. Divide the change in distance by the change in time to find the speed.

$$\text{speed} = \frac{\text{change in distance}}{\text{change in time}} = \frac{200\text{ m}}{20\text{ s}} = 10\text{ m/s}$$



Drawing a tangent

Sometimes you might have to work out the gradient on a curved part of the line. This is easy—you do it by drawing a line called a tangent. A tangent is a straight line that touches the curve without crossing it, matching the slope at the point in question. After drawing a tangent, complete a right-angled triangle as described above and use it to work out the change in distance divided by the change in time.

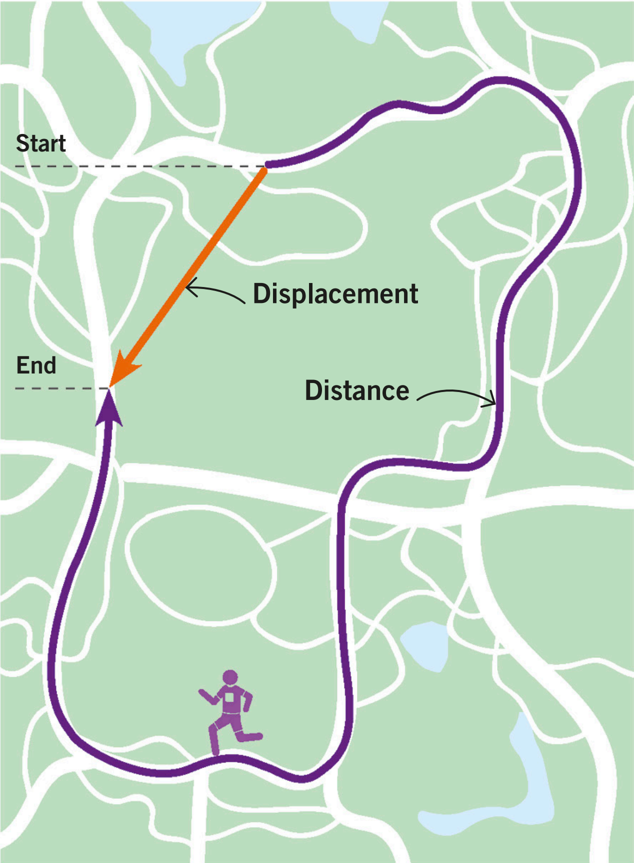


Scalars and vectors

Scientific measurements are either scalar quantities or vector quantities. Scalar quantities just have a magnitude (size), whereas vector quantities have magnitude and direction.

Distance and displacement

The map below shows the route a jogger takes around a park. How far has he traveled? One way to answer this is to measure the total distance of his winding path. This is a scalar quantity, as it has no particular direction. Another is to measure his displacement—his distance and direction in a straight line from his starting point. Displacement is a vector quantity because it has a direction as well as a magnitude.



Key facts

- ✓ **Scalar quantities have magnitude.**
- ✓ **Vector quantities have magnitude and direction.**
- ✓ **Distance is scalar; displacement is a vector.**

Vector quantities

Forces always have a direction, so all forces are vectors. Your weight is a force that acts downward toward Earth, so weight is a vector. In contrast, your mass (the amount of matter in your body) is a scalar quantity.

The velocity of an object is its speed in a particular direction. If a car is turning a corner at a steady 31 mph (50 km/h), its speed is constant but its direction is changing, so its velocity is changing, too.

Acceleration, in everyday language, means getting faster. However, the scientific meaning of acceleration is a change in velocity. Acceleration is a vector quantity and tells us if an object is getting faster, slower, or changing direction.

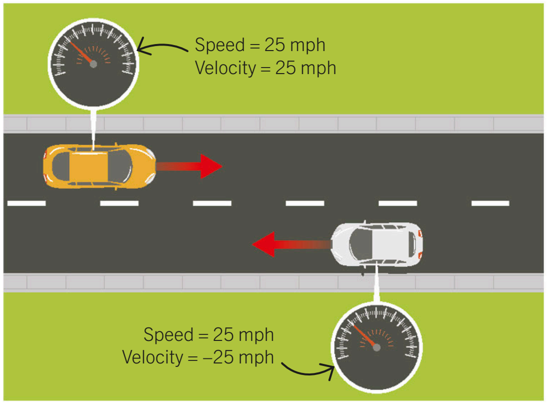
The momentum of an object is its mass multiplied by its velocity. Momentum is calculated from velocity and so is a vector quantity.

Velocity

Speed and velocity are not the same thing. Speed tells you how fast something is moving, but velocity is how fast something is moving in a particular direction. Unlike speed, which is a scalar quantity, velocity is a vector quantity—it has direction as well as magnitude.

Key facts

- ✓ **Velocity is the speed of a moving object in a particular direction.**
- ✓ **Velocity is a vector quantity—it has direction and magnitude.**
- ✓ **Speed is a scalar quantity—it has no direction.**



Speed and velocity
If two cars are traveling at the same speed but in opposite directions, they have different velocities. For example, the yellow car is traveling 25 mph (40 km/h) east, but the white car is traveling 25 mph (40 km/h) west. In physics, we can use a minus sign to show something is happening in the opposite direction. In this diagram, east is the positive direction, so the white car has a velocity of –25 mph (–40 km/h).

Changing velocity
When a car turns, its direction changes, which means that its velocity changes as well. The car here has driven at a constant speed all the way around a roundabout, but its velocity has been changing continually. Its average velocity going around the roundabout is 0 mph (km/h).

Frames of reference

Suppose you're standing on a train moving east at 50 m/s and you throw a ball forward at 10 m/s. What's the ball's velocity? The speed relative to you is 10 m/s, but for someone standing beside the track, the ball's velocity is 60 m/s. Likewise, if you throw the ball backward at 10 m/s, someone beside the track will see it moving forward at 40 m/s. All these quantities are correct, but each one depends on a different point of view. We call these different points of view "frames of reference."

Acceleration

Acceleration is the rate at which an object's velocity is changing. It doesn't just mean speeding up. Slowing down and changing direction are forms of acceleration, too.

Formula for acceleration

You can calculate acceleration using the formula below. The unit to use for acceleration is m/s^2 (meters per second squared).

$$\text{acceleration (m/s}^2\text{)} = \frac{\text{change in velocity (m/s)}}{\text{time taken (s)}}$$

Final velocity

$$a = \frac{v_f - v_i}{t}$$

Initial velocity

Calculating acceleration

To work out "change in velocity" in the right side of the formula, you need two figures: final velocity and initial velocity. Take care to get these the right way around. For example, a car traveling at a velocity of 13 m/s speeds up to 25 m/s in 10 seconds. What's its acceleration?

$$a = \frac{v_f - v_i}{t}$$

Put final velocity first and initial velocity second.

$$= \frac{25 \text{ m/s} - 13 \text{ m/s}}{10 \text{ s}}$$

$$= 1.2 \text{ m/s}^2$$

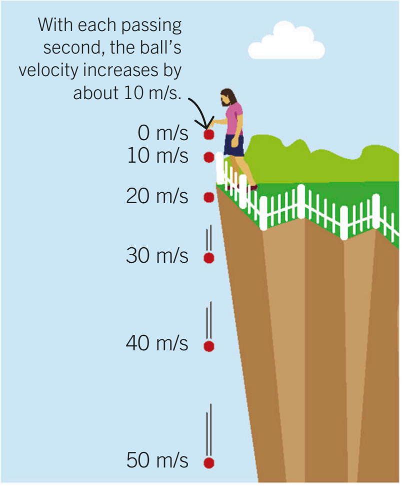
Acceleration is measured in meters per second squared (meters per second per second).

Key facts

- Acceleration is the rate at which velocity changes.
- The unit for acceleration is m/s^2.
- The uniform acceleration of a falling object at Earth's surface is 9.8 m/s^2 (*g*).

Acceleration due to gravity

When an object falls, the force of gravity at Earth's surface gives it a uniform acceleration of about 9.8 m/s^2. This means that with each passing second, its velocity increases by 9.8 m/s. This value is used so often in calculations that it has its own abbreviation, *g*. In real life, objects don't always accelerate uniformly at 9.8 m/s^2 because air resistance produces an upward force.



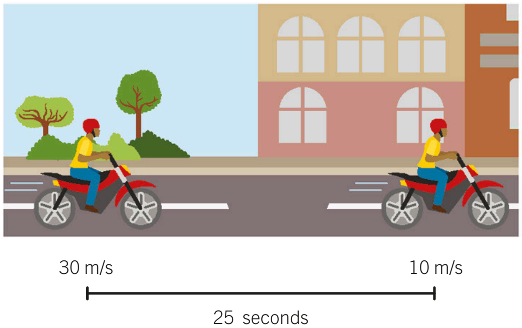
Drogue parachute

Some high-speed aircraft must slow down (decelerate) very quickly in order to land in confined spaces. One solution is to deploy a drogue parachute—a small parachute that dramatically increases the force of drag.

Slowing down

Question

If an object is slowing down, it has negative acceleration. A motorcycle is traveling at 30 m/s on a country road. It arrives at a town and the rider slows down to 10 m/s, taking 25 seconds to do so. What was the average acceleration?



Answer

$$a = \frac{v_f - v_i}{t}$$

$$= \frac{10 \text{ m/s} - 30 \text{ m/s}}{25 \text{ s}}$$

$$= -0.8 \text{ m/s}^2$$

Acceleration is negative here because the motorcycle was slowing down.

Using distance

Sometimes we have to calculate acceleration from a change in velocity over a certain distance rather than over a period of time. We use the equation below to do this.

Displacement (distance traveled)

$$v_f^2 - v_i^2 = 2as$$

Final velocity

Initial velocity

Finding acceleration

Question

A train pulls out from a station and accelerates uniformly for 1350 m until it reaches a velocity of 55 m/s. What is the train's acceleration?

Answer

Rearrange the formula to find *a*.

$$a = \frac{v_f^2 - v_i^2}{2s}$$

$$= \frac{(55 \text{ m/s})^2 - (0 \text{ m/s})^2}{2 \times 1350 \text{ m}}$$

$$= \frac{3025}{2700}$$

$$= 1.12 \text{ m/s}^2$$

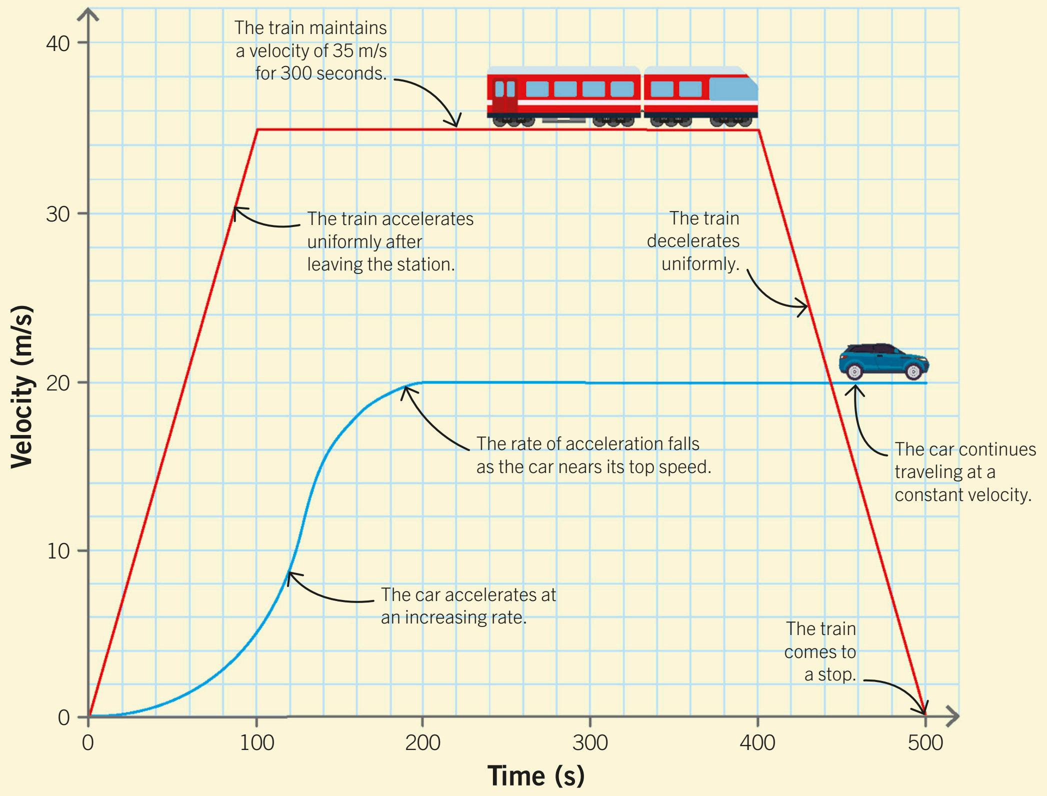
Velocity–time graphs

A velocity–time graph shows how an object's velocity changes over time. The gradient (steepness) of the line represents the object's acceleration or deceleration (negative acceleration). The graph can also show whether or not an object's acceleration is uniform.

Key facts

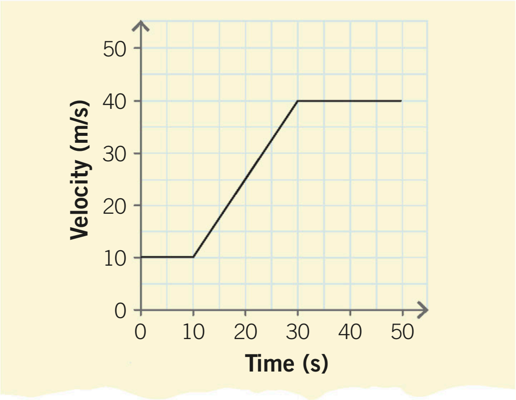
- ✓ A velocity–time graph shows how an object's velocity changes over time.
- ✓ The horizontal axis shows time and the vertical axis shows velocity.
- ✓ You can work out acceleration from the gradient (slope) of the line.
- ✓ The area under the line is the displacement (total distance traveled).

Understanding velocity–time graphs
This velocity–time graph shows two different journeys. Slopes with a straight line represent uniform acceleration, whereas curved lines represent changing acceleration. Flat horizontal lines represent constant velocity.



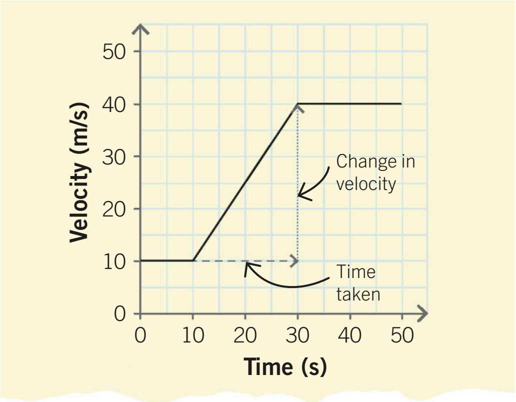
Calculating acceleration

Question
The graph below shows a car's journey. What was the car's acceleration between 10 and 30 seconds?



Answer

1. Acceleration is change in velocity divided by time taken, so work these out by drawing a triangle under the sloped part of the graph.

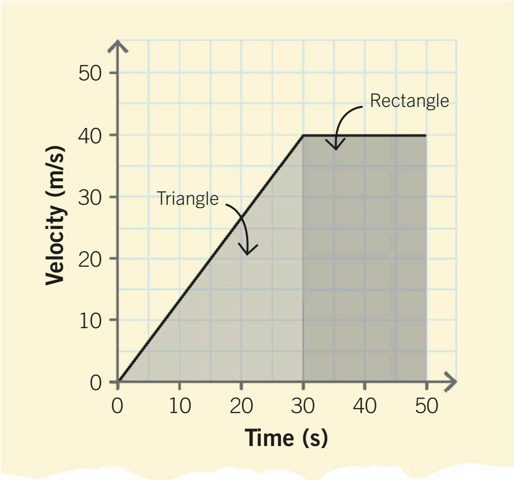


2. Change in velocity = final velocity – initial velocity
   = 40 m/s – 10 m/s
   = 30 m/s
3. Time taken = 30 s – 10 s
   = 20 s
4. Acceleration = $\frac{30 \text{ m/s}}{20 \text{ s}}$
   = 1.5 m/s^2

Calculating displacement

You can use a velocity–time graph to work out the displacement of a moving object—the total distance it has traveled. You do this by finding the area under the graph. This works because distance traveled = velocity × time.

Question
The graph shows a 50-second train journey. How far did the train travel?



Answer

1. Start by separating the space under the line into a triangle and a rectangle.
2. Next, work out the triangle's area using the formula for the area of a triangle:

   area = $\frac{\text{base} \times \text{height}}{2}$

   = $\frac{30 \text{ s} \times 40 \text{ m/s}}{2}$

   = 600 m

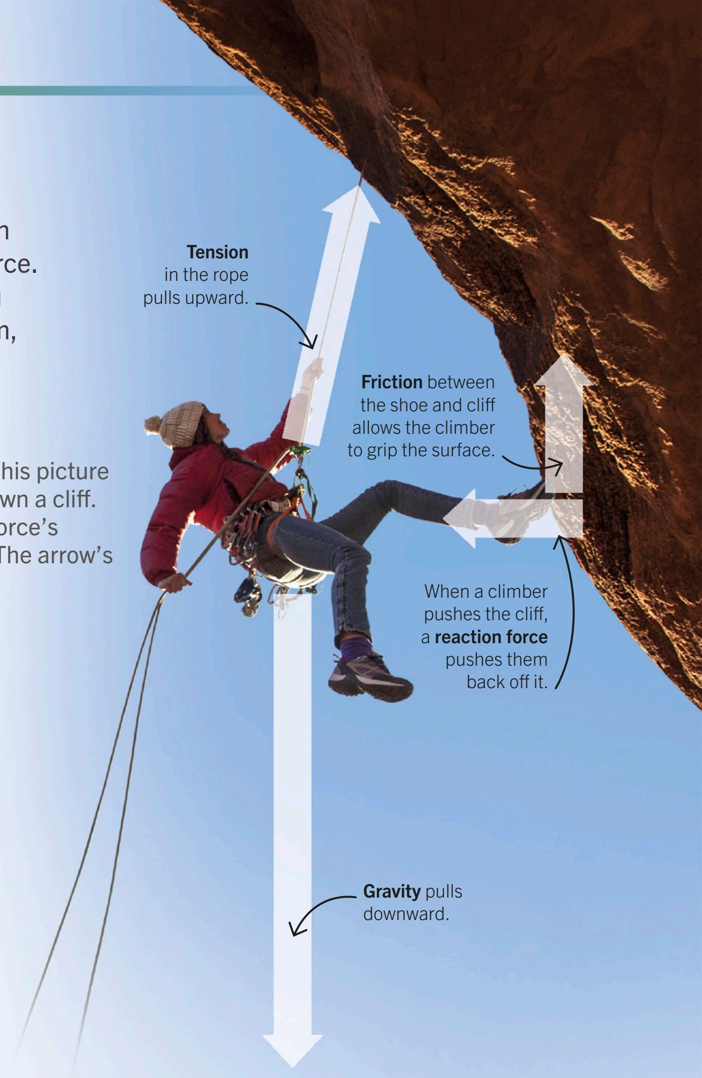
   The units are meters because the area under the line represents distance.
3. Now work out the area of the rectangle:
   area = base × height
   = 20 s × 40 m/s
   = 800 m
4. Add the two values to find the displacement:
   displacement = 600 m + 800 m
   = 1400 m

Forces

Forces

A force is a push or a pull that changes the motion or shape of an object. There are many types of force. Some require physical contact, such as when you kick a ball. Others, such as gravity and magnetism, are noncontact forces that work at a distance.

Forces at work
Several forces can act on an object at the same time. This picture shows the main forces acting on a climber abseiling down a cliff. Each force is represented by an arrow that shows the force's direction—forces are vector quantities (see page 66). The arrow's length here represents the size of the force.



Key facts

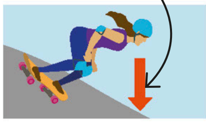
- ✓ **A force is a push or pull.**
- ✓ **A force can change the speed, direction of movement, or shape of an object.**
- ✓ **Forces can be contact or noncontact forces.**
- ✓ **The unit for force is the newton (N).**
- ✓ **Forces are vector quantities.**

Effects of forces

A force can have several effects on an object. Many forces affect the motion of an object—for instance, by making it speed up, slow down, or change direction. Forces can also change an object's shape.

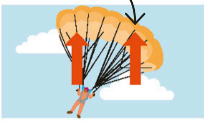

A force applied to a stationary object can make it move.

Gravity makes the skateboarder accelerate downhill.


When an object is already moving, a force in the same direction makes it move faster.


A force may also cause a moving object to change direction.

Air resistance slows the skydiver's fall.


A force in the opposite direction to a moving object makes it slow down or stop.

Tension bends the archer's bow.

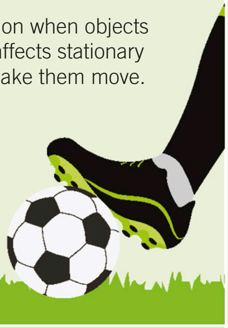

Forces can also cause temporary or permanent changes in an object's shape.

Types of force

Contact forces

Pushes and pulls are the contact forces we use to move things, from kicking a ball to tapping a keyboard.

Friction is a force that opposes motion when objects rub or slide together. Static friction affects stationary objects and must be overcome to make them move. Kinetic friction is the force between moving objects and is weaker than static friction.



Air and water resistance are forces that objects moving through air and water have to overcome. They are caused by the push of air and water in the way. Like friction, these forces always act opposite to the direction of motion.

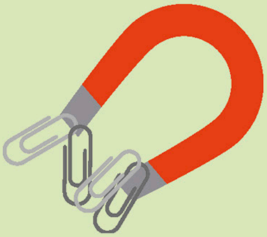
Noncontact forces

Gravity is a force of attraction between objects with mass. Earth's gravity makes things fall toward Earth.

Electrostatic force is the attraction or repulsion between objects with an electric charge.

An electrostatic charge on a person's hair makes the hairs repel each other, causing them to stand on end.

Magnetism is the force experienced when a magnetic material is near a magnet.



Reaction forces

Reaction forces occur in response to every force but act in the opposite direction. If one skateboarder pushes the other, they will both move, as the push results in a reaction force acting in the opposite direction.

Newtons

The unit for force is named the newton (N) after the English scientist Isaac Newton. One newton is about the weight of an apple. The scientific definition of a newton is the force needed to accelerate a 1 kg object by 1 m/s^2.

Balanced and unbalanced forces

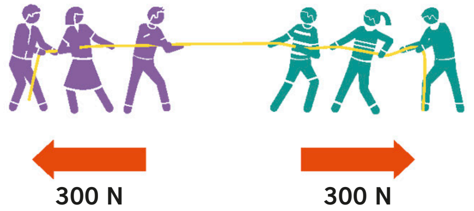
When forces acting on the same object in opposite directions are the same size, we say they are balanced. Balanced forces cancel each other out. A change in an object's motion only happens if the forces acting on it are unbalanced.

Key facts

- ✓ When two forces on an object are balanced, they are equal and act in opposite directions.
- ✓ Balanced forces cancel each other out, so they do not change the motion of an object.
- ✓ When the forces acting on an object are unbalanced, they change its motion.

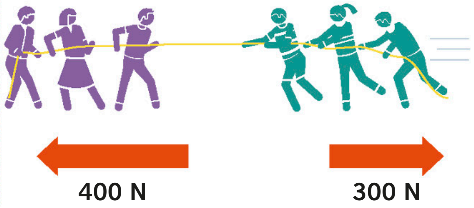
Balanced forces

These two tug-of-war teams are pulling with equal force. The forces are balanced and cancel each other out, so there is no movement.

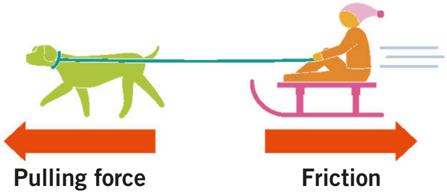


Unbalanced forces

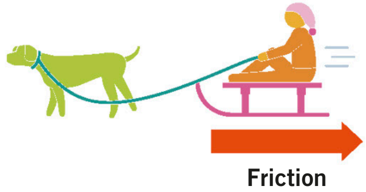
When the purple team pulls harder, there is an overall force in that direction and the teams begin to move.



When an object is moving at a constant velocity, the forces acting on it are balanced. Here, the pulling force from the dog is balanced by friction between the sled and the snow, which acts in the opposite direction. The dog and the sled both move forward at a constant velocity.

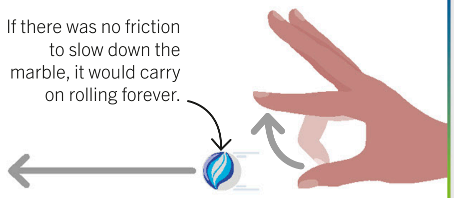


If the dog stops pulling, an unbalanced force is acting in the opposite direction to the sled's motion, so it slows down. An unbalanced force acting sideways (such as a strong wind) would change the direction of movement.



First law of motion

In the 18th century, the English scientist Isaac Newton described the effect of forces on motion with his first law of motion. This says that an object either remains at rest or moves in a straight line at a constant velocity unless an unbalanced force acts on it. For example, when you flick a marble, it continues rolling after the force from your finger has stopped.



Resultant forces

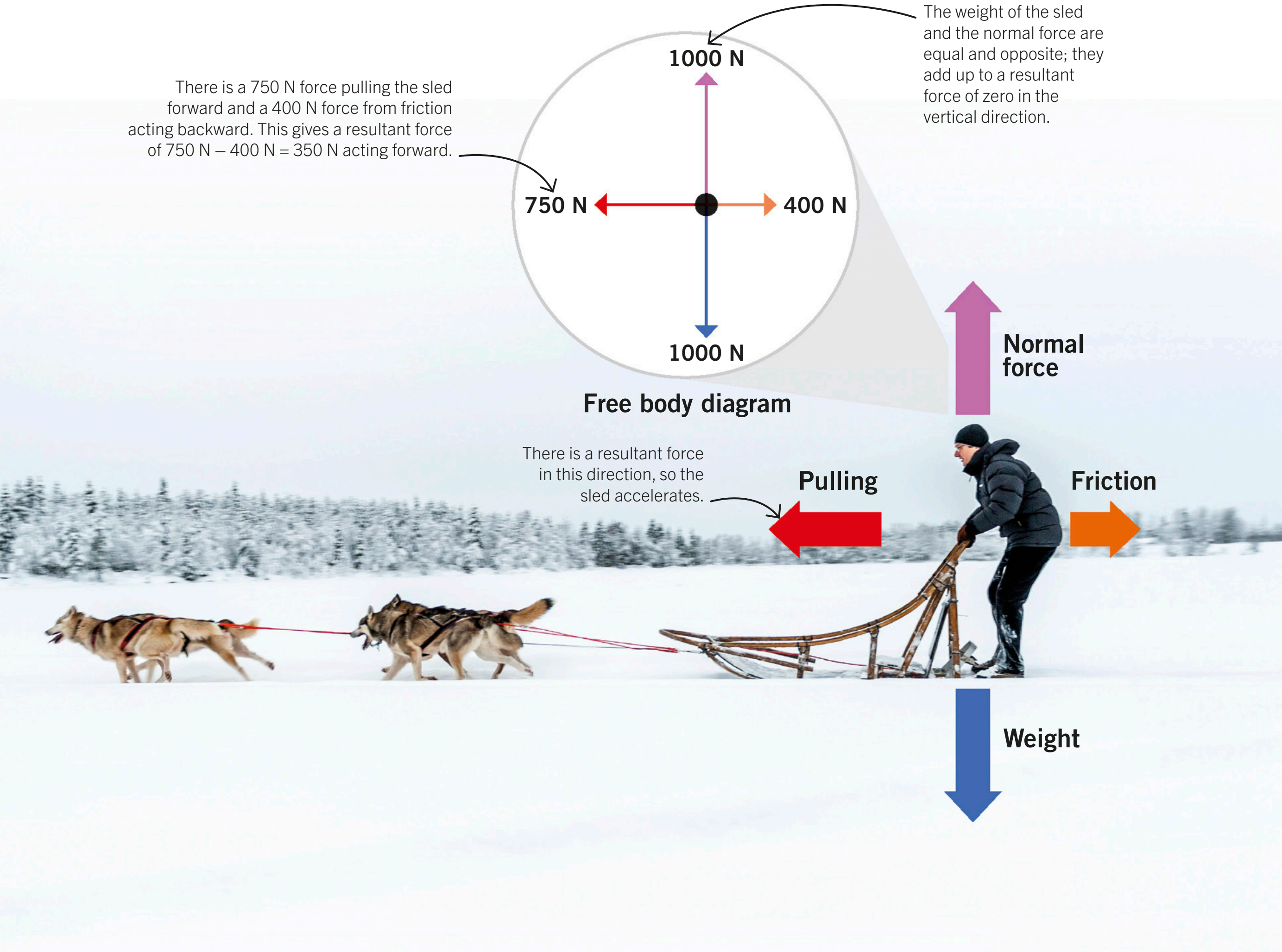
When several forces act on an object at the same time, their effects combine and act as though there is a single force, called a resultant force. The resultant force can be found by drawing the forces as arrows on a diagram.

Key facts

- ✓ When several forces act on an object, their effects combine and act as if there is a single force (a resultant force).
- ✓ Forces acting on an object can be shown on a free body diagram.
- ✓ If two forces are acting in the same direction, you can work out the resultant by adding them.
- ✓ If two forces are acting in opposite directions, work out the resultant by subtracting one from the other.

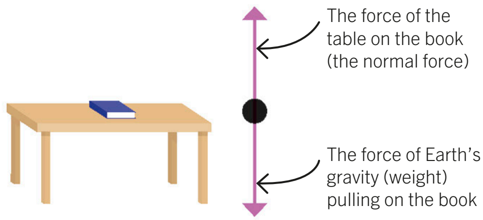
Finding resultant forces

The sled below has several different forces acting on it. The sled's weight pushing down on the ground is balanced by a reaction force (called a normal force) acting upward from the ground. The dogs are creating a pulling force (called tension) through the ropes, but friction with the ground creates a force in the opposite direction. If the pulling force is greater than friction, there is a resultant force that causes a change in motion: the sled accelerates.



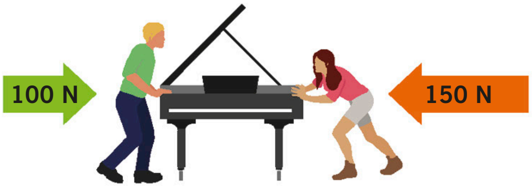
Free body diagrams

A free body diagram shows the forces acting on an object. The object can be represented by a dot or a square, and the forces are represented by labeled arrows pointing away from it. Here, a book is resting on a table. The diagram only shows forces acting on the book. (Forces acting on the table are omitted.)



Calculating resultant forces

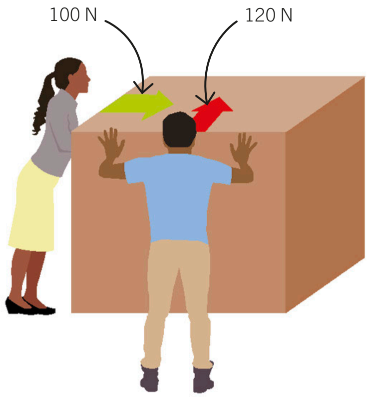
Question 1
One person pushes a piano with a force of 100 N, but another person pushes back the opposite way with a force of 150 N. What's the resultant force?



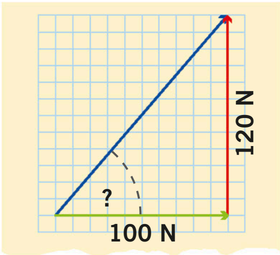
Answer 1
1. Draw a free body diagram showing the forces acting on the piano.

2. Find the answer by subtraction:
   Resultant force = 150 N – 100 N
   = 50 N to the left

Question 2
Two people try to push a heavy box. One person pushes with a force of 100 N. The other person pushes at right angles with a force of 120 N. What's the resultant force?



Answer 2
When forces (or any vector quantities) don't act in a straight line, you can add them by drawing a scale diagram.



1. Draw one force from the end of the other to form a triangle. In this diagram, 1 cm = 10 N.
2. Measure the sloping side of the triangle with a ruler to find the magnitude of the force.
3. Measure the angle with a protractor to find the direction of the force.
4. Write both in your answer:
   Force = 156 N at 50°.

Resolving forces

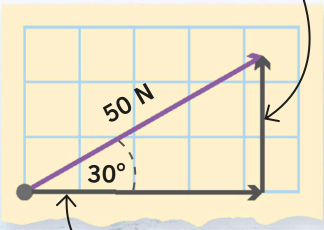
The effects of forces are easiest to understand when they act at right angles to each other, but a force can act at any angle. To get around the problem, it can help to break down a force into two components that are at right angles but have the same combined effect as the single force. This is known as resolving forces.

Key facts

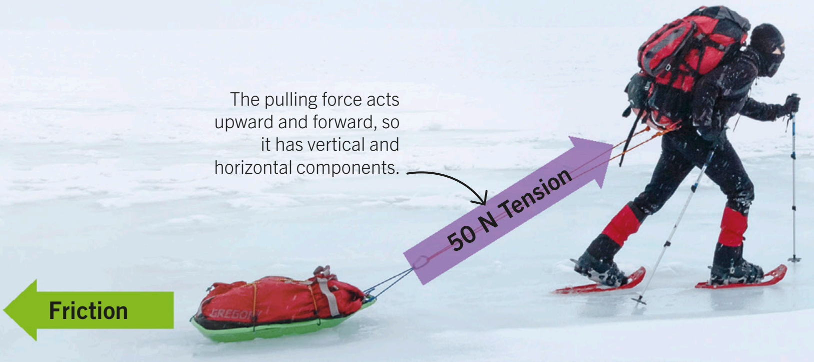
- ✓ **A single force can be resolved into component forces acting at right angles to each other.**
- ✓ **Resolve forces by drawing a scale diagram or by using trigonometry.**

Pulling power
This explorer is dragging a pack of heavy gear across a glacier, exerting a force of 50 N at an angle of 30° from the ground. Resolving this force into horizontal and vertical components is useful because we could then use the horizontal component to calculate the sled's acceleration. To resolve the force, draw a triangle to scale. In the triangle here, 1 cm represents 10 N of force. Measure the horizontal and vertical sides of the triangle to find the two components.

The vertical force arrow measures 2.5 cm, so the vertical component is 2.5 × 10 N = 25 N.

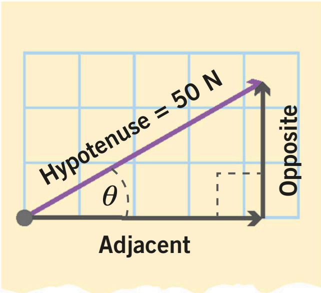


The horizontal force arrow measures 4.3 cm, so the horizontal component is 4.3 × 10 N = 43 N.



Resolving forces with math

Although forces can be resolved using scale drawings, it's faster and more accurate to use trigonometry. For instance, to find the vertical component of tension in the rope, we can use the sine formula on the right. This allows us to calculate the height of a right-angled triangle if we know the angle of the slope (θ) and the length of the slope (the hypotenuse).



$$\sin \theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

Rearrange the formula to make "opposite" the subject:

opposite = hypotenuse × sin θ
= 50 N × sin 30°
= 25 N

Use a calculator to find the sine of 30°.

Mass and weight

Some people might think that the kilogram is a unit of weight, but in science, we use kilograms to measure mass, not weight. Mass and weight are different. Mass is the amount of matter in an object. Weight is the pull of gravity on an object. It is a force and is measured in newtons.

Key facts

- ✓ Weight is the force that acts on an object due to gravity.
- ✓ Mass is measured in kilograms, but weight is measured in newtons.
- ✓ Weight can be measured using a force meter (newton meter).
- ✓ Weight can be calculated using mass and the strength of gravity.

The scale shows the force in newtons.

An apple with a mass of 0.1 kg is pulled downward by Earth's gravity with a force of 1 N.

Measuring weight

You can measure the weight of an object with a force meter (newton meter), which has a spring that stretches along a scale as the force pulling the hook increases. You can also calculate weight using the formula below. The formula takes into account the strength of gravity, which varies on different planets. An object's weight depends on the strength of gravity, but its mass is the same everywhere.

weight (N) = mass (kg) × gravitational field strength (N/kg)

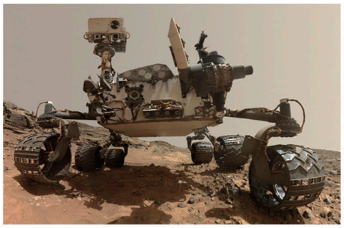
$$W = m \times g$$

On Earth's surface, the gravitational field strength (g) is 10 N/kg.

Calculating weight

Question

Curiosity is a car-sized rover on Mars. Its mass is 899 kg and the gravitational field strength on Mars is 3.7 N/kg. Calculate *Curiosity*'s weight on Mars. How much does it weigh on Earth?



Answer

Weight on Mars = $m \times g$

= 899 kg × 3.7 N/kg

= 3326 N = 3300 N (2 s.f.)

Weight on Earth = $m \times g$

= 899 kg × 10 N/kg

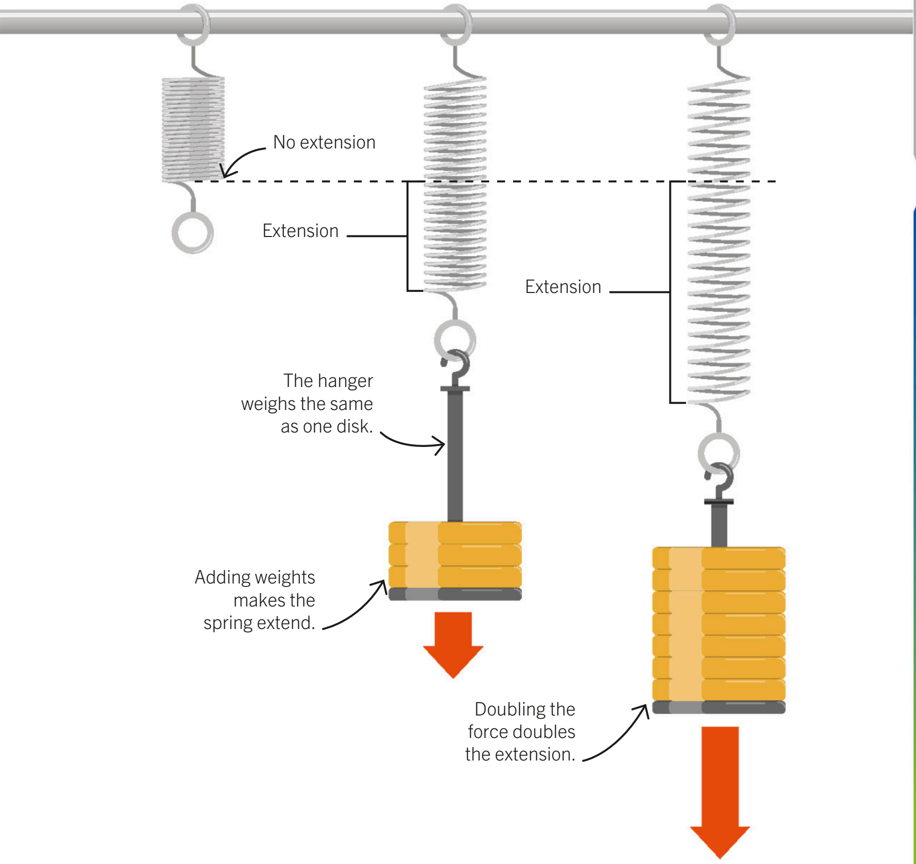
= 8990 N = 9000 N (2 s.f.)

Springs

When you stretch or squeeze a spring, the change in its length is proportional to the force you apply. This relationship is known as Hooke's law.

Hooke's law

Hang a weight on a spring and it stretches a little. Hang twice as much weight and it stretches twice as much. The extension (or compression) of springs and other elastic objects is proportional to the force applied. This relationship is summarized in the equation below. Force meters use this principle to measure forces—when you pull the hook on a force meter, it stretches a spring inside it.



force (N) = spring constant (N/m) × extension (m)

$$F = k \times x$$

Key facts

- ✓ Hooke's law says that the extension of a spring is directly proportional to the force applied.
- ✓ Elastic deformation is a reversible change in an object's shape.
- ✓ Inelastic deformation is an irreversible change in an object's shape.
- ✓ Hooke's law applies up to a point called the limit of proportionality.
- ✓ Work is done when a spring is deformed, storing elastic potential energy.

Calculating the spring constant

The value of k, the spring constant, varies between different springs. The higher the value of k, the stiffer the spring.

Question
A spring is stretched by a force of 2 N, making it extend 5 cm. Calculate the spring constant for this spring.

Answer
First, rearrange the equation to make k the subject. Remember to convert the extension to meters.

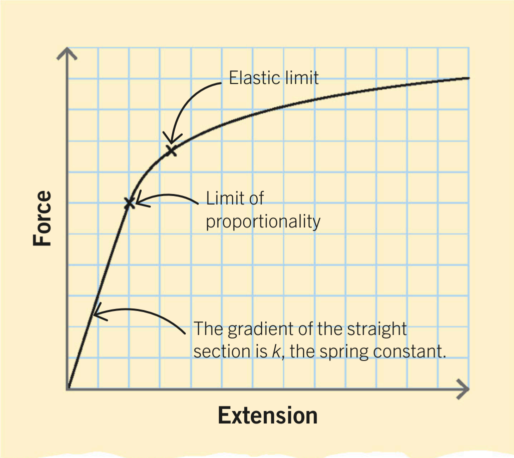
$$k = \frac{F}{x}$$

$$k = \frac{2\text{ N}}{0.05\text{ m}}$$

$$k = 40\text{ N/m}$$

Limit of proportionality

Hooke's law works only up to a certain point, called the limit of proportionality. Beyond this, the relationship is nonlinear. If you stretch or squeeze an elastic object even further, it may become damaged and unable to return to its original size. The point of no return is called the elastic limit and varies with different materials.



Elastic and inelastic deformation

If you stretch a spring and release it, it returns to its original shape. We call this elastic deformation. However, if you stretch it beyond its elastic limit, its shape changes permanently. We call this inelastic deformation. Different materials can sustain different amounts of elastic deformation before they reach their elastic limit.

A tennis ball can be squashed almost flat without reaching its elastic limit and will spring back into shape.

An aluminum can has a low elastic limit. If you squeeze it with enough force, it crumples and won't spring back into shape.

Glass has a high elastic limit, which is why marbles bounce, but too much force makes glass shatter.

Plasticine reaches its elastic limit almost immediately when a force is applied, making it ideal for molding.

Elastic potential energy

A force that extends or compresses an elastic object does work, storing elastic potential energy in the object. When the object is released, it returns to its former shape and the energy is transferred to kinetic energy. That's why a stretched elastic band flies across the room when you release it and a bungee jumper is pulled back up after falling. You can calculate elastic potential energy using this equation.

$$\text{elastic potential energy (J)} = \frac{1}{2} \times \text{spring constant} \times \text{extension squared}$$

$$E = \frac{1}{2} \times k \times x^2$$

Question

A bungee cord has a spring constant of 90 N/m and extends by 8 m after a bungee jumper comes to a standstill. How much elastic potential energy is it now storing?

Answer

$E = \frac{1}{2} \times 90 \text{ N/m} \times 8 \text{ m} \times 8 \text{ m}$

$E = 2880 \text{ J}$

Investigating springs

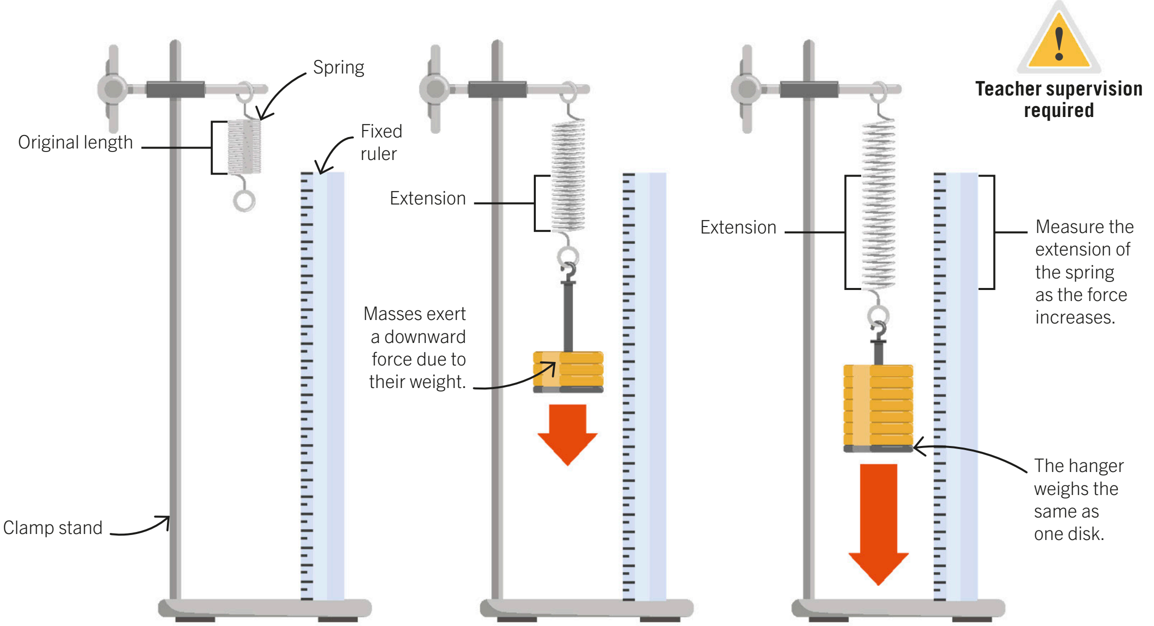
Forces can change the shape of an object, such as by stretching a spring. Investigating the effect of a pulling force on a spring shows that a spring's extension is directly proportional to the force applied.

Key facts

- ✓ Applying a force to a spring causes it to extend or contract.
- ✓ The increase in length of an object is known as its extension.
- ✓ The extension of a spring is directly proportional to the force applied.

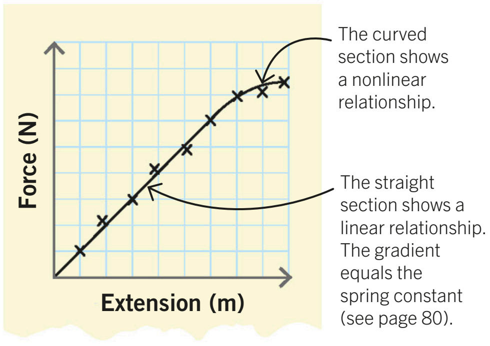
Setting up the experiment

In this investigation, increasing masses are hung from a spring suspended from a clamp. The resulting spring extension—the increase from the spring's original length—is measured with a ruler and recorded. The results are plotted on a graph to investigate the relationship between force and extension.



Results

Plot the results on a graph with force in newtons on the y-axis and the spring's extension on the x-axis. Joining the crosses should give you a straight line, which shows that the relationship is linear. The line should also pass through the origin (0, 0), which indicates that the extension is directly proportional to the force. (If you double the force, the extension doubles.) However, if you add too many masses (if you overload the spring), the relationship between force and extension becomes nonlinear and the line curves.



Deformations

As well as making objects move, forces can change their shape. We call these changes deformations. Changing the shape of a stationary object requires two or more forces acting in different directions.

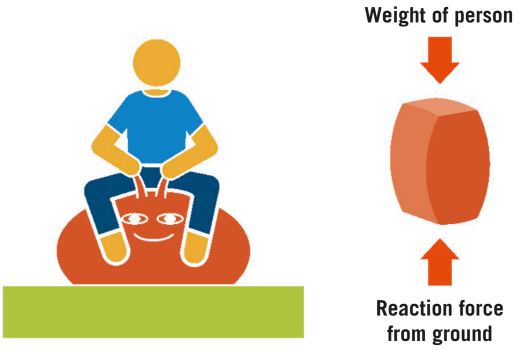
Key facts

- ✓ A change of shape caused by forces is called a deformation.
- ✓ Changing the shape of an object requires two or more forces acting in different directions.
- ✓ The type of deformation an object undergoes depends on the direction of the forces and where they act on the object.

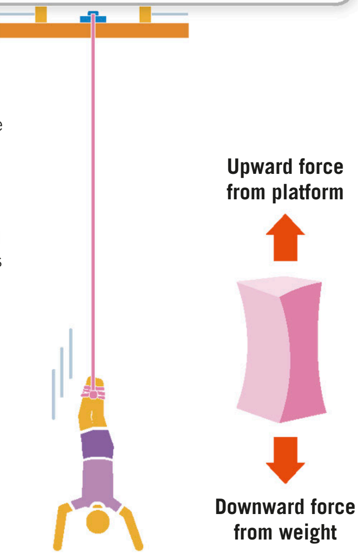
Types of deformation

Stretching, compressing, bending, and twisting—or combinations of these deformations—are some of the ways in which objects can change shape. How an object is deformed depends on the number and direction of forces applied to it.

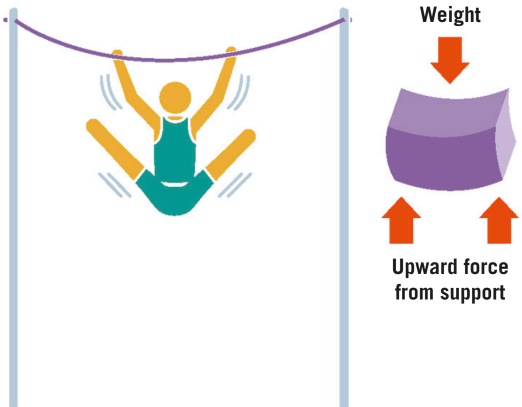
Compression
When a pair of forces push an object in opposite directions, this creates compression and squashes the object. A bouncy toy like a space hopper undergoes an elastic compression on each bounce before springing back to its original shape.



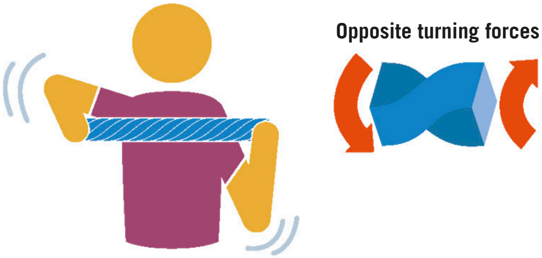
Tension
When a pair of forces pull an object in opposite directions, this creates tension and causes the object to stretch. During a bungee jump, the cord experiences a downward force due to the person's weight and an upward pull from the platform it's secured to.



Bending
When more than two forces act on an object in different directions, they can cause bending. For instance, the bars used by gymnasts—which allow a small amount of elastic deformation—bend when the gymnast's weight acts in the middle and upward forces from the supports act at each end.



Twisting
A pair of turning forces acting in opposite directions on different points of an object can cause it to twist.



Moments

To most people, a "moment" means a second or two, but in physics, it means something completely different. A moment is the turning effect caused by a force that makes an object rotate around a fixed point called a pivot. You use moments all the time—turning a door handle, pedaling a bike, or bending an arm.

Key facts

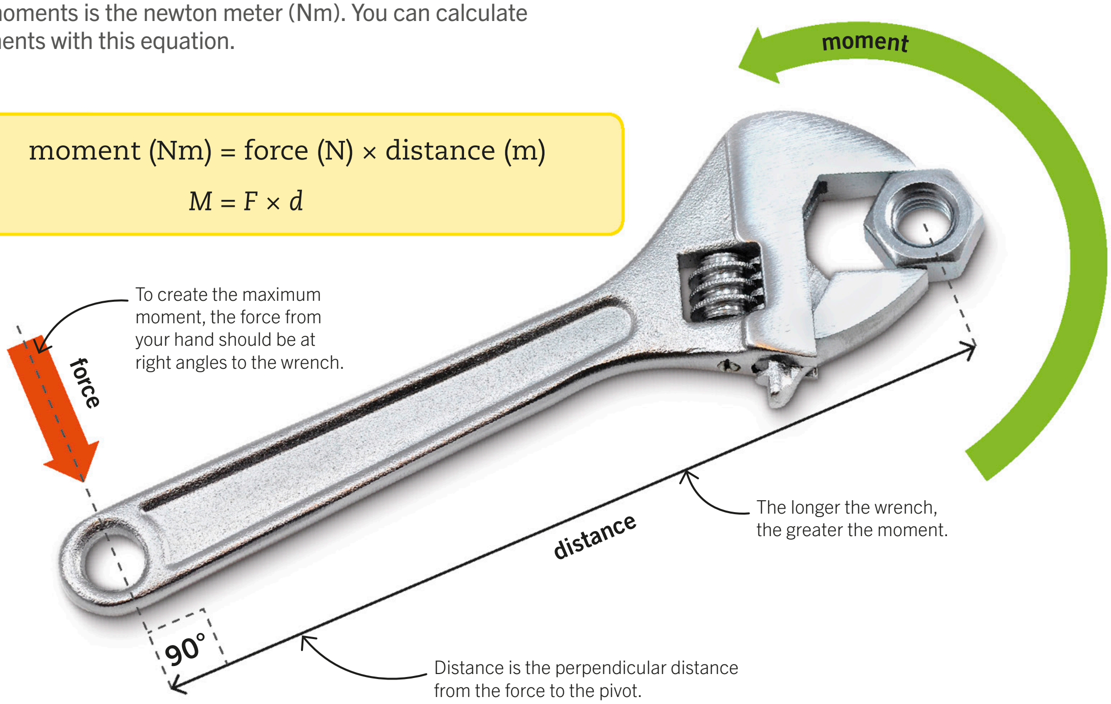
- ✓ A moment is the turning effect of a force.
- ✓ The equation for moments is moment = force × distance.
- ✓ Tools such as wrenches and levers work by generating a large moment.

How wrenches work

When you use a wrench to loosen a nut, the force of your hand produces a turning effect—a moment—that turns the nut. The longer the wrench, the greater the moment and the easier it is to loosen a tight nut. The unit for moments is the newton meter (Nm). You can calculate moments with this equation.

$$\text{moment (Nm)} = \text{force (N)} \times \text{distance (m)}$$

$$M = F \times d$$



To create the maximum moment, the force from your hand should be at right angles to the wrench.

The longer the wrench, the greater the moment.

Distance is the perpendicular distance from the force to the pivot.

Calculating moments

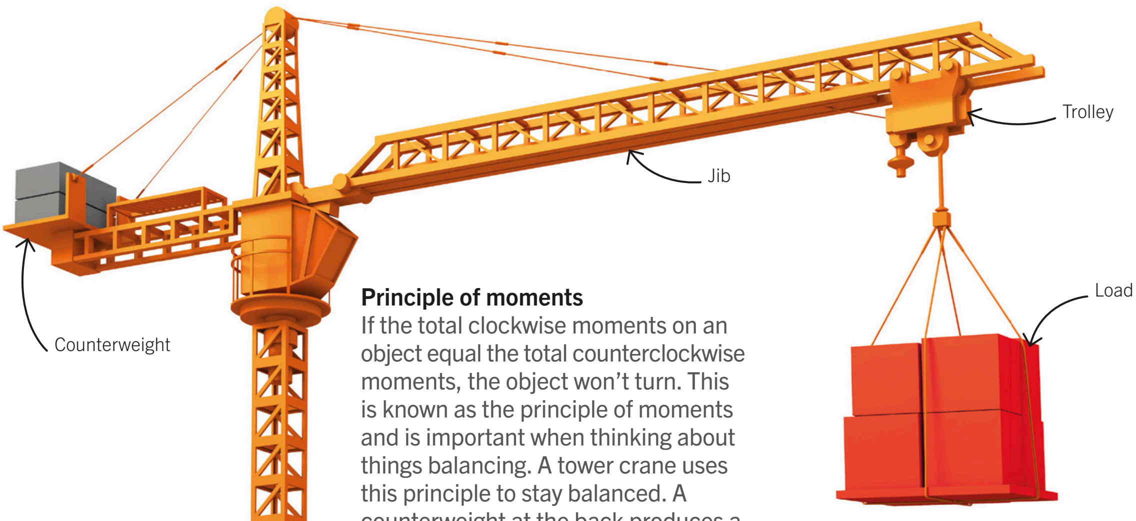
Question
A wrench 20 cm long is used to loosen a bolt. If a force of 30 N is applied at the end of the wrench, what is the size of the moment in Nm (newton meters)?

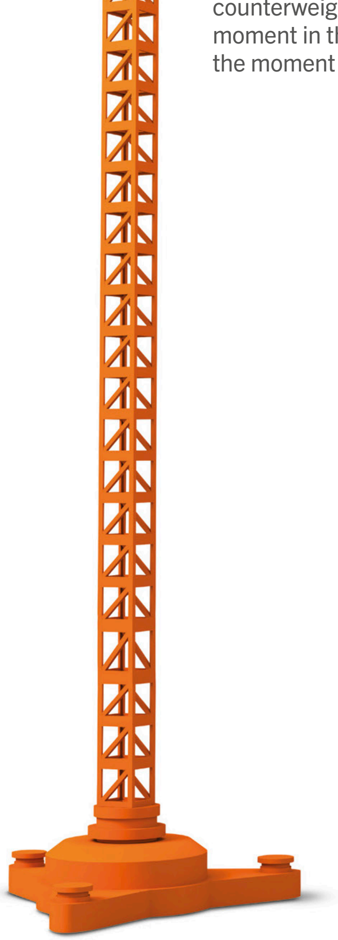
Answer
The distance must be in meters. 20 cm = 0.2 m.

$M = F \times d$

$= 30\text{ N} \times 0.2\text{ m}$

$= 6\text{ Nm}$





Tower crane

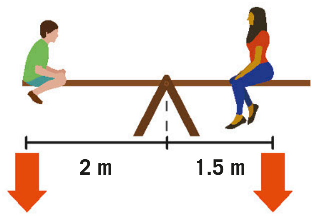
Principle of moments

If the total clockwise moments on an object equal the total counterclockwise moments, the object won't turn. This is known as the principle of moments and is important when thinking about things balancing. A tower crane uses this principle to stay balanced. A counterweight at the back produces a moment in the opposite direction to the moment produced by the load.

Staying balanced

Question

This seesaw is balanced. What is the weight in newtons of the person on the right?



Answer

1. First, work out the counterclockwise moment produced by the person on the left.

   $M = F \times d$

   $= 600\text{ N} \times 2\text{ m}$

   $= 1200\text{ Nm}$

2. The seesaw is balanced, so the clockwise moment is also 1200 Nm. Rearrange the moment equation to put force on the left to find the answer.

   $F = \dfrac{M}{d}$

   $= \dfrac{1200\text{ Nm}}{1.5\text{ m}}$

   $= 800\text{ N}$

Center of mass

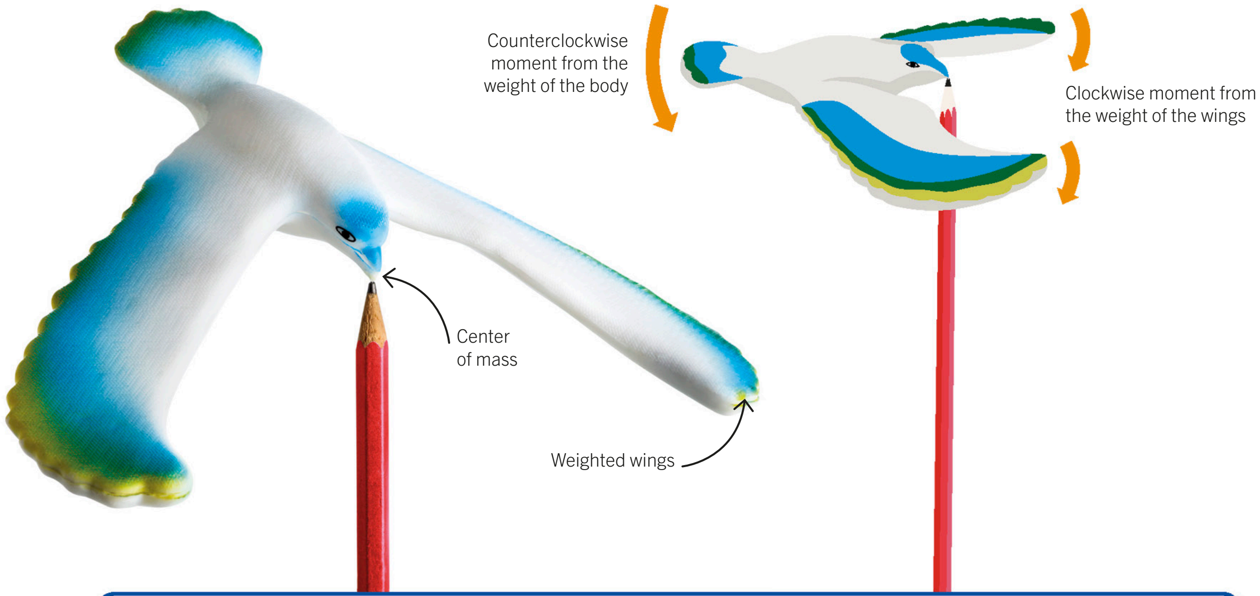
The weight of an object (or any other force acting on it) can be thought of as acting at a single point: the center of mass. Whether or not an object is stable depends on the position of its center of mass.

Key facts

- The weight of an object can be thought of as acting at a single point: the center of mass.
- The center of mass can be inside or outside an object, depending on its shape.
- An object is stable when its center of mass is above its base.
- An object will fall over if its center of mass is outside the base.

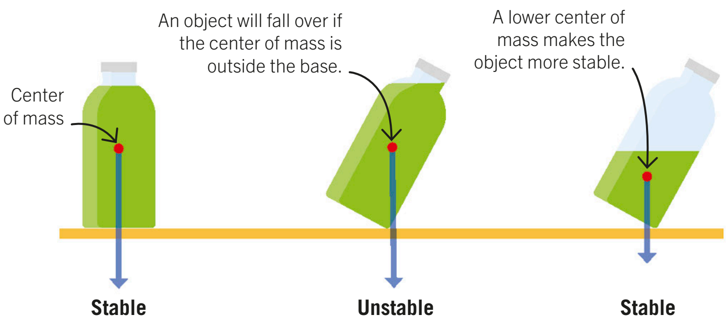
The balancing bird

This toy bird looks like it shouldn't be able to balance on its beak. However, because its wingtips extend forward and are weighted, the bird's center of mass is located at the beak. The heavy wings and the rear of the body both produce moments (turning forces), but these balance each other, much like people at opposite ends of a seesaw.



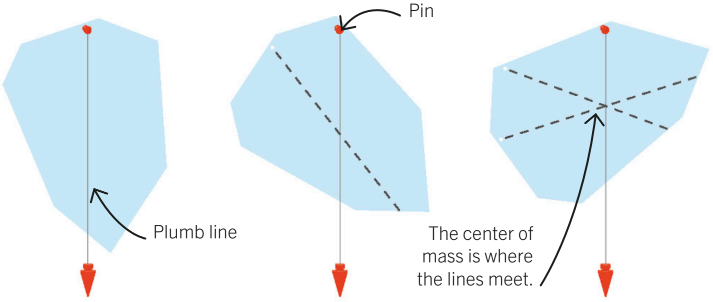
Stability

An object is stable when its center of mass is above its base. Tall objects with narrow bases fall over easily because even a small movement can push the center of mass outside the base. Stable objects tend to have a low center of mass and a wide base.

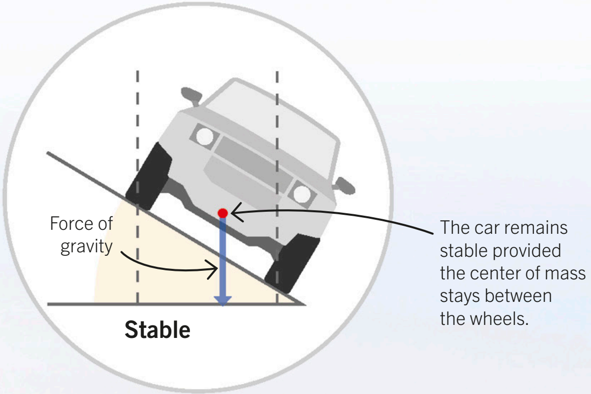


Finding the center of mass

To find the center of mass of an irregular 2D shape (a plane lamina), hang the shape from a vertical surface with a pin so it can swing freely. After it comes to rest, hang a plumb line (a weight on a string) from the pin and use it to draw a vertical line on the object. Repeat, hanging the shape from two more pivot points. The center of mass is the point where the lines intersect.



Off-road stability
Off-road vehicles are designed to have a very low center of mass and a wide wheelbase so they can negotiate steep or bumpy ground without becoming unstable.

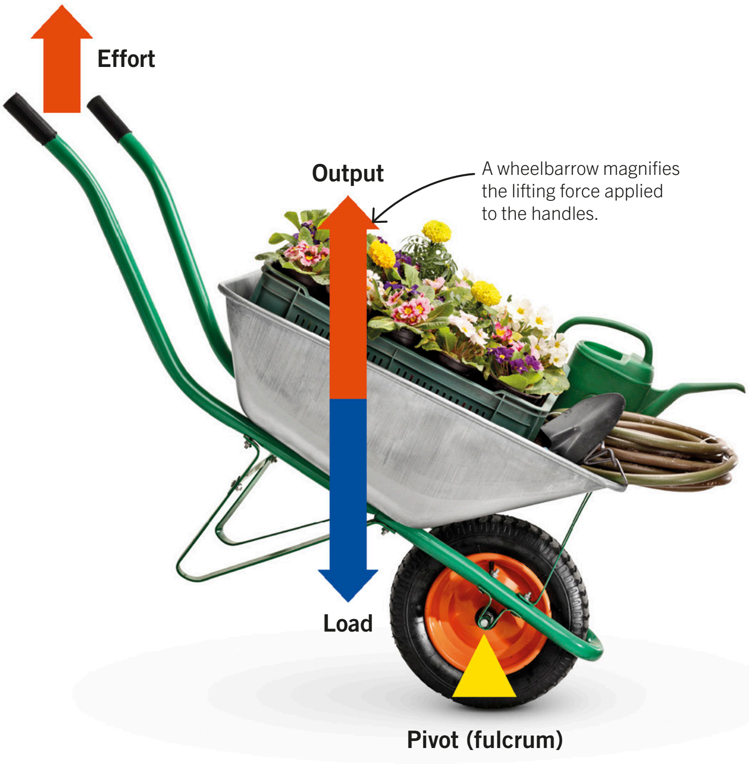


Levers

Levers are simple machines that magnify or reduce the effects of forces. We use them all the time, often without realizing. Scissors, wheelbarrows, door handles, and even our arms and legs work as levers.

How levers work

A wheelbarrow acts as a lever to make lifting easier. Like all levers, it rotates around a point called a pivot (or fulcrum), which in this case is the wheel. When a force (called the effort) is applied at the handles to lift the wheelbarrow, it is magnified to create a larger output force that overcomes the load in the barrow. The farther the effort is from the load, the greater the force is magnified.



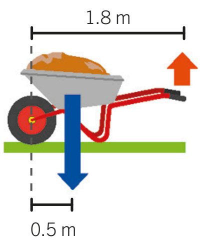
Key facts

- ✓ **A lever is a rigid object that can rotate around a fixed point called a pivot or a fulcrum.**
- ✓ **Levers can magnify or reduce the effect of a force.**
- ✓ **Levers that magnify a force reduce the distance traveled by the load.**
- ✓ **Levers that reduce a force increase the distance traveled by the load.**

Calculating effort

Question

A wheelbarrow is filled with soil weighing 450 N and with a center of mass 0.5 m from the wheel. If the handles are 1.8 m from the wheel, what is the effort needed to lift the soil?



Answer

First, use the equation for moments (see page 84) to calculate the moment due to the load.

moment (Nm) = force (N) × distance (m)
= 450 N × 0.5 m
= 225 Nm

Next, calculate the force needed to produce a moment of the same size when applied at the handles. Rearrange the equation to make force the subject.

$$F = \frac{M}{d}$$

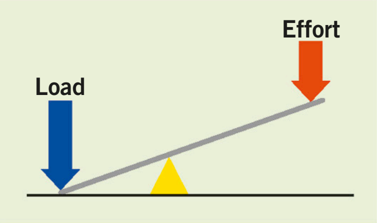
$$= \frac{225\text{ Nm}}{1.8\text{ m}}$$

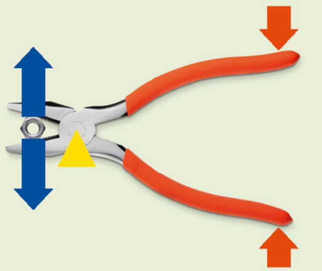
$$= 125\text{ N}$$

Lever classes

Levers come in three different classes, depending on where the effort, load, and pivot are in relation to each other. If the effort is farther from the pivot than the load, the lever magnifies the force. If the effort is nearer, the lever reduces the force but increases the distance moved.

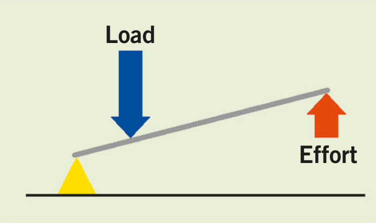
Class 1 Lever

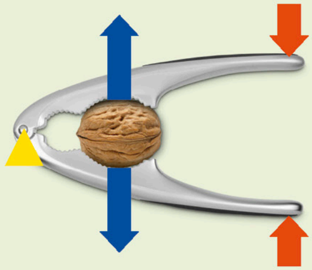




In class 1 levers, the pivot is between the effort and load. Class 1 levers can magnify or reduce forces. Pliers magnify forces to grip small objects tightly.

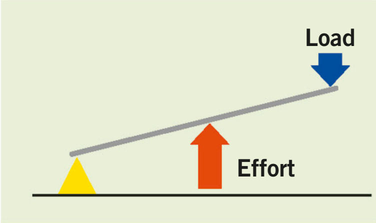
Class 2 Lever

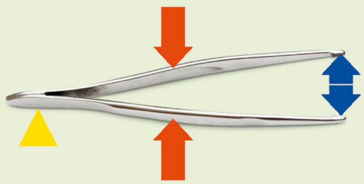




In class 2 levers, the load is between the pivot and the effort. These levers magnify the force you put in. Nutcrackers, for example, make it easier to crack nuts.

Class 3 Lever





In class 3 levers, the effort is between the pivot and the load. Tweezers and other class 3 levers reduce the force you put in, making it easier to handle delicate objects.

Machines

Mechanical devices that magnify or reduce forces (or that change the direction of forces) are known as machines. Simple machines such as levers often form parts of more complex machines with several moving parts. Here, a lever is connected via a gear to a toothed bar that moves down when the lever swings, magnifying the force from the user to squeeze oranges.

Gears

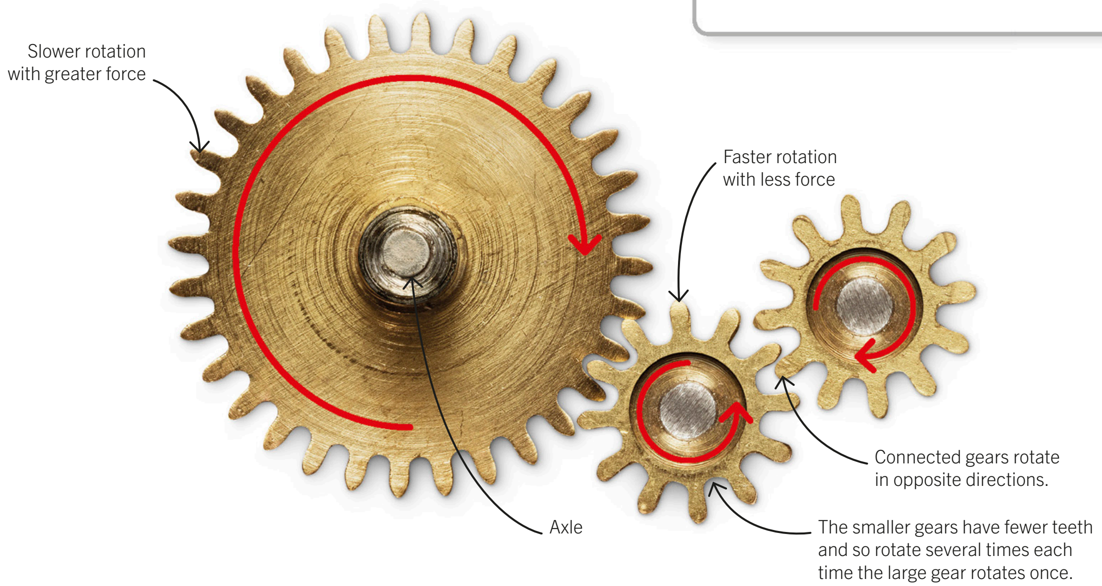
Gears are wheels with toothed edges that interlock to transmit rotational (turning) forces. Like levers, they can magnify or reduce the turning effects (moments) of forces.

How gears work

A gear transmits rotational force when its teeth mesh with those of another gear, causing it to turn as well. The forces acting at the teeth are the same for both gears, but the moments (the turning forces exerted on the axles) are different if connected gears have different numbers of teeth.

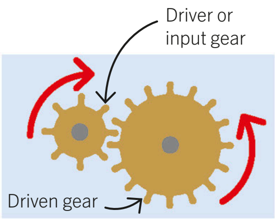
Key facts

- A gear is a wheel with a toothed edge.
- Gears transmit rotational forces.
- When the driven gear is larger than the gear driving it, it rotates more slowly but with a greater moment (stronger turning force).
- When the driven gear is smaller than the gear driving it, it rotates more quickly but with a smaller moment (weaker turning force).

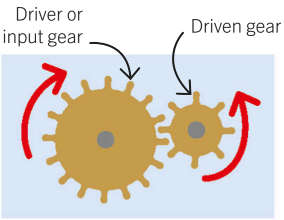


Using gears

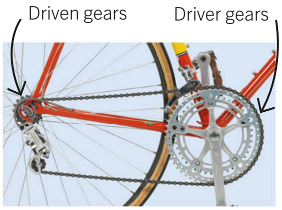
Gears can either magnify moments or increase the speed of rotation. Which they do depends on whether the driving gear is smaller or larger than the driven gear.



When the driven gear is larger than the gear driving it, the greater distance between the teeth and the axle means it produces a greater moment. This arrangement magnifies the input turning force.



When the driven gear is smaller than the driver gear, it produces a smaller moment on its axle but rotates faster. This arrangement increases speed.



The gears on a bike are connected by a chain. Choosing a small front gear and a large rear gear increases the moment—ideal for climbing a hill. Choosing a large front gear and small rear gear increases speed.

More simple machines

Levers and gears are not the only simple machines that can magnify or reduce forces. All the simple machines on this page make jobs easier by changing forces.

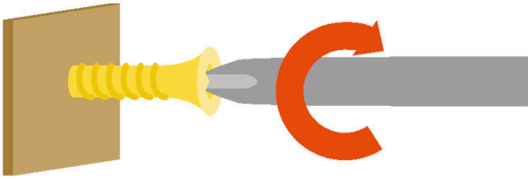
Key facts

- ✓ Simple machines can magnify or reduce forces or change their direction, making jobs easier.
- ✓ Simple machines include levers, gears, ramps, wedges, screws, wheels, and pulleys.

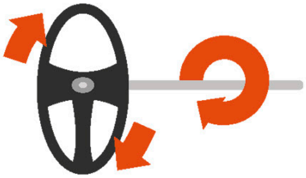
Wedges
A wedge is thick at one end and thin at the other. When you apply a force downward to the thick end, the thin end increases the force and drives it sideways, cutting or splitting an object.

Ramps
The sloping surface of a ramp makes it easier to raise a heavy object. The shallower the slope, the lower the input force needed. However, the load has to travel a longer distance, so the work done to lift the object is the same.

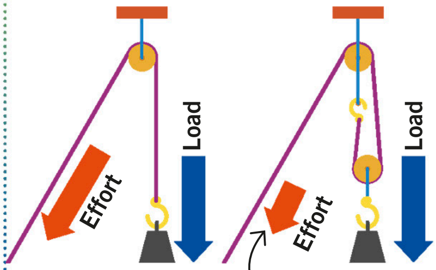
Screws
A screw is a ramp that has been coiled around a cylinder. Each twist of the screwdriver pushes the tip of the screw only a small amount forward but with greater force than the screwdriver exerts on the screw.



Wheels and axles
A wheel and axle work like a circular lever. Like levers, they can both increase or reduce forces. When the input force is applied to the rim, as with a steering wheel, the turning force around the circumference of the axle is magnified. When the input force is applied to the axle, the force at the rim is smaller but the rim moves faster than the circumference of the axle, as with a bicycle wheel.



Pulleys
A pulley is a rope or cable that runs around one or more wheels. If only one wheel is used, a pulley merely changes the direction of a force. However, if two wheels are arranged as shown below, the pulley doubles the lifting force. A three-wheel pulley can triple the lifting force.



A two-wheel pulley can halve the effort needed to lift a load.

Action–reaction forces

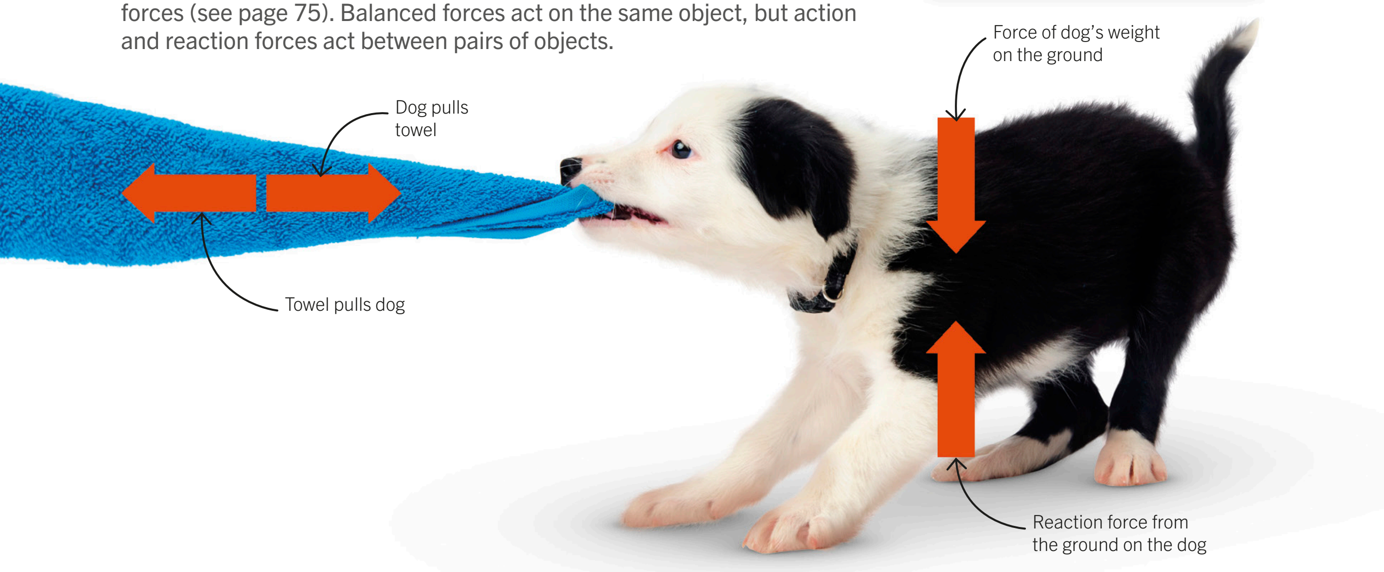
The English scientist Isaac Newton realized that forces always come in pairs. He said that every “action” (meaning force) has an equal and opposite “reaction” (opposing force). We call this Newton’s third law of motion.

Key facts

- ✓ Newton’s third law states that every force is accompanied by an equal force acting in the opposite direction.
- ✓ Pairs of action and reaction forces are always the same type of force and act between pairs of objects.
- ✓ Action and reaction forces shouldn’t be confused with balanced forces.

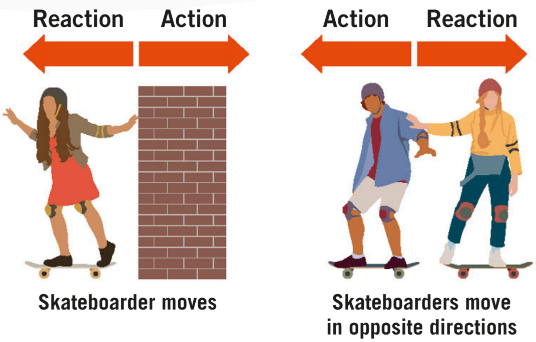
Action and reaction

This dog is pulling a towel, but the towel is also exerting a pulling force on the dog. These two forces are called action–reaction forces and exist whether the dog is moving or stationary. The dog also exerts a force on the ground because of its weight. This has a reaction force, too: the ground is pushing up on the dog. Action–reaction forces are not the same as balanced forces (see page 75). Balanced forces act on the same object, but action and reaction forces act between pairs of objects.



Effects of action–reaction pairs

Both forces in an action–reaction pair are real and can cause changes in motion or shape for the objects involved. For example, when a skateboarder pushes against a wall, she exerts a force on the wall and the wall exerts an equal and opposite force on her. The wall stays still, but the skateboarder gets a push in the opposite direction. If she pushes against another skateboarder, both move in opposite directions.

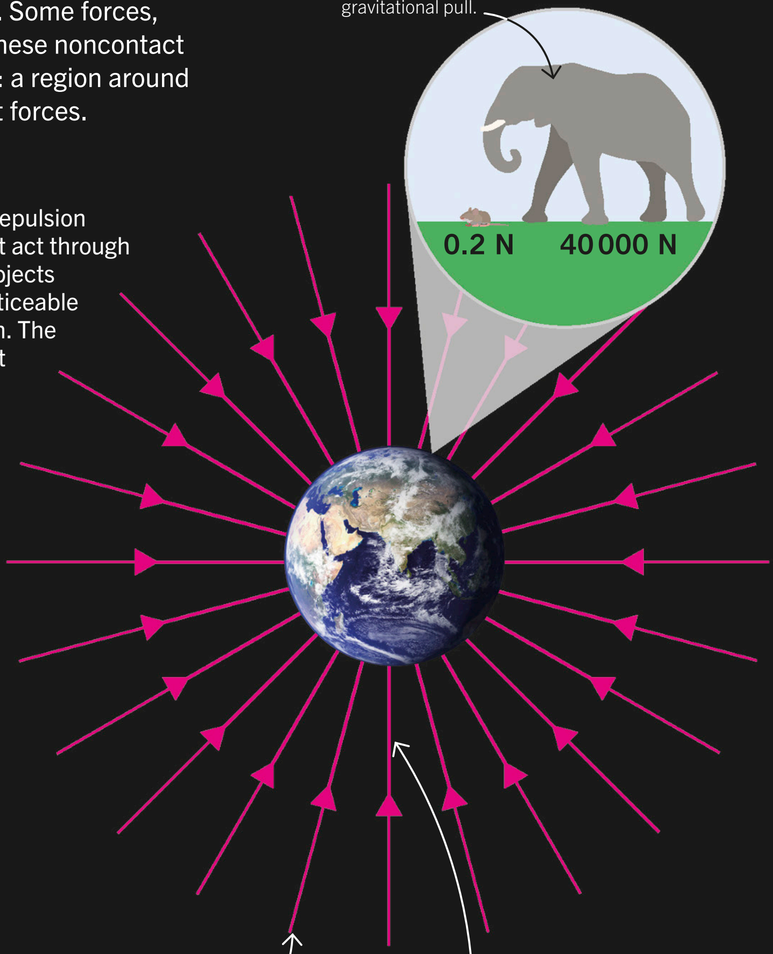


Fields

Not all forces require physical contact. Some forces, such as gravity, act from a distance. These noncontact forces involve something called a field: a region around an object in which the object can exert forces.

Action at a distance

Gravity, magnetism, and the attraction or repulsion between charged objects are all forces that act through a field. A gravitational field surrounds all objects with mass, but the pull of gravity is only noticeable around very massive objects, such as Earth. The strength of a noncontact force on an object depends on the strength of the field, the object's position within it, and the object's properties. For instance, Earth exerts a stronger gravitational pull on objects that are closer and that have more mass.

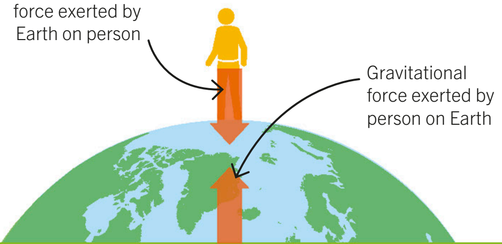


Key facts

- ✓ Noncontact forces act through a field.
- ✓ A field is the region around an object in which the object can exert forces.
- ✓ The size of the force depends on the strength of the field, the object's position within it, and the object's properties.

Newton's third law

Newton's third law says that every force has an equal and opposite reaction force. This holds true for noncontact forces exerted through fields. For instance, Earth exerts a gravitational pull on a person standing on its surface, but that person also has a gravitational field of their own and exerts an equal and opposite pull on Earth. But because Earth's mass is so vast, the effect of the reaction force on Earth is imperceptible.

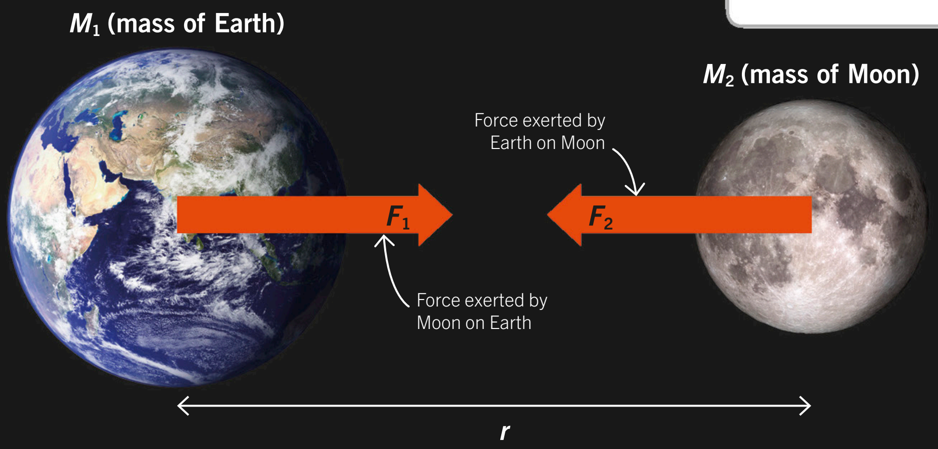


Law of gravity

All objects with mass, from galaxies to atoms, exert an attractive force on other objects with mass through their gravitational fields. The size of the force between any two objects can be worked out from Newton's law of universal gravitation, which was developed by the English scientist Isaac Newton.

Earth and Moon

Newton used observations of the Moon and planets to work out his law of gravity. He realized that the force of gravity between any two bodies is proportional to their masses multiplied together (the product of their masses). But gravity also declines as objects get farther apart, falling in proportion to the square of the distance between their centers. This relationship can be written as an equation.



The letter *G* stands for a number called the gravitational constant.

$$F_1 = F_2 = G\frac{M_1 \times M_2}{r^2}$$

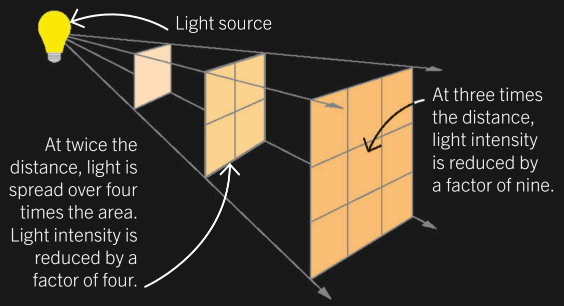
r is the distance between the centers of the two bodies.

Key facts

- All objects with mass are surrounded by a gravitational field in which other objects with mass are attracted.
- The gravitational force between two objects is proportional to the product of their masses.
- The gravitational force between two objects is inversely proportional to the square of the distance between them.

The inverse square law

Newton's law of universal gravitation follows a pattern known as the inverse square law: as the distance between two objects increases, the gravitational force between them falls in proportion to the square of the distance. In nature, there are many examples of a property following this pattern, including light intensity and the electrostatic force between charged objects.



Force and motion

Circular motion

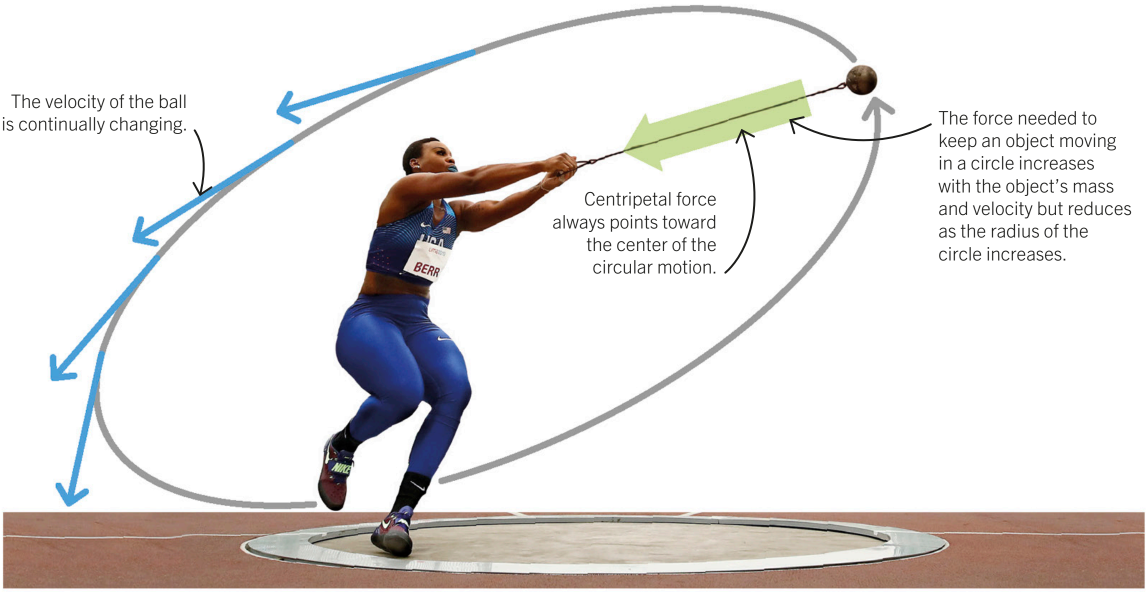
Many objects move along curved or circular paths, from the Moon orbiting planet Earth to the passengers on a fairground ride. The force that makes an object travel in a circle is called centripetal force.

Key facts

- ✓ Circular motion occurs due to a centripetal force, which acts inward.
- ✓ Without centripetal force, a moving object would travel in a straight line.
- ✓ Centrifugal force is a fictitious force experienced by objects traveling along a curved path.
- ✓ The force needed to keep an object moving in a circle increases with an object's mass and velocity but falls as the radius of the circle increases.

Centripetal force

In the hammer throw, a weighted ball is swung around in circles before being released. Its velocity is changing continually as it swings, which means the ball is accelerating. All accelerations are caused by a force, and in this case the force is tension in the cable. This is an example of centripetal force. If the centripetal force suddenly stops, the object flies off in a straight line.



Centrifugal force

On a swing ride, the riders experience what feels like a real force pulling them outward and making their seat rise. This is called centrifugal force, but it is not a real force. It only feels like a force from the point of view of the riders, so we call it a fictitious force. It is caused by centripetal force pulling them toward the center while their mass tries to move away in a straight line due to its inertia.

Newton's second law

When an unbalanced force acts on an object, the object accelerates. The English scientist Isaac Newton worked out a simple relationship between the size of the force, the mass of the object, and its acceleration. We call this Newton's second law.

Force, mass, and acceleration

A van with lots of luggage accelerates more slowly than a van with no luggage because it has more mass. The greater the mass, the smaller the acceleration. Cars with more powerful engines also accelerate faster because they can generate a greater pushing force. The greater the force, the greater the acceleration. The relationship between force, mass, and acceleration is shown by this equation.

$$\text{force (N)} = \text{mass (kg)} \times \text{acceleration (m/s}^2\text{)}$$

$$F = m \times a$$

The van with no luggage accelerates faster.

Key facts

- ✓ The larger the force on an object, the greater the acceleration.
- ✓ The greater the mass of an object, the smaller the acceleration.
- ✓ Newton's second law can be summed up by an equation: force = mass × acceleration.
- ✓ Inertial mass is a measure of how difficult it is to change an object's velocity.

Inertial mass

Massive objects are hard to get moving, and once moving, they're difficult to stop. We say they have lots of "inertia." The inertial mass of an object is a measure of how difficult it is to change its velocity. It is defined as the ratio of force over acceleration:

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

Calculating acceleration

Question

A 500 kg cart is pushed with a force of 90 N. What is its acceleration?

Answer

Rearrange the equation to make acceleration the subject.

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

$$= \frac{90\text{ N}}{500\text{ kg}}$$

$$= 0.18\text{ m/s}^2$$

Investigating acceleration

This experiment demonstrates the effect of force or mass on motion by using a hanging weight to pull a cart along a ramp. It shows that acceleration is directly proportional to force (doubling the force doubles the acceleration) and inversely proportional to mass (doubling the mass halves the acceleration).

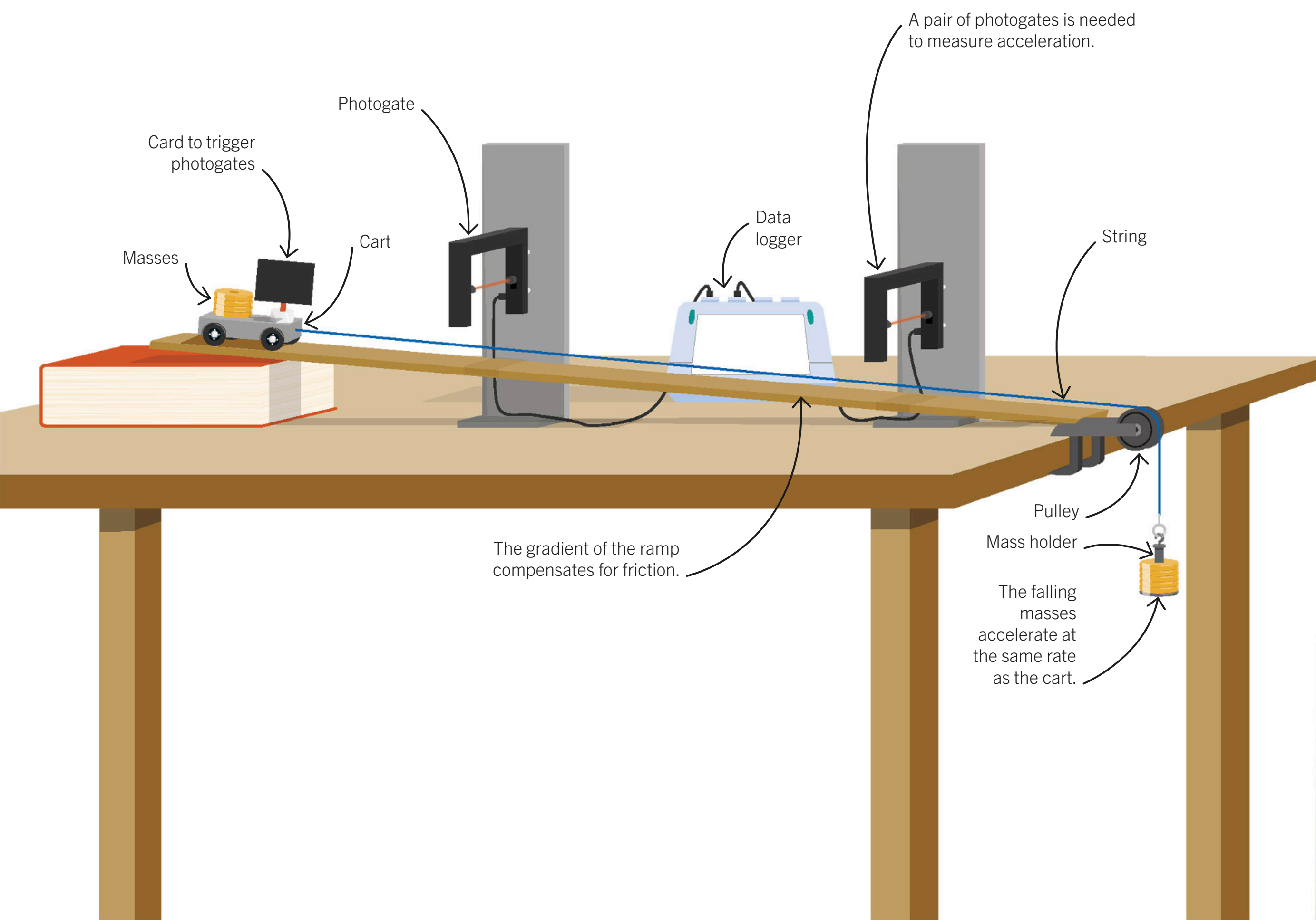
Key facts

- ✓ Increasing the force applied to a moving object increases its acceleration.
- ✓ Acceleration is directly proportional to force.
- ✓ Acceleration is inversely proportional to mass.

Accelerating cart

You can use a setup like the one below for the experiment. Photogates measure the cart's velocity at two points on a ramp, and a data logger uses the two velocities and the time between the measurements to calculate acceleration. The slope of the ramp compensates for friction.

Teacher supervision required



Methods

Method 1: Effect of force on acceleration

1. Set up the equipment as shown and set the data logger to calculate acceleration.
2. Adjust the gradient of the ramp until an unweighted cart rolls at a constant speed when given a gentle push.
3. Begin by placing a single mass at the end of the string and nine masses on the cart. If you use a mass holder designed to equal one mass, use that as the first mass. Record the total mass of the system (the cart plus all the masses).
4. Release the cart from the top of the ramp and record the acceleration. Roll the cart down the ramp two more times and take the average of the three measurements of acceleration.
5. Move a mass from the cart to the string to increase the force, then repeat step 4. Keep doing this until 10 masses are on the string. Record all of your data in a table.

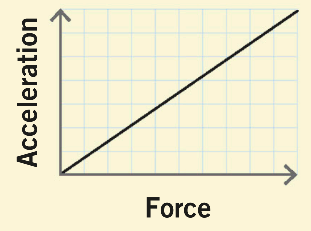
Method 2: Effect of mass on acceleration

1. Use the same setup as above, but place five masses on the end of the string and none on the cart to begin with.
2. Roll the cart down the ramp. Record the total mass (cart + masses) and the acceleration. Roll the cart two more times and take an average of the three acceleration readings.
3. Add a mass to the cart and repeat step 2. Repeat with additional masses until the cart has five masses.

Results

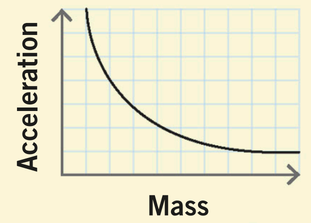
Result 1

Use the data from the first investigation to draw a graph of acceleration against force. Acceleration is the dependent variable, so it should go on the y-axis. The points should form a straight line that goes through the origin (0, 0). This shows that acceleration is directly proportional to the force.



Result 2

Plotting acceleration against mass on a graph produces a downward curve showing an inversely proportional relationship. (If mass doubles, acceleration halves.)



Ariel Atom
Some sports cars are designed to minimize mass so they can accelerate as fast as possible for the same engine power. The Ariel Atom has a naked chassis with no roof, doors, or windows, resulting in a mass about half that of a hatchback car.

Momentum

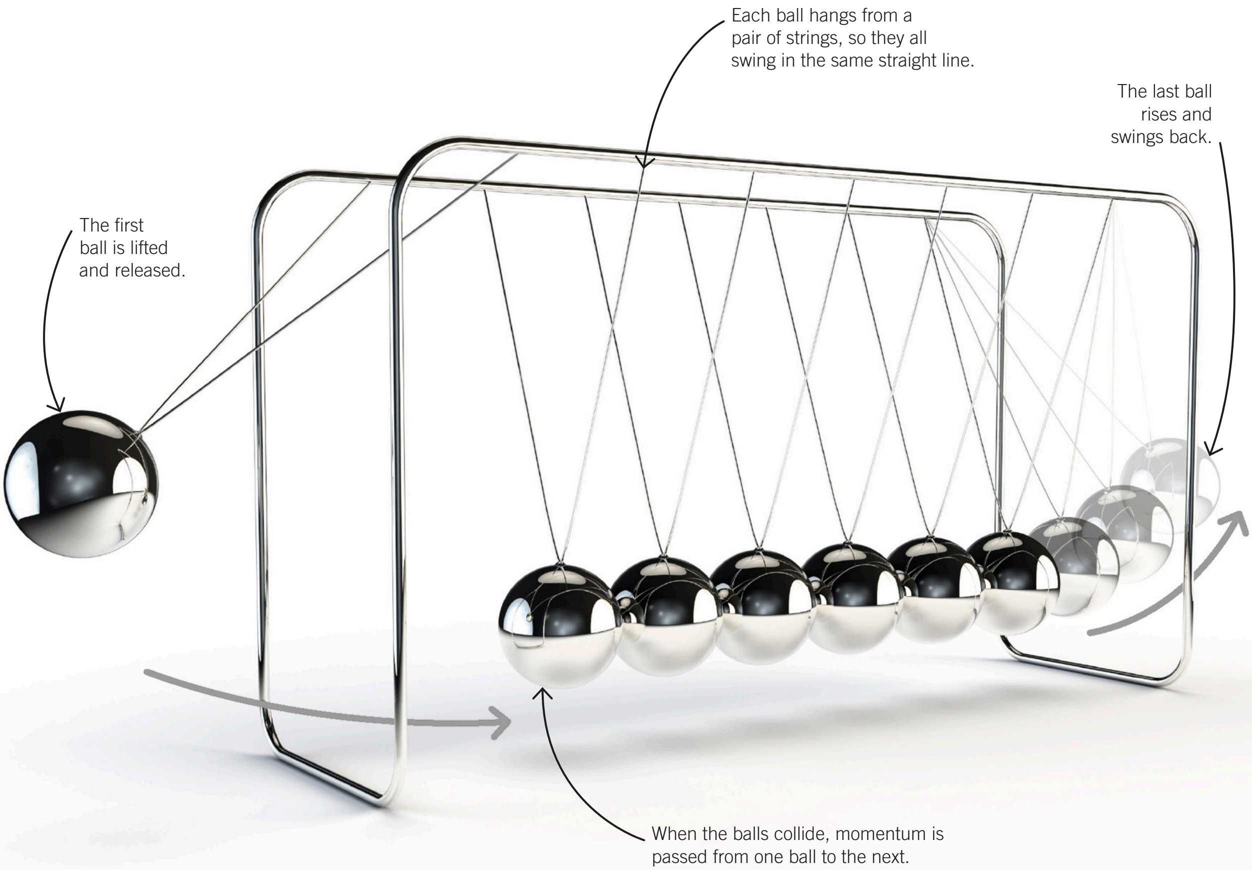
When objects collide, the effect one object has on another depends on a quantity called momentum. The greater the mass of a moving object or the faster the object is moving, the greater its momentum and the greater the effect it can have.

Key facts

- ✓ The greater an object's mass or the faster it is moving, the more momentum it has.
- ✓ Momentum = mass × velocity.
- ✓ The law of conservation of momentum says that in a system not affected by external forces, total momentum is the same before and after a collision.
- ✓ Momentum is a vector, so calculations must take into account the direction the object is moving in.

Conservation of momentum

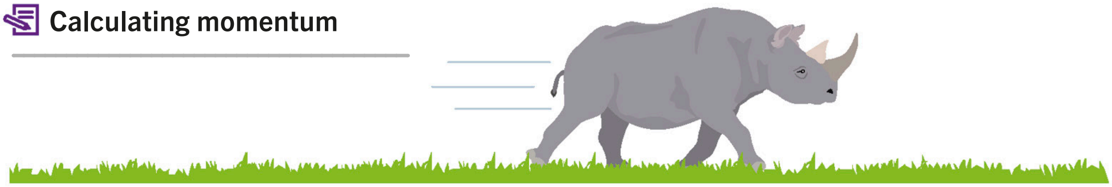
Newton's cradle is a device that demonstrates a law known as conservation of momentum. According to this law, when a system is not affected by external forces, the total momentum in the system is the same before and after a collision. When one of the metal balls is lifted and allowed to hit the others, its momentum passes from ball to ball, making the last ball rise and repeat the cycle.



Formula for momentum
Both velocity and mass affect an object's momentum, as the equation below shows. Shooting stars are often no bigger than grains of sand, but they have great momentum because of their speed. Large vehicles such as freight trains have enormous momentum due to their great mass and can cause dangerous collisions even when moving slowly. Momentum is a vector, so calculations must take into account the direction in which the object is moving.

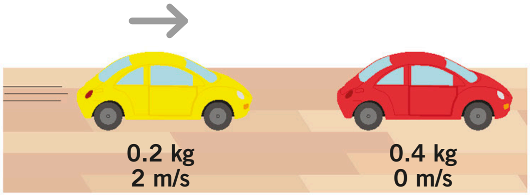
$$\text{momentum (kg m/s)} = \text{mass (kg)} \times \text{velocity (m/s)}$$
$$p = m \times v$$

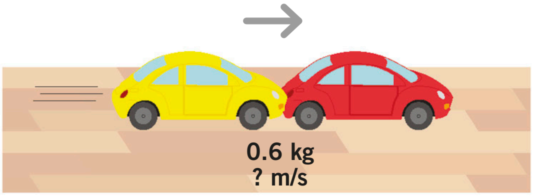
Calculating momentum



Question 1
A rhinoceros has a mass of 1000 kg and is traveling at 15 m/s. How much momentum does it have?

Answer 1
$p = m \times v$
$= 1000 \text{ kg} \times 15 \text{ m/s}$
$= 15000 \text{ kg m/s}$





Question 2
A toy car with a mass of 0.2 kg hits another toy car with a mass of 0.4 kg while traveling at 2 m/s. The two cars stick together and continue moving in the same direction. What speed are they going at?

Answer 2
The total momentum is conserved, so use the following equation to work out the answer:

momentum before collision = momentum after collision

momentum before = (0.2 kg × 2 m/s) + (0.4 kg × 0 m/s)
= 0.4 kg m/s
momentum after = 0.4 kg m/s

$v = \frac{p}{m}$

$= \frac{0.4 \text{ kg m/s}}{0.2 \text{ kg} + 0.4 \text{ kg}}$

$= 0.67 \text{ m/s}$

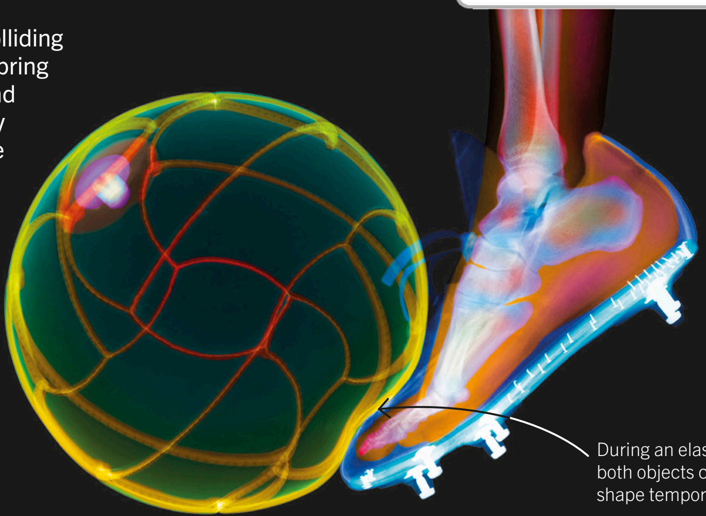
Elastic and inelastic collisions

When objects collide, the total momentum before and after the collision is conserved (see page 100). However, kinetic energy may not be. Whether kinetic energy is conserved or not depends on whether a collision is elastic or inelastic.

Key facts

- ✓ Collisions can be elastic or inelastic.
- ✓ Kinetic energy is conserved in an elastic collision and lost in an inelastic collision.
- ✓ Total momentum is the same before and after a collision.

Elastic collisions
During an elastic collision, the colliding objects change shape but then spring back into their original shapes and separate. The total kinetic energy of the moving objects is the same before and after the collision. Few collisions in the real world are perfectly elastic, as some kinetic energy is usually lost. For example, when a foot kicks a ball, some kinetic energy is transferred to sound.

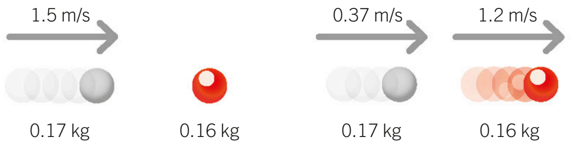


During an elastic collision, both objects change shape temporarily.

Calculating kinetic energy

Most collisions result in a loss of some kinetic energy. We can find out how much is lost by calculating the kinetic energy before and after the collision.

Question
During a game of billiards, a 0.17 kg white ball traveling at 1.5 m/s hits a stationary red ball with a mass of 0.16 kg. The red ball moves forward at 1.2 m/s and the white ball at 0.37 m/s. How much kinetic energy was lost?



Answer
Use the equation for kinetic energy from page 52 ($E_k = ½ \times m \times v^2$) to work out the total kinetic energy before and after the collision.

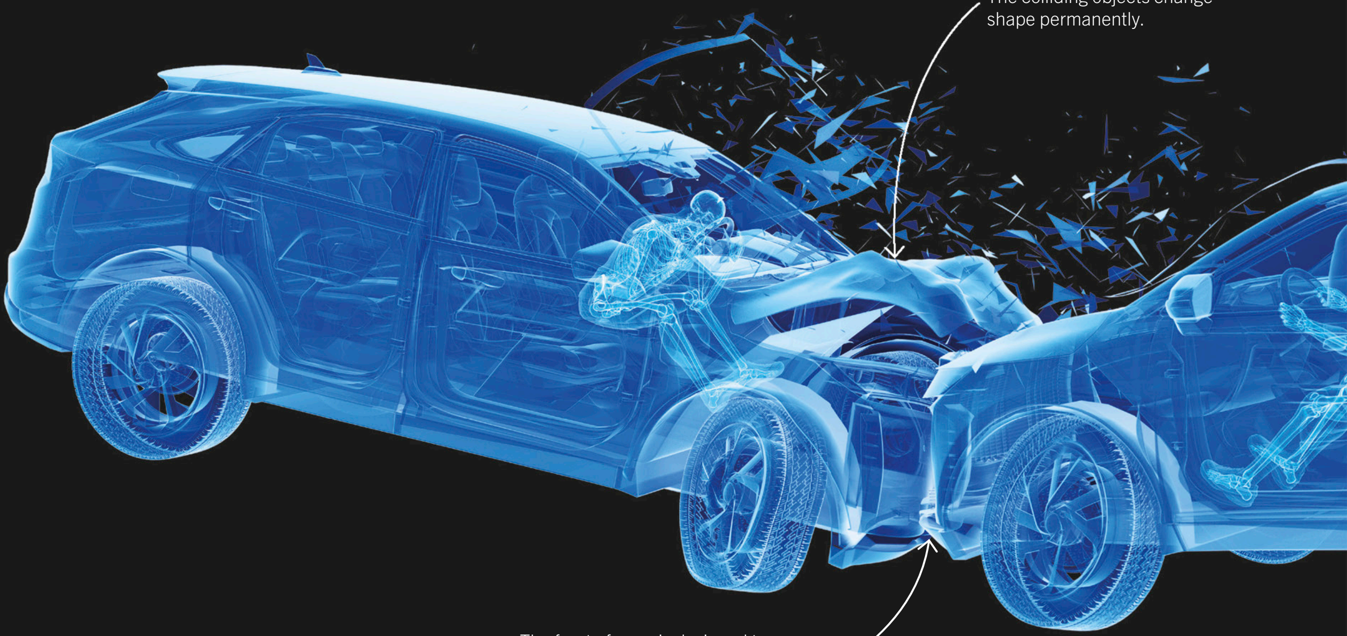
Kinetic energy before collision $= ½ \times 0.17 \times 1.5^2$
$= 0.19$ J

Kinetic energy after collision
$= (½ \times 0.17 \times 0.37^2) + (½ \times 0.16 \times 1.2^2)$
$= 0.13$ J

The energy lost $= 0.19$ J $- 0.13$ J
$= 0.06$ J

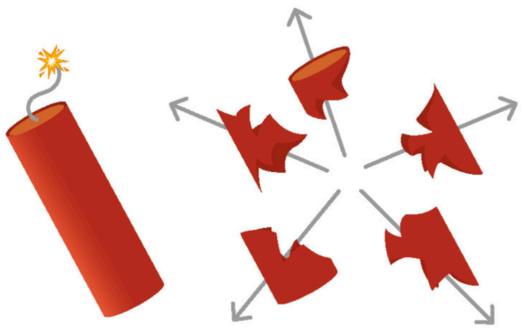
Inelastic collisions

In an inelastic collision, the colliding objects can change shape permanently and may join together. Kinetic energy is transferred to sound, internal energy, and other energy stores. For example, the car collision shown below is inelastic. Instead of rebounding like a soccer ball off a shoe, the cars lose kinetic energy and come to a halt. The shape of both cars is permanently changed.



Explosions

In an explosion, momentum is conserved but kinetic energy is not. An unexploded bomb has zero kinetic energy when it's stationary, but the exploding fragments have a huge amount of kinetic energy. However, momentum stays the same. The total momentum of a stationary bomb is zero, and the total momentum of the fragments is also zero. (Momentum is a vector quantity, and the fragments all travel outward in different directions.)



Changing momentum

Changing the momentum of a moving object—whether stopping a car or striking a tennis ball—requires a force. The greater the change in momentum or the more quickly the momentum changes, the greater the force required. Car crashes are dangerous because the very rapid change in momentum involves huge forces.

Key facts

- ✓ Changing an object's momentum requires a force.
- ✓ The more momentum an object has, the larger the force needed to stop it, or the longer the stopping force must be applied.

Force and momentum

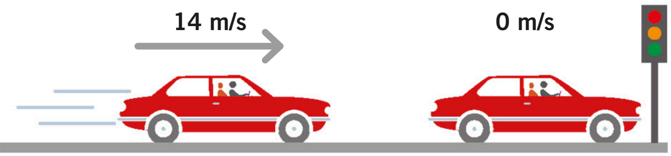
When a car comes to a halt, its momentum falls to zero. We can calculate the force needed to change the car's momentum using the equation here. As the examples below demonstrate, a far greater force is needed to stop a car suddenly than to slow it down gradually.

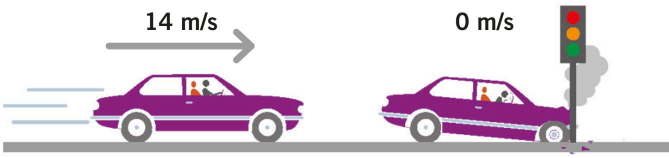
$$\text{force (N)} = \frac{\text{change in momentum (kg m/s)}}{\text{time (s)}}$$

Final velocity

$$F = \frac{mv_f - mv_i}{t}$$

Initial velocity





Stopping gradually

A car with a mass of 1000 kg is traveling at 14 m/s (about 31 mph [50 km/h]). The driver brakes for 10 seconds, bringing the car to a stop. What is the force acting on the car?

Remember to take the initial momentum away from the final momentum.

$$F = \frac{(1000\text{ kg} \times 0\text{ m/s}) - (1000\text{ kg} \times 14\text{ m/s})}{10\text{ s}}$$

$$= \frac{0 - 14\,000\text{ kg m/s}}{10\text{ s}}$$

$$= -1400\text{ N}$$

The force is negative because it acts in the opposite direction to the motion of the car.

Stopping suddenly

A car of the same mass is also traveling at 14 m/s. It hits a traffic light and decelerates to 0 m/s in 0.07 seconds. What is the force acting on this car?

$$F = \frac{(1000\text{ kg} \times 0\text{ m/s}) - (1000\text{ kg} \times 14\text{ m/s})}{0.07\text{ s}}$$

$$= \frac{0 - 14\,000\text{ kg m/s}}{0.07\text{ s}}$$

$$= -200\,000\text{ N}$$

The force that stops the car is equivalent to the weight of five elephants.

Stopping distance

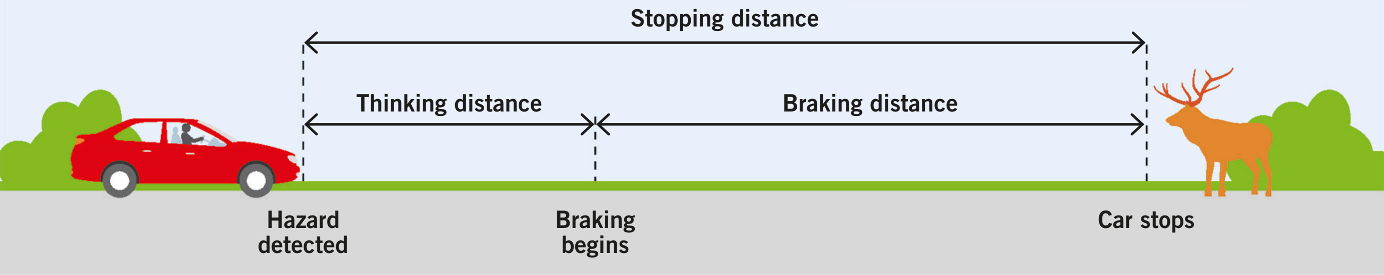
In an emergency, a driver may see a hazard and have to stop the car very quickly. The distance the car travels between the driver seeing the hazard and the car coming to a stop is called the stopping distance and is affected by the car's speed, mass, and other factors.

Key facts

- ✓ Stopping distance is the distance covered between the driver seeing a hazard and the vehicle stopping.
- ✓ Stopping distance is the sum of thinking distance and braking distance.
- ✓ Factors affecting thinking distance include tiredness, use of drugs or alcohol, distractions, and the vehicle's speed.
- ✓ Factors affecting braking distance include the vehicle's speed, mass, condition, and road and weather conditions.

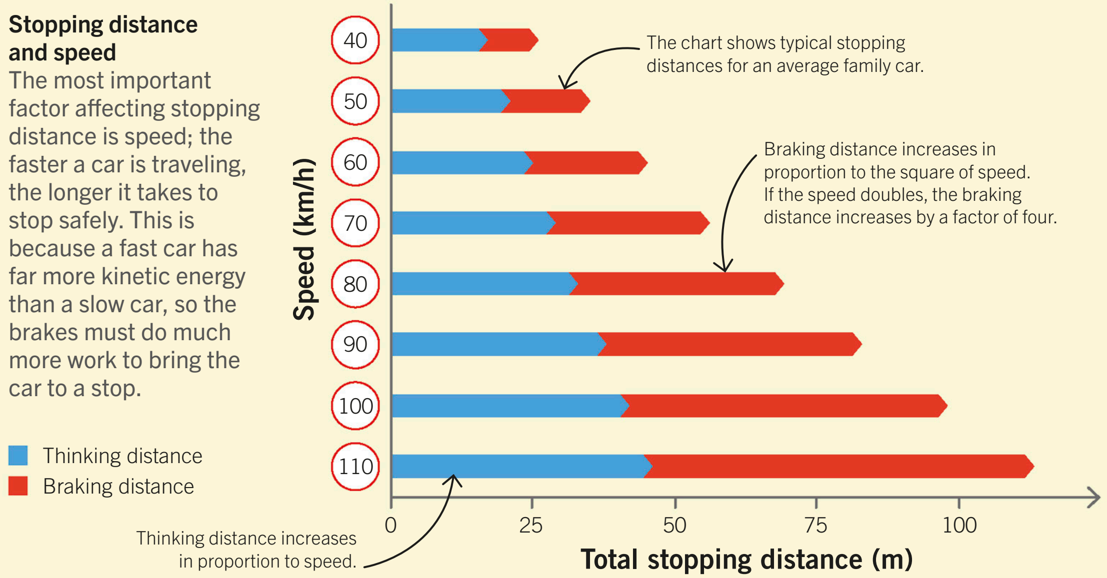
Thinking and braking

Total stopping distance can be divided into two parts: thinking distance and braking distance. Thinking distance is the distance the car travels during the time a driver takes to react and use the brakes after seeing a hazard. Braking distance is the distance the car travels after braking begins.



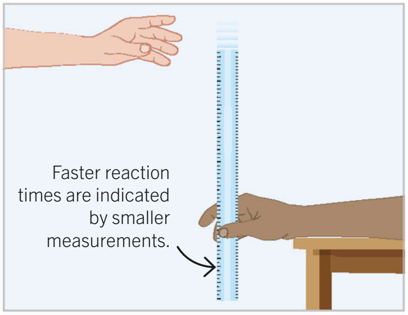
Stopping distance and speed

The most important factor affecting stopping distance is speed; the faster a car is traveling, the longer it takes to stop safely. This is because a fast car has far more kinetic energy than a slow car, so the brakes must do much more work to bring the car to a stop.

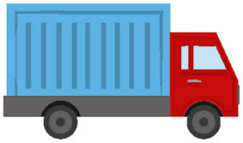


Reaction time

Most drivers take about 0.7 seconds to react to a hazard, but this time can more than triple if a driver has been drinking alcohol, has taken drugs, or is distracted by a mobile phone. Reaction times also vary from person to person and are affected by how tired we are. You can assess your reaction time with a simple experiment: ask a helper to drop a ruler without warning and see how quickly you can catch it.



Factors affecting braking distance



Massive vehicles have more kinetic energy than smaller vehicles, so they require a longer braking distance.

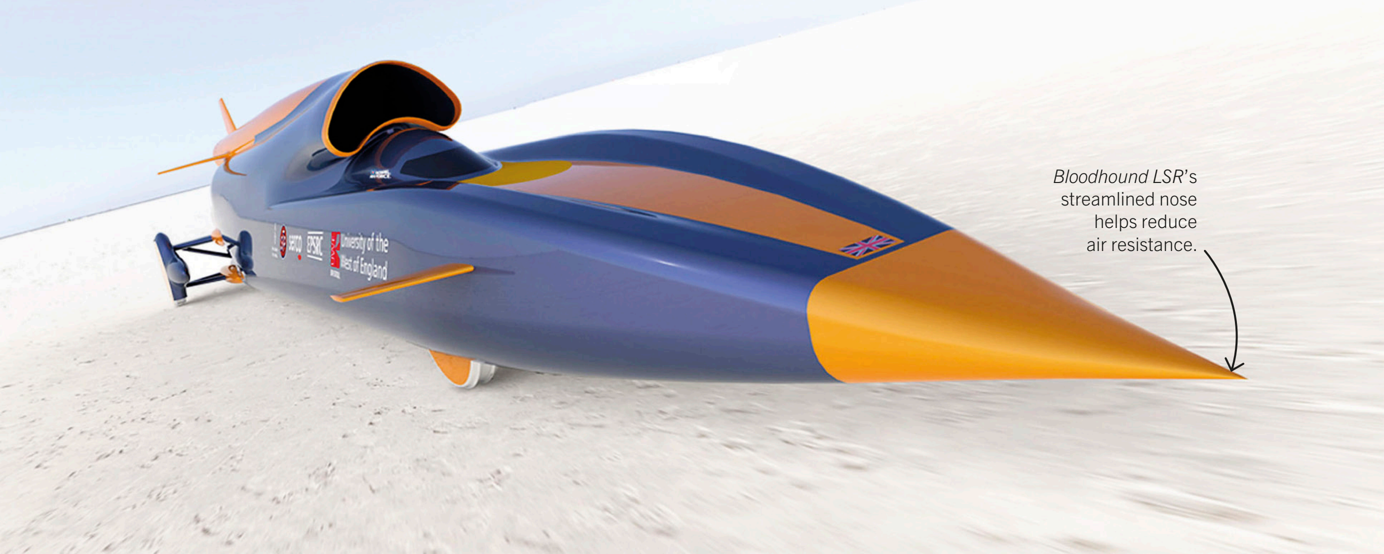
Fast vehicles have more kinetic energy than slow vehicles, so they require a longer braking distance.

Tire and brake condition affect braking distance. If they are worn or in poor condition, they create less friction, which means less force to reduce kinetic energy.

Wet or icy roads reduce friction, resulting in a smaller stopping force. They may also cause skids.

Supersonic stopping distance

Braking distance increases in proportion to the square of a car's speed. (Doubling the speed causes braking distance to increase by a factor of four.) As a result, the supersonic car *Bloodhound LSR*, which is designed to break the land speed record, has a braking distance of around 7.2 km, even with the assistance of a braking parachute.



Car safety features

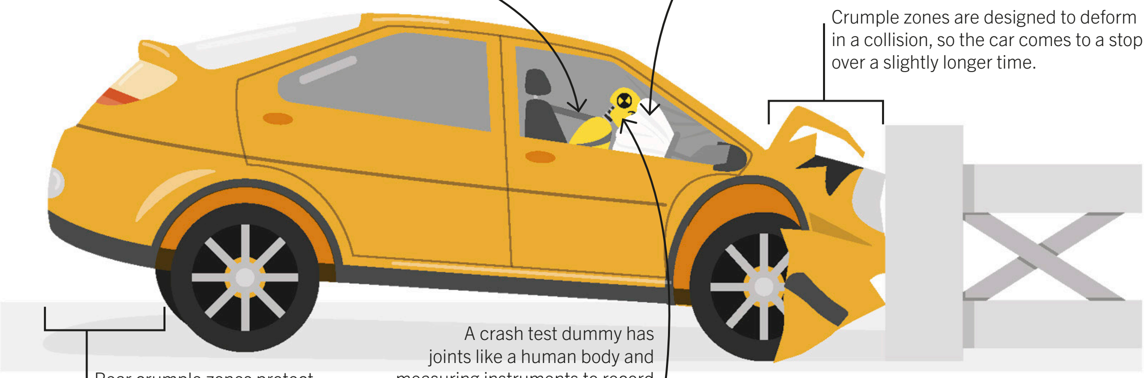
During a car crash, the car and everything inside it undergo a rapid change in momentum. The force on the people in the car from the collision is equal to the rate of change of their momentum. In order to minimize this large force, which can cause serious injuries, cars have safety features that slow the change in momentum.

Key facts

- ✓ Car crashes involve extreme changes in momentum and large, dangerous forces.
- ✓ Slowing down the change in momentum reduces the forces in a crash.
- ✓ Car safety features include airbags, seatbelts, and crumple zones.

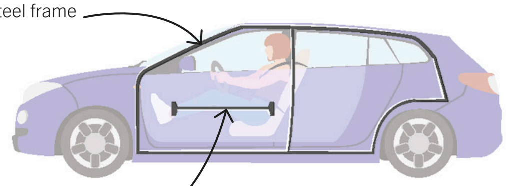
Crash test

Simulating car crashes allows engineers to measure the forces on different parts of a passenger's body and ensure that safety features are effective. The main safety features are seatbelts, the front and rear crumple zones, and airbags. Airbags and crumple zones increase the time it takes for the person's body to come to a stop, which reduces the change in momentum and hence the forces on the passengers.



Safety cage

Many parts of a modern car are designed to deform safely during a collision, reducing the forces on the passengers. However, some parts must be protected from crumpling, including the cabin containing the occupants and the fuel tank or battery. These areas are enclosed by a rigid steel frame called a safety cage, which can withstand huge forces without significant deformation.



Braking distance and energy

To stop a car, its kinetic energy must be transferred to other energy stores. The faster a car is moving, the more kinetic energy it has to transfer away and the greater its braking distance.

Key facts

- ✓ A braking force does work on a vehicle to change its motion.
- ✓ The work done braking is equal to the change in kinetic energy.
- ✓ The braking distance required to stop a car safely increases in proportion to the square of the car's speed.

Kinetic energy

A moving car has a store of kinetic energy. We can calculate how much by using the equation from page 52: kinetic energy = ½ × m × v^2. When the brakes are used to slow down the car, they exert a force and do work. Because the work done braking is equal to the change in kinetic energy, we can combine the equation for work (see page 55) with the equation for kinetic energy to make a new equation:

$$\text{work (J)} = \text{force (N)} \times \text{distance (m)}$$

$$\text{kinetic energy (J)} = \frac{1}{2} \times \text{mass (kg)} \times \text{speed}^2 \text{ (m/s)}^2$$

$$\text{force (N)} \times \text{distance (m)} = \frac{1}{2} \times \text{mass (kg)} \times \text{speed}^2 \text{ (m/s)}^2$$

$$F \times d = \frac{1}{2} \times m \times v^2$$

The combined equation is useful because it allows us to calculate braking distance (d) if we know a car's speed, mass, and the force of its brakes.

Calculating braking distance

Question
A uniform braking force of 2000 N is applied to the wheels of a 1100 kg car traveling at 13 m/s (about 29 mph/47 km/h). What is its braking distance? What would the braking distance be at twice that speed?

Answer 1
Rearrange the equation to make braking distance the subject.

$$d = \frac{\frac{1}{2} \times m \times v^2}{F}$$

$$= \frac{\frac{1}{2} \times 1100 \text{ kg} \times 13 \text{ m/s} \times 13 \text{ m/s}}{2000 \text{ N}}$$

$$= 46 \text{ m}$$

Answer 2

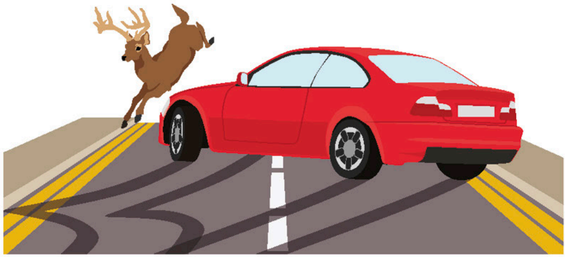
$$d = \frac{\frac{1}{2} \times 1100 \text{ kg} \times 26 \text{ m/s} \times 26 \text{ m/s}}{2000 \text{ N}}$$

$$= 186 \text{ m}$$

At twice the speed, braking distance is four times greater. Braking distance is proportional to the square of the speed.

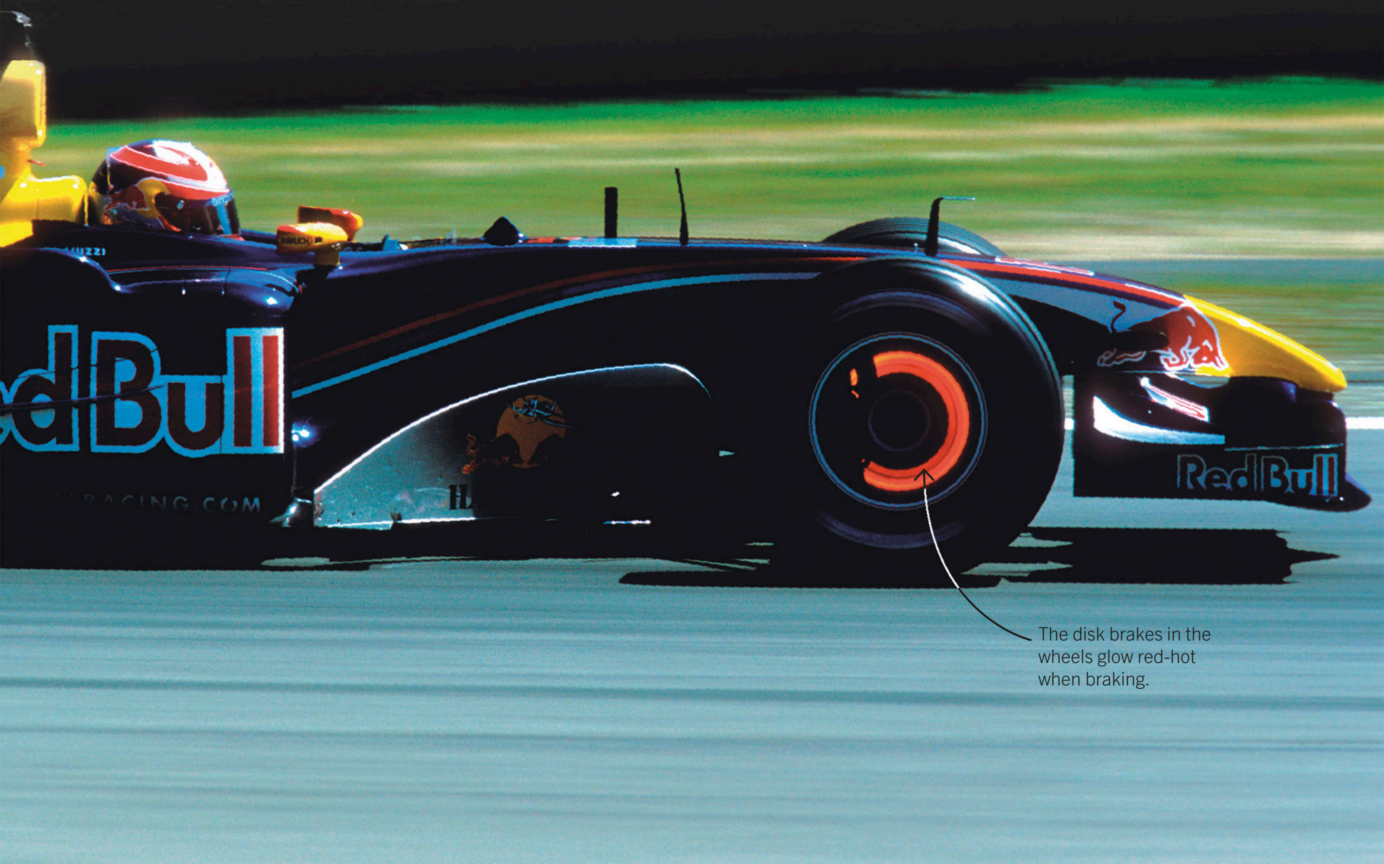
Speed and safety

The combined equation shows that braking distance increases in proportion to the square of a car's speed. In other words, if you double the speed, the braking distance is four times greater; if you triple the speed, the braking distance is nine times greater. This is one of the reasons that driving at high speeds is dangerous—a faster car not only has a lot more momentum than a slow car, but also needs far more room to stop.



Brake disks

When a car brakes, energy is transferred from its store of kinetic energy to thermal energy stores, making the brakes hot. Formula 1 cars are built to accelerate and decelerate incredibly quickly. Huge amounts of energy are transferred while braking, causing the brake disks to glow red hot.



The disk brakes in the wheels glow red-hot when braking.

Terminal velocity

Falling objects accelerate due to the pull of Earth's gravity. However, a falling object stops accelerating when it reaches terminal velocity. At this point, the downward force of its weight is balanced by the upward force of air resistance.

Key facts

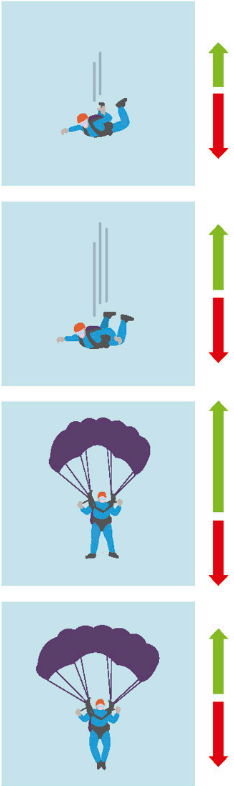
- ✓ Air resistance is a type of frictional force that acts in the opposite direction to an object moving through air.
- ✓ The faster an object moves through a fluid (gas or liquid), the greater the force of resistance.
- ✓ Terminal velocity is the constant velocity a falling object reaches when the vertical forces acting on it are balanced.

Skydivers
Skydivers typically reach a terminal velocity of 55 m/s (124 mph/200 km/h) about 12 seconds after jumping out of a plane. They spend a minute or so falling at this speed before opening their parachutes and experiencing a few seconds of intense deceleration, which reduces their speed to less than 8.3 m/s (19 mph/30 km/h).

When skydiving headfirst rather than spread-eagled, skydivers can reach a terminal velocity of 186 mph/300 km/h.

Using air resistance

Air resistance acts in the opposite direction to an object's motion. Planes and birds are streamlined to minimize air resistance, but parachutes work the opposite way: their large area creates maximum air resistance, allowing a person to fall to Earth at a very low terminal velocity.



1. When a skydiver leaps from a plane, air resistance is small to begin with. The skydiver's weight is greater than the force of air resistance, so the resultant force is downward. As a result, the skydiver accelerates.

2. As the skydiver speeds up, air resistance increases until it equals the skydiver's weight. The forces are now balanced, so the skydiver stops accelerating and falls at a constant speed: terminal velocity.

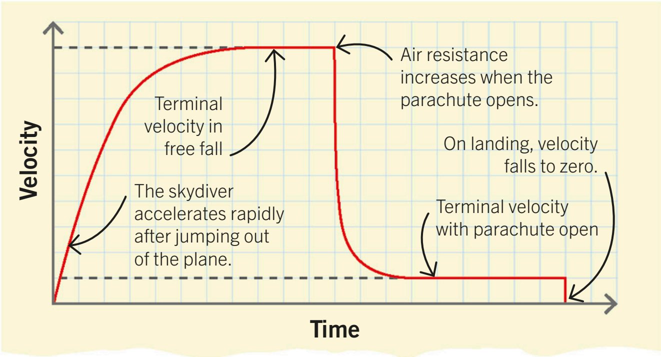
3. When the skydiver opens the parachute, air resistance increases dramatically. It is now much greater than the skydiver's weight, causing a resultant upward force. The skydiver decelerates (but continues to fall).

4. As the skydiver slows down, air resistance falls. Eventually, it matches weight again, and the skydiver reaches a new, lower terminal velocity that makes it safe to land.

Air resistance
Weight

Velocity—time graph

A skydiver's journey from plane to ground can be shown on a velocity—time graph. The two horizontal sections represent terminal velocity, and the sudden drop in velocity marks the sudden deceleration after the parachute opens.



Waves

Waves

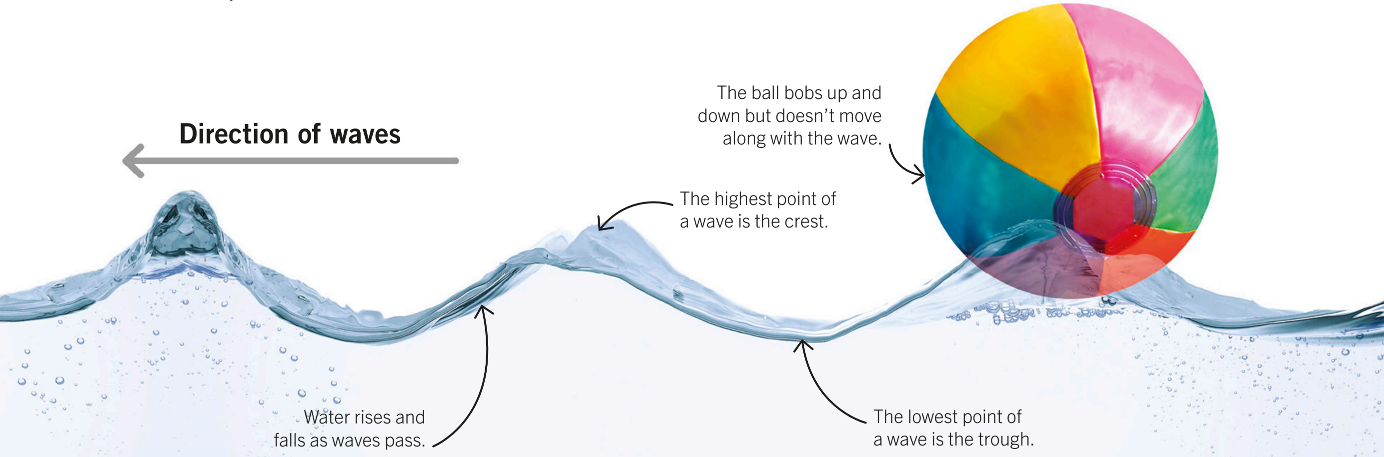
Waves are vibrations that transfer energy from place to place without transferring matter at the same time. Some waves, such as ripples in a pond or sound waves in air, can only travel through matter. Other kinds of wave, such as light, can travel through empty space.

Key facts

- Waves are vibrations that transfer energy without transferring matter.
- The wavelength of a wave is the distance from one wave peak to the next.
- The amplitude of a wave is the height of its peak above the midline.
- The frequency of a wave is the number of waves passing a fixed point each second.

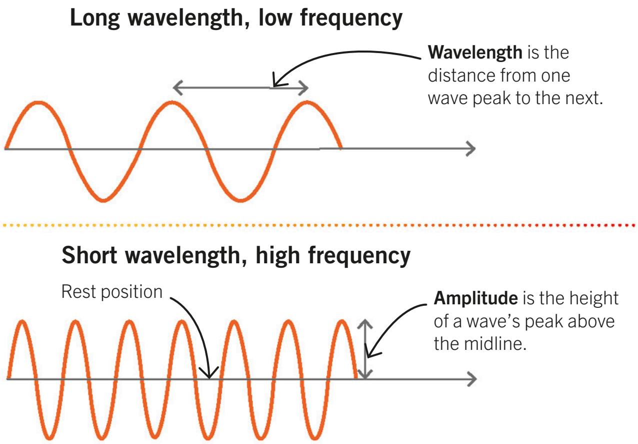
Waves in water

When you throw a stone in a pond, it creates circular waves that spread outward. It might look like the water is traveling outward, but it is actually only rising and falling as the energy of the waves travels through it. An object floating on the water bobs up and down as the waves pass.



Describing waves

All types of wave can be described using three different measurements. Wavelength is the length of one wave, and frequency is the number of waves that pass a fixed point each second. The longer the wavelength, the lower the frequency. Amplitude is the height of a wave's peak above the midline. The greater the amplitude, the greater the energy the wave transfers.



Sound

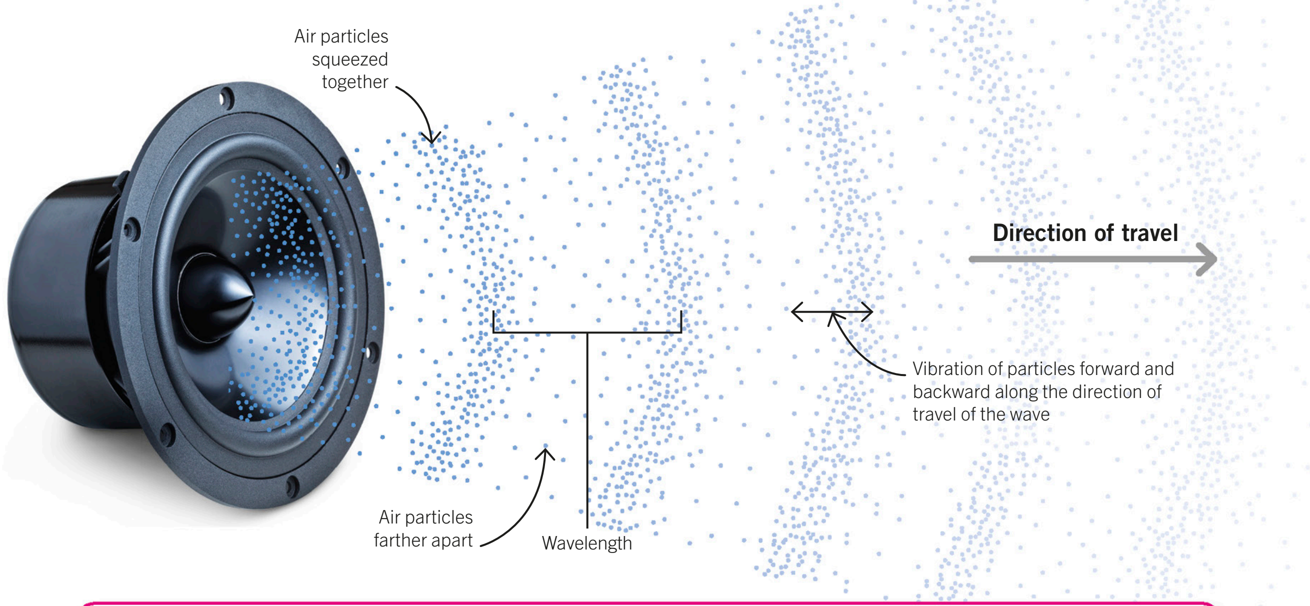
Sound consists of invisible waves that travel through matter (including air, water, and solid objects). They are created when objects vibrate. Plucking a guitar string or beating a drum, for instance, causes vibrations that pass into the air, producing waves that travel outward in all directions.

Key facts

- ✓ Sound consists of waves that travel through matter.
- ✓ Sound waves are created when objects vibrate.
- ✓ Sound waves are longitudinal waves: the vibration is forward and backward relative to the direction in which the wave travels.
- ✓ In transverse waves such as light, the vibration is at right angles to the direction in which the wave travels.

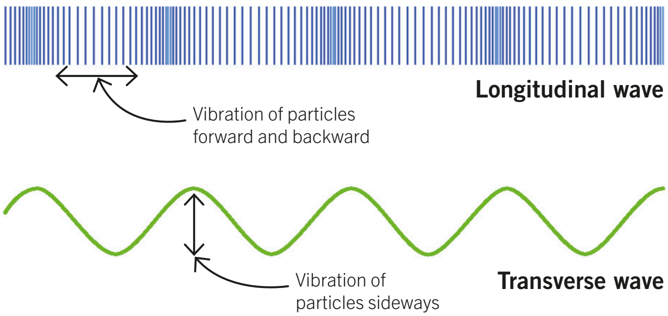
Sound waves

When a loudspeaker plays music, its surface moves very rapidly back and forth—it vibrates. As it does so, particles in the air are alternately pushed together and pulled apart. The moving particles collide with neighboring particles, causing waves of compression to travel outward. These are sound waves. Sound travels through liquids and solids in the same way.



Longitudinal and transverse waves

All waves involve some form of vibration. In sound waves, the vibration is forward and backward along the direction of travel of the wave. We call these longitudinal waves. In water waves and light waves, the vibration is sideways relative to the direction in which the wave travels. We call these transverse waves.

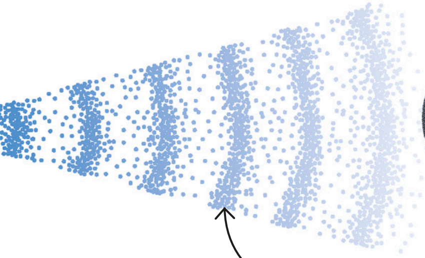


Oscilloscopes

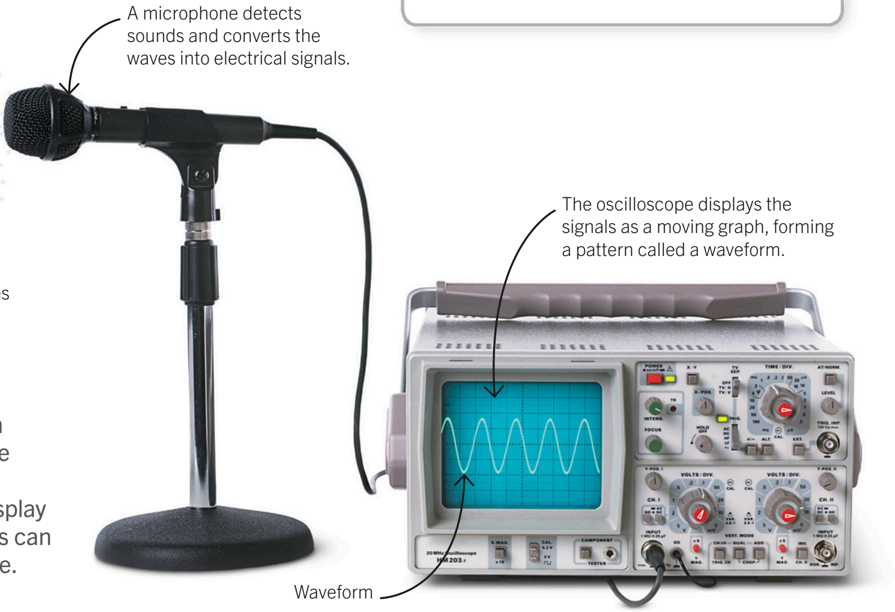
Sounds can vary from quiet to loud and from low-pitched to high-pitched. The loudness of a sound depends on the amplitude of the sound waves, and the pitch depends on their frequency. We can study these properties using an oscilloscope—a device that displays waves as a moving graph on a screen.

Key facts

- ✓ **The greater the amplitude of a sound wave, the louder it sounds.**
- ✓ **The higher the frequency of a sound wave, the more high-pitched it sounds.**
- ✓ **An oscilloscope allows us to visualize waves.**



Sound waves



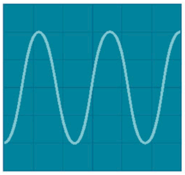
Seeing sound

Although sound waves are longitudinal, the waveform on an oscilloscope is a transverse wave, which makes it easy to interpret. The x-axis on the display represents time and the y-axis can be used to measure amplitude.

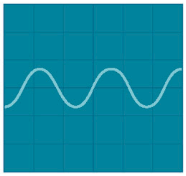
Different sounds

Different sounds produce distinct patterns on an oscilloscope, allowing us to see the wave's amplitude, frequency, and complexity.

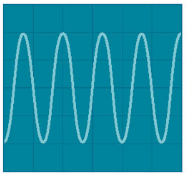
Complex waveforms are typical of musical instruments and give each type of instrument a distinct timbre (sound quality).



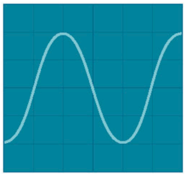
Loud sounds have a large amplitude, resulting in a tall waveform.



Quiet sounds have a low amplitude, resulting in a shallow waveform.



High-pitched sounds have a high frequency, resulting in a waveform with many peaks close together.



Low-pitched sounds have a low frequency, resulting in a longer waveform with fewer peaks.

Most sources of sound produce multiple waves. They combine to create a complex waveform.

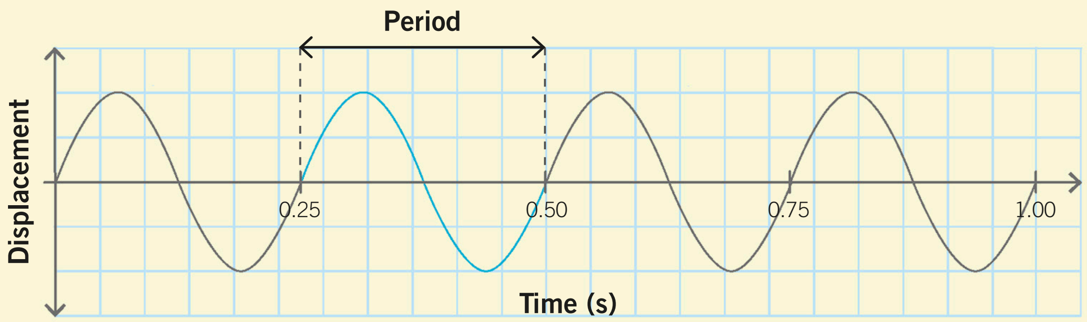
Wave equations

The speed at which waves travel and their wavelength, frequency, and period (the time for one wavelength to pass) are all related. The equations on these pages show you how.

Key facts

- ✓ The time it takes for one wavelength to pass is the wave's period.
- ✓ The frequency of a wave equals 1 divided by the wave's period.
- ✓ The speed of a wave = frequency × wavelength.

Frequency and period
Unlike most wave diagrams in this book, the graph below shows how a wave varies over a period of time. Each complete wavelength lasts a quarter of a second, which we call the wave's period. Every second, four complete waves pass—this is the wave's frequency, which we measure in units called hertz (Hz). One Hz means one cycle per second.



Frequency equation
The equation below shows how period and frequency are related. We say they are inversely related—as one halves, the other doubles.

$$\text{frequency (Hz)} = \frac{1}{\text{period (s)}}$$

$$f = \frac{1}{T}$$

Calculating frequency

Question
The piano key known as middle C plays a musical note with a period of 0.00382 seconds. What is the note's frequency?

Answer

$$f = \frac{1}{T}$$

$$= \frac{1}{0.00382\ \text{s}}$$

$$= 262\ \text{Hz}$$

Speed of waves
The equation here shows how the speed, frequency, and wavelength of any wave are related. The symbol for wavelength is the Greek letter lambda λ.

$$\text{speed (m/s)} = \text{frequency (Hz)} \times \text{wavelength (m)}$$
$$v = f \times \lambda$$

Speed of sound
Sound travels through air at around 343 m/s, but it moves faster in water (1480 m/s) and can pass through solids faster still (5000 m/s in steel). However, light travels about a million times faster than the speed of sound in air. As a result, when you watch fireworks or see a lightning storm, the flash of light reaches you faster than the sound.

Calculating wavelength

Question
A violinist plays a note with a frequency of 880 Hz. If the speed of sound in air is 343 m/s, what is the note's wavelength?

Answer
First, rearrange the equation to make lambda the subject.

$v = f \times \lambda$

$\lambda = \frac{v}{f}$

$\lambda = \frac{343 \text{ m/s}}{880 \text{ Hz}}$

$= 0.390 \text{ m}$

If you count the seconds between the light and sound, you can calculate how far away the firework or bolt of lightning is by using the speed of sound in air (the number of seconds divided by 3 gives the approximate distance in km).

Hearing sound

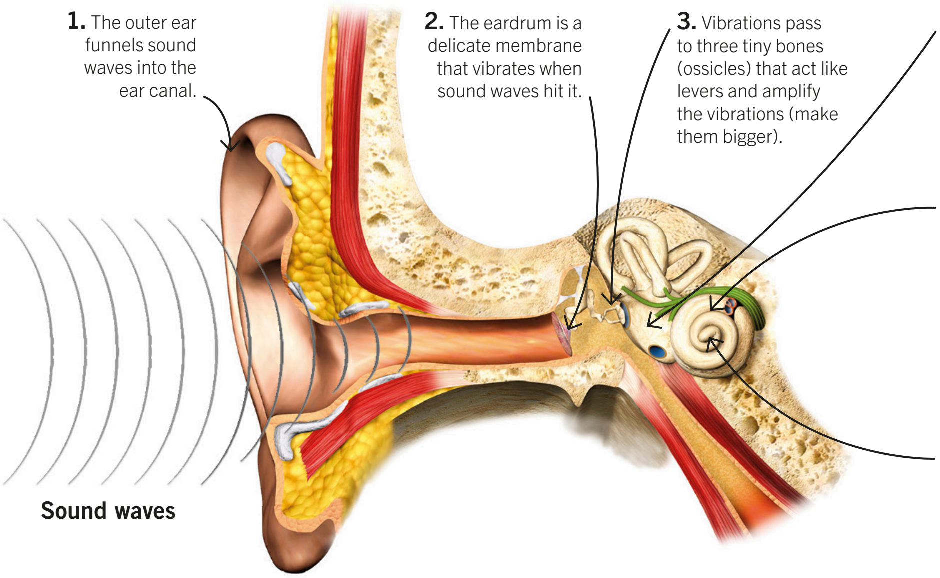
The human ear converts the energy transferred by sound waves into electrical impulses that are transmitted to the brain, where they are interpreted as sounds.

Inside the ear

Sound enters the ear as waves in the air but is converted into vibrations in solid materials by the eardrum. The way a solid vibrates when sound waves hit it depends on properties such as its stiffness. The eardrum and other structures in the ear vibrate only within a certain range of frequencies, which is why some sounds are too low or high for us to hear. As people age, the ear loses the ability to detect high-frequency sounds. Listening to very loud music can also damage our ears' sensitivity to certain sounds.

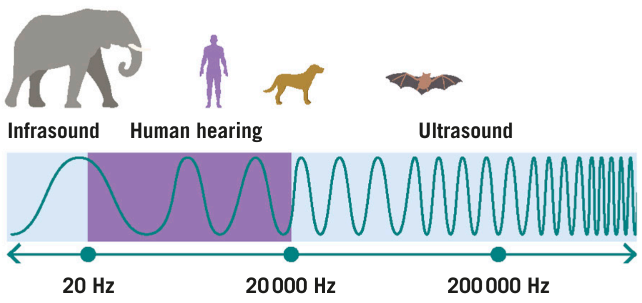
Key facts

- ✓ **The ear converts sound waves into electrical impulses that are sent to the brain, giving people the sense of hearing.**
- ✓ **Some sounds are too high or too low in pitch for humans to hear.**
- ✓ **Both aging and damage to the ears impair the sense of hearing.**



Highs and lows

Humans can hear sound within a frequency range, or pitch, of between roughly 20 Hz and 20 000 Hz. Frequencies too high for humans to hear are called ultrasound, and those too low are infrasound. Other animals have different ranges. Dolphins and bats, for example, can hear much higher ultrasound frequencies, and elephants can detect lower infrasound frequencies.



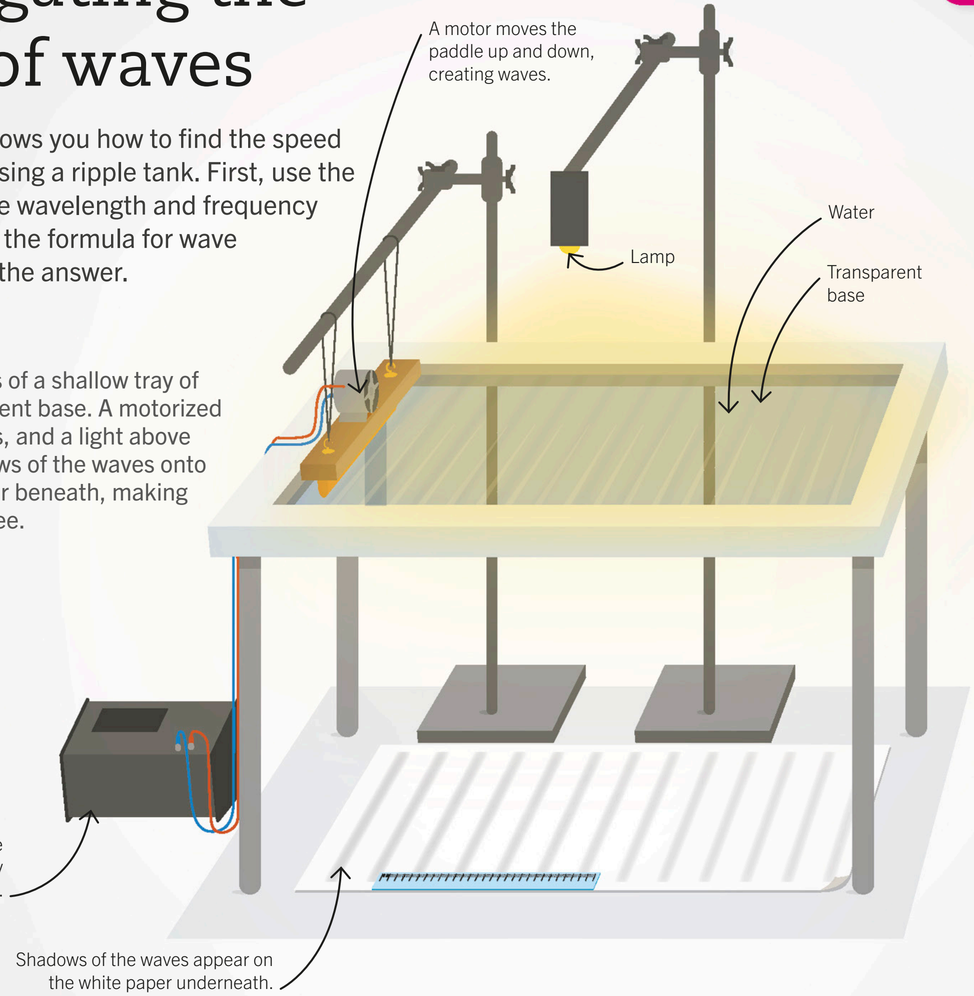
Investigating the speed of waves

This experiment shows you how to find the speed of waves in water using a ripple tank. First, use the tank to measure the wavelength and frequency of waves. Then use the formula for wave speed to calculate the answer.

Ripple tank

A ripple tank consists of a shallow tray of water with a transparent base. A motorized paddle creates waves, and a light above the tank casts shadows of the waves onto a sheet of white paper beneath, making the waves easier to see.

Teacher supervision required



Method

1. Set up the tank and adjust the voltage on the power supply so the paddle creates waves with wavelengths about half as long as the tank.

2. Place a ruler on the white paper and take a photograph of the waves' shadows to freeze their motion. Use the image of the ruler to measure the wavelength (the distance between two waves).

3. Next, measure the frequency. Mark a point on the white paper and use a timer to count how many waves pass it in 10 seconds. Divide the result by 10 to find the frequency in waves per second (Hz).

4. Use the formula for the speed of waves to find the answer:

   speed (m/s) = frequency (Hz) × wavelength (m)

5. To check the result, you can time how long one wave takes to pass between two points a measured distance apart on the paper. Then use this formula to calculate the speed again:

   $$\text{speed (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$

Measuring the speed of sound

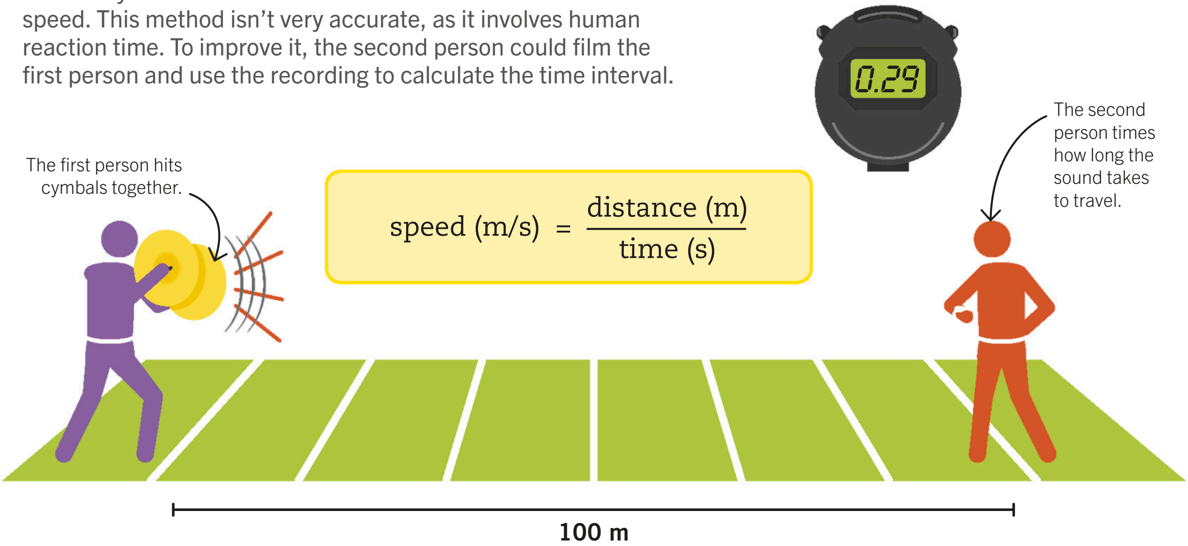
Sound can travel through solids, liquids, and gases. The experiments here show two ways of measuring the speed of sound: one in air, and one in a solid.

Key facts

- ✓ Sound can travel in solids, liquids, and gases.
- ✓ The speed of sound in air can be measured using a stopwatch.
- ✓ The speed of sound in a solid object can be calculated from the sound's frequency and the object's size.

Speed of sound in air

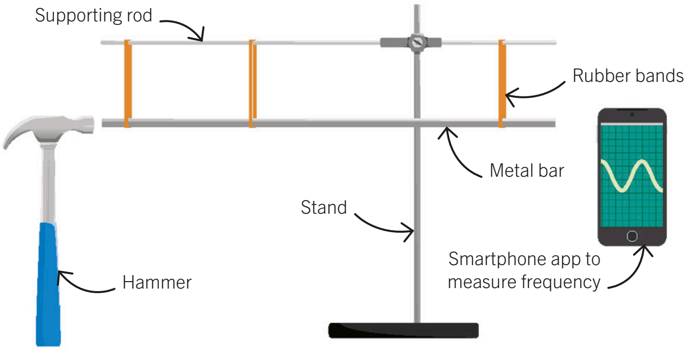
Two people stand at opposite ends of a field a measured distance apart. One person hits two cymbals to make a noise. The second person starts a timer when they see the cymbals hit and stops it when they hear the sound. The formula below reveals the sound's speed. This method isn't very accurate, as it involves human reaction time. To improve it, the second person could film the first person and use the recording to calculate the time interval.



$$\text{speed (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$

Speed of sound in a solid

To measure the speed of sound in a solid, suspend a metal bar loosely from a stand using thin rubber bands. Strike the bar with a hammer, and use a smartphone app to measure the frequency of the loudest sound detected when the phone is next to the bar. Vibration of the bar causes a "standing wave," the wavelength of which is twice the length of the bar. Use the formula below to calculate the wave's speed.



$$\text{wave speed (m/s)} = \text{frequency (Hz)} \times \text{wavelength (m)}$$

Using ultrasound

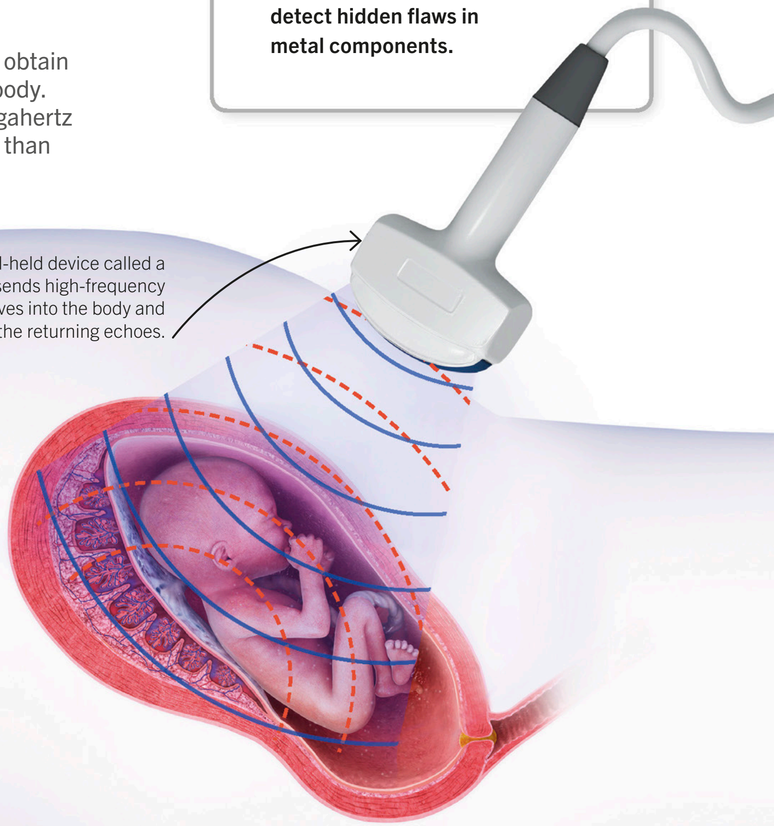
Sound that is too high in frequency for humans to hear is called ultrasound. Ultrasound has many uses: it can be used to look inside the human body, dislodge dirt from delicate jewelry, or find cracks in pipelines and railway tracks.

Key facts

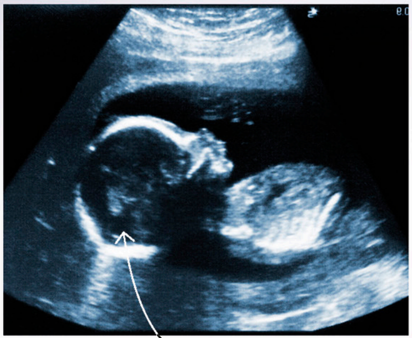
- ✓ Ultrasonic cleaning uses ultrasound vibrations to dislodge dirt.
- ✓ Ultrasound scanners allow doctors to obtain images of babies inside their mothers' bodies.
- ✓ Ultrasound can be used to detect hidden flaws in metal components.

Ultrasound scans

Ultrasound scanning machines allow doctors to obtain images of babies developing inside a mother's body. A typical scanner uses frequencies of 2–18 megahertz (2–18 million hertz)—hundreds of times higher than the upper limit of human hearing.



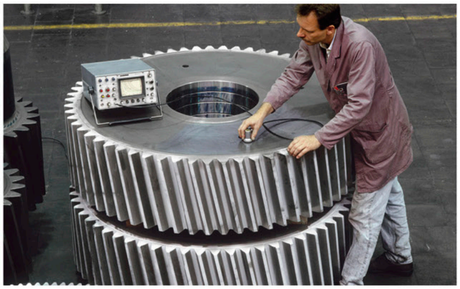
1. A hand-held device called a transducer sends high-frequency sound waves into the body and detects the returning echoes.



2. A computer processes the information and produces a real-time, moving image called a sonogram, which appears on a screen.

Scanning machinery

Ultrasound can be used to detect cracks in machinery, pipelines, and railway tracks that would otherwise remain hidden. When ultrasound waves hit a boundary between two materials, part of the wave reflects off the boundary, and part of it passes through. Cracks produce additional boundaries between materials, creating additional reflections, which are revealed as spikes on a graph.



Sonar

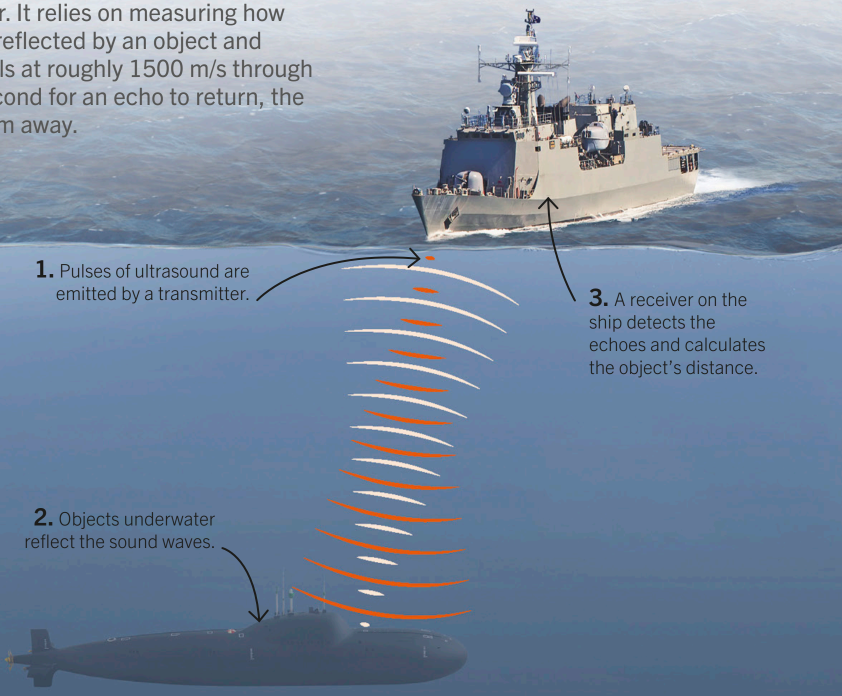
Sound waves can travel great distances underwater. This ability is exploited by sonar, a technology that uses ultrasound echoes to detect objects in the ocean, such as submarines.

Key facts

- ✓ Sonar uses ultrasound pulses to detect objects underwater.
- ✓ Sound travels through sea water at roughly 1500 m/s.
- ✓ Bats use echolocation to navigate and find their prey.

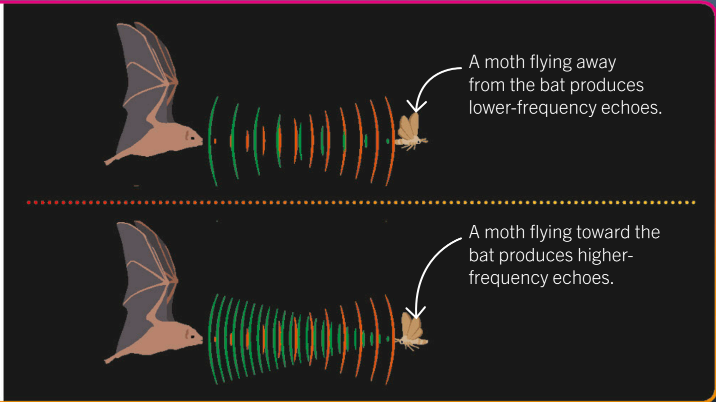
Searching for the sound

Sonar was invented during World War I to search for submarines, but today it is also used for locating shoals of fish or mapping the ocean floor. It relies on measuring how long it takes for a sound to be reflected by an object and return to the ship. Sound travels at roughly 1500 m/s through sea water, so if it takes one second for an echo to return, the reflecting object must be 750 m away.



Echolocation

Some animals, including bats and dolphins, use a system like sonar to navigate and find food in the dark. Bats send out ultrasound waves from their mouth and use the echoes to locate and catch moths in midflight. The time it takes for echoes to return reveals a moth's distance, and the frequency of the echoes reveals whether the moth is flying toward or away from the bat.



Investigating Earth’s interior

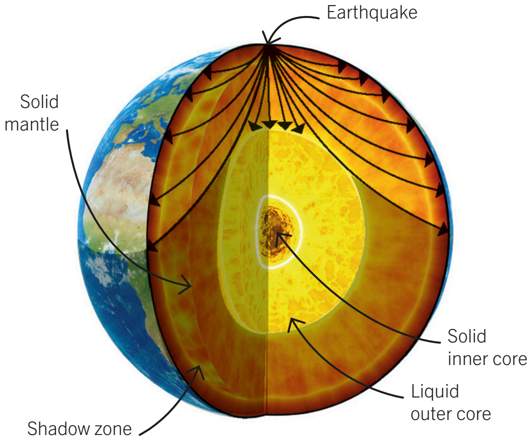
Earthquakes cause vibrations that send powerful seismic waves traveling through Earth’s interior. Studying the behavior of these waves has allowed us to build up a picture of the inside of our planet.

Key facts

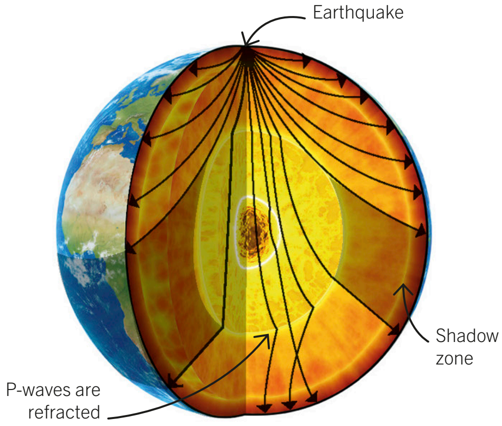
- ✓ Earthquakes generate seismic waves that travel through Earth’s interior.
- ✓ P-waves travel through both solids and liquids.
- ✓ S-waves only travel through solids.
- ✓ Shadow zones where P- and S-waves are not detected helped scientists discover Earth’s inner structure.

Earth’s interior

There are two types of seismic wave that help us investigate Earth’s structure: primary waves (P-waves) and secondary waves (S-waves).



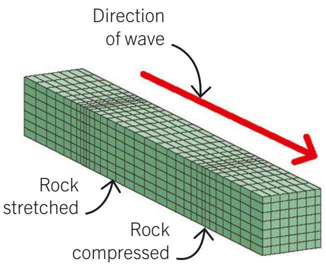
S-waves are only detected on the same side of Earth as the earthquake. These waves travel slowly and can only pass through solids, so their absence on the far side of the planet shows that Earth has a partly liquid interior.



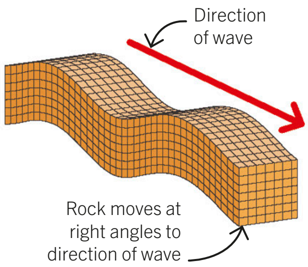
P-waves are detected on the far side of Earth after an earthquake, but there are shadow zones where they are missing. These fast-moving waves can pass through liquids but are refracted when they pass between different kinds of material. The pattern of shadow zones reveals the size of Earth’s liquid outer core and solid inner core.

P-waves and S-waves

P-waves and S-waves differ in the way they travel. P-waves, like sound waves, are longitudinal waves of pressure that can move through solids and liquids. S-waves, however, are transverse waves and can only travel through rigid materials such as solid rock. When they reach the molten rock of the outer core, they dissipate.



P-wave



S-wave

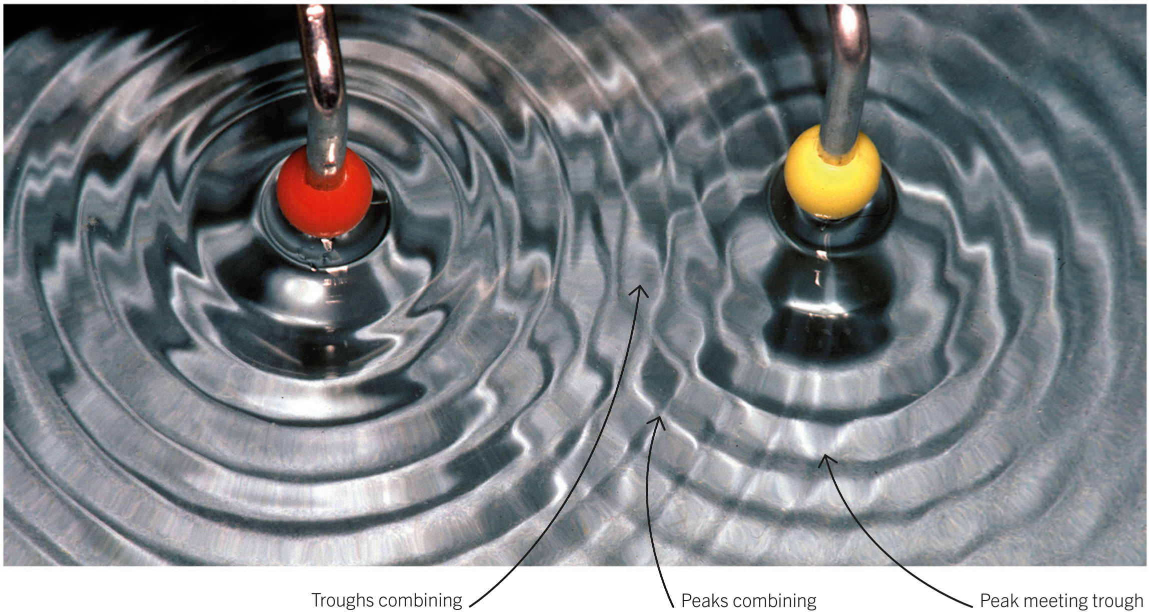
Interference

When waves meet, they interfere with each other. Interference can affect all kinds of waves. The shimmering colors on soap bubbles, for instance, are caused by interference in light waves.

Interference patterns
Interference patterns exist only where waves meet. After passing the meeting point, waves carry on with the same amplitude as they had before. You can produce interference patterns in a ripple tank by vibrating two balls touching the water surface. Where two peaks meet, the waves reinforce each other and produce higher peaks (constructive interference). Where peaks meet with troughs, they cancel each other out (destructive interference).

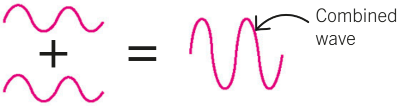
Key facts

- ✓ Constructive interference occurs when waves are in step and results in a higher amplitude.
- ✓ Destructive interference occurs when waves cancel each other out, resulting in a lower amplitude.
- ✓ Waves remain unchanged after they have passed through each other.



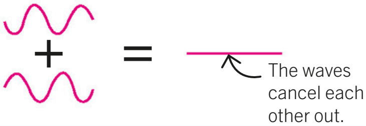
Constructive interference

When waves meet, their amplitudes add together. If the waves are in step, the combined wave has a larger amplitude.



Destructive interference

If the waves are out of step, the amplitude is reduced. Noise-canceling headphones use this principle to block out background sound.



Iridescence

When light hits a soap bubble, it reflects from both the inner and outer surface of the film of soap and water. The two sets of reflections interfere, enhancing certain frequencies but canceling out others. The shimmering colors this produces are described as iridescent. As water swirls around in the skin of the bubble, its thickness changes and the colors continually change. Butterflies and birds such as peacocks and hummingbirds also get their colors from iridescence.

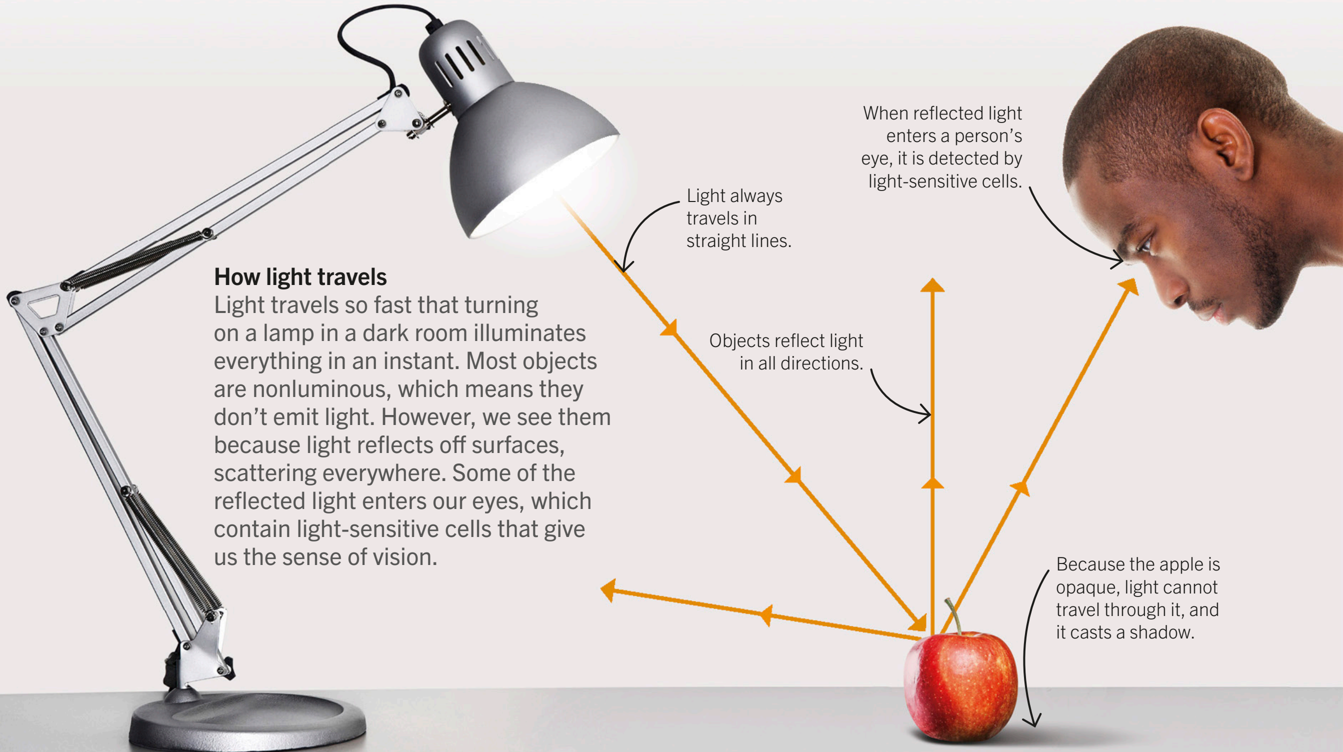
Light

Light and seeing

Luminous (glowing) objects, such as the Sun or electric lights, emit light energy. Light travels as a wave and passes through anything transparent, including air, water, glass, and the vacuum of space. Light traveling in a vacuum is the fastest thing in the Universe. It takes just 8 minutes and 19 seconds for light from the Sun to travel 150 million km to Earth.

Key facts

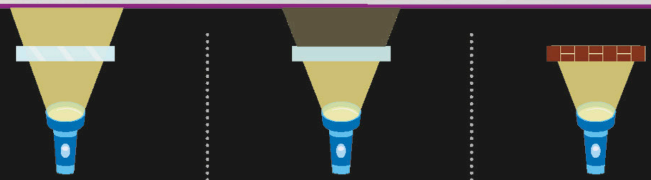
- ✓ **Light travels as waves.**
- ✓ **Luminous (glowing) objects, such as the Sun, emit light.**
- ✓ **Nonluminous objects can only be seen by reflected light.**



How light travels
Light travels so fast that turning on a lamp in a dark room illuminates everything in an instant. Most objects are nonluminous, which means they don't emit light. However, we see them because light reflects off surfaces, scattering everywhere. Some of the reflected light enters our eyes, which contain light-sensitive cells that give us the sense of vision.

Transparent, translucent, and opaque

Most solid objects block light, but some materials let light waves pass through.



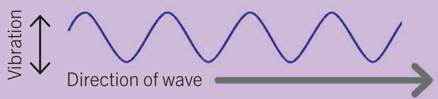
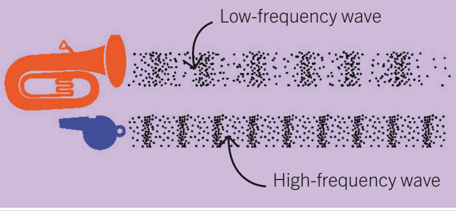
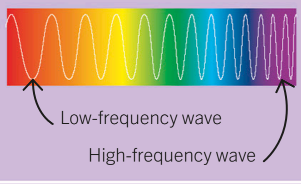
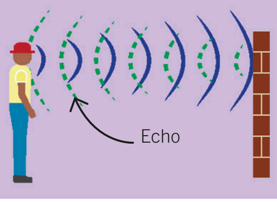
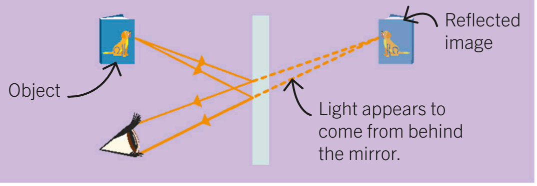
Transparent materials, such as glass, let light pass through. However, they also reflect a small amount of light, which is why we can see them.

Translucent materials, such as frosted glass, let some light through but scatter it.

Opaque materials let no light through and so cast a strong shadow.

Comparing sound and light

Sound and light both travel as waves, and they both transfer energy. They have certain features in common, but there are also important differences between them.

Sound	Light
Sound waves travel as vibrations of particles of matter, so they cannot travel through empty space. Sound can travel through solids, liquids, and gases.	Light waves travel as vibrations in electric and magnetic fields and can cross empty space. They can pass through air and water, but most solid materials block their path.
Sound is a longitudinal wave. The particles move forward and backward in the same direction as the wave travels in. 	Light is a transverse wave caused by vibrations in the electromagnetic field. The vibrations are at right angles to the wave's direction of travel. 
The amplitude of a sound wave determines its volume. The greater the amplitude, the louder the sound.	The amplitude of a light wave determines its brightness. The greater the amplitude, the brighter the light.
The frequency of a sound wave determines its pitch. The higher the frequency, the higher the pitch. 	The frequency of a visible light wave determines its color. Low-frequency visible light is red; high-frequency visible light is violet. 
Sound travels at around 343 m/s through air. Some jet aircraft can fly faster than this.	Light travels at around 300 million m/s through air (almost 1 million times faster than sound). That's why you see lightning flash before you hear thunder.
Sound waves can be reflected, refracted, and absorbed. A reflected sound is called an echo. 	Light waves can be reflected, refracted, and absorbed. The image we see in a mirror is a reflection. 

Pinhole cameras

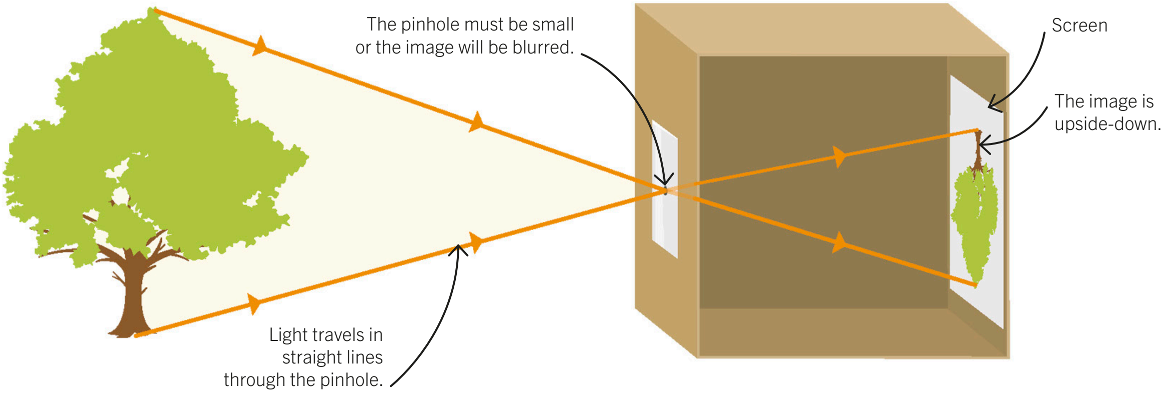
A pinhole camera is a box with a tiny hole in the front and a screen at the back. When you point it toward a brightly lit scene, a faint image appears on the screen. This simple setup was the ancestor of today's cameras.

Key facts

- ✓ Pinhole cameras do not need a lens.
- ✓ If the pinhole is too large, the image will be blurred.
- ✓ Pinhole cameras show that light travels in straight lines.

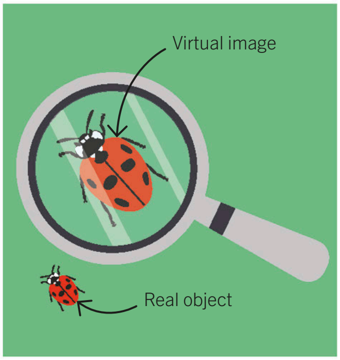
Ray diagram

We can explain how a pinhole camera works by drawing a diagram that shows light traveling in straight lines—a ray diagram. Ray diagrams include just a few rays of light as straight lines with arrows showing the direction light travels. This ray diagram shows that light rays cross as they pass through the small hole, resulting in an upside-down image. Ray diagrams are also very useful to show what happens when light is reflected, refracted, or focused by lenses.

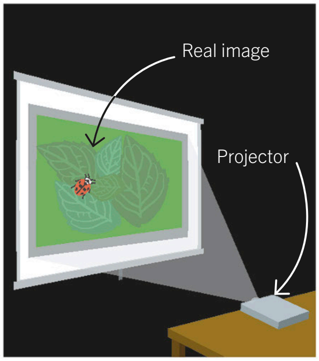


Real and virtual images

The image produced by a pinhole camera is called a real image because it can be captured on a screen, allowing people to see it from anywhere. In contrast, the enlarged image you see through a magnifying glass is a virtual image that can only be seen from a certain position. Unlike a real image, a virtual image cannot be captured on a screen.



Magnified ladybug



Projection on a screen

Reflection

When light strikes a surface, some of it bounces off—it is reflected. Luminous objects emit light, but we see everything else by reflected light. Most objects have a rough surface that reflects light in many directions (diffuse reflection). However, very smooth objects, such as mirrors, reflect light regularly (regular reflection).

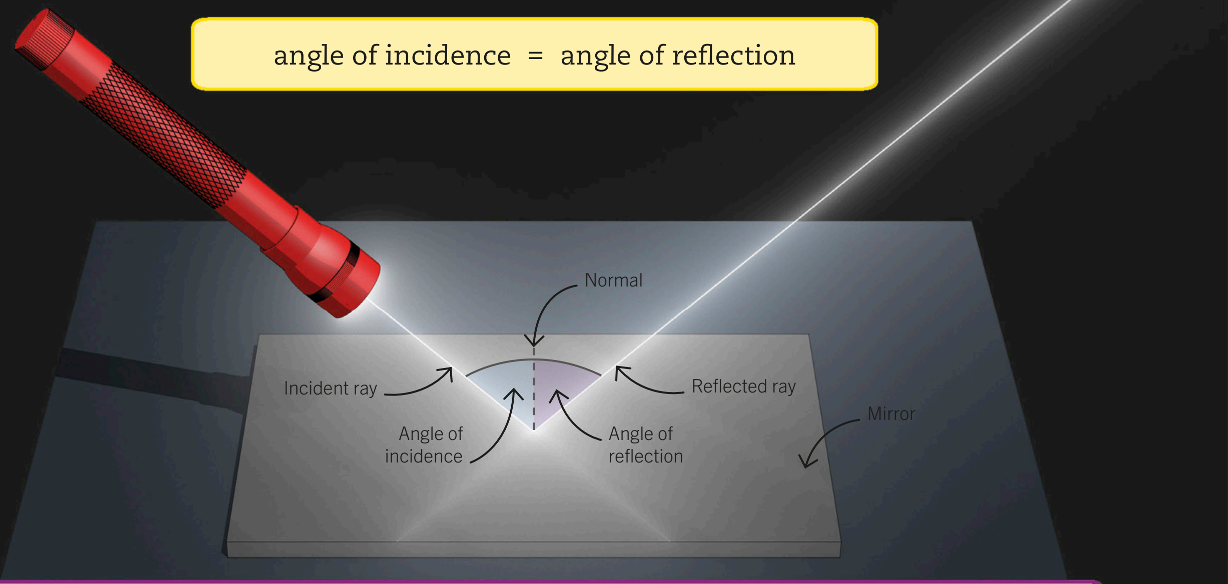
Key facts

- Regular reflection is the even reflection of light from a smooth surface such as a mirror.
- Diffuse reflection is the irregular reflection of light from a rough surface.
- When light is reflected by a mirror, the angle of incidence equals the angle of reflection.

The law of reflection

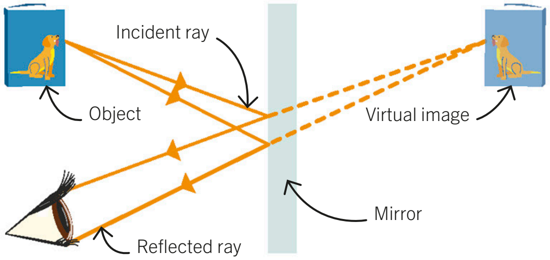
The picture below shows what happens when light is reflected by a mirror. The angle of the incoming ray (angle of incidence) is always the same as the angle of the reflected ray (angle of reflection). This is the law of reflection. Both angles are measured from a line called the normal, which is at right angles to the object's surface.

angle of incidence = angle of reflection



Mirror images

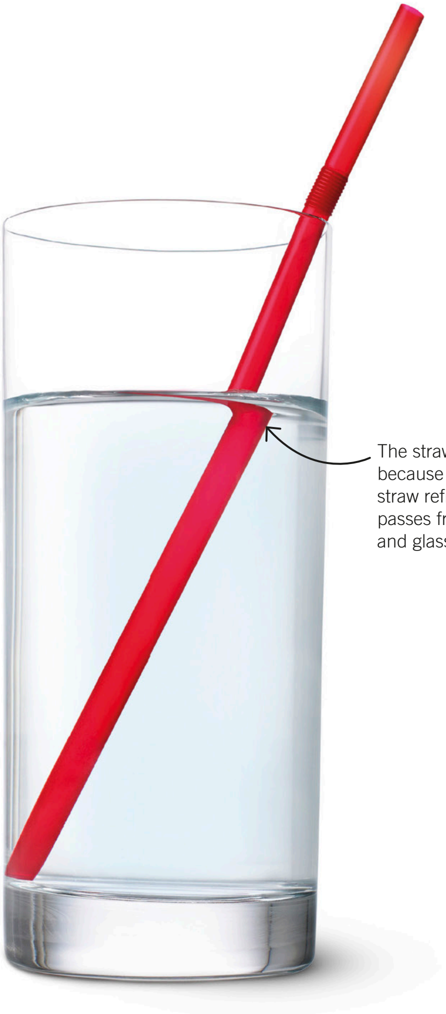
When you look in a flat mirror, you see a virtual image (see page 129) that appears to be behind the mirror. The ray diagram here shows how a mirror produces a virtual image. The dashed lines show where the light appears to come from. Mirrors don't reverse things left to right. Writing looks reversed in a mirror because we have to flip a book around to face the glass. Mirrors actually reverse images from front to back, along a line through the mirror.



Refraction

When light waves pass from one medium to another—such as from air to water—they change direction. This is known as refraction. Lenses use refraction to bend and focus light.

Refraction of light
Place a straw in a glass of water and it will appear bent or broken. This happens because light from the straw is refracted as it passes between the water, glass, and air on the way to our eyes. Our brains assume the light has traveled in a straight line, so the image of the straw in the water is distorted.

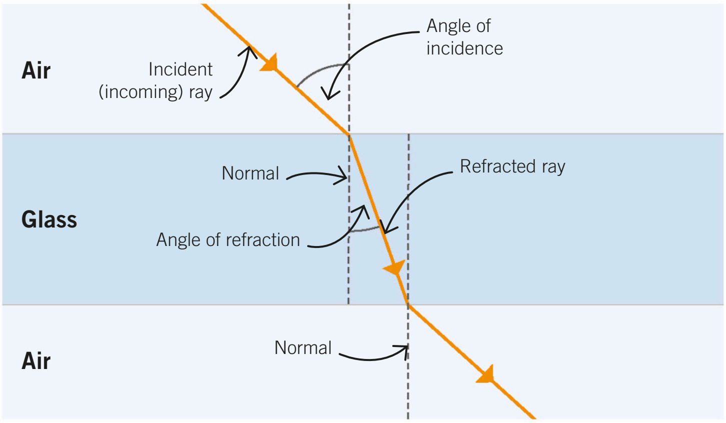


Key facts

- ✓ **Refraction is a change in the direction of waves as they pass from one medium to another.**
- ✓ **Waves bend toward the normal when they slow down and bend away from the normal when they speed up.**

Refraction ray diagram

A ray diagram helps explain what happens when light is refracted. The diagram includes a line called the normal, which is drawn at right angles to the boundary. When light crosses the boundary from air to water or glass, it slows down and bends toward the normal. When the light returns to the air, it speeds up and bends away from the normal.

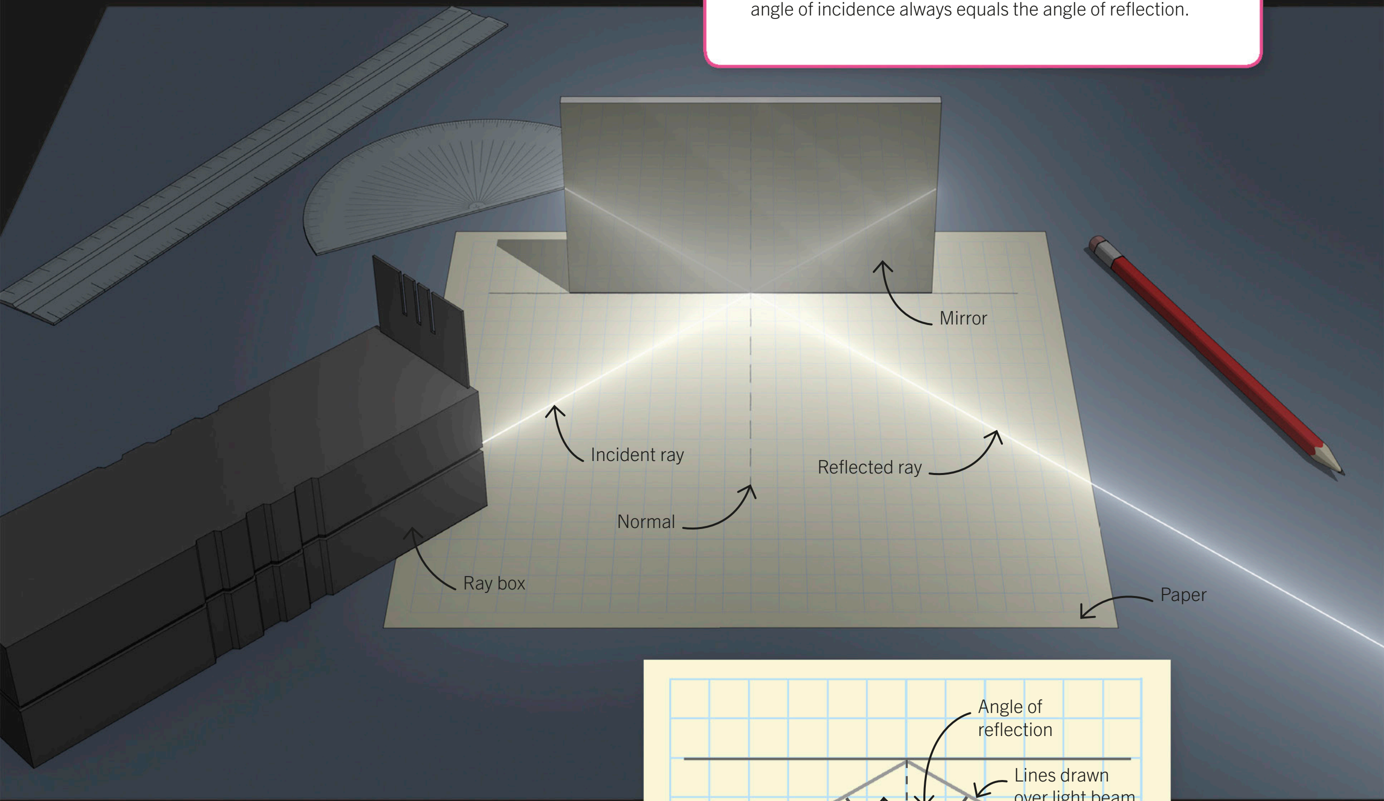


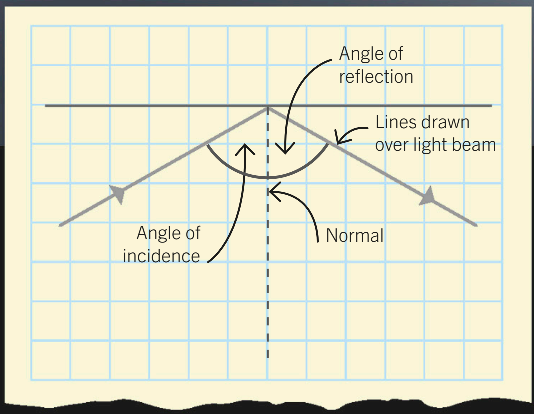
Investigating light

A ray box allows you to create ray diagrams using real rays of light. Follow the instructions here to investigate reflection and refraction.

Investigating reflection

1. Draw a straight line across a large piece of paper.
2. Draw a second line at right angles to the first line. This will be the normal in your ray diagram.
3. Place a mirror along the first line and use the ray box to shine a ray of light at the point where the two lines meet. Darkening the room may help make the rays easier to see.
4. Trace the incident ray and any reflected ray with a pencil.
5. Use a protractor to measure the angle of incidence and angle of reflection.
6. Repeat with different angles of incidence. You'll find that the angle of incidence always equals the angle of reflection.





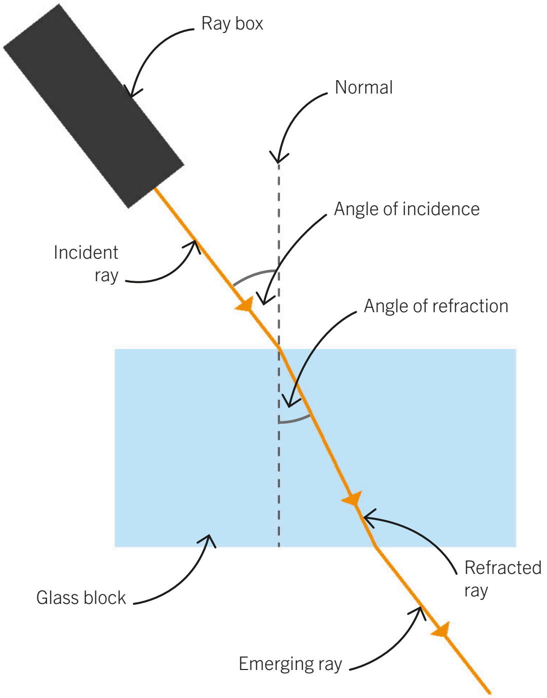
Law of reflection
Wherever you position the ray box, the angle of incidence (the angle between the incident ray and the normal) will always be the same as the angle of reflection (the angle between the reflected ray and the normal). This is called the law of reflection.

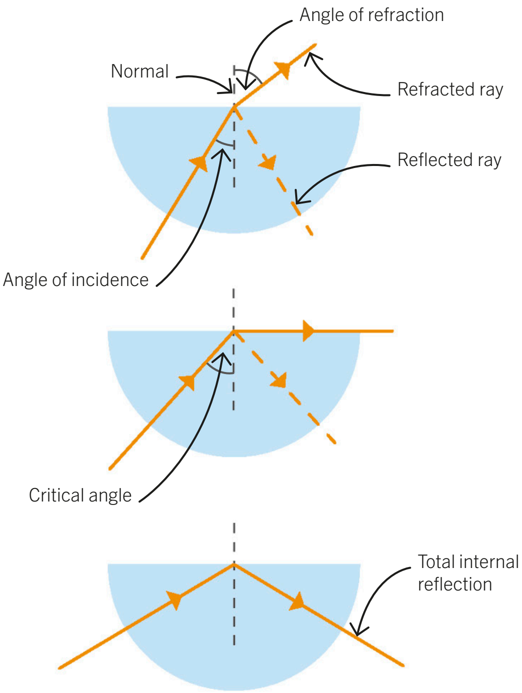
Investigating refraction

1. Place a glass block on a large sheet of paper and trace around it.
2. Draw a line at right angles to the long side of the block. This will be the normal in your ray diagram.
3. Darken the room and use a ray box to shine a ray of light diagonally into the block.
4. Use a pencil to mark the ray's path up to and beyond the block by drawing small crosses.
5. Remove the block, then use a pencil and ruler to connect the crosses and to draw the ray's path through the block.
6. Measure the angles of incidence and refraction.
7. Repeat with different angles of incidence. Light bends toward the normal when it passes from air to glass, so you'll find the angle of refraction from air to glass is always less than the angle of incidence.
8. Measure the angles of incidence and refraction at the point where the light leaves the block. Light bends away from the normal as it passes from glass to air, so in this case the angle of refraction will be larger than the angle of incidence.

Investigating internal reflection

1. Place a semicircular glass block on a large sheet of paper and draw around it.
2. Remove the block. Using a ruler and pencil, find and mark the center of the straight side. Draw a normal line through this point, perpendicular to the straight side, then replace the block.
3. Shine a ray of light from a ray box through the curved surface of the block to the point you marked.
4. The ray will bend away from the normal as it leaves the glass. Note that some light is also reflected by the straight surface of the glass block.
5. Move the ray to increase the angle of incidence. Note that the angle of refraction also increases. Continue increasing the angle of incidence until the refracted ray lines up with the flat surface of the block.
6. Increase the angle of incidence again. The light is now reflected completely, with no light escaping by refraction. This is known as total internal reflection (TIR). The angle of incidence at which TIR begins is called the critical angle.





Total internal reflection

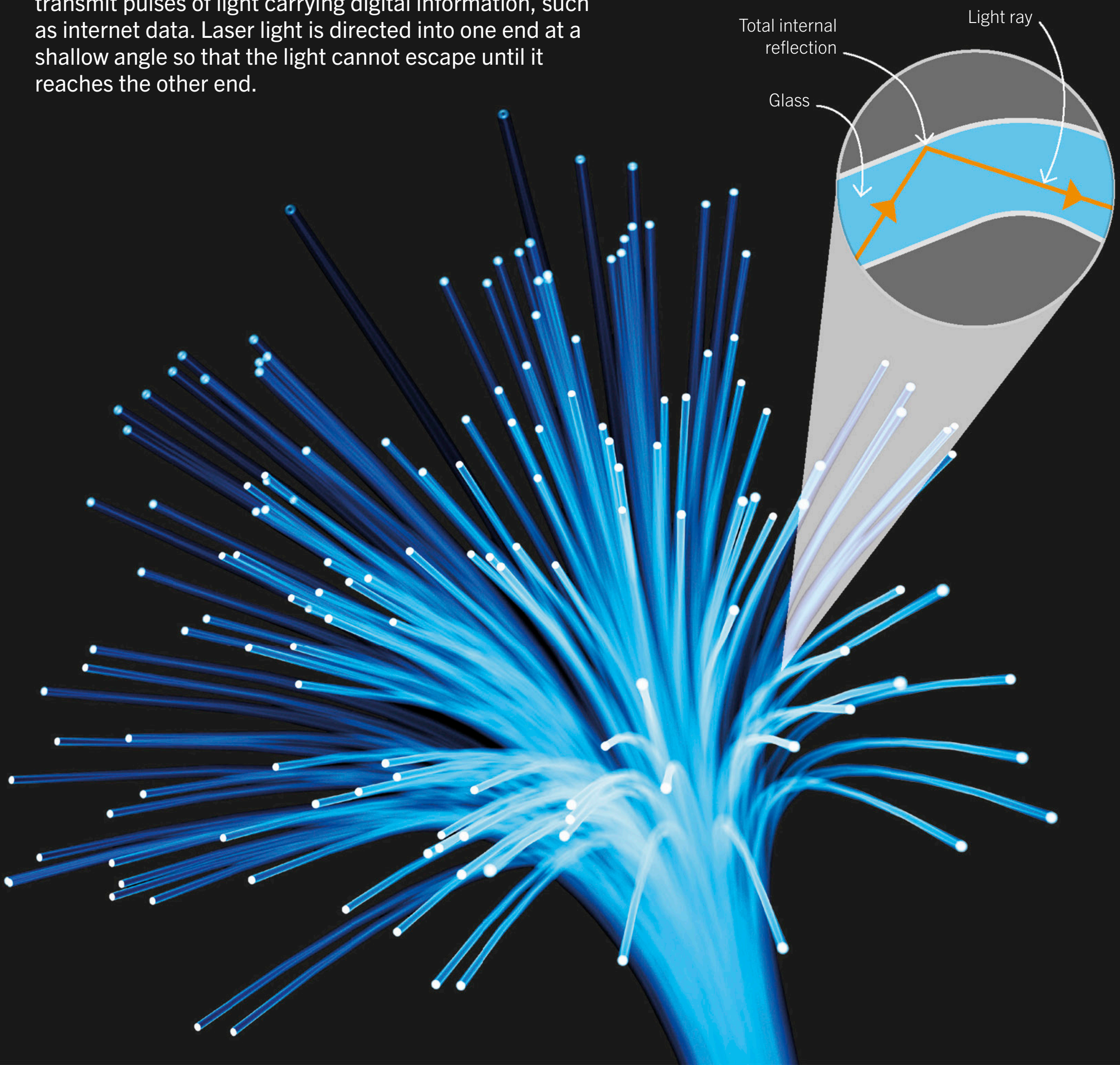
Light is refracted when it passes from one medium to another, such as from glass to air or air to water. However, if light going from glass or water to air hits the boundary at a shallow angle, all of it is reflected instead. This is called total internal reflection.

Key facts

- ✓ Total internal reflection takes place when the angle of incidence exceeds the critical angle.
- ✓ Optical fibers use total internal reflection to transmit digital data.

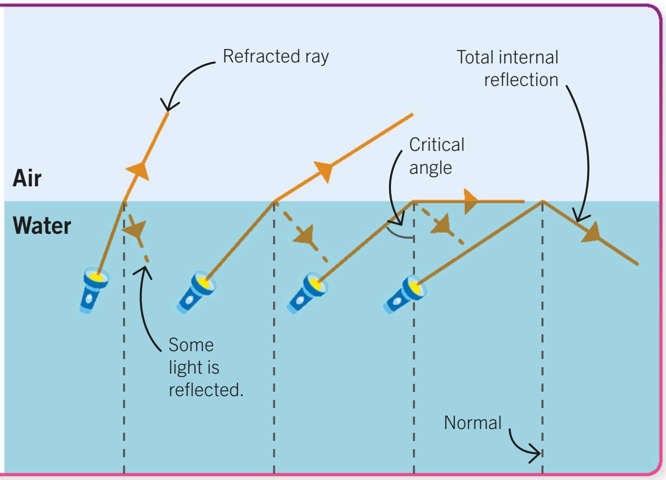
Optical fibers

An optical fiber is a strand of solid glass about as thin as a human hair. It uses total internal reflection to trap and transmit pulses of light carrying digital information, such as internet data. Laser light is directed into one end at a shallow angle so that the light cannot escape until it reaches the other end.

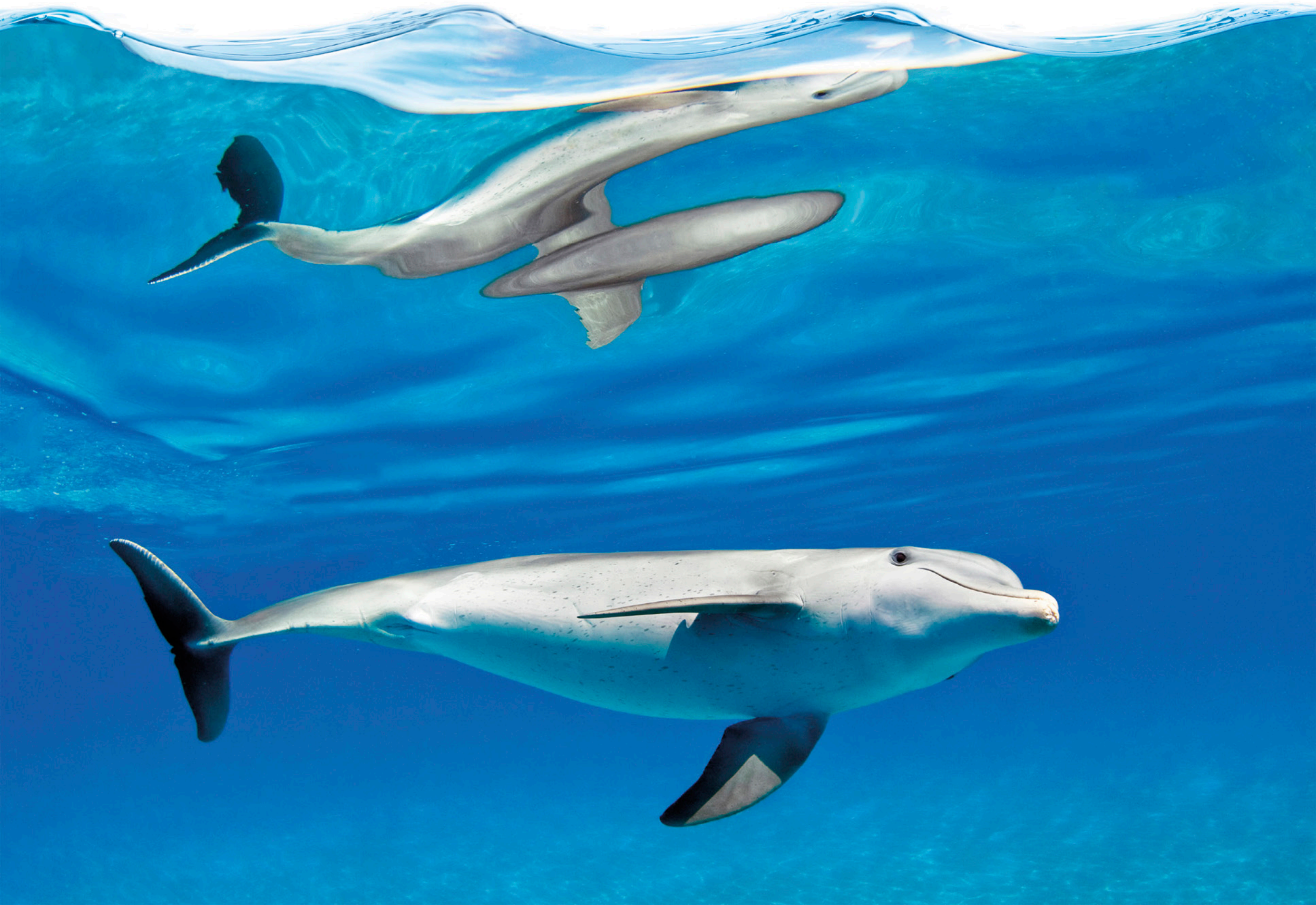


The critical angle

Total internal reflection occurs when the angle of incidence (the angle between the light and the normal) is more than a certain angle: the "critical angle." The critical angle varies with different materials, such as glass, water, or acrylic. The critical angle for light traveling from water to air is 49°. If a beam of light hits the water surface at less than 49° with the normal, it will pass through, though a small amount is reflected. If the angle is greater than 49°, it is all reflected.



Underwater reflection
When viewed from underwater, the water surface acts like a mirror due to total internal reflection. Here, a dolphin is reflected twice off the underside of two different waves.



Lenses

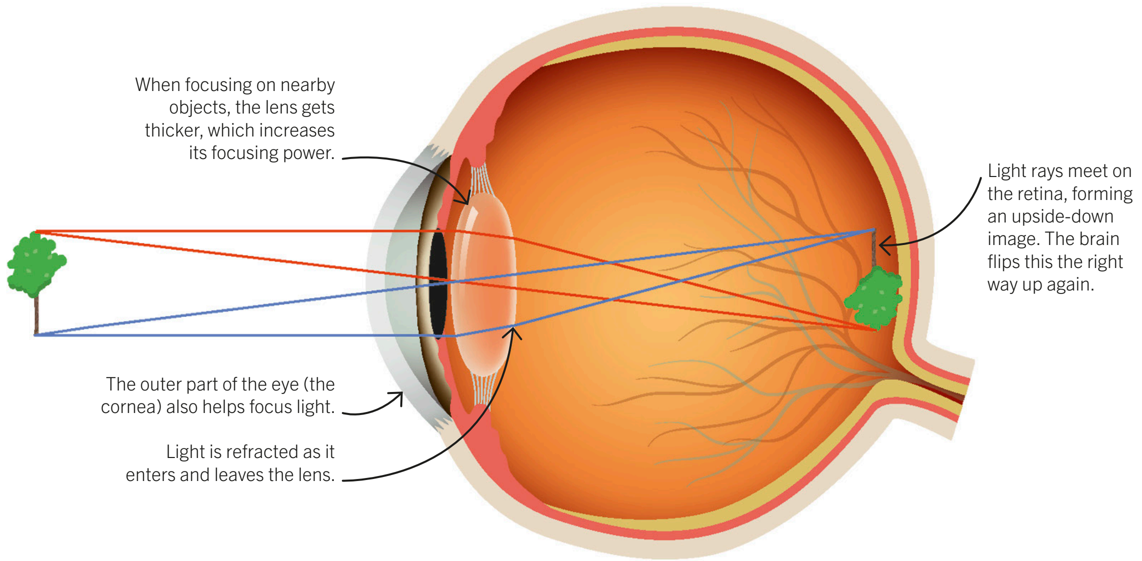
A lens is a piece of transparent material with curved surfaces. Its special shape makes light refract in a way that can form images. Eyes and cameras contain converging (convex) lenses—lenses that bulge outward in the middle and make rays of light converge to a point.

Key facts

- ✓ A lens is a piece of transparent material with curved surfaces that refract light.
- ✓ Eyes and cameras contain converging (convex) lenses, which focus light rays to form an image.
- ✓ The human eye adjusts focus by changing the shape of the lens.
- ✓ A camera adjusts focus by changing the position of the lens.

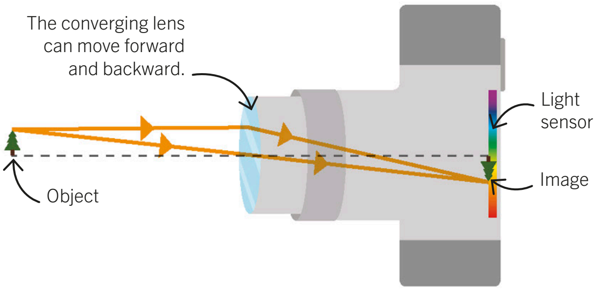
Inside an eye

The lens inside a human eye bends light rays so that they come together and form an image. This is called focusing. Diverging rays of light from the same point on a distant object are focused on the retina—a layer of light-sensitive cells that lines the back of the eyeball. The retina then sends nerve impulses to the brain, which creates the sense of sight.



Cameras

Cameras work in a similar way to the human eye. Incoming light is focused by a converging lens to form an image on a light-sensitive sensor in the back of the camera. Images are then stored in a memory chip. Unlike a human eye, a camera contains a glass lens that cannot change shape to adjust its focusing power. Instead, cameras with adjustable focus move the lens forward or backward.



Waves and refraction

Refraction is a change in the direction of waves when they slow down or speed up. Light waves refract when they pass from one medium to another, and water waves refract when they move between deep and shallow water.

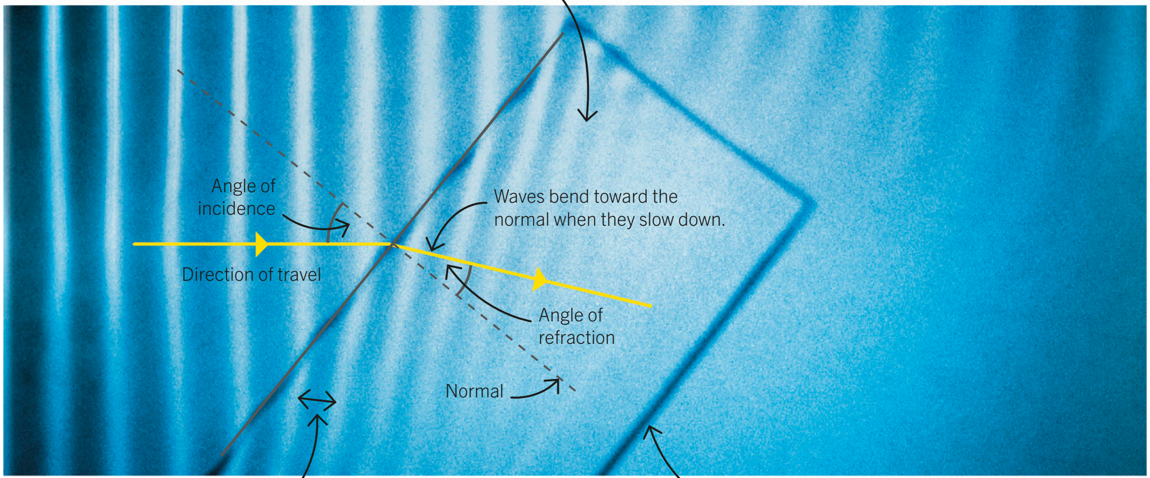
Key facts

- ✓ **Refraction is caused by a change in the speed of waves.**
- ✓ **The frequency of waves is unchanged after refraction, but the wavelength and speed change.**
- ✓ **If a wave slows down, it bends toward the normal.**
- ✓ **If a wave speeds up, it bends away from the normal.**

Refraction in water

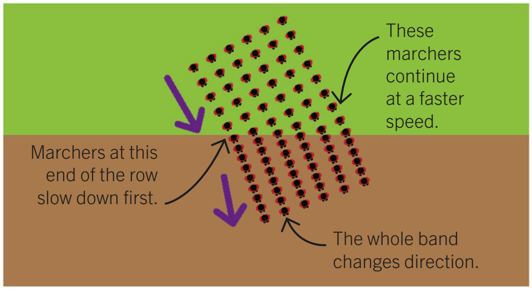
We can see refraction in action by using a ripple tank—a tank of water through which light is shone to make the ripples visible. A glass block placed at an angle on the bottom of the tank creates a zone of shallow water, which slows down the waves. When waves slow down, they bend toward the normal. When they speed up, they bend away from the normal. The frequency of the waves remains the same after refraction, but the slower waves have a shorter wavelength.

Teacher supervision required



Why refraction happens

To understand why a change in speed causes waves to change direction, imagine a marching band trying to stay in regular rows as they march from firm ground to muddy ground, where they slow down. If the band meets the boundary at an angle, one side slows down earlier than the other side. The faster marchers catch up a little until they reach the mud, so the whole band changes direction.



Refractive index

Light travels incredibly fast through a vacuum: 3×10^8 m/s (300 million meters per second). It travels almost as fast in air, but it slows significantly in water, glass, or other transparent materials. The refractive index of a material is a measure of how much the material slows down light.

Key facts

- ✓ The refractive index of a material is a measure of how much that material slows down light.
- ✓ Refractive index equals the speed of light in a vacuum divided by the speed of light in the material.
- ✓ Snell's law allows us to calculate refractive index from the angles of incidence and refraction.

Calculating refractive index

Light travels at different speeds in different materials, so each material has a different refractive index. The greater a material's refractive index, the more it slows down light and the more the light is refracted (bent). This equation shows how refractive index can be calculated from the change in the light's speed.

$$\text{refractive index } (n) = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the material}}$$

Refractive index is a ratio of two speeds and so has no units.




Material	Speed of light (m/s)	Refractive index
Air	2.997×10^8	1.0003
Acrylic	2×10^8	1.5
Glass	$(1.8–2.0) \times 10^8$	1.5–1.7
Diamond	1.25×10^8	2.4

Refractive index of water

Question

The speed of light in a vacuum is 3×10^8 m/s, and the speed of light in water is 2.3×10^8 m/s. What is the refractive index of water?

Answer

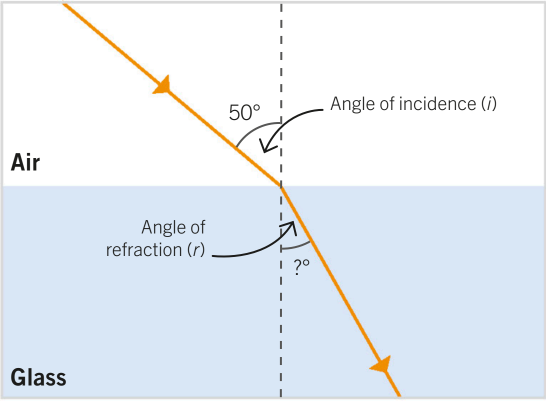
$$n = \frac{3 \times 10^8 \text{ m/s}}{2.3 \times 10^8 \text{ m/s}}$$

$$= 1.3$$

Snell's law

When light passes from air to a material with a higher refractive index, such as glass, it bends toward the normal. As a result, the angle of refraction is smaller than the angle of incidence. The equation here, called Snell's law, shows the relationship between the refractive index and the angles of incidence and refraction.

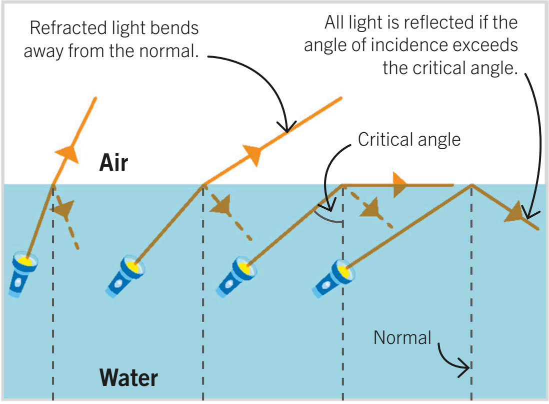
$$\underbrace{n_1}_{\text{Refractive index of first material}} \times \sin i = \underbrace{n_2}_{\text{Refractive index of second material}} \times \sin r$$



Total internal reflection

When light passes from a material with a high refractive index to a material with a lower one, such as from glass to air, it bends away from the normal. If the angle of incidence is more than a certain amount—the critical angle—the light is reflected internally. This equation shows how the critical angle and refractive index are related.

$$\sin \underbrace{c}_{\text{Critical angle}} = \frac{\overbrace{n_2}^{\text{Refractive index of second material}}}{\underbrace{n_1}_{\text{Refractive index of first material}}}$$



Calculating the angle of refraction

Question

Light enters a block of glass at an angle of incidence of 50°. If the refractive index of air is 1 and the refractive index of glass is 1.6, what is the angle of refraction?

Answer

1. First, rearrange Snell's law to make sin *r* the subject.

$$\sin r = \frac{n_1 \times \sin i}{n_2}$$

2. Put in the numbers and use a calculator to find the sine of 50°.

$$\sin r = \frac{1 \times \sin 50°}{1.6}$$
$$= 0.479$$

3. Use the $\sin^{-1}$ function on a calculator to find the answer.

$$r = 29°$$

Calculating the critical angle

Question

Diamonds get their sparkle from their high refractive index and small critical angle, which cause a lot of internal reflection off a diamond's faces before light escapes and reaches our eyes. If the refractive index of diamond is 2.4, what is the critical angle?

Answer

$$\sin c = \frac{\overbrace{1}^{\text{Refractive index of air}}}{2.4}$$

$$\sin c = 0.42$$
$$c = 25°$$

Converging and diverging lenses

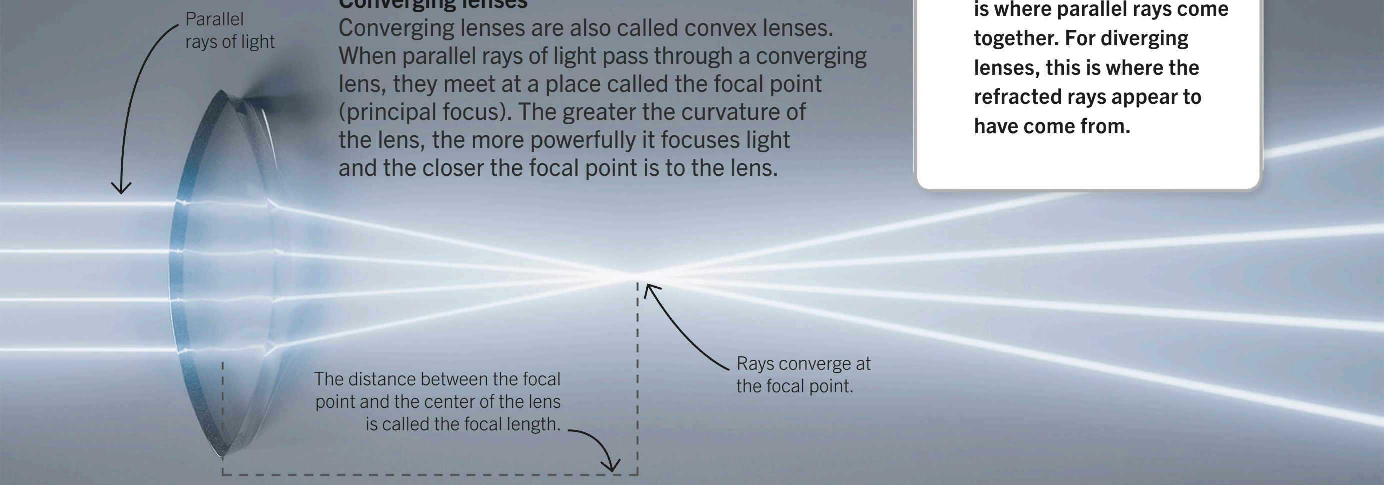
Lenses are shaped to change the direction of light by refraction. Converging lenses are lenses that bulge outward in the middle. They bend light rays so that they come together (converge). Diverging lenses are thinner in the middle. They make light rays spread out (diverge).

Key facts

- Converging lenses bulge outward in the middle and make parallel light rays converge.
- Diverging lenses are thinner in the middle and make parallel light rays diverge.
- Lenses have a focal point. For converging lenses, this is where parallel rays come together. For diverging lenses, this is where the refracted rays appear to have come from.

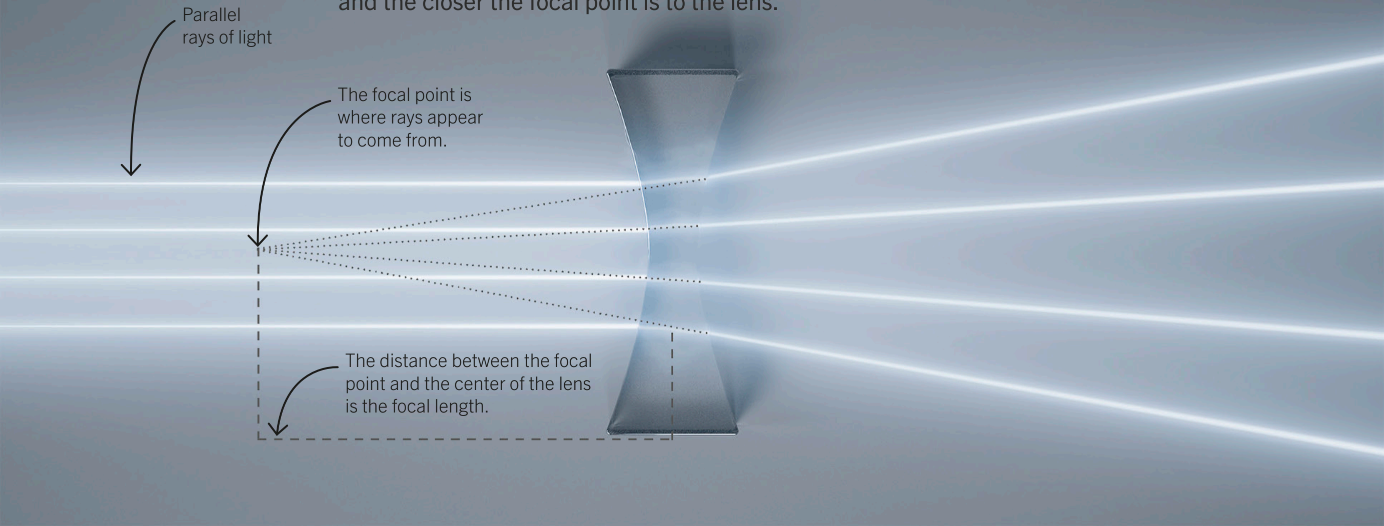
Converging lenses

Converging lenses are also called convex lenses. When parallel rays of light pass through a converging lens, they meet at a place called the focal point (principal focus). The greater the curvature of the lens, the more powerfully it focuses light and the closer the focal point is to the lens.



Diverging lenses

Diverging lenses are also called concave lenses. When parallel rays of light pass through a diverging lens, they spread out (diverge). The focal point of a diverging lens is the point which the diverging rays appear to come from. The greater the curvature of the lens, the more powerfully it focuses light and the closer the focal point is to the lens.



Correcting vision

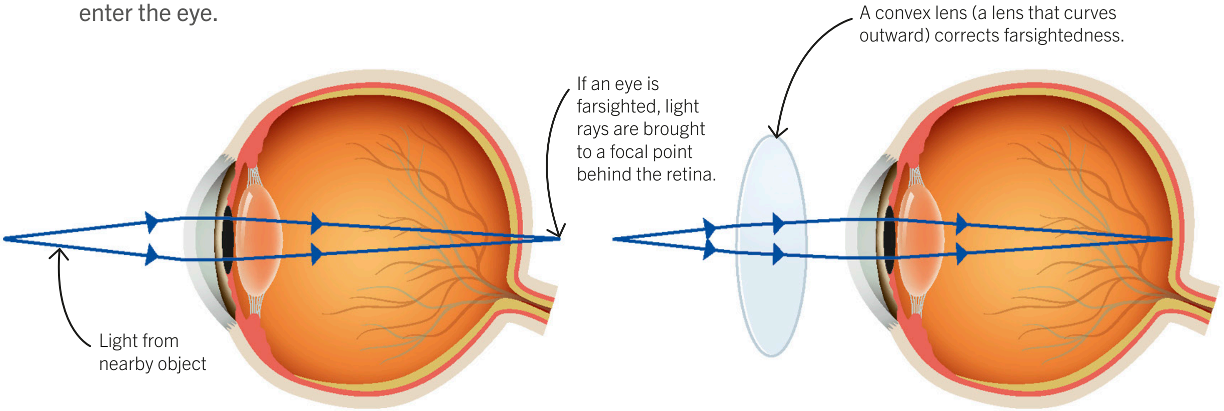
Converging and diverging lenses are used in glasses and contact lenses to correct two of the most common causes of blurred vision: nearsightedness and farsightedness.

Key facts

- ✓ **Converging and diverging lenses are used in glasses and contact lenses to correct vision.**
- ✓ **Diverging (concave) lenses are used to correct nearsightedness.**
- ✓ **Converging (convex) lenses are used to correct farsightedness.**

Farsightedness

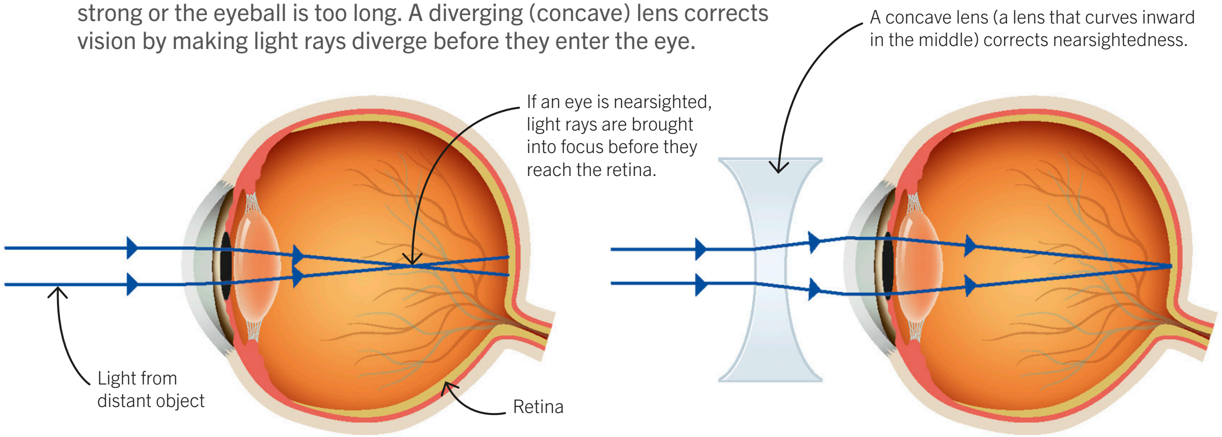
In a farsighted eye, light rays from nearby objects are focused toward a point behind the retina, making nearby objects look blurred. This happens because the eye's focusing power is not strong enough or the eyeball is too short. A converging (convex) lens corrects vision by making light rays converge before they enter the eye.



Farsighted eye **Corrected vision**

Nearsightedness

In a nearsighted eye, light rays from distant objects are brought into focus before they reach the retina, making distant objects look blurred. This happens either because the eye's focusing power is too strong or the eyeball is too long. A diverging (concave) lens corrects vision by making light rays diverge before they enter the eye.



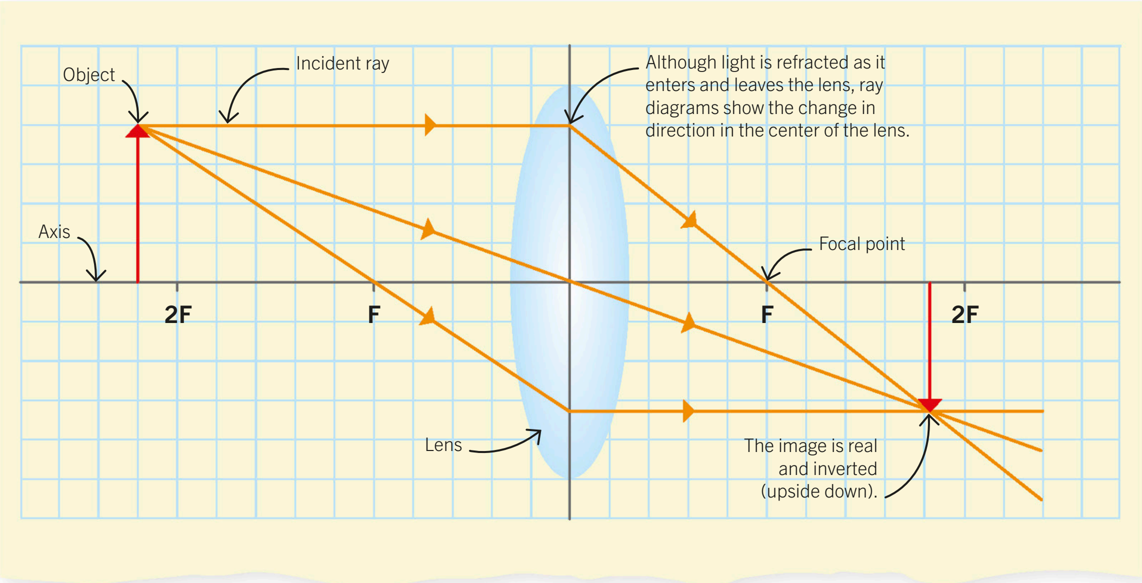
Nearsighted eye **Corrected vision**

Converging lens ray diagram

We can use ray diagrams to find out where the image produced by a converging lens appears. This diagram shows what happens when an object is farther from the lens than the lens's focal point. The lens produces a real image (see page 129) that is inverted (upside down) and diminished (smaller).

Key facts

- ✓ A ray diagram can be used to work out where the image produced by a lens appears.
- ✓ Incident rays that travel parallel to the axis are refracted through the focal point.
- ✓ Incident rays that travel through the focal point before reaching the lens are refracted to become parallel with the axis.
- ✓ An incident ray traveling through the center of the lens does not change direction.



How to draw a ray diagram for a converging lens

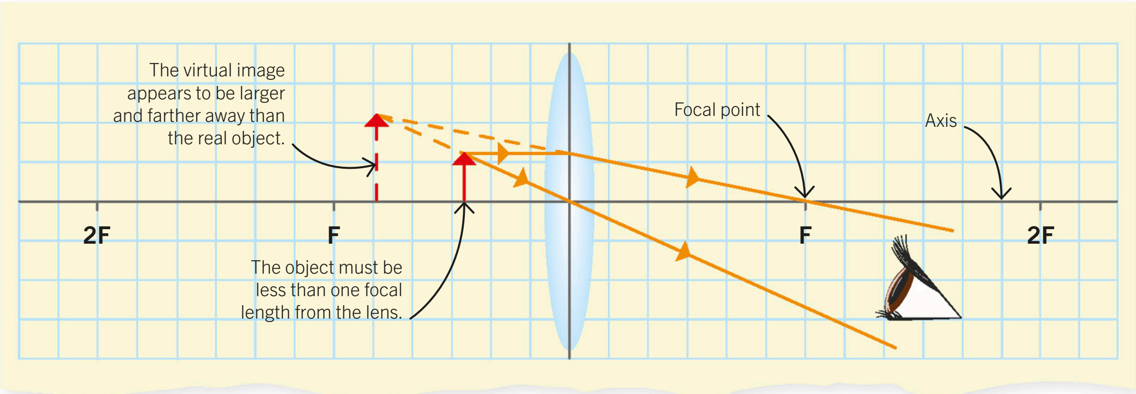
1. Draw a horizontal axis with a lens in the middle.
2. Mark the focal point (F) on both sides of the lens.
3. Draw the object as an arrow pointing upward.
4. Draw an incident ray from the top of the object to the lens, traveling parallel with the axis. Draw the refracted ray from the lens through the focal point.
5. For the second ray, draw a straight line from the top of the object through the center of the lens. This ray doesn't bend.
6. Where the lines cross is the bottom of the inverted image. (The image does not necessarily form at the focal point.)
7. To check, draw a third ray from the top of the object and through the left focal point to the lens. This ray refracts and continues in parallel with the axis.

Magnifying glass ray diagram

A converging lens works as a magnifying glass if the object is closer to the lens than the focal point. The image is enlarged, upright, and virtual (see page 129), so only someone looking through the magnifying glass can see it.

Key facts

- ✓ A magnifying glass is a converging (convex) lens.
- ✓ The magnifying glass produces an enlarged, upright, virtual image.
- ✓ The object must be within one focal length to produce the magnified image.



How to draw a ray diagram for a magnifying glass

1. Draw a horizontal axis with a lens in the middle.
2. Mark the focal point (F) on both sides of the lens.
3. Draw the object as an upward arrow closer to the lens than the focal point.
4. Draw an incident ray from the top of the object to the lens, traveling parallel with the axis. Then draw the refracted ray from the lens through the focal point.
5. Draw a second ray from the top of the object through the center of the lens. This ray doesn't bend.
6. Using a ruler, extend both rays backward as dotted lines. The point where they cross is the top of the virtual image. The bottom of the virtual image is on the axis.

Calculating magnification

Use this formula to work out the magnification of an image.

$$\textbf{magnification} = \frac{\textbf{image height}}{\textbf{object height}}$$

Question

A beetle measuring 9 mm long is viewed through a magnifying glass, producing a 28 mm virtual image. What is the magnification?

Answer

$$\text{magnification} = \frac{28\text{ mm}}{9\text{ mm}}$$

$$\text{magnification} = 3.1$$

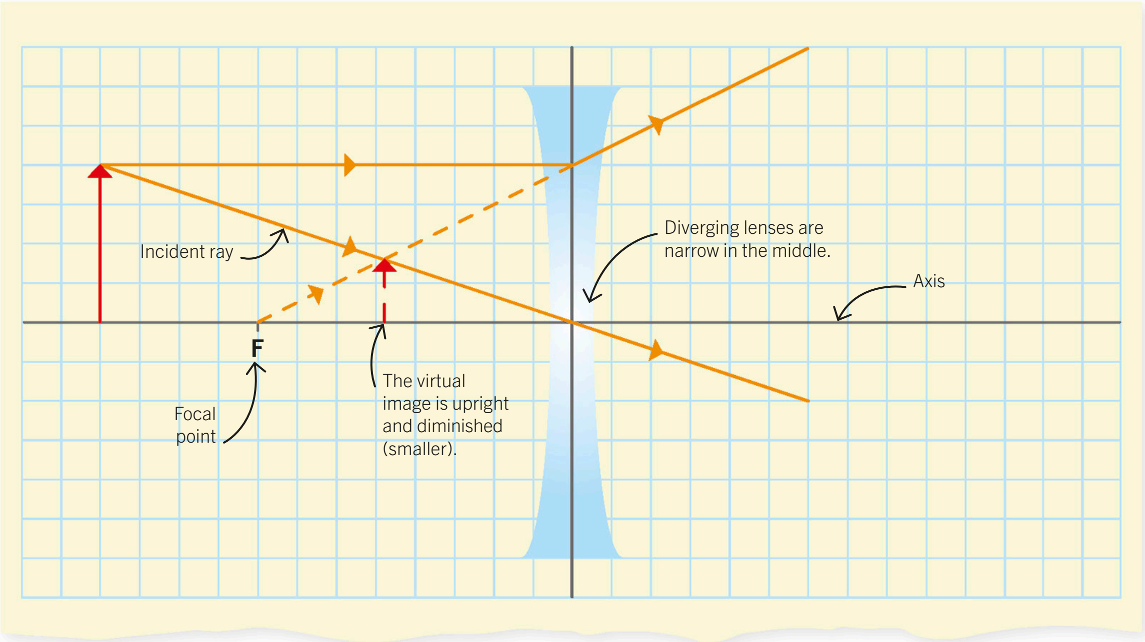
Magnification is a ratio, so the answer has no units.

Diverging lens ray diagram

If you look through a diverging lens, it makes things look smaller. A diverging lens produces a virtual image that is upright but diminished (smaller). Drawing a ray diagram allows you to work out where the image will appear and how small it is.

Key facts

- ✓ A ray diagram shows where the image produced by a lens appears.
- ✓ Incident rays that travel parallel to the axis are refracted outward by a diverging lens as though they came from the focal point.
- ✓ An incident ray traveling through the center of the lens does not bend.



How to draw a ray diagram for a diverging lens

1. Draw a horizontal axis with a lens in the middle.
2. Mark the focal point (F) on the left of the lens.
3. Draw the object as an arrow pointing upward.
4. Draw an incident ray from the top of the object to the lens, traveling parallel with the axis.
5. The refracted ray will travel as though it came from the focal point on the left of the lens. Use your ruler to draw a dotted line from the focal point to the lens, and continue this as a solid line traveling away.
6. Draw a second ray traveling straight through the center of the lens. This ray doesn't refract.
7. Where the dotted line and the second ray meet is the top of the virtual image.

Light and color

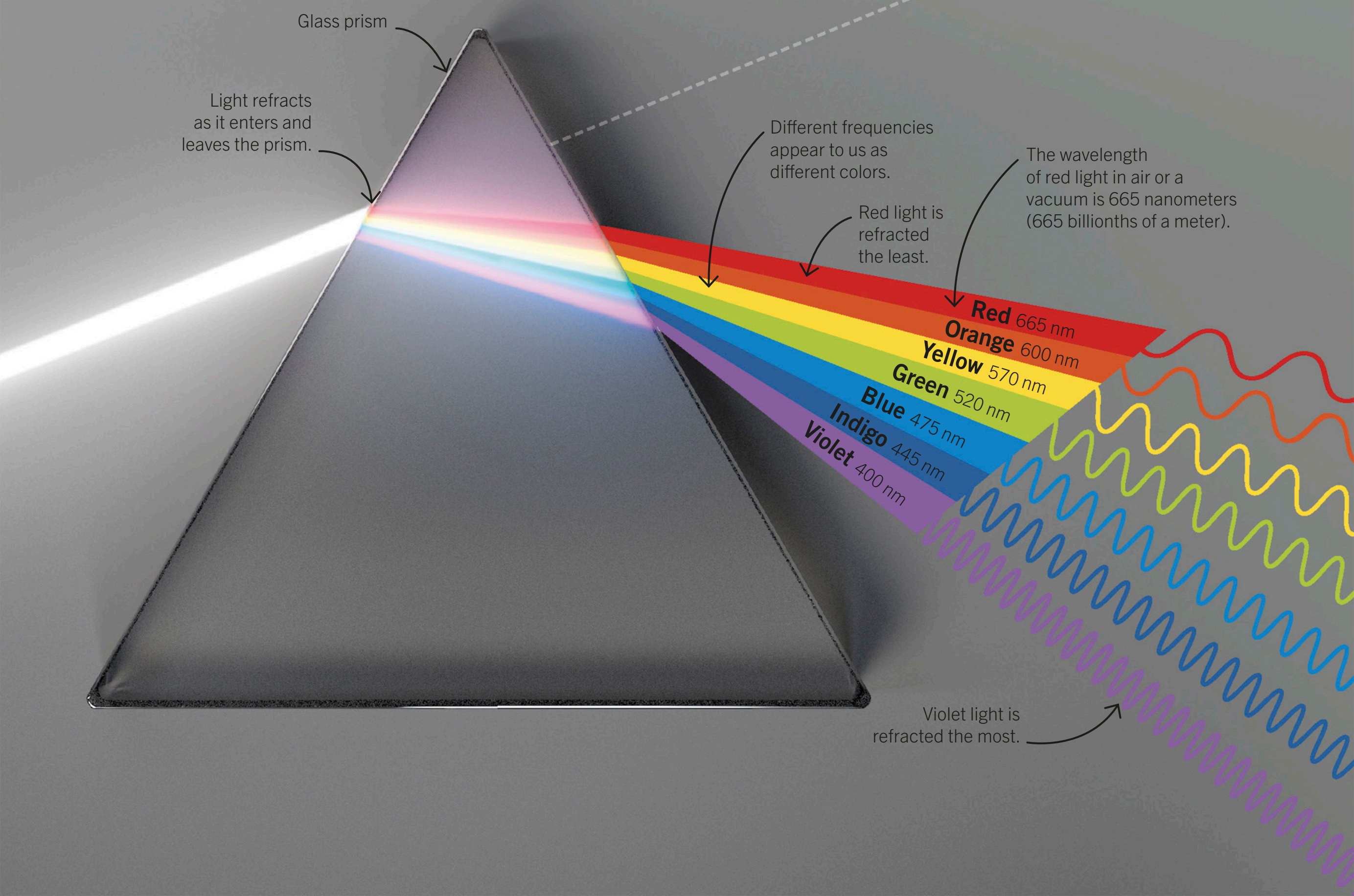
Light from the Sun is made up of a wide range, or spectrum, of different frequencies. The range of frequencies we can see—the visible spectrum—is just a tiny part of this. Different frequencies of visible light appear to our eyes as different colors. When all the visible frequencies are mixed together, they make white light.

Key facts

- ✓ Different frequencies of visible light appear to our eyes as colors.
- ✓ White light is a mixture of different frequencies.
- ✓ A glass prism can refract white light and split it into its component colors.

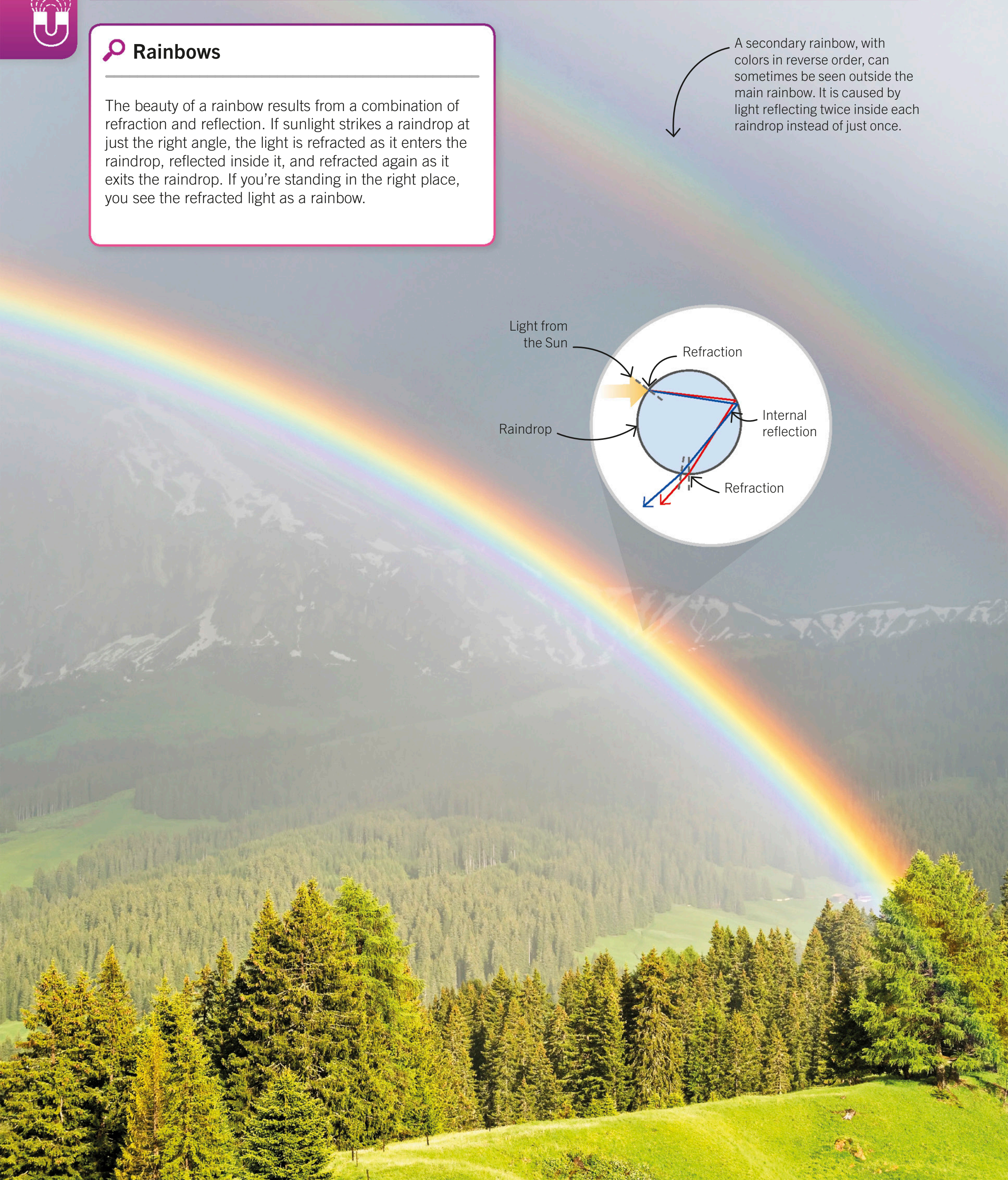
Visible light spectrum

We can split white light into its component colors by shining it through a triangular block of glass called a prism. The glass refracts each frequency differently. Colors with higher frequencies, such as violet, refract more than colors with lower frequencies, such as red. As a result, a beam of white light spreads out to produce a colorful spectrum. Although the visible spectrum is traditionally shown with seven colors, most people can't distinguish indigo and blue, so they can only see six.



Rainbows

The beauty of a rainbow results from a combination of refraction and reflection. If sunlight strikes a raindrop at just the right angle, the light is refracted as it enters the raindrop, reflected inside it, and refracted again as it exits the raindrop. If you're standing in the right place, you see the refracted light as a rainbow.



A secondary rainbow, with colors in reverse order, can sometimes be seen outside the main rainbow. It is caused by light reflecting twice inside each raindrop instead of just once.

Reflecting and absorbing

White light is a mixture of all the colors of the visible spectrum. When light strikes an object, some wavelengths are absorbed and others are reflected. The color of an object depends on which wavelengths are reflected.

Key facts

- ✓ White light is a mixture of all the colors of the visible spectrum.
- ✓ Objects appear colored because they absorb some wavelengths and reflect others.
- ✓ Colored filters absorb most colors but allow some colors to pass through.

Absorption and reflection
These billiard balls are different colors because they each absorb a different range of wavelengths. Wavelengths that aren't absorbed are reflected, giving the objects their colors.

A red billiard ball looks red because its surface absorbs all wavelengths of visible light except red, which is reflected.

A black ball looks black because it absorbs every color and reflects little light.

A white ball looks white because it reflects all the different wavelengths of visible light.

Color filters

The color of transparent materials depends on which wavelengths are absorbed and which are transmitted (let through). Colored filters, such as stained glass, don't add colors to light—they subtract them. A red filter absorbs all wavelengths except red, for example.

A red filter absorbs all colors apart from red light.

A green filter absorbs all colors apart from green light.

A blue filter absorbs all colors apart from blue light.

Electromagnetic radiation

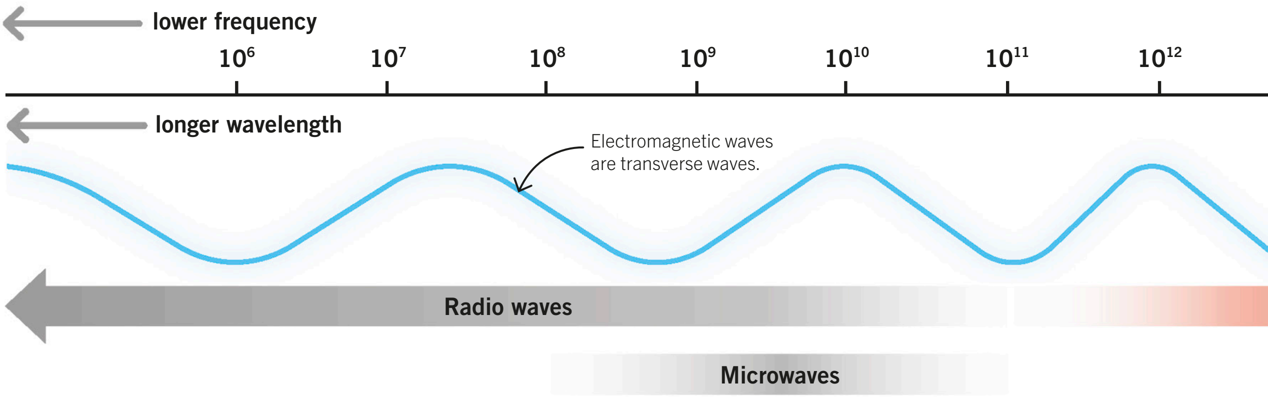
The light we can see is just a small part of a much larger electromagnetic spectrum. Electromagnetic waves transfer energy from atoms that emit them to atoms that absorb them. They don’t require a medium to travel through and can cross the vacuum of space. All types of electromagnetic waves travel at the speed of light: about 300 million m/s in air or space.

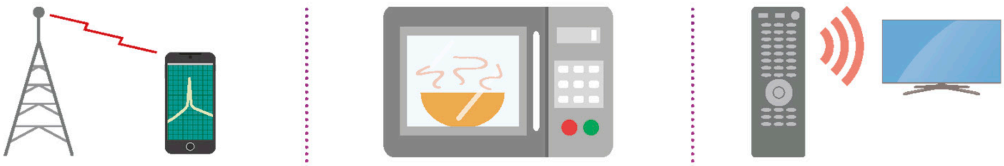
Key facts

- ✓ Visible light is a small part of the electromagnetic spectrum.
- ✓ Electromagnetic waves are generated by changes in atoms.
- ✓ Electromagnetic waves travel at the speed of light and do not require a medium.

The electromagnetic spectrum

Electromagnetic waves range from radio waves (with wavelengths from millimeters to thousands of kilometers long) to gamma rays (which have wavelengths smaller than atoms). The shorter the wavelength of electromagnetic radiation, the higher its frequency and the greater the amount of energy it transfers.





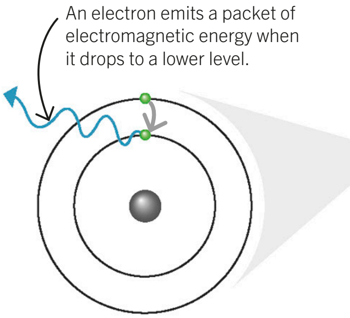
Radio waves are used for communication, such as transmitting phone calls, TV programs, and internet data. Long-wave radio waves can bend around hills and around Earth’s curved surface.

Microwaves are short-wavelength radio waves and are used for communication. Certain frequencies of microwave radiation are absorbed by water molecules in food and are used for heating in microwave ovens.

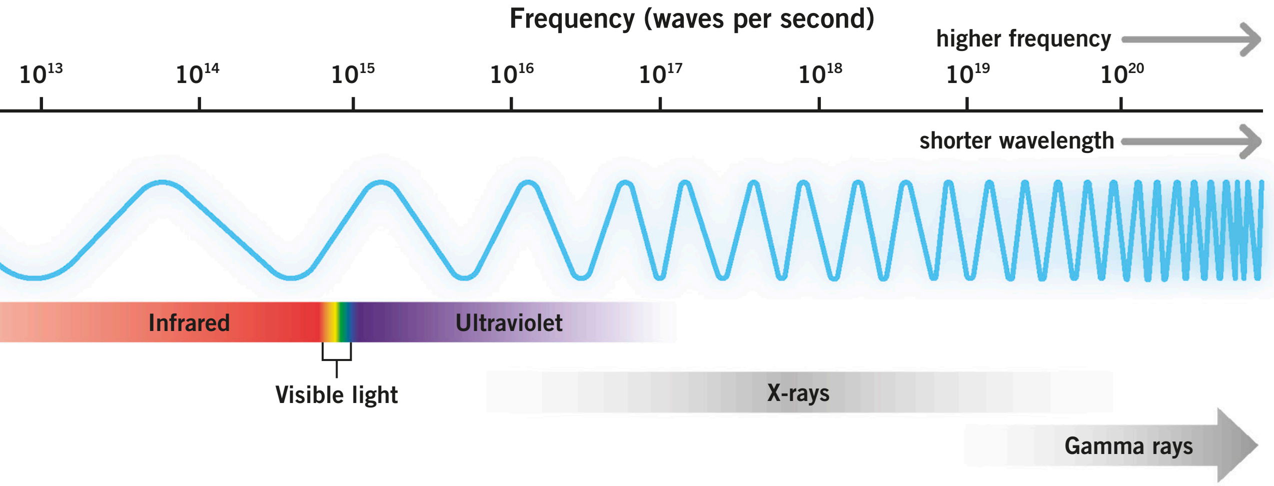
Infrared is the heat you can feel when you warm your hands by a fire or stand in the Sun. TV remote controls use infrared beams to send signals to the TV, and night-vision goggles that detect infrared radiation allow people to see in the dark.

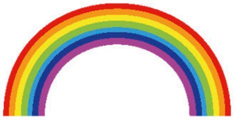
Electromagnetic waves

Electromagnetic waves can be generated by changes in atoms. For instance, light is emitted when electrons move from high-energy levels to lower levels. The frequency and wavelength of the light depend on how far the electron moves. Near Earth's poles, oxygen atoms in the atmosphere emit a greenish light when they release energy after being struck by high-speed particles from the Sun. The light causes the aurora borealis (northern lights).



Oxygen atom





Visible light is the small part of the electromagnetic spectrum we can see. We use it to illuminate our surroundings and to generate images on TVs and phone screens.

Ultraviolet (UV) rays cause tanning and sunburn. UV lamps are used to kill bacteria and viruses, to detect forged paper currency, and to make fluorescent objects glow in clubs.

X-rays are high-energy electromagnetic waves that pass through soft body tissues but not bones or teeth. They are used for medical imaging and to check the contents of luggage in airport security.

Gamma rays emitted by radioactive materials (see pages 240—241) are used to sterilize medical instruments, create medical images, and kill cancer cells.

Radio waves

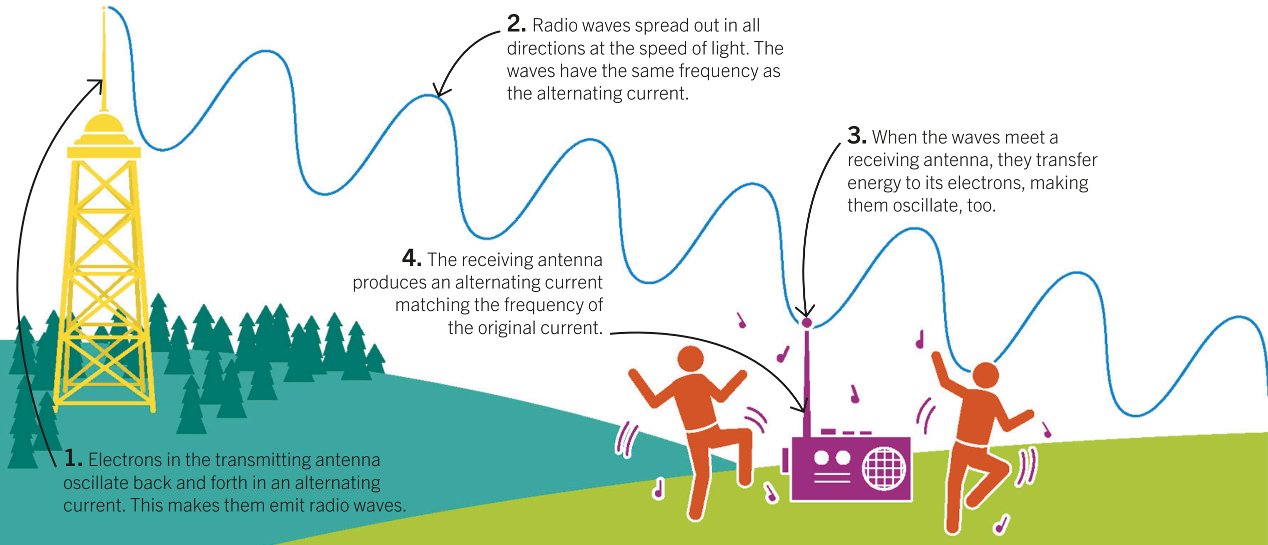
Electromagnetic waves can be generated by the acceleration of electrons—the negatively charged particles that form the outside of atoms. When electrons oscillate back and forth at certain frequencies, they emit radio waves. These waves are used for communication.

Key facts

- ✓ Radio waves are produced by alternating electrical currents.
- ✓ Radio waves induce alternating currents in antennae (aerials).
- ✓ The frequency of a radio wave is the same as the frequency of the alternating current that generated it.

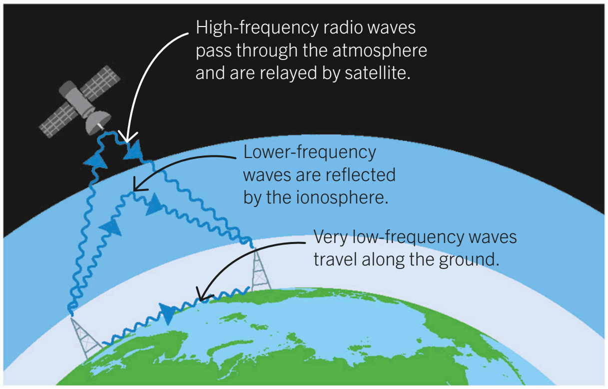
How radio communication works

Radio waves are produced by alternating currents, which cause electrons to oscillate back and forth in an antenna (aerial). The radio waves have the same frequency as the alternating current and trigger a current with a matching frequency in the receiving antenna. Data is transmitted as variations in the frequency (or amplitude) of the waves.



How radio waves travel

Radio frequencies used for communication vary from low frequencies (with wavelengths kilometers in length) to high frequencies (with wavelengths just centimeters long). High-frequency waves can only travel in straight lines but can be relayed by satellites. Lower-frequency radio waves are reflected by the ionosphere (an electrically charged layer in Earth's upper atmosphere), allowing them to travel beyond the horizon.



Hazardous radiation

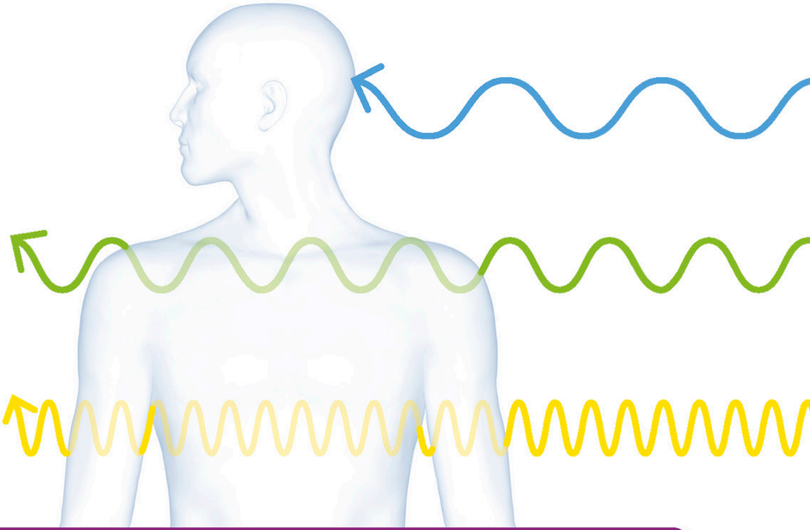
Exposure to high-energy electromagnetic radiation can be harmful to living things. The higher the frequency of the waves, the more energy they transfer and the more likely they are to do harm.

Key facts

- ✓ **Electromagnetic radiation is divided into nonionizing and ionizing radiation.**
- ✓ **Nonionizing radiation does not have enough energy to remove electrons from atoms.**
- ✓ **Ionizing radiation is energetic enough to remove electrons from atoms and break chemical bonds.**
- ✓ **Exposure to ionizing radiation may result in tissue damage and cancer.**

Effects on the body

Low-frequency waves, such as radio waves, pass through living tissue without being absorbed and are not dangerous. However, gamma rays, X-rays, and high-frequency ultraviolet rays are all types of ionizing radiation—they have enough energy to remove electrons from atoms and break chemical bonds, which can damage the molecules in living cells.



Ultraviolet radiation cannot penetrate the body, but it can harm skin cells, leading to sunburn and an increased risk of cancer. It can also damage parts of the human eye, leading to visual defects or blindness.

X-rays penetrate the body and can damage the DNA in cells, leading to mutations that cause cancer. The risk depends on the dose, which is measured in units called sieverts. The X-ray machines in hospitals expose the body to very small doses of X-ray radiation.

Gamma rays penetrate the body and are the most dangerous form of electromagnetic radiation. They damage DNA and increase the risk of cancer. Large doses cause radiation sickness, which can be fatal.

Benefits and risks

Although ultraviolet radiation, X-rays, and gamma rays can all be harmful, there are benefits, too. Exposure to the ultraviolet rays in sunlight helps the body make vitamin D. X-ray machines help dentists check teeth for decay and help doctors examine fractured bones or other conditions. Gamma radiation can be used to detect and to destroy cancer cells. In each case, the potential benefits need to be weighed against the risks.

Finger bones are clear on this X-ray of a person's hand.

Electrical circuits

Current electricity

Unlike static electricity, which can stay in one place, current electricity is always moving. All the electric devices we use rely on flowing electric current. Some, such as headphones and mobile phones, use only a small current, but appliances such as stoves and electric heaters use a much larger current.

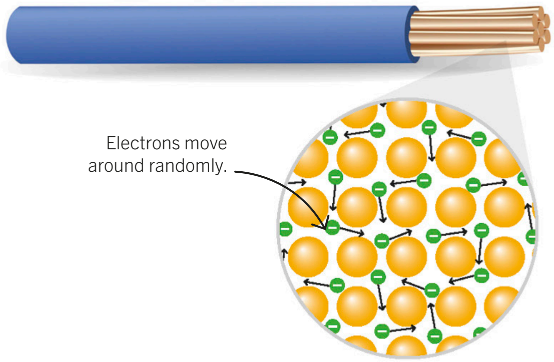
Key facts

- ✓ Current electricity depends on the movement of free electrons in materials such as metals.
- ✓ When pushed by an electrical voltage, free electrons move in one direction. This is an electric current.
- ✓ Materials that let electricity flow through them are called conductors.
- ✓ Materials that block the flow of electricity are called insulators.

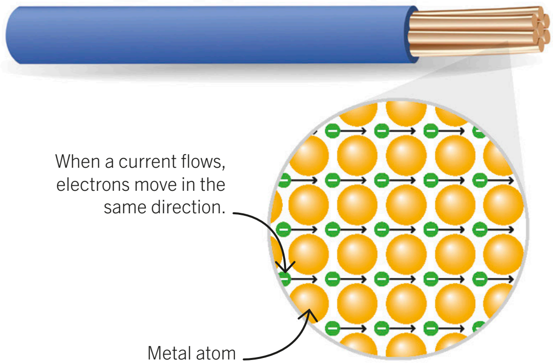
Moving electrons

Current electricity depends on the movement of electrons—the tiny, negatively charged particles that form the outer parts of atoms. In metals, some of the electrons are free to move around. These free electrons normally move around randomly, but when a circuit is switched on, they all move in the same direction. The electrons themselves move slowly, but all the electrons in a wire are affected at once, causing electromagnetic energy to flow through a circuit at close to the speed of light.

Current not flowing



Current flowing



Conductors and insulators

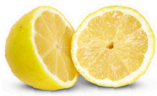
Materials that allow electricity to flow through them are called conductors. Metals are good conductors because their atoms have outer electrons that can separate from the atoms and move freely. Solutions containing dissolved ions (charged particles) can also conduct electricity. Materials with no free charged particles are called insulators because they block the flow of electricity.

Conductors


Copper


Gold


Silver


Lemon juice

Insulators


Ceramic

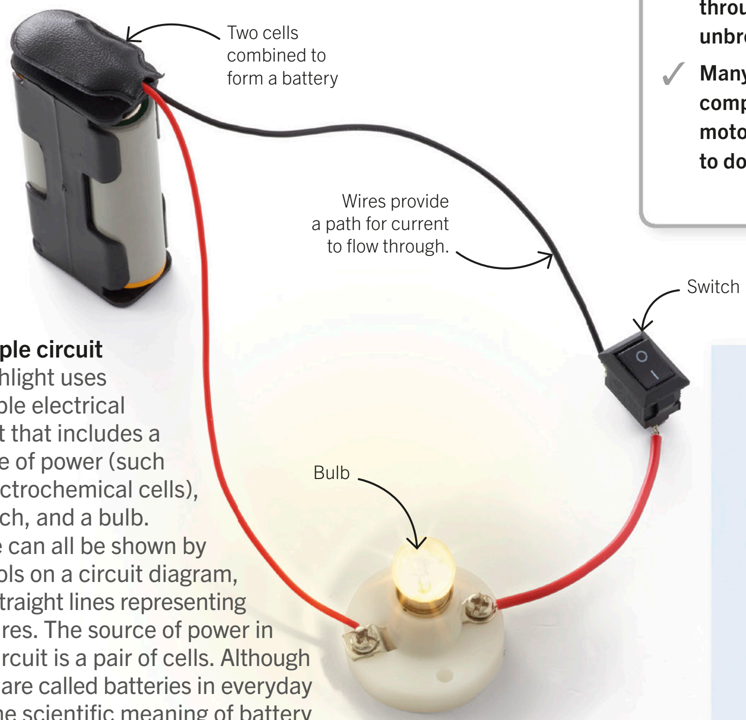

Wool


Rubber


Wood

Electrical circuits

Much of modern life is dependent on electricity and electrical circuits. Some circuits are simple, like the one shown below. Others are much more complex, like those in mobile phones, computers, and many other gadgets.

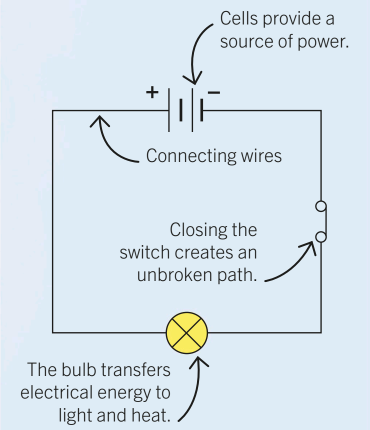


A simple circuit
A flashlight uses a simple electrical circuit that includes a source of power (such as electrochemical cells), a switch, and a bulb. These can all be shown by symbols on a circuit diagram, with straight lines representing the wires. The source of power in this circuit is a pair of cells. Although these are called batteries in everyday life, the scientific meaning of battery is a group of cells. An electric current can only flow in a circuit when the switch is closed, creating an unbroken path.

Key facts

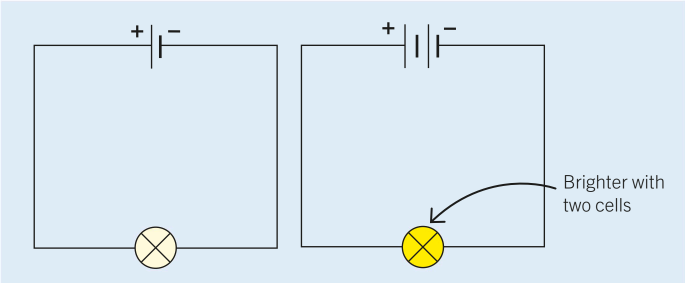
- ✓ All electrical circuits need a source of energy, such as a cell.
- ✓ Two or more cells used together make up a battery.
- ✓ Electric current will only flow through a circuit if there is an unbroken conducting path.
- ✓ Many electrical circuits have components such as bulbs or motors, which transfer energy to do useful jobs.

Circuit diagram



Voltage

The voltage of a cell is a measure of how powerfully it pushes current around a circuit. Adding an extra cell creates twice the voltage, making twice as much current flow. As a result, the bulb glows brighter.



Series and parallel circuits

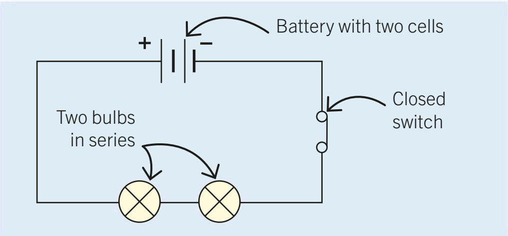
Circuits can be connected in two basic ways. If all the components are connected in a single loop, they are said to be connected in series. If the circuit splits into branches, they are said to be connected in parallel.

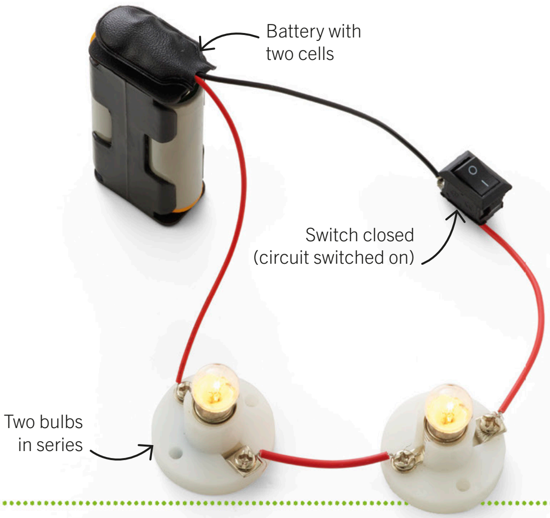
Key facts

- ✓ Electrical circuits can be connected in series or in parallel.
- ✓ In a series circuit, the components are connected in a single loop and can all be switched on or off together.
- ✓ In a parallel circuit, the circuit divides so that components are on different branches. If one branch breaks, the other can continue working.

Series circuit

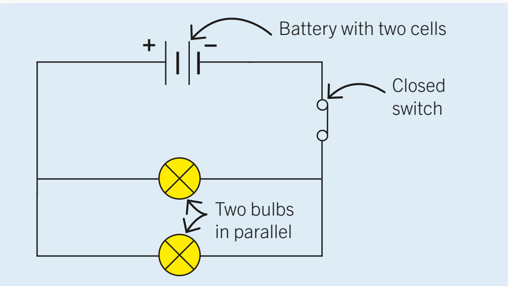
In a series circuit, the components are connected one after another in a single loop. The two bulbs here are connected in series. If one bulb breaks, the current cannot flow through and the other bulb stops working, too. If extra bulbs are added, they will all be dimmer because each bulb reduces the flow of current through the circuit.

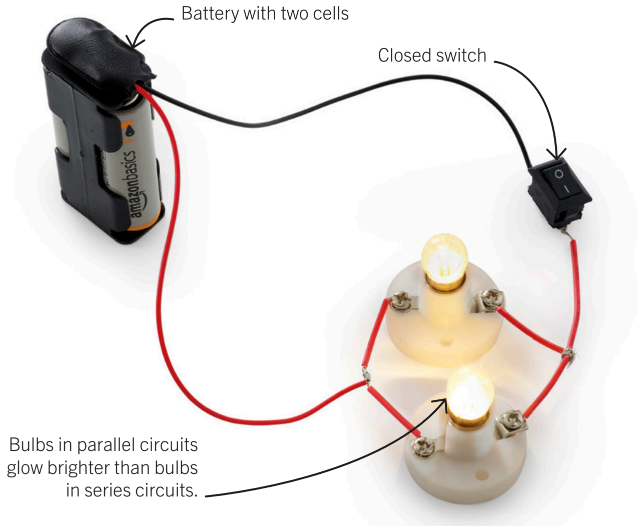




Parallel circuit

In a parallel circuit, the components are on separate branches. There's more than one path for the current to take, so if one bulb breaks, the other continues working. In each branch, the electric current only has to flow through a single bulb, which means more current can flow than in the series circuit. As a result, the bulbs are brighter. The wiring in homes is arranged as parallel circuits.



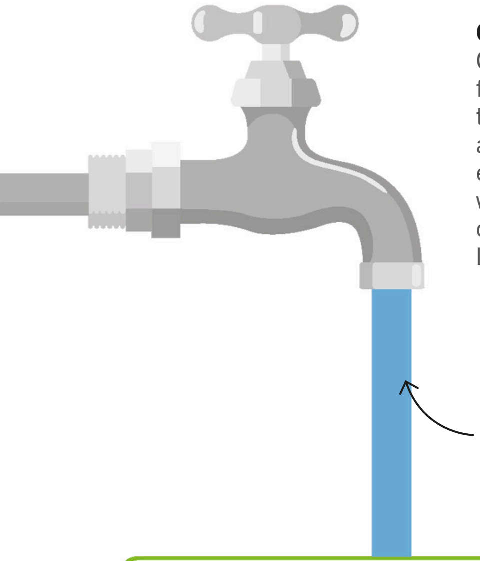


Measuring electricity

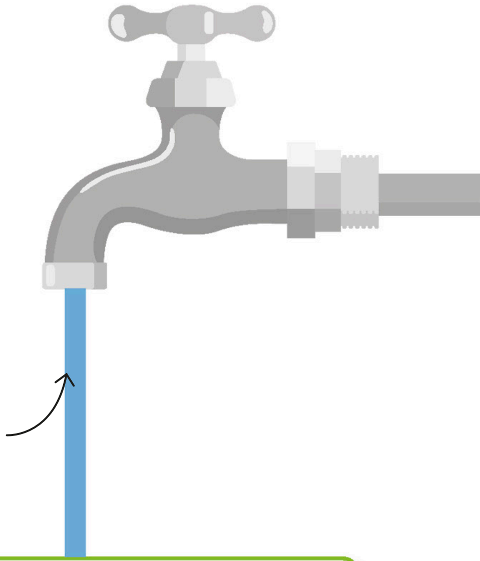
Measuring electricity is a bit like measuring the way water from a tank flows through pipes. The rate at which electric charge flows through a circuit is called current, and we measure it in units called amps. The size of the current depends on two main things: the strength of the driving force (called voltage or potential difference) that pushes electricity along, and how much resistance the electricity meets in the circuit.

Key facts

- ✓ Current is the rate of flow of electric charge. We measure it in units called amps (A).
- ✓ Current is measured by an ammeter, which is connected in series.
- ✓ Voltage (potential difference) is a measure of how strongly charge is pushed through a circuit. We measure it in volts (V).
- ✓ Voltage is measured by a voltmeter, which is connected in parallel.
- ✓ Resistance is anything that uses up electrical energy, reducing the flow of electric current. We measure resistance in ohms (Ω).



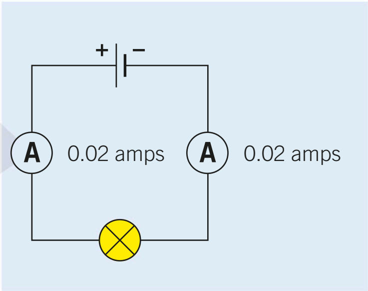
Current
Current is the rate at which charge flows through a circuit. Like water flowing through a pipe, a large current means a lot of electric charge is flowing past every second, transferring lots of energy, whereas a small current means the charge is trickling by, transferring less energy.



Measuring current

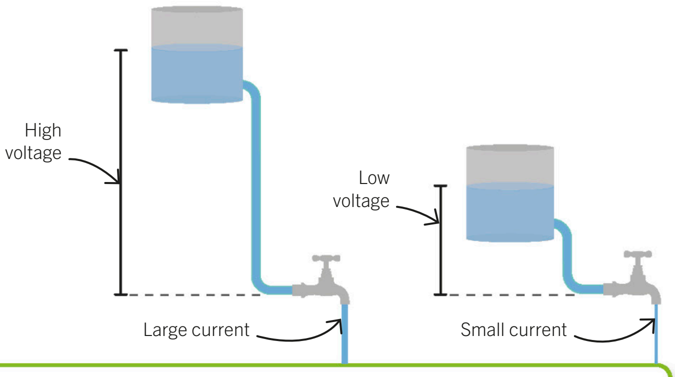
We measure current in units known as amps or amperes (A), using a device called an ammeter. An ammeter has to be connected in series wherever we want to measure the current. It doesn't matter where you put it in a series circuit, as the current is the same in every part of the circuit. The symbol for an ammeter on a circuit diagram is the letter A in a circle.

Ammeter



Voltage (potential difference)

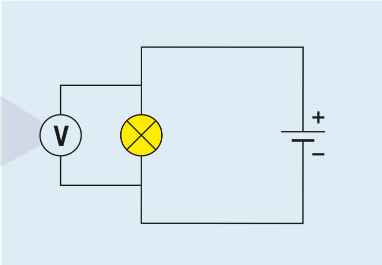
A current can't flow unless something pushes it. The push comes from the difference in electric potential energy at the start and end of the circuit, which we call voltage or potential difference. It works a bit like water pressure. When a water storage tank is up high, the force of gravity creates a higher pressure, making the rate of flow of water through the tap bigger.



Measuring voltage

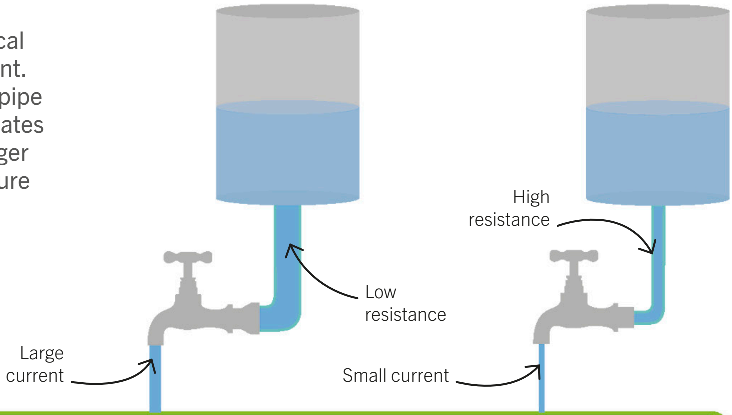
We measure voltage in units called volts (V), using a device called a voltmeter. The voltmeter must be connected in parallel with the component. The symbol for a voltmeter on a circuit diagram is the letter V in a circle.


Voltmeter



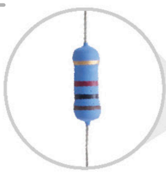
Resistance

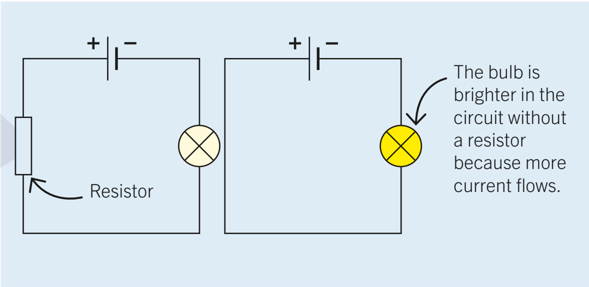
Anything in a circuit that uses up electrical energy reduces the flow of electric current. We call this resistance. Just as a narrow pipe reduces the flow of water, a thin wire creates resistance and reduces the current. Longer wires also increase resistance. We measure resistance in units called ohms (Ω).



Resistors

In some circuits, a component called a resistor is added to ensure the current doesn't become high enough to damage other components. The symbol for a resistor in circuit diagrams is a rectangle.


Resistor



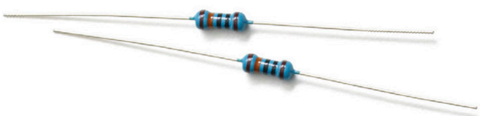
Series and parallel circuit rules

Here are the main rules that you need to know about currents and voltages in series and parallel circuits.

Key facts

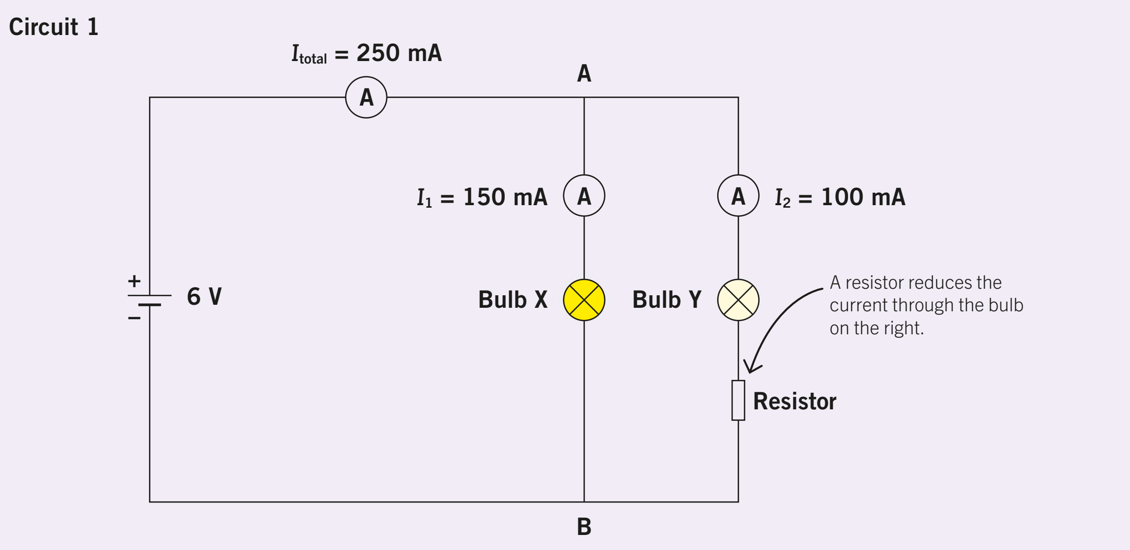
- The sum of currents flowing toward any point in a circuit is equal to the sum of currents flowing away from it (current in equals current out).
- The voltages across components in series add up to the voltage of the power supply.
- Components connected in parallel have the same voltage across them.

Rule 1: Current in equals current out
The sum of currents flowing toward any point in a circuit is always equal to the sum of currents flowing away from it. In the circuit below, a current of 250 mA (milliamps) flows toward A, where it splits into two. The two currents flowing away from A, 150 mA and 100 mA, add up to 250 mA.



$$I_{total} = I_1 + I_2$$

The symbol for current is the capital letter I.



Calculating current

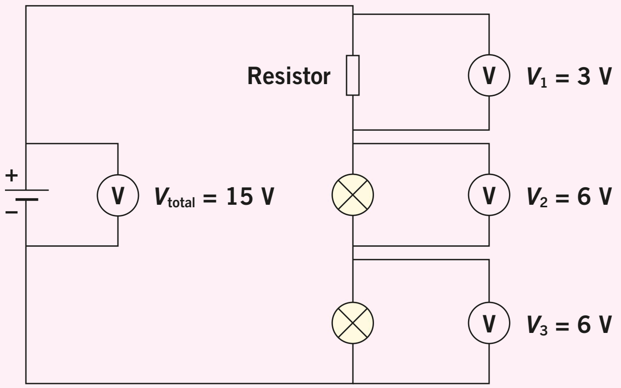
Question 1
In circuit 1, what's the size of the current flowing away from B?

Answer 1
Current in equals current out, so the answer is 250 mA.

Rule 2: Voltages in series add up
When components are connected in series, such as the two bulbs and the resistor shown here, the voltages across each component add up to the voltage of the power supply.

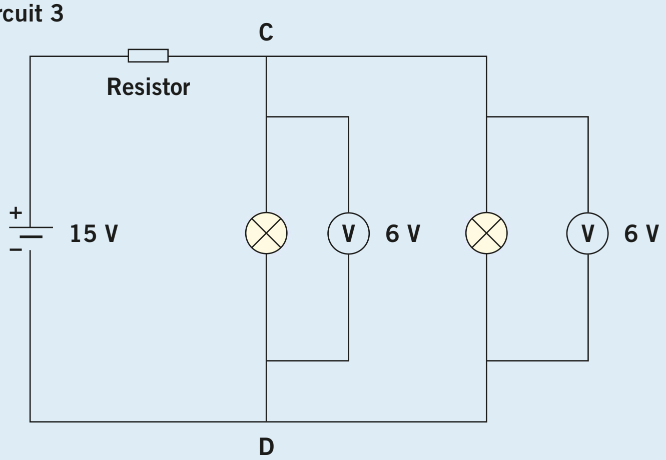
$$V_{total} = V_1 + V_2 + V_3$$

Circuit 2



Rule 3: Voltages in parallel are the same
In a parallel circuit, each parallel branch has the same voltage across it. In the example shown here, the two bulbs have the same voltage across them.

Circuit 3



Calculating voltage

Question 2
In circuit 3, what's the voltage across the resistor?

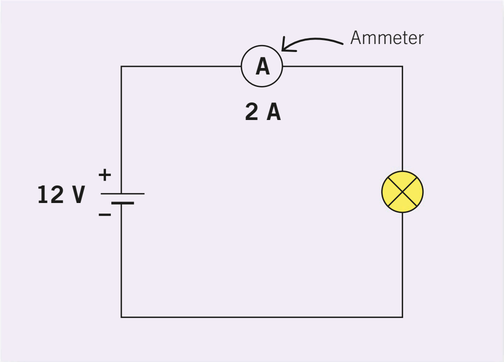
Answer 2
The circuit has a total voltage of 15 V, and the voltage between C and D is 6 V. The voltage across the resistor must therefore be 15 V – 6 V, which is 9 V.

Question 3
The voltage across the resistor in circuit 1 is 4 V. What is the voltage across bulb Y?

Answer 3
The voltage across each branch of the circuit is 6 V. In the right branch, 6 V is divided between bulb Y and the resistor, so the voltage across bulb Y is 6 V – 4 V = 2 V.

Charge

Electrons all have negative charge. When a circuit is switched on, the moving electrons cause an electric charge to flow through it. We measure charge in units called coulombs. Electric current is the rate of flow of charge: a current of 1 amp means 1 coulomb of charge flows past every second. The equations on this page show how charge, current, voltage, and energy are related.



Charge and current

The size of an electric current tells you how much charge moves past any point in a circuit each second. In this circuit, the reading of 2 amps on the ammeter shows that 2 coulombs of charge pass through the cell and the bulb every second. This relationship between charge, current, and time is summed up in the equation below.

$$\text{charge (C)} = \text{current (A)} \times \text{time (s)}$$

$$Q = I \times t$$

Charge and energy

Electrical devices do useful jobs by transferring energy. For instance, the circuit above transfers energy from the cell to light. If you know how much charge flows through a component and the size of the voltage (potential difference) pushing the charge, you can calculate how much energy the circuit transfers using the equation below.

$$\text{energy transferred (J)} = \text{charge (C)} \times \text{voltage (V)}$$

$$E = Q \times V$$

Key facts

- ✓ The unit of electric charge is the coulomb (C).
- ✓ A current of 1 amp means 1 coulomb of charge passes through a circuit each second.
- ✓ When 1 coulomb of charge moves through a potential difference of 1 volt, it transfers 1 joule of energy.

Calculating charge and energy

Questions

1. A flashlight bulb uses a 3 V battery and a current of 0.25 A flows through the bulb. The flashlight is turned on for 5 minutes. How much charge passes through the flashlight bulb?
2. How much energy is transferred from the battery to the bulb in that time?

Answers

1. First, work out the time in seconds:
   5 minutes = 300 seconds
   $Q = I \times t$
   $= 0.25\ \text{A} \times 300\ \text{s}$
   $= 75\ \text{C}$
2. Use the second equation to calculate energy transferred:
   $E = Q \times V$
   $= 75\ \text{C} \times 3\ \text{V}$
   $= 225\ \text{J}$

Changing resistance

Sometimes it's useful to change the resistance in a circuit to control how much current can flow. This makes it possible to change the brightness of a lamp, the speed of a motor, or the loudness of a radio.

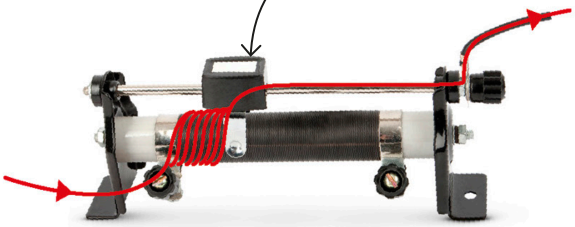
Key facts

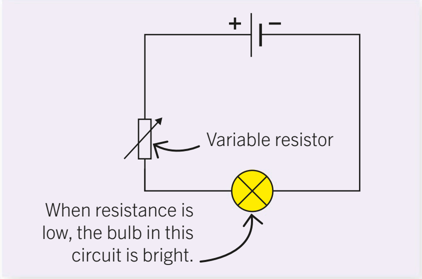
- ✓ A variable resistor consists of a resistance coil and a sliding contact.
- ✓ The current, voltage, and resistance of a circuit are linked by the equation voltage = current × resistance.

Variable resistor

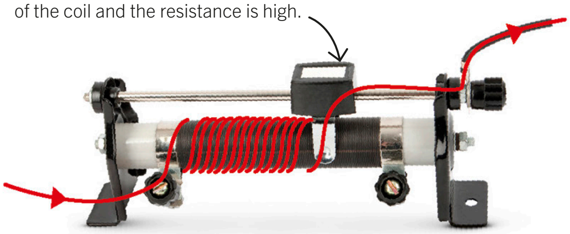
The component used to change resistance is called a variable resistor. It consists of a long, coiled wire that creates resistance and a sliding contact that can be moved to vary how much coil the current flows through.

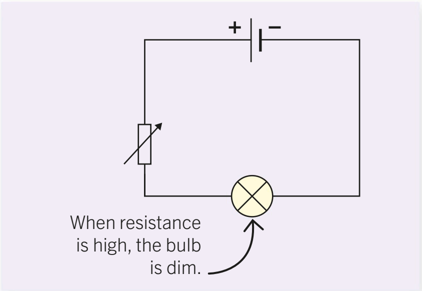
With the slider near the left end of the coil, the current does not have to pass through many turns of wire and the resistance is low.





With the slider near the right end, the current has to pass through most of the coil and the resistance is high.





Calculating current, voltage, and resistance

The current, voltage, and resistance in a circuit or component are linked by the equation below, which is known as Ohm's law.

voltage (V) = current (A) × resistance (Ω)

$$V = I \times R$$

Question

A current of 0.5 A flows through a bulb when there is a voltage of 6 V across it. Calculate the resistance of the bulb.

Answer

Rearrange the equation to make resistance the subject:

$$R = \frac{V}{I}$$

$$R = \frac{6\ \text{V}}{0.5\ \text{A}}$$

$$R = 12\ \Omega$$

Investigating resistance in wires

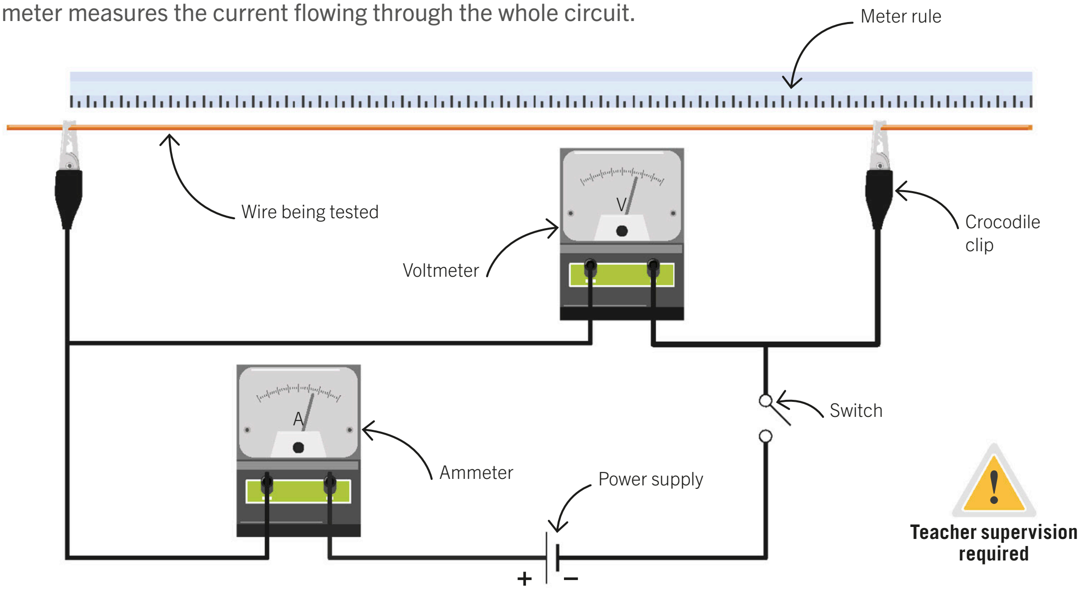
The resistance of a component depends on many factors. This experiment investigates how the resistance of a wire varies with the wire's length.

Key facts

- ✓ **The resistance of a wire increases with the wire's length.**
- ✓ **Resistance can be calculated by dividing voltage by current.**

The circuit

The two crocodile clips in this circuit allow you to vary the length of a piece of wire through which the current flows. The voltmeter measures the voltage (potential difference) across this wire, and the ammeter measures the current flowing through the whole circuit.



Method

1. With help from a teacher, set up a circuit as shown above.
2. Fasten one crocodile clip to the wire at the zero mark on the ruler. Fasten the other crocodile clip at 30 cm.
3. Set the power supply to a low voltage (3–4 V) or use a cell.
4. Turn on and note the readings on the ammeter and voltmeter. Turn off again as soon as you've done this to stop the wire from becoming hot.
5. Write your results in a table with column headings for wire length, current, and voltage.
6. Move the crocodile clip to 40 cm and repeat steps 4 and 5.
7. Repeat every 10 cm up to 100 cm.

Warning

Your teacher will provide a special kind of wire (Constantan or Eureka wire with a diameter of about 0.5 mm) that is safe to be used as a resistor in this experiment. Do not use ordinary wire. The wire should either be raised or supported on a heat-resistant mat made of a material that does not conduct electricity. Take readings quickly and then disconnect the power to prevent the wire from heating up. Do not touch the naked wire when the circuit is turned on.

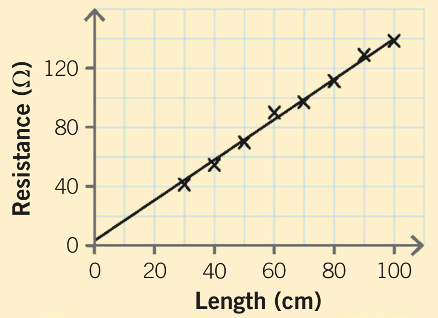
Results

1. Use Ohm's law (below) to calculate the resistance for each length of wire, and record the answers in a new table.

$$\text{resistance } (\Omega) = \frac{\text{voltage (V)}}{\text{current (A)}}$$

Wire length (cm)	30	40	50	60	70	80	90	100
Calculated resistance (Ω)	44	53	71	88	95	112	127	138

2. Draw a graph of resistance against length of wire, and join the points with a line of best fit. The points should be on a straight line that passes through the origin (0, 0). This shows that the resistance of the wire is proportional to its length. In other words, if its length doubles, its resistance doubles.



3. You may find that the straight line on your graph doesn't pass through the origin. This is caused by what's known as a systematic error—an error that affects all your readings. In this case, it could be that one crocodile clip was not exactly at the zero point on the ruler, so all your measurements of length are incorrect by the same amount. Another possible cause of systematic error is resistance from the other wires in the circuit, especially if they are long.

Resistance is useful

Resistance is caused by collisions between the free electrons in a wire and the lattice of fixed metal ions. The collisions transfer energy to the ions, increasing their store of thermal energy. Electric heaters and electric light bulbs exploit this process to generate heat and light. The filament in a light bulb gets so hot that it glows white hot, flooding its surroundings with light.

Resistance in wires

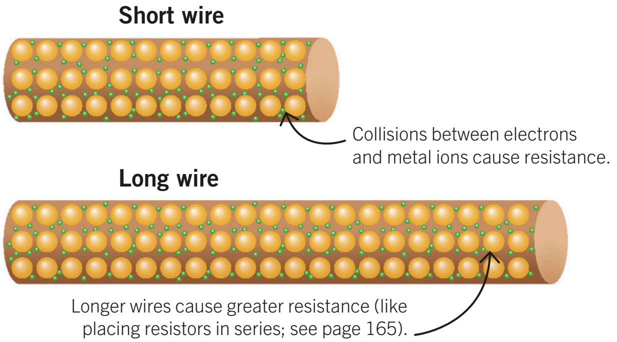
Why do some substances make it difficult for electricity to pass through them? Insulators have huge resistance because there are no free electrons to carry charge, but metals have lots of free electrons. However, electricity flows more easily through some wires than others.

Key facts

- ✓ Resistance in metals happens because free electrons collide with metal ions as they move through the wire.
- ✓ Short wires have less resistance than long wires.
- ✓ Thick wires have less resistance than thin wires.
- ✓ Some metals conduct better than others.

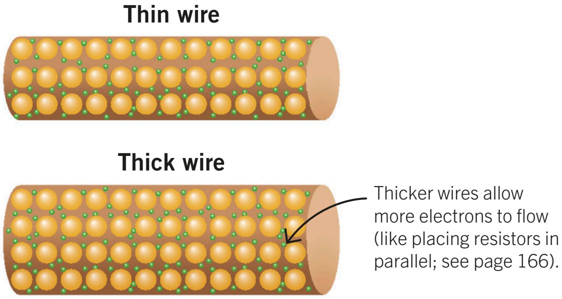
Wire length

Wires create resistance because the free electrons bump into the fixed metal ions as they move, transferring some of their energy to the ions. The longer the wire, the greater the resistance. Resistance is proportional to the length of the wire.



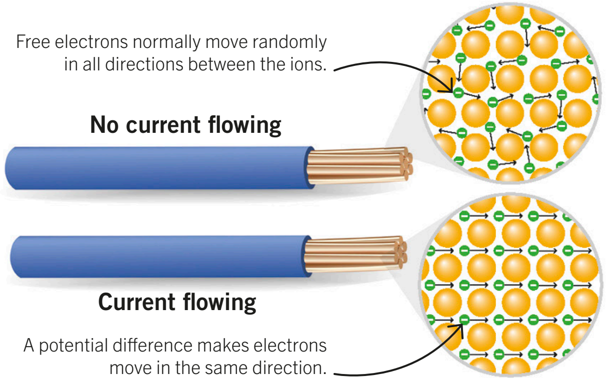
Wire thickness

In thicker wires, there are more electrons to flow, allowing a greater current and therefore lower resistance. Resistance is inversely proportional to the cross-sectional area of a wire. If the cross-sectional area doubles, the resistance halves. If the diameter of the wire doubles, the resistance goes down by a factor of four.



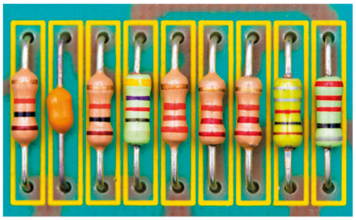
Free electrons

Atoms in a metal are held together in a regular lattice. The atoms' outermost electrons can easily separate to become free electrons, leaving behind positively charged ions. These free electrons normally move randomly in all directions inside the metal, but when a voltage (potential difference) is applied, the electrons all flow in the same direction. Some metals (such as copper and silver) are better conductors than others because their atoms lose the outer electrons more easily.



Investigating resistors in series and parallel

We use resistors to control the amount of current flowing through a circuit. This experiment investigates how much resistance they create when multiple resistors are connected in series or parallel.

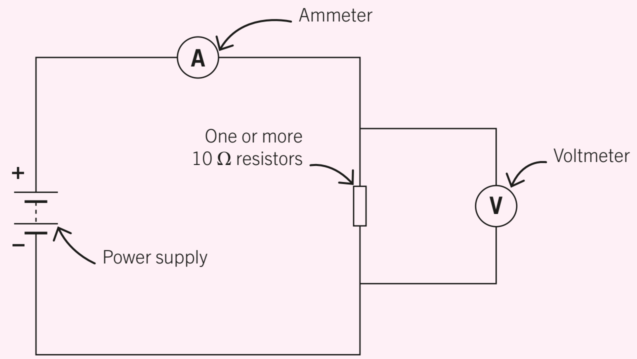


Resistors on a circuit board

Resistors in series

Use a circuit like the one below to find out what happens when you add resistors in series. This experiment shows that when resistors are added in series, the total resistance in the circuit increases.

Teacher supervision required



Method

1. Set up the circuit shown, with just one 10 Ω resistor held between two crocodile clips.
2. Turn on the power supply and record the voltage across the resistor and the current.
3. Turn off and add another 10 Ω resistor in series with the first. Turn on and record the current and voltage again.
4. Repeat step 3 until you've tested the circuit with four resistors in it.
5. Use the following equation to calculate the total resistance of the circuit for each test:

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

Results

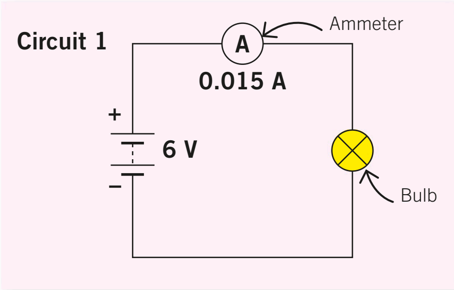
Record your readings in a table like the one shown here. The results show that the resistance of the circuit increases by 10 Ω every time a 10 Ω resistor is added in series. The total resistance is the sum of the resistors in the chain. This is shown by the equation below.

$$R_{total} = R_1 + R_2 + \ldots$$

Number of 10 Ω resistors	Voltage (V)	Current (A)	Calculated resistance (Ω)
1	2.0	0.200	10
2	2.0	0.100	20
3	2.0	0.067	30
4	2.0	0.050	40

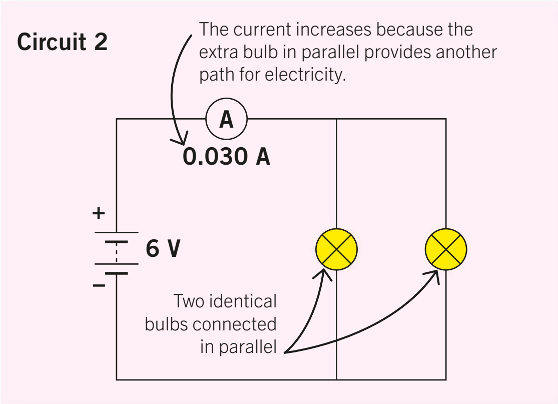
Resistors in parallel

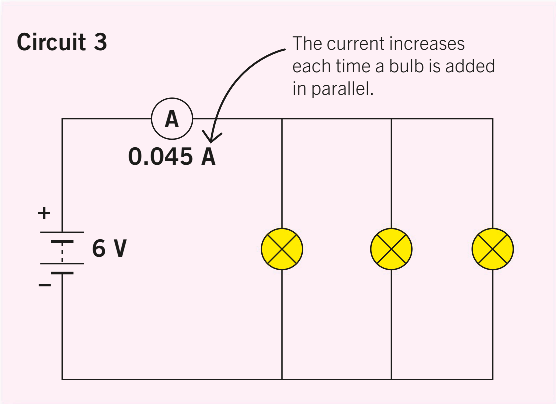
We can investigate the effect of resistors in parallel using the circuits below. The bulbs serve as resistors here, but we would get similar results using actual resistors. This experiment shows that when resistors are added in parallel, the overall resistance of the circuit falls and the current in the main part of the circuit increases.



Method

1. Set up the circuit with a single bulb and note the current on the ammeter.
2. Turn off the power and add a second bulb in parallel. Turn on the power and note the new reading. The current will have doubled because the new path allows more electricity to flow through the circuit.
3. Add a third bulb in parallel and take another reading. The current will have tripled.





Calculating resistance for components in parallel

The total resistance of components in parallel can be calculated using this equation:

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$

Question

Each bulb in the circuits above has a resistance of 400 Ω. What is the total resistance of the circuit with two bulbs?

Answer

$$\frac{1}{R_{\text{total}}} = \frac{1}{400\ \Omega} + \frac{1}{400\ \Omega}$$
$$= \frac{2}{400\ \Omega}$$
$$R_{\text{total}} = \frac{400\ \Omega}{2}$$
$$= 200\ \Omega$$

Note that this is half the resistance of one resistor by itself.

Check the answer using the equation $V = I \times R$ (voltage = current × resistance). For this circuit, $I = 0.030$ A and $V = 6$ V.

$V = 0.030\text{ A} \times 200\ \Omega$
$= 6\text{ V}$

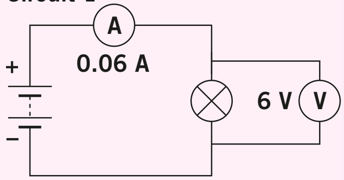
Current and voltage calculations

Previous pages in this chapter have introduced lots of ideas about series and parallel circuits, and some equations. The calculations here show you some ways in which these ideas can be used. The first three questions feature series circuits. The rest are about parallel circuits.

Series circuits key facts

- ✓ Resistances of components in series add up to the total resistance: $R_{total} = R_1 + R_2$.
- ✓ Voltage = current × resistance: $V = I \times R$. This is known as Ohm's law.
- ✓ Ohm's law works everywhere in the circuit, whether we're looking at individual components, a part of the circuit, or the whole circuit.

Circuit 1



Question

What's the resistance of the bulb in circuit 1?

Answer

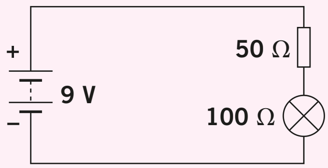
You know the voltage across the bulb and the current flowing through it, so rearrange the equation $V = I \times R$ (Ohm's law) to calculate the resistance.

$$R = \frac{V}{I}$$

$$= \frac{6\ \text{V}}{0.06\ \text{A}}$$

$$= 100\ \Omega$$

Circuit 2



Question

What's the total resistance in this circuit? Use the answer to calculate the current that flows through the circuit.

Answer

The resistances of components connected in series add up.

$$R_{total} = R_1 + R_2$$

$$= 100\ \Omega + 50\ \Omega$$

$$= 150\ \Omega$$

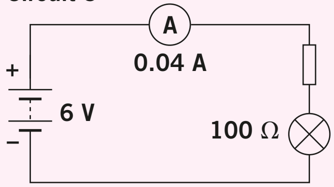
You know the resistance and voltage, so rearrange $V = I \times R$ to calculate the current.

$$I = \frac{V}{R}$$

$$= \frac{9\ \text{V}}{150\ \Omega}$$

$$= 0.06\ \text{A}$$

Circuit 3



Question

The bulb in this circuit has a resistance of 100 Ω. What's the resistance of the resistor?

Answer

Start by working out the total resistance of the circuit, using the voltage of the battery and the current.

$$R = \frac{V}{I}$$

$$= \frac{6\ \text{V}}{0.04\ \text{A}}$$

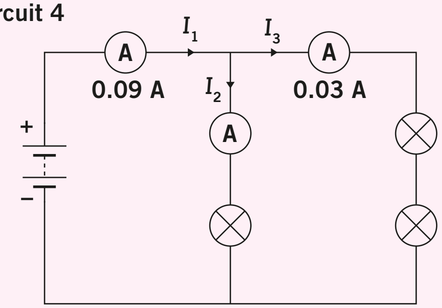
$$= 150\ \Omega$$

The resistances of the bulb and resistor add up to 150 Ω, so:

$$R_{resistor} = 150\ \Omega - 100\ \Omega$$

$$= 50\ \Omega$$

Circuit 4



Parallel circuits key facts

- ✓ **Current flowing into a junction equals current flowing out: $I_1 = I_2 + I_3$.**
- ✓ **The total resistance of components in parallel is smaller than the resistance of either of the components.**
- ✓ **Each branch of a parallel circuit has the same voltage across it.**

Question

All the bulbs in this circuit are the same. What's the current I_2? Explain why I_2 is greater than I_3.

Answer

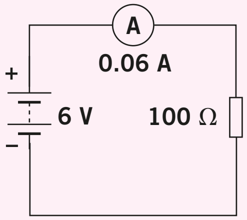
The current going into a junction equals the total current coming out of the junction.

$0.09 \text{ A} = I_2 + 0.03 \text{ A}$

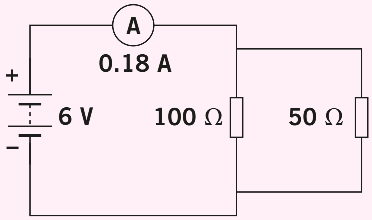
$I_2 = 0.06 \text{ A}$

I_2 is flowing through one bulb, but I_3 flows through two. The two parallel branches have the same voltage, but two bulbs create twice as much resistance, so the current through I_3 is half the size.

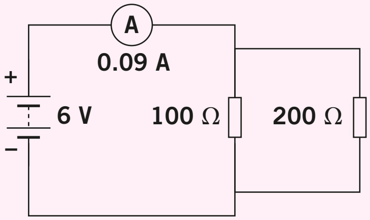
Circuit 5



Circuit 6



Circuit 7



Questions

1. Which of the three circuits above has the smallest total resistance?
2. Which resistor has the highest voltage across it?
3. Explain why the current is highest in circuit 6.

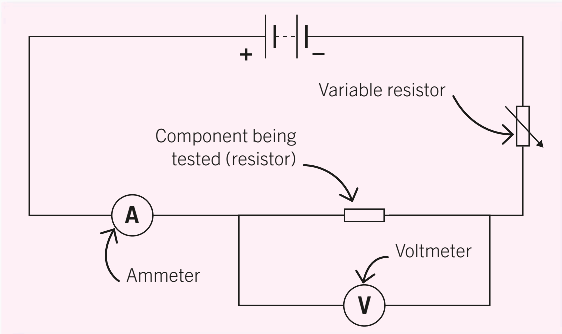
Answers

1. Circuit 6. All the circuits have the same voltage supplied by the battery, and the current is biggest in circuit 6.
2. They all have 6 V across them. In the parallel circuits, each branch of the circuit has the same voltage across it.
3. The current through the 100 Ω resistor is the same in all three circuits. In circuits 6 and 7, more current can flow through the extra resistors. A higher current will flow through the 50 Ω resistor in circuit 6 than through the 200 Ω resistor in circuit 7, so the total current in circuit 6 is highest.

Current and voltage graphs

Resistors and wires are called ohmic conductors because they obey Ohm's law ($V = I \times R$). In other words, a resistor or a wire has constant resistance, and the current flowing through it is proportional to the voltage across it. Not all components obey this law, however. You can investigate the resistance of different components using the circuit below.

Teacher supervision required



Key facts

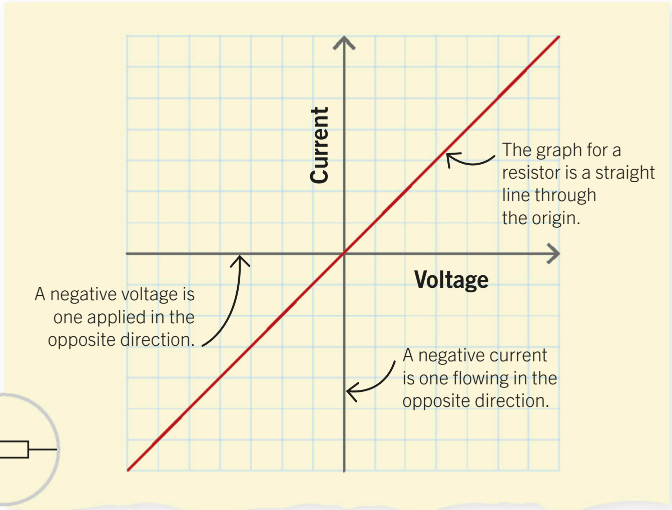
- ✓ The graph of current against voltage for an ohmic conductor is a straight line passing through the origin (0, 0).
- ✓ Filament bulbs and diodes are examples of nonohmic conductors.
- ✓ The resistance of metals increases with temperature.
- ✓ Diodes only allow current to pass through in one direction.

Method

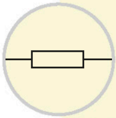
1. Set up the circuit shown in the diagram.
2. Use the variable resistor to change the current to 10 different values. Make a note of the voltage for each different current. Write down your results in a table.
3. Swap the connections to the battery over, and repeat step 2. Your current and voltage readings will now have negative values.
4. Repeat steps 2 and 3 with a filament bulb instead of the resistor, and then with a diode.
5. Plot a graph of current against voltage for each component.

Results for a resistor

A graph of current and voltage for a resistor forms a straight line that passes through the origin (0, 0). As resistance can be calculated from voltage divided by current, this shows that the resistance is constant and doesn't change when the direction of the voltage and current changes. A resistor is an ohmic conductor.

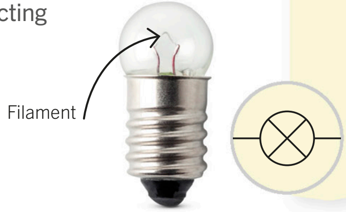


Resistor

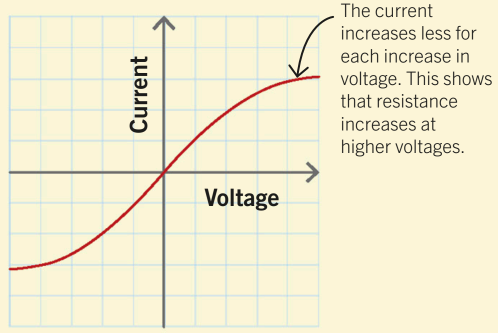


Results for a filament bulb

The graph for a filament bulb shows the line curving at higher voltages. This indicates that resistance is increasing, so a filament bulb is not an ohmic conductor. The filament in a light bulb gets white hot when current passes through, transferring electrical energy to light. Resistance increases because the metal atoms vibrate more as they get hotter, obstructing the flow of free electrons.



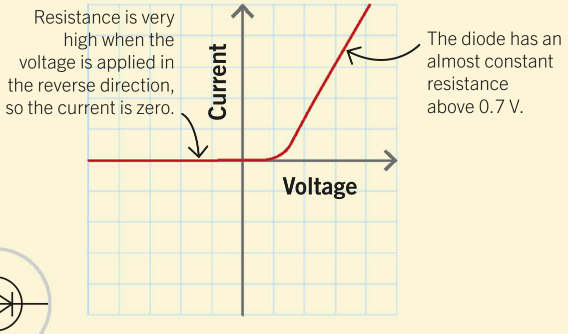
Bulb



Results for a diode

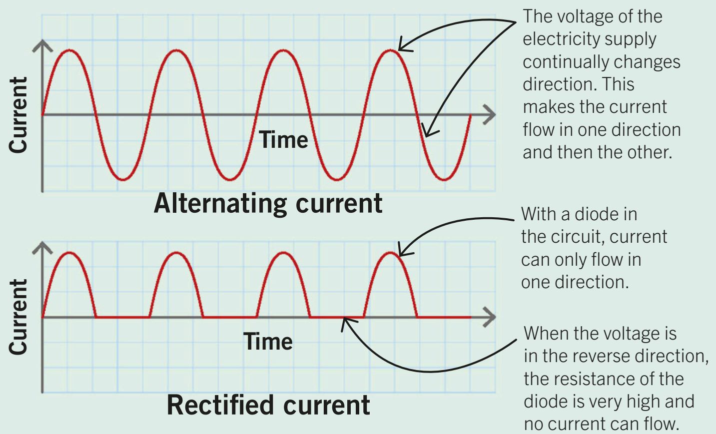
A diode is like a one-way street: current can flow freely in one direction but not the other. As the graph shows, a diode is not an ohmic conductor.

Diode



Rectification

Diodes are used in rectifier circuits, which convert alternating current (a.c.) from electricity supplies to direct current (d.c.) for electronic devices.



Power in circuits

Electrical devices transfer energy from a power supply such as a battery to components such as lamps, heaters, and motors. Electrical power is the amount of energy transferred each second. We measure it in watts (W).

Key facts

- ✓ Power is measured in watts (W).
- ✓ One watt means that one joule of energy is transferred in each second. 1 W = 1 J/s.
- ✓ Electrical power can be calculated using three equations:
  power = current × voltage
  power = (current)^2 × resistance
  power = (voltage)^2 ÷ resistance.

Power equations

The energy transferred by an electrical device depends on the current and voltage. We can calculate power—the amount of energy transferred each second—using the equation below. The equation doesn't need to include a term for time, as current is a measure of flow of the charge passing each second.

power (W) = current (A) × voltage (V)

$$P = I \times V$$

If we combine the equation above with Ohm's law (voltage = current × resistance), we can derive two new equations for power. One, shown below, calculates power from current and resistance. The other calculates power from voltage and resistance: power = (voltage)^2 ÷ resistance.

voltage = current × resistance

power = current × voltage

power (W) = current^2 (A)^2 × resistance (Ω)

$$P = I^2 \times R$$

Calculating power

Question
A flashlight uses a 6 V battery, and the current through the lamp is 300 mA. What's the power of the flashlight? What's the resistance of the lamp?

Answer
Use the first equation to calculate power. Remember that 300 mA is 0.3 A.

$P = I \times V$
$= 0.3\text{ A} \times 6\text{ V}$
$= 1.8\text{ W}$

To find resistance, rearrange either $V = I \times R$ or $P = I^2 \times R$ to make R the subject.

$$R = \frac{P}{I^2}$$

$$= \frac{1.8\text{ W}}{(0.3\text{ A})^2}$$

$$= 20\ \Omega$$

Calculating energy

From flashlights and phones to electric cars and high-speed trains, all electrical devices transfer energy. The amount of energy transferred can be calculated using several related equations.

Key facts

- ✓ Energy transferred by a device equals power multiplied by the time the device is used for: $E = P \times t$.
- ✓ Energy transferred by a device equals the charge that has passed through it multiplied by the voltage across it: $E = Q \times V$.
- ✓ Energy transferred by a device equals current × voltage × time: $E = I \times V \times t$.

Equation 1

The power of a device is the energy used per second, so if you multiply the power by the number of seconds it is turned on, you can find the energy transferred.

$$\text{energy (J)} = \text{power (W)} \times \text{time (s)}$$

$$E = P \times t$$

Equation 2

The voltage of an electricity supply is the energy it transfers for each coulomb of charge, so you can work out the energy transferred by multiplying charge by voltage.

$$\text{energy (J)} = \text{charge (C)} \times \text{voltage (V)}$$

$$E = Q \times V$$

Equation 3

The power of an electrical device can be found by multiplying the current and the voltage. Combine this with energy = power × time and you get the following equation.

$$\text{energy (J)} = \text{current (A)} \times \text{voltage (V)} \times \text{time (s)}$$

$$E = I \times V \times t$$

Calculating energy, charge, and current

Question
This 3 kW oven took 30 minutes to cook an apple pie. The voltage is 230 V. Calculate the energy transferred, the total amount of charge that flowed during this time, and the current used.

Answer
There's a lot to work out here! Start by writing down what you know, but convert the information into the correct units:

power = 3 kW = 3000 W
time = 30 minutes = 1800 s
voltage = 230 V

Use the first equation to calculate the energy transferred.

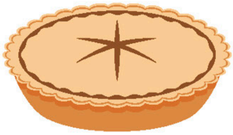
$$E = P \times t$$
$$= 3000 \text{ W} \times 1800 \text{ s}$$
$$= 5\,400\,000 \text{ J } (5.4 \text{ MJ})$$

Now that you know the energy, you can use the second equation to calculate charge.

$$E = Q \times V$$
$$Q = \frac{E}{V}$$
$$= \frac{5\,400\,000 \text{ J}}{230 \text{ V}}$$
$$= 23\,478 \text{ C} = 23\,000 \text{ C}$$

Use the last equation (or just $P = I \times V$) to calculate the current:

$$E = I \times V \times t$$
$$I = \frac{E}{V \times t}$$
$$= \frac{5\,400\,000 \text{ J}}{230 \text{ V} \times 1800 \text{ s}}$$
$$= 13 \text{ A}$$



Electrified railway
High-speed trains, such as France's TGV (*Train à Grande Vitesse*), are powered by electricity supplied by overhead cables, giving the locomotive at the front of the train a power of 9.3 megawatts (9.3 million watts).

Light-dependent resistors

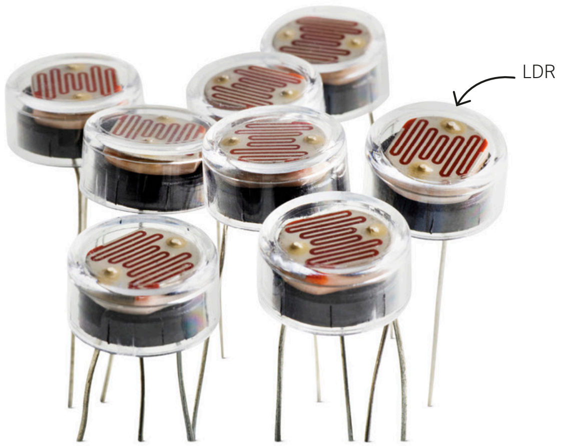
Light-dependent resistors (LDRs) are resistors that sense the brightness of light falling on them: as the light gets brighter, an LDR's resistance falls. LDRs have many applications. They are used in night lights, streetlights, burglar alarms, and smartphone screen dimmers.

Key facts

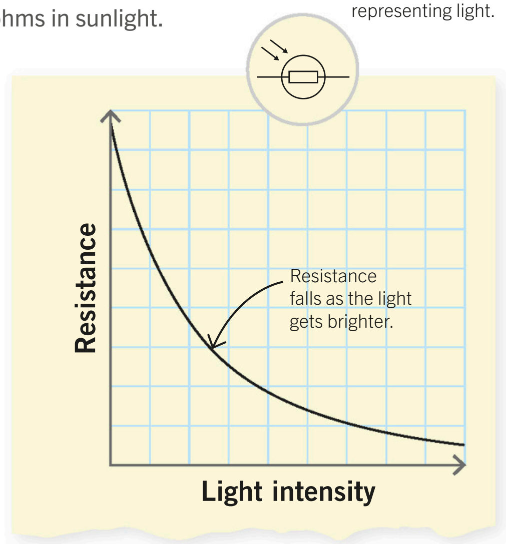
- ✓ **The resistance of LDRs falls as the brightness of the light increases.**
- ✓ **LDRs are used in night lights, streetlights, burglar alarms, and smartphone screen dimmers.**

How LDRs work

Also known as photoresistors, LDRs are small circuit components made of a semiconductor material. When light shines on the semiconductor, electrons are released from atoms, allowing a larger current to flow and so reducing resistance. The higher the light intensity (brightness), the lower the resistance, as the graph here shows. In darkness, a typical LDR has a resistance of over 1 000 000 Ω, but this falls to a few hundred ohms in sunlight.

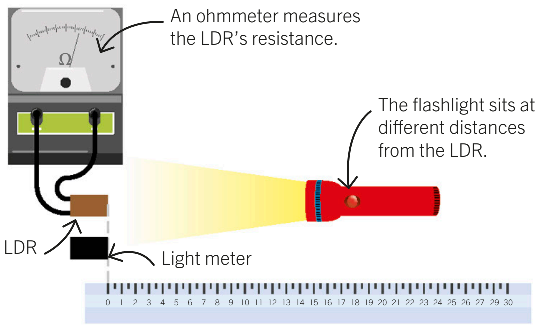


The circuit symbol for an LDR is a rectangle in a circle with arrows representing light.



Investigating LDRs

You can investigate how the resistance of an LDR changes using the apparatus shown here. Carry out the experiment in a darkened room so the only light falling on the LDR comes from the flashlight. Place the flashlight at different distances from the LDR and use an ohmmeter connected to the LDR to measure resistance. Place a light meter next to the LDR to measure light intensity. Use your data to plot a graph of resistance against light intensity.



Thermistors

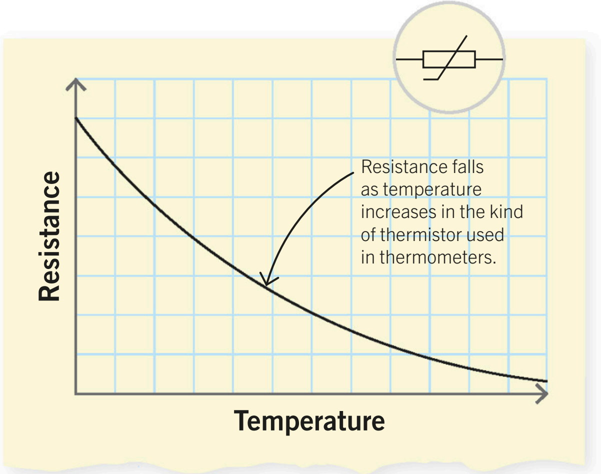
Thermistors are resistors that react to a change in temperature. When the temperature rises, a thermistor's resistance may either rise or fall, depending on the type of thermistor. Thermistors are used as temperature sensors in many kinds of device, from digital thermometers to refrigerators, ovens, and thermostats.

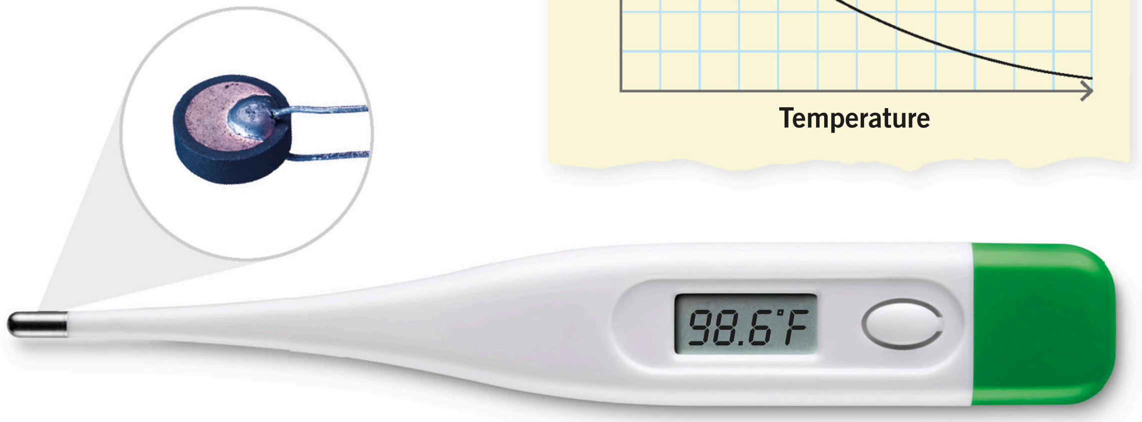
Key facts

- ✓ In thermistors, the resistance changes as temperature increases.
- ✓ Thermistors are used in devices that measure or control temperature.

How thermistors work

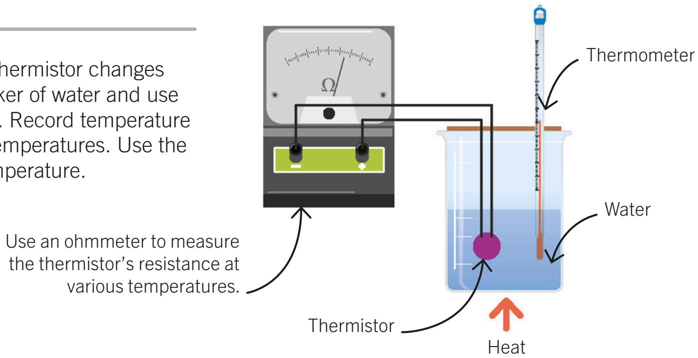
Thermistors are found in the tips of digital thermometers. These thermistors are made from a semiconductor material that releases more free electrons as it gets hotter, allowing more current to flow. The higher the temperature, the lower the resistance, as the graph shows.





Investigating thermistors

You can investigate how the resistance of a thermistor changes using this setup. Place a thermistor in a beaker of water and use a heat source to raise the water temperature. Record temperature and resistance at the same time at various temperatures. Use the data to plot a graph of resistance against temperature.



Teacher supervision required

Sensor circuits

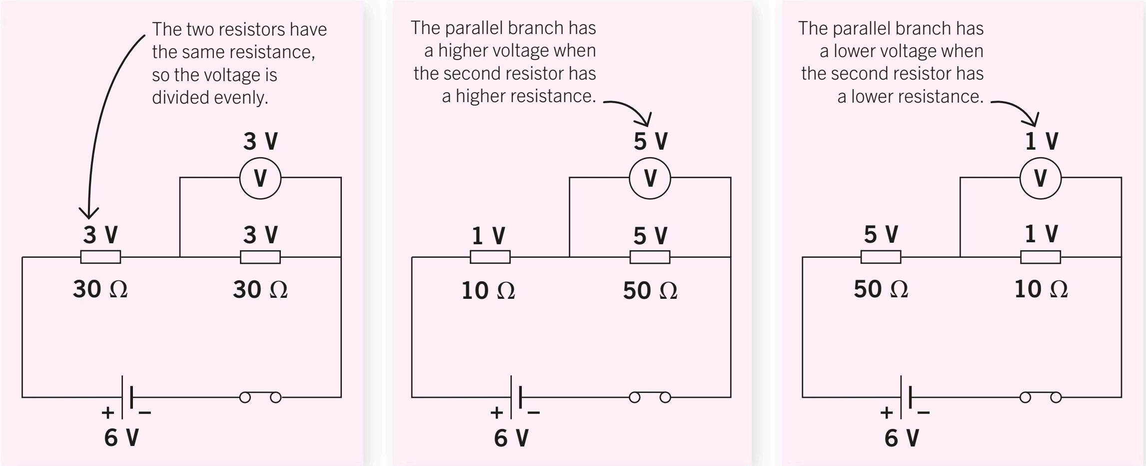
Sensor circuits are used to control electric devices automatically, such as streetlights that turn on when it gets dark and heating or cooling systems that keep the temperature in buildings comfortable all year round.

Key facts

- ✓ LDRs and thermistors can be used as sensors to control lights, heaters, and other devices.
- ✓ The LDR or thermistor is connected in series with another resistor, forming a potential divider.
- ✓ A potential divider is a circuit that uses resistors in series to control the voltage supplied to a different part of the circuit.

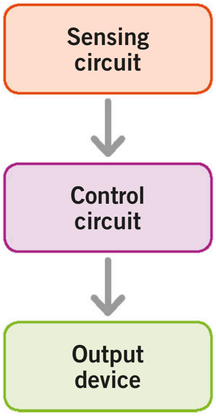
Potential dividers

Sensor circuits often use potential dividers. A potential divider is a circuit that uses resistors in series to control how much voltage is supplied to a parallel branch of the circuit. It works because voltage is divided between components in series but is equal across parallel branches. Changing the combination of resistors changes the voltage in the parallel branch.



Control circuits

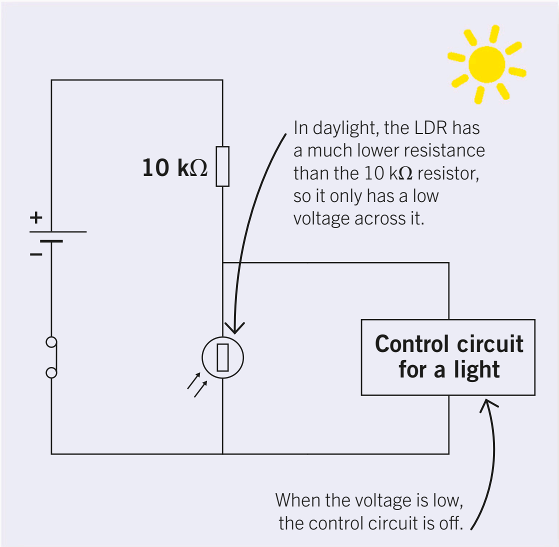
When a light-dependent resistor or thermistor is used as one of the resistors in a potential divider, the voltage in the parallel branch varies depending on the light level or temperature. This varying voltage can then be used to activate a control circuit that switches on when the voltage rises above (or falls below) a chosen level. The control circuit does not draw current from the sensing circuit—it has a different power supply and provides the much larger current needed to power a device such as a streetlight, heater, or fan.

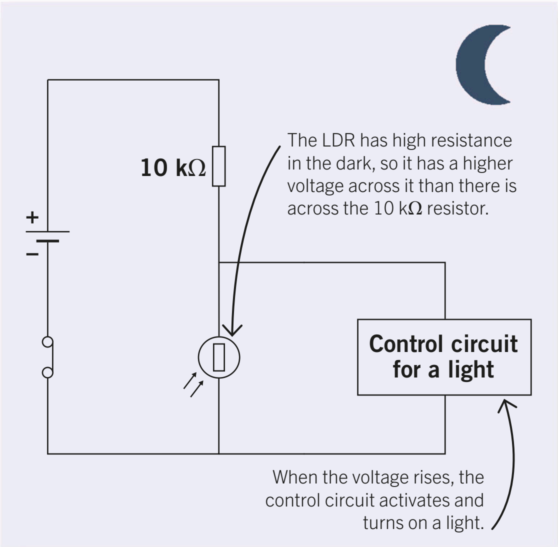


Controlling lights

The circuit below uses an LDR (light-dependent resistor) and a potential divider to send a signal to a control circuit that turns on a light at night as it gets darker.

Light-dependent resistor (LDR)

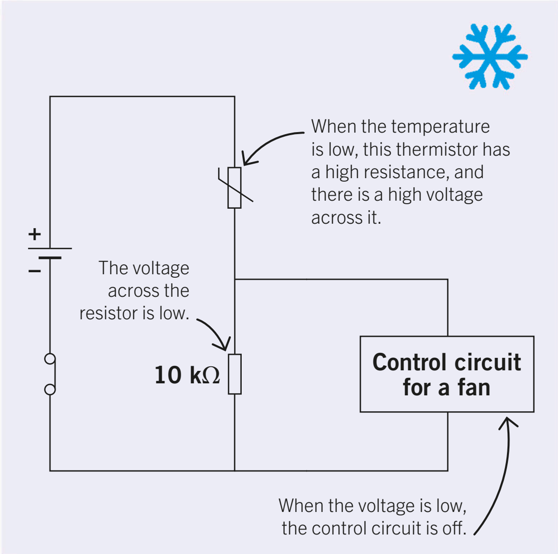


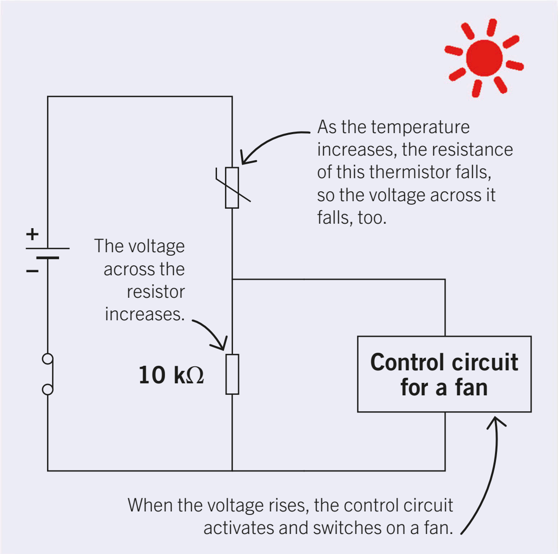


Controlling temperature

The circuit below uses a thermistor and a potential divider to send a voltage signal to a control circuit that controls a fan. A similar circuit could be used to control an air-conditioning unit or a refrigerator.

Thermistor





Using electricity

Direct and alternating current

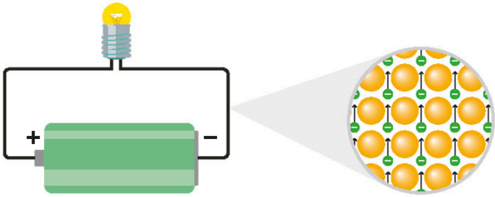
Depending on the way it's produced, electricity can take two different forms: direct current (d.c.) and alternating current (a.c.). Small portable devices typically use d.c., but the electricity supplied to our homes is a.c.

Key facts

- ✓ Direct current (d.c.) is electricity that flows in one direction only.
- ✓ Alternating current (a.c.) is electricity that reverses direction many times a second.
- ✓ The voltage of an a.c. current is continually changing.

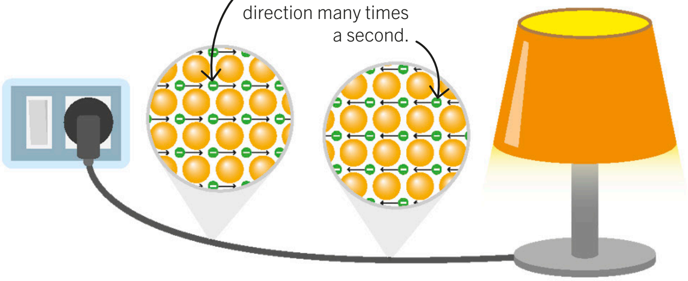
Direct current

Batteries produce d.c. electricity. This is a continuous electric current that flows in one direction only. The d.c. electricity from a battery has a steady voltage, but devices that convert a.c. to d.c. produce a voltage that fluctuates but is always positive, ensuring the current always flows in the same direction.



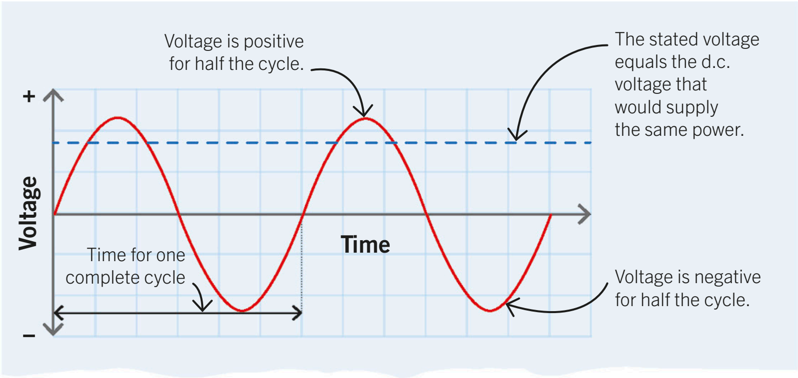
Alternating current

Power stations supply our homes with a.c. electricity. The voltage of a.c. electricity cycles from positive to negative and back 50 or 60 times a second (50 or 60 Hz), causing the current to reverse direction 100 or 120 times a second. Most electrical appliances in homes are powered by a.c. electricity, but electronic devices such as computers have power supply units that convert a.c. to d.c.



Voltage graphs

The voltage of an a.c. electricity supply changes as shown in the graph. Depending on the country you live in, your electricity supply may have a stated voltage between 100 V and 240 V. This figure, shown by the dashed line, is a kind of average called a root mean square.



Electrical wiring

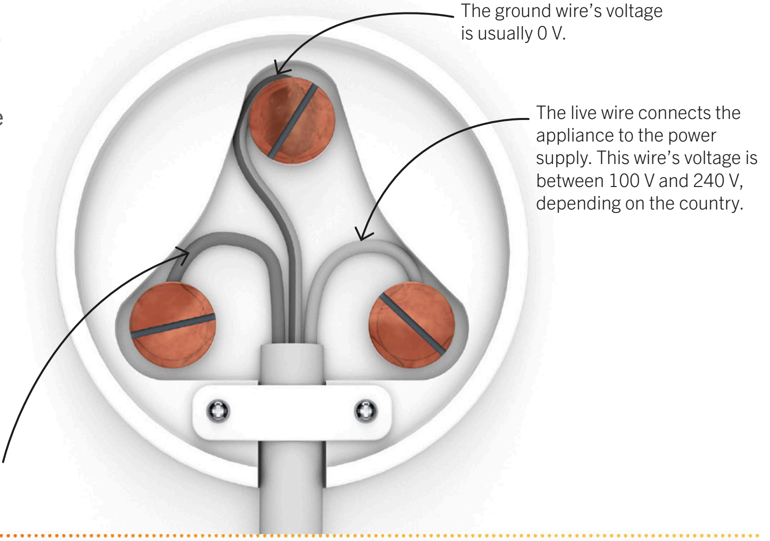
Appliances are connected to the electricity supply via a cable and plug. Electricity cables have two or three different wires inside, each with a different function. These attach to two or three metal pins in a plug, which make contact with the power when the plug is inserted in a socket.

Key facts

- ✓ The cables that join appliances to plugs have two or three separate wires inside them.
- ✓ The live wire carries the full power voltage (between 100 V and 240 V, depending on the country).
- ✓ The neutral wire is usually at 0 V.
- ✓ The ground wire is for safety and is usually at 0 V.

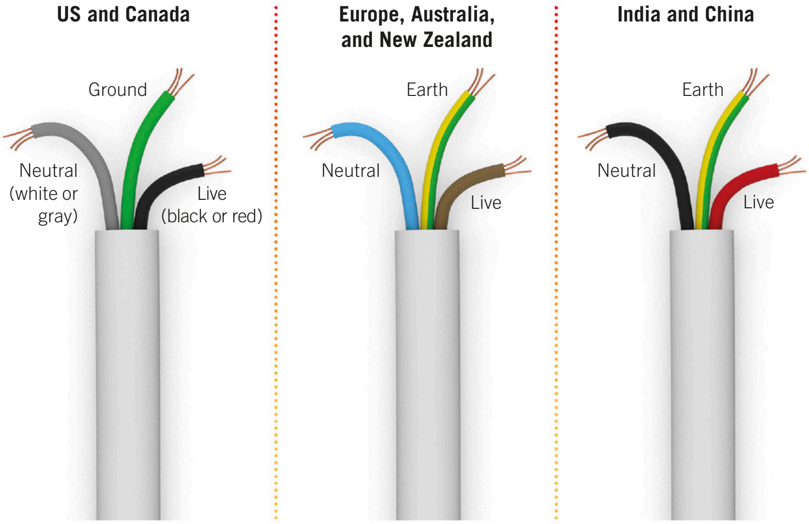
Inside a plug

All plugs have at least two wires inside. The live wire and neutral wire create a circuit when an appliance is turned on, and the ground wire is for safety—it provides a path for electricity to flow away if an electrical fault occurs. Some devices don't need a ground wire and have two-pin plugs in many countries. For instance, "double-insulated" appliances have a layer of insulating plastic between the outer casing and the internal circuit, making them safe to touch even if a fault occurs.



Color coding

It is important that each wire in a cable is connected to the correct pin in the plug and so to the correct part of the wiring in the electrical socket. For this reason, the wires in cables each have their own insulation color. The colors vary in different parts of the world, but the functions of the three wires are the same. Color-coding systems can change, so always consult your country's local guidelines or a qualified electrician before wiring a plug.



Fuses and circuit breakers

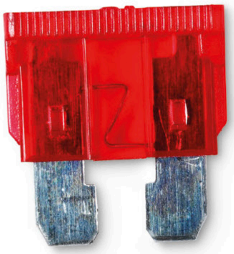
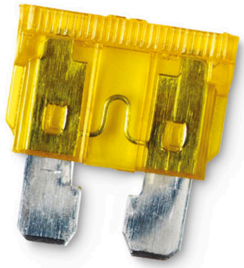
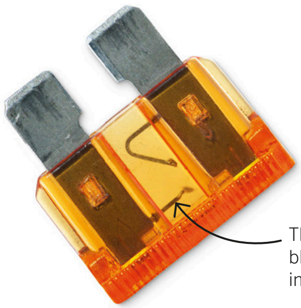
Fuses and circuit breakers are safety devices that automatically stop the flow of electricity if an electrical fault causes a dangerous surge in current.

Key facts

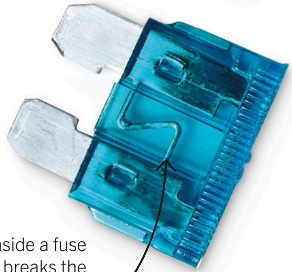
- ✓ Fuses and circuit breakers are used to protect electrical cables from overheating.
- ✓ Fuses must have the correct value for the appliances they are used for.

Fuses

If an electrical device develops a fault such as a broken wire, electricity can flow through the metal casing of the device, causing a dangerous surge in current that could start a fire or give someone an electric shock. Fuses contain thin wires that melt during a surge in current, breaking the circuit. It's important to choose a fuse with a rating in amps just above the current an electrical device normally uses. If the value is too low, the fuse will blow when the appliance is working normally. If the value is too high, too much current may flow, causing overheating.

This car fuse has blown—the wire inside it has melted.

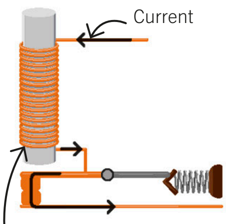



This wire inside a fuse melts and breaks the circuit if the current gets too high.

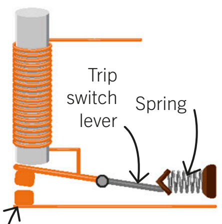
Circuit breakers

A circuit breaker automatically disconnects the power supply if the current flowing through the circuit is too high. Many circuit breakers use a coil of live wire to create an electromagnet. If the current surges, the electromagnet becomes powerful enough to separate two contacts, turning a "trip switch" to the off position and breaking the circuit.

The trip switch can be reset when the fault has been fixed.



In normal operation, the electromagnet is not strong enough to separate the contacts.



If a faulty appliance causes an increase in current, the electromagnet separates the contacts, breaking the circuit.

Preventing shocks

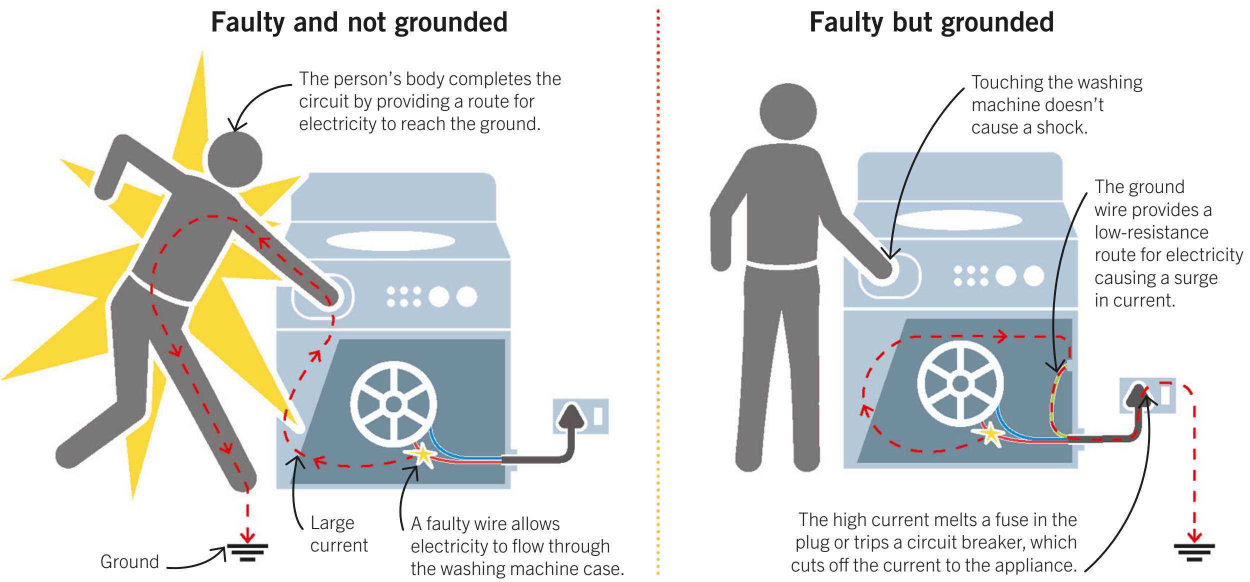
Sometimes a fault in an appliance can cause the outside of the appliance to become live—meaning that you can get a shock if you touch it. An electric shock hurts and can cause burns or even kill you. Ground wires and fuses (see page 181) can prevent this from happening.

Key facts

- ✓ The ground wire protects against electric shocks by providing a path for electricity to flow through if a fault happens.
- ✓ Appliances with plastic cases do not need to be grounded, as plastic is an insulating material.

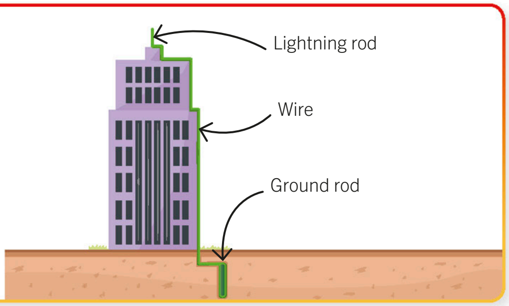
Ground wires

If a fault happens in an appliance with a metal casing, electricity can travel through the casing. When you touch the object, your body provides a route for electricity to reach the ground, creating a circuit and giving you a shock. Powerful devices such as washing machines have ground wires and three-pin plugs to prevent this from from happening—the ground wire provides a low-resistance route to the ground. Appliances with plastic cases don't need ground wires, as plastic is an insulating material.



Lightning rods

Tall buildings have lightning rods connected to the ground to provide a low-resistance route for electricity to flow during a lightning strike. Like the ground wire in an electrical appliance, this allows electrical energy to flow away safely without harming the building or the people inside.



Electrical appliances

Electrical appliances transfer the electrical energy supplied to them to sound, light, movement, or heat. The power rating on appliances tells you how much energy they use each second and therefore how expensive they are to run.

Power ratings

Electrical appliances usually have a power rating sticker on the base or on the back that tells you how much power they use in watts. The power needed depends on whether the device's main output is light, sound, movement, or heat. All appliances (except electric heaters) waste some energy as heat.

Digital radio
Appliances that transfer energy mainly to light or sound, such as radios, TVs, and light bulbs, use little energy and have a low power rating. This digital radio has a power rating of only 5 W.

ROY RADIOS 99
AC: 230–240 V~50 Hz
Power: 5 W
Made in the USA

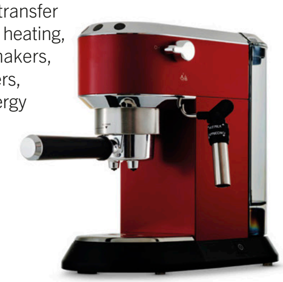
A power rating of 5 W means the radio transfers 5 J of energy every second.

Blender
Appliances that transfer energy mainly to movement, such as blenders, drills, and fans, have a higher power rating.

CHOPRA CHOPPER Z50
AC: 220–240 V~50 Hz
Power: 500 W
Made in India

The blender uses 100 times as much energy per second as the radio.

Coffee maker
Appliances that transfer energy mainly by heating, such as coffee makers, ovens, and heaters, use the most energy and have high power ratings.



BARISTA BREWS 66
AC: 220–240 V~50 Hz
Power: 1200 W
Made in China

The higher the power rating, the faster the coffee machine heats water.

Key facts

- ✓ **The main power output from appliances may be light, sound, movement, or heat.**
- ✓ **All appliances (except electric heaters) waste some energy as heat.**
- ✓ **The power rating of an appliance in watts is how much energy is transferred each second.**

Fuses

If an appliance is faulty, it may draw too much current from the power supply and cause wires to overheat. To prevent this from happening, high-power devices sometimes have fuses in their plugs. A fuse contains a delicate wire that melts in a power surge, breaking the circuit and turning off the appliance. You can work out the correct type of fuse to use from the device's power rating and the equation power = current × voltage ($P = I \times V$).

Question
A hair dryer runs off a 230 V power supply and has a power rating of 1800 W. Which of the following fuses should be fitted in the plug: 5 A, 10 A, or 15 A?

Answer
Rearrange the equation to make current (I) the subject.

$$I = \frac{P}{V}$$

$$= \frac{1800\ \text{W}}{230\ \text{V}}$$

$$= 7.8\ \text{A}$$

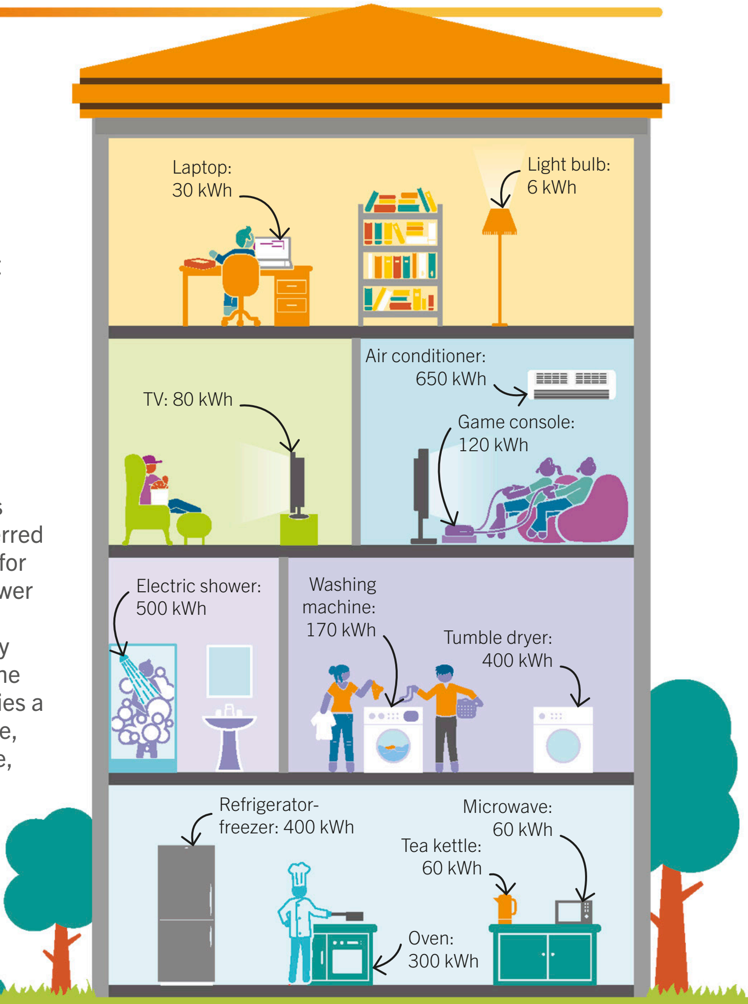
The 5 A fuse is too small and the 15 A fuse is too large. The correct fuse rating is 10 A.

Energy use at home

The scientific unit for energy is the joule, but 1 joule is a small amount of energy—it takes at least 340 000 joules just to boil a liter of water. So instead of using joules, energy companies measure energy in kilowatt-hours (kWh).

Kilowatt-hours

Kilowatts are units of power, but kilowatt-hours are units of energy. 1 kWh is the energy transferred if you use a device with a power rating of 1 kW for an hour. Most household appliances have a power rating much lower than 1 kW. However, some devices, such as refrigerators and freezers, stay turned on all day, so they use a lot of energy. The amount of energy different households use varies a great deal and depends on the size of the house, the number of occupants, and the local climate, which affects heating and air-conditioner use.



The amount of energy a house might use in one year

Key facts

- ✓ The unit of energy used in energy bills is the kilowatt-hour (kWh).
- ✓ 1 kWh = 3 600 000 joules (3.6 MJ)

Calculating energy usage

You can calculate how much energy an appliance uses by multiplying its power rating by the number of hours it's used:

energy transferred (kWh) = power (kW) × time (h)

Question

An electric shower with a power rating of 7.2 kW is used for 15 minutes each day. How much energy does the shower transfer in a week?

Answer

Total number of hours used in a week = 0.25 h × 7 days
= 1.75 h

Energy transferred = 7.2 kW × 1.75 h
= 12.6 kWh

Wasted energy

All electrical devices waste some energy when we use them. Sometimes energy is wasted by sound or light, but most wasted energy is transferred to the surroundings as heat.

Key facts

- ✓ All electrical devices waste some energy.
- ✓ Energy losses refer to energy transfers that aren't useful to us.
- ✓ Most energy losses are caused by unwanted heating.

Heat and electricity

When electrons move through a wire or an electrical component, they collide with metal atoms and transfer some energy to them, causing the metal and its surroundings to heat up. Some devices transfer energy as heat deliberately, but in most devices, the heat wastes energy. The amount of energy transferred by heating can be reduced by keeping wires short and by using good conductors, such as gold, silver, and copper.

Wasteful heating

Light bulbs transfer energy as heat and light, but only the light is a useful energy transfer.

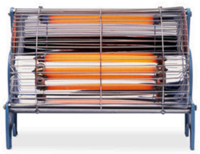
Powerful computers use fans to dissipate unwanted heat from their central processing units.

Mixers contain electric motors that waste some energy by generating heat and sound.

Useful heating

Tea kettles transfer most of the energy to the thermal energy store of the water inside, but some heat escapes to the surroundings.

Electric toasters use heat to toast bread, but a lot of energy escapes.



Electric heaters transfer nearly all the energy supplied to them as heat, making them very efficient.

Overheating

The heat produced by electrical devices or wires can be dangerous if it builds up—it can melt the plastic insulation around wires or start a fire. Never plug several powerful appliances into a single wall socket with an adapter, as it can overload the socket and draw too much current, heating up the socket. Overheating can be prevented by using good conductors and short wires and by plugging appliances into separate sockets. Extension cables should be unwound before use and fitted with appropriate fuses.

Overloading this extension lead caused the plastic to melt.

Power transmission

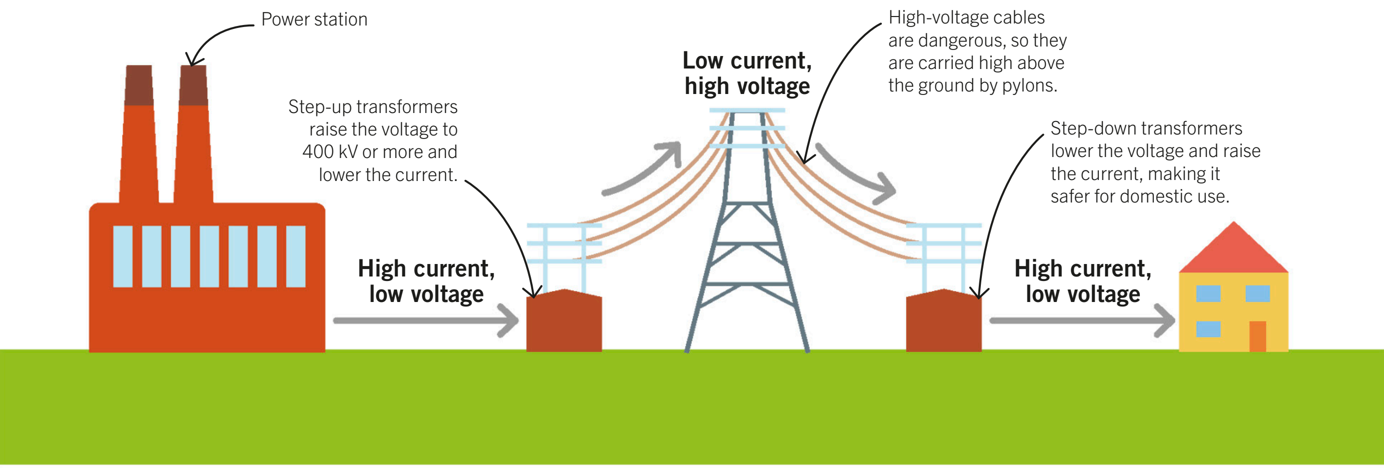
Power stations may be a long way from where electricity is used, so electricity has to be transmitted long distances by cables. All cables have resistance, which means they heat up and waste energy. The waste is reduced by using transformers to change the voltage and current of electricity in the cables.

Reducing the waste

The amount of power lost due to heating in cables can be calculated using the power equation from page 171: power loss = current^2 × resistance ($P = I^2 \times R$). Because power loss is proportional to current squared, the most effective way to reduce power loss is to reduce the current. This is what the transformers at electricity substations do. The same power can be transmitted with either high current and low voltage or low current and high voltage, so transformers raise the voltage for long-distance transmission and then lower it again for use in the home.

Key facts

- ✓ **Energy is wasted when electricity is transmitted through cables.**
- ✓ **Energy loss is reduced by increasing the voltage of electricity and lowering the current.**
- ✓ **Step-up and step-down transformers in electricity substations change the voltage and current of electricity for long-distance transmission.**



Calculating power loss

Question

If a transmission cable has a resistance of 20 Ω, how much power is wasted as heat when a current of 10 A flows? If the current is reduced by a transformer to 1 A, what will the wasted power be?

Answer

Use the equation $P = I^2 \times R$ to find both answers.

At 10 A:
$P = (10\text{ A})^2 \times 20\ \Omega$
$= 2000\text{ W}$

At 1 A:
$P = (1\text{ A})^2 \times 20\ \Omega$
$= 20\text{ W}$ The loss is 100 times smaller even though the cable has the same resistance.

Static electricity

Attracting and repelling

Have you ever noticed a sweater crackling when you pull it over your head or your hair standing on end after you brush it? These effects are caused by static electricity. Static charges can cause objects to attract or repel each other without touching.

Key facts

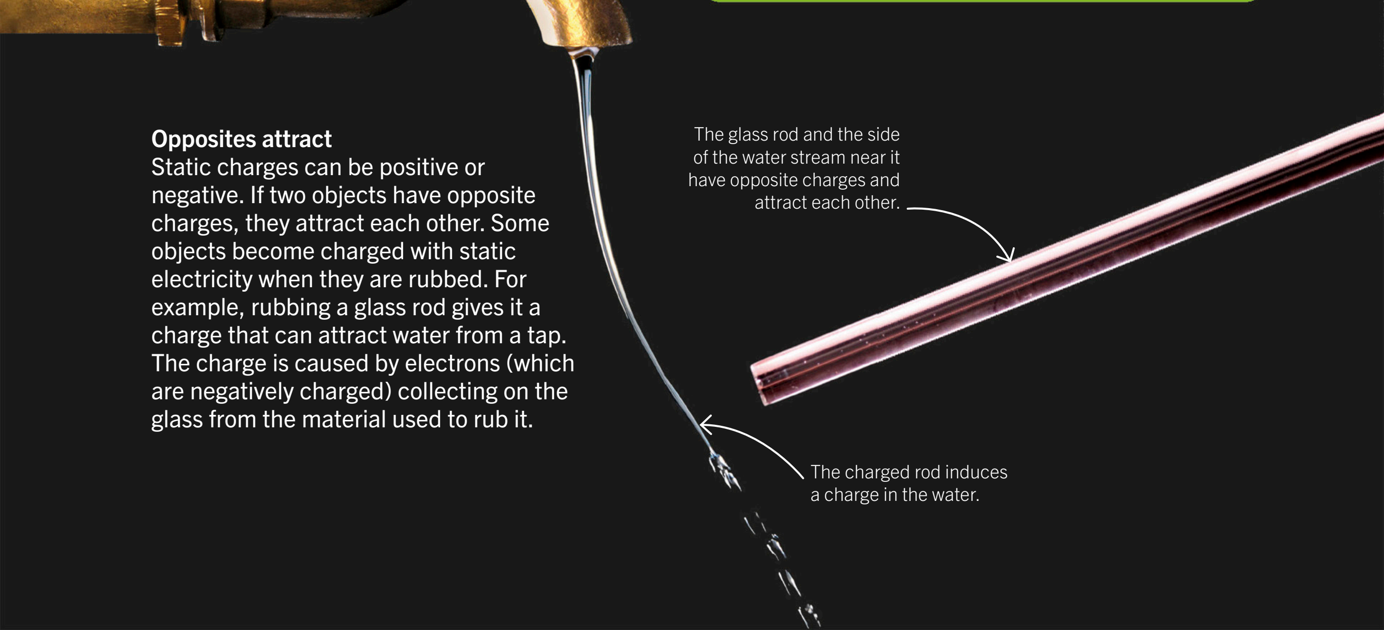
- ✓ Some objects can become charged with static electricity when rubbed.
- ✓ Objects can be given a positive or negative charge.
- ✓ Charged objects exert forces on each other: similar charges repel and opposite charges attract.

Static cling

Static electricity builds up most easily on insulating materials such as plastic and rubber. The effects are easiest to see on a dry day, when there is little moisture in the air.

Plastic objects can become charged with static electricity when rubbed. For example, a comb can become charged when it moves through a person's hair.

Plastic wrap becomes charged when it unrolls. The static charge helps it cling to items of food or to itself.

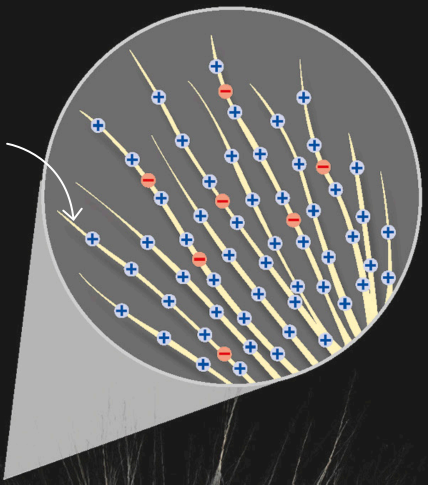


Opposites attract

Static charges can be positive or negative. If two objects have opposite charges, they attract each other. Some objects become charged with static electricity when they are rubbed. For example, rubbing a glass rod gives it a charge that can attract water from a tap. The charge is caused by electrons (which are negatively charged) collecting on the glass from the material used to rub it.

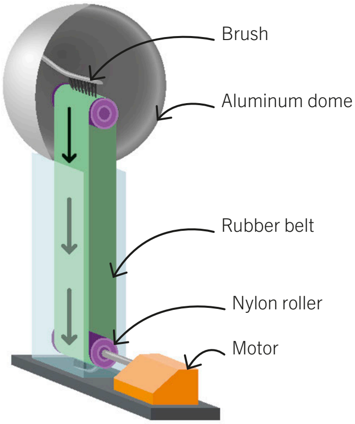
Similar charges repel
Objects with the same static charge repel each other. You can see this demonstrated with a Van de Graaff generator—a device that creates a positive charge on a metal dome. Anyone that touches the dome while insulated from the ground becomes positively charged, too, which makes their hair stand on end.

Hairs stand on end because they all become positively charged, which makes them repel each other.



Van de Graaff generator

A Van de Graaff generator contains a moving belt made of an insulating material, such as rubber, that picks up a static charge as it moves around two nylon rollers. The charge is transferred via a small brush to an aluminum dome at the top.



Attraction by induction

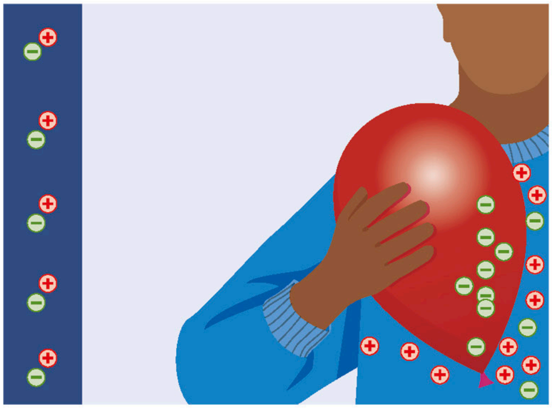
Rubbing a balloon on a wool sweater causes a build-up of charge on the balloon. If you hold the balloon near a wall, it sticks to the wall. This happens because a charged object can induce an opposite charge in nearby objects.

Key facts

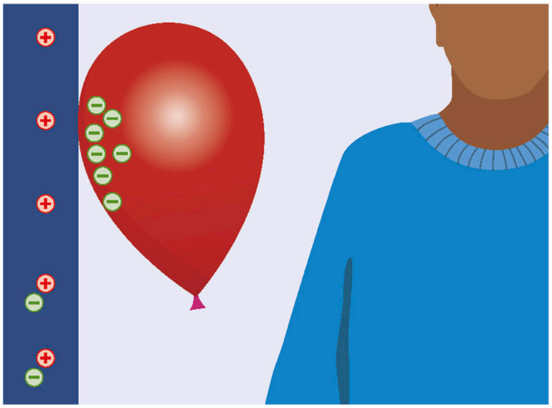
- ✓ Electrons can be transferred between some objects through rubbing.
- ✓ Gaining electrons causes an object to become negatively charged, and losing electrons causes it to become positively charged.
- ✓ A charged object can induce a charge in another object, causing the two to attract.

Sticky balloon

Most objects contain equal amounts of positive and negative charge, resulting in no overall charge. However, when some objects are rubbed, electrons can break away from atoms and transfer from one object to another, giving both objects a charge. When a charged object is held close to something else, it can induce a charge in it, making them attract.



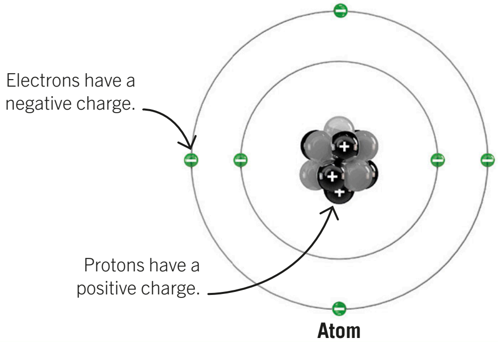
Rubbing a balloon on a sweater causes a build-up of electrons on the balloon, giving it a negative charge.



When the balloon is near the wall, the negative charge on the balloon repels electrons in the wall, making the wall's surface near the balloon positive. The two opposite charges attract and the balloon sticks to the wall.

Where static charge comes from

An atom normally contains equal numbers of protons (with a positive charge) in its nucleus and electrons (with a negative charge) surrounding the nucleus, making it electrically neutral. Rubbing some materials can transfer electrons from one object to another, causing a build-up of negative charge on one object and leaving the other object with an overall positive charge.



Using static electricity

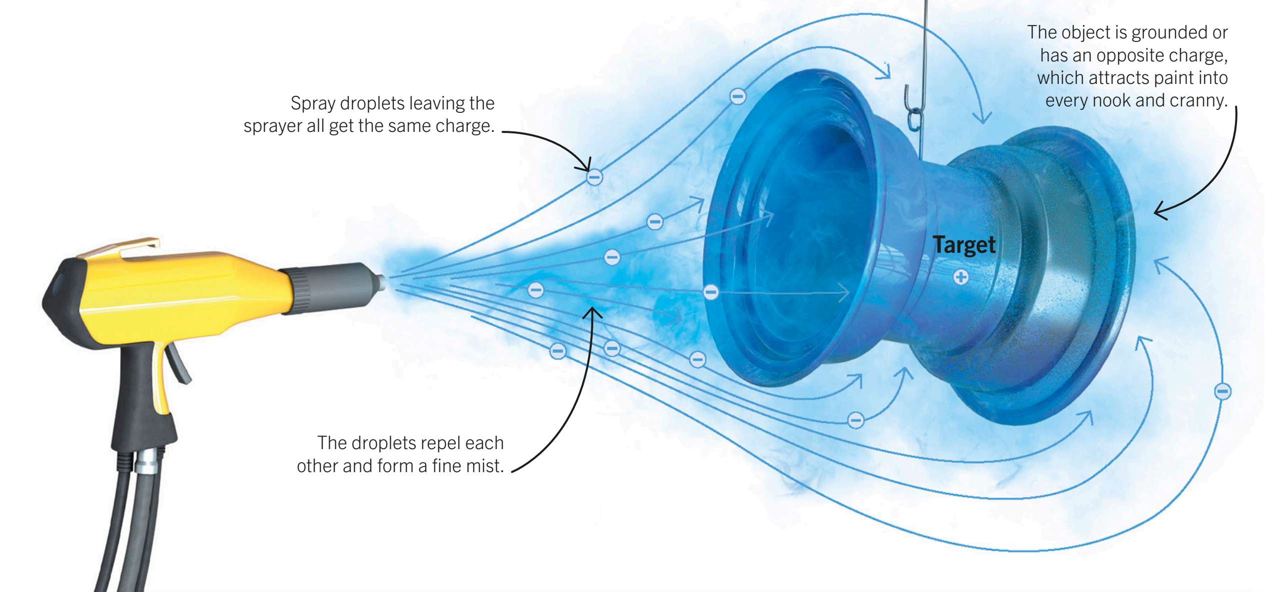
Static electricity is not as useful as current electricity, but some devices make use of it. For example, photocopiers, inkjet printers, and paint sprayers use static charges to guide a spray of chemicals.

Key facts

- ✓ **Electrostatic paint sprayers charge droplets of paint, causing them to repel each other and spread out evenly.**
- ✓ **Photocopiers and inkjet printers guide toner or ink to the right place on paper using electrostatic attraction.**

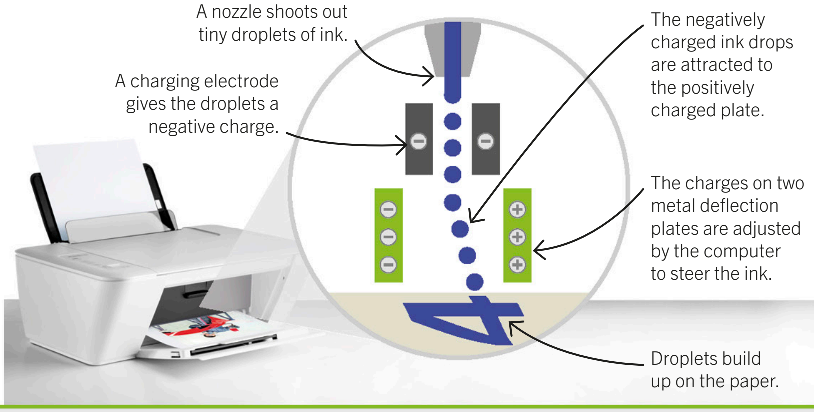
Electrostatic paint sprayers

Car manufacturers use electrostatic sprayers to give cars an even coat of paint. The sprayer charges the mist of fine paint droplets, causing them to repel each other and spread widely and evenly. An opposite charge on the part being painted attracts the paint so that it coats the whole surface.



Inkjet printers

As a sheet of paper rolls through an inkjet printer, a printhead moves back and forth along a rail, firing a stream of tiny colored ink droplets at the paper. The ink droplets are given a charge of static electricity and steered to the correct place on the paper using charged plates.



Dangers of static electricity

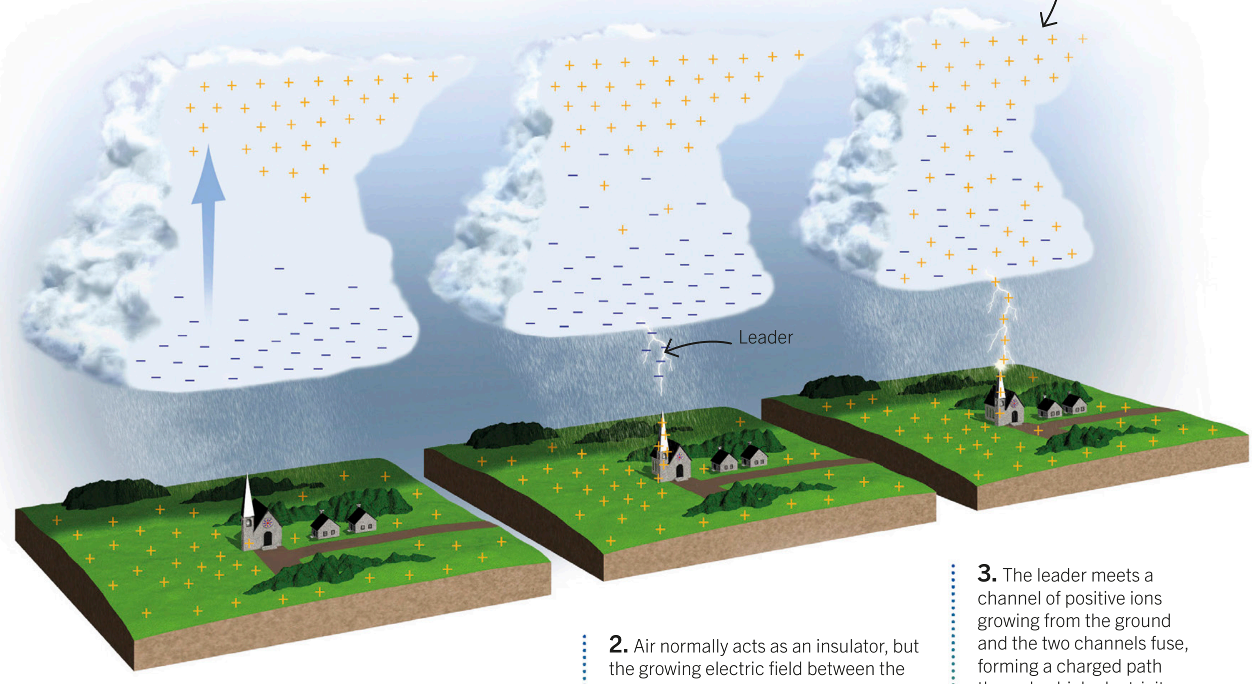
Static electricity can sometimes be dangerous. If a large static charge builds up, it may cause sparks when it is released. These sparks can burn people or start fires.

Key facts

- ✓ Lightning and sparks are caused by the sudden discharge of static electricity.
- ✓ Sparks can burn people and start fires.
- ✓ A build-up of static charge when vehicles are being refueled can be dangerous.

Lightning
Lightning is caused by a build-up of static electricity inside a thundercloud as water droplets and ice crystals rush past each other. It can be deadly if it strikes a person directly and can cause fires if it strikes buildings. Lightning can strike from cloud to cloud or from cloud to ground. The diagram below shows how a cloud-to-ground strike occurs.

Most lightning storms are caused by a type of cloud called cumulonimbus, which typically has a towering shape and a spreading top.



1. Strong winds inside a storm cloud cause ice crystals and droplets of water to tumble around, creating static charges. A negative charge builds up at the bottom of the cloud, inducing a positive charge in the ground.

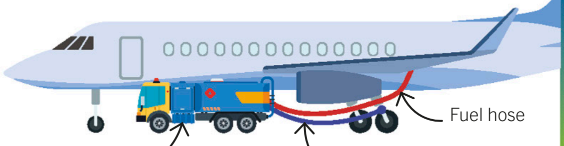
2. Air normally acts as an insulator, but the growing electric field between the cloud and ground causes air molecules to ionize (split into charged particles). A channel of ionized air called a leader reaches down from the base of the cloud.

3. The leader meets a channel of positive ions growing from the ground and the two channels fuse, forming a charged path through which electricity can flow—a bolt of lightning.

Energy release
A bolt of lightning is a giant spark only a few centimeters wide but kilometers in length. The massive flow of electrical energy superheats the air to around 30 000°C, causing it to radiate brilliant light. The sudden release of heat makes the air expand explosively, producing the boom of thunder.

Grounding aircraft

A build-up of static electricity in fuel can be extremely dangerous—a spark could trigger an explosion. While a plane's fuel tanks are being refilled, wires are used to connect the plane to the filling truck. The wires prevent a charge from building up between the two vehicles as a result of friction from the rapid movement of large volumes of fuel.



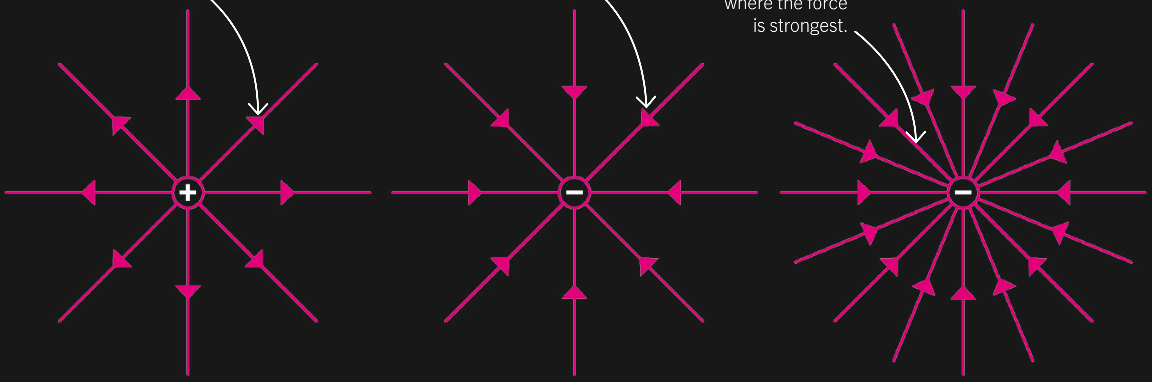
Electric fields

All charged objects are surrounded by an electric field in which other charged objects experience a force. Attraction, repulsion, sparking, and other static effects are caused by electric fields.

Key facts

- ✓ A charged object is surrounded by an electric field in which other charged objects experience a force.
- ✓ An object's electric field is strongest nearby and gets weaker with distance.
- ✓ Attraction, repulsion, and sparking are caused by electric fields.
- ✓ The strength and direction of electric fields can be shown in diagrams using arrows.

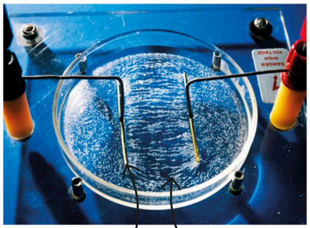
Electric field diagrams
As electric fields are invisible, we use diagrams with lines and arrows to represent them. The arrows always show the effect the field would have on a positive charge placed within it. The three examples below show the fields around charges at a single point. The arrows show that a positive charge repels other positive charges, but a negative charge attracts positive charges. The density of the lines indicates how strong the field (and therefore the force) is.

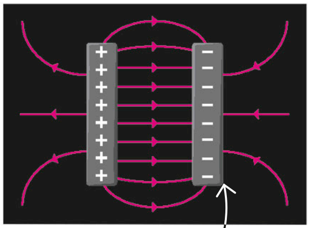


Field around a positive charge | **Field around a negative charge** | **Field around a strong negative charge**

Parallel plates

A pair of parallel plates with opposite charges produces a uniform electric field—the field strength is the same everywhere between the plates (except near both ends). In this photo, grains of semolina suspended in castor oil reveal the uniform electric field lines between two charged plates.





Magnetism and electromagnetism

Magnets

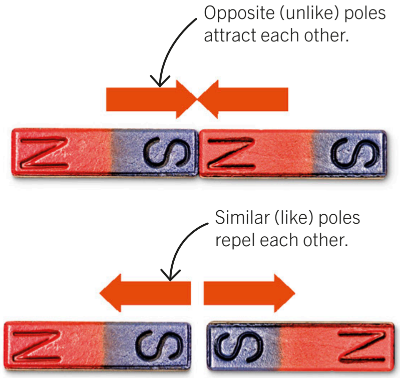
Magnets attract objects made from magnetic materials, such as iron, nickel, and cobalt. Magnets come in many shapes and sizes, but they all have two ends (or sides) called the north pole and the south pole.

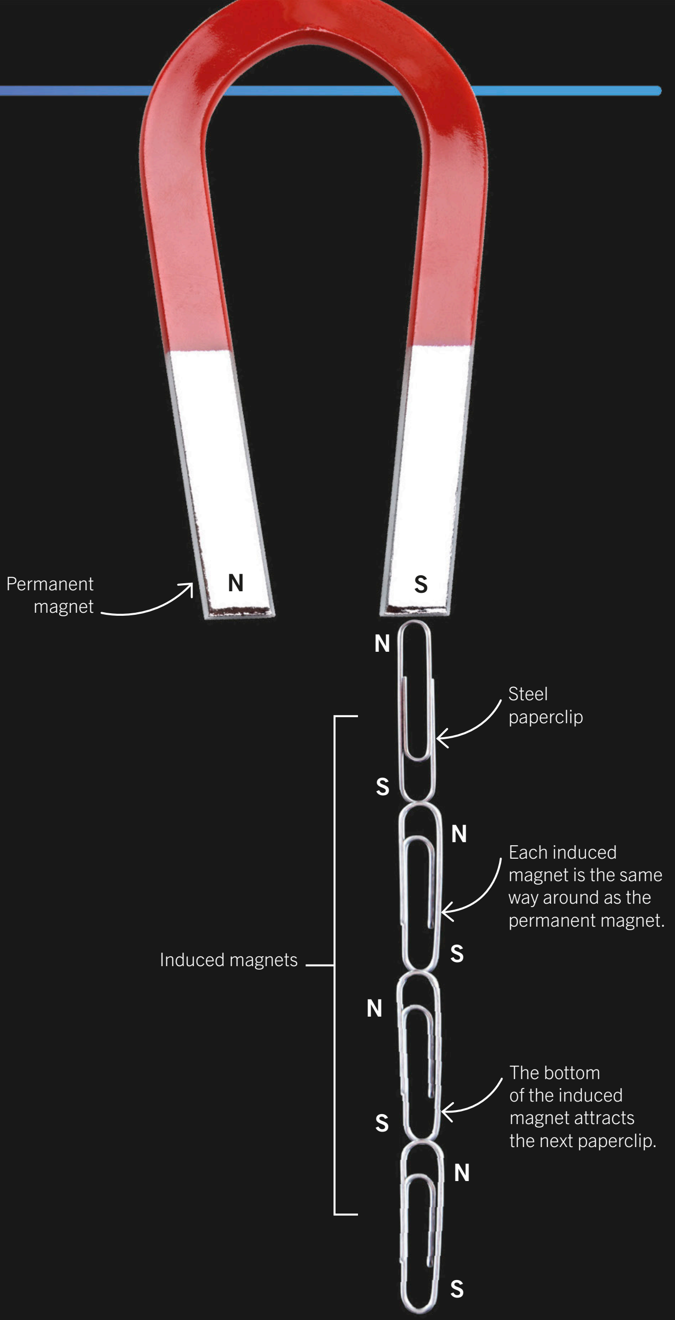
Key facts

- ✓ **A magnet has a north pole and a south pole.**
- ✓ **Opposite (unlike) poles attract each other. Similar (like) poles repel each other.**
- ✓ **When a piece of magnetic material is brought close to a magnet, it becomes an induced magnet.**

Attracting and repelling

If you arrange two bar magnets so the north pole of one is close to the south pole of the other, they will attract each other. But if you bring two north poles close or two south poles close, the magnets will repel (push away) each other.





Magnetism
Paperclips stick to a magnet because they are made of steel, which is a magnetic material. Magnetism is a force that works at a distance, so the paperclips are pulled even before they touch the magnet. Horseshoe magnets and bar magnets are permanent magnets—they are always magnetic. When a piece of magnetic material is brought close to a permanent magnet, it becomes a magnet itself. We call this induced magnetism. It stops being magnetic when it is taken away from the permanent magnet.

Magnetic fields

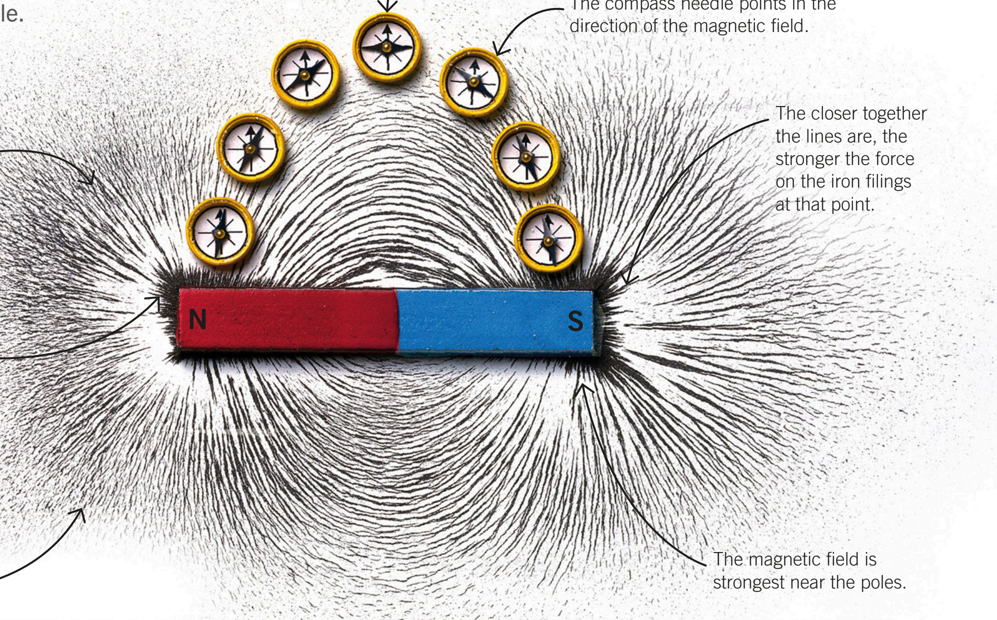
Magnetism is a force that can affect certain objects or materials from a distance without physical contact. All magnets are surrounded by a magnetic field—a zone around the magnet in which it can exert forces on other magnets or on magnetic materials. The field around a bar magnet can be revealed by scattering iron filings over it.

Key facts

- ✓ Magnets are surrounded by a magnetic field.
- ✓ The lines in a magnetic field always point from the north pole to the south pole of the magnet.
- ✓ A compass can be used to trace a magnetic field.

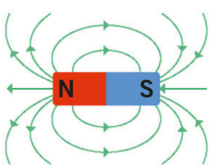
Field around a bar magnet

A magnet produces a magnetic field—a zone in which magnetic materials are affected. The field curves out from the magnet's north pole and back to the south pole.

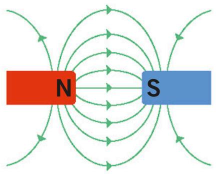


Field lines

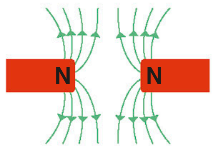
A magnetic field can be shown by drawing lines around magnets. Arrows show direction and always point from a magnetic north pole to a magnetic south pole.



In a bar magnet, the field lines curve from the north pole to the south pole.



When opposite poles come close, the field lines run from the north pole of one magnet to the south pole of the other. The magnets attract each other.



When similar poles of two magnets come close, the field lines point outward. The magnets repel each other.

Earth’s magnetic field

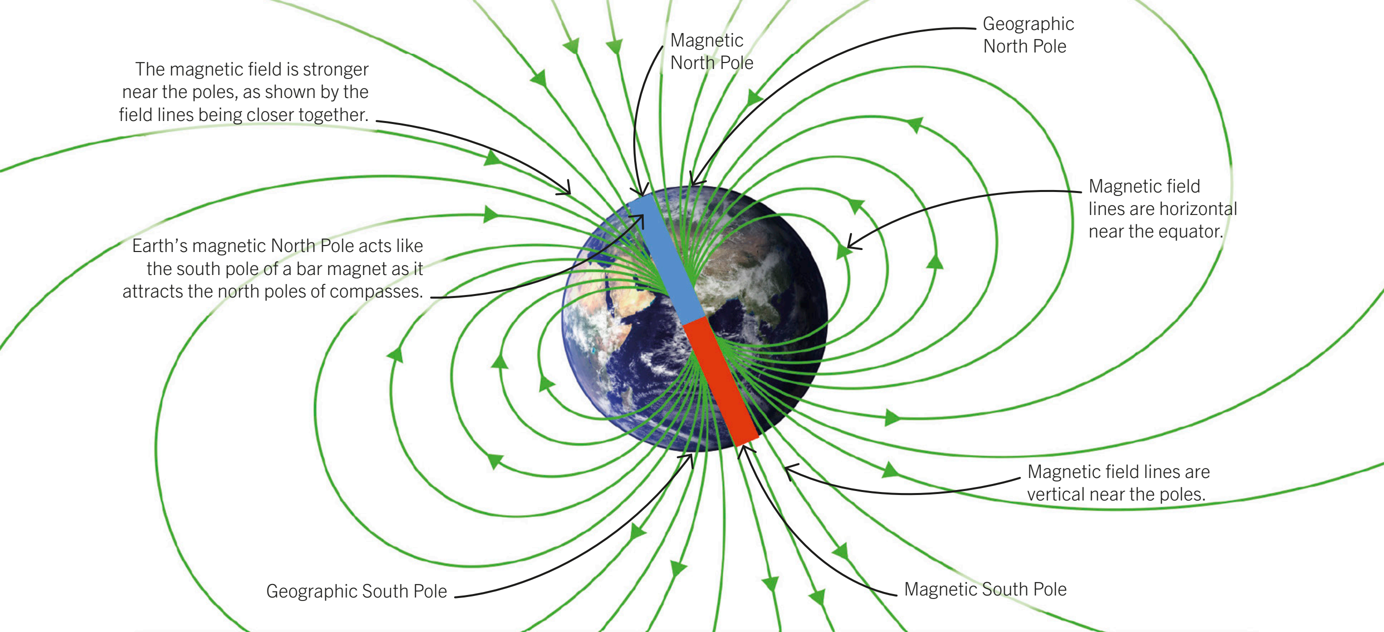
For many centuries, sailors navigated using compasses—tiny magnets that point north if allowed to swing freely. Compasses point north because Earth behaves like a giant magnet, with its own magnetic field.

Key facts

- ✓ Earth’s magnetic field is similar in shape to that of a bar magnet.
- ✓ Compasses can be used to determine the shape of the magnetic field.

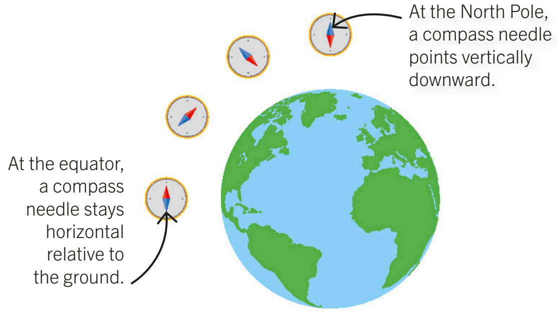
The shape of Earth’s magnetic field

At the center of Earth is a hot, partially molten iron core that acts like a giant magnet, producing a huge magnetic field. This field extends thousands of kilometers into space and resembles the magnetic field around a bar magnet. Earth’s magnetic field is dynamic—the poles are constantly moving, the strength changes over time, and every once in a while (on average, every few hundred thousand years) the north and south magnetic poles flip places.



Magnetic dip

A compass contains a small magnetic needle mounted on a pivot that allows it to swing. The needle aligns with Earth’s magnetic field, so as well as pointing north, it tilts downward in the northern hemisphere and upward in the southern hemisphere. The angle of tilt, called magnetic dip or magnetic inclination, varies from 0° at the equator to 90° at the poles. Studying magnetic dip allowed scientists to work out the shape of Earth’s magnetic field.



Electromagnets

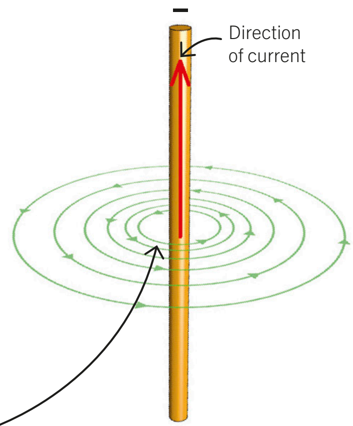
Electricity and magnetism are linked. An electric current creates a magnetic field around it, and we can use a coil of wire (called a solenoid) to strengthen this magnetic field. Adding an iron core to a solenoid makes the field even stronger, forming a powerful electromagnet. Electromagnets are useful because they are magnets that can be turned on and off.

Key facts

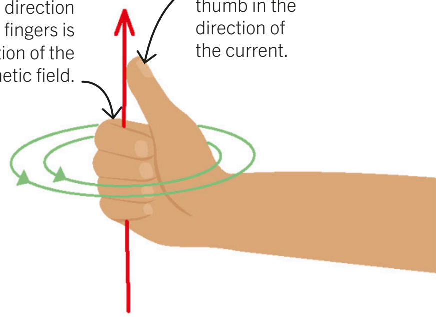
- ✓ **A current flowing through a wire creates a circular magnetic field around the wire.**
- ✓ **When a current flows through a solenoid, the magnetic fields from the loops combine to strengthen the field inside the coil.**
- ✓ **An iron core inside the solenoid strengthens the field of an electromagnet.**

Magnetic field around a wire

When an electric current flows through a wire, it forms a circular magnetic field around the wire. You can see the shape of the magnetic field by holding a compass near the wire. If you increase the current, the strength of the magnetic field increases. If you change the direction of the current, the direction of the magnetic field changes.

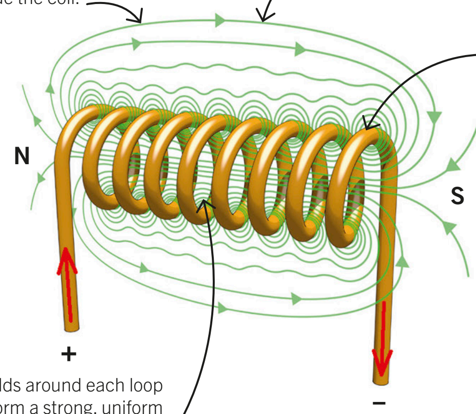


You can use your right hand, with your fingers curled, to help remember the direction of the magnetic field around a current.



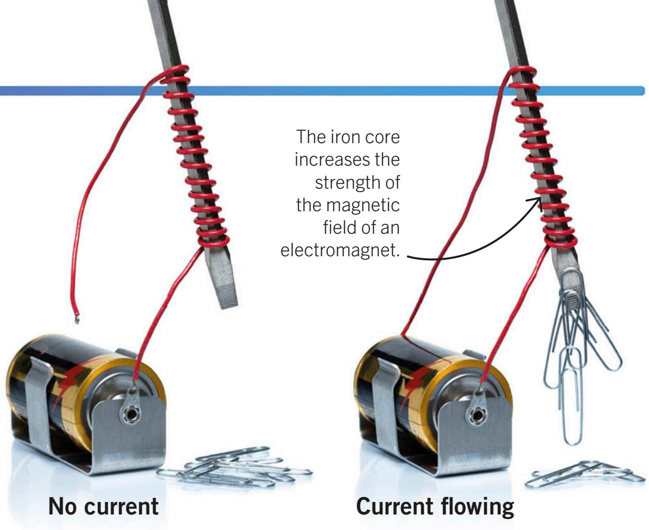
Magnetic field around a coil

The magnetic field around a single wire is weak, but if the wire is wound into a coil (called a solenoid), the fields around each loop reinforce each other. This creates a strong, uniform magnetic field inside the coil. The field outside the coil is similar to the field around a bar magnet, with north and south poles at the ends.



Iron core

One type of electromagnet is a solenoid with a core made of a magnetic material, which makes the magnetic field stronger. The core is usually iron, which is easy to magnetize but also loses its magnetism very easily. This is ideal for electromagnets, because it means they can be turned on and off.



Scrap yard magnet

The grab magnets used in scrap yards are powerful electromagnets. They are used to separate magnetic metals such as iron and iron alloys from nonmagnetic metals such as copper, aluminum, and lead. Separating materials this way allows them to be recycled.

Using electromagnets

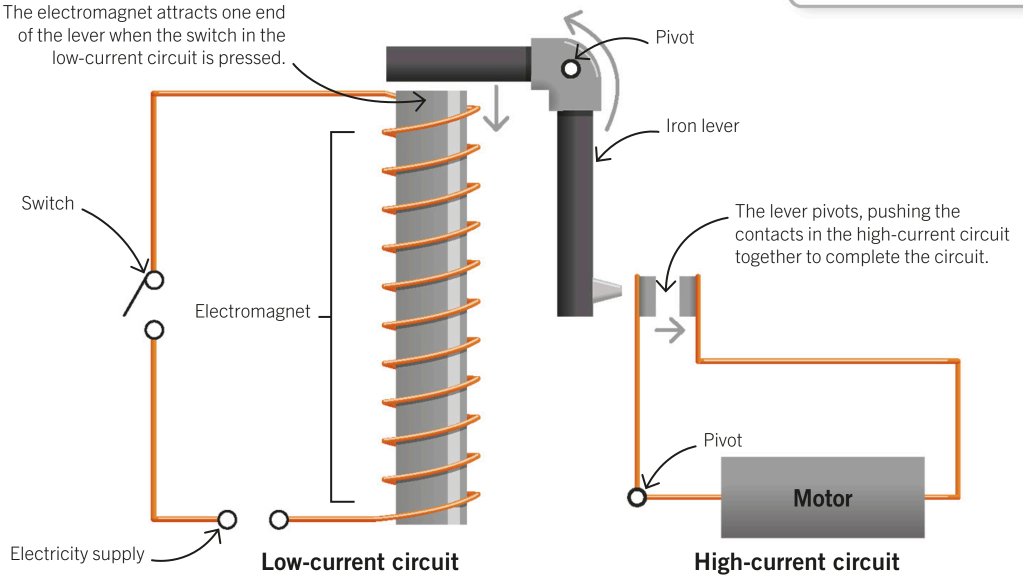
Electromagnets are very useful, as they can be turned on and off and can create a variable magnetic force. They are used in many electrical devices, including loudspeakers, electric bells and buzzers, relays, and maglev trains.

Key facts

- ✓ Electromagnets can be turned on and off and can create a variable magnetic force.
- ✓ Relays allow a switch in one circuit to be used to turn a separate circuit on or off.
- ✓ Maglev trains use electromagnets to float above the track, allowing them to reach high speeds.

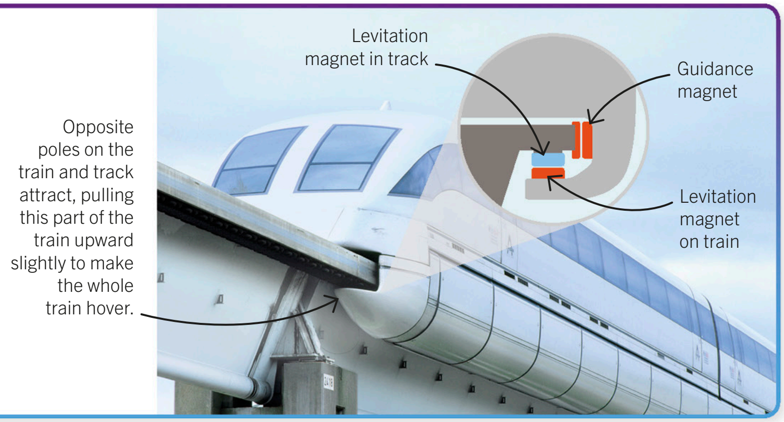
Relays

A relay is an electrical switch in which a small electric current is used to turn on another circuit that has a larger current. For example, when a driver turns the key in a car, it turns on a low-current circuit with a relay switch. The relay then activates the high-current circuit that starts the motor.



Maglev trains

Maglev (magnetic levitation) trains use electromagnets on the train and the track to make the train float above the track. Some of the electromagnets are also used to make the train move. Maglev trains can reach speeds of 250 mph (400 km/h)—far faster than conventional trains—as there is no physical contact between the train and track and therefore no friction.



The motor effect

When a current flows through a wire, it creates a magnetic field around the wire. If the wire is also placed near a permanent magnet, the two magnetic fields interact and cause the wire to move. This is called the motor effect.

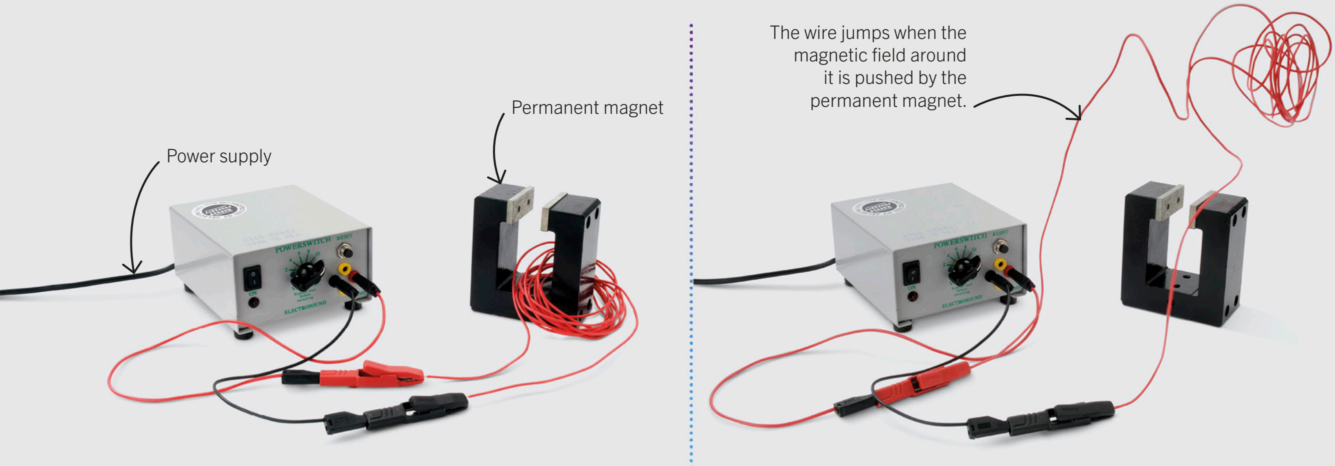
Key facts

- ✓ A wire carrying a current through an existing magnetic field experiences a force.
- ✓ The force caused by the interaction between a current-carrying wire and a magnet is the motor effect.
- ✓ You can work out the direction of the force using Fleming's left-hand rule.

Jumping wire

In the jumping wire experiment shown below, a coil of wire is wrapped around a permanent magnet. When the circuit is switched on, the magnetic field around the wire is pushed by the permanent magnet and the wire jumps. This shows the motor effect in action.

Teacher supervision required

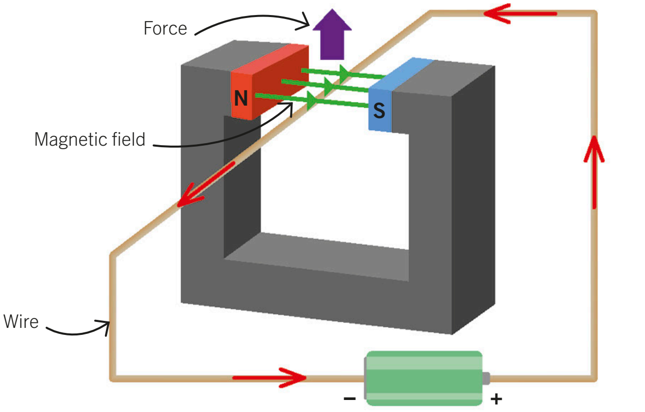


No current

Current flowing

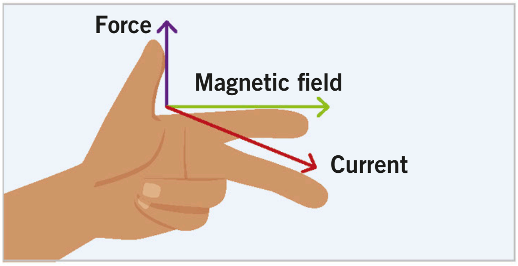
Direction of the force

The force produced by the motor effect is greatest when the wire is at right angles to the permanent magnetic field. The direction of the force is at right angles to both the current and the magnetic field. Fleming's left-hand rule (see next page) helps you remember how the force, current, and magnetic field are oriented.



Fleming's left-hand rule

You can work out the direction of the force produced by the motor effect by using Fleming's left-hand rule. Using your left hand, hold your thumb, index finger, and second finger at right angles. Your thumb shows the force, your index finger represents the magnetic field, and your second finger is the current.



The force equation

The size of the force produced by the motor effect depends on the strength of the current, the strength of the existing magnetic field, and the length of the wire. The equation below shows how all of these are related. The strength of the magnetic field is also called magnetic flux density and is measured in units called teslas (T).

The units for magnetic field strength are teslas (T), and the symbol is B.

force on conductor carrying current at 90° to magnetic field (N) = current (A) × length (m) × magnetic field strength (T)

$$F = I \times l \times B$$

The symbol for current is I (uppercase i).

This is a lowercase L.

Using the equation

Question 1
A magnet produces a magnetic flux density of 0.4 T. If a 2 m wire is at right angles to the magnetic field, with a current of 3 A flowing through it, what is the size of the force on the wire?

Answer 1
$F = I \times l \times B$
$= 3\text{ A} \times 2\text{ m} \times 0.4\text{ T}$
$= 2.4\text{ N}$

Question 2
There is a force of 1 N on a wire carrying a current of 0.2 A at right angles to a magnetic field. The length of wire in the field is 0.5 m. Calculate the magnetic flux density of the magnetic field.

Answer 2
Rearrange the equation:

$$B = \frac{F}{I \times l}$$

$$= \frac{1\text{ N}}{0.2\text{ A} \times 0.5\text{ m}}$$

$$= 10\text{ T}$$

Electric motors

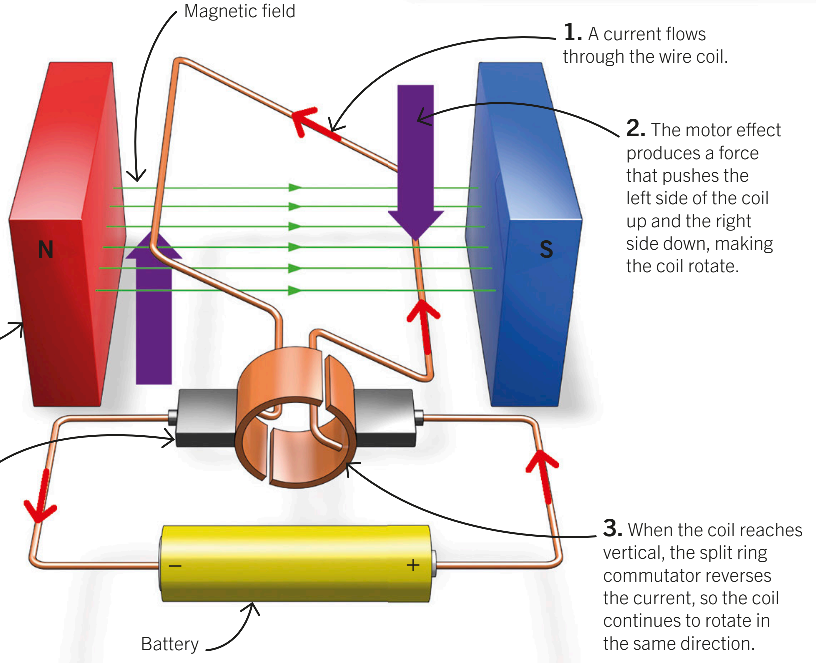
Electric motors use the motor effect (see page 202) to turn a coil of wire in a magnetic field. There are many designs of motor, from the tiny ones used in watches to the large ones that power electric cars. All types depend on a wire carrying current in a magnetic field.

Key facts

- ✓ **An electric motor uses the motor effect to make a coil of wire spin.**
- ✓ **The magnetic field is provided by permanent magnets or electromagnets.**
- ✓ **The direction of the current must be reversed every half-turn in order for the coil to keep rotating.**

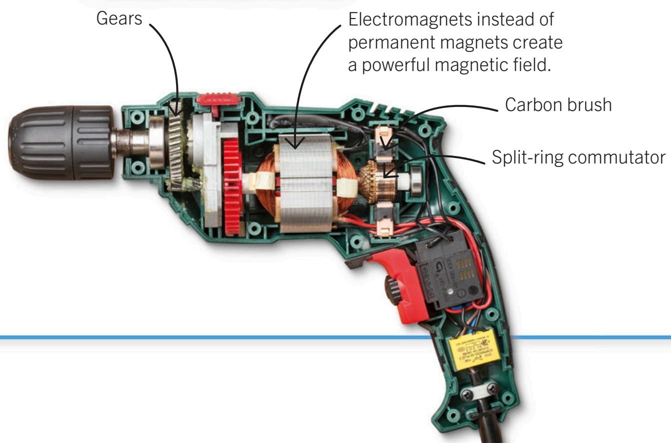
A simple electric motor

When a current flows through a coil of wire in a magnetic field, the force produced by the motor effect makes the coil rotate. The direction of the current needs to be switched every half-turn to prevent the coil from coming to a halt. This is achieved by using a split-ring commutator.



Powerful motors

Electric motors can be made more powerful by adding more turns to the coil, by increasing the current, or by increasing the power of the magnet. Electric drills also use multiple coils at different angles to maximize the force produced by the motor effect.



Electromagnetic induction

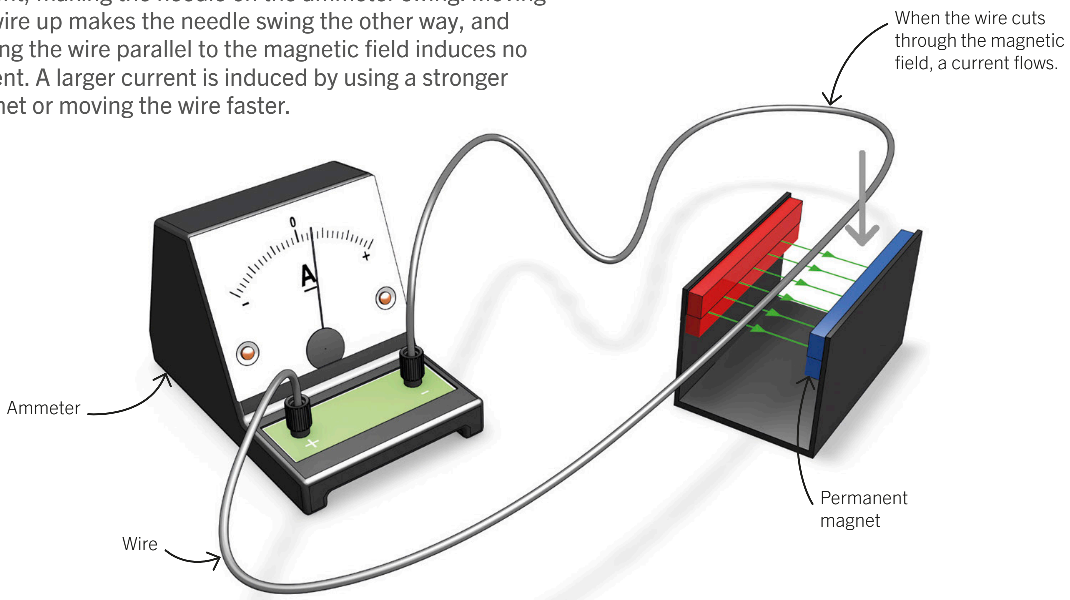
Electricity can be generated by a process known as electromagnetic induction. When a wire that is part of a circuit is moved across a magnetic field (or when a magnetic field is moved across a wire), a voltage is "induced" in the wire, causing a current to flow.

Key facts

- ✓ When a wire that is part of a circuit moves through a magnetic field, a voltage is induced in the wire.
- ✓ The size of the induced voltage depends on the magnetic field strength and on how fast the wire is moving.
- ✓ The direction of the induced voltage changes if the direction of movement changes.

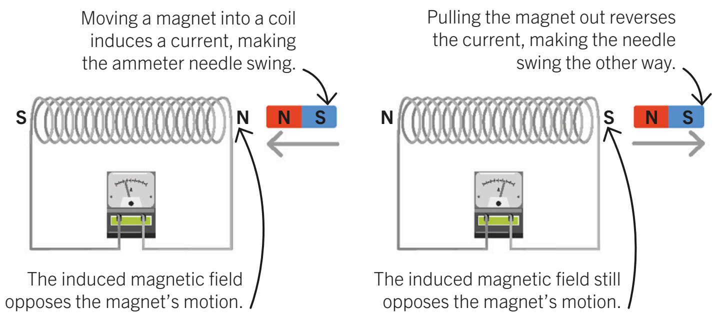
Moving wire experiment

In the experiment shown here, a wire connected to an ammeter is moved so it cuts through the magnetic field of a permanent magnet. Moving the wire down creates a small current, making the needle on the ammeter swing. Moving the wire up makes the needle swing the other way, and moving the wire parallel to the magnetic field induces no current. A larger current is induced by using a stronger magnet or moving the wire faster.



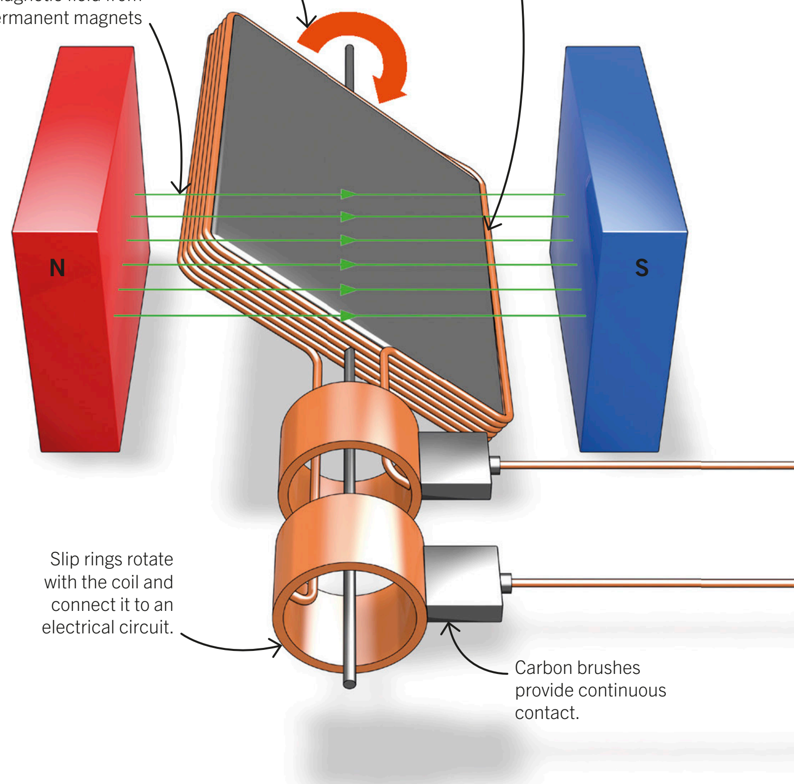
Opposing forces

Moving a magnet into a coil of wire has just the same effect as moving a wire through a magnetic field—it induces a current in the wire. The induced magnetic field always opposes the movement of the original magnet, whichever way it is moving.



Generators

Generators are devices that harness the kinetic energy of a moving object to generate electricity by electromagnetic induction (see page 205). Generators that produce alternating current (a.c.) are called alternators. Generators that produce direct current (d.c.) are called dynamos. Nearly all the electricity that powers our homes comes from generators.



Key facts

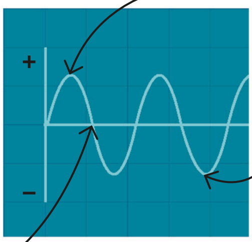
- ✓ **Generators are devices that use electromagnetic induction to generate electricity from kinetic energy.**
- ✓ **The voltage induced in a generator's coil varies as the coil spins around.**
- ✓ **An alternator produces alternating current.**
- ✓ **A dynamo produces direct current.**

Alternators

An alternator has a large coil of wire that spins around within a magnetic field. As it turns, a current is induced in the wire. With each half-turn, the coil's own magnetic field flips over and so the direction of the current reverses. A current that changes direction like this is called an alternating current (a.c.).

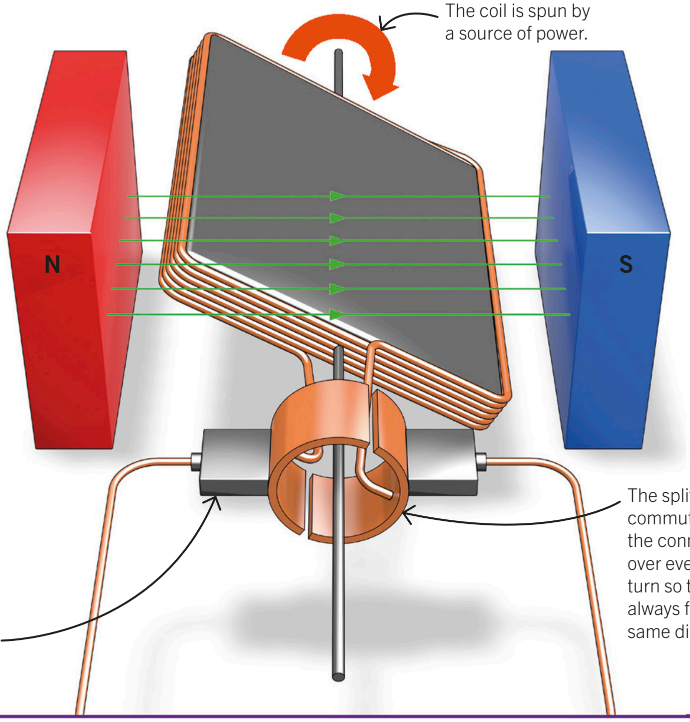
Producing alternating current

An oscilloscope (see page 115) shows that as the coil of wire in an alternator spins around, the voltage induced in it varies. The voltage peaks when the coil is oriented parallel to the magnetic field but drops to zero when the coil is perpendicular to the field. The current changes direction as the coil flips over, causing the voltage to change from positive to negative.



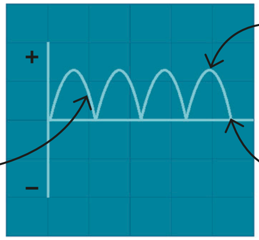
Dynamos

Many electrical devices need direct current—current that always flows in the same direction. If a generator is connected to the external circuit by a split-ring commutator, the connections swap over each time the current in the coil reverses. As a result, the current in the external circuit always flows in the same direction instead of reversing every half-turn. A generator like this is called a dynamo.



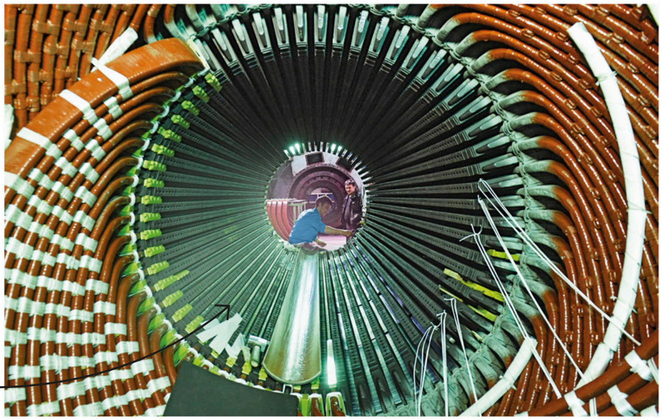
Producing direct current

Unlike alternators, dynamos produce direct current (d.c.) electricity. An oscilloscope shows that the voltage rises and falls with each half-turn of the coil, but it remains positive, as the direction of the electric current doesn't change.



Power station generators

The huge generators used in power stations use electromagnets rather than permanent magnets, as they can produce a much stronger magnetic field. Instead of using the source of power to spin a coil inside a magnet, they spin electromagnets inside a huge coil of copper wire. The picture here shows a coil under construction.

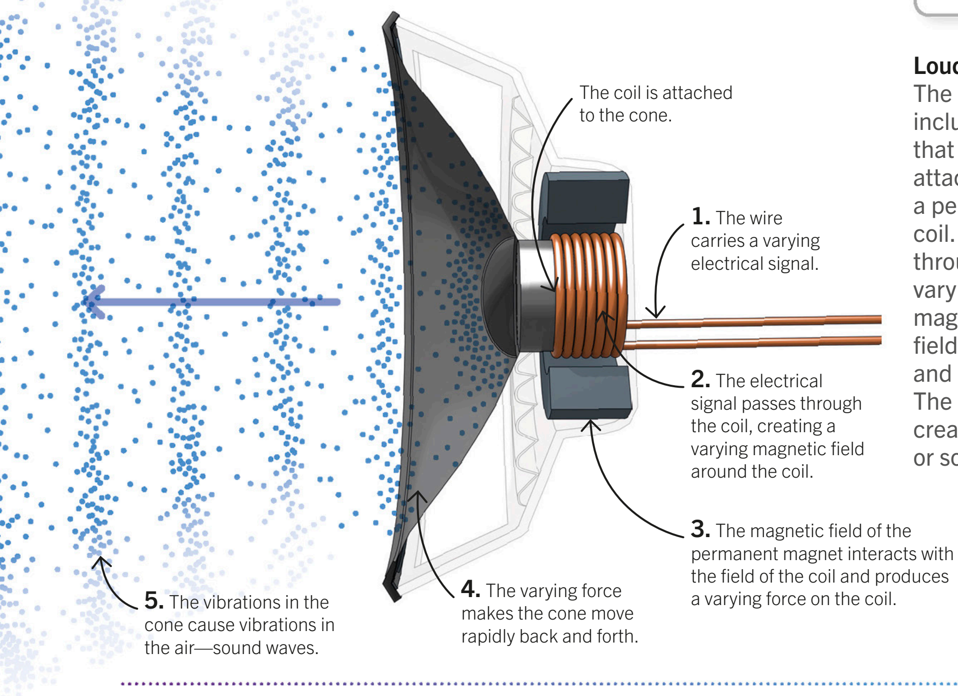


Loudspeakers and microphones

Loudspeakers and headphones (which are really just small loudspeakers) use the motor effect to convert a changing electrical current into sound waves. Microphones do the opposite—they convert sound waves into a changing current using electromagnetic induction.

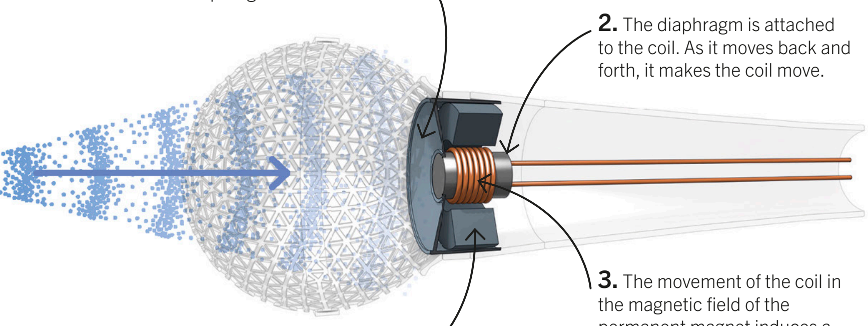
Key facts

- ✓ Loudspeakers turn a changing current into sound waves using the motor effect.
- ✓ Microphones turn sound waves into a changing current using electromagnetic induction.



Loudspeakers

The key parts of a loudspeaker include a large cone (diaphragm) that can vibrate, a coil of wire attached to the cone's base, and a permanent magnet around the coil. A varying current passes through the coil, creating a varying magnetic field. This magnetic field interacts with the field of the permanent magnet and causes the cone to vibrate. The moving cone (diaphragm) creates variations in air pressure, or sound waves (see page 114).



Microphones

A microphone contains similar components to a loudspeaker—a diaphragm, a coil attached to the diaphragm, and a permanent magnet—but they act in reverse. They convert variations in air pressure (sound waves) into a changing electrical signal by using electromagnetic induction (see page 205).

Transformers

A transformer is a device that changes the current and voltage (potential difference) of electricity by using electromagnetic induction. Huge transformers are used to reduce energy losses when electricity is transmitted over long distances, while smaller ones are used in electrical devices in the home. Transformers only work with alternating current (a.c.).

Key facts

- ✓ **Transformers change the voltage of an a.c. supply.**
- ✓ **Step-up transformers increase the voltage; step-down transformers reduce it.**
- ✓ **The voltage output of a transformer depends on the ratio of the number of turns in its two coils.**
- ✓ **For a transformer with 100% efficiency, the power output is equal to the power input.**

How transformers work

Transformers are made from two coils of wire (a primary coil and a secondary coil) on an iron core. The alternating current in the primary coil produces a magnetic field that changes direction many times each second. This induces an alternating current in the secondary coil. The two coils have a different number of loops, resulting in a change in voltage.

Calculating voltage

The change in voltage made by a transformer depends on the number of turns (loops) of wire in the two coils. The ratio of the voltages in the primary and secondary coils is the same as the ratio of the number of turns on each coil.

$$\frac{\text{voltage across primary coil (V)}}{\text{voltage across secondary coil (V)}} = \frac{\text{number of turns in primary coil}}{\text{number of turns in secondary coil}}$$

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

Primary coil

Secondary coil

Transformer calculations

Question 1

A television uses the 230 V power supply but only needs 46 V. Its transformer has 200 turns in the secondary coil. How many turns of wire does it have in the primary coil?

Answer 1

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\frac{230\text{ V}}{46\text{ V}} = \frac{N_p}{200\text{ turns}}$$

$$5 = \frac{N_p}{200\text{ turns}}$$

$$N_p = 5 \times 200\text{ turns}$$
$$= 1000\text{ turns}$$

Question 2

A step-up transformer outside a power station has 3200 turns in its primary coil and 51 200 turns in its secondary coil. The voltage across the primary coil is 25 000 V. What's the voltage of the electricity supplied by the transformer?

Answer 2

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\frac{25\,000\text{ V}}{V_s} = \frac{3200\text{ turns}}{51\,200\text{ turns}}$$

$$\frac{25\,000\text{ V}}{V_s} = 0.0625$$

$$V_s = \frac{25\,000\text{ V}}{0.0625}$$
$$= 400\,000\text{ V}$$
(400 kV)

Power input and output

Energy cannot be created or destroyed, so if a transformer is 100 percent efficient, its power output equals its power input. Because power = voltage × current, the relationship between the voltage and current entering and leaving a transformer can be written as shown in the equation below. (In reality, no transformer is perfectly efficient, as some energy is lost to things like resistance.)

$$\text{voltage across primary coil (V)} \times \text{current in primary coil (A)} = \text{voltage across secondary coil (V)} \times \text{current in secondary coil (A)}$$

Primary coil $V_p \times I_p = V_s \times I_s$ Secondary coil

Using the power equation

Question

A transformer has a voltage across the secondary coil of 12 V and a current of 0.8 A. The current in the primary coil is 0.04 A. Calculate the voltage across the primary coil.

Answer

$$V_p \times I_p = V_s \times I_s$$

$$V_p \times 0.04\text{ A} = 12\text{ V} \times 0.8\text{ A}$$

$$V_p = \frac{12\text{ V} \times 0.8\text{ A}}{0.04\text{ A}}$$
$$= 240\text{ V}$$

Matter

States of matter

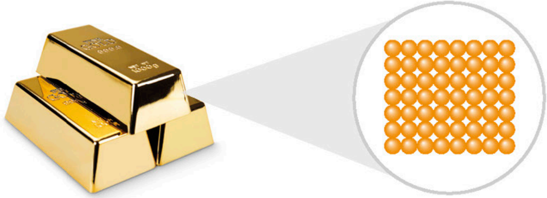
All matter is made of billions of tiny particles. Solids, liquids, and gases have different properties because of the way their particles are arranged.

Key facts

- ✓ All matter is made of billions of tiny particles.
- ✓ The particles in solids are held close together in fixed arrangements.
- ✓ The particles in liquids are close together but can move around.
- ✓ The particles in gases are very far apart, with relatively weak forces between them.

Solids

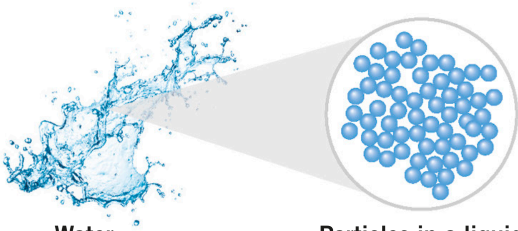
The particles in a solid are held closely together in fixed arrangements by powerful forces. This is why solids keep their shape and are difficult to compress (squash).



Gold   Particles in a solid

Liquids

The particles in a liquid are close together, but the forces between them are not as strong as in solids. As a result, liquids can be poured and take the shape of the container, but they are difficult to compress.



Water   Particles in a liquid

Gases

The particles in a gas are very far apart, and there are only very weak forces between them. Gases spread out to fill their containers and are easy to compress.

Iodine vapor   Particles in a gas

Conservation of mass

When an ice cube melts, its particles end up in a different arrangement. But all the same particles are still present, so the mass of the water is the same as the mass of ice. We say that the mass is conserved. The same thing happens when the water evaporates to form a gas or the gas condenses back into a liquid.

Changes of state

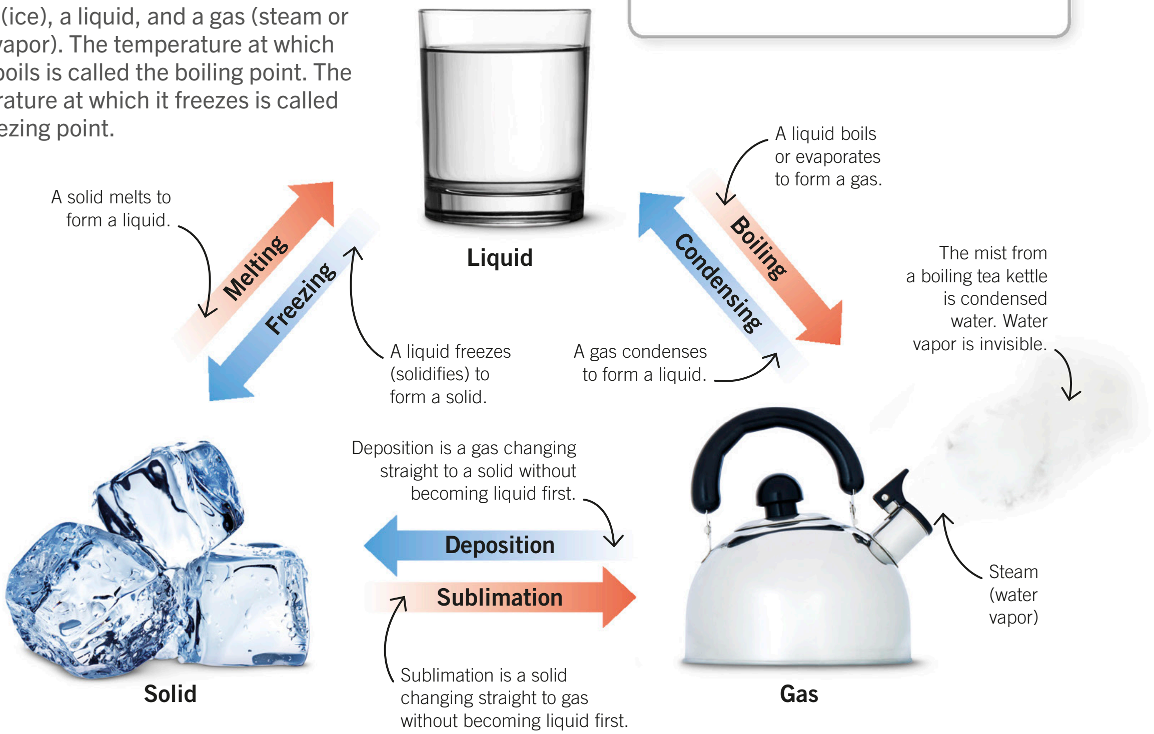
Solids, liquids, and gases are three states of matter. Each state has its own characteristics, and a material can change from one state to another. A change of state is a physical change rather than a chemical change, as no chemical reactions take place.

Key facts

- ✓ **Substances can exist in solid, liquid, or gas states.**
- ✓ **The three states of water are called ice, water, and steam.**
- ✓ **Steam is an invisible gas. Clouds in the sky, and the mist that forms above boiling tea kettles, are made of tiny drops of water.**

Changing state

Water can exist in three different states: as a solid (ice), a liquid, and a gas (steam or water vapor). The temperature at which water boils is called the boiling point. The temperature at which it freezes is called the freezing point.



Clouds and steam

Steam is an invisible gas. The white cloud we often call steam actually consists of lots of tiny drops of liquid water floating in the air.


Steam emerging from a boiling tea kettle is invisible. As it cools, it condenses to form clouds of liquid drops.


The clouds we see in the sky are made up of water drops or tiny ice crystals.


When humans or other animals breathe out on a cold day, water vapor in breath condenses into liquid droplets, forming visible mist.

Particles in motion

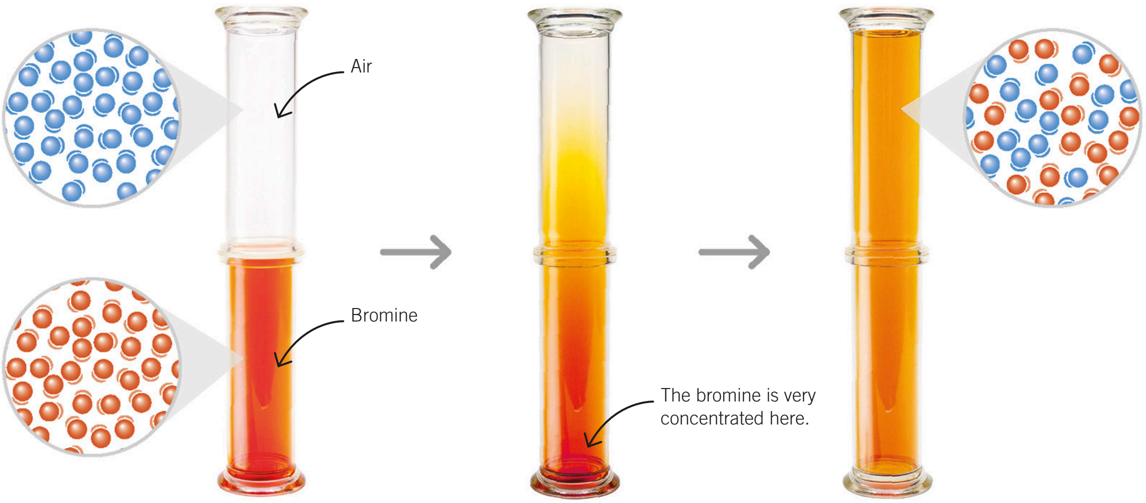
The particles in fluids (liquids and gases) are continually moving. As a result, they gradually spread from areas of high concentration to areas of low concentration—a process called diffusion. Particle movement also causes Brownian motion—the random jiggling motion of small specks of matter (such as dust particles) floating in air or water.

Key facts

- ✓ **Particles in fluids (liquids and gases) are moving around all the time.**
- ✓ **Particle movement causes different fluids to mix by diffusion.**
- ✓ **Substances diffuse from places with a high concentration to places with a low concentration.**

Diffusion

Diffusion causes different liquids or gases to gradually mix together. Think of spraying perfume into the air. A breeze will spread the smell quickly, but the smell will spread even in still air. This happens because the particles in fluids are moving all the time. A substance will spread out from a place where it is concentrated into places where it is less concentrated.



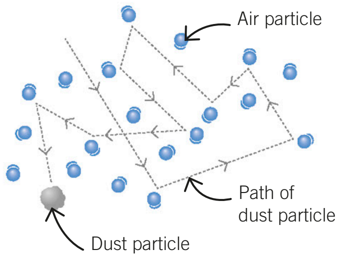
1. A jar of bromine gas and a jar of air are placed together, with a glass barrier between them.

2. When the barrier is removed, bromine diffuses into the air, and air diffuses into the bromine.

3. Eventually, the gases are evenly mixed by diffusion.

Brownian motion

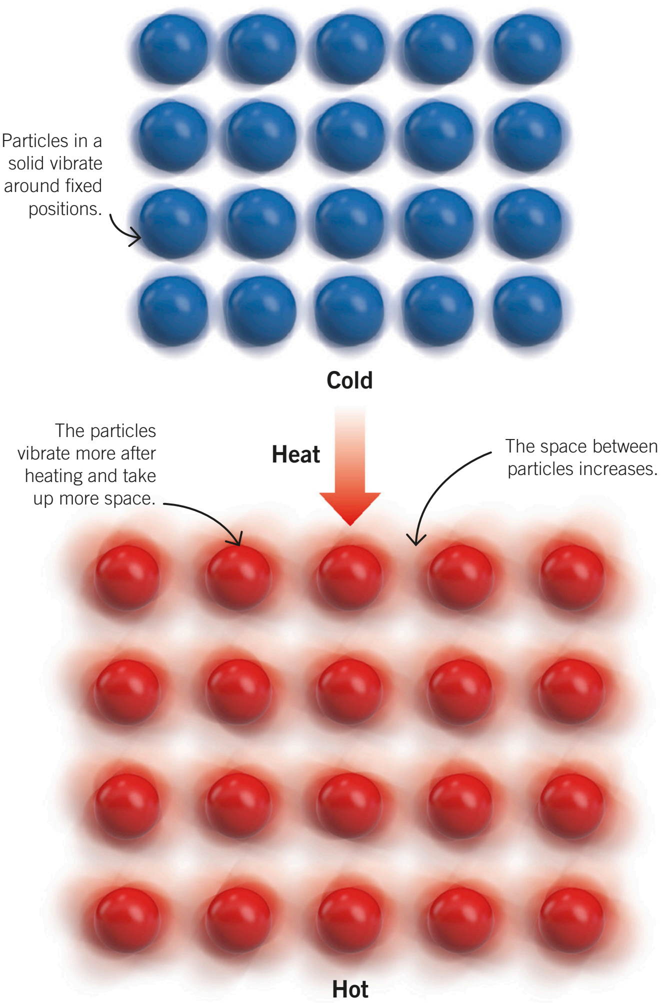
Have you ever noticed specks of dust dancing around in a beam of light? Most of the movement is due to air currents, but dust and smoke particles also jitter around in still air. This effect is called Brownian motion, after the Scottish scientist Robert Brown. He studied it in 1827, but it wasn't until 1905 that Albert Einstein explained what causes it: the specks of dust keep being hit by fast-moving air particles, making them move randomly.



Heat expansion

The way particles move depends on their temperature. When a substance is heated, its particles move faster, which makes the substance take up more space—it expands.

Expanding solids
Unlike gas and liquid particles, which move around separately, the particles in solids are fixed in place. However, they are not motionless—they continually vibrate (move back and forth). When solids are heated, the particles vibrate faster and farther, making the solid expand.



Key facts

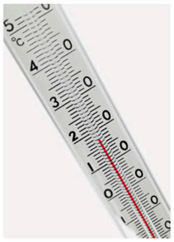
- ✓ Particles in solids vibrate all the time, and particles in fluids move around.
- ✓ Particles vibrate or move around faster when a material is warmer.
- ✓ Materials expand when they are heated and contract when they cool.

Thermal expansion

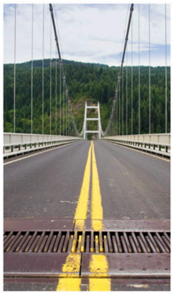
The expansion of materials as they get hotter is called thermal expansion. Thermal expansion can be useful, but it can also be a nuisance at times.

Hot air balloons use a burner to heat up the air inside the balloon. The hot air expands, which makes it less dense than the air outside. This makes the balloon rise.

Thermometers use thermal expansion of liquids to measure temperature. As the liquid inside the bulb gets hotter, it expands up the thin glass tube inside the thermometer.



Expansion joints allow bridges to expand a little in hot weather and contract in cold weather. If these mobile joints were not used, the forces caused by expansion and contraction could bend or break the structure. Engineers design expansion joints to allow for these changes in size.



Density

We think of metal as being heavier than wood, but this is not always true. The weight of an object depends on its size, as well as what it's made of, so a small piece of metal weighs less than a large piece of wood. Density is a way of comparing materials by saying how much mass there is in a certain volume.

Key facts

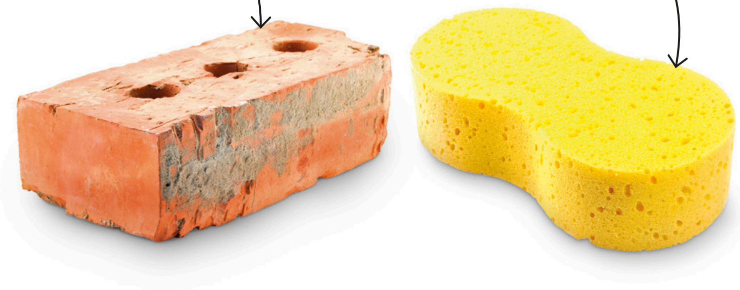
- ✓ **Density is the mass of a substance in a certain volume.**
- ✓ **The density of a material depends on the mass of its particles and on how closely packed they are.**
- ✓ **Materials expand when heated, reducing their density.**

Density and particles

A brick and a sponge have about the same volume, but the brick weighs much more because it is far more dense. The brick has more mass than the sponge because it has fewer air spaces within it and because it's made of elements with a greater atomic mass than those in the sponge.

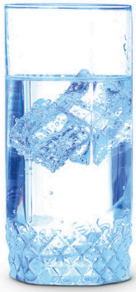
The brick weighs more because it has a greater mass.

The sponge has less mass but a similar volume—it's less dense.



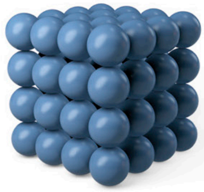
Water and ice

When most substances freeze, the particles get a little closer together. This means that the solid is more dense than the same substance as a liquid. However, water is unusual. When it freezes, the particles link together in a way that spreads them farther apart, which makes ice less dense than cold water. This is why ice cubes float in a drink and icebergs float in the ocean.



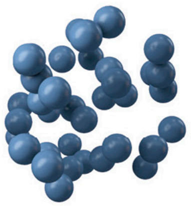
Density and states of matter

When a substance is heated but its mass stays the same, it expands and its volume increases, making it less dense. Changes of state (such as melting or evaporating) also affect density. This is because the particles usually become less tightly packed when a substance melts to become a liquid or evaporates to become a gas.



The particles in solids are usually tightly packed, making solids more dense than liquids or gases.

The particles in liquids are usually less tightly packed than in solids, making liquids less dense than solids.



The particles in a gas spread out, giving gases very low density.

Finding the density

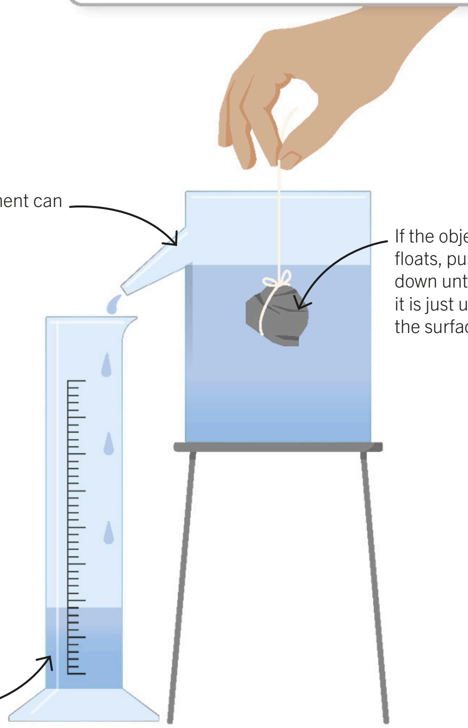
The density of a substance is its mass divided by its volume. This is easy to find for a liquid, but to calculate the density of a solid, you first need to measure its volume. There are two different ways of doing this, depending on whether the object has an irregular or a regular shape.

Key facts

- ✓ The density of a substance is its mass divided by its volume.
- ✓ To find the density of a solid object, you first need to measure its volume.
- ✓ A displacement can is used to measure the volume of irregular objects.

The displacement method

To measure the density of an irregular object, use a special container called a displacement can or eureka can. Fill the displacement can with water to just below the spout, then lower the irregular object into the water. The volume of the object is equal to the volume of water displaced. Place the object on a balance to find its mass, then use the formula below to calculate density.



$$\text{Density (kg/m}^3\text{)} = \frac{\text{mass (kg)}}{\text{volume (m}^3\text{)}}$$

$$\rho = \frac{m}{V}$$

The symbol for density is the Greek letter rho (pronounced "roe").

Density of a regular object

To calculate the density of a regularly shaped object, you first need to work out its volume. You can do this for a cube or a rectangular prism by measuring its dimensions and using the formula volume = length × width × height. Then use a balance to measure the object's mass, and finally use the density formula to work out the answer.

Question

Iron has a density of about 8000 kg/m³. What is the mass of a cube of iron with edges 5 m long?

Answer

1. First, work out the cube's volume.
   Volume = 5 m × 5 m × 5 m
   = 125 m^3
2. Rearrange the density equation to find the mass.
   Mass = density × volume
   = 8000 kg/m³ × 125 m³
   = 1 000 000 kg

Internal energy

The particles in objects are always in motion—either vibrating back and forth (in solids) or moving around separately (in liquids and gases). When you heat an object, the particles within it gain kinetic energy and move faster. The total kinetic and potential energy of all the particles in an object make up its store of internal energy (thermal energy).

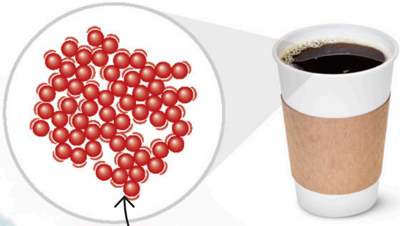
Key facts

- ✓ Heating transfers energy to the kinetic energy stores of particles in an object, making them move faster.
- ✓ The internal energy (thermal energy) of an object is the total kinetic and potential energy of all its particles.
- ✓ Temperature and internal energy are not the same thing.
- ✓ The temperature of an object is a measure of the average kinetic energy of its particles.

Internal energy and temperature

The internal energy of an object is not the same as its temperature. Temperature is a measure of the average kinetic energy of the particles—the faster the particles are moving, the higher the temperature. But temperature is not a measure of an object's total internal energy. A large object can store more internal energy than a small object even if its temperature is lower.

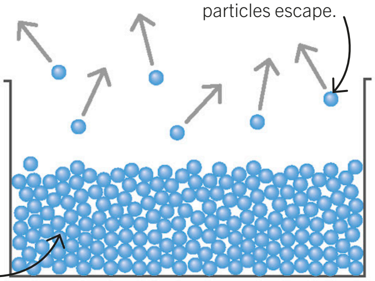
An iceberg has a much greater store of internal energy than a cup of hot coffee because it has more particles.



The water particles in a hot drink are moving faster than in ice, giving it a higher temperature. But a cup of coffee has less internal energy than an iceberg because it has fewer particles.

Cooling by evaporation

Why does a wet towel feel cold? The particles in water are always moving but not at the same speed—some move much faster than others. When water evaporates, it's the fastest particles that escape. The particles left behind therefore have a lower average speed. Because temperature depends on the particles' average speed, the temperature of the remaining water falls—the towel gets cold.

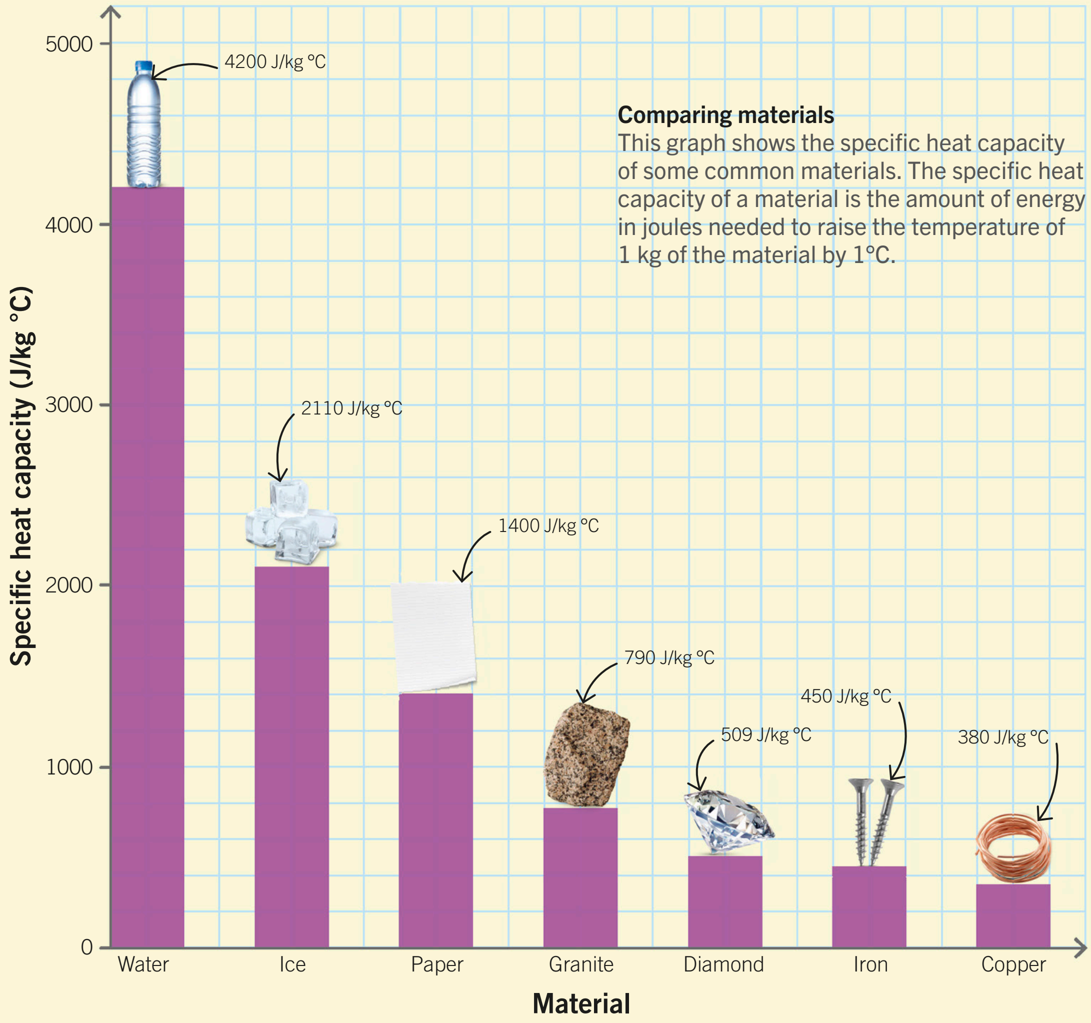


Specific heat capacity

The amount of heat energy needed to make something hotter varies a lot from one substance to another. For instance, you need nearly 10 times as much energy to heat water by 1°C as you need to heat the same mass of iron by 1°C. We say that water has a higher specific heat capacity than iron.

Key facts

- ✓ Different substances require different amounts of heat energy to raise their temperature by the same amount.
- ✓ The specific heat capacity of a material is the amount of energy in joules needed to raise the temperature of 1 kg of the material by 1°C.



Comparing materials
This graph shows the specific heat capacity of some common materials. The specific heat capacity of a material is the amount of energy in joules needed to raise the temperature of 1 kg of the material by 1°C.

Formula for specific heat capacity

The formula below shows how we can use the specific heat capacity of a substance to work out how much energy is needed to raise its temperature.

$$\text{change in thermal energy (J)} = \text{mass (kg)} \times \text{specific heat capacity (J/kg °C)} \times \text{change in temperature (°C)}$$

$$\Delta E = m \times c \times \Delta T$$

The triangle symbol is the Greek letter delta and means a change in quantity.

This is the unit of specific heat capacity.

Calculating change in temperature

Question

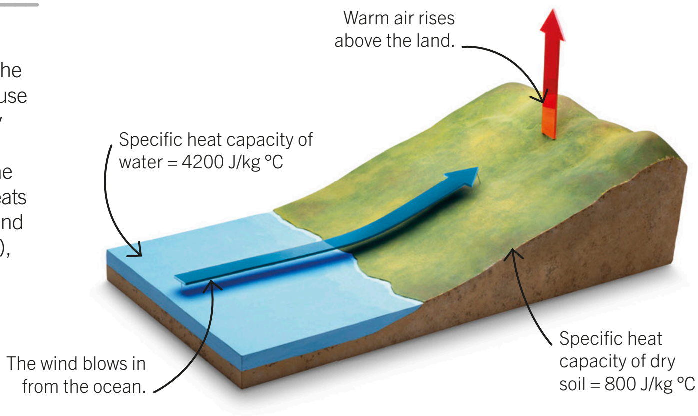
This cup holds 300 g (0.3 kg) of tea. If the tap water used to brew the tea was 7°C, and the specific heat capacity of water is 4200 J/kg °C, how much energy was needed to bring the water to boiling point?

Answer

1. First, work out the change in temperature (ΔT):
   $\Delta T = 100°C - 7°C = 93°C$
2. Now work out the change in the water's store of internal energy (ΔE):
   $\Delta E = m \times c \times \Delta T$
   $= 0.3 \text{ kg} \times 4200 \text{ J/kg °C} \times 93°C$
   $= 117\,180 \text{ J } (117.2 \text{ kJ})$

Ocean breezes

If you live near the coast, you've probably noticed that the wind often blows in from the ocean on sunny days. This happens because the land has a lower specific heat capacity than the ocean. When the Sun shines, it takes less energy to warm the land than the ocean, so the land warms up faster and heats the air above it. The warmer air over the land rises in a convection current (see page 48), which draws in cooler air from the ocean.



Finding specific heat capacity

You can find the specific heat capacity of a substance by measuring the energy needed to heat up a known mass by a certain temperature. The accuracy of the result depends on how much energy escapes to the surroundings during the experiment.

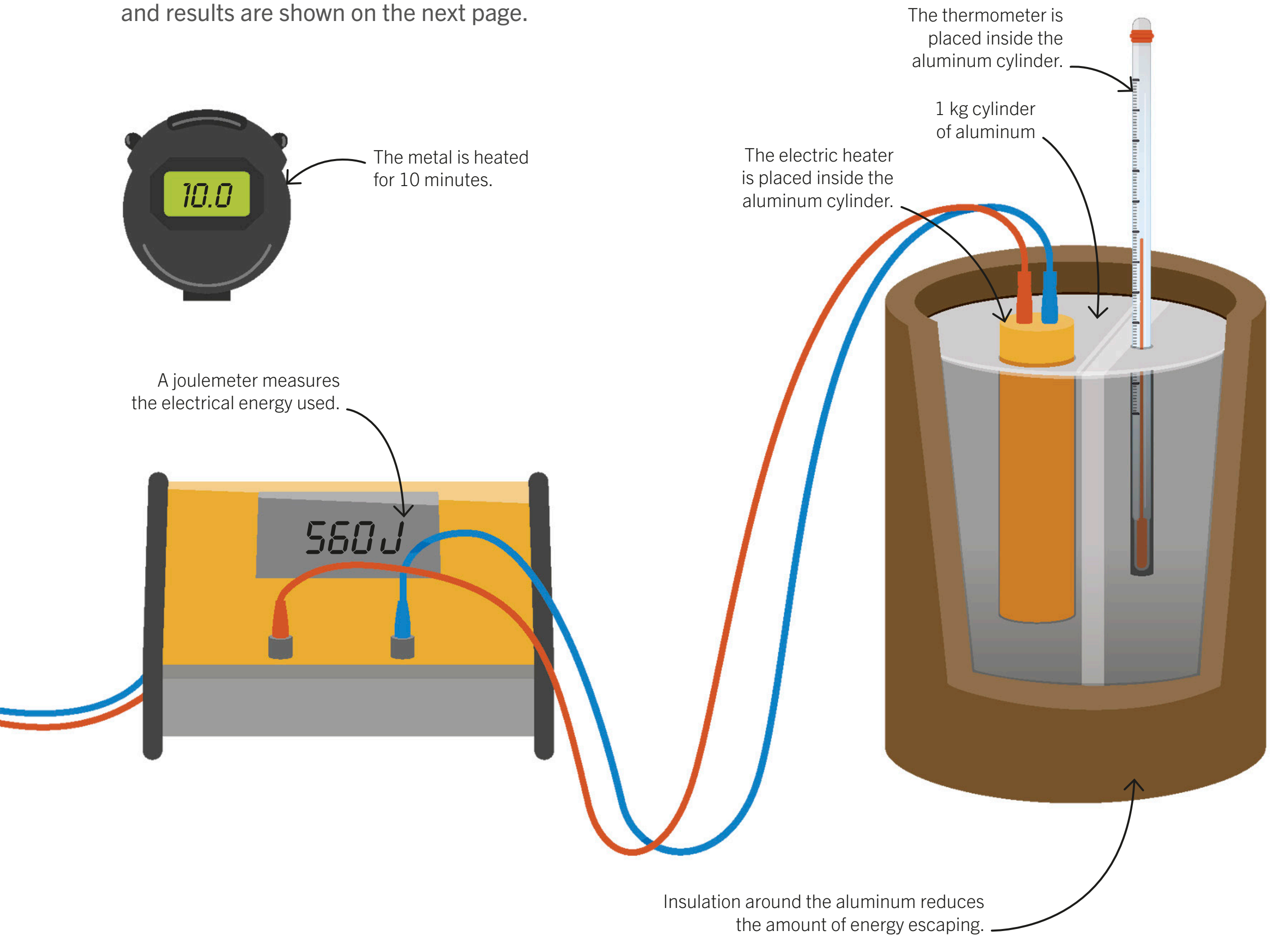
Key facts

- ✓ Specific heat capacity is determined by measuring the energy needed to raise the temperature of a known mass of a substance.
- ✓ The apparatus must be insulated to reduce the energy transferred to the surroundings.

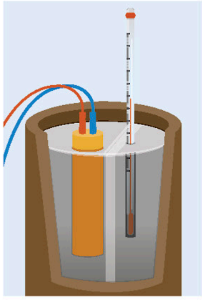
Specific heat capacity of aluminum

This page shows how to measure the specific heat capacity of a 1 kg cylinder of aluminum, but you can use the same technique for a different mass or a different kind of metal. The metal is heated by an electric heater, and a joulemeter measures how much electrical energy is used. The method and results are shown on the next page.

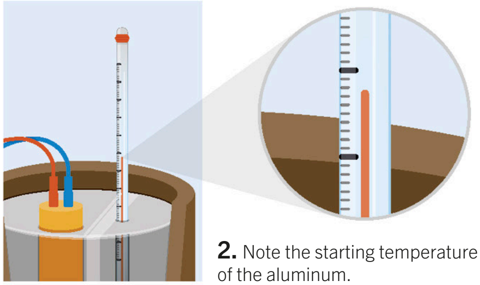
Teacher supervision required



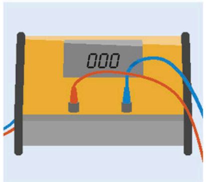
Method



1. The aluminum cylinder has two holes drilled in it. Place the electric heater in the large hole and the thermometer in the small hole. Put a little oil in the thermometer hole to help conduct heat from the metal to the thermometer.

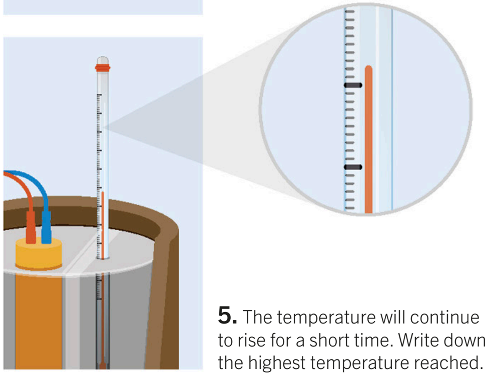


2. Note the starting temperature of the aluminum.



3. Zero the joulemeter and then turn on the heater.

4. After 10 minutes, turn off the heater.



5. The temperature will continue to rise for a short time. Write down the highest temperature reached.

Results

1. Record your results in a table like this one.

Mass of aluminum	**1 kg**
Starting temperature	**18°C**
Highest temperature	**42°C**
Energy transferred	**22 313 J**

2. Calculate the temperature change:
$\Delta T = 42°C - 18°C = 24°C$

3. Now use the equation from page 220 to calculate the specific heat capacity. Rearrange it to calculate c:

$$\Delta E = m \times c \times \Delta T$$

$$c = \frac{\Delta E}{m \times \Delta T}$$

$$= \frac{22\,313 \text{ J}}{1 \text{ kg} \times 24°C}$$

$$= 930 \text{ J/kg °C}$$

Evaluation

You can work out how accurate your measurement was by comparing your result to the true specific heat capacity of aluminum, which is 897 J/kg °C. Some of the energy will have escaped to the surroundings during your investigation, so the energy value you used in your calculation is probably too high, giving an overestimate of aluminum's specific heat capacity. You could improve the accuracy of the experiment by putting insulation over the top of the metal block, leaving holes for the wires and the thermometer.

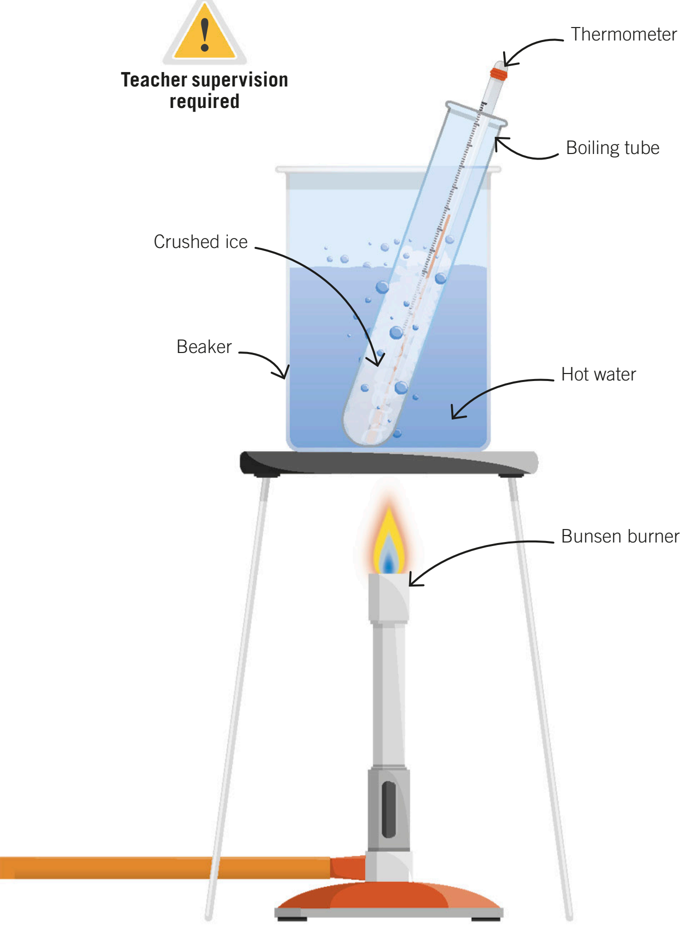
Heating curves

Transferring energy to a substance by heating normally makes its temperature rise. However, when solids melt or when liquids boil, they take in energy without a change of temperature. This experiment investigates what happens when you heat ice to make it melt. The results form a graph called a heating curve.

Heating ice

A thermometer is placed in a tube of crushed ice, which is then placed in a beaker of hot water. The temperature is recorded regularly until after all the ice has melted.

Teacher supervision required



Method

1. Half fill a boiling tube with ice and put a thermometer in it. Record the temperature of the ice.

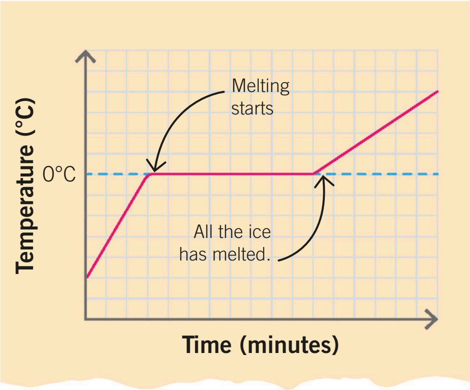
2. Put the boiling tube into a beaker of hot water. Keep the water hot using a Bunsen burner.

3. Record the temperature of the ice every minute. Note the time when the temperature reaches 0°C and the ice starts to melt.

4. Note the time when the ice has completely melted. Keep taking the temperature for another 3 minutes.

Results

Use your results to plot a line graph of temperature (y-axis) against time (x-axis). When you put the tube of ice into the water bath, the temperature starts to rise, which is why the first part of the graph is an upward slope. When the temperature reaches 0°C, the ice starts to melt and the temperature remains constant even though energy is still being transferred from the hot water. This energy, called latent heat, melts the ice rather than raising the temperature, so the middle part of the graph is flat. After all the ice melts, the temperature rises again.



Temperature and changes of state

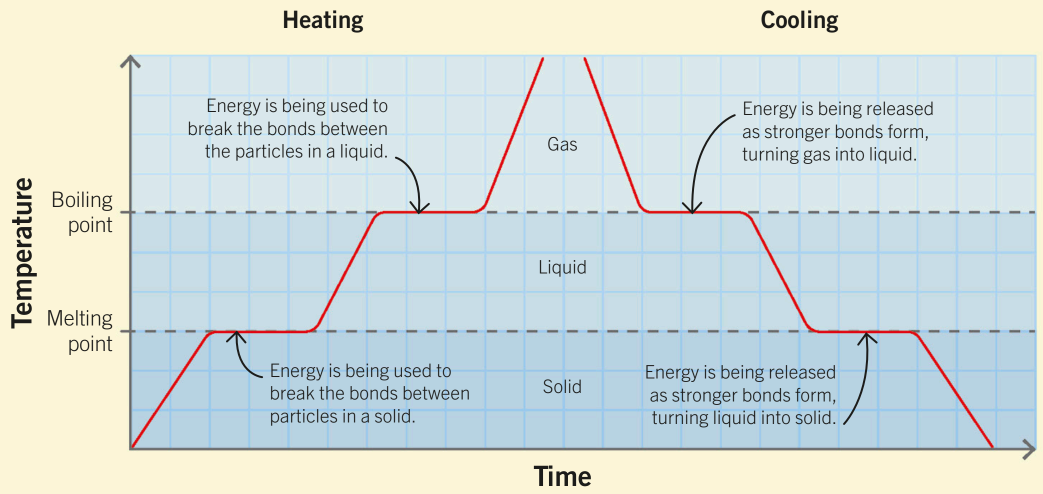
Energy is needed to melt a substance or make it boil. The energy needed to do this is called latent heat. When a gas condenses or a liquid solidifies, the latent heat is released again.

Heating and cooling curves

The graph below shows how temperature changes as a substance changes state. When a substance melts or boils, the energy supplied is used to overcome the forces between the particles, so the temperature remains the same, resulting in a flat section on the graph. When a gas condenses or when a liquid freezes, the formation of bonds releases energy and so keeps the temperature constant.

Key facts

- ✓ When a substance is heated, its temperature remains constant while it is melting or while it is boiling.
- ✓ When a substance is cooled, its temperature remains constant while it is condensing or while it is freezing.
- ✓ The energy absorbed or released while the change of state is taking place is called latent heat.
- ✓ Evaporation can happen from the surface of a liquid at any temperature.



Evaporation and boiling

Evaporation can happen from the surface of a liquid at any temperature. For example, puddles dry up even though the temperature of the water in them never reaches boiling point. Boiling happens when water turns to gas so quickly that lots of bubbles form deep within the liquid. These bubbles contain water vapor, not air.

Latent heat calculations

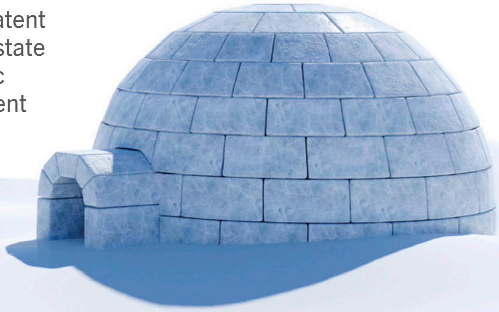
Latent heat is the energy needed to change a solid to a liquid (called the latent heat of fusion) or a liquid to a gas (the latent heat of vaporization) without changing the temperature. When the reverse happens and a gas condenses or a liquid freezes, latent heat is released.

Key facts

- ✓ Latent heat is the energy needed to change a solid to a liquid or a liquid to a gas.
- ✓ The same amount of energy is released when the reverse state change happens.
- ✓ Specific latent heat is the energy needed to change the state of 1 kg of a substance at a constant temperature. Its unit is J/kg.

Latent heat of fusion

You can calculate how much energy is needed to melt a given mass of ice (without changing the temperature) by using the equation below. The equation uses a value called specific latent heat, which is the amount of energy needed to change the state of 1 kg of a substance. The example below uses the specific latent heat of fusion for water. Every substance has a different specific latent heat of fusion and vaporization.



$$\text{energy for a change of state (J)} = \text{mass (kg)} \times \text{specific latent heat (J/kg)}$$

$$E = m \times L$$

For instance, to melt an ice igloo with a mass of 750 kg:

energy for a change of state (J) = 750 kg × 334 000 J/kg

= 250 500 000 J or 251 MJ

Scalding steam

Be careful you don't scald yourself when your hand is near the spout of a boiling tea kettle. Steam can cause a nasty scald partly because it releases latent heat when it condenses. The latent heat of vaporization is much higher than the latent heat of fusion. This is because more energy is needed to separate particles completely to turn a liquid into a gas than is needed to turn a solid into a liquid.

Question

How much energy is transferred if 1 g of steam condenses? The specific latent heat of vaporization of water is 2 256 000 J/kg.

Answer

First, convert the mass into kilograms: 1 g = 0.001 kg

energy released = $m \times L$

= 0.001 kg × 2 256 000 J/kg

= 2256 J

Pressure

Surface pressure

When you press on an object, the force might be spread across your hand or concentrated in the tip of one finger. Pressure is a measure of how much a force is concentrated by the surface area it acts through. What happens to an object when a force acts on it can depend on the pressure.

Raising the pressure

Pressing a balloon with a fingertip squashes it, but applying the same force with a pin bursts the balloon. The tip of the pin has an extremely small surface area, so the same force produces a much greater pressure. You can calculate pressure using the equation below. Pressure is the force per unit of surface area. We measure it in units called pascals: 1 Pa is 1 N of force applied over 1 m^2.

$$\text{pressure (Pa)} = \frac{\text{force (N)}}{\text{area } (m^2)}$$

$$p = \frac{F}{A}$$

Key facts

- ✓ Pressure is the force per unit of surface area.
- ✓ The effect a force has on a surface depends on the pressure it exerts.
- ✓ The pascal (Pa) is a unit of pressure and represents 1 N of force per square meter.

Calculating pressure

Question

A suitcase weighing 15 N is placed on a bed. Its base is 0.8 m long and 0.5 m wide. How much pressure does it exert on the bed?

Answer

First, calculate the surface area in square meters:

$A = 0.8 \text{ m} \times 0.5 \text{ m}$

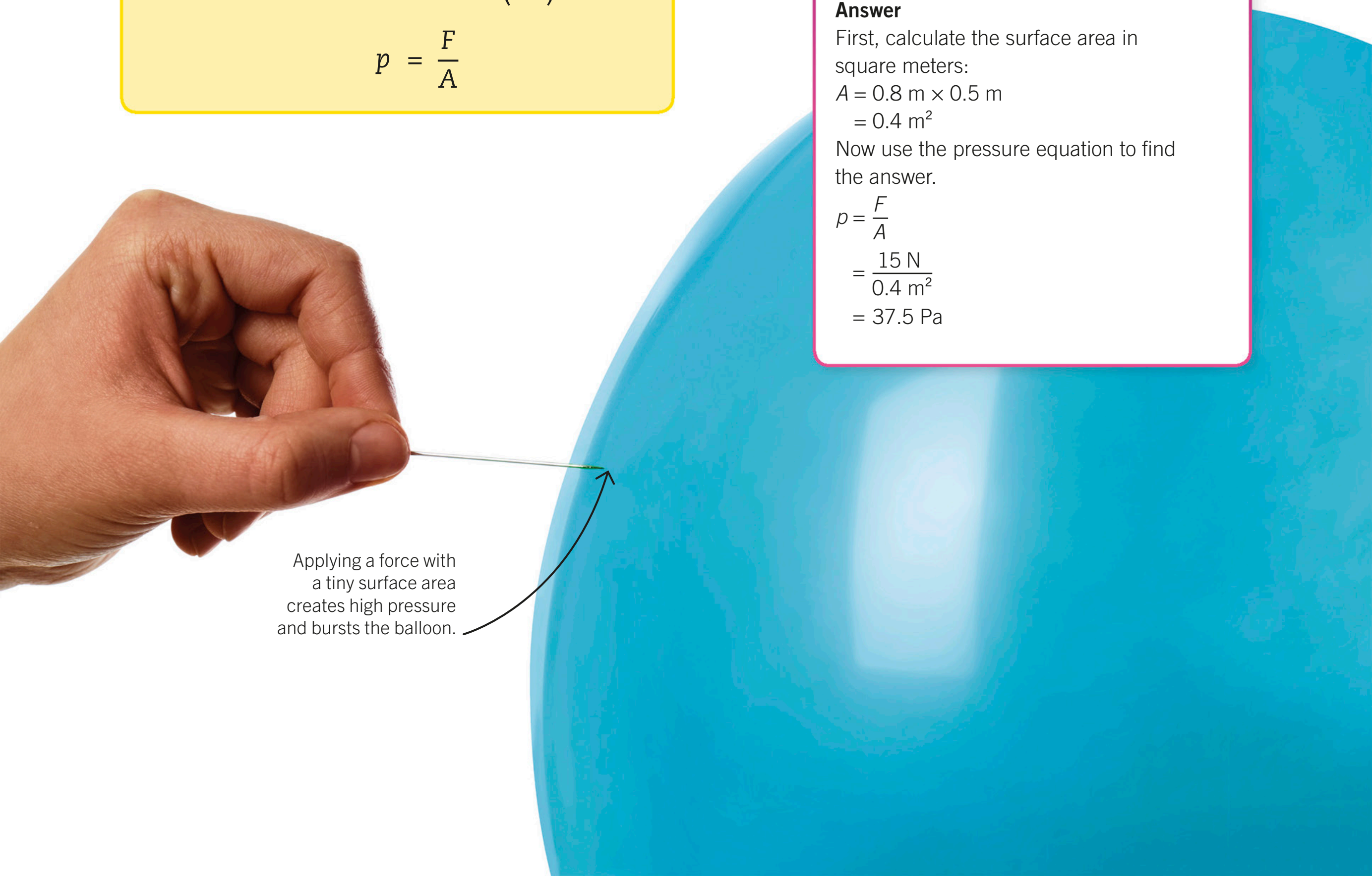
$\quad = 0.4 \text{ m}^2$

Now use the pressure equation to find the answer.

$p = \frac{F}{A}$

$\quad = \frac{15 \text{ N}}{0.4 \text{ m}^2}$

$\quad = 37.5 \text{ Pa}$



Applying a force with a tiny surface area creates high pressure and bursts the balloon.

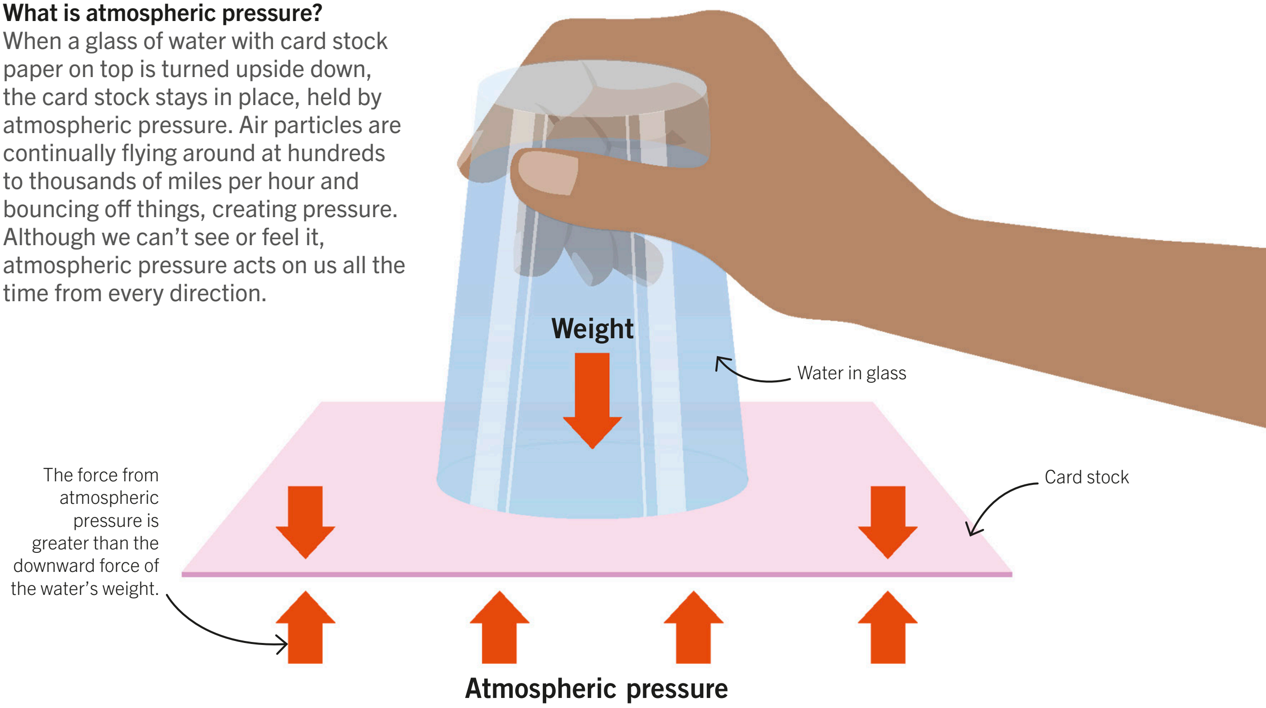
Atmospheric pressure

The atmosphere is the layer of air that surrounds Earth. Atmospheric pressure is the pressure on Earth's surface caused by the weight of this air. It is greatest at lowest altitudes and decreases with increasing height above the ground.

Key facts

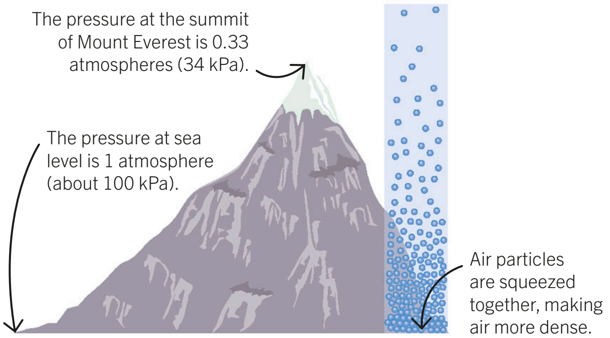
- ✓ Atmospheric pressure is the pressure on Earth's surface caused by the weight of air in the atmosphere.
- ✓ Atmospheric pressure falls with increasing altitude.

What is atmospheric pressure?
When a glass of water with card stock paper on top is turned upside down, the card stock stays in place, held by atmospheric pressure. Air particles are continually flying around at hundreds to thousands of miles per hour and bouncing off things, creating pressure. Although we can't see or feel it, atmospheric pressure acts on us all the time from every direction.



Pressure and altitude

When you climb a mountain, the pressure falls as you get higher. This is because pressure is caused by the weight of the atmosphere, and the higher you climb, the less air there is above you. As altitude increases, the air also becomes less dense, making it harder to breathe. This happens because gases, unlike liquids, are compressible. The higher pressure at sea level squeezes air into a smaller space than the lower pressure at high altitudes.

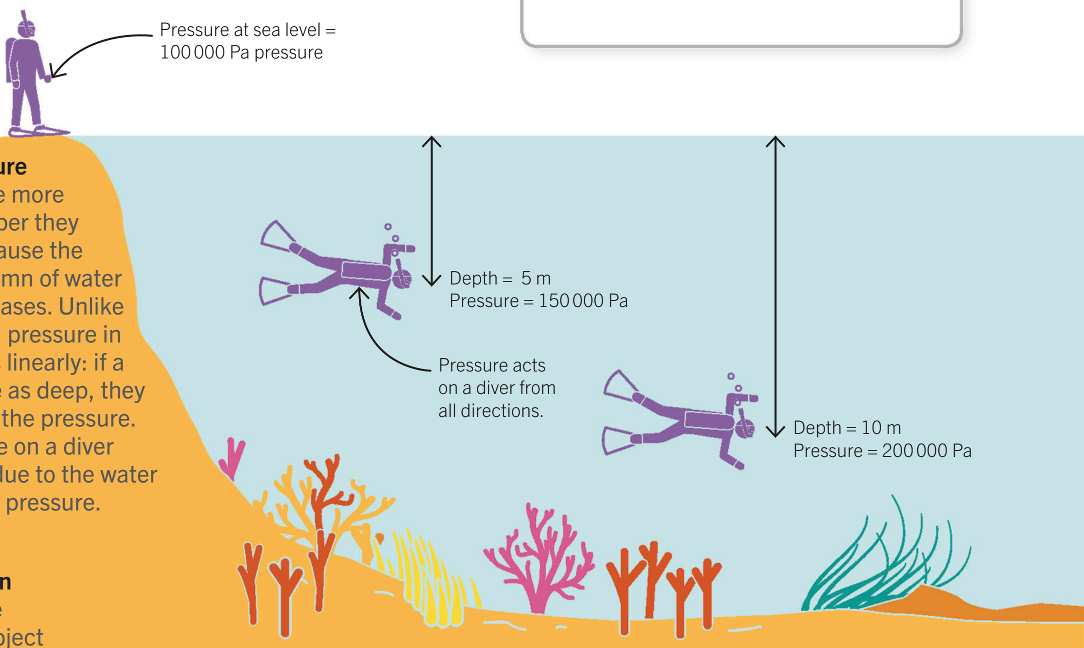


Pressure in a liquid

The pressure on an object submerged in liquid is caused by the weight of the column of liquid above it. Pressure in liquids varies with depth and density: it's higher at greater depths and in denser liquids.

Key facts

- ✓ **Pressure in a liquid increases with depth and with density.**
- ✓ **Total pressure underwater equals pressure due to the water plus pressure due to the atmosphere.**



Depth and pressure

Divers experience more pressure the deeper they swim. This is because the height of the column of water above them increases. Unlike pressure in a gas, pressure in a liquid increases linearly: if a diver swims twice as deep, they experience twice the pressure. The total pressure on a diver equals pressure due to the water plus atmospheric pressure.

Pressure equation

You can calculate pressure on an object in a liquid with this equation. The height of the liquid above the object is *h*, the density of the liquid is ρ, and *g* is gravitational field strength (10 N/kg near the surface of Earth).

$$\text{pressure (Pa)} = \text{height (m)} \times \text{density (kg/m}^3\text{)} \times \text{gravitational field strength (N/kg)}$$

$$P = h \times \rho \times g$$

Pressure due to liquid

The symbol for density is the Greek letter rho (pronounced "roe").

Calculating pressure

Question

The density of water is 1000 kg/m^3. Calculate the total pressure experienced by a penguin diving 30 m to catch fish if the pressure at sea level is 100 000 Pa.

Answer

First, calculate the pressure due to the water at 30 m depth.

$P = 30 \text{ m} \times 1000 \text{ kg/m}^3 \times 10 \text{ N/kg}$
$= 300\,000 \text{ Pa}$

Then add the pressure at sea level to find the answer.

Total pressure = 300 000 Pa + 100 000 Pa
= 400 000 Pa (400 kPa)

Floating and sinking

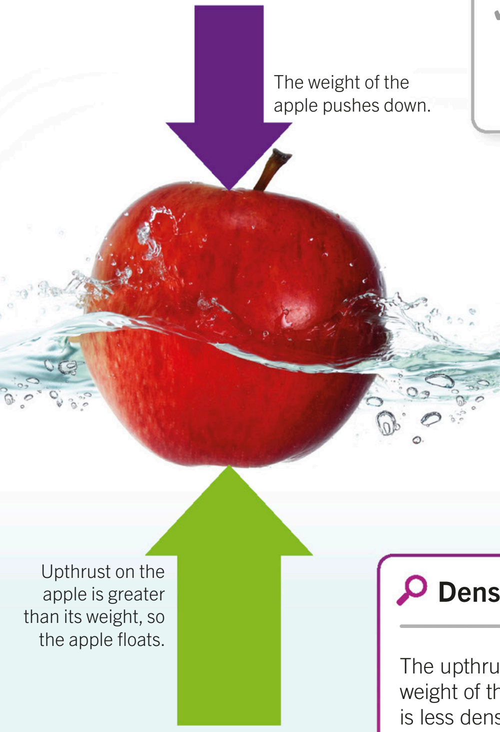
Apples float on the water surface, strawberries sink, but fish and dolphins do neither. Whether an object floats or sinks depends on the forces acting on it.

Upthrust

Because pressure increases as you go deeper underwater, a submerged object experiences greater pressure on its bottom surface than on top. This difference results in an overall upward force: upthrust. If the upthrust is greater than the object's weight, it will float. If the upthrust is less, it sinks.

Key facts

- ✓ An object in a fluid experiences an upward force called upthrust.
- ✓ Upthrust is equal to the weight of the fluid displaced.
- ✓ If upthrust is greater than an object's weight, it will float.



The weight of the apple pushes down.

Upthrust on the apple is greater than its weight, so the apple floats.

The weight of the strawberry pushes down.

Upthrust on the strawberry is less than its weight, so the strawberry sinks.

Density and buoyancy

The upthrust on an object is equal to the weight of the water it displaces. If the object is less dense than water, the water it displaces weighs more than the object, so the upthrust exceeds its weight and it floats. Likewise, if the object is more dense than water, it sinks. Steel is denser than water, but a steel ship floats because it contains large air spaces, making it less dense overall than water. This is why ships weighing half a million tons don't sink.

Barometers and manometers

Barometers and manometers are instruments used to measure pressure in fluids. Barometers measure atmospheric pressure. Manometers measure the difference in pressure between two gases.

Key facts

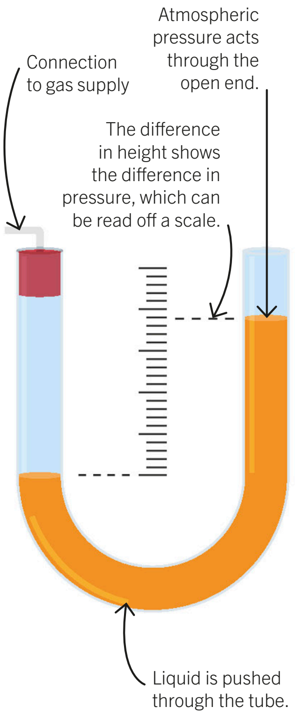
- ✓ Barometers measure atmospheric pressure.
- ✓ Manometers measure the difference in pressure between two gases.

Barometers

There are several different types of barometer. A Goethe barometer (below) consists of a glass container that is half-filled with water and has a long, open-ended spout. When atmospheric pressure rises, the water level in the spout drops. Changes in atmospheric pressure can be used to predict the weather because high pressure usually brings fine weather, whereas low pressure brings changeable weather.

Manometers

The simplest type of manometer is a U-shaped tube partially filled with liquid. When the manometer is not connected to anything, atmospheric pressure acts on both surfaces and the levels are equal. Applying gas pressure to one end pushes liquid through the tube.



Pressure in gases

A gas is made up of particles that are in random motion, colliding with each other and with other objects. This creates pressure.

Trapped gas

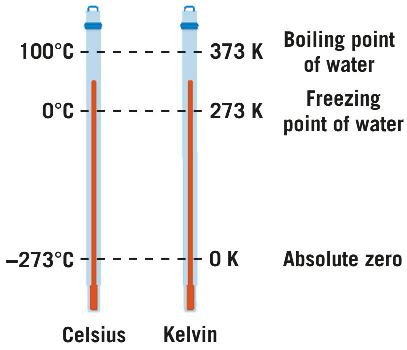
When a gas is trapped inside a container, the gas particles constantly collide with the walls of the container and exert tiny forces, creating pressure. The more gas particles there are in the container, the greater the number of collisions and the greater the pressure. This is why the pressure in a bicycle tire rises when more air is pumped into it. If the temperature of a gas rises, the speed of the particles increases. This causes pressure to rise because the particles hit the walls of the container harder and more often.

Key facts

- ✓ A gas trapped in a container exerts pressure because the gas particles collide with the container walls.
- ✓ As the temperature of a gas rises, the speed of particles increases and so does the pressure.
- ✓ The theoretical temperature at which all the particles in a gas are still is called absolute zero.
- ✓ The Kelvin (K) scale for measuring temperature begins at absolute zero.

Absolute zero

The temperature of a substance is a measure of the average kinetic energy of its particles. The faster the particles are moving, the more kinetic energy they have and the higher the temperature. The lowest temperature that is theoretically possible is the point at which every particle is completely still. This is known as absolute zero and is –273°C on the Celsius temperature scale. Absolute zero is also the starting point for the Kelvin temperature scale. An increment of 1 kelvin is the same as 1 degree Celsius.



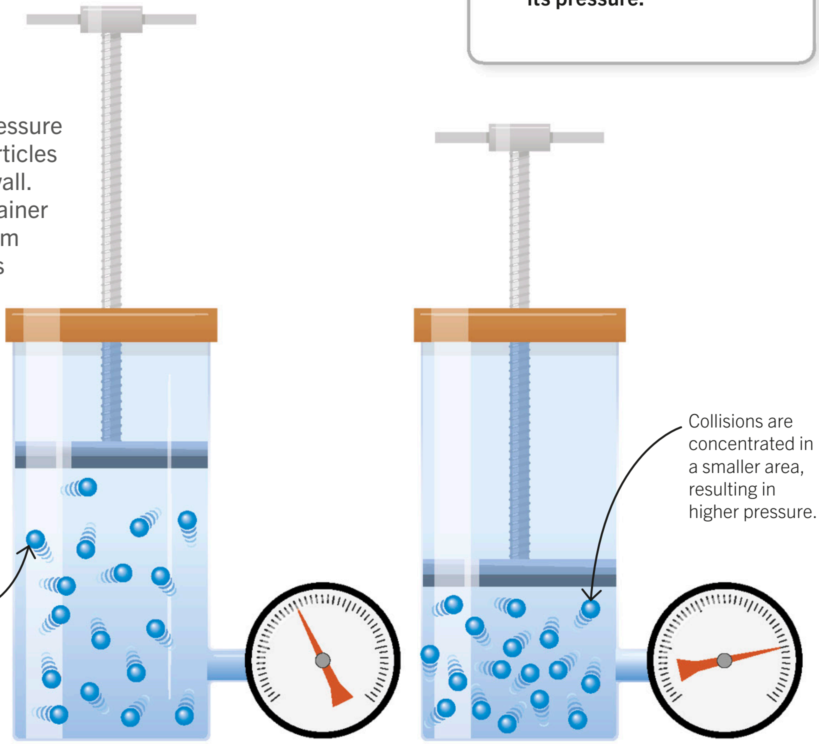
Pressure and volume

The pressure exerted by a gas on its container depends on the container's volume. If the temperature doesn't change, squeezing a gas into a smaller volume increases the pressure. Allowing a gas to spread out in a larger volume reduces the pressure.

Key facts

- ✓ Increasing the volume of a gas at constant temperature reduces its pressure.
- ✓ Reducing the volume of a gas at constant temperature increases its pressure.

Changing volume
Gases exert pressure on their containers because the gas particles constantly collide with the container walls. The pressure is the total force from all the particles per square meter of container wall. Increasing the volume of a container gives the gas particles more room and so results in fewer collisions per square meter and therefore lower pressure. Reducing the volume has the opposite effect and pressure increases.



Calculating change in pressure

When either pressure or volume increases, the other quantity decreases. We say the two quantities are inversely proportional. This means that when you multiply them together, the product remains the same:

Pressure before — Pressure after

$$\boxed{P_1 \times V_1 = P_2 \times V_2}$$

Question
A container holds 0.25 m^3 of air at a pressure of 100000 Pa. A piston is pressed down, reducing the volume of the trapped air to 0.1 m^3. If the temperature remains the same, what is the new pressure?

Answer
Rearrange the equation to make the new pressure (P_2) the subject:

$$P_2 = \frac{P_1 \times V_1}{V_2}$$

$$= \frac{100000 \text{ Pa} \times 0.25 \text{ m}^3}{0.1 \text{ m}^3}$$

$$= 250000 \text{ Pa} = 250 \text{ kPa}$$

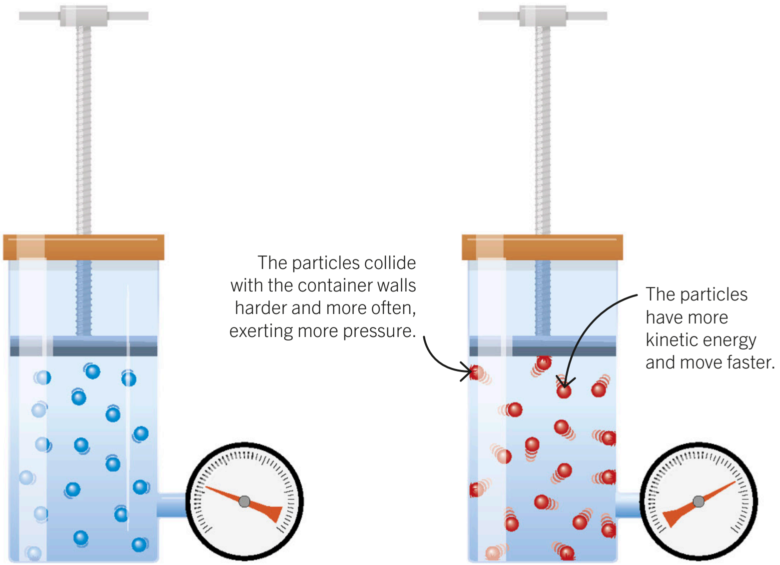
Pressure and temperature

Temperature is an indication of the average speed at which particles are moving. When the temperature of a gas rises, its particles move faster, causing the pressure to rise. The higher or lower the temperature, the higher or lower the pressure.

Key facts

- ✓ Changing the temperature of a gas at constant volume changes its pressure.
- ✓ Heating a gas increases its pressure and cooling it reduces its pressure.

Heating a gas
When a gas is heated, its particles gain kinetic energy and move faster. If the gas is trapped in a container and the volume does not change, the particles collide with each other and the container walls harder and more often. This results in increased force on the interior of the container and therefore greater pressure.



Low temperature **High temperature**

Calculating change in pressure

The equation below shows how the temperature and pressure of a gas with a fixed volume are related. If temperature doubles, pressure doubles. (Pressure increases in direct proportion with temperature.) This equation only works when using the Kelvin scale for temperature.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Pressure before
Pressure after
Temperature in kelvin

Question
A sealed jar is filled with air. On a hot day, the temperature of the air increases from 20°C to 32°C. If the air starts at 100 000 Pa, what pressure does it reach?

Answer
First, convert the temperatures to kelvin by adding 273:
20 + 273 = 293 K
32 + 273 = 305 K

Then rearrange the equation to make P_2 the subject:

$$P_2 = \frac{P_1 \times T_2}{T_1}$$

$$= \frac{100\,000 \text{ Pa} \times 305 \text{ K}}{293 \text{ K}}$$

$$= 104\,096 \text{ Pa} = 104 \text{ kPa}$$

Work and temperature

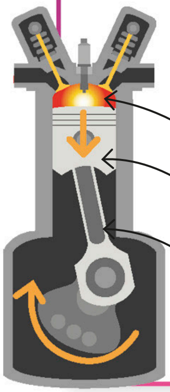
When energy is transferred by a force, we say the force is doing work. Pumping up a bicycle tire does work on the trapped gas, increasing its store of energy and so making the temperature rise.

Key facts

- ✓ Doing work on a gas transfers energy to its internal energy store.
- ✓ Doing work on a gas raises its temperature.

When a gas does work

While work can be done on a gas, a gas can also do work on other objects. In an internal combustion engine (the type of engine found in a gasoline car), the expansion of hot gases in an enclosed chamber results in an increase in pressure. This pushes a piston, which transfers force to a rotating shaft (a crankshaft).



Pump action

In physics, we use the word “work” to refer to the energy transferred when a force acts on an object (see page 55). The energy transferred is described as work done. When you inflate a bicycle tire, the pump exerts a force on the air and transfers kinetic energy to the air particles. The air particles move faster, so the temperature of the air in the tire rises.

Atoms and radioactivity

Atomic structure

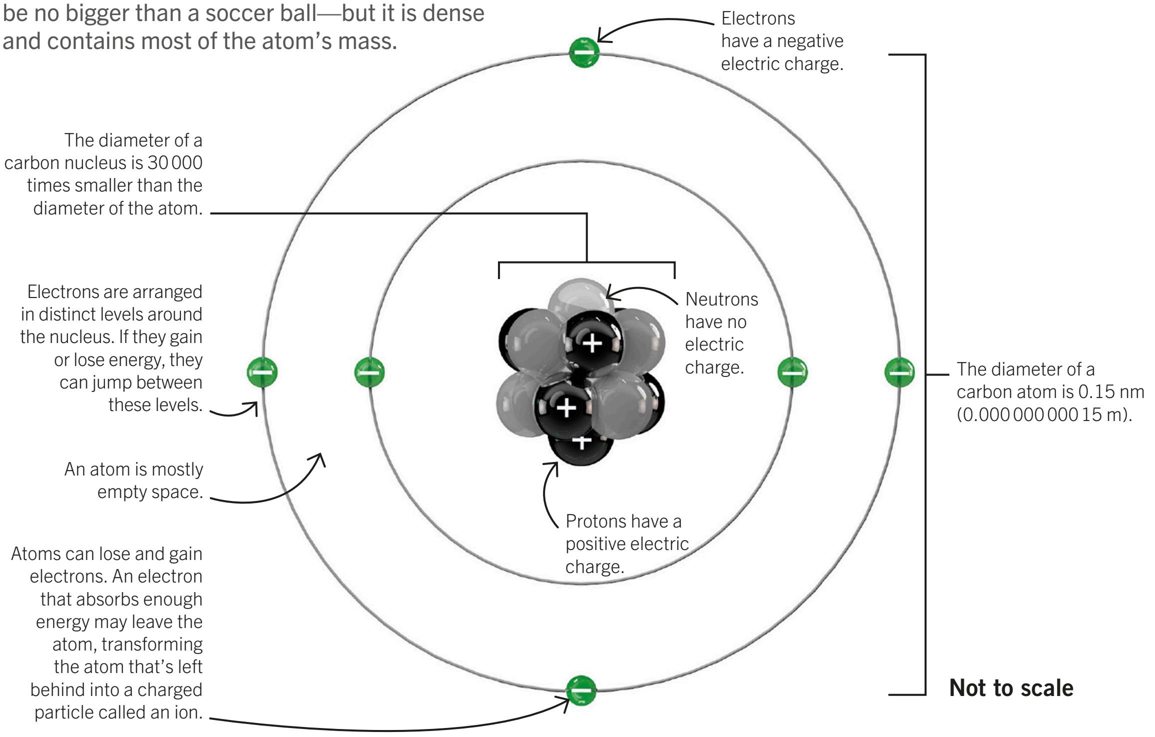
Scientists used to think that atoms were the smallest building blocks of matter. However, atoms can be divided further into three smaller particles: protons, neutrons, and electrons. Protons and neutrons form the nucleus at the center of the atom. Outside this are even tinier particles called electrons.

Key facts

- ✓ Atoms are made up of three types of particle: protons, neutrons, and electrons.
- ✓ Protons and neutrons are bound together to form atomic nuclei.
- ✓ Electrons are outside atomic nuclei at distinct energy levels.
- ✓ Protons have a positive charge, electrons have a negative charge, and neutrons have no electrical charge.

Inside an atom

An atom has a nucleus in the middle containing a cluster of protons and neutrons. The nucleus is small compared to the atom—if an atom was the size of a sports stadium, the nucleus would be no bigger than a soccer ball—but it is dense and contains most of the atom's mass.



Particle properties

The protons and neutrons account for nearly all the mass of an atom and have the same mass as each other. Protons and electrons have opposite charges and so attract each other.

	Charge	Mass	Location
Proton	+1	1	Inside nucleus
Neutron	0	1	Inside nucleus
Electron	–1	0.0005	Outside nucleus

Elements and isotopes

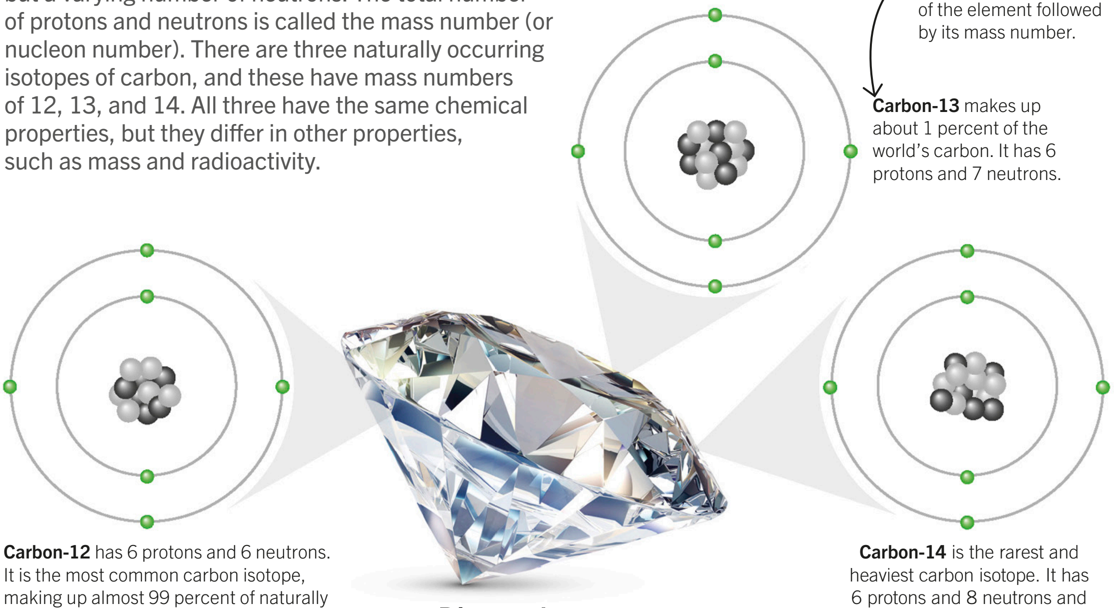
Pure substances made of only one kind of atom, such as gold or oxygen, are called elements. The atoms of an element always have the same number of protons in the nucleus (the atomic number or proton number). However, the number of neutrons can vary. Atoms of the same element with different numbers of neutrons are called isotopes.

Key facts

- ✓ Pure substances made of only one kind of atom are called elements.
- ✓ The number of protons in an atom is its atomic number (proton number).
- ✓ The total number of protons and neutrons in an atom is its mass number (nucleon number).
- ✓ Isotopes are forms of an element with different mass numbers.

Carbon isotopes

Carbon is an element with six protons in its atomic nucleus but a varying number of neutrons. The total number of protons and neutrons is called the mass number (or nucleon number). There are three naturally occurring isotopes of carbon, and these have mass numbers of 12, 13, and 14. All three have the same chemical properties, but they differ in other properties, such as mass and radioactivity.



Isotope names are written using the name or symbol of the element followed by its mass number.

Carbon-13 makes up about 1 percent of the world's carbon. It has 6 protons and 7 neutrons.

Carbon-12 has 6 protons and 6 neutrons. It is the most common carbon isotope, making up almost 99 percent of naturally occurring carbon.

Diamond (a form of carbon)

Carbon-14 is the rarest and heaviest carbon isotope. It has 6 protons and 8 neutrons and is radioactive.

Isotope symbols

Instead of writing out the name of an isotope in full, we can write it as a symbol. For example, carbon-14 is represented by the symbol $^{14}_{6}C$. This shows that it contains 6 protons and a total of 14 protons and neutrons. You can work out the number of neutrons by subtracting the atomic number from the mass number (14 – 6 = 8 neutrons).

Total number of protons and neutrons (mass number)

Element symbol

$$^{14}_{6}\mathrm{C}$$

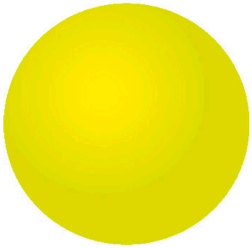
Number of protons (atomic number)

The atomic model

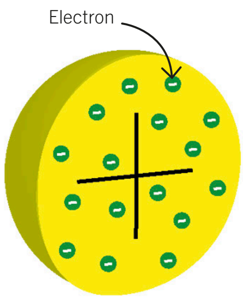
Over the last two centuries, the models we use to represent atoms have evolved as scientists have discovered more about how atoms work.

Key facts

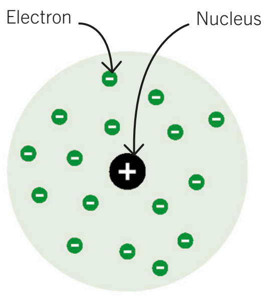
- ✓ The scientific model of the atom has changed over time.
- ✓ The gold foil experiment showed that the mass of an atom is concentrated in the nucleus.



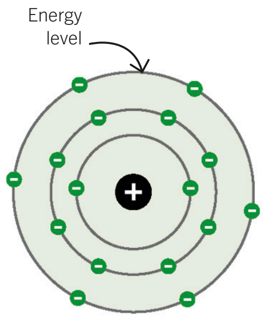
1. Dalton's "billiard ball"
The first model of the atom was devised by English chemist John Dalton. He suggested atoms were solid spheres that could not be divided.



2. Thomson's "plum pudding"
British physicist J. J. Thomson discovered electrons in 1904. He proposed the plum pudding model, in which negatively charged electrons are embedded in a positively charged sphere.



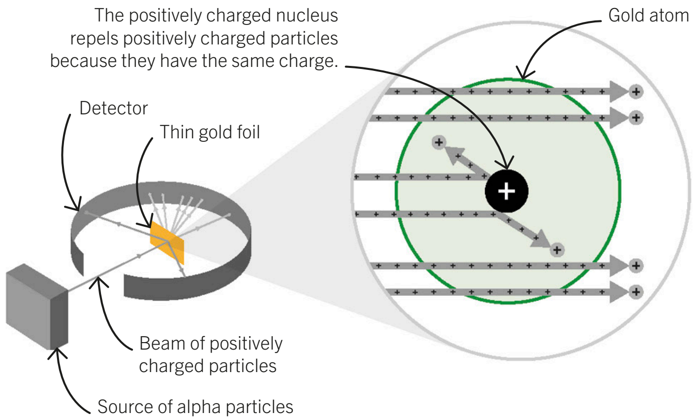
3. Rutherford model
British physicist Ernest Rutherford proposed an atomic model with a positive nucleus in the center of a scattered cloud of electrons. He later discovered protons—the positively charged particles in the nucleus.



4. Bohr model
Danish physicist Niels Bohr proposed the modern atomic model, with electrons arranged in energy levels at certain distances from the nucleus. This helped explain why atoms absorb or emit only certain wavelengths of light.

Discovery of the nucleus

In the early 1900s, physicists carried out an experiment to test the plum pudding model. They fired positively charged particles (alpha particles) at a thin piece of gold foil and discovered that while most of the particles flew straight through, a few were scattered in random directions, repelled by a positive charge. The results suggested that atoms have only a very small zone of positive charge and that most of the alpha particles had missed it. The scientists concluded that atoms are largely empty space, with most of their mass concentrated in small, positively charged nuclei.



Radioactive decay

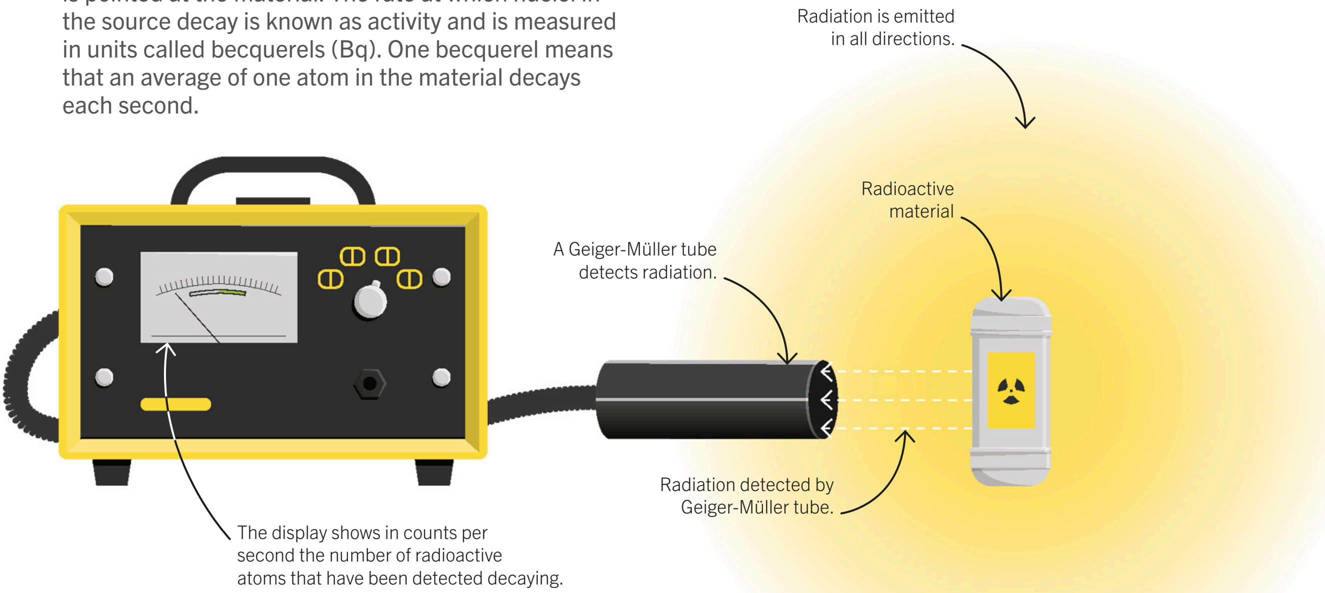
Some atoms are unstable, which means they can break down and release high-energy particles or waves known as radiation. We call such atoms radioactive. The release of radiation by radioactive atoms is known as radioactive decay and can make an unstable atomic nucleus more stable. Radioactive decay is a random process: it is impossible to predict when a particular atom will decay.

Key facts

- ✓ Unstable atomic nuclei decay and emit radiation.
- ✓ Radioactive decay is random.
- ✓ Radioactive decay can cause an atomic nucleus to change into a different element.
- ✓ Radiation can be detected by a device called a Geiger-Müller tube.

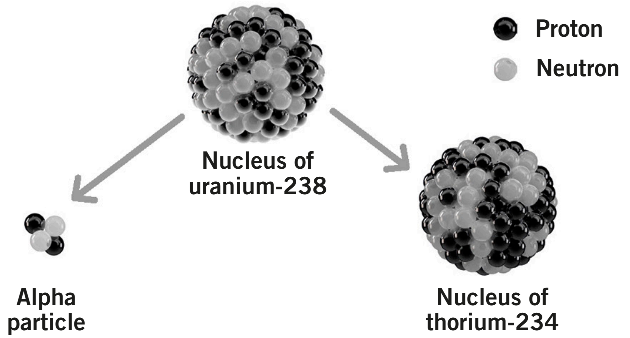
Detecting radiation

Radiation from a radioactive material can be detected using a device called a Geiger-Müller (GM) tube, which is pointed at the material. The rate at which nuclei in the source decay is known as activity and is measured in units called becquerels (Bq). One becquerel means that an average of one atom in the material decays each second.



Forming new elements

In some types of radioactive decay, the unstable atom changes from one element to another. For example, when uranium-238 decays, it emits something called an alpha particle, which consists of two protons and two neutrons. Because the remaining nucleus has two fewer protons, it is now the element thorium.



Different types of radiation

When radioactive atoms decay, they emit radiation. There are five kinds of radiation emitted by radioactive nuclei: alpha particles, beta particles, positrons, neutrons, and gamma radiation. All are known as ionizing radiation because they can knock electrons out of atoms, turning atoms into charged particles (ions).

Key facts

- ✓ There are five types of ionizing radiation emitted by radioactive nuclei: alpha particles, beta particles, positrons, neutrons, and gamma radiation.
- ✓ Most types of radiation emitted by radioactive nuclei are particles. However, gamma radiation is a form of electromagnetic radiation.

Alpha (α) radiation

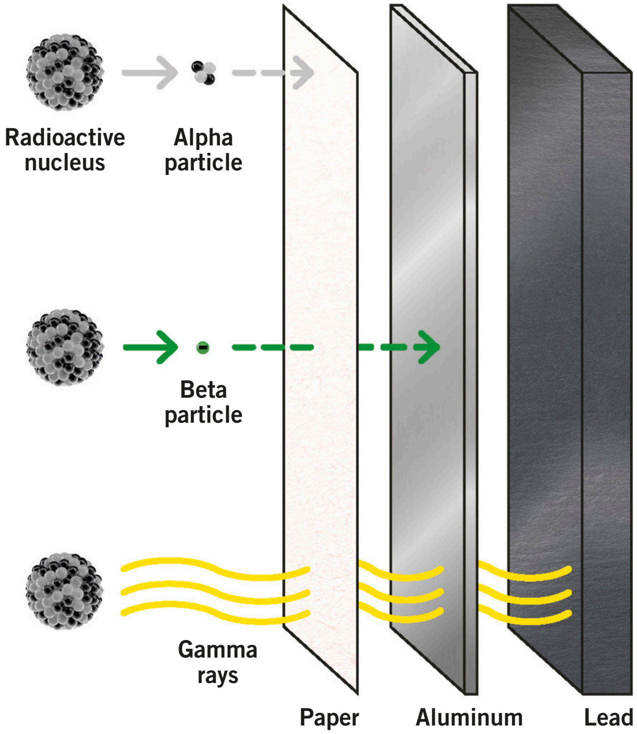
Alpha radiation is made of particles—one alpha particle consists of two neutrons and two protons (a helium nucleus). It is highly ionizing but cannot penetrate far through materials. Even a sheet of paper, a few centimeters of air, or human skin can block it.

Beta (β) radiation

Beta radiation is made up of fast-moving electrons emitted from unstable atomic nuclei when neutrons change into protons. It is not as ionizing as alpha radiation but has greater penetrating power. It can travel a short distance through air and pass though paper but is blocked by a thin sheet of aluminum.

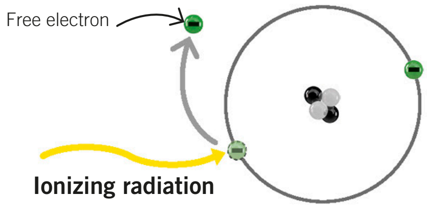
Gamma (γ) radiation

Like light or radio waves, gamma rays are a form of electromagnetic radiation. They are only weakly ionizing but penetrate materials much more powerfully than alpha or beta radiation. Several centimeters of lead or several meters of concrete or water are required to block gamma radiation.



Ionizing radiation

All forms of ionizing radiation can knock electrons out of atoms. Because electrons have a negative charge, when an atom loses one, it is left with a net positive charge and so becomes an ion (a charged atom). Ionizing radiation can be dangerous, as it can damage living tissue.



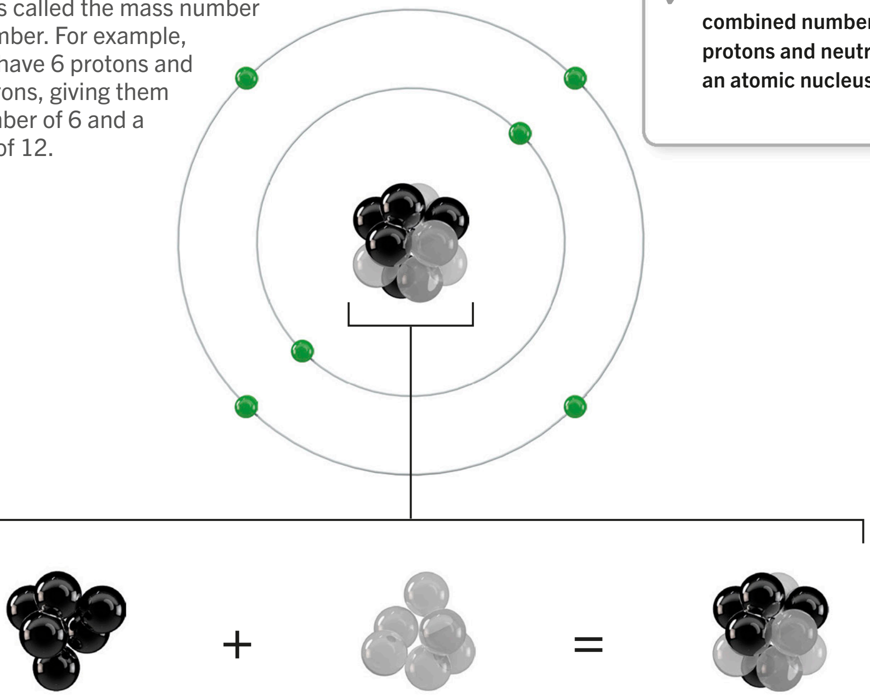
Nuclear equations

When radioactive decay takes place, the number of protons and neutrons in an atom may change, which causes the atom to transform into a new element. We can describe these changes by writing a nuclear equation.

Key facts

- ✓ Nuclear equations show the changes that take place during radioactive decay of an atom.
- ✓ A nuclear equation must be balanced.
- ✓ Atomic number is the number of protons in an atom's nucleus.
- ✓ Mass number is the combined number of protons and neutrons in an atomic nucleus.

Atomic number and mass number
The atomic number (proton number) of an atom is the number of protons in its nucleus. The total number of protons and neutrons is called the mass number or nucleon number. For example, carbon atoms have 6 protons and usually 6 neutrons, giving them an atomic number of 6 and a mass number of 12.



Atomic number (number of protons)	+	Number of neutrons	=	Mass number (protons + neutrons)
6		6		12

Symbols in nuclear equations

In nuclear equations, we write atomic number and mass number as small numbers next to the element's symbol.

Mass number

$^{12}_{6}\mathrm{C}$

Atomic number

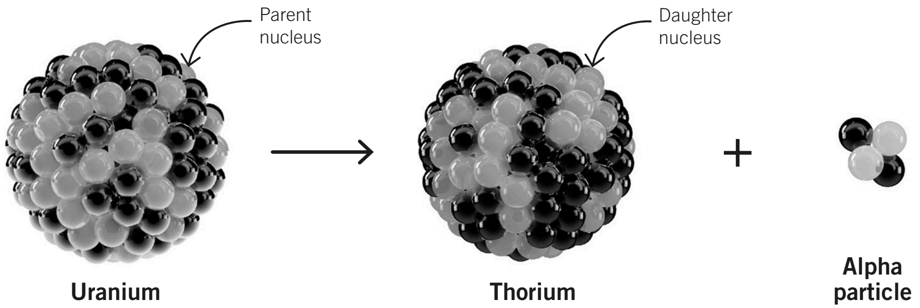
Alpha decay
An alpha particle consists of two protons and two neutrons. When an atom such as uranium emits an alpha particle, the atom's atomic number falls by 2 and its mass number falls by 4. The change in the number of protons causes the atom to become a different element (uranium, for instance, turns into thorium). The nuclear equation showing this change must be balanced—the mass numbers on both sides must add to the same value, and so must the atomic numbers.

The mass numbers on both sides of the equation must balance (238 = 234 + 4).

$$^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

The atomic numbers on both sides must balance (92 = 90 + 2).

The alpha particle is shown as a helium nucleus.



Beta decay
During beta decay, a neutron in the nucleus of an atom turns into a proton and emits a high-speed electron called a beta particle. The atomic number increases by 1, but the mass number remains the same. (Although the nucleus loses a neutron, it gains a proton.) As with alpha decay, nuclear equations showing beta decay must balance.

A beta particle is written with –1 because it has a negative charge—the opposite of the positive charge carried by protons.

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e}$$

Six protons

Seven protons

Half-life

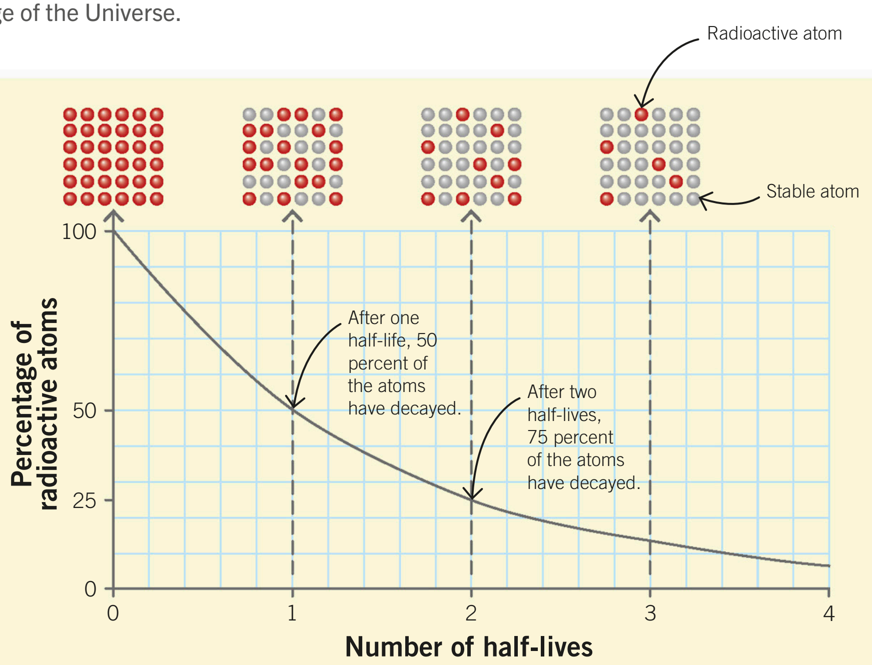
Radioactive decay is random—it is impossible to predict when a particular atomic nucleus will decay. However, because there are so many atoms in a sample of a radioactive isotope, it is possible to predict what fraction of atoms will decay in a certain time. The time taken for half the atoms in a sample to decay is the half-life of that isotope.

Key facts

- ✓ **Half-life is the time taken for half the unstable atoms in a sample of radioactive material to decay.**
- ✓ **Different isotopes have different half-lives.**

Decay curve

After one half-life, the number of radioactive atoms is half the initial number. This falls to a quarter after two half-lives, an eighth after three half-lives, and so on, until there are barely any radioactive atoms left. The process can be shown on a graph called a decay curve. The half-lives of different isotopes vary from fractions of a nanosecond to trillions of times greater than the age of the Universe.



Calculating radioactive decay

Question
The radioactive isotope iodine-131 has a half-life of 8 days. If you leave a 20 g sample for 24 days, how much iodine-131 remains?

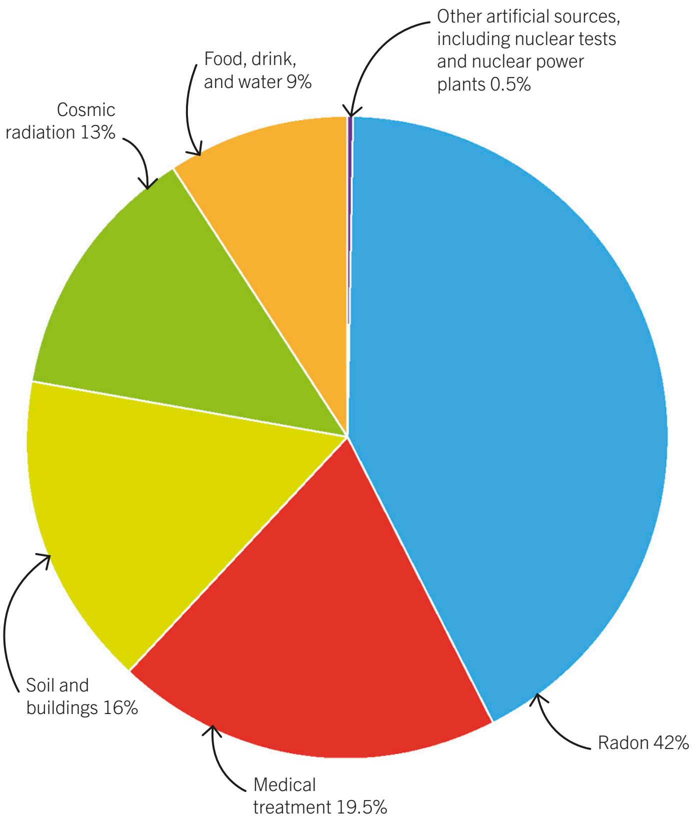
Answer
Start: 20 g
After 8 days (1 half-life): 10 g
After 16 days (2 half-lives): 5 g
After 24 days (3 half-lives): 2.5 g

Background radiation

Anywhere you go, you will find background radiation. This is the radiation emitted by natural sources such as the ground, rocks, and space, as well as by artificial sources such as medical treatment machines. Background radiation is usually harmless.

Sources of background radiation

The largest source of background radiation is the gas radon, which is found in the ground. Radon can be harmful if it seeps into buildings and becomes trapped. Earth is also constantly bombarded with cosmic radiation from the Sun and stars. About 20 percent of background radiation comes from artificial sources such as medical treatment machines, nuclear weapons testing, coal-fired power stations, and nuclear accidents.



Estimates of worldwide sources of background radiation

Key facts

- ✓ Background radiation is the radiation present in the environment.
- ✓ Background radiation comes from a variety of natural and artificial sources.
- ✓ The presence of background radiation must be accounted for when measuring the activity of radioactive material.

Background radiation levels

Background radiation levels vary from place to place. Because of this, people with certain jobs and lifestyles receive higher doses. For example, pilots and astronauts are exposed to higher levels of cosmic radiation from space because they are less shielded by Earth's atmosphere than people on the ground. To monitor background radiation in the environment, scientists use a Geiger-Müller tube. When measuring the activity of a radioactive material, the background reading is subtracted to find the true radioactivity of the material.

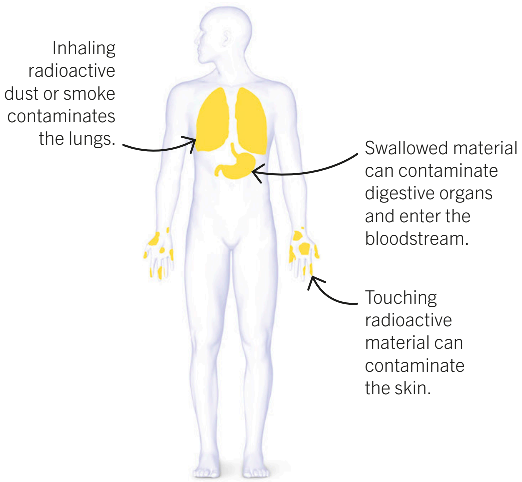
Using a Geiger-Müller tube

Radioactive hazards

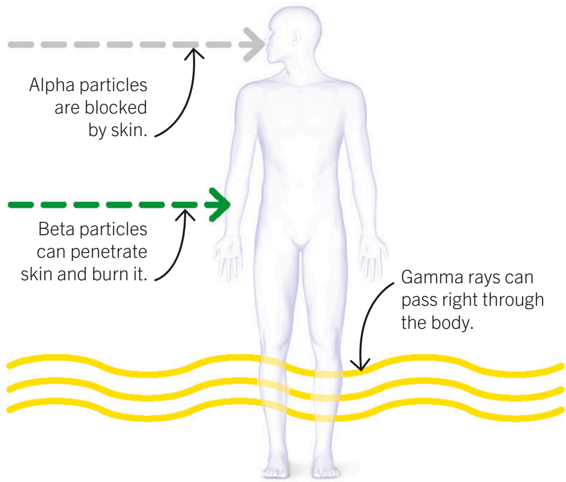
Ionizing radiation can be harmful. Radioactive materials, such as those used in hospitals or nuclear power stations, must be handled, used, and stored carefully to prevent harm by irradiation or contamination.

Key facts

- ✓ **Ionizing radiation can be harmful because it can kill cells and cause cancer.**
- ✓ **Contamination occurs when a radioactive material enters or gets onto a person's body.**
- ✓ **Irradiation is exposure to a radioactive material outside the body.**



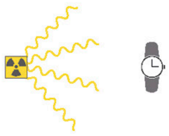
Contamination
Radioactive contamination occurs when radioactive material enters a person's body or gets on their skin or hair. Once inside the body, it is very difficult to remove and continues to release ionizing radiation, which can kill cells or cause mutations in DNA that lead to cancer.



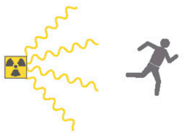
Irradiation
Irradiation happens when a person is exposed to radioactive material outside the body. As with contamination, this can kill cells or cause cancer. It does not cause objects to become radioactive themselves, and it can be blocked with protective shielding. Irradiation stops as soon as the radioactive source is removed.

Staying safe

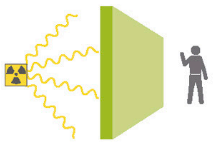
There are three main ways to stay safe when working with a radioactive material. The precautions taken depend on the material's half-life and on the type of radiation it emits. Sources with a short half-life are the most dangerous, as they can release huge amounts of radiation in a short time.



Limiting time spent near a radioactive material reduces the dose of radiation received.



Increasing distance from the radioactive source reduces the dose of radiation received.



Shielding to block radiation varies from gloves and face masks for alpha radiation to lead screens for gamma rays.

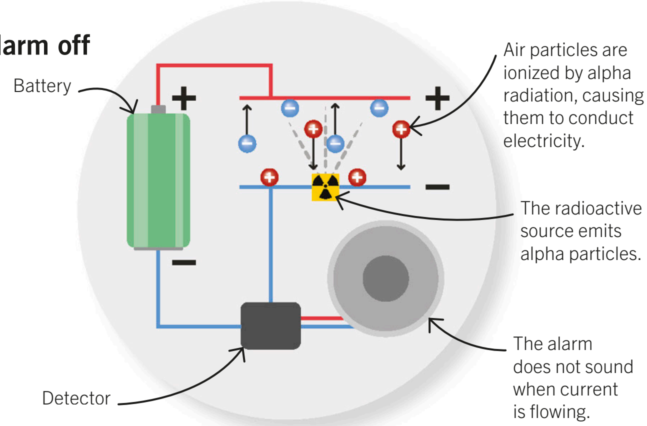
Using radioactive isotopes

Ionizing radiation is used for all sorts of purposes at home and in industry, including in food safety and manufacturing. The properties of different radioisotopes (such as their penetrating power) make them appropriate for different applications.

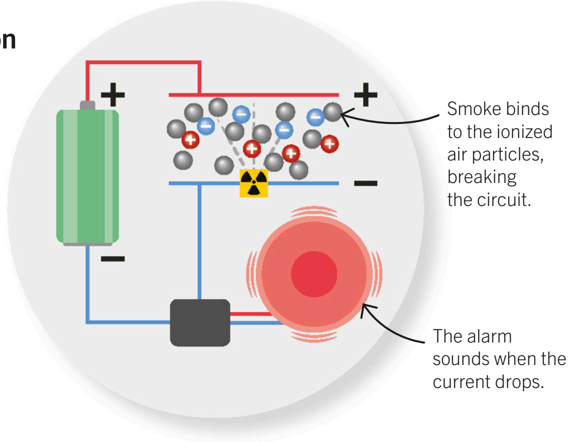
Smoke alarms

Smoke detectors contain americium-241, a radioactive isotope with a half-life of 460 years. It emits alpha radiation that ionizes air particles, making them electrically charged. This completes a circuit inside the alarm, allowing current to flow. If smoke enters the alarm, smoke particles attach to the ions and reduce the current, causing the alarm to sound.

Alarm off



Alarm on



Key facts

- ✓ Ionizing radiation can be used for domestic and industrial purposes.
- ✓ Sources of alpha radiation are used in some smoke detectors.
- ✓ Beta radiation is used in paper mills to monitor the thickness of paper.
- ✓ Gamma radiation is used to irradiate food and medical equipment.

Other uses

Measuring paper thickness
Beta radiation is used to measure the thickness of paper in paper mills. The thicker the paper, the less radiation passes through it to a detector, which then sends signals to a machine that adjusts the paper's thickness.

Irradiating food
Food can be preserved by exposing it to a source of gamma radiation. The high-energy gamma rays kill microorganisms in the food, preventing decay. Unlike heating, irradiating food does not affect its taste.

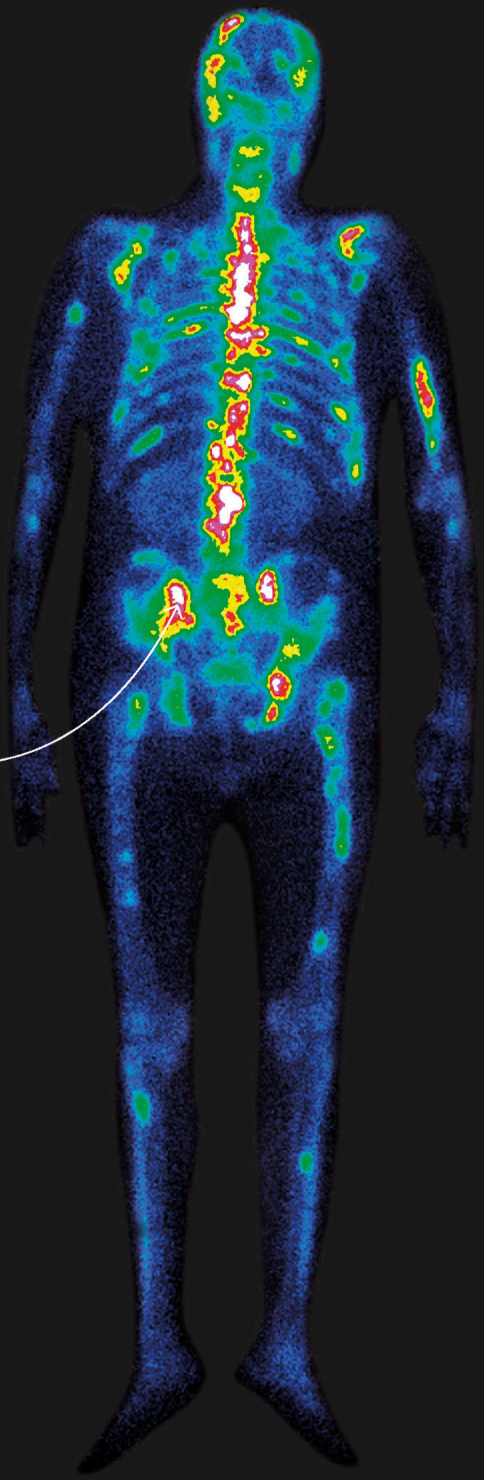
Sterilizing equipment
Gamma radiation is used in hospitals to sterilize surgical equipment, making it safe to use in operations.

Nuclear medicine

Hospitals use radioactive substances both to diagnose and treat disease. In radionuclide scanning and PET (positron emission tomography) scanning, a radioactive material is put inside the body to help create images called scans. In radiotherapy, radioactive materials are used to kill cancer cells.

Diagnosing disease

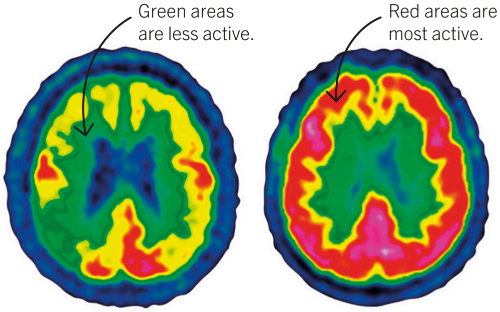
Radioactive isotopes that emit gamma rays are used to help diagnose diseases. A radioactive substance, called a tracer, is injected into a patient's body. The tracer accumulates in certain areas and decays, releasing gamma rays, which are detected by a gamma camera. The image here, for instance, shows the isotope technetium-99m concentrating in bones affected by cancer.



Bright areas show where the radioactive tracer has accumulated in tumors.

Key facts

- ✓ Doctors use radiation to diagnose and treat disease.
- ✓ PET (positron emission tomography) is an imaging technology that uses radioactive isotopes attached to other molecules to reveal active tissues in the body.
- ✓ In radiotherapy, ionizing radiation is used to kill cancer cells.
- ✓ Radiation can be applied internally or externally.



Brain with Alzheimer's disease

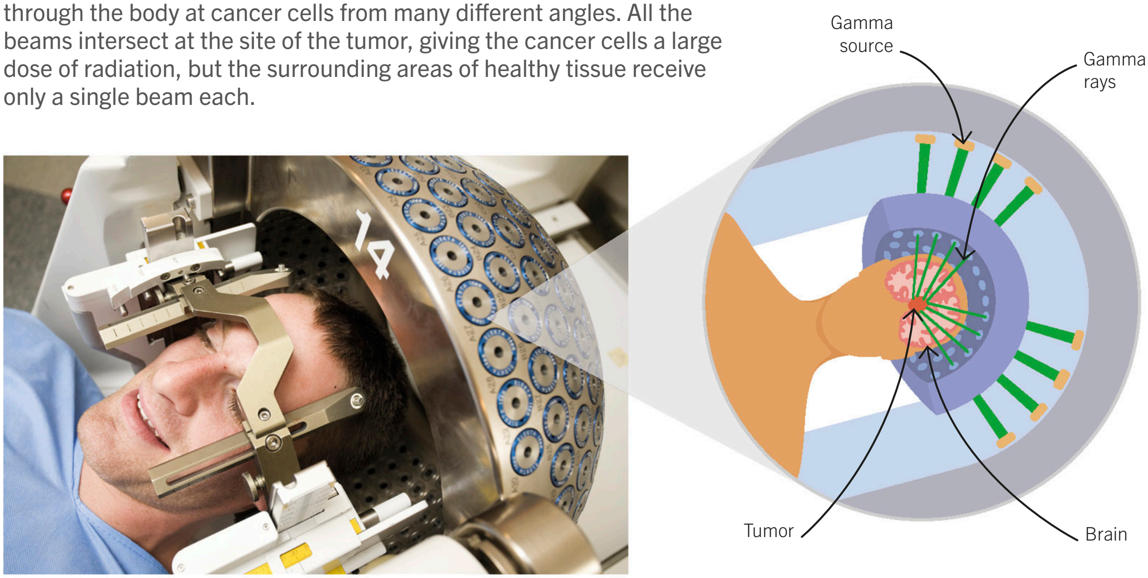
Healthy brain

PET scanning

In PET (positron emission tomography) scanning, doctors use radioactive isotopes attached to other molecules to highlight parts of the body that are active. For instance, the isotope fluorine-18 can be attached to sugar molecules to highlight tissues that are actively using blood sugar. This makes it possible to identify active tumors or organs that are less active than normal, such as a brain affected by Alzheimer's disease.

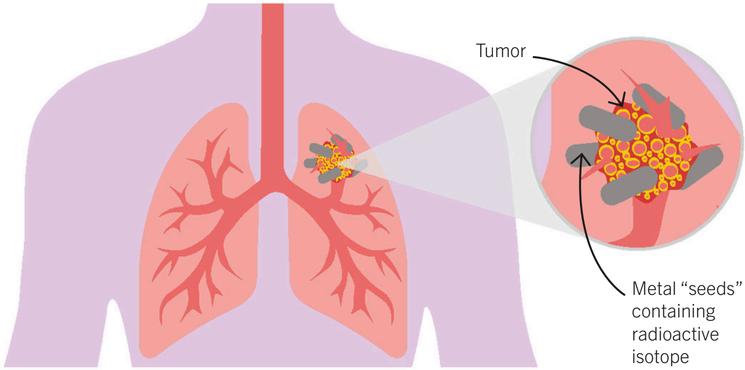
External beam radiotherapy

In external beam radiotherapy, narrow beams of radiation are directed through the body at cancer cells from many different angles. All the beams intersect at the site of the tumor, giving the cancer cells a large dose of radiation, but the surrounding areas of healthy tissue receive only a single beam each.



Internal radiotherapy

In internal radiotherapy, a radioactive source is implanted inside the body beside a tumor. This means that only the local area is affected, minimizing radiation exposure for the rest of the body. Radioisotopes that emit short-range radiation (alpha radiation) are ideal for this treatment.



Nuclear fission

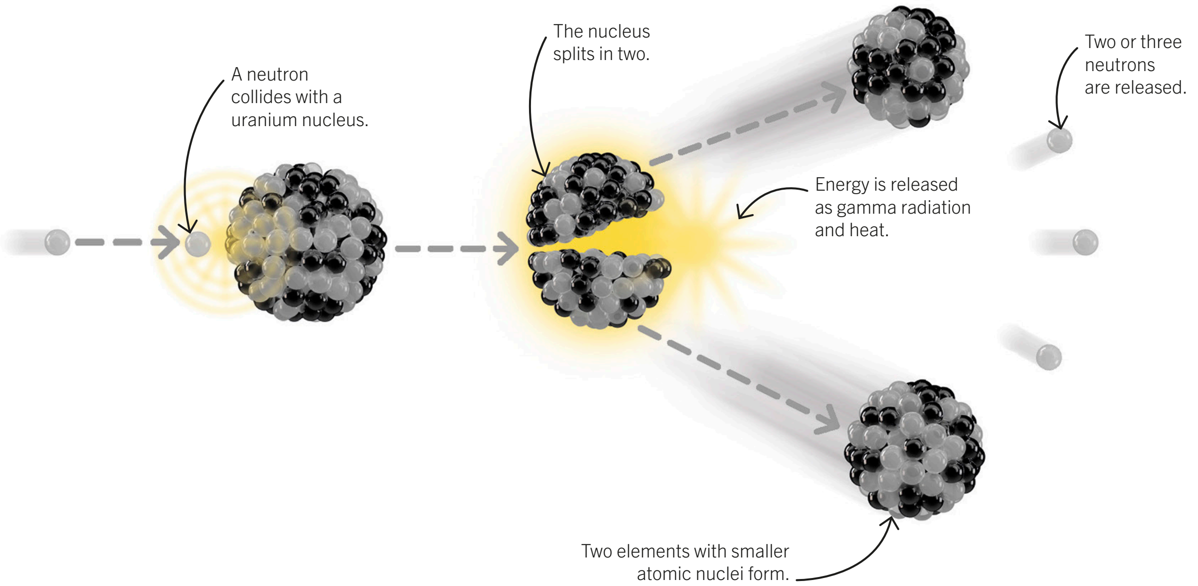
Nuclear fission happens when an atomic nucleus splits into smaller nuclei and releases a large amount of energy. This energy can be used to generate electricity in nuclear power stations or to power spacecraft or submarines.

Key facts

- ✓ Nuclear fission is the splitting of an unstable atomic nucleus into two or more smaller nuclei.
- ✓ Fission normally occurs after a heavy, unstable nucleus absorbs a neutron.
- ✓ Nuclear fission releases a large amount of energy in the form of gamma radiation and heat.
- ✓ In a chain reaction, neutrons released during fission cause further fission reactions.

Fission of uranium

Nuclear fission is usually caused by a neutron colliding with an unstable atomic nucleus. Uranium-235, a naturally occurring isotope of the element uranium, is used in nuclear power stations. It splits to form the nuclei of new elements and releases energy along with two or three neutrons.

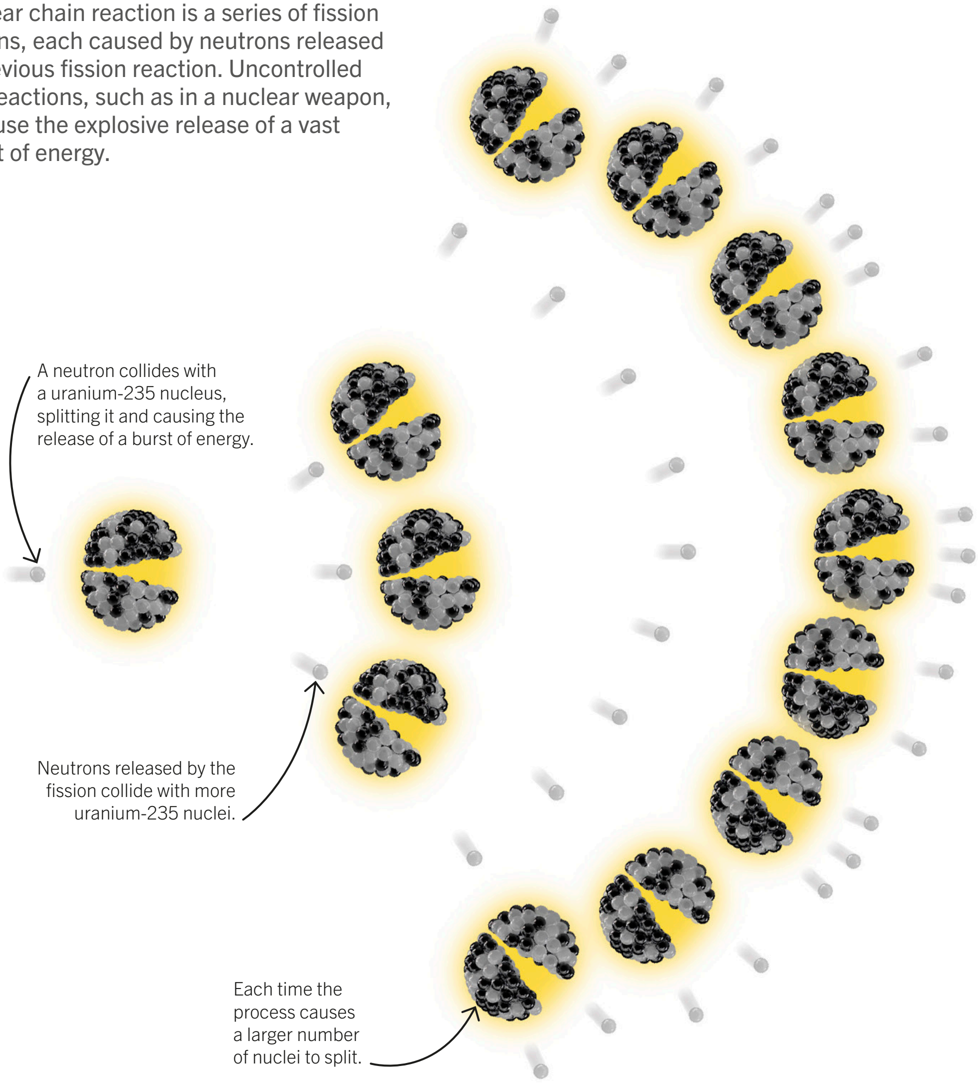


Energy from fission

A vast amount of energy is released by the fission of uranium—millions of times more energy than is released burning the same mass of coal. This energy comes from a tiny amount of the mass of the original atomic nucleus that is converted into energy.

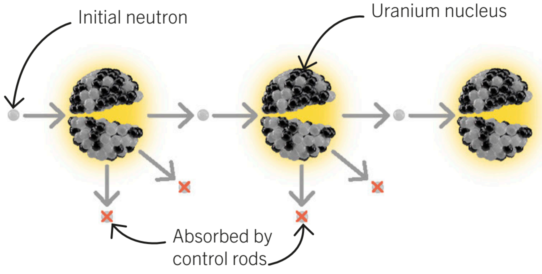
Chain reactions

A nuclear chain reaction is a series of fission reactions, each caused by neutrons released in a previous fission reaction. Uncontrolled chain reactions, such as in a nuclear weapon, can cause the explosive release of a vast amount of energy.



Controlled chain reactions

Nuclear chain reactions can build, fade, or remain stable depending on how many fission reactions are caused by the products of a previous fission. If each fission reaction leads on average to only one more, this results in a stable (controlled) chain reaction. Nuclear power stations control chain reactions by inserting control rods into the reactor core. These absorb neutrons, slowing the reaction down.



Nuclear power

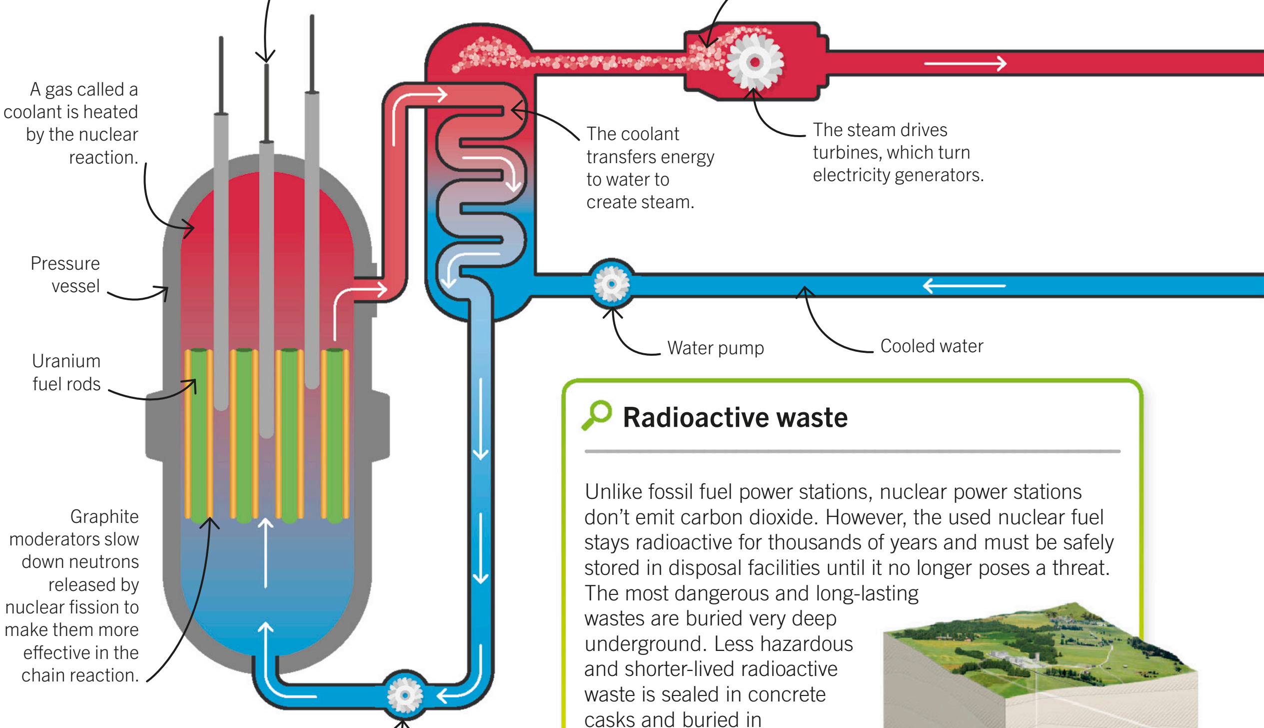
Nuclear power is the generation of electricity using nuclear fission as a source of energy. Nuclear power plants generate about 10 percent of the world's electrical power. Making use of nuclear energy means that we use less fossil fuel.

Key facts

- ✓ Nuclear power plants use the energy from nuclear fission to generate heat and electricity.
- ✓ Nuclear power does not generate carbon dioxide emissions.
- ✓ Nuclear power stations create hazardous radioactive waste that must be disposed of carefully.

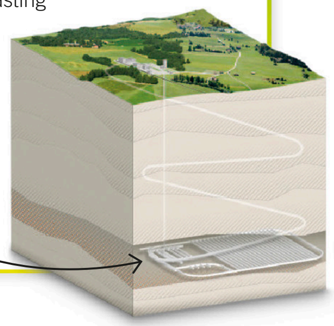
Nuclear reactor

A nuclear reactor contains radioactive uranium in fuel rods. Placing these close together triggers a chain reaction that releases large amounts of energy. The energy released boils water to make steam, which powers generators. The reaction is managed by moving control rods in and out of the reactor core. These absorb neutrons and slow the chain reaction down.



Radioactive waste

Unlike fossil fuel power stations, nuclear power stations don't emit carbon dioxide. However, the used nuclear fuel stays radioactive for thousands of years and must be safely stored in disposal facilities until it no longer poses a threat. The most dangerous and long-lasting wastes are buried very deep underground. Less hazardous and shorter-lived radioactive waste is sealed in concrete casks and buried in shallow pits.



The most hazardous waste is buried deep underground.

Fusion

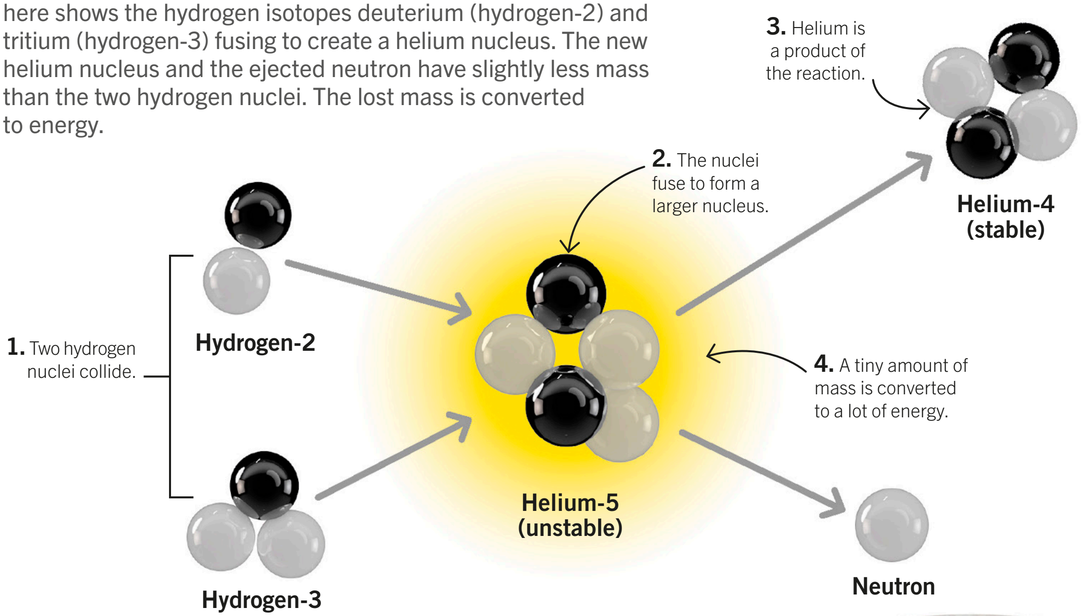
Nuclear fusion—in which two or more atomic nuclei fuse to form a heavier nucleus—is the process that powers the Sun. Scientists and engineers are working on ways of harnessing this source of energy to generate electricity.

Key facts

- ✓ Nuclear fusion occurs when atomic nuclei are forced together to form a heavier nucleus.
- ✓ During nuclear fusion, a small amount of mass is converted into energy.
- ✓ Extreme heat and pressure are required to initiate fusion.

Hydrogen fusion

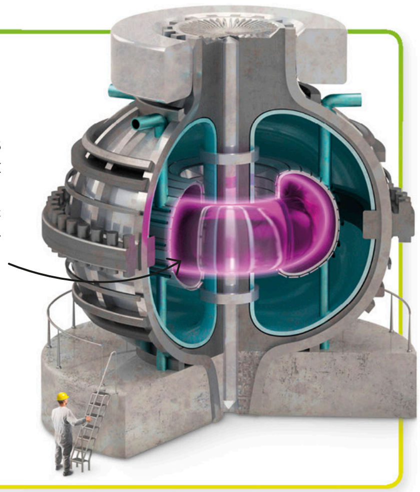
During nuclear fusion, the nuclei of two atoms are forced together by very high temperatures and pressures. The reaction here shows the hydrogen isotopes deuterium (hydrogen-2) and tritium (hydrogen-3) fusing to create a helium nucleus. The new helium nucleus and the ejected neutron have slightly less mass than the two hydrogen nuclei. The lost mass is converted to energy.



Harnessing fusion

The nuclei of atoms are positively charged and repel each other, so fusion can only take place if nuclei are pushed extremely close together, overcoming this repulsion. This is why fusion only occurs in extremely hot and high-pressure environments like the cores of stars. These requirements make it very difficult to build a fusion reactor on Earth to initiate and sustain fusion. Scientists working at experimental fusion reactors have briefly sustained fusion using powerful magnetic fields to confine the hot matter. However, it currently takes more energy to run the reactor than the reactor produces.

In the core of this fusion reactor, hot matter is confined by magnetic fields in a donut-shaped ring.



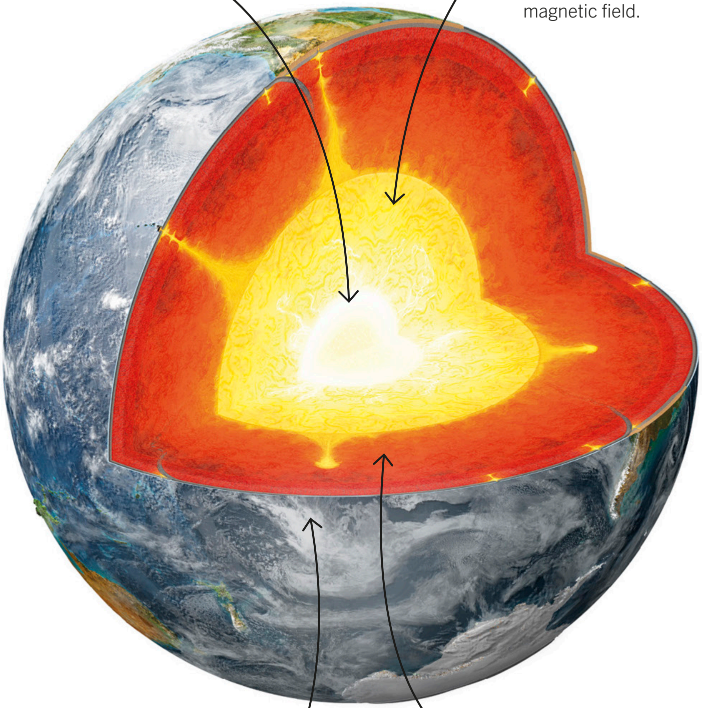
Space

Structure of Earth

Studies of seismic waves from earthquakes (see page 123) reveal that Earth's interior consists of distinct layers. Heavier elements, such as metals, are concentrated in the planet's center, while lighter materials, such as rock, form the outer layers.

Inside Earth

Earth's interior consists of four distinct layers: the inner core, outer core, mantle, and crust. The crust and the uppermost part of the mantle are joined to form a rigid structure called the lithosphere, which is divided into sections called tectonic plates. These move very slowly over time, changing the shapes of continents and oceans.

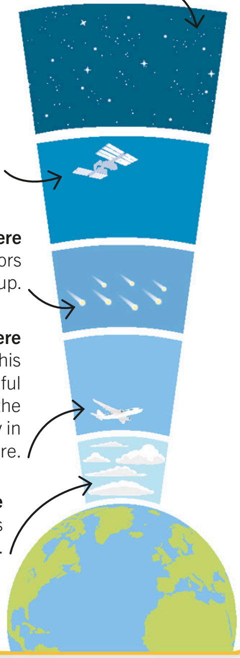


Key facts

- ✓ **Earth's interior has four distinct layers: the inner core, outer core, mantle, and crust.**
- ✓ **The crust and uppermost part of the mantle form a rigid structure that is divided into tectonic plates, which move slowly over time.**
- ✓ **The atmosphere is a layer of gases trapped by gravity.**

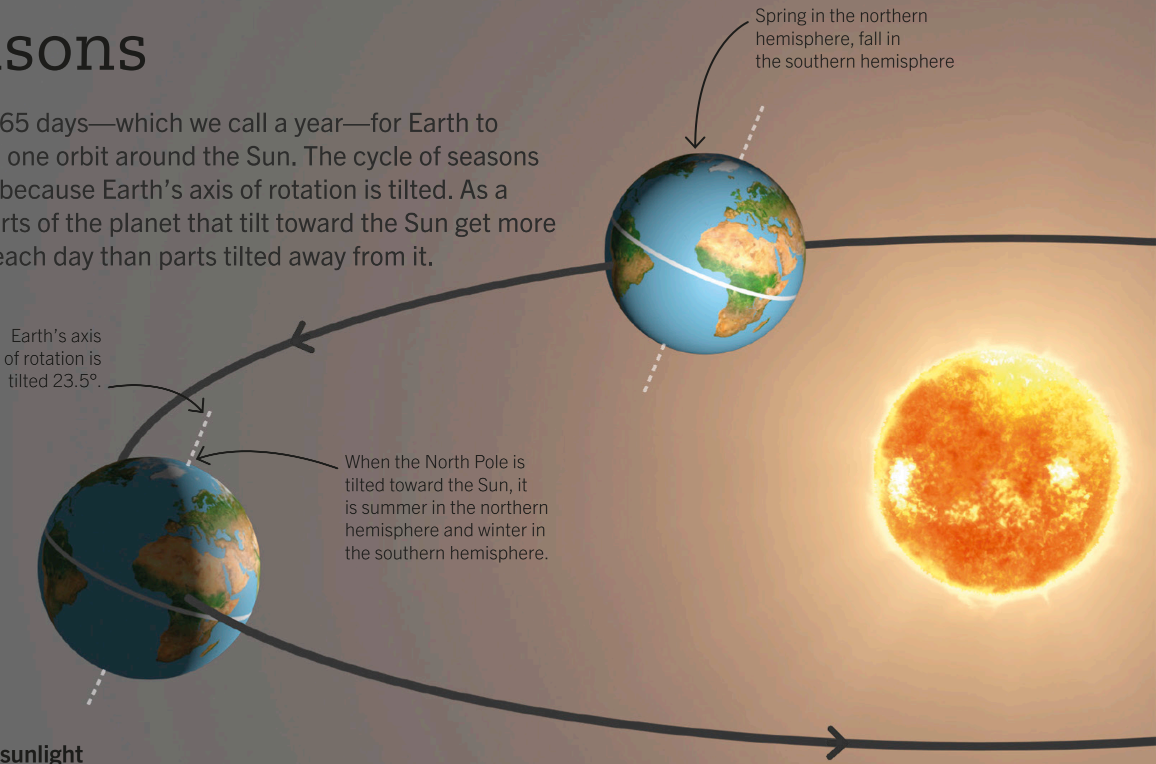
The atmosphere

Earth's atmosphere is a mixture of gases that are held in place by gravity. The atmosphere is divided into layers with distinct properties. It has no clear upper edge and fades gradually into space.



Seasons

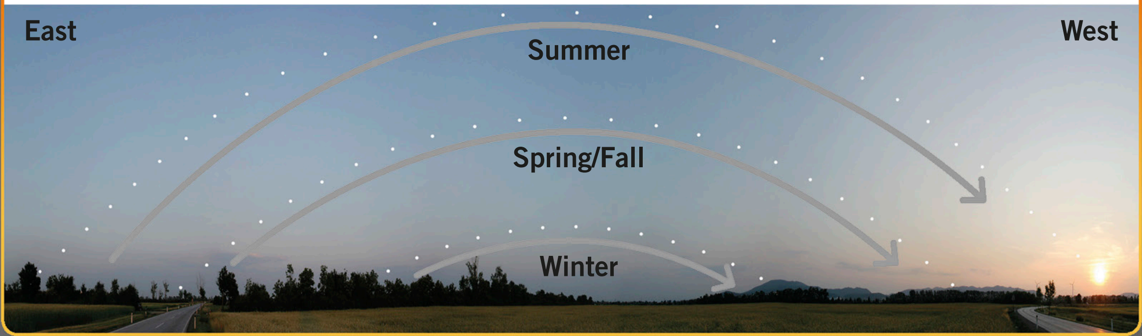
It takes 365 days—which we call a year—for Earth to complete one orbit around the Sun. The cycle of seasons happens because Earth's axis of rotation is tilted. As a result, parts of the planet that tilt toward the Sun get more sunlight each day than parts tilted away from it.

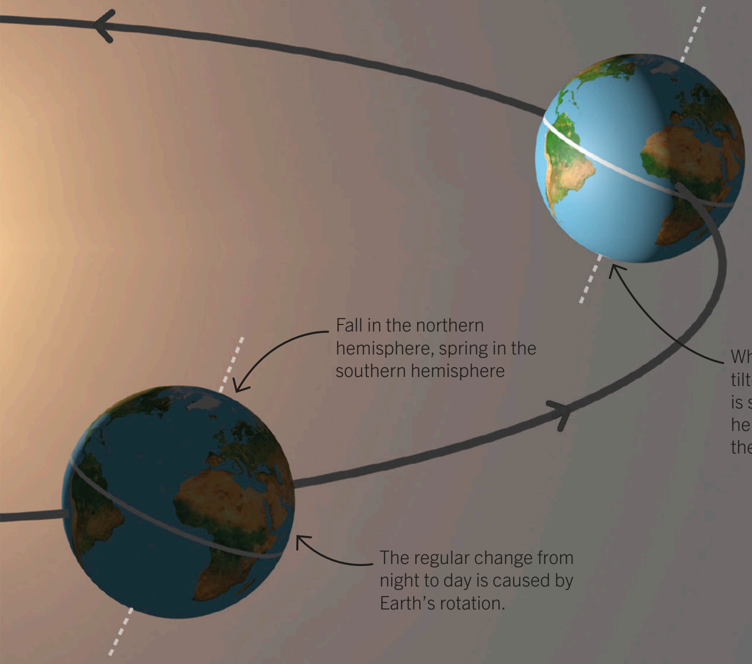


Changing sunlight
Earth's axis of rotation remains at the same angle all year round. The hemisphere that is tilted toward the Sun experiences longer days and stronger heating from the Sun, while the one that is tilted away has shorter days and is heated less.

The Sun's path

During summer, the Sun is visible for longer each day and reaches higher in the sky than in winter. This time-lapse photo from a northern-hemisphere location shows the Sun's path through the sky in midsummer (top) and midwinter (bottom). Between them is its path through the sky during the spring and fall equinoxes—the two times of year when day and night are the same length.



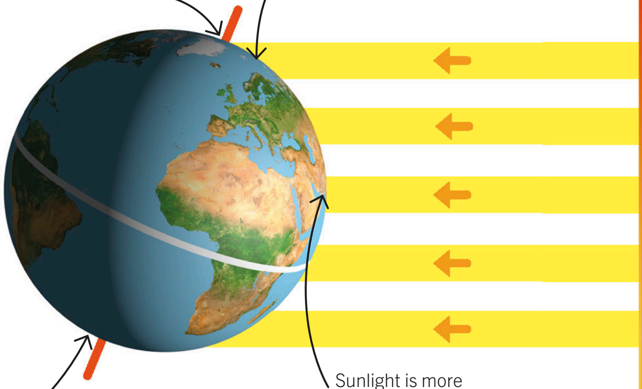


Key facts

- ✓ The cycle of seasons happens because Earth's axis is tilted.
- ✓ When the North Pole is tilted toward the Sun, it is summer in the northern hemisphere.
- ✓ When the South Pole is tilted toward the Sun, it is summer in the southern hemisphere.

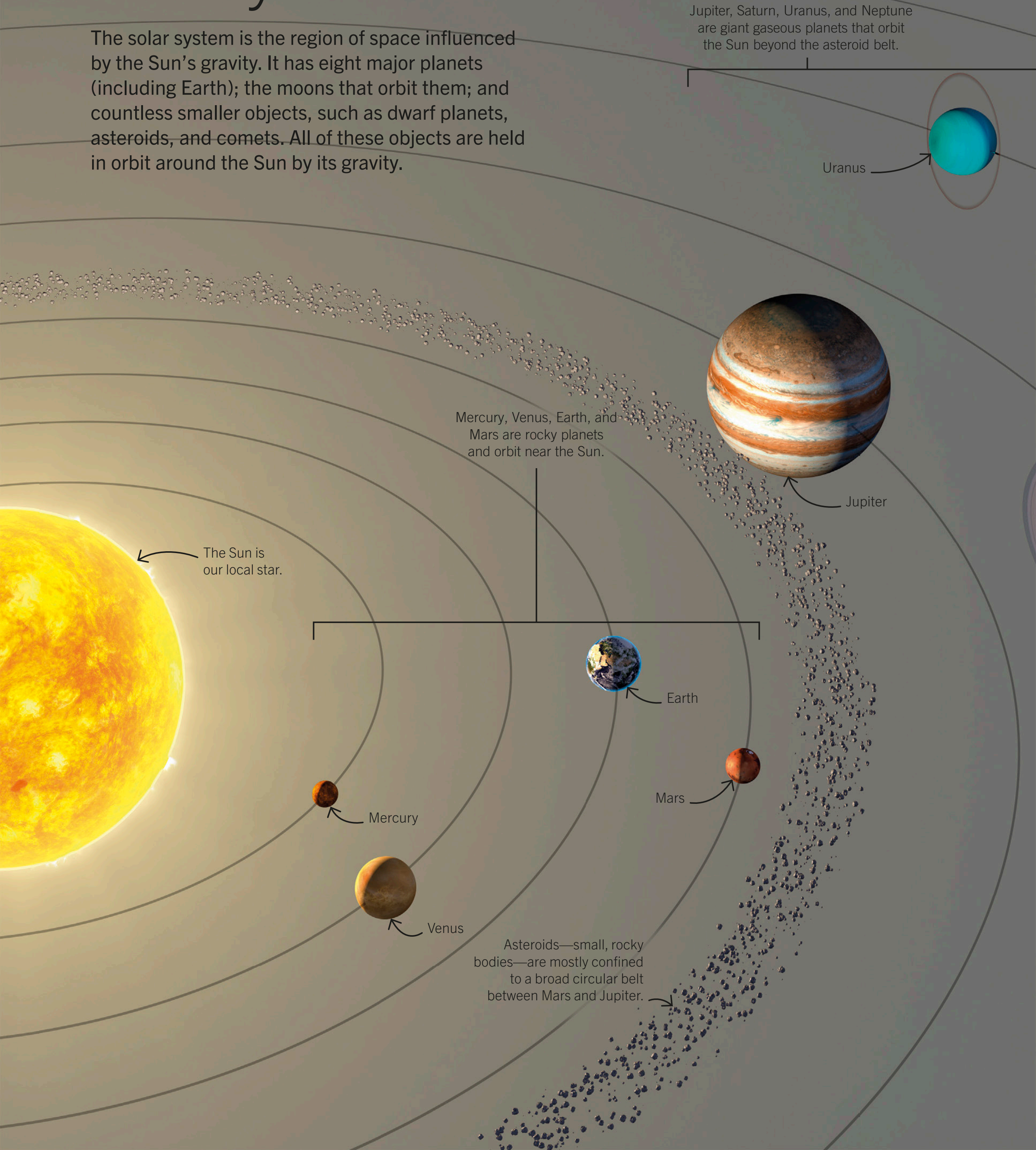
Solar heating

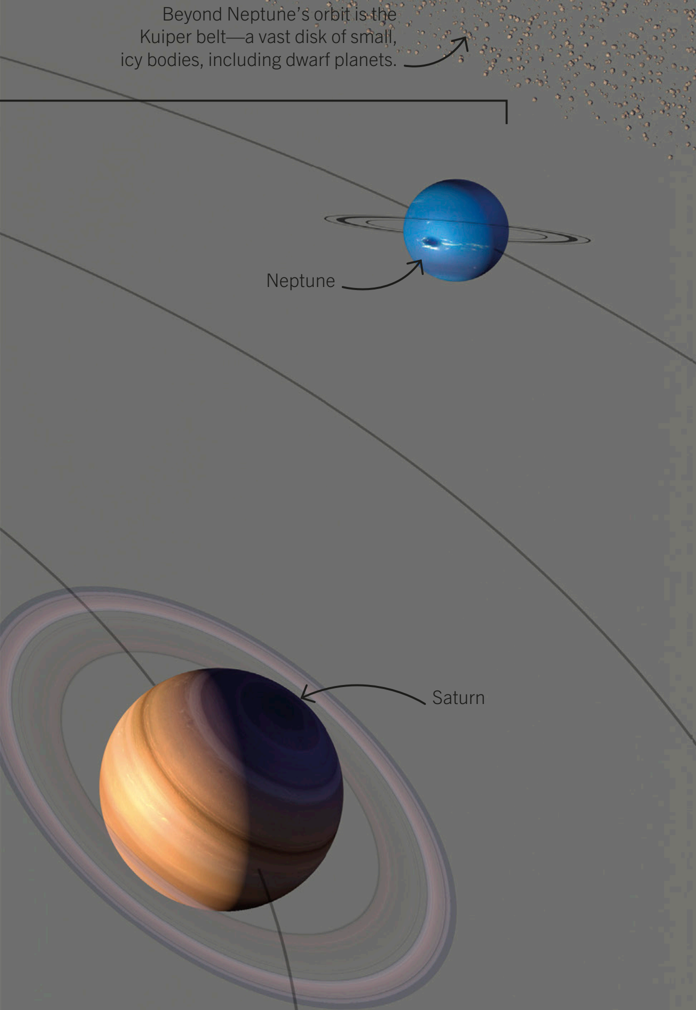
Because Earth is spherical, sunlight hits the planet's surface at an angle in the north and south, spreading the Sun's energy over a much larger area. As a result, the Sun feels much cooler at midday in winter than in summer, and tropical countries are usually much warmer than countries farther from the equator.



Solar system

The solar system is the region of space influenced by the Sun's gravity. It has eight major planets (including Earth); the moons that orbit them; and countless smaller objects, such as dwarf planets, asteroids, and comets. All of these objects are held in orbit around the Sun by its gravity.





The planets
Planets are large, spherical objects that orbit a star and that have sufficient mass to clear their orbits of other material. The solar system’s four innermost planets are rocky planets—solid balls of rock and metal. The planets of the outer solar system are much larger and more widely separated. They all have thick atmospheres of gases, including hydrogen and helium, and each has a system of rings and moons orbiting it.

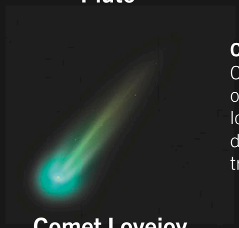
Key facts

- ✓ Objects in the solar system are held in orbit by the Sun’s gravity.
- ✓ Planets are large, spherical objects that orbit a star and that clear their orbits of other material. There are eight in the solar system.
- ✓ Moons (natural satellites) are large bodies that orbit planets.
- ✓ Asteroids are small, rocky bodies that are mostly found between Mars and Jupiter.

Smaller bodies


Pluto

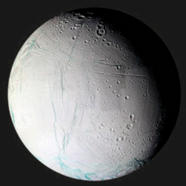
Dwarf planets
Objects with enough mass to form a spherical shape but not enough to clear their orbits of other material are called dwarf planets. Pluto is the best-known dwarf planet.


Comet Lovejoy

Comets
Comets are made from a mix of rock and ice. They have long, elliptical orbits and often develop bright tails as they travel close to the Sun.


Asteroid Ida

Asteroids
Asteroids are usually irregular bodies made of rock and metal left over from the formation of the planets. Most asteroids orbit the Sun between the orbits of Mars and Jupiter.


Enceladus

Moons
Moons are large bodies that orbit planets and are sometimes called natural satellites. There are more than 200 moons in the solar system, most of which orbit the giant planets.

The Moon

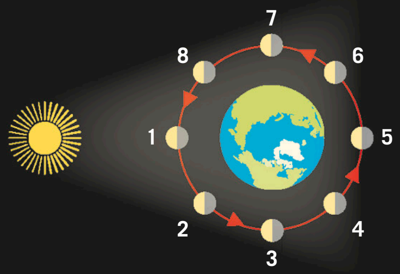
The Moon is a natural satellite of Earth and orbits our planet once every 27.3 days. It doesn’t produce its own light, but we can still see it because it reflects light from the Sun.

Key facts

- The Moon is a natural satellite of Earth.
- The Moon passes through a series of phases every 29.5 days.
- Tides are primarily caused by the pull of the Moon’s gravity on Earth’s oceans.

Lunar phases

Every 29.5 days, the Moon passes through a series of phases as we see different parts of its surface illuminated by the Sun. When the Moon is directly between Earth and the Sun, it cannot be seen from Earth and is called a new moon. When it’s on the opposite side of Earth from the Sun, we see its whole face illuminated: a full moon. We always see the same face of the Moon because tidal forces exerted on the Moon by Earth slowed the Moon’s period of rotation over millions of years until it matched the time it takes to orbit Earth once.




1. New moon


2. Waxing crescent


3. First quarter


4. Waxing gibbous


5. Full moon

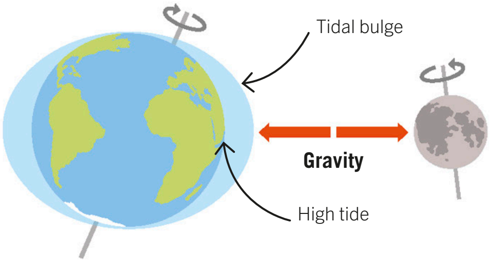

6. Waning gibbous


7. Last quarter


8. Waning crescent

Tides

Ocean tides are caused mainly by the Moon’s gravity. The Moon’s gravity is strongest on the side of Earth facing the Moon, as it is slightly closer. This force pulls the ocean toward the Moon, causing a slight bulge. On the opposite side of Earth, where the Moon’s gravity is weakest, inertia causes the water to bulge in the opposite direction as it tries to keep moving in a straight line. As a result, high tides occur twice a day.



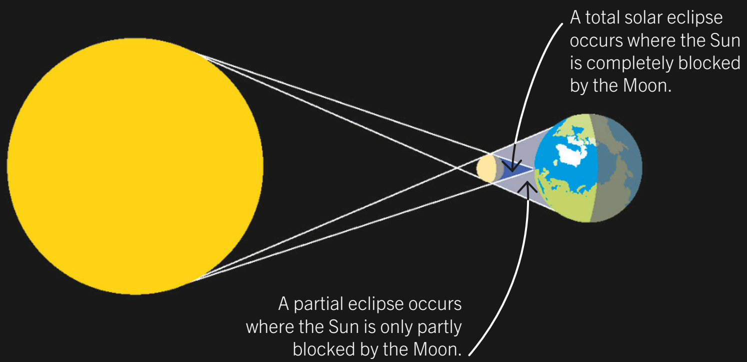
Eclipses

Eclipses happen when Earth, the Sun, and the Moon line up in space. When the Moon passes directly between the Sun and Earth, it casts a shadow on Earth and creates a solar eclipse. A lunar eclipse happens when Earth casts its shadow on the Moon.

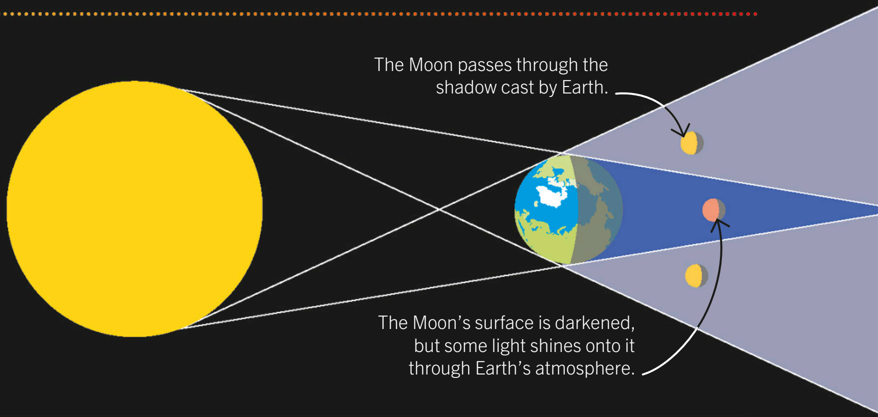
Key facts

- ✓ Eclipses occur when Earth, the Moon, and the Sun line up.
- ✓ Solar eclipses happen when the Moon casts a shadow on Earth.
- ✓ Lunar eclipses happen when Earth casts a shadow on the Moon.

Solar eclipse
Solar eclipses happen when the Moon comes directly between the Sun and Earth and so casts a shadow on part of Earth's surface. Although the Moon is much smaller than the Sun, it is much closer to Earth and can block the Sun completely, causing a total solar eclipse. When they occur, total solar eclipses are visible from only a small part of Earth.

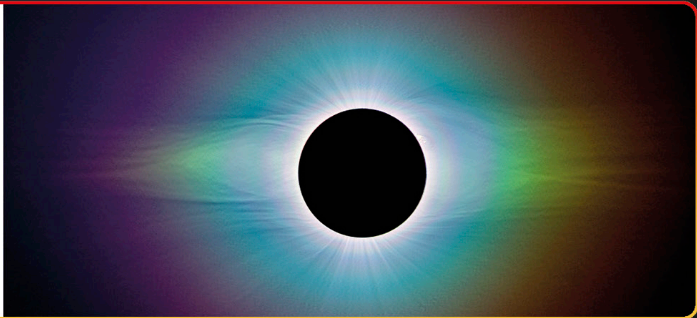


Lunar eclipse
Lunar eclipses occur during a full moon if the Moon passes through Earth's shadow. Sometimes only part of the Moon passes through Earth's shadow, but when the whole Moon falls in Earth's shadow, the Moon can turn a reddish color. This is because light refracted (bent) through Earth's atmosphere can still reach the Moon's surface.



The Sun's atmosphere

When the Moon completely obscures the Sun during a total solar eclipse, astronomers can see the Sun's faint outer atmosphere—the corona. The corona extends millions of miles (kilometers) into space but is difficult to study because it is usually hidden by the Sun's glare.



Orbits

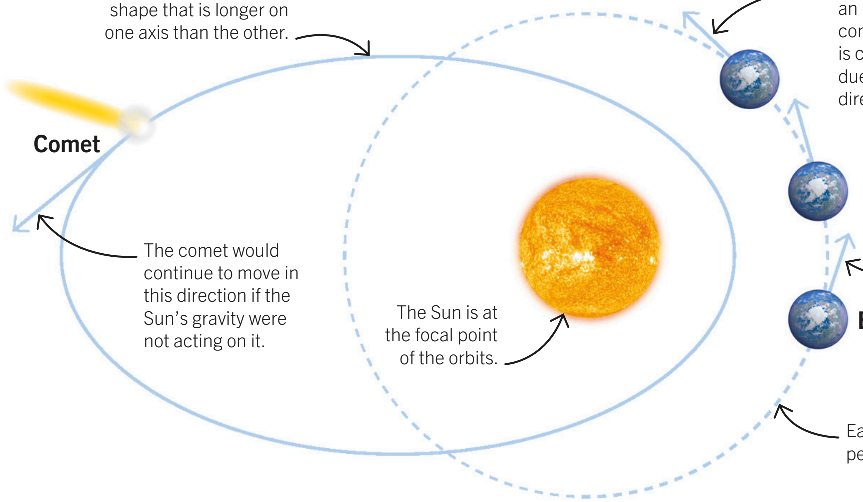
The planets of the solar system travel around the Sun because they are trapped by the force of gravity. The paths that planets follow around the Sun or that moons follow around planets are called orbits.

Key facts

- ✓ An orbit is the path that an object takes as it moves around another object in space.
- ✓ The force of gravity causes objects in space to travel in orbits.
- ✓ Orbits can be circular or elliptical.
- ✓ In a circular orbit, an object's speed is constant but its velocity is always changing as its direction is changing.

Shapes of orbits

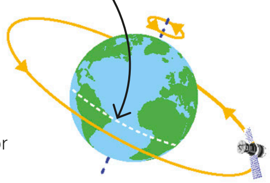
The planets in the solar system have nearly circular orbits. The pull of gravity from the Sun provides the centripetal force (see page 96) that stops them from flying away in a straight line. Smaller bodies, such as comets, have very elliptical orbits. Their speed increases as they get closer to the Sun.



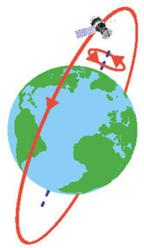
Types of orbit

Artificial satellites are placed in different types of orbit depending on the job they do. Two common types of satellite orbit are geostationary and polar.

Geostationary orbits
Geostationary satellites stay above the equator and complete one orbit every 23 hours 56 minutes, matching Earth's period of rotation. This means they stay above the same point on the planet all the time. Geostationary orbits are used for weather and communications satellites.



Polar orbits
Satellites with polar orbits travel around the planet from pole to pole. Because Earth rotates beneath them while they orbit, they pass over different parts of the planet with each orbit. Polar orbits are used for Earth-monitoring satellites.

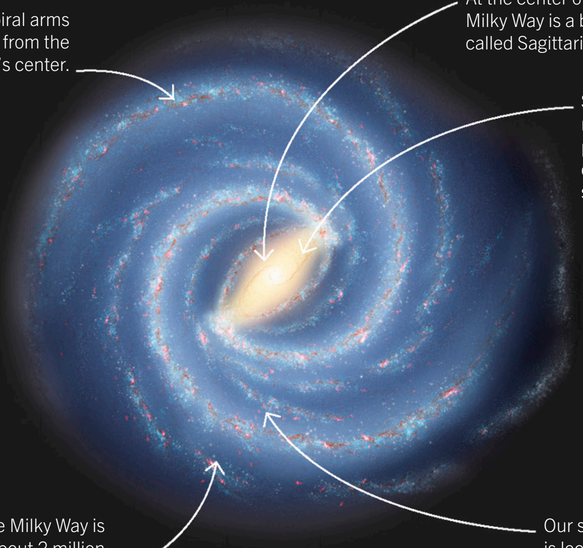


Galaxies

A galaxy is a spinning group of stars held together by gravity. The Universe may have as many as 2 trillion galaxies, and each galaxy may hold billions or trillions of stars. Vast distances separate galaxies and the stars within galaxies.

Types of galaxy

Galaxies can be sorted into different kinds based on their shape. These include spiral, barred spiral, lenticular, elliptical, and irregular. The Sun is part of the Milky Way galaxy, which is a barred spiral galaxy—a spiral galaxy with a central bar shape made of stars. All the stars we see in the night sky belong to the Milky Way. The artist's impression below shows what it might look like from outside.



Lenticular galaxies, like spiral galaxies, are disk-shaped with a central bulge. However, they lack spiral arms.

Elliptical galaxies are shaped like a squashed sphere. The stars in elliptical galaxies tend to be older than those in other galaxy types.

Irregular galaxies have no particular shape and lack spiral arms. About a quarter of all galaxies are irregular.

Key facts

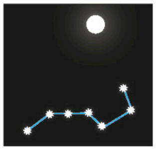
- ✓ Galaxies are groups of stars held together by gravity.
- ✓ The different types of galaxy include spiral, barred spiral, lenticular, elliptical, and irregular.
- ✓ Our solar system is in the Milky Way galaxy.

Scale of the Universe

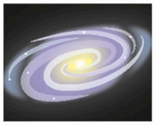
Distances in space are so great that we measure them in light-years. One light-year is the distance light travels in a year: about 9.5 trillion km.

The Sun is 8 light-minutes from Earth.

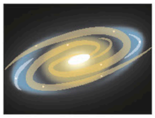
Our nearest neighboring star, Proxima Centauri, is 4.2 light-years away.



Polaris, the North Star, is 320 light-years away.



We are 26 000 light-years away from the center of the Milky Way galaxy.



Andromeda, the galaxy closest to us, is 2.5 million light-years away.

Observing space

The main way we learn about the Universe is by capturing the visible light and other radiation that reaches Earth from far away. Telescopes are tools that collect this radiation and produce images that are brighter and more detailed than the naked eye can see.

Key facts

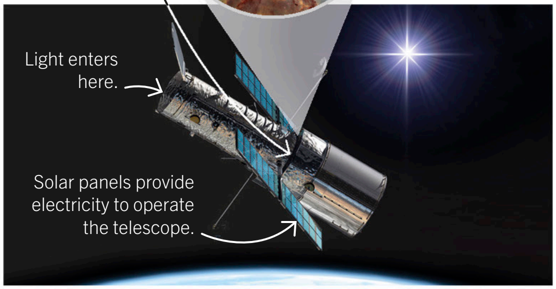
- ✓ Astronomers use different kinds of telescopes to pick up different kinds of electromagnetic radiation from objects in space.
- ✓ Some telescopes are sent into space to give us clearer images.

Telescopes

Our understanding of space has been transformed over the past century thanks to powerful telescopes. Early astronomers had to draw what they saw, but today cameras record images and computers are used to analyze them. Astronomers use telescopes located both on Earth and in space to capture and study radiation from the whole electromagnetic spectrum.

Telescopes on Earth
Earth-based telescopes, such as the Arecibo Observatory in Puerto Rico, can be much bigger than space telescopes because they don't need to be launched into space. Radio telescopes such as Arecibo need huge dishes because radio waves have a much longer wavelength than visible light.

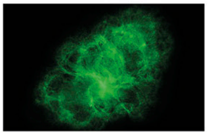
This image of the Pillars of Creation in the Eagle Nebula was formed from digital images taken by the HST.

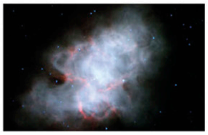


Space telescopes
Like most modern telescopes, the Hubble Space Telescope (HST) uses mirrors rather than lenses to collect and focus light. Orbiting telescopes such as Hubble can observe space without clouds and dust in the atmosphere getting in the way and can detect types of radiation absorbed by Earth's atmosphere, such as infrared.

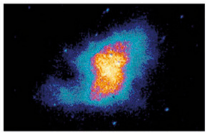
Invisible radiation

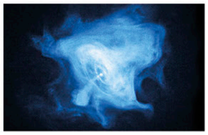
Stars and other space objects give off radiation across the whole electromagnetic spectrum. Astronomers can learn more about objects in space by studying images at different frequencies. These pictures show the Crab Nebula—the glowing remains of a star that exploded—in different electromagnetic frequencies.


Radio


Infrared


Visible light


Ultraviolet rays


X-rays

Redshift

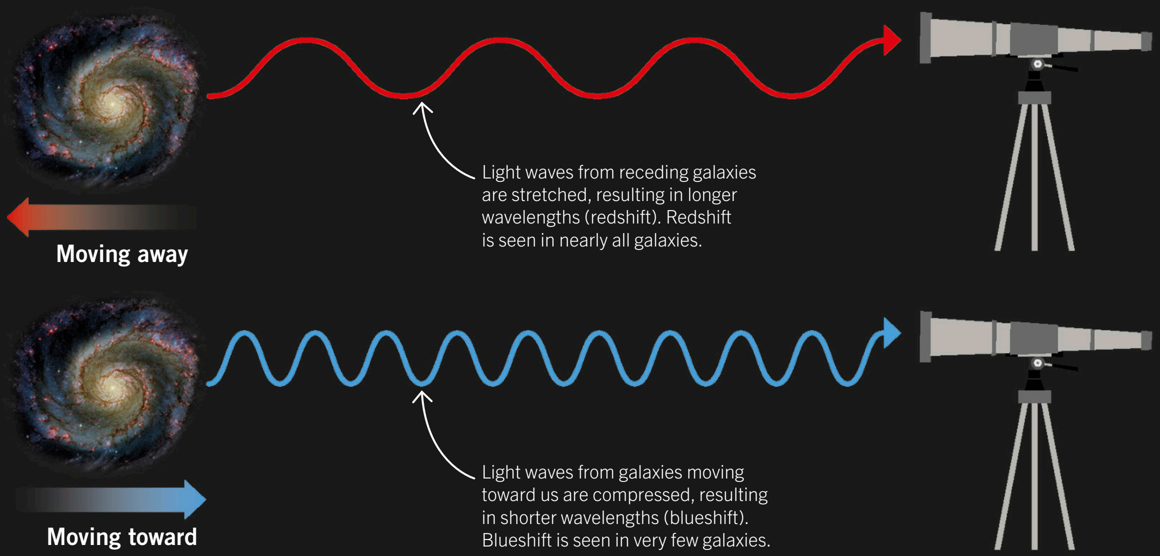
When astronomers analyze the light from distant galaxies, they find that its wavelength is slightly longer than that of light from closer objects. This difference, imperceptible to the naked eye, is caused by an effect called redshift, and it shows that the Universe is expanding.

Key facts

- ✓ Redshift is an increase in the wavelength of light from distant galaxies that are receding (moving away from us).
- ✓ Redshift studies show that the farthest galaxies are receding fastest.
- ✓ The observed redshift provides evidence that the Universe is expanding and supports the Big Bang theory.

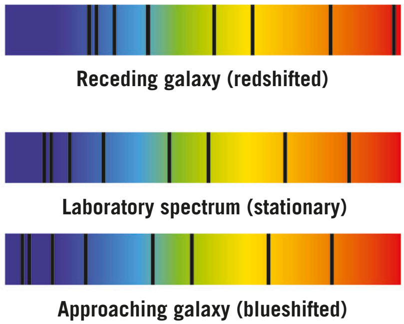
Moving light

Light waves from objects that are receding (moving away) have a slightly elongated wavelength. The faster the object is receding, the greater the increase in wavelength. By studying redshift, astronomers discovered that the farthest galaxies are receding fastest. This shows that the whole Universe is expanding in a pattern that supports the Big Bang theory (see page 267).



Studying starlight

Astronomers study the light from stars and galaxies with a technique called spectroscopy. In one form of spectroscopy, the visible light from a star has distinctive black gaps because chemical elements in stars or in space absorb and block certain wavelengths. Redshift (or occasionally blueshift) causes these lines to shift, and the amount they move reveals how fast a star or galaxy is moving toward or away from us. Redshift affects all kinds of electromagnetic radiation, not just visible light.

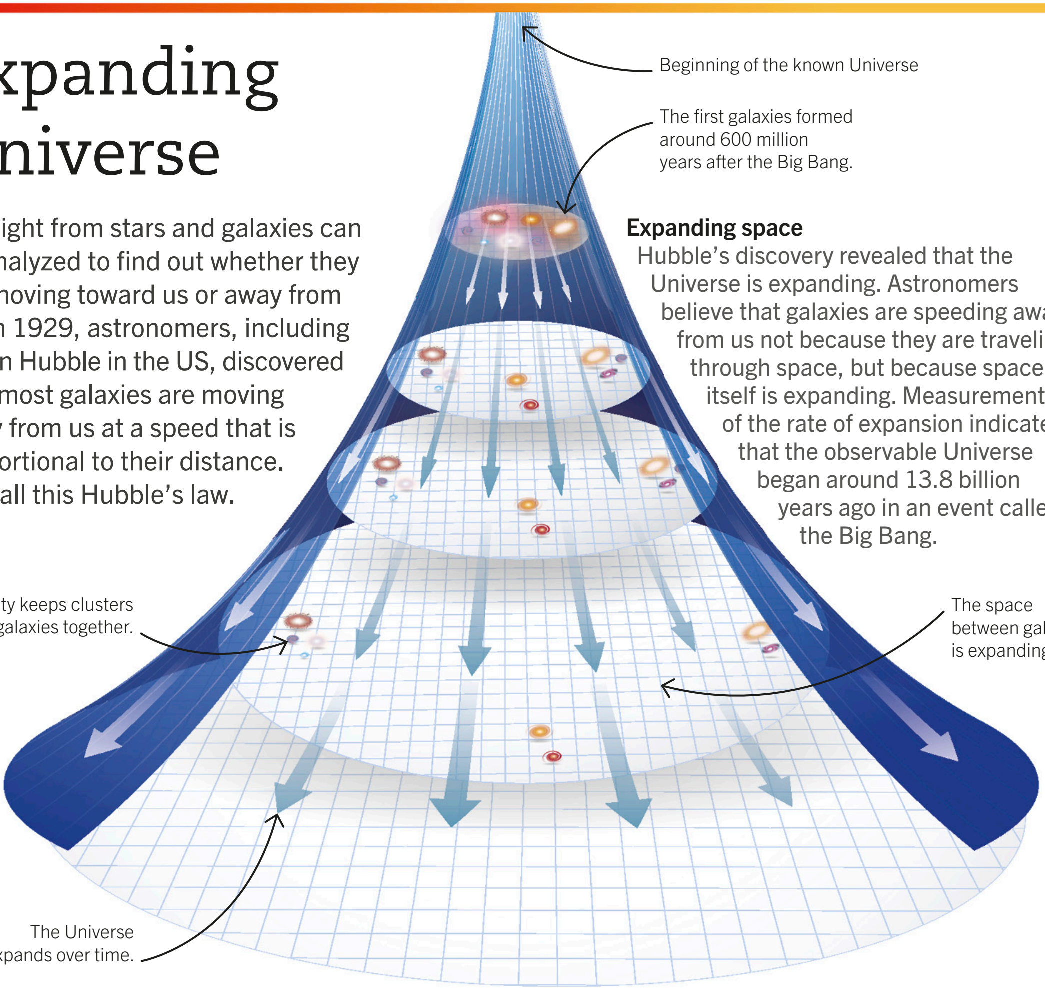


Expanding Universe

The light from stars and galaxies can be analyzed to find out whether they are moving toward us or away from us. In 1929, astronomers, including Edwin Hubble in the US, discovered that most galaxies are moving away from us at a speed that is proportional to their distance. We call this Hubble's law.

Expanding space

Hubble's discovery revealed that the Universe is expanding. Astronomers believe that galaxies are speeding away from us not because they are traveling through space, but because space itself is expanding. Measurements of the rate of expansion indicate that the observable Universe began around 13.8 billion years ago in an event called the Big Bang.

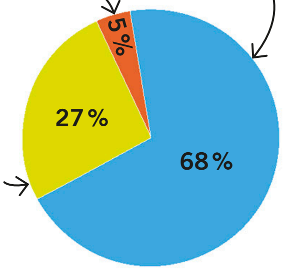


Key facts

- Most galaxies are moving away from us.
- The speed at which galaxies are moving away increases in proportion to their distance from us.
- Hubble's observations show the Universe is expanding and support the Big Bang theory.

Dark matter and dark energy

Measurements of the light from supernovas in distant galaxies suggest that the expansion of the Universe is accelerating. Scientists think the acceleration is driven by an unknown source of energy, named dark energy. They also think there must be more mass in galaxies than we can see, as there isn't enough visible mass to properly explain the observed motion of stars and galaxies. The undetected mass is called dark matter.



Content of the Universe

Big Bang or steady state?

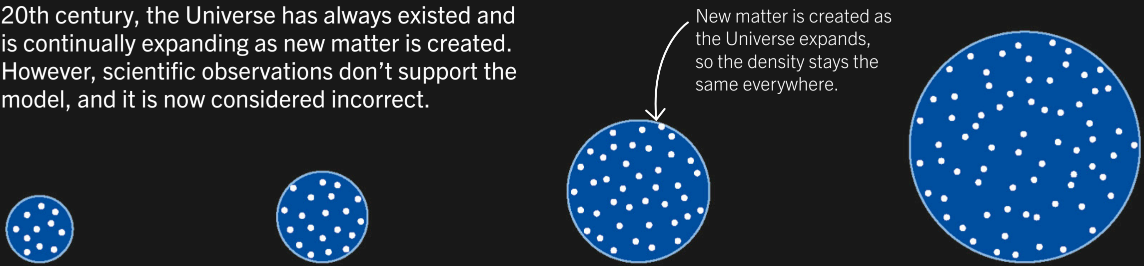
There are two different theories to explain the expansion of the Universe. The Big Bang theory says that the expansion can be traced back to a beginning at a single point. The steady-state model says that something is continuously creating matter and making the Universe expand.

Key facts

- ✓ The Big Bang theory says the Universe began at a single point 13.8 billion years ago and has been expanding ever since.
- ✓ The steady-state model says that matter is continuously created to fill the Universe as it grows.
- ✓ The Big Bang is the currently accepted theory and the steady-state model is now considered incorrect.

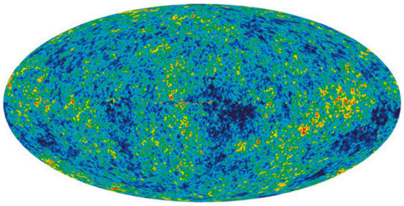
The Big Bang theory
According to the Big Bang theory, space expanded suddenly from a single point of origin 13.8 billion years ago. All the matter and energy the Universe would ever have was present from the beginning. As the Universe expanded, matter and energy became ever more widely spread. Most evidence suggests the Big Bang theory is correct.

Steady-state model
According to this rival model, proposed in the early 20th century, the Universe has always existed and is continually expanding as new matter is created. However, scientific observations don't support the model, and it is now considered incorrect.



Cosmic microwave background radiation

In 1964, two radio astronomers discovered a weak radio signal coming from all over the sky. They realized they had picked up radiation from the Big Bang that is now spread thinly across the entire Universe. The existence of this energy had been predicted by the Big Bang theory but not the steady-state model, so its discovery supported the Big Bang.



Cosmic microwave background radiation

Star life cycles

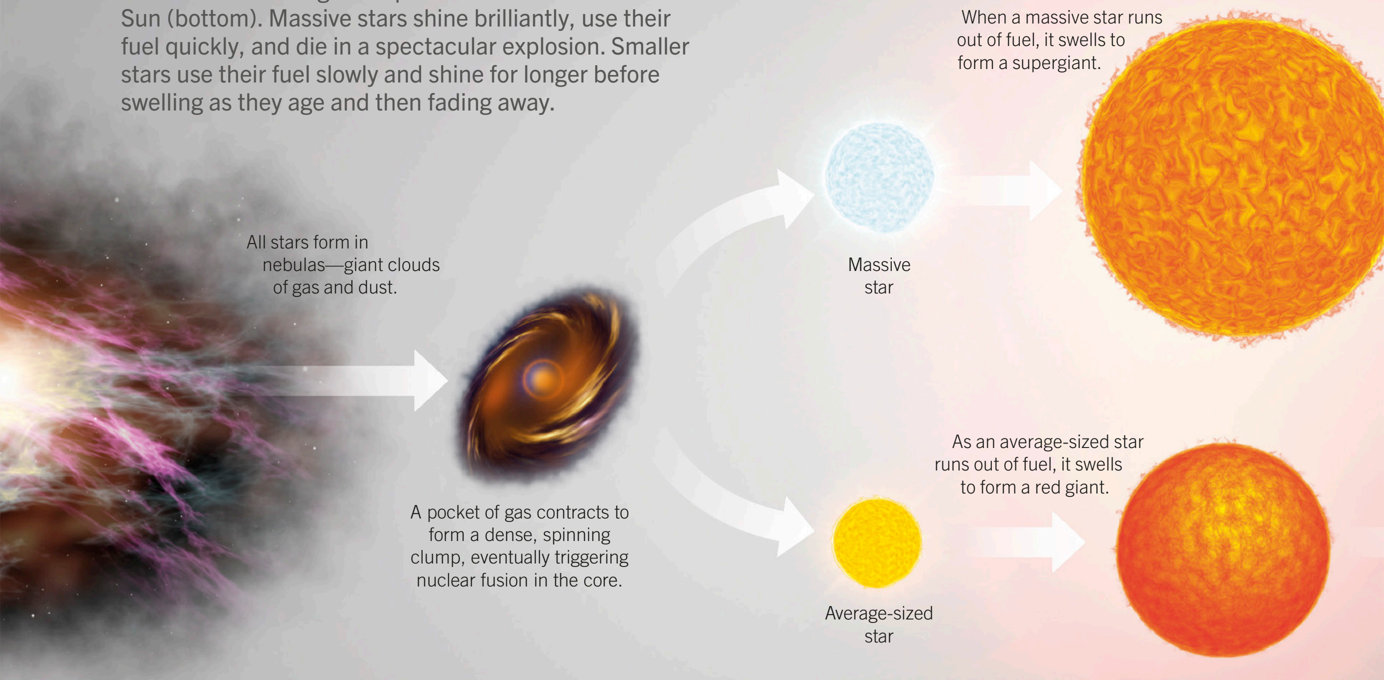
Stars form inside gigantic clouds of gas and dust that contract due to the force of gravity until nuclear fusion reactions are triggered inside them. The life cycle a star passes through as it ages and uses up its fuel depends on the star's mass.

Key facts

- ✓ Stars form from clouds of gas and dust called nebulas.
- ✓ Planets form from the debris left behind after star formation.
- ✓ The stages in a star's life depend on its mass.

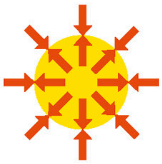
Different lives

The diagram here shows the typical life cycles of massive stars (along the top) and stars the size of our Sun (bottom). Massive stars shine brilliantly, use their fuel quickly, and die in a spectacular explosion. Smaller stars use their fuel slowly and shine for longer before swelling as they age and then fading away.

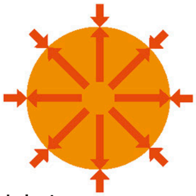


Stellar equilibrium

Stars shine stably as long as they can maintain a balance between the inward pull of their own gravity and the outward pressure of radiation from fusion reactions in the core. When the fuel inside the star begins to run out, the forces become unbalanced and the star changes, sometimes dramatically and violently.



Normal star
In a star like our Sun, the inward pull of gravity balances outward pressure from the core.

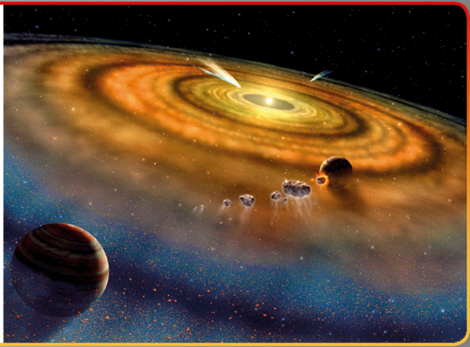


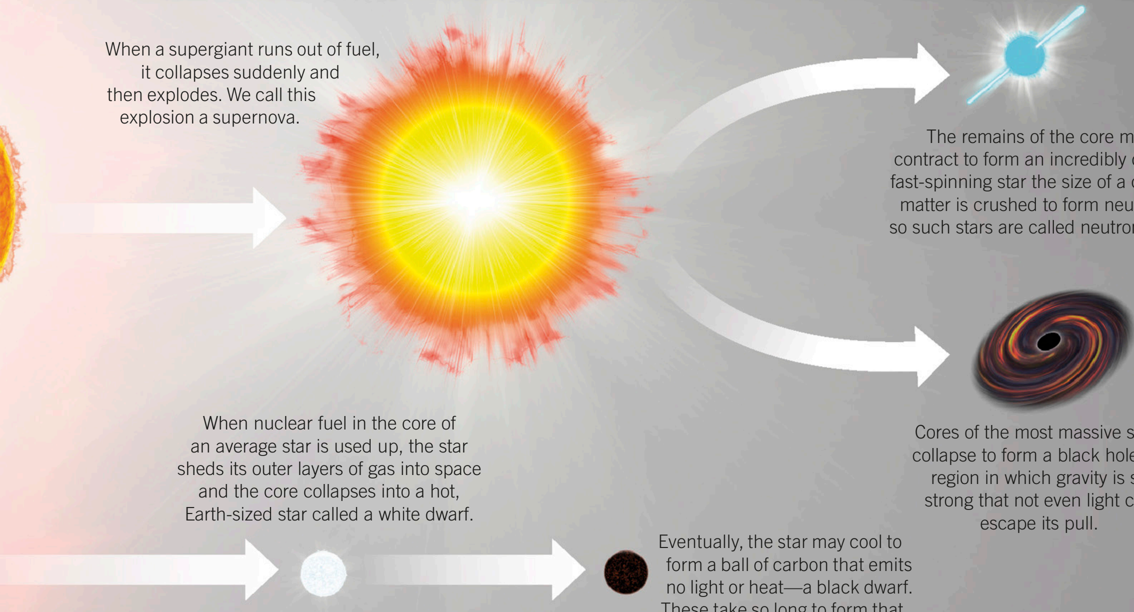
Red giant
In an aging star, the core heats up and the forces become unbalanced. The star swells in size until the forces balance again. It is now a giant star.

Black hole
When the most massive stars run out of fuel, the force of gravity far exceeds pressure from the core and the star collapses into a black hole.

Star formation

Stars form in vast, interstellar clouds of gas and dust called nebulas. If a nebula is disturbed—for instance, by a shock from an exploding star—part of it may start to contract due to gravity to form a dense, rotating clump. As the clump becomes more dense, its gravitational pull grows stronger, drawing more material in, and its core heats up. Eventually, the core is so dense and hot that nuclear fusion reactions are triggered, causing a star to shine. The remaining material orbits the star as a disk of dust and gas in which planets and other bodies form.





When a supergiant runs out of fuel, it collapses suddenly and then explodes. We call this explosion a supernova.

The remains of the core may contract to form an incredibly dense, fast-spinning star the size of a city. All matter is crushed to form neutrons, so such stars are called neutron stars.

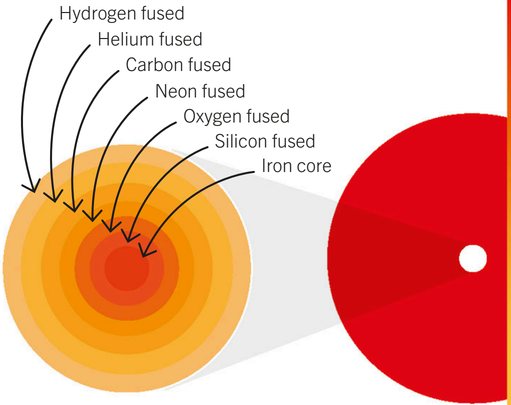
Cores of the most massive stars collapse to form a black hole—a region in which gravity is so strong that not even light can escape its pull.

When nuclear fuel in the core of an average star is used up, the star sheds its outer layers of gas into space and the core collapses into a hot, Earth-sized star called a white dwarf.

Eventually, the star may cool to form a ball of carbon that emits no light or heat—a black dwarf. These take so long to form that none are thought to exist yet.

Making elements

Stars are made mostly of hydrogen, the simplest element in the Universe. They shine by nuclear fusion (see page 253): hydrogen nuclei are forced together to form larger atomic nuclei, such as helium, releasing energy in the process. Toward the end of a star's life, its core runs out of hydrogen and starts to fuse other elements instead. Sunlike stars fuse helium to make carbon, and more massive stars go on to make heavier elements such as nitrogen, oxygen, and iron. When massive stars explode as supernovas, elements even heavier than iron are produced, and the explosion scatters the elements through space to form new nebulas. Many of the chemical elements in our bodies formed this way.

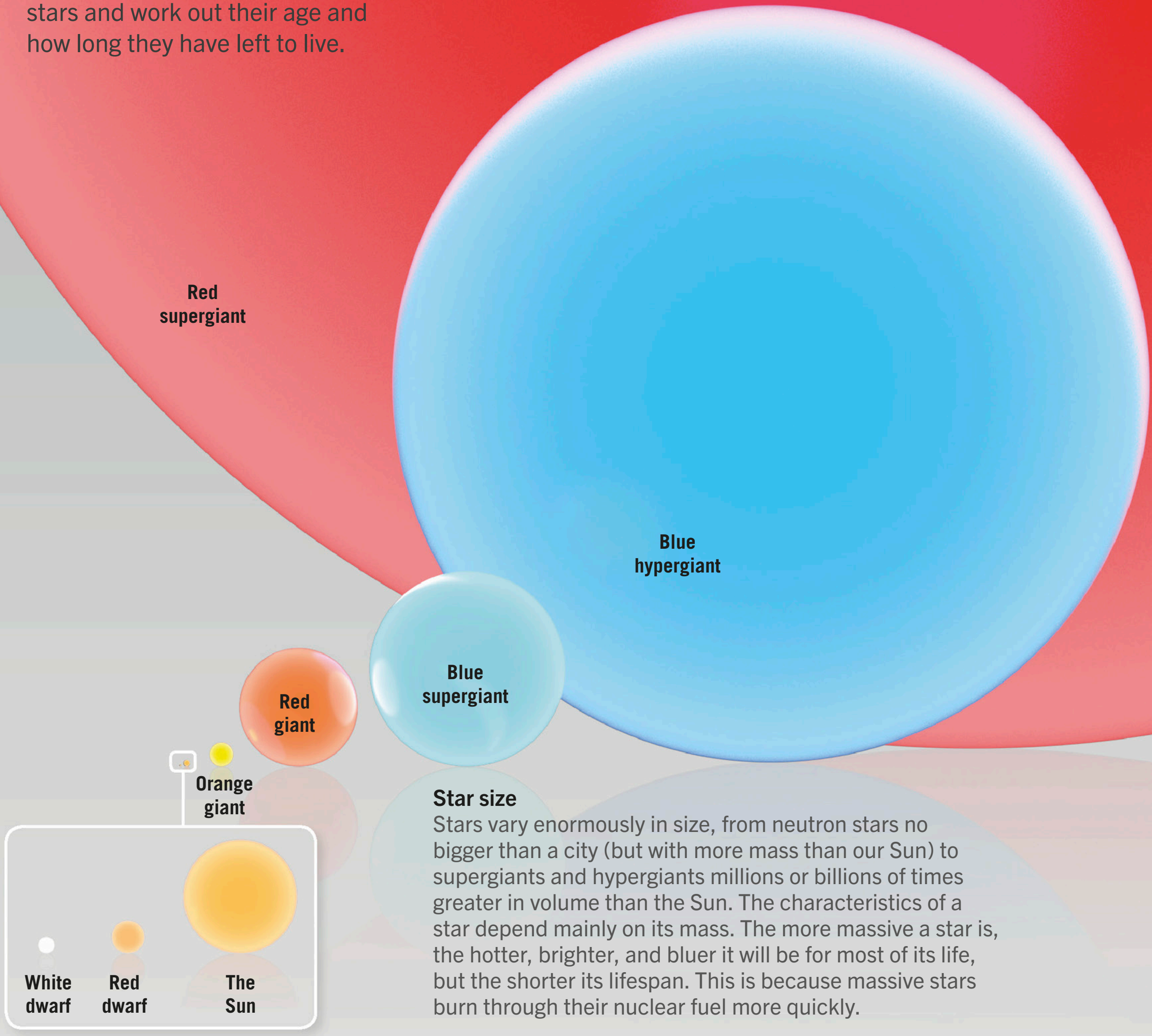


Classifying stars

Stars may look like pinpricks of light to the naked eye, but astronomers can use the light they emit to calculate their temperature, distance from Earth, diameter, and mass. These characteristics are used to classify stars and work out their age and how long they have left to live.

Key facts

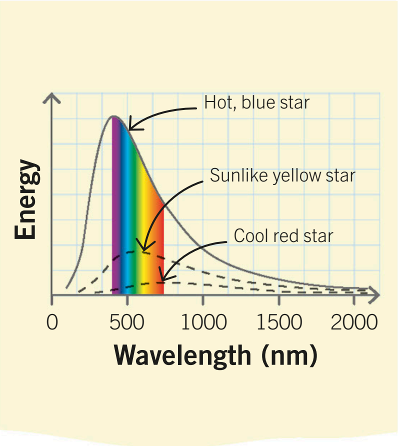
- ✓ The light from a star can be used to calculate its temperature.
- ✓ Apparent magnitude is how bright a star appears from Earth.
- ✓ Absolute magnitude is how bright a star appears from a standard distance.
- ✓ A Hertzsprung–Russell diagram is a graph showing the temperatures of stars plotted against brightness.



Star size
Stars vary enormously in size, from neutron stars no bigger than a city (but with more mass than our Sun) to supergiants and hypergiants millions or billions of times greater in volume than the Sun. The characteristics of a star depend mainly on its mass. The more massive a star is, the hotter, brighter, and bluer it will be for most of its life, but the shorter its lifespan. This is because massive stars burn through their nuclear fuel more quickly.

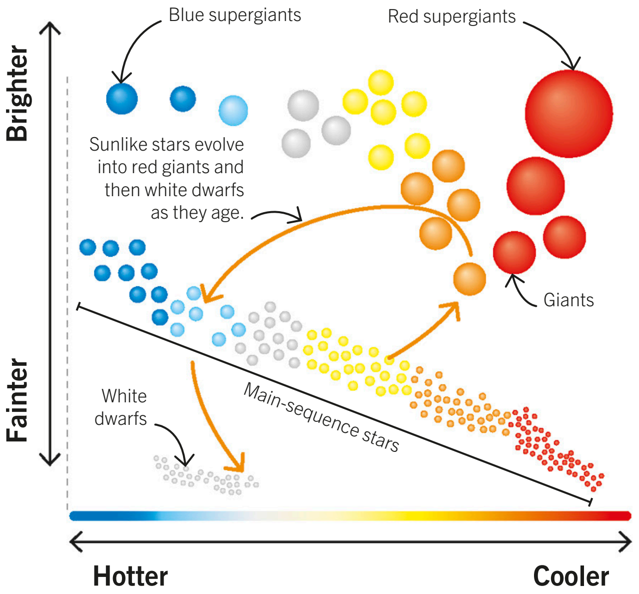
Color and temperature

All objects emit radiation, whatever their temperature. As the temperature of an object rises, the amount of radiation it emits increases, but the peak wavelength of the radiation decreases. That's why the light from a very hot object changes from red-hot to white-hot as its temperature rises. Astronomers use this principle to measure the surface temperature of stars. Although not always obvious to the naked eye, cooler stars emit red light more strongly and hotter stars emit blue light more strongly.



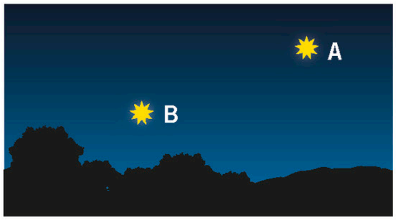
Hertzsprung–Russell diagrams

About 100 years ago, the Danish astronomer Ejnar Hertzsprung and the US astronomer Henry Russell independently discovered a pattern in the properties of stars. If stars are plotted on a graph of brightness against temperature, they form a distinctive pattern that reflects their stage of life. Most stars occupy a diagonal band called the main sequence. These are stars that are relatively small in volume and that fuse hydrogen in their cores. Other stars, such as aging giant stars that are running out of fuel, form clusters away from the main sequence.

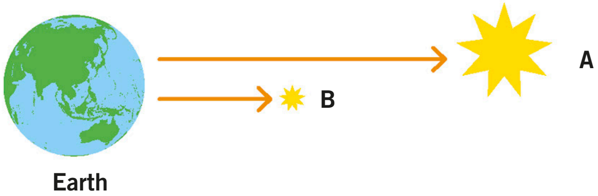


Magnitude

Astronomers use the word magnitude for the brightness of a star. There are two ways of measuring magnitude. Apparent magnitude is how bright a star looks from Earth, but this can be misleading, as distant stars look fainter. Absolute magnitude is a standardized measure of how bright all stars would look from the same distance (32.6 light-years).



These two stars look equally bright in the night sky, but in reality, star A is brighter but farther away.



Glossary

Absolute magnitude The brightness of a star when observed from a standard distance. This is useful for comparing the brightness of stars regardless of their distance from Earth.

Absolute zero The lowest temperature possible, when all atoms stop moving. In the three main temperature scales (Kelvin, Celsius, and Fahrenheit), absolute zero is 0 K, –273°C, and –459°F.

Absorption spectrum A pattern of dark lines in the spectrum of light that has passed through a gas, such as in the outer layers of a star. These lines show the wavelengths of light absorbed by the gas, which represent elements present in the star.

Acceleration The rate of change of velocity. Acceleration can mean speeding up, slowing down, or changing direction. Acceleration is a vector quantity. Units are m/s^2.

Acceleration due to gravity The rate at which a falling object accelerates due to gravity in the absence of air resistance. On Earth, this is about 9.8 m/s^2 and often rounded to 10 m/s^2.

Aerodynamic Relating to the way air moves over objects. It is often used to mean a smooth shape that reduces air resistance.

Air resistance The force that resists the movement of objects through the air. This force is mostly due to collisions with air particles.

Alpha decay A form of radioactive decay in which an atomic nucleus gives off an alpha particle.

Alpha particle A particle that consists of two neutrons and two protons (the same as a helium nucleus). Alpha particles are emitted from some atomic nuclei during radioactive decay.

Alternating current (a.c.) An electric current that reverses direction at regular intervals. *See also* direct current (d.c.).

Alternator An electric generator that makes alternating current from mechanical motion, usually by spinning a coil of wire in a magnetic field. *See also* generator.

Ammeter A device that measures electrical current.

Ampere (A) The unit of electrical current, often called an amp.

Amplitude The maximum displacement of a wave from its average position. It is the height of a wave's peak above the midline (half the vertical distance from the peak of a wave to a trough).

Angle of incidence The angle between the incident (incoming) light ray and the normal line.

Angle of reflection The angle between the reflected light ray and the normal line.

Apparent magnitude How bright a star appears to us on Earth. *See also* absolute magnitude.

Asteroid A rocky body that orbits the Sun. Most asteroids are in the asteroid belt between Mars and Jupiter.

Asteroid belt A region between the orbits of Mars and Jupiter where many asteroids exist. Jupiter's strong gravity prevents the asteroids from forming a new rocky planet.

Atmosphere The layer of air that surrounds a planet.

Atmospheric pressure The force of the atmosphere pressing on a square meter of Earth's surface, caused by the weight of air above. Units are Pascal (Pa), where 1 Pa = 1 N/m^2.

Atom The smallest part of an element that has the chemical properties of that element. An atom is made up of protons, neutrons, and electrons.

Atomic energy Sometimes referred to as nuclear energy, this is energy stored in the bonds between the neutrons and protons in an atomic nucleus. This energy may be released during nuclear fission or nuclear fusion.

Atomic number Sometimes called the proton number, this is the number of protons in an atom's nucleus. Each element has a different atomic number.

Average speed The average speed of a journey is the total distance traveled divided by the time taken. *See also* instantaneous speed.

Background radiation Low-intensity radiation that is around us all the time. Some of it is emitted by radioactive substances in rocks and other materials around us, and some comes from space (cosmic radiation).

Balanced forces The forces acting on an object are balanced if they add up to a net force of zero newtons. For example, the forces on a cyclist are balanced when the forward force from pedaling is equal to the forces of air resistance and friction.

Battery Two or more electrical cells connected in series make up a battery. *See also* cell.

Becquerel (Bq) A unit of radioactive decay. 1 Bq means that, on average, one atomic nucleus is decaying each second in the sample being measured.

Beta decay A form of radioactive decay in which an atomic nucleus gives off a beta particle.

Beta particle A high-speed electron. Beta particles are emitted from some atomic nuclei during radioactive decay.

Big Bang The event in which the Universe is thought to have begun, around 13.8 billion years ago, rapidly expanding from a singularity (a single point).

Biofuel Any fuel made from recently living plant or animal matter—for example, the conversion of sugar cane into ethanol fuel. If the sugar cane is regrown as quickly as it is harvested, then this biofuel can be considered renewable.

Bond A force between atoms or molecules that holds them together. Chemical reactions involve the making and breaking of bonds.

Braking distance The distance traveled by a vehicle from the moment the brake is pressed until the vehicle stops.

Cell A device that stores energy and produces an electric current when it is part of a complete circuit.

Celsius A temperature scale based on the freezing point (0°C) and boiling point (100°C) of water at sea level.

Center of mass Sometimes called the center of gravity, this is a point in an object where all its weight appears to be concentrated. You can balance a pencil halfway along its length because that's where its center of mass is.

Centripetal force A pulling force that causes an object to move along a curved or circular path—for example, the tension force in a string tied to a heavy object that's being swung around in circles.

Chain reaction A chemical or nuclear reaction in which the products trigger similar reactions. Uncontrolled chain reactions can cause explosions.

Change of state A change between two states of matter (solid, liquid, gas).

Charge (or electric charge) A basic property of some particles, such as electrons or protons, that makes them feel a force in an electromagnetic field. Charge can be positive or negative. Similar charges repel; opposite charges attract.

Chemical Any element or compound, especially those produced or extracted in an industrial process. Water, iron, salt, and oxygen are all examples of chemicals.

Chemical change A chemical change occurs when atomic bonds are made and broken in a chemical reaction. This results in a new chemical substance being formed.

Chemical energy The energy stored in the bonds between atoms. It may be released during a chemical reaction, for example, as heat and light. Food, fuels, and electrical cells store chemical energy.

Chemical reaction A process that changes substances into new substances by breaking and making chemical bonds.

Circuit The path through which an electric current can flow.

Climate The pattern of weather and seasons a place experiences in a typical year.

Climate change Long-term changes in Earth's weather patterns. *See also* global warming.

Closed system A system that matter does not leave or enter. However, energy may enter or leave the system. *See also* system.

Comet A mass of ice and rock that travels around the Sun in an elliptical orbit. Some of the dust may stream out to form a tail that points away from the Sun.

Compass A device containing a small magnetic needle allowed to rotate freely. The needle lines up with Earth's magnetic field.

Component of a force The part of a force that acts in a particular direction. For example, when pushing a wheelbarrow, some of your push force moves the wheelbarrow forward (horizontal) and some acts upward, lifting the wheelbarrow (vertical).

Compound A substance consisting of two or more elements whose atoms have bonded.

Compression Pressing together or squeezing.

Concave lens A lens that curves inward in the middle. Also called a diverging lens.

Concentration A measure of the amount of particles of a substance when mixed with another substance. For example, the concentration of carbon dioxide in air is about 412 particles for every million air particles.

Condensation The change of state when a gas turns into a liquid.

Conduction The movement of heat or electricity through a substance.

Conductor A substance through which heat or electric current flows easily.

Conservation of energy *See* Law of conservation of energy.

Conservation of momentum *See* Law of conservation of momentum.

Constant A quantity that does not vary, symbolized by a letter in an equation. Constants usually represent a physical property, such as how easily stretched a spring is (spring constant).

Contact force Any force delivered through direct contact. Examples include air resistance, friction, and tension.

Contamination Contamination occurs when unwanted, often toxic substances enter a system, such as radioactive material entering a human body. *See also* irradiation.

Continuous variable A variable that can take any value (between limits) and is not limited to whole numbers, such as a person's height. *See also* discrete variable.

Control variable A variable that needs to be kept constant in an experiment. This is done to see properly the effect of changing the independent variable on the dependent variable—for example, keeping room temperature constant during an experiment to measure the temperature of hot water as it cools.

Convection The transfer of heat through a fluid (liquid or gas) caused by particles rising from hotter, less dense areas and sinking from cooler, more dense areas.

Converging lens A lens that curves outward in the middle. Also called a convex lens. Converging lenses make parallel beams of light come together.

Convex lens A lens that curves outward in the middle. Also called a converging lens.

Correlation A correlation between two variables means that as one variable changes, the other also changes in a predictable way. Correlation does not necessarily mean that changing one variable causes the other to change.

Cosmic microwave background radiation (CMBR) Faint microwave radiation found throughout the Universe. It is thought to be energy left over from the Big Bang.

Cosmic rays Highly energetic particles, such as electrons and protons, that travel through space at close to the speed of light.

Coulomb (C) The unit of electrical charge. One coulomb is the quantity of charge moved in one second by a current of one amp.

Critical angle An angle of incidence greater than the critical angle causes total internal reflection (TIR) instead of refraction.

Crumple zone A safety feature in which parts of a vehicle are designed to deform (crumple) in a collision. This means that the vehicle decelerates over a longer period of time, reducing the chance of serious injuries.

Crust (Earth) The thin, rigid outer surface of Earth made of rock.

Current (electric) A flow of charged particles such as electrons or ions. The unit is the ampere (A).

Curve of best fit A smooth curve drawn through the points on a graph that comes as close to as many of them as possible. *See also* line of best fit.

Dark energy A poorly understood force that acts in the opposite direction to gravity, causing the Universe to expand. About two-thirds of the content of the Universe is dark energy.

Dark matter Invisible matter that can only be detected by its gravitational effect on visible matter. Dark matter helps hold galaxies together.

Data Information gathered in an experiment.

Decay (radioactive) The process by which a radioactive atom's nucleus spontaneously emits ionizing radiation, often transforming into a different element.

Deceleration Slowing down. In this case, the acceleration is in the opposite direction to the velocity.

Density The mass (amount of matter) of a substance per unit volume. Units are kg/m^3 or g/cm^3.

Dependent variable The variable that you measure in an experiment.

Diffuse reflection This occurs when light is reflected in random directions from an uneven surface.

Diffusion The gradual mixing of two or more substances as a result of the random movement of their particles.

Diminished (of an image) An image that is smaller than the object.

Diode An electronic component that lets electricity flow in one direction only.

Direct current (d.c.) An electric current that flows in one direction only. *See also* alternating current (a.c.).

Discrete variable A variable that may only have certain values, such as months of the year.

Displacement 1. The straight line distance between two points in a particular direction (a vector quantity). Units are meters (m) or kilometers (km). 2. The moving aside of a medium by an object placed in that medium, such as bath water rising when a person gets in it.

Dissipate The process by which something spreads out, becoming less concentrated as it does so and effectively disappearing. For example, heat escaping from a poorly insulated house will dissipate into the atmosphere.

Diverging lens A lens that curves inward in the middle. Also called a concave lens. Diverging lenses make parallel beams of light spread out.

Drag Another name for air resistance or water resistance.

Dwarf planet A small, planetlike object that is massive enough to have become rounded by its own gravity but not massive enough for its gravity to have cleared the surrounding space of objects.

Dynamo A generator that produces direct current.

Efficiency A measure (usually a percentage) of how much of a system's input energy is converted into useful energy.

Effort A force applied against a load, such as the lifting force used to raise a wheelbarrow.

Elastic An object is elastic if it returns to its original size and shape after being stretched or compressed.

Elastic collision A collision between objects that spring back into their original shape after impact, with no loss of kinetic energy.

Elastic limit The maximum amount that a material can be stretched or compressed and still return to its original shape.

Elastic potential energy The energy stored in a stretched or compressed material, sometimes called strain energy. This stored energy comes from the work done in stretching or compressing the material.

Electric current A flow of charged particles such as electrons or ions. The unit is the ampere (A).

Electric field A region surrounding a charged particle (such as an electron or ion) in which other charged particles experience a force.

Electrical power The amount of electrical energy converted every second into other forms of energy. It is measured in watts (W).

Electricity The effects caused by the presence and/or movement of electric charge.

Electromagnet A coil of wire that becomes magnetic when electricity flows through it.

Electromagnetic induction The process by which a voltage is induced in a conductor when the conductor moves across a magnetic field. If the conductor is part of a complete circuit, then a current will flow in that circuit.

Electromagnetic radiation A form of energy that travels at the speed of light, is a transverse wave, and can travel through a vacuum.

Electromagnetic spectrum The complete range of electromagnetic radiation from radio waves to gamma rays. *See also* spectrum and visible spectrum.

Electron One of the three main particles in an atom (with the proton and neutron). It has a negative charge.

Electron shell One of the layers in which electrons are arranged outside the nucleus of an atom.

Electrostatic force The force experienced by a charged particle when it is in an electric field.

Element A pure substance that cannot be broken down into other substances by chemical reactions. Examples include carbon, hydrogen, and oxygen.

Ellipse An oval shape like a flattened circle.

Energy The capacity to do work. Energy can be stored and transferred in different ways. For example, energy can be stored in the chemicals in a cell and transferred by electricity when the cell is put into a circuit.

Energy resource A store or source of energy that can be used.

Equilibrium A state of physical or chemical balance.

Evaporation A change of state in which a liquid turns into a gas (vapor).

Fair test A scientific experiment in which the only things that change are the independent and dependent variables.

Farsighted Unable to see nearby objects clearly. Farsightedness can be corrected by wearing glasses with converging lenses.

Field The region in which a noncontact force such as gravity or magnetism has an effect.

Field lines Lines in a diagram of a force field that show the direction in which the force acts. The field is strongest where the lines are closest together.

Fluid A substance that can flow, such as a gas or liquid.

Focal length The distance between the focal point of a lens and the center of the lens.

Focal point The point at which parallel rays of light are focused by a converging lens or the point from which rays of light appear to have come from after passing through a diverging lens.

Force A push or a pull. Forces change the speed, direction, or shape of objects. Force is a vector quantity, and the units are newtons (N).

Force field The region in which a force can be detected.

Force meter Also called a newton meter, a force meter is any device that measures force.

Fossil fuel A fuel derived from the fossilized remains of living things. Coal, crude oil, and natural gas are fossil fuels.

Free body diagram A diagram showing all the forces acting on an object. The forces are represented by arrows showing the direction of the forces.

Freezing point The temperature at which a liquid turns into a solid. It is the same temperature as the melting point of the solid.

Frequency The number of waves that pass a point every second. The units are hertz (Hz).

Friction A force that resists or stops the movement of objects that are in contact with one another.

Fulcrum The point around which an object rotates. Also called pivot.

Fuse A safety device used in electrical circuits. It contains a thin wire that melts if too much current passes through, breaking the circuit.

g A measure of gravitational field strength. The value for Earth is 9.8 N/kg, which causes falling objects to accelerate at 9.8 m/s^2 in the absence of air resistance.

Galaxy A large collection of stars and clouds of gas and dust that are held together by gravity.

Gamma decay A form of radioactive decay in which an atomic nucleus emits gamma radiation—a dangerous, high-energy type of electromagnetic radiation.

Gamma rays Electromagnetic radiation with the highest energies, highest frequencies, and shortest wavelengths. It is emitted from the nuclei of decaying radioactive atoms.

Gas A state of matter in which the particles are far apart and move about randomly and quickly.

Gears Mechanical devices such as interlocking cogs that make the turning effect of a force bigger or smaller. Gears can make machines like cars move faster (but with less force) or slower (with more force).

Geiger-Müller (GM) tube An instrument used to detect and measure radiation. It consists of two plates with a high voltage across them. Ionizing radiation causes a spark to jump between the plates, which is detected by circuitry in the instrument. This circuitry and the GM tube are together called a Geiger counter.

Geocentric model A model of the Universe with Earth at its center.

Geostationary orbit A satellite in geostationary orbit is positioned over the equator, moves in the same direction that Earth turns, and takes about 24 hours to orbit Earth once. To an observer on Earth, the satellite appears stationary in the sky.

Global warming A rise in the average temperature of Earth's atmosphere caused by increasing levels of greenhouse gases. One of the main causes is the burning of fossil fuels, which releases the greenhouse gas carbon dioxide.

Gradient The steepness of a line. Gradient is measured by dividing the vertical distance between two points on the line by the horizontal distance between these same two points.

Gravitational constant (*G*) More commonly referred to as "big *G*," this is a tiny number used in gravity calculations. Its smallness tells us that gravity is a very weak force that needs very massive objects to produce a noticeable gravitational field.

Gravitational field The space surrounding an object with mass, in which another object with mass will experience an attractive, gravitational force.

Gravitational field strength The force with which a gravitational field pulls on a mass of 1 kg. Units are N/kg. *See also* acceleration due to gravity.

Gravitational potential energy (GPE) The energy that a body has as a result of its mass and position (usually height) in a gravitational field. Lifting an object increases its store of GPE.

Gravity A force of attraction between all objects that have mass. Earth's gravity keeps our feet on the ground and makes objects fall when we drop them.

Greenhouse effect The way in which gases such as carbon dioxide trap heat in Earth's atmosphere. The build-up of these gases leads to global warming.

Greenhouse gases Gases such as carbon dioxide and methane that absorb energy reflected by Earth's surface, stopping it from escaping into space.

Ground wire Also known as an earth wire, a wire connected to the metal case of an appliance such as a tea kettle. If there is a fault and the case becomes "live," then a large current immediately flows from the case through the ground wire. This causes a fuse to melt or triggers a circuit breaker, making the appliance safe.

Grounded An electrical appliance is grounded if it is connected to a ground wire.

Half-life The time taken for radioactivity in a sample to drop to half of its original value. In other words, the time taken for half the radioactive atoms in the sample to decay.

Heat Energy stored in the movement of atoms (vibrations for solids). Heat can be transferred by conduction, convection, and infrared radiation.

Heliocentric model A model of the solar system with the Sun at its center.

Hertz (Hz) The SI unit of frequency. One hertz is one cycle (one complete wave) per second.

Hooke's law This law says that the deformation (stretching or squeezing) of a material is proportional to the force applied to it. This law applies up to the elastic limit, beyond which the material will not spring back into its original shape when the force is removed.

Hypothesis An educated guess or idea about how something works. Scientists test their hypotheses by carrying out experiments.

Incident ray The ray of light that enters a lens or shines upon ("is incident upon") a mirror.

Independent variable The variable in an experiment that is deliberately changed so its effect on the dependent variable can be measured.

Induced magnet A material that becomes temporarily magnetized when placed in a magnetic field. For example, the iron core of an electromagnet becomes an induced magnet when the electromagnet is switched on.

Industrialization The widespread development of industries in a country, often leading to the growth of cities and road or rail networks.

Inelastic collision A collision in which kinetic energy is lost and the colliding objects change shape permanently. A collision between cars is inelastic. *See also* elastic collision.

Inertia The tendency of an object to keep moving in a straight line or remain at rest until a force acts on it.

Inertial mass A measure of how difficult it is to change the velocity (speed and/or direction) of an object.

Infrared radiation Electromagnetic radiation with a lower frequency and longer wavelength than visible light. Infrared radiation transfers heat and is used by remote control devices for televisions.

Infrasound Sound with a frequency less than about 20 Hz. This sound cannot be heard, as it is too low for the human ear to detect.

Instantaneous speed The speed at which an object is traveling at any particular moment. Speedometers on cars show instantaneous speed. *See also* average speed.

Insulator A material that reduces or stops the transfer of heat, electricity, or sound.

Interference The process whereby two or more waves combine, either reinforcing each other or cancelling each other out.

Internal energy The total kinetic and potential energies of all the particles in a system.

Inversely proportional If two variables (such as pressure and volume of a fixed amount of gas in a container) are inversely proportional, then as one increases, the other decreases in such a way that their product (pressure × volume) remains constant. For example, if you double the pressure of a gas at constant temperature, then the volume will halve.

Inverted image An image that is upside down in comparison with the object being viewed.

Ion An atom (or group of atoms) that has lost or gained one or more electrons and so become electrically charged.

Ionizing radiation Radiation (nuclear or electromagnetic) with enough energy to remove the electrons from the outer shells of atoms to form ions.

Irradiated An object or material that has been exposed to ionizing radiation.

Isolated system A system that matter and energy cannot leave or enter.

Isotopes Forms of an element that have different numbers of neutrons in the atomic nucleus but the same number of protons.

Joule (J) The unit of energy, equal to the work done by a force of 1 N moving 1 m in the direction of the force.

Kelvin (K) A scale of temperature that begins at absolute zero (–273°C). Its unit of measurement is the kelvin. A rise or fall of 1 K is the same as a rise or fall of 1°C.

Kilowatt (kW) A unit of power equal to 1000 watts.

Kilowatt-hour (kWh) A unit of energy used by utility companies in energy bills. 1 kWh is the energy transferred when a 1 kW appliance is used for 1 hour. 1 kWh is equal to 3 600 000 joules.

Kinetic energy The energy stored in an object because of its movement. Its value increases with the object's speed and mass.

Latent heat The energy transferred during a change of state at constant temperature. Latent energy is absorbed when ice melts and when water boils but is released when steam condenses and when water freezes.

Law of conservation of energy A law stating that you cannot create or destroy energy. Energy can only be stored or transferred.

Law of conservation of momentum A law stating that the total momentum of a system before and after a collision remains constant as long as no outside resultant forces are acting on the system.

Law of reflection This law says that when light is reflected from a plane (flat) mirror, the angle of incidence equals the angle of reflection.

LED Light-emitting diode. An electrical component that only allows current to flow in one direction and that emits light when current flows through it.

Lens A curved, transparent piece of plastic or glass that can bend light rays using refraction.

Lift The upward force produced on a wing when it moves through the air.

Light Electromagnetic radiation that our eyes can see. White light is a mixture of all the colors of the rainbow, which together make up the visible spectrum. Some scientists use the term "visible light" for radiation our eyes can see and "light" for all kinds of electromagnetic radiation.

Light-dependent resistor (LDR) A component whose resistance increases or decreases in a predictable way when the amount of light that it absorbs changes. LDRs are useful in control systems—for example, in automatically turning street lights on when it gets dark.

Light-year A unit of distance used in astronomy. One light-year is the distance traveled by light in one year, equal to 9.46 trillion km (9.46×10^{15} m).

Limit of proportionality If you stretch a material beyond this point, then Hooke's law won't apply. The relationship between force and extension is no longer a straight-line graph (linear); it becomes curved (nonlinear).

Line of best fit A line drawn through scattered data points on a graph so that it comes close to as many of them as possible. Drawing a line of best fit helps identify the relationship between the independent and dependent variables.

Linear relationship Two variables have a linear relationship if the graph of this relationship is a straight line. For example, a material that obeys Hooke's law shows a linear relationship between the force applied to it and the extension.

Liquid A state of matter between a solid and a gas in which the particles can slide around but remain close together and attract one another.

Live wire The wire in an electrical circuit that carries the electric current.

Load The total force pushing on an object or opposing the movement of an object, such as the weight of heavy material in a loaded wheelbarrow.

Longitudinal wave A wave in which particles vibrate back and forth along the direction of travel of the wave.

Lubrication Using oil or other lubricants to reduce friction.

Luminous A luminous object emits its own light—for example, a candle or a star.

Magnet Any object that produces a magnetic field.

Magnetic field The space around a magnet where it can affect magnetic materials. Magnetic fields decrease in strength as you move farther from the magnet.

Magnetic poles 1. The two ends of a magnet, called the north and south poles. 2. The two points on Earth toward which a compass needle points.

Magnetism The property of some materials, especially iron, to attract or repel similar materials.

Main sequence star A star in the middle of its life. A main sequence star, like our Sun, emits energy by fusing hydrogen into heavier elements such as helium.

Mantle (Earth) The large part of Earth's interior between the outer core and the crust, made of rock.

Mass The amount of matter in an object, measured in grams, kilograms, or tons. Mass and weight are not the same. Weight is the gravitational force between Earth and the object with mass being considered.

Mass number Also called the nucleon number, the total number of protons and neutrons in the nucleus of an atom.

Matter Anything that has mass and occupies space.

Medium The matter through which a wave is traveling.

Megawatt (MW) A large unit of power equal to 1 million watts (10^6 W). This unit is commonly used in describing electricity generation.

Melting point The temperature at which a solid turns into a liquid. It is the same temperature as the freezing point of the liquid.

Microwaves Electromagnetic waves with a wavelength longer than that of infrared rays but shorter than that of radio waves. Microwaves are sometimes said to be a type of radio wave.

Molecule A particle of matter made of two or more atoms strongly bonded together.

Moment Also known as torque, the turning effect of a force, such as a wrench turning a nut. The moment of a force is calculated by multiplying the force by its perpendicular distance from the pivot. The unit is the newton meter (Nm).

Momentum The tendency of an object to keep on moving, equal to its mass times its velocity. Units are kg m/s.

Motor A machine that uses electricity and magnetism to produce motion that is usually rotational.

Nearsighted Unable to see distant objects clearly. Nearsightedness can be corrected by wearing glasses with diverging lenses.

Nebula A huge cloud of dust and gas in space in which new stars may form.

Net force When you add up the forces on an object and take into account their directions, the result is a single force that would have the same effect, called the net force or resultant force.

Neutral wire The wire that completes the circuit in electrical circuits. It is usually kept at zero volts.

Neutron One of the two main particles in the nucleus of an atom. It has no electric charge and a relative mass of 1.

Newton (N) The unit of force.

Newton meter (Nm) The unit of the moment of a force.

Noncontact force Any force that acts at a distance. Noncontact forces include gravity, magnetism, and electrostatic forces.

Nonlinear A relationship between two variables that is not a straight line on a graph. For example, if you double the current flowing in an electrical device, then the power of the device rises by four times.

Nonrenewable resource A resource that will eventually run out, such as coal, oil, or gas.

Normal A line drawn at 90 degrees to the plane of a mirror or lens. Angles of light rays are measured from this line.

Normal force The part of a contact force that acts at 90 degrees to the surface being considered.

Nuclear energy 1. Energy stored in the bonds between the particles in an atomic nucleus. This may be released by nuclear fusion or nuclear fission. 2. Electricity generated by a nuclear power station.

Nuclear equation Similar to a chemical equation, a nuclear equation describes the changes that take place during nuclear reactions such as fission, fusion, and radioactive decay.

Nuclear fission A process in which the nucleus of an atom splits into two smaller nuclei, releasing energy.

Nuclear fuel The fuel for nuclear reactors. Most commonly, this is enriched uranium (uranium-235), but some reactors use other fuels, such as plutonium or thorium.

Nuclear fusion A process in which atomic nuclei fuse (join) to form heavier nuclei, releasing energy. Stars such as the Sun are powered by the fusion of hydrogen nuclei to make helium.

Nuclear power station A power station in which energy released by nuclear fission reactions is used to generate electricity. This energy is used to heat water to make steam, which is used to drive generators to produce electricity.

Nucleon A proton or a neutron; in other words, any particle in an atom's nucleus.

Nucleon number The total number of protons and neutrons in the nucleus of an atom. Also called mass number.

Nucleus (plural nuclei) The center of an atom, made up of protons and neutrons. It contains most of the atom's mass.

Ohm (Ω) The unit of electrical resistance.

Orbit The path of a body around another, more massive body, such as the path of Earth around the Sun.

Oscillation A regular movement back and forth.

Oscilloscope An instrument that shows electrical signals on a screen. It is often used to help us visualize waves, such as sound waves.

Outlier An item of data that does not fit the pattern of the other data points. Outliers are usually errors but may sometimes reveal something unexpected about a system. Ideally, an experimenter will return to the experiment and try to measure the outlier again.

Parallel (electrical circuits) Components connected in parallel are connected side by side in parallel branches rather than in a line (in series).

Particles Basic units from which all substances are made, such as atoms or molecules. Subatomic particles are those smaller than an atom, such as protons.

Pascal (Pa) The unit of pressure. 1 Pa is a force of 1 N spread over an area of 1 m^2.

PET scanner A machine used in medicine to form images of processes in the body to help diagnose diseases. PET stands for positron emission tomography.

Photogate A device that detects moving objects when they pass between a source of light and a light sensor, allowing precise measurements of time to be taken.

Physics The scientific study of force, motion, matter, and energy.

Pivot The point around which an object rotates. Also called fulcrum.

Plane A flat surface.

Plate tectonics The theory that explains volcanoes, earthquakes, and other geological phenomena. It says that the surface of Earth is divided into large plates that are able to move against each other.

Position–time graph A graph that represents a journey with distance on the vertical (y) axis and time on the horizontal (x) axis. The slope of the line at any point is the speed at that moment.

Potential difference Also called voltage, the difference in electric potential between two points. Potential difference can be thought of as providing the "push" that makes electric current flow. It is measured in volts (V).

Potential divider An electric circuit that uses resistors in series for controlling the voltage supplied to a parallel branch in the circuit. One of the resistors is usually a component such as an LDR or thermistor.

Potential energy Energy stored in the shape or position of something. Gravitational potential energy is the energy stored in an object because of its height. Elastic potential energy is stored in objects when they are stretched, squeezed, or twisted.

Power A measure of how quickly energy is transferred. For example, a bulb with a power rating of 100 W converts 100 J of electrical energy every second into heat and light energy. The unit of power is the watt (W).

Pressure The force per unit area. For example, the pressure exerted by you on the ground is equal to your weight divided by the total area of your soles and heels. The units are N/m^2 or pascals (Pa).

Prism A triangular wedge of glass or other transparent material that can split white light into a spectrum of colors.

Proportional Two variables are proportional to each other if their graph is a straight line through the origin. If one variable is multiplied by a number, the other variable is also multiplied by the same number (so if one doubles, the other doubles, too).

Proton One of the two main particles found in the nucleus of an atom. It has a relative mass of 1 and a charge of +1.

Proton number Sometimes called the atomic number, the number of protons in an atom's nucleus. Each element has a different proton number.

Radiation An electromagnetic wave or a stream of particles from a source of radioactivity.

Radio waves The longest wavelength, lowest frequency, and lowest energy form of electromagnetic radiation. Uses include communication and radar.

Radioactive A material is radioactive if it contains unstable atomic nuclei that decay into smaller nuclei, releasing ionizing radiation as they do so.

Radiotherapy The use of radioactive materials to treat cancer by destroying cancerous body tissue. This radioactivity may be focused on a very small spot in the body so there is minimal damage to healthy surrounding areas.

Ray diagram A diagram that represents light rays and how they are affected by lenses or mirrors.

Real image An image formed when light rays are focused on a surface such as a screen.

Red giant A late stage in a star's life when hydrogen in the star's core has been converted to helium, the core has collapsed, and outer parts of the star have cooled and greatly expanded, forming a large, red star.

Red supergiant An aging star similar to a red giant but on a much larger scale. These are the largest stars in the Universe.

Redshift The apparent stretching of light waves from distant galaxies into longer wavelengths. This is strong evidence that these galaxies are moving away from us and from each other, which indicates that the Universe is expanding.

Refraction The bending of a wave as it speeds up or slows down on moving from one medium to another. Refraction of light makes a stick placed in water look bent at the point it enters the water.

Regular reflection Reflection of light off a smooth surface, such as a mirror.

Relative mass The mass of a particle or molecule in comparison to one-twelfth of the mass of a carbon-12 atom. It is a useful unit when working with very small masses. Carbon-12 is chosen as a standard for convenience and historical reasons. Protons and neutrons have a relative mass of 1.

Renewable energy A source of energy that will not run out, such as sunlight, wave power, or wind power.

Repeatable (experiment) An experiment is repeatable if making the same measurement with the same equipment gives the same result.

Reproducible (experiment) An experiment is reproducible if someone else follows your method with different equipment and gets the same result.

Resistance A measure of how much a material opposes the flow of electric current. The units are ohms (Ω).

Resultant force When you add up the forces on an object and take into account their directions, the result is a single force that would have the same effect, called the resultant force or net force.

Sankey diagram A diagram that uses arrows of different widths to represent the quantity of energy flowing into a system and the useful and wasted energy leaving it. It is useful in showing and calculating the efficiencies of devices.

Scalar A quantity that has a magnitude (size) but no direction. Mass and temperature are scalar quantities. *See also* vector.

Seismic wave A wave that travels through Earth from an earthquake, large explosion, or other source.

Semiconductor A material partway between an electrical conductor (such as a metal) and an insulator (such as glass). Semiconductors are used in most electronic circuits.

Series (electrical circuits) Components connected in succession in an electrical circuit are described as being in series. The same current flows through all of them. *See also* parallel.

SI unit The standard, agreed international units for physical measurements. For example, the SI unit for mass is the kilogram. SI stands for Système International.

Significant figures The number of figures (digits) that an experimenter considers accurate in a measurement. For example, if timing a 100 m sprinter by hand with a stopwatch, including hundredths of a second would not be reasonable, as a human cannot be that accurate. Three significant figures in this case would be sufficient (two for seconds and one for tenths of a second).

Solenoid A cylindrical coil of wire that becomes a magnet when an electric current is passed through it.

Solution A mixture in which the molecules or ions of a substance are spread out in a liquid. For example, salt water is a solution.

Sonar Sound navigation and ranging. A method of detecting objects underwater by sending out sound waves and interpreting their echoes.

Sound A kind of wave that travels through matter, alternately squeezing particles together and then pulling them apart. Sound waves in air are detected by the human ear.

Specific heat capacity The amount of energy it takes to heat 1 kg of a substance by 1°C. The same quantity of energy is released when 1 kg of the substance cools by 1°C. Units are J/kg °C.

Specific latent heat The amount of energy taken in or released when 1 kg of a substance changes state without a change of temperature. The units are J/kg. *See also* latent heat.

Spectrum (electromagnetic) The range of the wavelengths of electromagnetic radiation. The full spectrum ranges from gamma rays, with wavelengths shorter than an atom, to radio waves, whose wavelengths may be many kilometers long. The visible spectrum is the part we can see.

Speed The distance traveled in a particular time. Speed is a scalar quantity and does not have a direction. Units are m/s, km/h, or mph. *See also* velocity.

Split-ring commutator A device in electric motors that reverses the electric current in the rotating coil at every half-turn of the coil. This means that the electromagnetic force acting on the coil is always pushing the coil in the same direction.

Spring constant A number describing the strength of a spring, usually represented by the letter *k*. The greater the spring constant, the more force is needed to stretch the spring. The units are N/m.

Standard form Also called scientific notation, a way of abbreviating very large or small numbers. The significant figures are written with a decimal point after the first figure, followed by the power of 10 this needs to be multiplied by. For example, the speed of light, which is about 300 000 000 m/s, can be written as 3.0×10^8 m/s.

Standing wave A standing wave forms when a wave interferes with its own reflection, resulting in peaks and troughs that do not move. Waves formed in the bodies and strings of musical instruments are standing waves.

Star A massive ball of incandescent gas inside which nuclear fusion produces large amounts of electromagnetic radiation. The fusion processes in stars produce nearly all the chemical elements in the periodic table.

States of matter The different physical forms that matter can take, such as solid, liquid, and gas.

Static electricity An electric charge held on an object, caused by the gain or loss of electrons.

Stopping distance The total distance traveled between a driver seeing a hazard on the road and the car stopping. Stopping distance = thinking distance + braking distance.

Streamlined Shaped to reduce the force of air or water resistance. Streamlined objects are usually narrow, with smooth, tapering shapes.

Subatomic particle A particle that is smaller than an atom, such as a proton, neutron, or electron.

Sublimation A change of state from solid straight to gas without becoming a liquid.

Supernova An explosion caused by the collapse of a massive star. A supernova may be many billion times brighter than the Sun. The vast energies of supernovas are enough to produce elements heavier than iron by nuclear fusion.

System The environment in which physical phenomena being studied exist. For example, in studying gases, we may choose a cylinder and piston as the system, but for studying climate change, it may be the entire planet.

Systematic error An experimental error typically caused by faulty equipment, such as a balance that has not been zeroed correctly. This type of error is nonrandom and makes every measurement wrong by the same amount.

Temperature A scientific measure of how hot or cold something is. Temperature is a measure of the average kinetic energy of particles in a system but not total internal energy. The units are °C (degrees Celsius) or K (kelvin).

Tension When forces pull an object in opposite directions, the object is in tension.

Terminal velocity The maximum velocity a falling object reaches when the force of air resistance balances the force of gravity pulling it downward. For example, when the air resistance experienced by a parachutist becomes equal to their weight, they stop accelerating and fall at terminal velocity.

Tesla (T) The unit of magnetic flux density. It is closely related to the strength of a magnetic field.

Thermal image A picture produced using infrared radiation rather than visible light, with colors representing temperature. Hotter objects are usually depicted as redder and colder objects as bluer.

Thermistor A resistor whose resistance changes with temperature.

Thinking distance The distance traveled by a vehicle between a driver seeing a hazard on the road and pressing the brake. It depends on the reactions of the driver.

Total internal reflection Reflection of light within a medium such as glass or water when the angle of incidence is greater than a certain critical angle, resulting in an angle of refraction more than 90°. Total internal reflection is used to trap light in fibre-optic cables.

Transformer A device that uses electromagnetic induction to increase or decrease the voltage of an alternating electricity supply.

Transverse wave A wave in which the particles of the medium vibrate at right angles to the direction in which the wave travels. Waves on water are transverse.

Turbine A machine with blades like a fan that spins when air or liquid flows through it. Turbines are used to drive the generators in power stations.

Ultrasound Sound with frequencies above 20 000 Hz, which are too high for humans to hear.

Ultraviolet (UV) light Electromagnetic radiation with a shorter wavelength than visible light. Higher-energy UV radiation is ionizing and can cause sunburn or even cancer. Uses of UV include security marking and disinfection.

Unbalanced forces Unbalanced forces produce a resultant (net) force on an object, causing acceleration or deformation (squashing or stretching).

Universe The whole of space and everything it contains.

Unstable isotope An isotope whose atomic nuclei are likely to break down and release radiation.

Upthrust The upward force exerted by a liquid or a gas on an object within it.

Uranium A radioactive element used as the fuel in nuclear power stations or as the active component in an atomic bomb.

Vacuum A space in which there is no matter.

Variables Things that might change in an experiment. Variables can be independent (the things you change), dependent (the thing you measure), or controlled (things you must keep the same).

Vector A quantity that has both magnitude (size) and direction, such as a force. *See also* scalar.

Velocity A measure of an object's speed and direction. Velocity is a vector quantity. The units are m/s or km/h.

Vibration Rapid back-and-forth movement. Musical instruments use vibration to generate sound waves.

Virtual image An image formed where light rays appear to be focused, such as a reflection in a mirror. Virtual images cannot be projected on a screen.

Visible spectrum The range of electromagnetic waves that we can see. The visible spectrum can be divided into seven colors: red, orange, yellow, green, blue, indigo, and violet.

Volt (V) The unit for potential difference (voltage).

Voltage A common term for electrical potential difference.

Voltmeter A device used to measure potential difference (voltage).

Volume The amount of space an object takes up. The units are m^3 or cm^3.

Water resistance A force that resists the movement of objects through water. Like air resistance, it always acts in the opposite direction to the object's motion.

Watt (W) The unit of power. 1 watt = 1 joule per second.

Wave Sound, light, and other energy transfers travel as waves—regular oscillations that spread out rapidly through matter or space.

Wavelength The distance between two successive peaks or two successive troughs in a wave.

Weight The force due to gravity felt by any object with mass. Weight is a force, so the units are newtons (N).

White dwarf The very hot, small, dense remains of a dead star.

Work The energy transferred when a force moves an object in a particular direction. The units are joules (J).

X-ray Electromagnetic radiation with high energy and frequency and very short wavelength. X-rays can penetrate most matter, which makes them useful for making images of bones and teeth.

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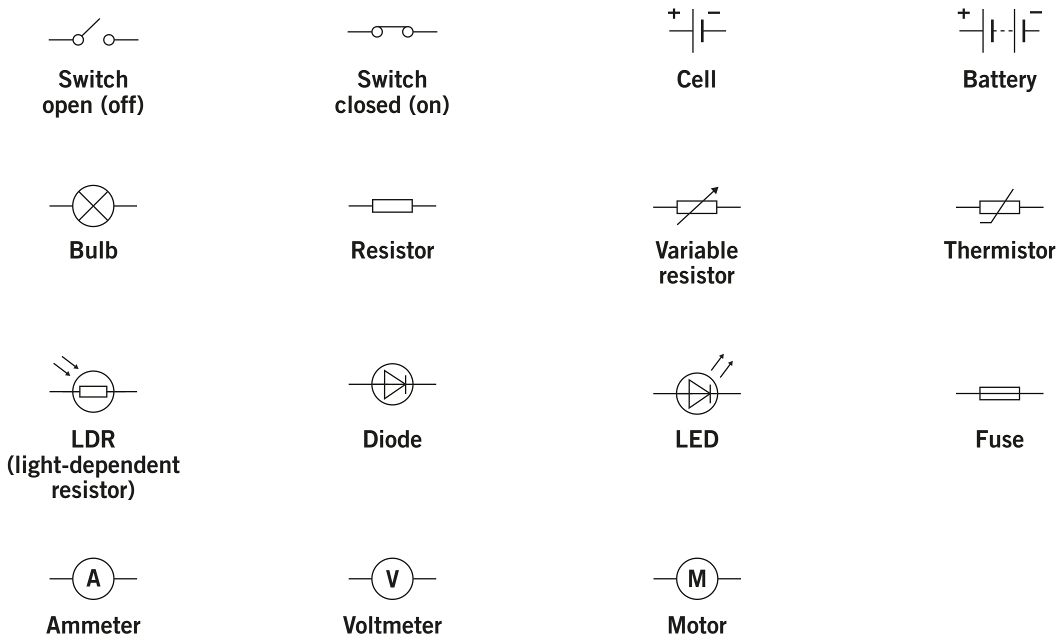

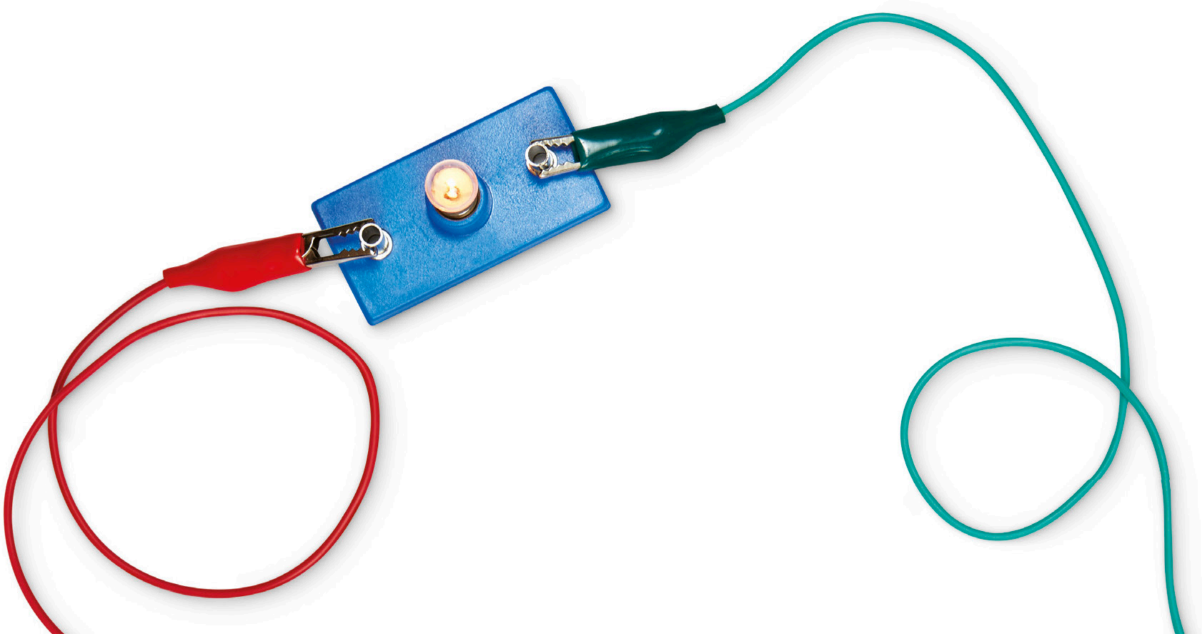

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