

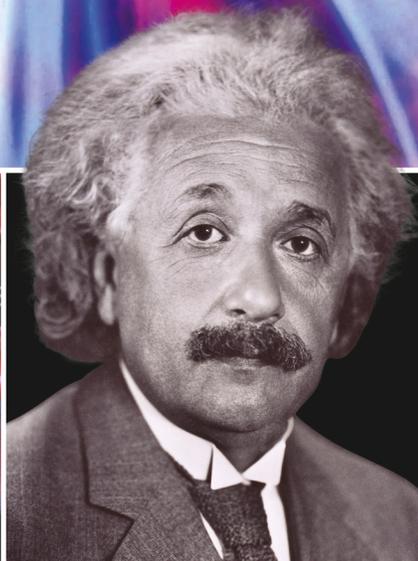
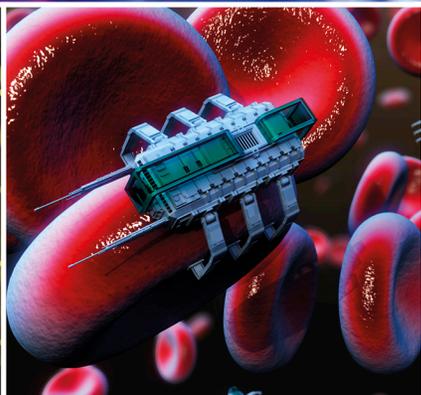
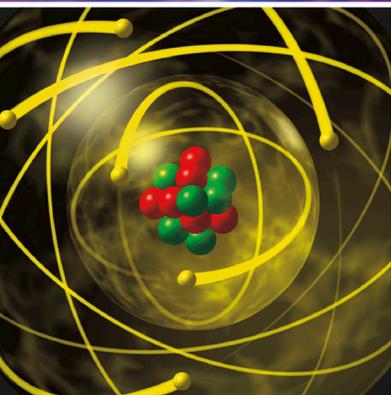
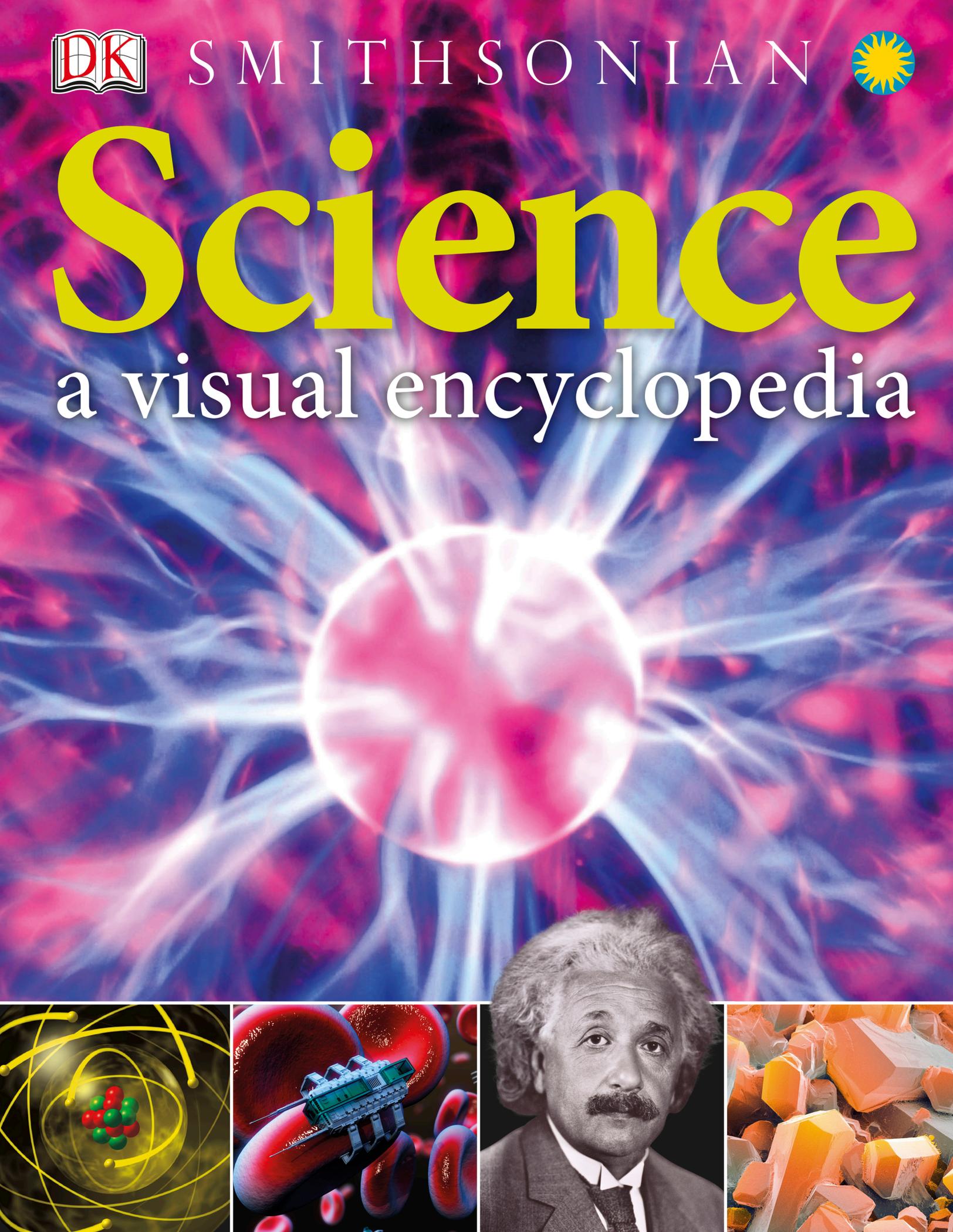


SMITHSONIAN



# Science

a visual encyclopedia





# Science

a visual encyclopedia







SMITHSONIAN



# Science

a visual encyclopedia





LONDON, NEW YORK,  
MELBOURNE, MUNICH, and DELHI

**Authors** Chris Woodford, Steve Parker

**Senior Editor** Daniel Mills  
**Senior Art Editor** Vicky Short  
**US Senior Editor** Shannon Beatty  
**US Editor** John Searcy  
**Senior Art Editor** Vicky Short  
**Art Editor** Mandy Earey  
**Managing Editor** Paula Regan  
**Managing Art Editor** Owen Peyton Jones  
**Preproduction Producer** Nikoleta Parasaki  
**Production Controller** Mary Slater  
**Jacket Designer** Laura Brim  
**Jackets Editor** Maud Whatley  
**Jacket Design Development Manager** Sophia MTT  
**Publisher** Sarah Larter  
**Art Director** Phil Ormerod  
**Associate Publishing Director** Liz Wheeler  
**Publishing Director** Jonathan Metcalf

**DK India**

**Senior Editor** Sreshtha Bhattacharya  
**Senior Art Editors** Anjana Nair, Chhaya Sajwan  
**Editor** Suparna Sengupta  
**Art Editors** Supriya Mahajan, Rakesh Khundongbam,  
Pallavi Narain  
**Assistant Art Editors** Ankita Mukherjee,  
Namita, Shruti Singhal  
**Managing Editor** Pakshalika Jayaprakash  
**Managing Art Editor** Arunesh Talapatra  
**Production Manager** Pankaj Sharma  
**Pre-production Manager** Balwant Singh  
**DTP Designers** Vishal Bhatia, Rajesh Singh Adhikari,  
Nand Kishor Acharya, Syed Md Farhan  
**Picture Researcher** Deepak Negi  
**Picture Research Manager** Taiyaba Khatoon

First American edition, 2014  
 Published in the United States by  
 DK Publishing, 345 Hudson Street,  
 New York, New York, 10014

Copyright © 2014 Dorling Kindersley Limited  
 All rights reserved

14 15 16 17 18 10 9 8 7 6 5 4 3 2 1  
 001-192677-08/2014

Without limiting the rights under copyright reserved above, no part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of both the copyright owner and the above publisher of this book. Published in Great Britain by Dorling Kindersley Limited.

A catalog record for this book is available from the Library of Congress.

ISBN: 978-1-4654-2046-6

DK books are available at special discounts when purchased in bulk for sales promotions, premiums, fund-raising, or educational use. For details, contact: DK Publishing Special Markets, 345 Hudson Street, New York, New York 10014 or SpecialSales@dk.com.

Printed and bound in China by South China Printing Co.

Discover more at [www.dk.com](http://www.dk.com)



Smithsonian  
Institution

**THE SMITHSONIAN**

Established in 1846, the Smithsonian—the world's largest museum and research complex—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 137 million. The Smithsonian is a renowned research center, dedicated to public education, national service, and scholarship in the arts, sciences, and history.

# Contents

<b>MATTER</b>	<b>6</b>
Defining matter	8
Atoms	10
Molecules	12
Solids	14
Liquids	18
Gases galore	20
Changing states	22
All the elements	24
Mixtures	26
Solutions and solvents	28
Acids and bases	30
Incredible reactions	32
Metals	36
Strange metals	38
Nonmetals	40
Hydrogen	42
Oxygen	44
Water	46
Nitrogen	50
Air	52
Carbon	54
Organic chemistry	56
<b>MATERIALS</b>	<b>58</b>
Defining materials	60
Plastics	62
Glass	64
Ceramics	66
Synthetic fibers	68
Composites	70
Earth's resources	74
Industrial materials	76
Recycling	78
Future materials	80
<b>FORCES AND MACHINES</b>	<b>84</b>
What are forces?	86
Forces and movement	88
Turning forces	90
Friction	94
Gravity	96
Bending and stretching	98
Simple machines	100
Engines and vehicles	104



Flight	106
Planes and helicopters	108
Rockets and spaceflight	110
Under pressure	112
Floating and sinking	116
Boats and submarines	118

## ENERGY 120

What is energy?	122
Types of energy	124
Potential and kinetic energy	126
Energy spectrum	128
Heat	132
Heat transfer	134
Radioactivity and nuclear power	136
Energy conversion	138
Waves	140
Sound	142
Music	146

## LIGHT 148

Light and shadows	150
Color	152
Lasers	156
Reflection and mirrors	158
Refraction and lenses	160
Telescopes and microscopes	162
Cameras	166
Moving pictures	168
Communicating with light	170

## ELECTRICITY AND MAGNETISM 172

Electricity	174
Circuits and current	176
Static electricity	178
Magnetism	182
Electromagnetism	184
Electric motors and generators	186
Using electricity	188
Electricity supply	190
Energy sources	192
Electronics	196
Radio and television	198
Computers	200
Cell phones	202
The Internet	204
Robots	206
Future technology	210

## LIVING ORGANISMS 212

Life on Earth	214
Classifying life	216
DNA and genes	218
Evolution	222
Simple life forms	224
Fungi	228
Plants	230
Photosynthesis	232
Plant life cycles	234
Invertebrates	236
Vertebrates	240
Energy from food	242
Predators and prey	244
Senses	248
Communication	250
Living together	252
Migration and hibernation	254
Habitats and ecosystems	256
Ecology and conservation	258
The human body	260
Body systems	262

## GREAT DISCOVERIES 264

Progress in science	266
Ancient science	268
Islamic science	270
Planets and pendulums	272
Gravity and rainbows	274
Evolution and adaptation	276
Invisible rays	278
It's all relative	280
Inside the atom	282
The secret of life	286
Great inventions	288
Glossary	292
Index	296
Acknowledgments	302





# MATTER

## **PARTICLE TRACKS**

All matter is made up of tiny particles called atoms. Scientists have figured out how to break atoms down into even smaller parts, which create beautiful curling patterns as they move through a detector.



Matter is the stuff of the physical universe. You are made of matter. So is this book, the air around us, planet Earth, the sun, and distant stars.



# Defining matter

Matter is the stuff of the universe—solids, liquids, and gases. And matter is not just here on Earth. It makes up all the stars, planets, moons, and the bits of dust and wisps of gas drifting in space, as well as the Earth and everything on it. The whole universe, as far as we know, is made up of matter and energy.

## STARDUST

Stars are made of matter. Sometimes, at the end of their lives, they explode, leaving behind clouds of dust called nebulae. Over billions of years, these nebulae come together and form new stars and planets. In fact, our Earth, and everything on it, is made of stardust.

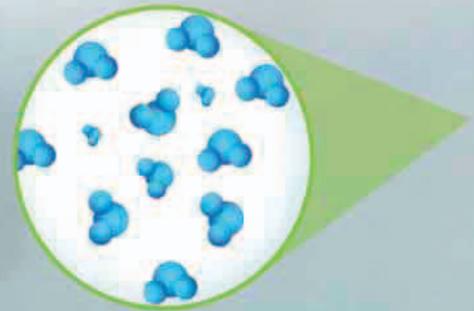


## STATES OF MATTER

All matter on Earth exists in one of three forms: solid, liquid, or gas. Some matter is solid—it is hard, tough, and keeps its shape. Some is liquid—it flows or runs, but it cannot be squeezed smaller or stretched bigger. Some is gas—it flows, and it can expand or be squeezed. These three forms are known as the states of matter.



▲ **SOLID** *In a solid, such as ice, particles of matter are close together and fixed in place.*



▲ **GAS** *The particles of matter in a gas, such as water vapor, are far apart, move fast, and change their distance from each other.*

► **LIQUID** *In water and other liquids, particles of matter are very close and can move around, but cannot change distance from each other.*





## PRECIOUS MATTER

Some matter and materials are common and not very special, such as ordinary rocks and soil. Other matter and materials are valuable for various reasons. Diamonds, rubies, and other jewels are prized because they are rare, have beautiful colors, and can be polished to a bright shine.

▲ SPARKLING STONES *This butterfly brooch is made from platinum and diamonds—two of the most expensive kinds of matter.*

WOW!

Matter can be converted to energy.

A tiny amount of matter makes an enormous amount of energy!

▼ STATES OF WATER *All you can see in this geyser at Yellowstone National Park is matter—steam (gas) rises from a pool of hot water (liquid), which is surrounded by snow (solid).*

## MATTER AND ENERGY

Matter can trap energy inside it.

The gunpowder in fireworks contains lots of chemical energy.

When it catches fire, it burns very fast, releasing the energy as light, heat, and sound. Gasoline in a car does the same, providing energy to move us around.



▲ RELEASING ENERGY *Adding various substances to the gunpowder in fireworks makes them burn with different colors. Iron produces yellow sparks, and copper gives blue-green sparks.*

## OTHER FORMS OF MATTER

There are two states of matter that are only found under special conditions. Plasma is formed when the particles in a gas gain an electronic charge. It is found in the sun, and also inside neon lights and plasma lamps. The other special state is called a Bose-Einstein condensate, which can be formed by cooling special gases to extremely low temperatures.

► PLASMA GLOBE *This globe contains a mixture of gases. A high-voltage electrode at the center gives the particles of gas an electric charge, forming glowing plasma.*



# Atoms

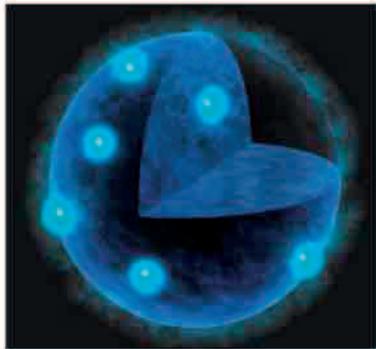
All matter is made up of tiny particles known as atoms. For a long time, people thought that there was nothing smaller than an atom, but we now know that atoms in turn are made up of even smaller *subatomic* particles called protons, electrons, and neutrons. Different types of atoms have different numbers of subatomic particles inside them. For example, hydrogen atoms have only one proton inside, while gold atoms have 197 protons.

## INSIDE AN ATOM

In the middle of an atom is the nucleus. This contains parts known as protons and neutrons, which hardly move from their central position. Whizzing fast around the nucleus are much tinier pieces called electrons. They travel around and around at a fixed distance from the nucleus, called a shell. Electrons only leave their shells if they absorb a jolt of energy.

## OLDER MODELS OF THE ATOM

We now know that atoms have a nucleus in the center surrounded by electrons. In the past, scientists had different ideas about how particles inside an atom fit together, and came up with different models to describe what atoms look like.



▲ “PLUM PUDDING” MODEL *In this old model, the parts of the atom are placed at random, like plums in a pudding.*



▲ PLANETARY MODEL *This later model shows electrons orbiting the nucleus of the atom, like planets around the sun.*

WOW!

Atoms are incredibly small. The dot on this *i* contains about one trillion atoms.





## PARTS OF AN ATOM

Despite their tiny size, each part of an atom has a mass (weight) and a type of electricity, or charge. A proton has a mass of 1 and a positive charge. A neutron also has a mass of 1 but carries no charge. An electron's mass is 1,850 times less than a proton's and it has a negative charge. Since positive and negative charges attract, electrons keep moving around protons and do not fly away.

PARTICLE	CHARGE	MASS	LOCATION
Proton	Positive (+)	1	Nucleus
Neutron	Neutral (0)	1	Nucleus
Electron	Negative (-)	1/1,850th	Shell

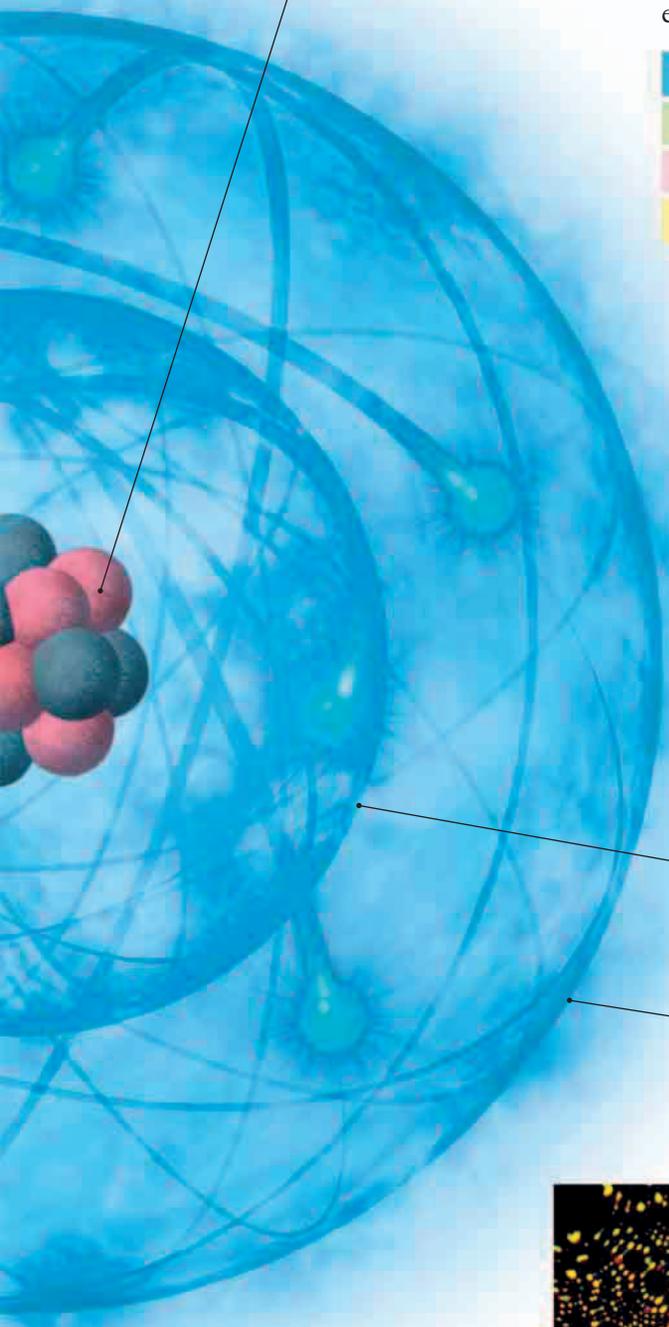
## MAKING MATTER

The number of protons, neutrons, and electrons in an atom determines what kind of substance it is. All atoms of sodium (a soft, silvery metal) have 11 protons, 12 neutrons, and 11 electrons. If the number of protons and electrons changes, a different substance is formed.

► **SODIUM LAMP** *This lamp passes energy into sodium atoms, making them rush around and give off light. Different types of atoms give off different colors of light when they are energized.*



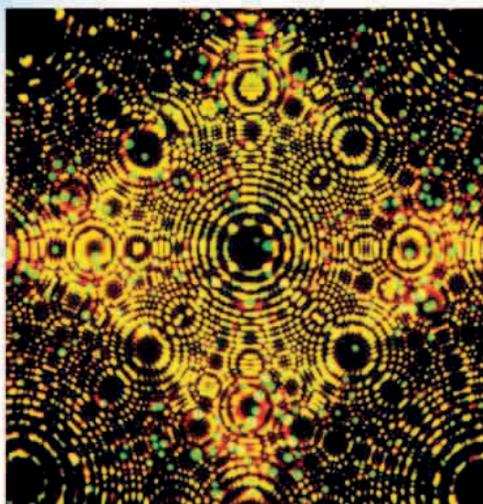
*Nucleus made up of protons (red) and neutrons (blue)*



*Inner layer (shell) of electrons*

*Outer layer (shell) of electrons*

▲ **SHELL MODEL** *The modern idea of an atom shows electrons moving in ball-shaped zones called shells. Each shell is at a fixed distance from the nucleus.*



## SEEING ATOMS

The most powerful microscopes make things appear millions of times larger, and can even show atoms. These microscopes do not use light rays. They are electron microscopes—they use beams of electrons aimed very carefully to pick up tiny details.

◀ **IRIDIUM ATOMS** *This electron microscope view shows atoms of the hard metal iridium as black spots with rings around them.*

# Molecules

Atoms rarely exist on their own. Usually they join with, or bond to, other atoms. Two or more atoms joined together are known as a molecule. If the atoms in a molecule are of different elements, they form a compound. Molecules vary hugely in size.

Some are just two atoms, such as molecules of the gas oxygen in air. Other molecules have millions of atoms, in materials such as wood, plastic, and rubber.

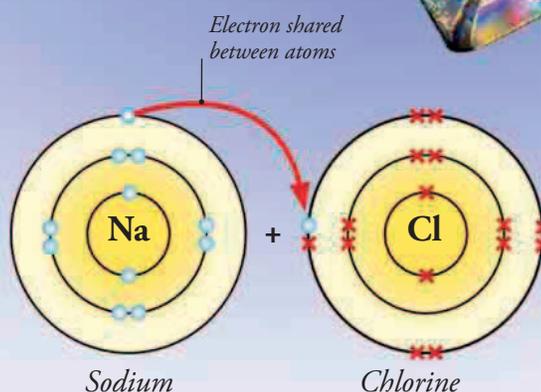
## SALT CRYSTAL

In salt, each molecule has two atoms. One is sodium (Na), which in its pure form is a very lightweight metal. The other is chlorine (Cl), which on its own is a greenish poison gas. Joined together, they produce a very different substance—sodium chloride (NaCl)—as tiny grains or crystals.

► **TRANSLUCENT CRYSTAL** *Billions of salt molecules arrange in regular patterns, like tiny bricks, to form a pyramid shape known as a crystal. It has flat sides, angled edges, and sharp corners.*

## HOW ATOMS JOIN

Atoms join into molecules in several different ways. One is to “share” the outermost parts of their atoms, called electrons. An atom of sodium has just one electron in its outermost zone or shell. Chlorine has seven, with a neat space for just one more. In a molecule, sodium’s outermost electron spends some time in its own atom, and some in the chlorine atom. This keeps the two atoms near each other.

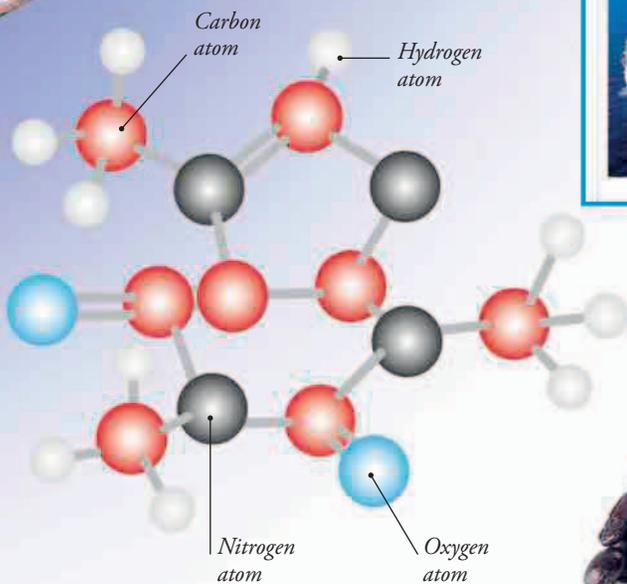
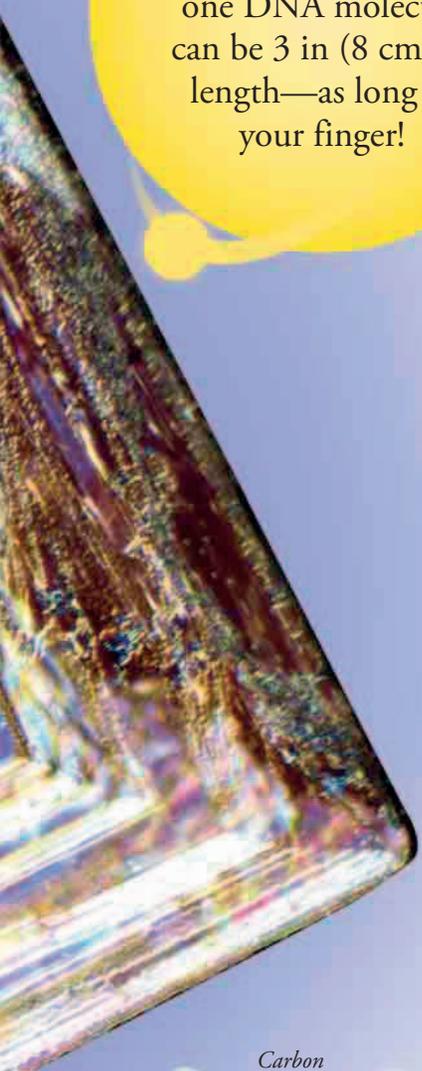


◀ **SODIUM CHLORIDE** *Electrons are negative, so the chlorine atom with an extra electron is negative, while the sodium atom without one is positive. Negative and positive attract, or pull nearer, helping the atoms stay together.*



WOW!

In a human body, one DNA molecule can be 3 in (8 cm) in length—as long as your finger!



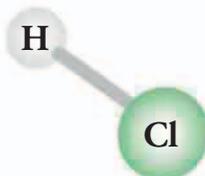
Caffeine molecule ( $C_8H_{10}N_4O_2$ )



◀ **COFFEE BEANS** In beans, caffeine is mixed with more than 1,000 other substances, including lactones and phenylidanes, which cause the bitter taste.

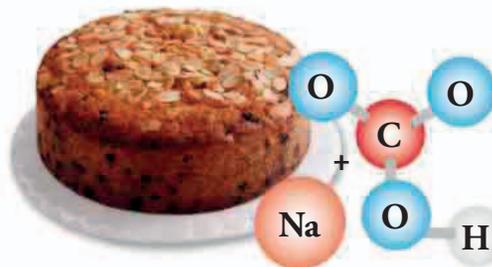
## SIMPLE MOLECULES

Most of the substances around us are compounds, which means their molecules contain atoms of more than one element. The simplest molecules have just two atoms, but even so they can be very different from the elements that make them up.



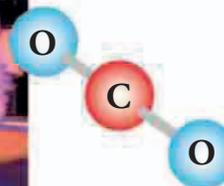
### Hydrochloric acid

Each molecule has just two atoms—hydrogen (H) and chlorine (Cl)—making hydrochloric acid (HCl). This acid is very powerful. The human body produces it inside the stomach to break down and digest food.



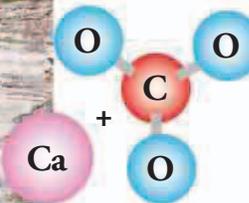
### Baking soda

Used in cooking, cleaning, and medicine, this molecule has six atoms: one sodium (Na), one hydrogen (H), one carbon (C), and three oxygen (O). As  $NaHCO_3$ , it is usually known as sodium bicarbonate.



### Dry ice

Dry ice (not frozen water) molecules have three atoms: two oxygen (O) and one carbon (C), forming carbon dioxide ( $CO_2$ ). It makes misty, foggy effects for stage shows.



### Chalk

One atom of the metal calcium (Ca) joins to one carbon (C) and three oxygen (O) to make calcium carbonate ( $CaCO_3$ ). One form of this is the bright white rock called chalk.

## COMPLEX MOLECULES

Some molecules can contain hundreds, even thousands, of atoms to make complicated structures. Carbon is particularly good at making complex molecules, since each atom of carbon can join to up to four neighboring atoms. Most living things are made of molecules containing carbon.

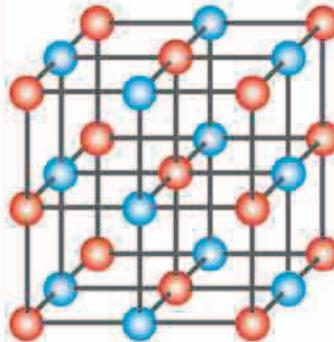


# Solids

In a solid, such as a brick or a lump of metal, the atoms or molecules are usually fixed in place. They cannot move around, or move nearer to or farther from each other. This means that most solid substances have a fixed shape that is difficult to change, except by powerfully squeezing or stretching them, or by breaking them apart. However, some solids are elastic, meaning their atoms can move apart slightly and come back together without breaking to pieces.

## INSIDE A SOLID

The molecules and atoms in a solid are joined by links known as bonds. These bonds are very strong and difficult to bend or break, which is why the solid keeps its shape. The bonds hold atoms together in regular shapes such as rows of six-sided boxes.



In this solid, the molecules form rigid, stiff cubes.

## TYPES OF SOLIDS

Solids can be light or heavy, hard or soft, shiny or dull, sharp or smooth. Some, like see-through crystals, have no color at all. The weight of a solid depends on the types of atoms inside it and the distance between them. Very heavy solids have close-packed, big, heavy atoms. The stronger the links, or bonds, between them, the more difficult it is to change the solid's shape.

WOW!

The heaviest naturally occurring solid is the metal osmium. It is twice as dense as lead.



▲ **LIGHT** One of the lightest solids is graphene aerogel—it can balance on a flower. It is made of atoms of the substance carbon, with lots of empty space in between.



▲ **MEDIUM** Wood has several kinds of small, light atoms, mostly of the substance carbon. There are also spaces between the atoms that were filled with water when the tree was alive.



▲ **HEAVY** Rocks such as basalt have atoms packed close together, which are extremely difficult to move. The atoms, which include those of the metal iron, are also heavy.



Amethyst quartz contains atoms of iron, which give it its violet color.



## CHANGING SHAPE

If you press or pull almost any solid with enough power, it will change shape or even break. While the molecules in the solid cannot move closer together, you can squeeze out air trapped between them.

Large lumps of a solid are hard to squash or stretch, but thin bars and sheets can often be bent or molded. This is known as deforming a solid.

- ▶ **CRUSHED** *Cars have lots of thin parts, and an industrial crusher has enough pressure to squash them almost flat.*

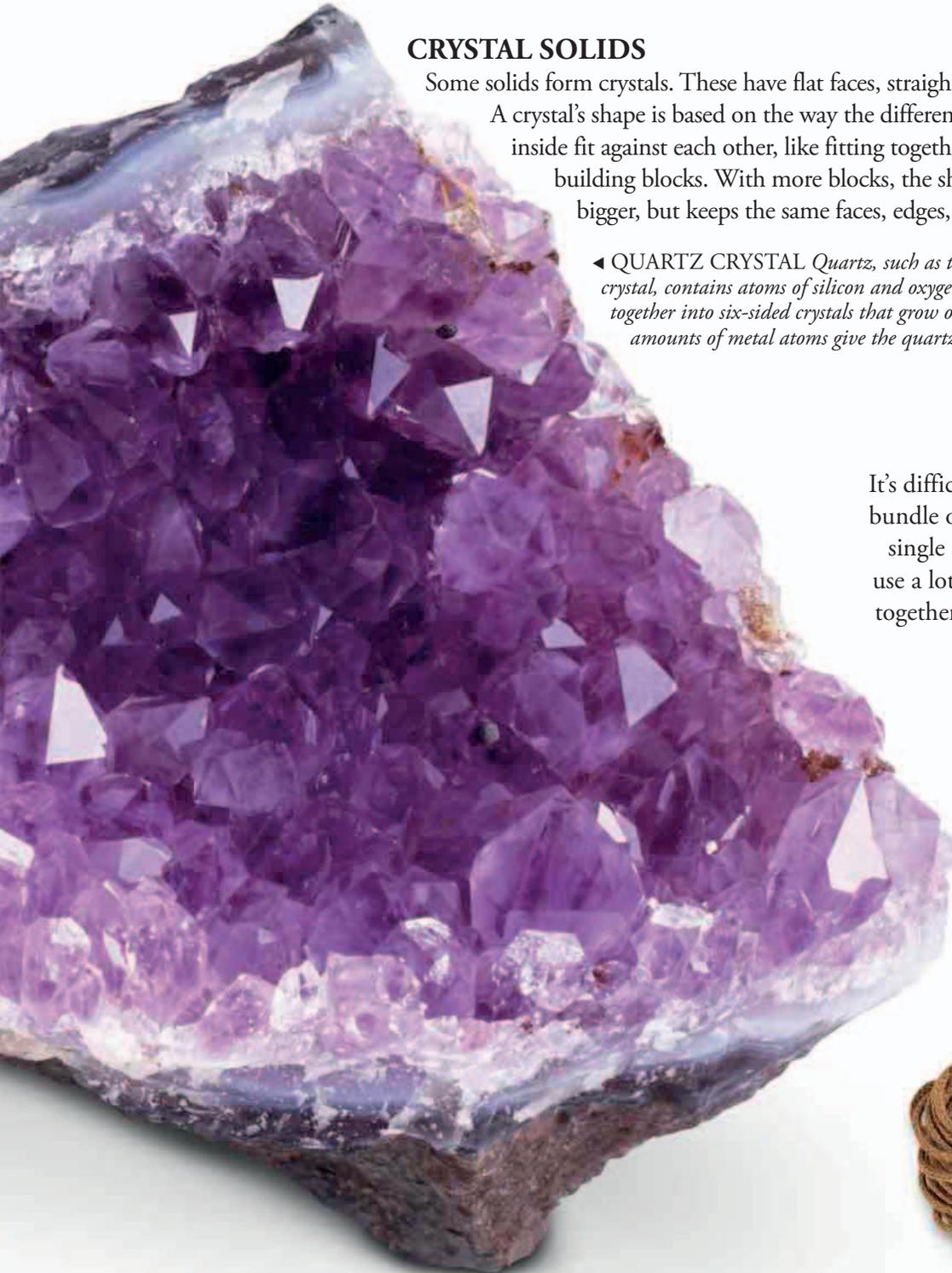


## CRYSTAL SOLIDS

Some solids form crystals. These have flat faces, straight edges, and sharp corners.

A crystal's shape is based on the way the different atoms and molecules inside fit against each other, like fitting together different-shaped building blocks. With more blocks, the shape gradually grows bigger, but keeps the same faces, edges, and corners.

- ◀ **QUARTZ CRYSTAL** *Quartz, such as this amethyst crystal, contains atoms of silicon and oxygen, which fit together into six-sided crystals that grow on each other. Tiny amounts of metal atoms give the quartz different colors.*



## FIBROUS SOLIDS

It's difficult to change the shape of a thick bundle of rope. Unwind the bundle and a single strand bends easily. Fibrous solids use a lot of fragile fibers twisted or woven together to create a much stronger fabric.

- ▼ **FIBERS** *Each fiber of rope or string is as thin as a hair. Twisted together, they are less flexible and much stronger.*



## CRYSTAL CAVE

Deep beneath the hills of northern Mexico lies a cave of natural wonders, full of giant white crystals of a mineral called gypsum. Intense heat and humidity from below the earth's surface have made the crystals grow to enormous sizes—up to 39 ft (12 m) long and weighing 55 tons (50 metric tons).





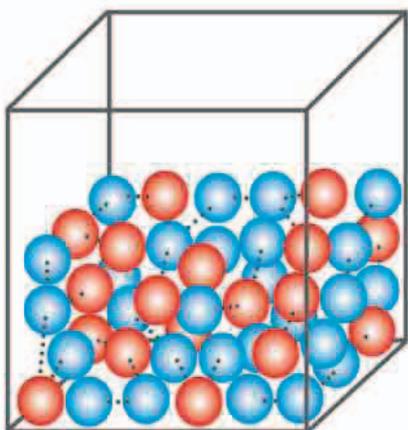
# Liquids

In liquids, unlike in solids, the atoms and molecules can move around. But they cannot alter their distances from each other. This means that a liquid can move and change shape, flowing to fill the space around it. It cannot change its volume—the amount of space it takes up—so liquids resist being squeezed or compressed.



## INSIDE A LIQUID

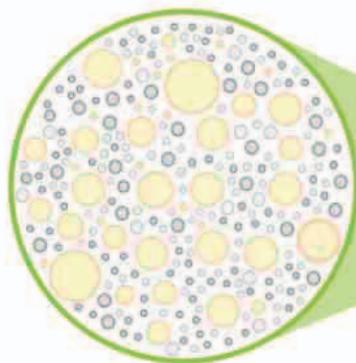
Atoms and molecules in a liquid are linked to each other, but in a loose, ever-changing way. They are free to move around in any direction, provided they stay the same distance from each other. They flow to the bottom of any container.



In liquids, bonds break and reform, allowing atoms and molecules to move.

## TWO LIQUIDS IN ONE

Milk is actually two liquids that do not mix, one floating around in the other. One liquid is tiny blobs, too small to see, of a substance called butterfat. These blobs are spread through the other liquid, which is mainly water. The scientific name for this type of double liquid is an emulsion. Some kinds of paints are also emulsions.



### ▲ MILK MAGNIFIED

*A microscopic view of the milk would show two kinds and sizes of liquids in it: large drops of butter fat and tiny molecules of water.*



## RESISTING PRESSURE

When trying to squeeze a liquid, the pressing force, called hydraulic pressure, spreads equally through all the liquid, which tries to escape through any gap or weak point. Turn on a faucet and the water inside, under hydraulic pressure, quickly flows out.

### ◀ PRESSURE POWER

*Opening these valves lets the high-pressure water inside come out fast. The higher the pressure, the stronger the spray.*



## THICK AND THIN

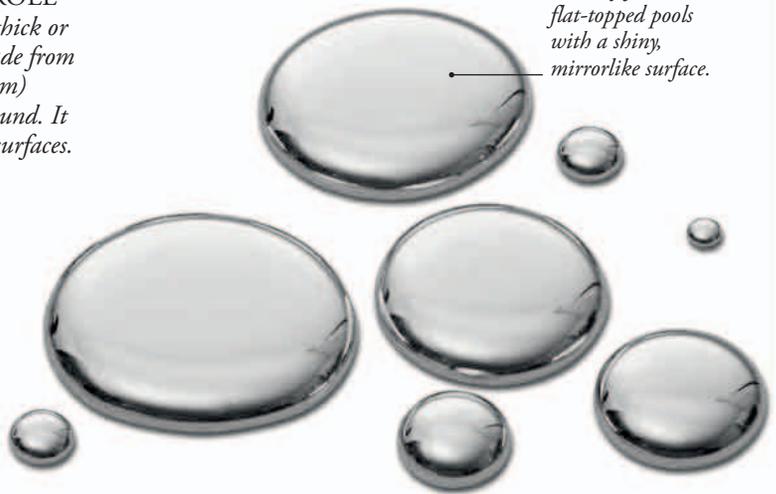
Some liquids, such as water and gasoline, are runny and thin. They flow and spread easily. Others, such as molasses and diesel fuel, are thicker and goeey, and do not flow as well. This feature of liquids is known as viscosity. Low viscosity means more runny, while high viscosity means thick and sticky.

### ◀ READY TO ROLL

*Asphalt is a very thick or viscous liquid, made from crude oil (petroleum) from under the ground. It is used to lay road surfaces.*

*Poured ribbons and folds of asphalt take a long time to spread out.*

*Larger blobs of mercury form flat-topped pools with a shiny, mirrorlike surface.*



## LIQUID METAL

Most metals are hard solids at normal temperatures. The exception is mercury, which is a shiny, silvery liquid. It does not turn solid, or freeze, until it gets below  $-38.2^{\circ}\text{F}$  ( $-39^{\circ}\text{C}$ ), which is much colder than the inside of a household freezer. (Water turns solid, or freezes, at  $32^{\circ}\text{F}$  or  $0^{\circ}\text{C}$ .)

**WOW!**

Pitch, a hard black substance, is so viscous that, when poured, it takes 10 years between drops!



# Gases galore

Like a liquid, a gas has no shape of its own. But, unlike a liquid, a gas can change its volume because its atoms and molecules can vary their distance apart. So a gas gets bigger and expands to fill its container as its atoms and molecules spread out. If there is no container, the atoms and molecules keep spreading apart, farther and farther.

MATTER



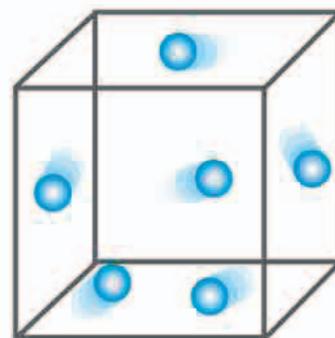
## GASES AND PRESSURE

In the same way that a gas expands to fill the space available, it can also be squeezed into a smaller space by a pushing force, or pressure. For example, when you pump air into a bicycle tire, you're squeezing gas into a tight space. The atoms and molecules bump into each other more, which makes the gas hotter. Take away the pressure and the gas expands once again.

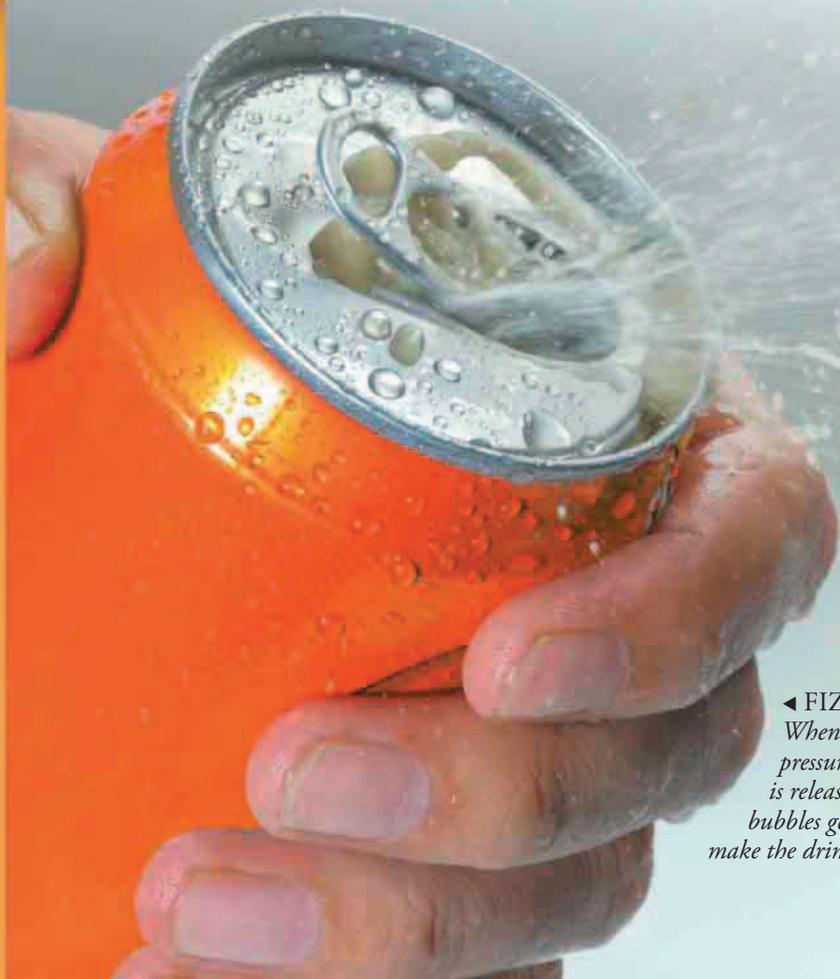


## INSIDE A GAS

Atoms and molecules in a gas are not linked to each other. They are free to wander, knock into each other, and bump into the sides of their container. Each time they collide, the atoms and molecules change direction but keep moving.



In a gas, the molecules roam freely.



### ◀ FIZZING

*When the gas under pressure in this can is released, its tiny bubbles get bigger and make the drink fizz.*

WOW!

Tungsten hexafluoride is such a heavy gas that a balloon filled with it falls through the air, almost like a stone.



▲ **HELIUM BLIMP** *This huge blimp is a giant version of a party balloon, filled with the very light gas helium.*

## FLOATING IN AIR

The air around us is a mixture of about 15 gases, each one weighing a different amount. The second-lightest gas is helium, making up five parts in every million parts of air. Collect enough helium to fill a balloon, or even a blimp, and it floats easily because it is lighter than air—that is, the mixture of gases around it is heavier.



## BURNING GASES

Materials such as metals are joined by a method called welding. A gas called acetylene burns in oxygen to create a flame so hot that it melts metal. The white flame has a temperature of up to 6,330°F (3,500°C)—three times the temperature of a log fire. The flame melts the edges of two pieces of metal so they flow together and, when cool, become one piece.

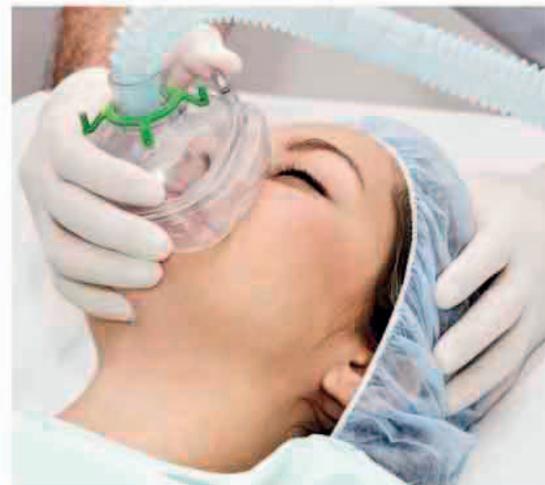
### ◀ HOT SMOKE

*A welder needs thick gloves and a pair of goggles to protect against the heat and brightness of a welding flame.*

## SLEEPING GAS

Every few seconds, we breathe in air because we need one gas in it—oxygen—to keep us alive. Before a hospital operation, doctors may give patients a mixture of other gases, called an anesthetic.

This makes the brain go to sleep, so that the patient does not feel pain during the operation.



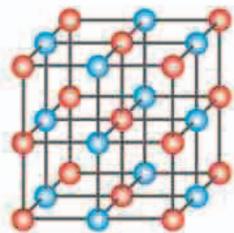
# Changing states

Most matter exists in one of three main states—solid, liquid, or gas.

Things change between the three depending on their temperature. Rock is usually hard and solid, but when it is heated to above 1,832°F (1,000°C) deep below the earth's crust, it melts to form a thick liquid known as magma. Water is a liquid at room temperature, but if we heat it to 212°F (100°C), it becomes a gas—water vapor.

## SOLIDS, LIQUIDS, AND GASES

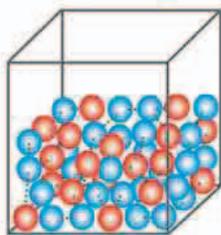
Almost any solid substance will melt—change from solid to liquid—if it gets hot enough. Add more heat and it bubbles and boils, turning from liquid into gas. Take heat away from it and the reverse happens: It condenses from gas to liquid, then freezes or solidifies from liquid to solid.



◀ **SOLIDS**  
*Low-energy atoms and molecules stay fixed in position and hardly move.*

Melting

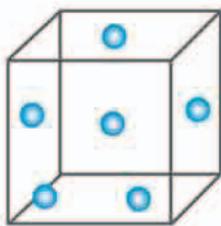
Freezing



◀ **LIQUIDS**  
*Medium-energy atoms and molecules flow but remain the same distance apart.*

Boiling

Condensing



◀ **GASES** *High-energy atoms and molecules fly around at random, changing distance and direction.*



## CHANGING ENERGY

When you heat a solid substance, its atoms get more energy. They begin to move around more, or vibrate. Eventually the atoms have enough energy to break out of their fixed positions in the solid. Then they start to move around and flow—at this stage, the solid becomes a liquid.

▲ **MELTING CHOCOLATE** *As heat seeps into solid chocolate from the outside, the parts around the edges melt. The inner parts are still slightly cooler, so they stay solid for a little longer.*

SUBSTANCE	MELTING POINT	BOILING POINT
Water	32°F (0°C)	212°F (100°C)
Chocolate	86–95°F (30–35°C)	230–248°F (110–120°C)
Candle wax	140–149°F (60–65°C)	464–482°F (240–250°C)
Cooking oil	–63°F (–17°C)	437–446°F (225–230°C)
Lead	620.6°F (327°C)	3,180.2°F (1,749°C)

## MELTING AND BOILING POINT

Every substance changes state at particular temperatures, known as the melting and boiling points. Pure chemicals, such as water or lead, have very precise melting and boiling points. Substances such as chocolate and cooking oil contain different ingredients mixed together, so their melting and boiling points can change.

WOW!

The metal rhenium has the highest boiling point of any element.

It turns to gas at 10,105°F (5,596°C).



## MISSING A STAGE

Some chemicals do not melt with increasing temperature. Instead, they turn from solid directly to gas, in a process called sublimation. These chemicals include carbon dioxide, iodine (above), and arsenic. Under suitable conditions, water ice can also turn directly into water vapor. The reverse process, when a gas changes directly into a solid, is called deposition.



## KEEPING COLD

Changing states involves energy. For example, melting takes in heat energy, while condensing gives off energy. A refrigerator works by turning a substance, called coolant, from liquid to gas and back again. Liquid coolant boils as it takes heat from inside the refrigerator, then cools to a liquid again by passing the heat to the air outside.

- ▶ **ELECTRIC COOLING** A refrigerator needs the energy of electricity to work its compressor. This sends the coolant around and around, moving heat from inside to outside.

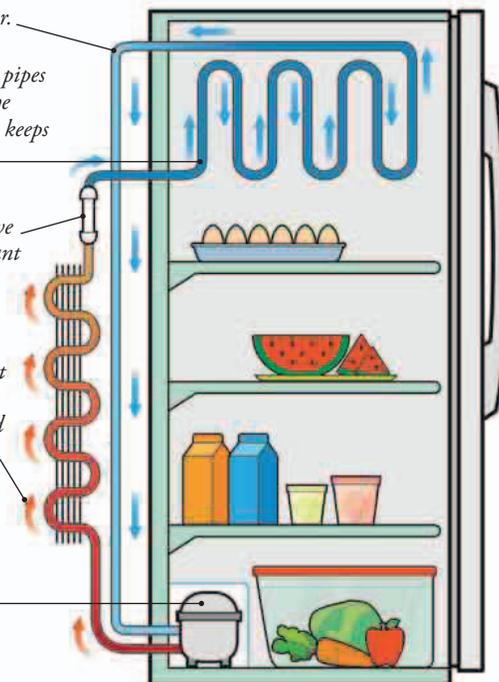
5. Gas coolant turns into liquid and goes back to compressor.

4. Gas coolant in pipes absorbs heat in the refrigerator—this keeps the inside cold.

3. Expansion valve turns liquid coolant into cooler gas.

2. Hot gas coolant releases heat through coils, and becomes a liquid.

1. Compressor pumps coolant.



# All the elements

An element is a pure chemical substance. All of its atoms are the same, and they are different from the atoms of any other substance. There are more than 100 elements. Some we see and use every day, while others are very rare and have strange features. Each element has a scientific symbol of one or two letters, such as *H* for hydrogen and *Ca* for calcium.

## SEEN AND UNSEEN

The periodic table allows us to predict how one element will react with another. The element iron, with the scientific symbol *Fe*, is a hard and shiny solid. In a common chemical reaction, one atom of iron joins with two atoms of the element oxygen (O) from the air around us. The result is the red-brown powder known as iron oxide or rust ( $\text{FeO}_2$ ).



Iron nail



Rusty nail

▲ **TWO ELEMENTS JOINED** *Shiny iron and invisible oxygen link together to form a very different substance—the compound iron oxide (seen as rust).*

## REACT OR NOT?

The elements at the far left of the table, alkali metals, are rarely on their own in nature. They are too reactive—they nearly always join with other elements to make compounds. On

the right of the table in the final column of elements, noble gases are the most unreactive—they hardly ever join with other atoms.



▲ **SODIUM** *A very lightweight metal, sodium always wants to react, even with water or air—it can suddenly burst into flames.*

## TABLE OF ELEMENTS

Elements are listed in a chart known as the periodic table. It shows two main features. Most of the elements on the left are metals, while those on the right are nonmetals. The elements in the rows, or periods, across the top are lighter, while toward the bottom they get heavier.

1 <b>H</b> Hydrogen 1		4 <b>Be</b> Beryllium 9			
3 <b>Li</b> Lithium 7					
11 <b>Na</b> Sodium 23		12 <b>Mg</b> Magnesium 24			
19 <b>K</b> Potassium 39	20 <b>Ca</b> Calcium 40	21 <b>Sc</b> Scandium 45	22 <b>Ti</b> Titanium 48	23 <b>V</b> Vanadium 51	24 <b>Cr</b> Chromium 52
37 <b>Rb</b> Rubidium 85	38 <b>Sr</b> Strontium 88	39 <b>Y</b> Yttrium 89	40 <b>Zr</b> Zirconium 91	41 <b>Nb</b> Niobium 93	42 <b>Mo</b> Molybdenum 96
55 <b>Cs</b> Cesium 133	56 <b>Ba</b> Barium 138	57–71 Lanthanide group	72 <b>Hf</b> Hafnium 179	73 <b>Ta</b> Tantalum 181	74 <b>W</b> Tungsten 184
87 <b>Fr</b> Francium 223	88 <b>Ra</b> Radium 226	89–103 Actinide group	104 <b>Rf</b> Rutherfordium 261	105 <b>Db</b> Dubnium 262	106 <b>Sg</b> Seaborgium 266
57 <b>La</b> Lanthanum 139	58 <b>Ce</b> Cerium 140	59 <b>Pr</b> Praseodymium 141	60 <b>Nd</b> Neodymium 144	61 <b>Pm</b> Promethium 145	62 <b>Sm</b> Samarium 151
89 <b>Ac</b> Actinium 227	90 <b>Th</b> Thorium 232	91 <b>Pa</b> Protactinium 231	92 <b>U</b> Uranium 238	93 <b>Np</b> Neptunium 237	94 <b>Pu</b> Plutonium 244



▲ **XENON** *A very rare gas, xenon is very unreactive. It has a few special uses in electronics, lasers, and medical scanners.*

26. Atomic number is the number of protons in an atom of the element.

**Fe** Symbol is a shorthand version of the element's scientific name.

Iron. Element's common name

56. Mass number is the total number of protons and neutrons in an average atom of the element.

◀ **READING THE TABLE**  
The table has more than 100 elements. Each element has an atomic number, symbol, name, and atomic mass.

Elements in the same column are called a group.

Rows of elements are called periods.

25 <b>Mn</b> Manganese 55	26 <b>Fe</b> Iron 56	27 <b>Co</b> Cobalt 59	28 <b>Ni</b> Nickel 58	29 <b>Cu</b> Copper 63	30 <b>Zn</b> Zinc 64	31 <b>Ga</b> Gallium 69	32 <b>Ge</b> Germanium 73	33 <b>As</b> Arsenic 75	34 <b>Se</b> Selenium 78	35 <b>Br</b> Bromine 80	36 <b>Kr</b> Krypton 85
43 <b>Tc</b> Technetium 99	44 <b>Ru</b> Ruthenium 102	45 <b>Rh</b> Rhodium 103	46 <b>Pd</b> Palladium 106	47 <b>Ag</b> Silver 107	48 <b>Cd</b> Cadmium 113	49 <b>In</b> Indium 115	50 <b>Sn</b> Tin 119	51 <b>Sb</b> Antimony 122	52 <b>Te</b> Tellurium 128	53 <b>I</b> Iodine 127	54 <b>Xe</b> Xenon 132
75 <b>Re</b> Rhenium 168	76 <b>Os</b> Osmium 191	77 <b>Ir</b> Iridium 193	78 <b>Pt</b> Platinum 195	79 <b>Au</b> Gold 197	80 <b>Hg</b> Mercury 201	81 <b>Tl</b> Thallium 205	82 <b>Pb</b> Lead 208	83 <b>Bi</b> Bismuth 209	84 <b>Po</b> Polonium 209	85 <b>At</b> Astatine 210	86 <b>Rn</b> Radon 222
107 <b>Bh</b> Bohrium 264	108 <b>Hs</b> Hassium 277	109 <b>Mt</b> Meitnerium 268	110 <b>Ds</b> Darmstadtium 281	111 <b>Rg</b> Roentgenium 272	112 <b>Cn</b> Copernicium 285	113 <b>Uut</b> Ununtrium 284	114 <b>Fl</b> Flerovium 289	115 <b>Uup</b> Ununpentium 288	116 <b>Lv</b> Livermorium 292	117 <b>Uus</b> Ununseptium 294	118 <b>Uuo</b> Ununoctium 294

MATTER



63 <b>Eu</b> Europium 152	64 <b>Gd</b> Gadolinium 158	65 <b>Tb</b> Terbium 159	66 <b>Dy</b> Dysprosium 163	67 <b>Ho</b> Holmium 165	68 <b>Er</b> Erbium 168	69 <b>Tm</b> Thulium 169	70 <b>Yb</b> Ytterbium 174	71 <b>Lu</b> Lutetium 175
95 <b>Am</b> Americium 243	96 <b>Cm</b> Curium 247	97 <b>Bk</b> Berkelium 247	98 <b>Cf</b> Californium 251	99 <b>Es</b> Einsteinium 254	100 <b>Fm</b> Fermium 257	101 <b>Md</b> Mendelevium 258	102 <b>No</b> Nobelium 259	103 <b>Lr</b> Lawrencium 262

- KEY**
- Alkali metals
  - Alkaline earth metals
  - Transition metals
  - Lanthanides
  - Actinides
  - Poor metals
  - Semimetals
  - Nonmetals
  - Halogens
  - Noble gases
  - Unknown

### STRANGE ELEMENTS

A few elements are so common that we mention their names often, such as carbon, iron, and tin. Others are rare and strange, with unfamiliar names and few uses. Some elements take their names from famous scientists, from the places the elements were first discovered or purified, or from ancient languages. The symbol for lead, *Pb*, comes from the ancient Roman name for lead, *plumbum*.

39  
**Y**  
Yttrium  
89

## Yttrium

- **Property** Soft, silvery metal
- **Atomic number** 39
- **Atomic mass** 89

This metal is named after the village of Ytterby in Sweden, where rocks rich in Yttrium were collected for chemical tests. It was first made in pure form in 1828.



87  
**Fr**  
Francium  
223

## Francium

- **Property** Heavy, reactive metal
- **Atomic number** 87
- **Atomic mass** 223

Discovered in 1939, francium is very hard to purify. It tries to combine with other elements and its atoms rapidly break apart, giving off radioactivity.



# Mixtures

A mixture occurs when different substances are mixed together, but no chemical reactions have happened between them. They may be swirled up and jumbled together, but all the individual parts are still on their own. They can be separated again fairly easily.

Mixtures of big things, such as rocks and sand, are easy to spot, but other mixtures, such as the air around us, are harder to see, and harder to split apart.

*Air is a mixture of several gases.*

*Seawater contains mixtures dissolved from rocks.*

◀ **BIGGEST** *Rocks are mixtures of several different chemicals.*

◀ **SMALLEST** *Sand is a mixture of many kinds of rock and shell, all ground up together.*

**WOW!**

Seawater is a mixture of more than 100 different substances, including salts, minerals, ores, and gases.

## MIXTURES ALL AROUND

A rocky shore is a mixture with all kinds and sizes of materials—sand, shingle, pebbles, and boulders heaped together. But waves may help separate these parts into different sizes, known as sorting. Slow-moving water easily picks up small grains of sand and swishes them together. Shingle is bigger and heavier and needs stronger waves, while pebbles are heavier still. Big boulders are hardly ever moved, even by the most powerful waves, and so are left higher on the shore.

## DIFFERENT KINDS OF MIXTURES

Some mixtures have large or coarse particles that are easy to see. Some have tiny ones we can hardly see, which float and stay still, or suspend, in a liquid. An alloy is a mixture of a metal with another substance. For example, steel is made of iron mixed with other metals and carbon to make it stronger. In a solution, the tiniest particles of a substance float in a liquid, but can be separated by boiling the liquid away.



## SEPARATION

A mixture can usually be divided into its separate parts physically, for example by shaking, filtering, or floating. This is because the parts have not joined or combined chemically to produce new substances, as they do in molecules and compounds. When a mixture's parts are sorted out and separated from each other, they are the same as before they were mixed together.



▲ **MAGNETIZING** Iron is pulled towards, or attracted by, a magnet, while sand is not. So a magnet can attract tiny bits of iron from a mix with sand, leaving behind the sand grains.

Different substances travel across the paper at different speeds, separating them from one another. This can help us see what is in the mixture.



▲ **COARSE MIXTURE** The different parts are easy to see in a seed mix. Sand and gravel are also coarse mixtures.



▲ **SUSPENSION** In muddy water, tiny particles of soil float around (are suspended) in the liquid.



▲ **ALLOY** The alloy brass, used to make instruments, is a mixture of copper and zinc. It combines features of both metals.

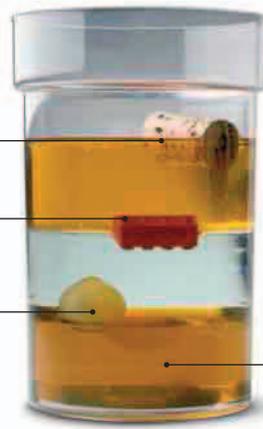


▲ **SOLUTION** Substances such as sugar dissolve in water. If the water dries out, the sugar is left behind.

Cork floats on oil.  
Oil floats on water.

Plastic brick sinks in oil but floats on water.

Onion sinks through oil and water but floats on syrup.



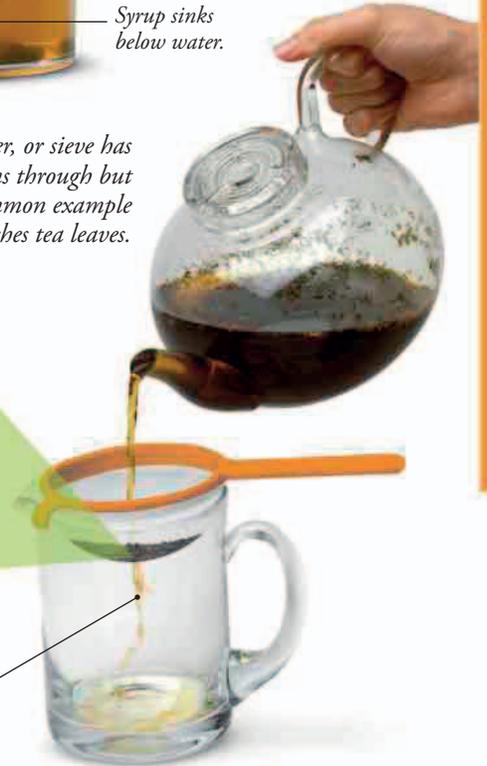
◀ **FLOATING** Shaken together, these substances mix. Left for a while in a jar, they separate again. The lightest ones float to the top—liquid oil, as well as the solid cork.

▼ **FILTERING** A filter, strainer, or sieve has holes that allow small items through but hold back larger ones. A common example is a strainer that catches tea leaves.



Tea leaves trapped by mesh of strainer.

Water flows through strainer.



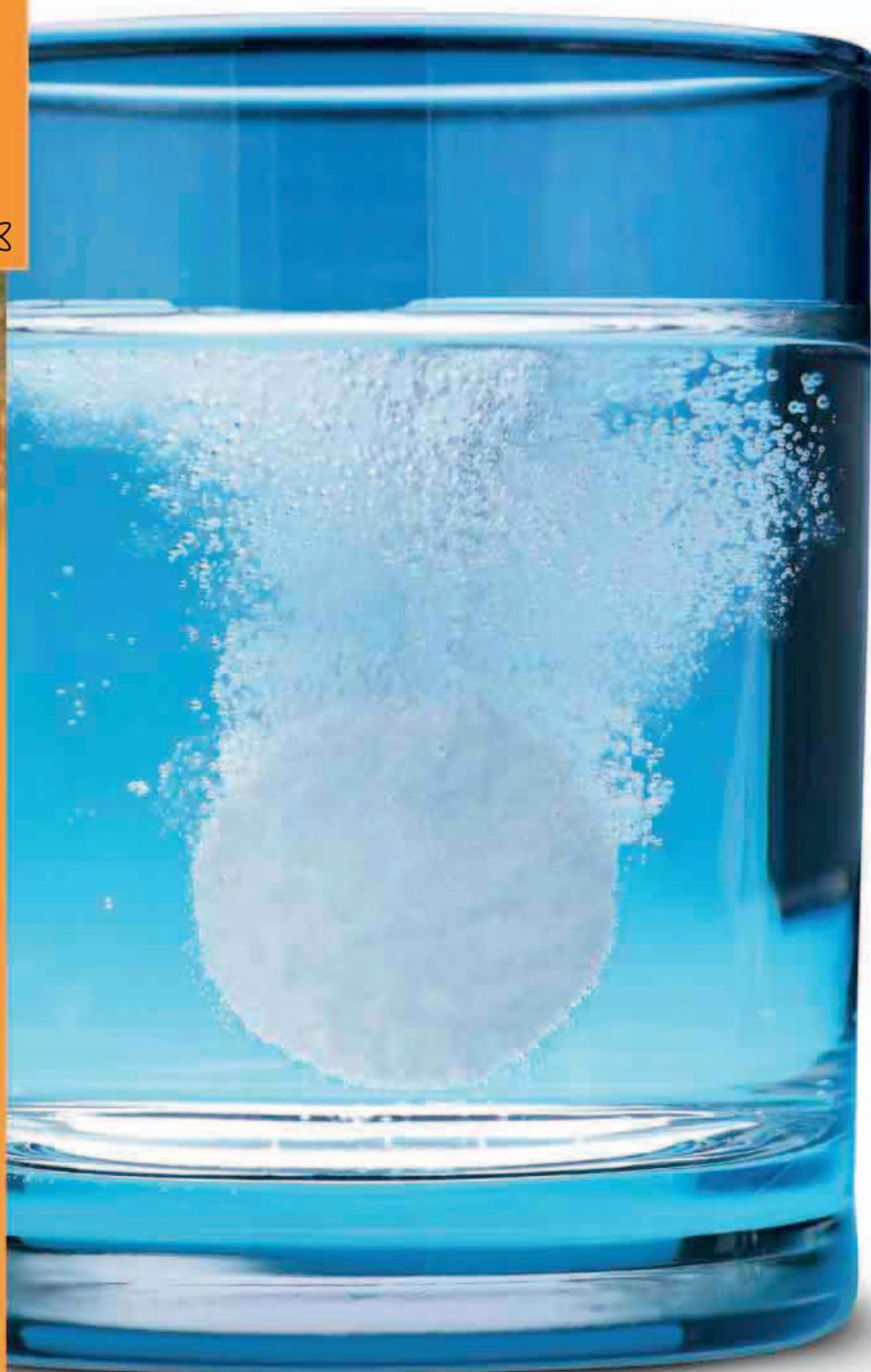
## SEPARATED BY SIZE AND SPEED

In the scientific method called chromatography, a liquid or gas is added to a mixture. This is then passed through a special substance, such as paper or gel. The smallest particles of the mixture move along fastest, the medium ones slower, and so on. The result is that the particles of the mixture separate by size, so we can analyze the mixture.



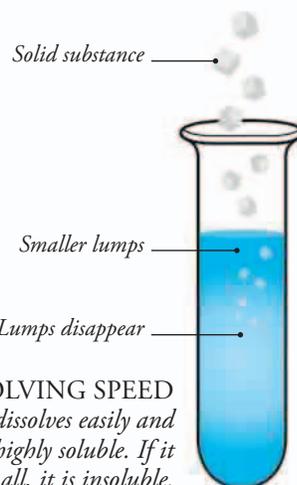
# Solutions and solvents

Some liquids, such as water, can pull solids apart. You can see this if you add sugar to water—the sugar seems to disappear as its molecules are pulled in different directions by molecules of water. This is a special kind of mixture called a solution.



## SMALLER AND SMALLER

We may be able to see a solid substance breaking apart into smaller and smaller pieces in a process called dissolving. It may break into several lumps. Each lump gets smaller as it loses material from the outside, which floats away in the liquid. The liquid in a solution is known as the solvent, while the stuff that dissolves is called the solute.



### ► DISSOLVING SPEED

*Something that dissolves easily and quickly is said to be highly soluble. If it does not dissolve at all, it is insoluble.*

## DILUTE AND CONCENTRATED

When a solute dissolves, it breaks up into tiny pieces—usually its smallest possible form, called molecules. These mix and float around among the molecules of the solvent. Just a little solute makes a dilute solution, while a lot makes it concentrated. The solute and the solvent do not join or combine. They form a mixture and can be separated again.

◀ **FIZZING** *As a tablet dissolves in water, some bits of it combine with water to make gas bubbles, while the rest dissolves and becomes invisible.*



## SATURATED SOLUTIONS

As more solute is added to a solution, the spaces between the solvent's molecules gradually fill. Eventually, there is no room left, so no further solute can dissolve. Any more of it stays as a solid. The solution is then said to be saturated. Heating the solution increases the movement of the solvent molecules, allowing a bit more solute to dissolve.

◀ **BACK TO SOLID** *When a hot saturated solution cools, some of the solute can no longer stay dissolved. It turns back into a solid, usually crystals, like the sodium acetate in this picture.*

## COMMON SOLVENTS

The most common solvent is water, in which many substances dissolve. In daily life, we use other solvents for special purposes—sometimes for solutes that do not dissolve in water, and therefore are hard to wash away.

NAME OF SOLVENT	DESCRIPTION
Petroleum spirit	Makes paint thinner (more dilute), cleans paintbrushes, removes paint stains and grease
Nail polish remover	Gets rid of nail polish, which is specially designed not to be washed away by water
Laundry stain remover	A mix of solvents that dissolve various substances that water cannot dissolve, such as fat and wax
Hand cleanser	Breaks up, dissolves, and removes oil and grease, plus the dirt and germs stuck in them



## DISSOLVED COLORS

Watercolor paints are made from special substances called pigments, which have strong colors and are soluble in water. Mix the paint with water and these colored pigments dissolve and spread out. After painting, the water evaporates (dries) and leaves behind the colored pigment. Other types of paints contain different solvents, such as alcohol or oil.

**WOW!**

The solvent DMSO (dimethyl sulfoxide) dissolves thousands of substances—which makes it very poisonous.

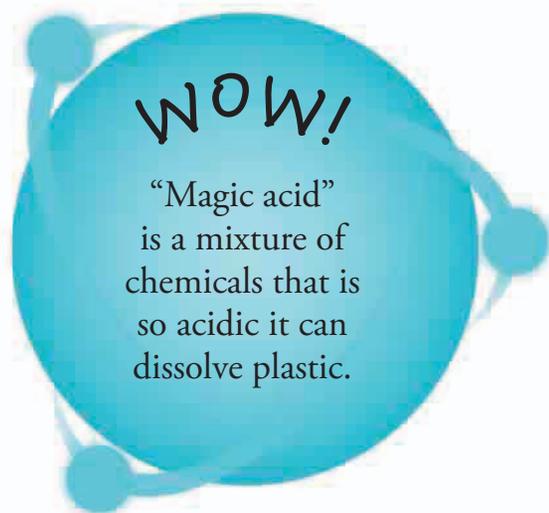
## NOT DISSOLVING

Oil does not mix with or dissolve in water. An oil spill in a river, lake, or sea floats on the water's surface, causing terrible pollution and harming wildlife. Chemicals called solvents and dispersants break the oil into tiny blobs, which spread out and float away, causing less harm.



# Acids and bases

Liquid substances have a level of acidity, a property that describes how they react to other substances. At the opposite ends of this scale, acids and bases are made by dissolving particular substances in water. At their strongest, they can be very dangerous, eating away metals and other solids and causing burns if they touch human skin. In their weaker forms, acids and bases are safe to eat, and are very common in food and drinks.



## HOW STRONG IS IT?

Scientists use a scale called pH to measure how acidic or basic a liquid is. The scale runs from 1 for very strong acids to 14 for very strong bases. Neutral liquids have a pH of 7. We can measure pH with special chemicals called indicators, which change color to show how acidic or basic a liquid is. The most common is universal indicator, which shows reds and orange for acids, greens for neutral, and blues and purples for basic solutions.



▲ VINEGAR *Common vinegar is a solution of acetic acid and has a pH of 2–3.*



▲ TOMATO JUICE *Tomato juice contains citric acid, giving it a pH of around 5–6.*

Acid

## ACIDS

Strong acids can eat away metals and some kinds of stone. They are used in the chemical industry, and in batteries for cars and other vehicles. Hydrochloric acid, one of the strongest, is created inside your stomach to break down the food you eat. Weak acids have a sharp flavor, which you can taste in many kinds of fruit and in vinegar.

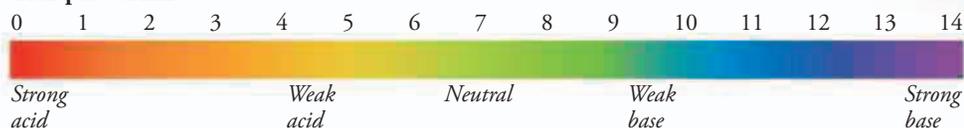


▲ BATTERY ACID *A car battery contains very strong sulfuric acid with a pH of 1–2.*



▲ ORANGE JUICE *Citrus fruits such as lemons and grapefruits have acidic juice. Orange juice has a pH of 3–5.*

## THE pH SCALE



## BASES

Strong bases can be useful cleaning materials, since they are good at dissolving grease and killing bacteria. They must be handled with care since they can cause burns to unprotected skin. Weaker bases are sometimes used in medicine to neutralize acids in the body, for example to treat stomach pain caused by excess acid.



▲ **WATER** Pure water is almost exactly neutral, with a pH very close to 7.



▲ **ANTACID TABLET** Taken to cancel out too much stomach acid, antacids are around pH 10.



▲ **DRAIN CLEANER** A chemical called lye is a very strong base, often used for cleaning. Its pH is 13–14.

## NEUTRALIZING



When acids and bases come into contact, they undergo a chemical reaction called neutralization. The acid and base cancel each other out, leaving behind water and a kind of chemical called a salt. Sometimes a gas is also produced.

◀ **BUBBLING OVER** Add red dye to baking soda inside a model volcano, pour on vinegar, and the volcano bubbles and “erupts”!



Base



▲ **COW'S MILK** Most kinds of cow's milk are very slightly acidic, at pH 6.5–6.8.

▶ **TOOTHPASTE** Because of the substances added to strengthen teeth, toothpaste is a base with pH 8–9.



▼ **CEMENT** Cement includes a chemical called calcium hydroxide, which is a powerful base with pH 11–13.



# Incredible reactions

Many substances stay the same for a long time. Some mountains have been around for billions of years. But other substances change—and not just by dissolving, or altering state from liquid to gas. Their molecules break apart into their separate atoms, and these join or bond together in new ways and new combinations. This is called a chemical reaction because the original substances react or alter each other to make a new, different chemical substance.



◀ **SLOW AND STEADY** *As soon as water is added to cement, chemicals in the cement dissolve and start to react. After a time, they set into a hard solid.*

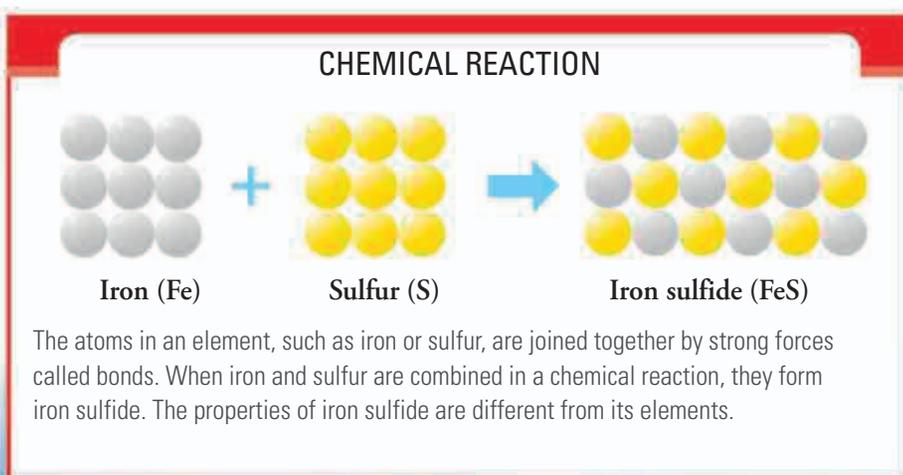
## SLOW REACTIONS

Cement is a mixture of chemicals, which react together when water is added. The reaction may take a few hours or even days, but at the end of it the powdery cement has set into a hard solid. Slow reactions give off heat just like fast ones, but much more gradually.

## FAST REACTIONS

Some chemical reactions take place very quickly. Dynamite explodes in a fraction of a second. Adding an acid to a base can produce a violent reaction in just a second or two, with fizzing and bubbling as a gas is given off. Both reactions produce heat.

► **SWIRLS AND FUMES** *Adding two chemicals together must always be done under safe conditions. Here, they react quickly, swirling the liquid and giving off gas fumes.*



*Gas fumes are heavy and float over the flask edge and down.*

**WOW!**

The fastest chemical reactions happen in just a few quintillionths of a second.

*Liquid churns and swirls with the force and heat of the reaction.*

► **PROTECTIVE BALLOON** Nitrogen gas blows up the air bag like a balloon, so the person is protected from the force of the crash.

## HOT REACTIONS

One of the most familiar chemical reactions is burning, also known as combustion. This is a reaction in which a fuel, such as wood, coal, charcoal, or gas, combines with oxygen in the air. Unlike the other reactions shown on this page, combustion is not spontaneous—it does not start on its own. The fuel has to become very hot—that is, we light the fire. Once the reaction starts, it gives off its own heat, which lights more fuel.

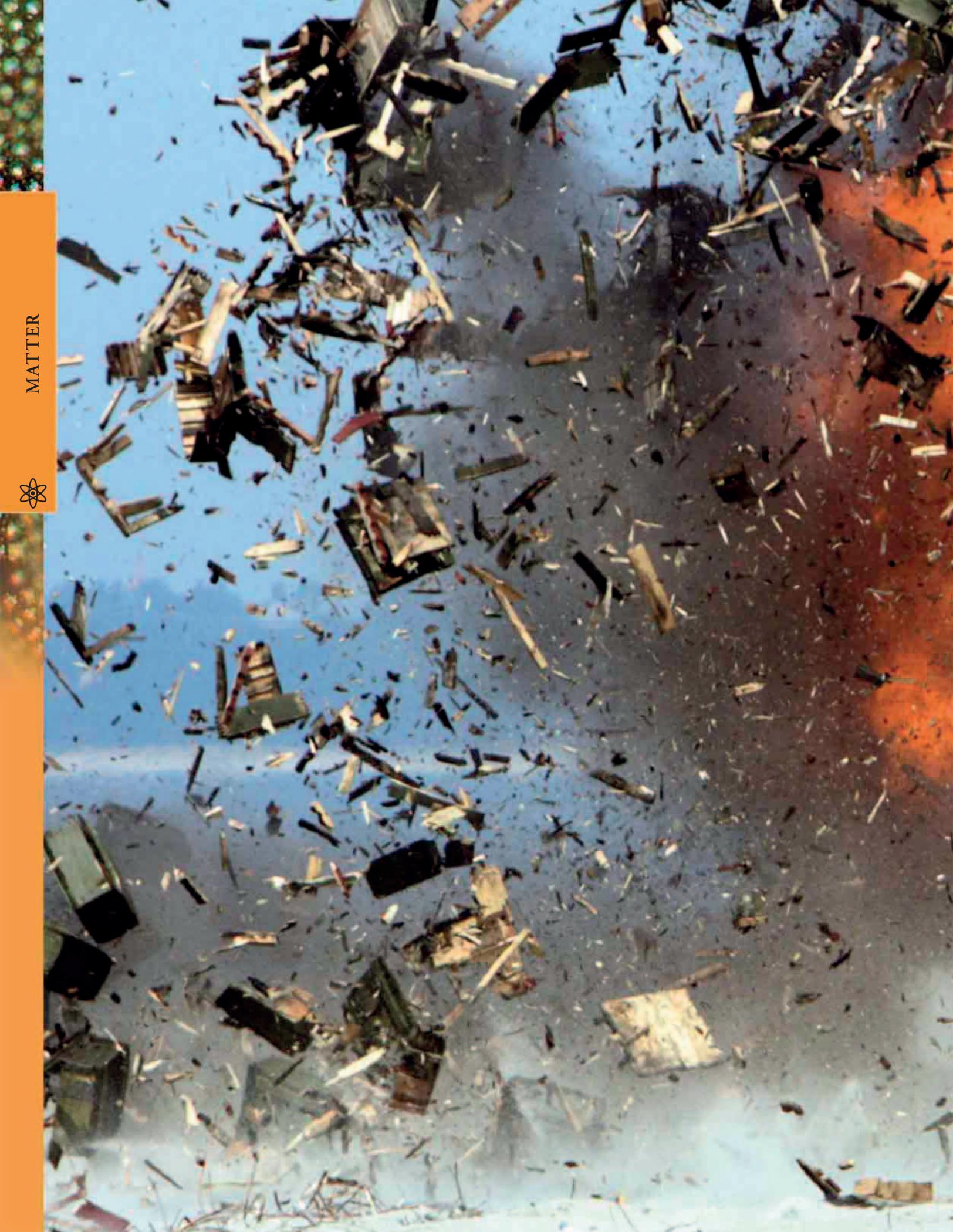


▲ **PRODUCING ENERGY** When charcoal burns, its atoms rearrange to form new molecules. This reaction gives off energy in the form of heat, light, and often sound.

## LIFESAVING REACTIONS

Reactions are all around us, in cooking, cleaning, vehicle engines, and many other parts of daily life. One very fast reaction that helps save lives occurs in a vehicle air bag. A sudden stop makes the chemical sodium azide ( $\text{NaN}_3$ ) in the air bag split apart, or decompose, to give off nitrogen gas ( $\text{N}_2$ ), which fills the air bag. This all happens in just 1/25th of a second.





MATTER





## CHEMICAL REACTION

Some chemical reactions are slow and gentle, but others are fast and release a lot of energy. The chemicals in this picture are old military explosives that are being detonated to dispose of them safely. They react to produce heat energy and hot gas, which burst outward in an explosion.

# Metals

About 90 of the pure substances, or chemical elements, are metals. They are used to make many familiar things around us, such as aluminum in soda cans, copper in electrical wires, iron in saucepans, nickel or lithium in rechargeable batteries, and solid gold in jewelry. Most metals are strong and tough. They are also good conductors, since they carry electricity and heat well.

## COMMON METALS AND THEIR USES

About 30 of the 90 metals are known as transition metals. These form the central block of the periodic table. Transition metals are typically hard and shiny. They can be hammered and bent into shape, and have high melting points. They are the best conductors, and do not react easily with other substances. These features make them very useful.



▲ **TITANIUM** *This lightweight metal has superstrength, which is why it is used in some bicycles frames.*

► **STAINLESS STEEL**  
*Steel is mostly made of iron. The stainless type has other substances mixed in to prevent rusting.*



▲ **COPPER** *This metal is often used in pipes and in electrical wiring.*

▲ **GOLD** *A symbol of wealth and power, gold polishes well and has a rich color, which does not fade or rust. This mask of the Egyptian king Tutankhamun (reigned 1333–1323 BCE) is made of 22 lb (10 kg) of gold.*



## MAKING METALS

Some metals are found in a natural pure form, such as gold nuggets. But usually their metal atoms are combined with other elements in rocks. If a rock is rich in metal, it is known as an ore. The ore is heated with chemicals until it melts, in a process called smelting. The pure metal separates out as a liquid, which cools and hardens.



▲ 1. ORE Sometimes small pieces of metal can be seen in the ore, such as these flecks of gold.



▲ 2. MELTING The heat is carefully controlled to make the ore melt but not turn to vapor.



▲ 3. COOLING The melted liquid gold collects and can be poured or skimmed off to solidify.

WOW!

Tungsten, the hardest metal, also has the highest melting point—6,192°F (3,422°C), or three times as high as gold.



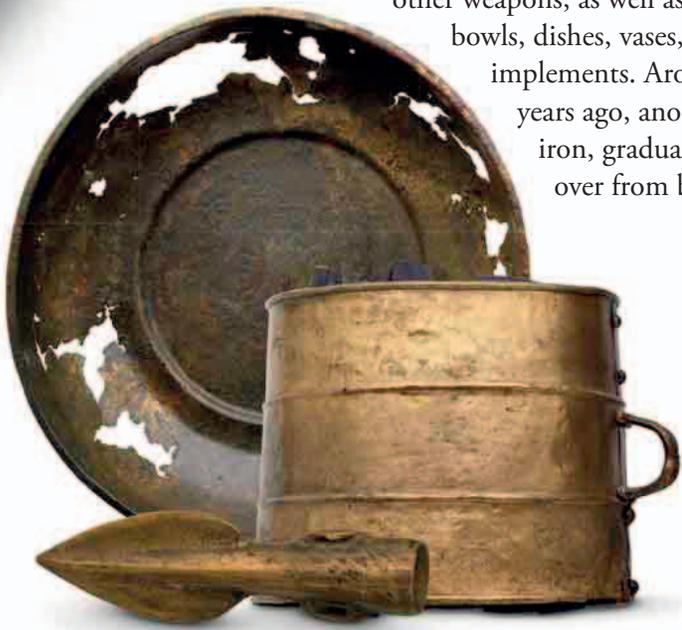
Metallic colored pigments

## COLORED METALS

Many strongly colored substances, called pigments, contain transition metals. The color does not come from the metal, but from compounds made when the metal reacts with other elements. Copper compounds tend to be blue-green or green, manganese compounds are brown, and cobalt compounds are an intense blue.

## ANCIENT ALLOY

The Bronze Age began more than 5,000 years ago when people discovered that melting and mixing two metals—copper and tin—made a much harder material. The mixed metal, or alloy, was bronze. It made stronger, sharper swords, spears, and other weapons, as well as long-lasting bowls, dishes, vases, and other implements. Around 3,200 years ago, another metal, iron, gradually took over from bronze.



◀ LONG LASTING  
Bronze items do not rust like iron, and some last thousands of years.



Rhodium-coated gold alloy ring

## MORE VALUABLE THAN GOLD

The metal rhodium is rare, hard, shiny, and difficult to obtain, as well as very costly. It has a very high melting temperature of almost 3,632°F (2,000°C), much higher than gold (2,919°F or 1,064°C) and iron (2,800°F or 1,538°C). Depending on supply and demand around the world, rhodium can cost 10 times as much as gold.



# Strange metals

The metals we see every day, such as iron, silver, and copper, come from a group called transition metals. They are hard, shiny, and only melt at high temperatures. There are other kinds of metals that behave very differently. They are divided into groups such as alkali metals, alkaline earth metals, and poor metals. Some are common in daily life while others are rare, with specialized uses, and a few are very dangerous.



## HEAVY AND SOFT

Lead, like aluminum, is a poor metal. It is heavy, soft, and flexible, but resistant to rusting and crumbling. It used to be popular for roofing and for items that needed to be heavy but small, such as weights in old clocks. But lead was discovered to harm humans, other living things, and the environment, so many of its uses have faded away.

WOW!

The metal cesium is so reactive that it catches fire in the air, and, if added to water, it will cause an explosion.

## LIGHT YET STRONG

Aluminum comes from a group known as poor metals. They are softer and easier to melt than transition metals. However, aluminum can be hardened by adding chemicals to make a strong, lightweight metal that is easy to shape and does not rust. This is why it is used in many items, from cooking foil and saucepans to ladders, casings for electronic gadgets, magnets, aircraft, and all kinds of machinery.



▲ **DULL SHINE** *Silver-colored aluminum is often used for building aircraft, since it is strong yet light, and easily shaped into curved sheets.*





*Pure silicon mixed with other elements is the main material used in computer chips.*

## SEMICONDUCTORS

The substances silicon and germanium are partly like metals and partly not, so they are called metalloids. They are also semiconductors, meaning they only conduct electricity under certain conditions. These in-between features make them ideal for use in microchips in electronic gadgets, such as cell phones and computers.

▲ **SILICON POWER** *Silicon microchips are the thinking power behind computers like this laptop.*

## ALKALINE EARTH METALS

Calcium is in the group called alkaline earth metals. When pure, it is gray and soft. But it is hardly ever found pure since it reacts so easily with many other substances to form salts and other compounds, and some of these are very hard and tough. Calcium compounds can be found in the hard parts of living things, such as bones, teeth, and shells.



▲ **SHELLS** *About half of a seashell is calcium in the form of calcium carbonate. The shell lasts much longer than the animal inside.*

*All kinds and sizes of planes use aluminum since it resists rusting.*



## USE WITH CARE

One of the most poisonous substances is arsenic. It is not quite a metal or a nonmetal, and so is known as a metalloid.

Arsenic affects the digestive system of human beings and animals. That is why it is used in controlled amounts in some items, such as insecticides. In nature, it can soak through rocks into water supplies, making the water deadly to drink.



# Nonmetals

Of the more than 100 natural chemical elements, only about 17 are nonmetals. Most of these are gases at room temperature, while others, such as sulfur, phosphorus, and carbon, are solids. They are mostly soft rather than hard, powdery rather than shiny, and do not carry heat or electricity.

## SULFUR

Pure sulfur is a bright yellow powder made of tiny crystals. It sometimes occurs naturally in rocks and around hot springs. Sulfur is one of the most important substances in industry, used to make hundreds of different chemicals, rubbers, papers, fertilizers, pesticides, and preservatives.

WOW!

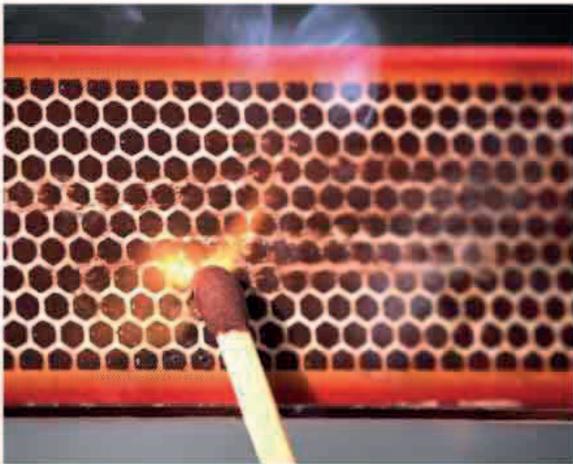
Jupiter's moon Io is covered in huge yellow plains made of the nonmetal sulfur.

▼ **SULFUR SPRINGS**  
*At this hot spring in Dallol, Ethiopia, water containing natural sulfur and other minerals has dried up, leaving behind a yellow crust.*



## STRIKE A MATCH

Pure phosphorus is not found in nature because it reacts with other substances too easily, forming phosphates and similar compounds. These compounds are obtained from ore rocks and are widely used as fertilizers. Some forms of phosphorus catch fire easily when rubbed and are used in match heads.



## GERM KILLERS

One group of nonmetals is known as halogens. These are fluorine, chlorine, bromine, iodine, and astatine. In pure form, fluorine and chlorine are gases, bromine is a liquid, and iodine and astatine are solids. All halogens, when used in certain quantities, can be harmful, or toxic, to living things. Yet they can also be used with great care in health and medicine.



◀ **FLUORINE** *In its pure form, fluorine gas can damage the eyes, nose, airways, and inner organs. But tiny amounts in toothpaste help teeth stay strong.*



◀ **IODINE** *Less toxic than other halogens, iodine and its compounds are helpful germ killers, as antiseptics on skin and disinfectants on nonliving objects.*

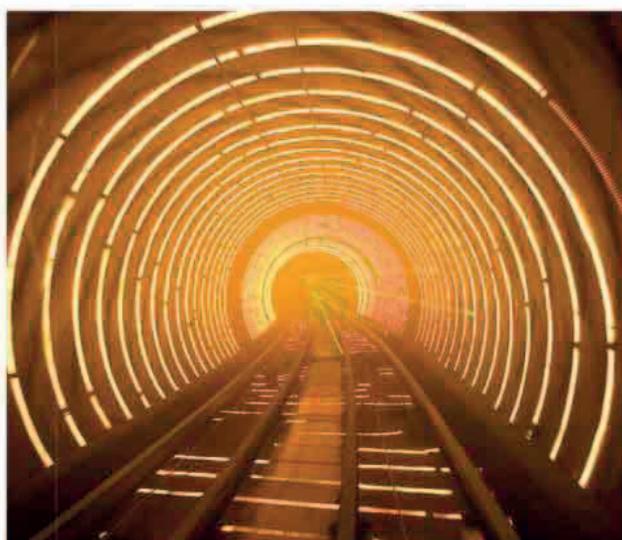


◀ **CHLORINE** *A greenish choking gas at ordinary temperatures, chlorine is added to water to kill germs, while larger amounts are used in bleaches.*

## NOBLE GASES

The six chemicals on the far right of the table of elements (p.24) rarely react with any substances, including themselves. They are helium, neon, argon, krypton, xenon, and radon. Because they are all gases and they were once seen as better than or superior to other chemicals, they are known as noble gases.

▶ **NEON LIGHTS** *Since noble gases are so unreactive, neon glows without reacting when electricity passes through, so it makes long-lasting lights.*

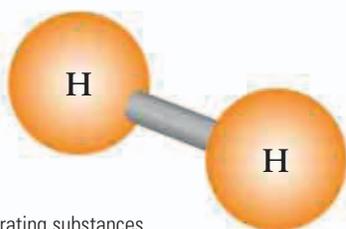


# Hydrogen

Hydrogen is the lightest of all the elements. Each of its atoms has just one electron moving around one proton. Hydrogen accounts for about three-fourths of the mass of all the atoms we can see in the universe. On Earth, it is one of the elements in water ( $\text{H}_2\text{O}$ ), but as a gas it is only found in very small traces in our atmosphere. Since hydrogen burns easily in air and creates almost no pollution, it could become a fuel of the future.

## HYDROGEN FACTS

- **Formula**  $\text{H}_2$
- **Group** Nonmetals
- **Density** 0.012 oz/gallon (0.09 gm/l)
- **Melting point**  $-434^\circ\text{F}$  ( $-259^\circ\text{C}$ )
- **Boiling point**  $-423^\circ\text{F}$  ( $-253^\circ\text{C}$ )
- **Main sources** Treating oil (petroleum) with superhot steam; splitting water using electricity
- **Main uses** Many industries—for example, separating substances in oil; making strong acids and bases; altering foods such as margarines and cooking oils; welding; electronics; keeping things ultracold



Hydrogen molecule

## FLOATS AND BURNS

Hydrogen is about 14 times lighter than air, so a balloon filled with hydrogen floats upward like a bubble in the heavier air around it. Many years ago, hydrogen was used in huge balloons and airships, lifting them up into the air. Since hydrogen catches fire easily when mixed with air, and even explodes, airships today use safer gases.



▲ TIED DOWN A balloon filled with hydrogen is kept from floating away by a heavy weight.



▲ BLOWN UP A flame melts the balloon, and sets fire to the hydrogen inside.

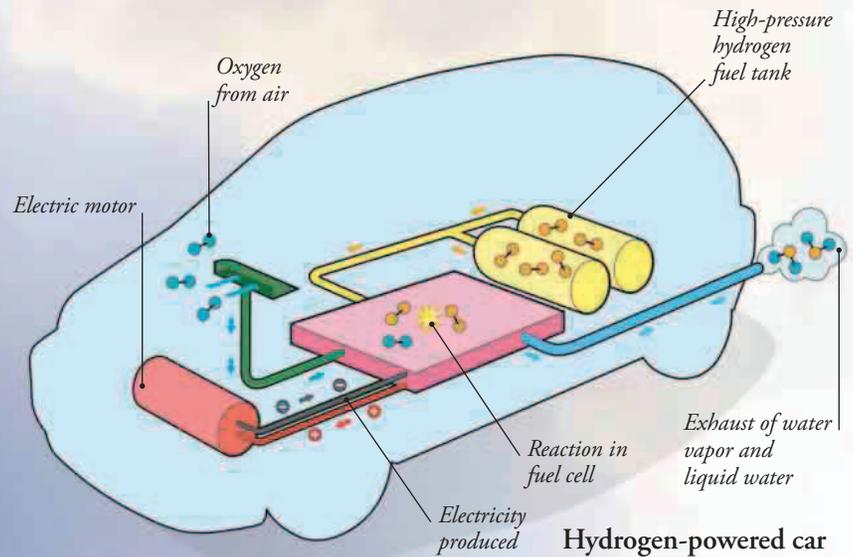
WOW!

You would have to cool hydrogen to  $-423^\circ\text{F}$  ( $-253^\circ\text{C}$ ) to turn it from a gas into a liquid.



## ROCKET FUEL

Hydrogen burns by combining with oxygen to produce water. A spacecraft's rocket uses liquid hydrogen, along with liquid oxygen, as a fuel. These two elements are mixed in the spacecraft's main rocket engines and then ignited. As soon as hydrogen burns, it explodes, generating a thrust (a push with force) that lifts the spacecraft into space.

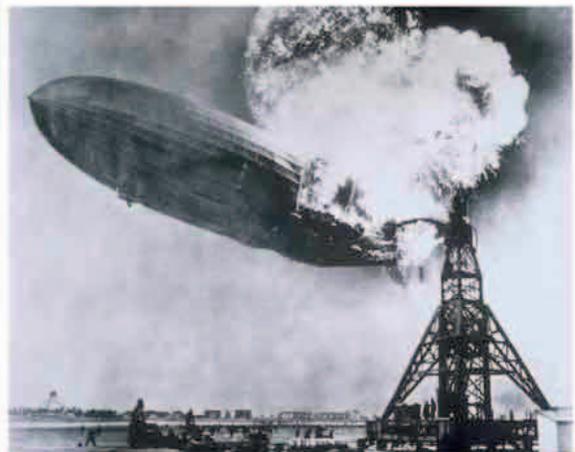


## FUEL OF THE FUTURE?

Clean-burning hydrogen could one day replace gasoline and diesel as a vehicle fuel. It can be combined with oxygen from air inside a fuel cell, generating electricity for an electric motor. Hydrogen-fueled cars produce only water in their exhaust.

## HYDROGEN DISASTER

In the 1920s and 1930s, gigantic hydrogen-filled airships carried passengers across continents and oceans. Then, in 1937, the hydrogen in the German airship *Hindenburg* caught fire, probably from a stray spark. The massive fireball and explosion killed 36 people. Since then, airships have mostly used other, less flammable gases.



The *Hindenburg* explosion, 1937

▲ **SPACE SHUTTLE** At liftoff, the enormous brown fuel tank of NASA's space shuttle contained 705 tons (630 metric tons) of liquid oxygen (LOX) and 118 tons (106 metric tons) of liquid hydrogen (LH<sub>2</sub>), which reacted together to push the spacecraft away from the earth.

# Oxygen

Oxygen is vital to much of the life on Earth. Unless living things breathe it in every few seconds from the air around them, they cannot survive. Oxygen is also in every molecule of another vital substance—water—which all animals, plants, and other life forms need to stay alive. Oxygen from the atmosphere enables us to burn fuels such as wood and gasoline, providing most of the energy for our homes and vehicles.

## CRITICAL FOR LIFE

All living things, including humans, use oxygen to turn food into energy that powers our bodies. Smaller land animals, such as insects, absorb oxygen from the air through their skin, while larger ones, such as humans, breathe it into their lungs. Water also has oxygen dissolved in it, which underwater animals absorb using gills.



Feathery red gills

◀ **GILLS OUTSIDE** *Fish have gills under covers on the neck. The axolotl, a salamander-like amphibian, has frilly gills on the outside of its head.*

## BREATHING UNDERWATER

Human beings drown because our lungs cannot extract oxygen from water the way a fish's gills can. However, we can stay underwater for long periods by taking oxygen gas with us. Oxygen can be squeezed, or compressed, into metal tanks, so we can breathe it through a tube and face mask. This equipment is known as scuba (self-contained underwater breathing apparatus).

▶ **CARRYING OXYGEN** *Some scuba tanks contain gases with more oxygen than exists in normal air, so the diver can stay underwater for longer.*



## OXYGEN FACTS

- **Formula**  $O_2$
- **Group** Nonmetals
- **Density** 0.18 oz/gallon (1.4 gm/l)
- **Melting point**  $-362^{\circ}F$  ( $-219^{\circ}C$ )
- **Boiling point**  $-297^{\circ}F$  ( $-183^{\circ}C$ )
- **Main sources** Air, by cooling it into a liquid and then warming gently until oxygen gas is given off
- **Main uses** Needed by almost all living things; burning fuels in vehicles, heating, cooking, and industry; medical oxygen masks



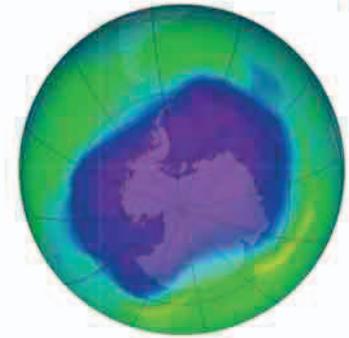
Oxygen molecule

WOW!

Solid oxygen is pale blue, but you have to cool it to  $-362^{\circ}\text{F}$  ( $-219^{\circ}\text{C}$ ) before it freezes.

## OXYGEN SHIELD

Normal oxygen gas has two atoms,  $\text{O}_2$ . There is another form, ozone, with three atoms,  $\text{O}_3$ . Ozone collects in a layer high above Earth's surface, where it is continually made and destroyed. The ozone layer protects us from the sun's harmful ultraviolet rays. Human-made chemicals called chlorofluorocarbons (CFCs) destroyed some of this ozone, but it is slowly returning now.



Ozone hole (dark purple) over Antarctica in 2006

## ESSENTIAL FOR BURNING

Any kind of burning or combustion requires oxygen. Molecules in the fuel break down as they join with the oxygen, producing light and heat. One way to stop burning is to prevent oxygen from reaching the fuel. Spraying special foams containing nonoxygen gases onto the flames do this. So do fire blankets, gases such as carbon dioxide ( $\text{CO}_2$ ), or other chemicals from a fire extinguisher.



## LIQUID OXYGEN

Oxygen becomes liquid below  $-297^{\circ}\text{F}$  ( $-183^{\circ}\text{C}$ ), 10 times colder than a home freezer. Such low temperatures preserve medical samples for long periods. This is also a way to transport oxygen in a small space. Liquid oxygen (LOX) takes up 860 times less room than the gas, and it can be warmed later to turn it back into a gas.

◀ **SUPERCOLD** *Touching liquid oxygen to a living body part would make it freeze solid and snap off.*

## ▼ PUTTING OUT FLAMES

*Firefighters spray a foam blanket that stops oxygen in the air from reaching the fire.*



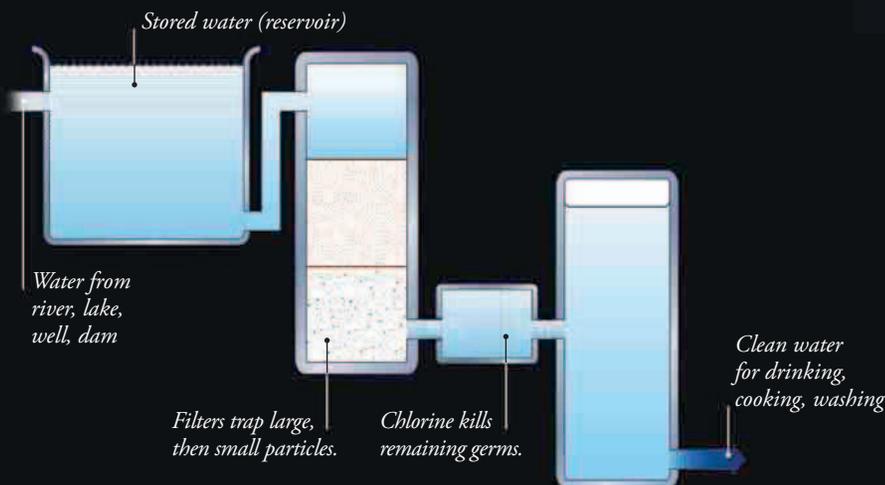
# Water

Water is the only substance on Earth that is commonly found in all three states of matter, as solid ice, liquid water, and gaseous water vapor. A water molecule is simple, with two atoms of hydrogen and one of oxygen. But it is perhaps the most important substance on Earth. Most of our planet's surface is covered with water and it makes up 60 percent of our own bodies.



## WATER TO DRINK

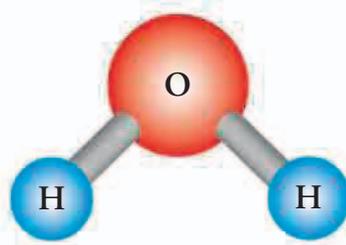
Water without dirt or germs is essential for good health. To make it clean, dirty water is passed through a series of filters. These remove smaller and smaller items, from floating twigs and leaves, to bits of sand and grit, and finally some of the tiny germs. Adding chemicals such as chlorine then kills any remaining germs.



Water processing

## WATER FACTS

- **Formula** H<sub>2</sub>O
- **Group** Oxides
- **Density** 8.34 lb/gallon (1 kg/l)
- **Melting point** 32°F (0°C)
- **Boiling point** 212°F (100°C)
- **Main sources** Rivers, lakes, rain, melted snow and ice, purified from seawater by removing dissolved salts
- **Main uses** Needed by all living things to survive; for washing, cooking, and cleaning; for agriculture and farming; making electricity in hydroelectric dams; as a lubricant to reduce friction



Water molecule

## ICE FLOATS

Cooled down to 39.2°F (4°C), water gets smaller or contracts, and so it is heavier (more dense). Below 39.2°F (4°C), it starts to get bigger or expand. So when it freezes as ice at 32°F (0°C), it is lighter than the liquid water around it—and floats.

► **HIDDEN DEPTHS** *Ice just about floats. Up to 90 percent of a giant iceberg is below the surface.*

Only a small part of the iceberg can be seen above the surface.



## DRYING UP

Water needs heat to “dry”—that is, turn from liquid into gas. This is why puddles dry up faster on hot, sunny days. Our sweat is mostly water. It dries by drawing heat from the body, which keeps us cool in hot conditions.



▲ **COOLING EFFECT** Hippos spend up to 16 hours a day submerged in rivers and lakes to keep their massive bodies cool.

## CLOUDS AND WATER VAPOR

The gas form of water, known as water vapor, is invisible. It can make up as much as 0.04 percent of the air around us, but we cannot see it. What we can see is when this vapor cools and turns back into tiny droplets of liquid water, so small and light that they float—what we call clouds.



Each cloud contains trillions of water droplets.

## PLANET WATER

Only one-third of planet Earth is covered with land, rocks, and soil. The rest is water. Almost 97.5 percent of this is salty water, in seas and oceans. Less than 2.5 percent is fresh water in rivers, lakes, soil, and rocks. And less than 0.01 percent of this fresh water is easily available for us to use, in lakes and rivers.



▲ **OCEAN COVER** Almost half of Earth's surface is the water of the Pacific Ocean.

WOW!

All the water on Earth gathered into a ball would measure 870 miles (1,400 km) across.



MATTER





### **SNOWFLAKE**

Snow falls as billions of little flakes. Tiny crystals form when water vapor attaches to pollen or dust particles in the air and freezes into ice. These grow into six-sided crystals, which float to the ground. Every snowflake has a unique shape. The flakes here are surrounded by smaller frost crystals.

# Nitrogen

Nitrogen is one of the most common chemical elements on Earth. It is all around us, making up 78 percent of air. It is the fourth most common substance in the human body (after oxygen, carbon, and hydrogen), and it is found in similar amounts in all other living things. Nitrogen compounds are especially valuable in the soil, helping crops and plants grow.

## LIQUID NITROGEN

If nitrogen gas is cooled below  $-321^{\circ}\text{F}$  ( $-196^{\circ}\text{C}$ ), it becomes liquid. In this form, it is often used in extremely cold (or cryogenic) freezers, for storing blood, cells, eggs, seeds, and other parts of plants, animals, and humans. Liquid nitrogen is also used in science laboratories to cool superfast electric motors, generators, and supercomputers.



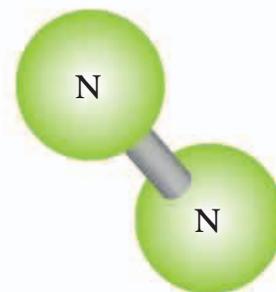
*These tissue samples have been frozen in liquid nitrogen.*

## IN THE SOIL

All plants need nitrogen compounds in the soil in order to grow. Certain plants “fix” nitrogen, which means they take in nitrogen gas from the air to make nitrogen-containing substances in their own bodies and in the soil. Farmers often add nitrogen-rich fertilizers to the soil to help crops grow.

## NITROGEN FACTS

- **Formula**  $\text{N}_2$
- **Group** Nonmetals
- **Density** 0.16 oz/gallon (1.25 gm/l)
- **Boiling point**  $-321^{\circ}\text{F}$  ( $-196^{\circ}\text{C}$ )
- **Melting point**  $-346^{\circ}\text{F}$  ( $-210^{\circ}\text{C}$ )
- **Main sources** Atmosphere (air), minerals such as saltpeter (niter), animal droppings, plant and animal bodies
- **Main uses** Food preserving; fertilizers and soil nutrients; making common industrial chemicals such as ammonia ( $\text{NH}_3$ ) and nitric acid ( $\text{HNO}_3$ ); explosives; superfreezing



Nitrogen molecule

▼ **BETTER CROPS**  
*Adding nitrogen-rich fertilizer to soil makes crops grow better.*



## EXPLOSIVES

Many common explosives, including gunpowder, dynamite, and TNT, contain nitrogen compounds. Human beings have used these chemicals for many centuries to dig out tunnels and pits, and to open up mines and quarries to extract valuable minerals. They can also be used in explosive weapons, and in fireworks.



**Gunpowder**  
(Potassium nitrate,  $\text{KNO}_3$ )



**Dynamite**  
(Nitroglycerin,  $\text{C}_3\text{H}_5\text{N}_3\text{O}_9$ )



▲ **HIGH-SPEED LANDING** *Tires filled with nitrogen stay pressurized for longer than air-filled tires. They also cope well with changing air pressure as the aircraft climbs and descends to land.*

### KEEPING SAFE

Tires on aircraft and some vehicles are filled with almost pure nitrogen, rather than air. Nitrogen does not leak through the tire's rubber as easily as air does. Nitrogen also changes less in volume when the pressure outside changes as the plane rises and falls, and it contains less water vapor, which might damage the rubber.

### FUN WITH NITROGEN

Paintball guns and similar gas-powered devices use a quick blast of compressed (highly squeezed) gas from a tank to fire each paintball. At one time, high-pressure carbon dioxide was a popular gas for this. Then nitrogen took over, since it is safer to use. More recently, compressed air, which is 78 percent nitrogen, has become more common.



*Paintball fired by blast of high-pressure gas*



# Air

All around us is an invisible mixture of gases we call air. It contains about 15 different gases, although most of it is just two—nitrogen and oxygen. The exact content of air varies from place to place. For example, damp air has more water vapor than dry air. Hazy air contains more floating dust particles than clean air. The blanket of air around Earth is known as the atmosphere and this is where weather happens.

MATTER



▲ **WIND PUMP** *In dry regions, windmills work pumps to lift water from deep underground.*

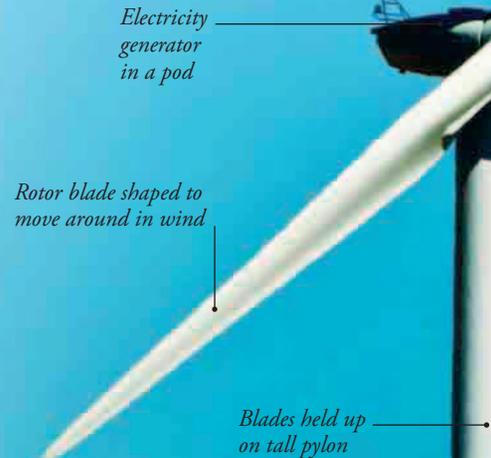


▲ **WINDSURFER** *Wind pushes the sails of windsurfers, kitesurfers, yachts, and other craft.*

## ENERGY FROM AIR

As the Earth and its atmosphere spin around once each day, the sun warms different areas by different amounts.

Warmed air is lighter and rises, so cooler air flows along to take its place. This moving air is wind—and it is a form of energy. We catch and use wind energy in many ways, from ancient windmills that grind grain and lift water, to the latest wind turbines producing electricity.



Electricity generator in a pod

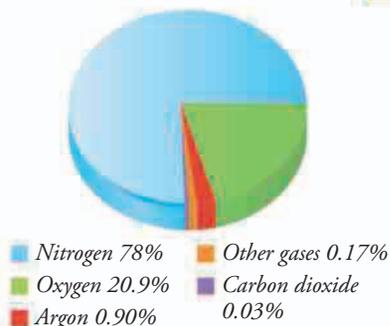
Rotor blade shaped to move around in wind

Blades held up on tall pylon

► **WIND GENERATOR** *These turbines turn energy from the wind into electricity.*

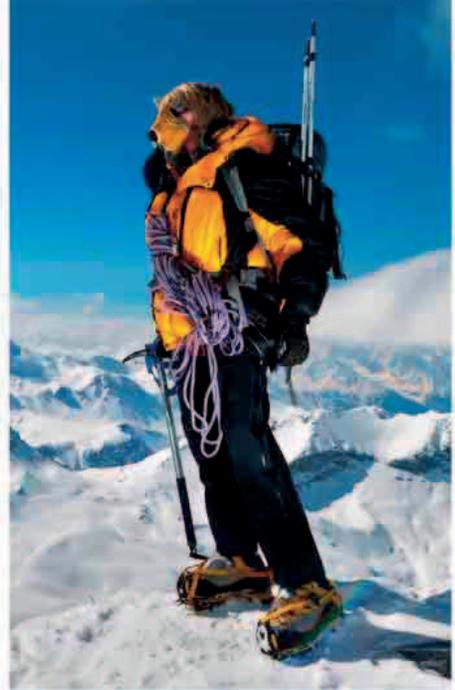
## WHAT IS IN AIR?

Almost all of air—about 99 percent—is nitrogen and oxygen. The rest is made up of the noble gases (p.41), especially argon, but also neon, krypton, and xenon. The gas that varies most is water vapor, from almost zero in desert areas to about 4 percent where it is very moist or damp. Carbon dioxide and methane also vary with human activities such as burning fuels.



## LESS AIR

The higher you go, the thinner the Earth's atmosphere becomes. By 3.4 miles (5.6 km) high, the air pressure falls by half, then this halves again after another 3.4 miles (5.6 km), and so on. The temperature of the air also reduces with height, falling to  $-76^{\circ}\text{F}$  ( $-60^{\circ}\text{C}$ ) by 6 miles (10 km), although it rises again to  $23^{\circ}\text{F}$  ( $-5^{\circ}\text{C}$ ) by 31 miles (50 km). The atmosphere almost completely disappears by 62 miles (100 km) high—which is the official start of outer space.



► **STAYING ALIVE** *The air on top of the highest mountains is too thin to breathe, so climbers must carry oxygen in tanks.*

*Rotor angle changes with wind speed.*



## NOISY AIR

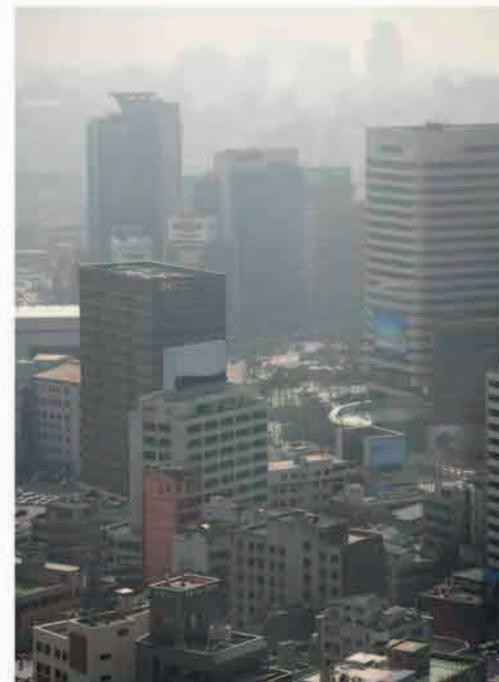
The sounds we hear are made by vibrations in the air. These travel into our ears, where nerves pick up the vibrations and send signals to our brains. Our voices, musical instruments, and horns and sirens all make noise by causing vibrations in the air.

◀ **LIGHT AND SOUND** *In addition to bright lights, lighthouses use loud foghorns to let people know where they are when fog makes it hard to see.*

## POLLUTED AIR

Smog is a mixture of smoke and fog. It forms in built-up areas where dust, smoke, fumes, and chemicals from cars and other vehicles, factories, and power plants all make the air hazy. Smog is worse when there is no wind, or when warmer air flows over the polluted air and traps it near the ground. It can cause breathing problems and other health hazards.

► **HAZY DAY** *Bright sunlight worsens smog by making polluting chemicals in the air react together to produce dustlike particles.*



# WOW!

All the air in the atmosphere weighs 6.1 quadrillion tons (5.5 quadrillion metric tons), about one-millionth of Earth's weight.



# Carbon

Carbon is the fourth most common element in the universe. Unlike most other elements, it occurs in nature in several very different forms. By reacting with oxygen and other elements, it forms substances essential for life on Earth. It is also vital in our modern world for making all kinds of materials—from the hardest steels to the lightest fibers—and provides many of our main sources of fuel for cars, heating, and electricity.

## CARBON FACTS

- **Formula** C
- **Group** Nonmetals
- **Density** About 16.7 lb/gallon (2 kg/l)—as solid powder
- **Melting and boiling point**  
Pure carbon is never found as a liquid—it turns from solid into gas at temperatures of 6,588°F (3,642°C).
- **Main sources** Mostly found in natural rocks, such as coal and diamond, and deposits of oil and natural gas
- **Main uses** Carbon compounds are used for fuel and making plastics



## CARBON DATING

Some carbon atoms (known as carbon-14) are radioactive. Over thousands of years, these atoms break down, leaving ordinary carbon (carbon-12). By measuring the amounts of carbon-14 and carbon-12 in an ancient object, scientists can figure out how old it is, in a process known as carbon dating.



### ◀ HOW OLD?

*This bone came from a human being thought to have died in the Middle Ages. By taking a small sample, scientists can figure out exactly how long ago the person died.*

## FOSSIL FUELS

All living things on Earth use carbon to build up their bodies. Coal, oil, and gas are the remains of the bodies of animals and plants that have been buried under the earth for millions of years. We can extract these carbon-rich substances (called fossil fuels) and burn them to release energy.

### ▶ COAL MINING

*Giant excavators carve coal out of the ground. Coal is an important fuel, although burning it creates air pollution.*



## FORMS OF CARBON

Each carbon atom has four links, or bonds, which can be at slightly different angles to each other. This allows carbon atoms to join to each other in different ways to make very different substances. Coal, diamond, and graphite are all pure carbon, but they look and behave very differently because of the way the atoms inside them join together. Most forms of carbon are black and fairly soft, but diamond is clear, and is the hardest known natural substance.



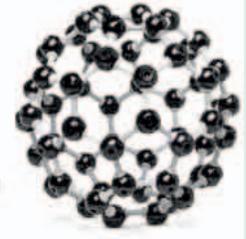
In coal and soot, carbon atoms are all jumbled up.



Atoms in hard diamond are fixed in rigid boxes.



Soft graphite has atoms arranged in layers.



This artificial form of carbon is called "buckyball."



## CARBON FIBER

Carbon atoms can be joined into long chains of fibers that are 15 times thinner than a human hair, yet extremely strong. These carbon fibers are then added to other substances, such as plastics, to make very strong yet lightweight materials known as composites.

▲ **STRONG BUT LIGHT** *Carbon fiber composites are used to make the bodies of race cars and other speedy machines, which need to stay strong without weighing the vehicle down.*



WOW!

More than  
8 billion tons  
(that's 8,000,000,000)  
of coal are mined  
around the world  
every year.



# Organic chemistry

The chemical element carbon is so important in living things that it has its own area of science, called organic chemistry. Carbon atoms can join with up to four other atoms, meaning they can be part of long and complicated molecules with very special properties. These are known as organic compounds. They are the building blocks of living plants and animals, fossil fuels such as oil and coal, and useful substances such as plastics, gasoline, and medicines.

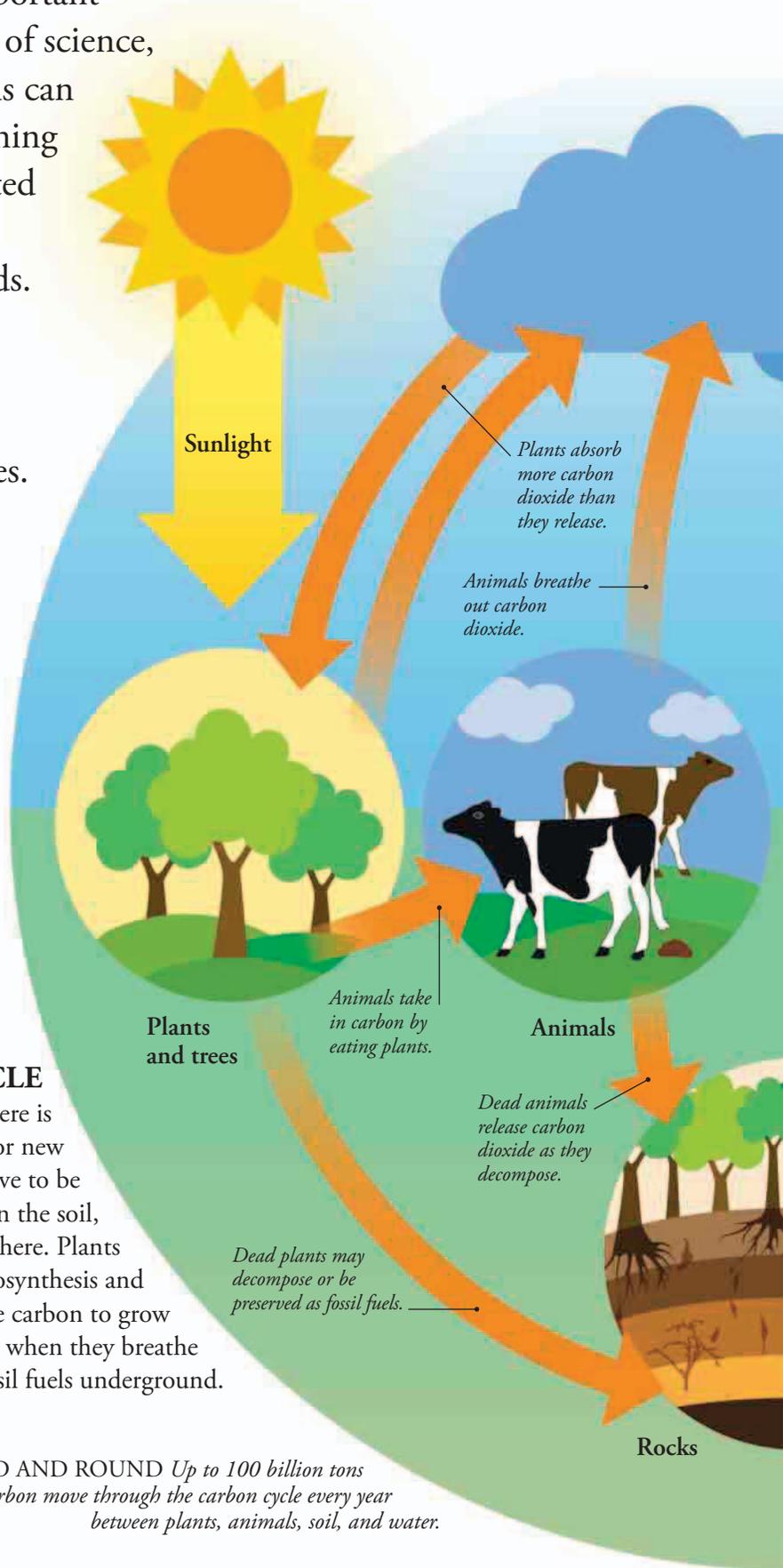


**WOW!**

There are 10 times as many organic substances as there are inorganic substances (those without carbon in them).

## THE CARBON CYCLE

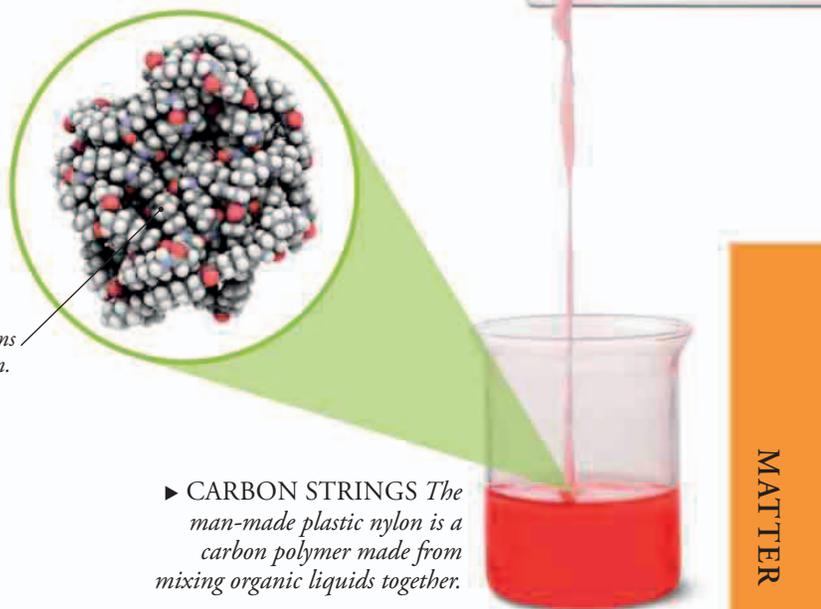
Living things are about 20 percent carbon. But there is only a limited amount of carbon in the world, so for new animals and plants to grow, carbon atoms have to be recycled. Dead plants and animals rot away in the soil, releasing carbon dioxide gas into the atmosphere. Plants absorb this carbon dioxide in a process called photosynthesis and turn it into food. Animals eat the plants, using the carbon to grow and give them energy. They release carbon dioxide when they breathe out. Carbon is also trapped in oceans and in fossil fuels underground.



► **ROUND AND ROUND** *Up to 100 billion tons of carbon move through the carbon cycle every year between plants, animals, soil, and water.*

## CARBON CHAINS

With four chemical bonds each, carbon atoms can form long chains joined to one another, and to other atoms. Many of these long molecules have the same small group of atoms repeated hundreds, even millions, of times. These giant molecules are known as polymers, and are used in plastics.



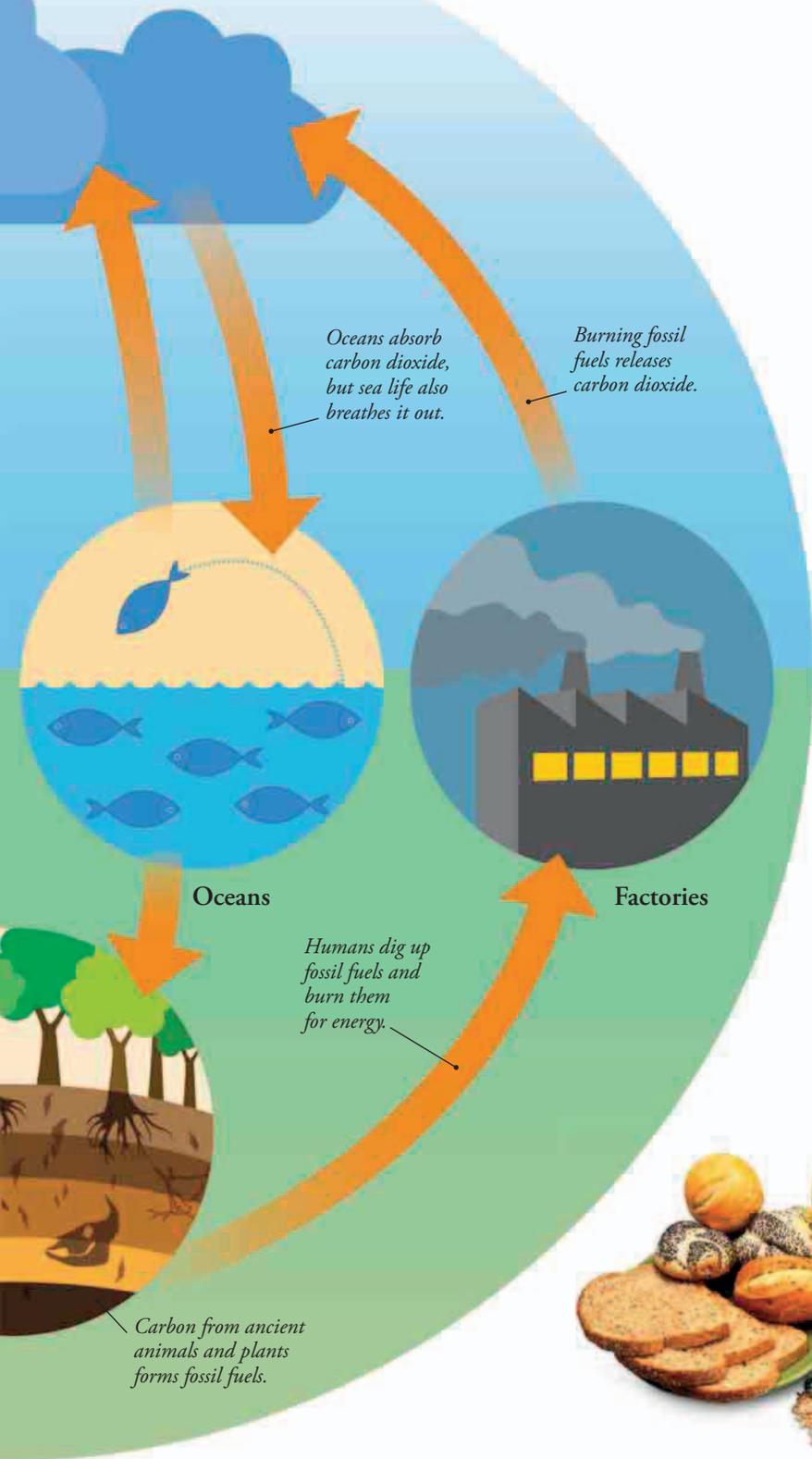
Gray carbon atoms form a long chain.

► **CARBON STRINGS** *The man-made plastic nylon is a carbon polymer made from mixing organic liquids together.*

MATTER



### Carbon dioxide in the atmosphere



Skunks use smelly organic molecules to drive off attackers.



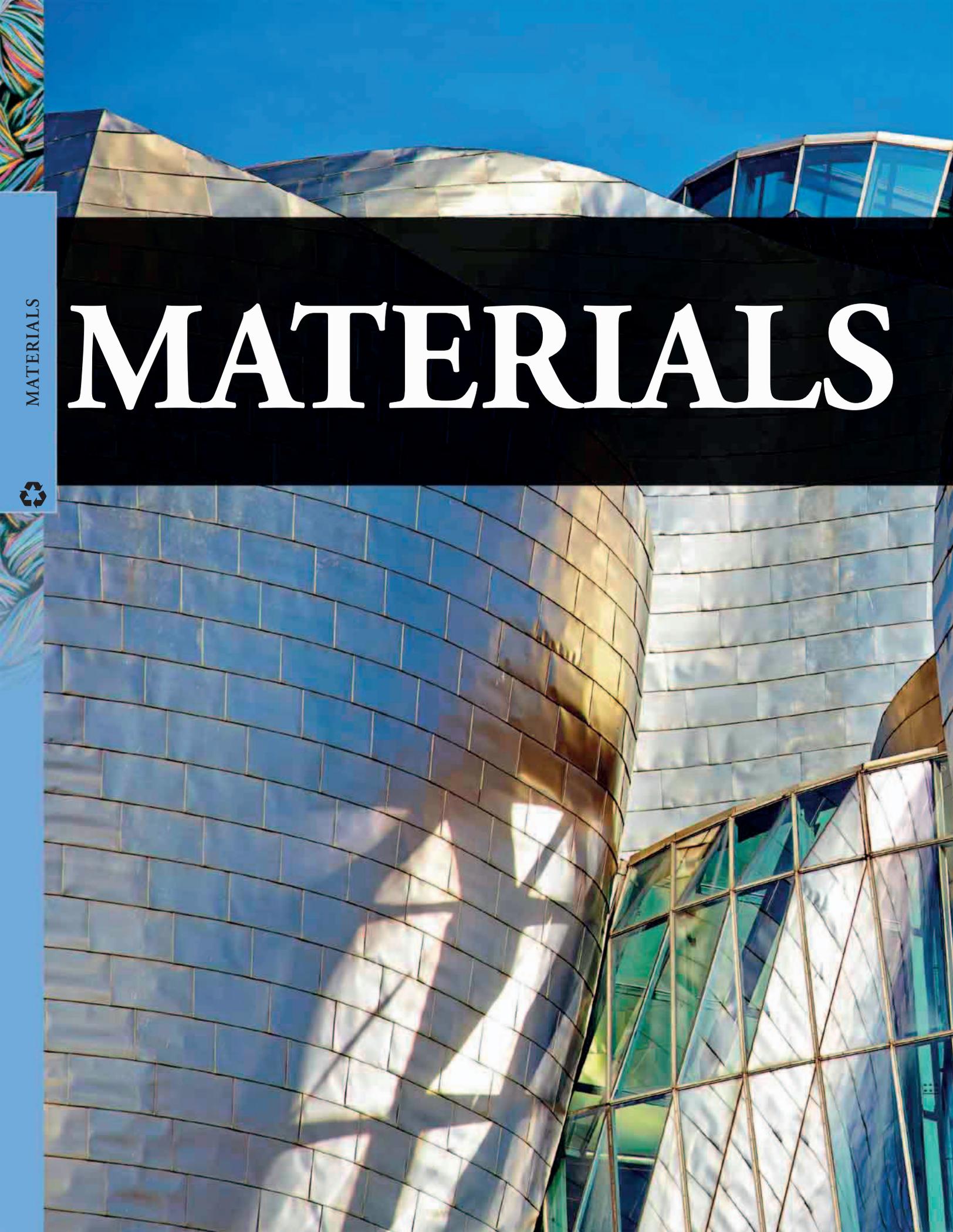
## SMELLY CHEMICALS

Many organic substances have strong smells, such as sweet-scented flowers, strong herbs and spices, and the stench of a skunk's spray. This is partly because the compounds are volatile—that is, they turn into a vapor at normal temperatures. They float through the air and into our noses.

## CARBOHYDRATES

Carbon molecules in plants can join with oxygen and hydrogen to make carbohydrates, such as sugar and starch. Many animals, including humans, rely on carbohydrates in their diet, since they are easily broken down in the body to give us energy.

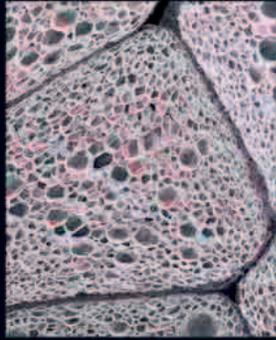
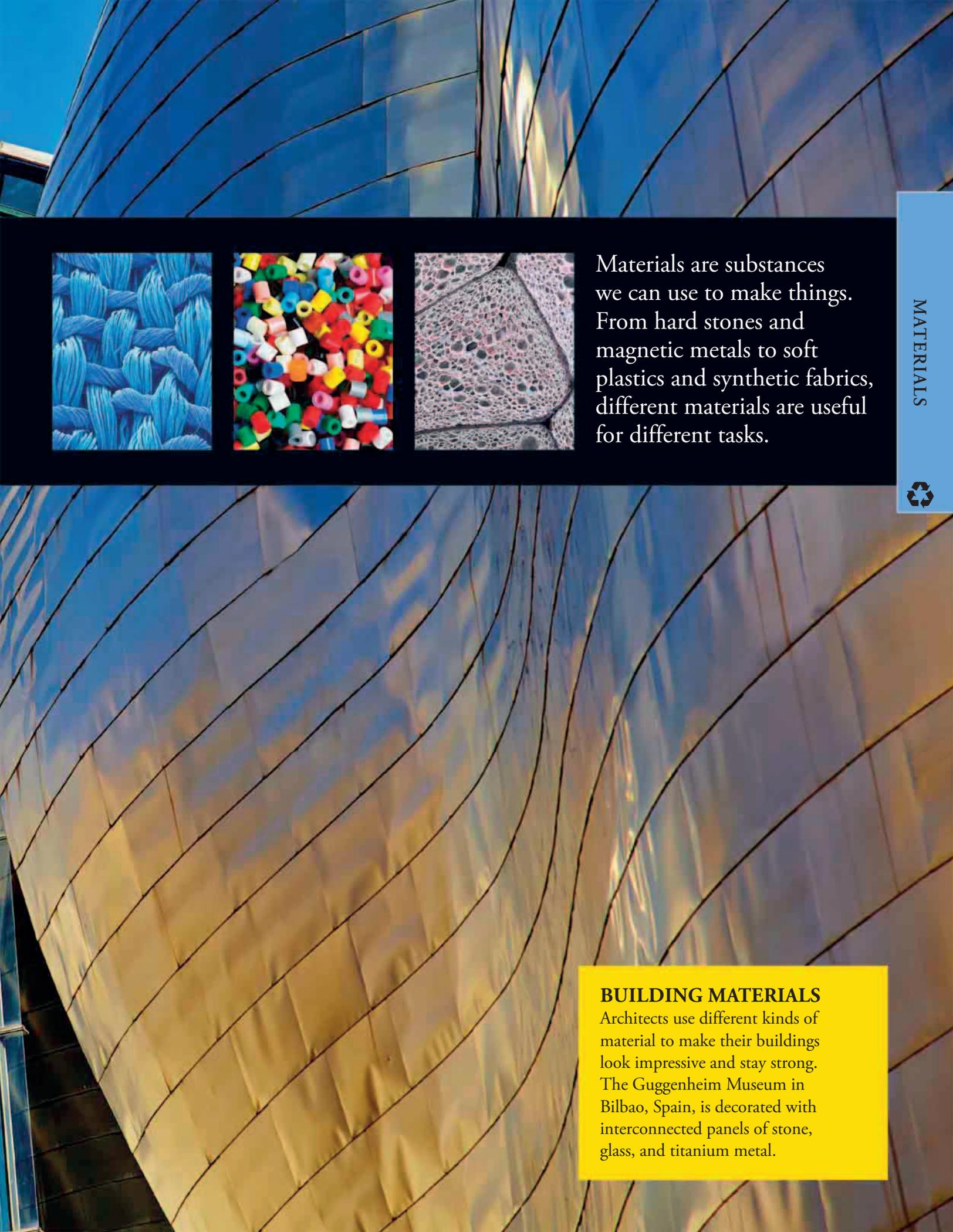




MATERIALS

# MATERIALS





Materials are substances we can use to make things. From hard stones and magnetic metals to soft plastics and synthetic fabrics, different materials are useful for different tasks.



### **BUILDING MATERIALS**

Architects use different kinds of material to make their buildings look impressive and stay strong. The Guggenheim Museum in Bilbao, Spain, is decorated with interconnected panels of stone, glass, and titanium metal.

# Defining materials

Materials are substances we use to make things. They range from hard metals to soft fabrics, natural wood to human-made plastics. Different materials have different properties, which make them useful in different ways. Engineers and inventors are experts at choosing the right material for every job.

## INNOVATIVE USES

Most buildings consist of several different materials, such as brick, glass, concrete, and wood, each chosen for its features and qualities. However, traditional materials can also be adapted for new uses. For example, cardboard may be treated to make it waterproof and flame-resistant, and then used as a construction material.

◀ MATERIAL REVOLUTION *The 700-seat Cardboard Cathedral in Christchurch, New Zealand, opened in 2013. Its main structure is made from 98 massive cardboard tubes.*

Polycarbonate plastic roof

Wood-strengthened, weatherproof cardboard tubes

Stained glass end wall

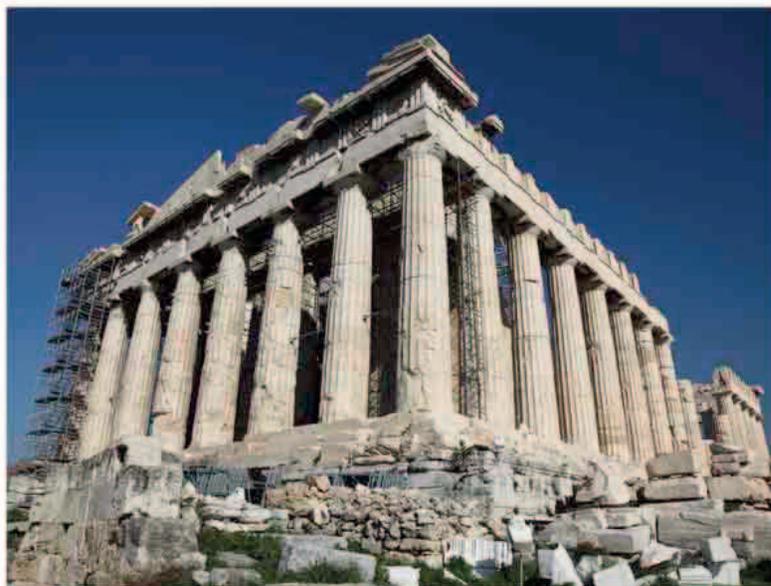
Metal shipping container side walls





## CHOSEN FOR LOOKS

The appearance of a material can be as important as its strength or hardness. For example, stone blocks for buildings are carefully chosen for their colors, patterns, and how well they polish into a shine, as well as for their long-lasting strength. Different kinds of wood also have their own individual appearance, from white birch to black ebony.



▲ **MARBLE WONDER** *The Parthenon, an ancient Greek temple in Athens, Greece, is more than 2,400 years old. Its tall columns are made from a gleaming white rock called marble.*



*Flint was shaped and used as a cutting tool.*

## FIRST MATERIALS

The first materials ever used by people were natural stone, wood, and animal parts such as bones and horns. The earliest stone tools date back more than 2 million years. Wood is easier than rock to shape, carve, and paint, although it does not last as long. However, some very old wooden spears and tools, dating back more than 200,000 years, have been found preserved in bogs.

◀ **EARLIEST TOOLS** *In prehistoric times, stones such as flint, basalt, and sandstone were used to make hammerstones, hand axes, and other large cutting tools.*

*Wooden handle*

## PROPERTIES OF MATERIALS

Each material has some features, called properties, that make it suitable for certain uses. For example, is it hard or soft, strong or weak, stiff or flexible? The ability to be shaped by hammering, like red-hot metal, is called malleability. A material that carries heat well is a conductor, while one that does not is an insulator.

PROPERTY	EXAMPLE
Chemically reactive	Sodium
Chemically unreactive	Glass
Electrical conductor	Copper
Electrical insulator	Ceramic
Magnetic	Iron
Nonmagnetic	Wood
Hard	Diamond
Soft	Clay
Dense	Granite
Light	Foamed plastic
Flammable	Paper
Nonflammable	Stone
Rigid	Steel
Flexible	Rubber

**WOW!**

The material called Wurtzite Boron Nitride (WBN) is even harder than diamond, but you need an explosion to make it!

*Concrete slab base*

# Plastics

The first synthetic (entirely human-made) plastic was produced in the early 1900s. Today, it is one of our most useful and adaptable materials. There are hundreds of different kinds of plastics, in all kinds of different colors, and with all kinds of different properties, from strong and hard to soft and flexible. Most plastics melt when they're heated, so they're easy to mold into any shape. This makes them useful for many different things.

## SOURCE OF PLASTIC

Most modern plastics are made from crude oil, which is extracted from deep underground. The oil is separated into different chemicals, which can be turned into plastics. When the world runs out of crude oil, we will have to rely on plastics made from plant material (bioplastics).

## PLASTICS EVERYWHERE

Plastics are extremely useful, and our lives would be very different without them. Plastics are waterproof and do not rot away, making them great for storing liquids. They can be easily cleaned, making them safe and hygienic for preparing and storing food. They can be made into almost any shape, so can be used to make machines and toys. And they can take on bright colors in almost any shade.

## SOFT AND HARD PLASTICS

Plastics usually contain several other chemicals, called additives, to give them different properties. Some are mixed with hardeners so they are tough and resist scratching. Others have softener additives so they will squash and bend easily, then spring back to their original shape, like natural rubber.



Soft plastic toy



Hard industrial plastic pipes



▲ **BASIC BEADS** *Plastics are often produced as pellets or beads, which can be melted down to make useful products.*



### SEE-THROUGH PLASTIC

Lighter than glass, and much less fragile, transparent plastics are ideal for everything from windows to water bottles. We can see through these plastics because of the way their molecules are arranged. All plastics are made up from long chains called polymers. If these polymers all line up side-by-side, the plastic becomes see-through.

### PROPERTIES

- Adaptable—can take on many different shapes, colors, and properties
- Easy to shape—can be melted and reshaped again and again
- Flexible—able to bend or squash rather than splinter or snap
- Waterproof—good for storing water or keeping things dry
- Insulating—protect against electricity, and keep things warm or cool

### PLASTIC RECYCLING

Most plastics are long-lasting and do not rot away. This makes them very useful, but also causes problems when we no longer need them. Unlike wood and natural textiles, plastics stay around when we throw them away, building up in rubbish heaps. The best way to deal with this is to melt down used plastic and turn it into new products we can use again. This process is called recycling.

► **PLASTIC FOR RECYCLING** *Instead of throwing away old plastic bottles, we can melt them down to make new products.*



# Glass

People have been making glass for thousands of years by heating up special kinds of sand mixed with other chemicals. For centuries, glass was the only see-through material available, so it was used in the earliest windows and lenses. It is also easy to shape when it's heated up, and does not rot or melt away in water, making it useful for bottles and vases. But glass cannot be used everywhere because it is very fragile, and can be dangerous if it breaks.

## BEAUTIFUL OBJECT

Glass can be blown into almost any shape, and pigments (colored dyes) can easily be added to give it special colors. Humans have been using glass to create beautiful ornaments and decorations ever since it was first invented. Clever glassmakers can even create shapes inside other shapes, as in this vase.

## MAKING GLASS

When glass gets hot enough, it becomes a thick, sticky liquid that can be molded into different shapes. Today, most glass objects are made in factories. In the past, glassworkers used to blow down long metal tubes to create bubbles of glass that they could shape into bottles and vases.



◀ **GLASS BLOWING**  
*These glassworkers are shaping globs of molten glass by blowing air into them. The glass has to be kept at exactly the right temperature.*





## SAFETY GLASS

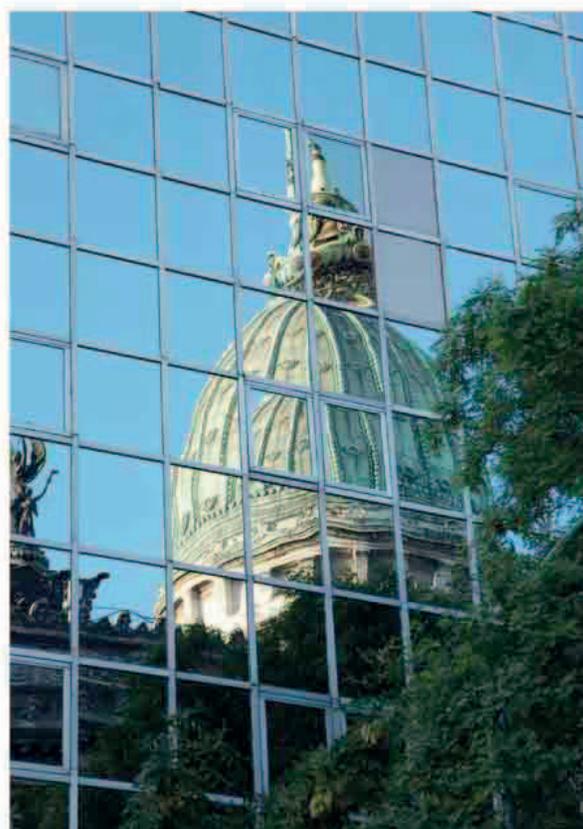
Car windshields need to be hard and see-through, without breaking into dangerous pieces if there is a crash. Most windshields are made of laminated glass, which is two sheets of glass with a thin layer of clear plastic sandwiched between them. If the glass breaks, the pieces stay stuck to the plastic, so there is much less danger from flying shards. As an extra safety measure, modern glass is often specially treated so that it breaks into small, square lumps rather than long, sharp shards.

### PROPERTIES

- Long-lasting—resists water, heat, cold, damp, decay, and rot
- Transparent—but can also be made opaque to let in light without letting you see through to the other side
- Easy to shape—can make everything from giant windows to tiny lenses
- Unreactive—not affected by most chemicals, even strong acids
- Does not conduct electricity

## REFLECTIVE GLASS

Certain kinds of chemical coatings can turn glass into a mirror, reflecting light coming toward it. The other side of the glass can also be a mirror—or just ordinary glass. This can be used to make windows that are easy to see out of but hard to see in through.



▲ **MIRROR WINDOWS** Many modern buildings have whole walls of glass windows hung on a metal frame, making the insides feel light and airy.



▲ **ANCIENT GLASS** Early glass beads, bowls, and vases were made in bright colors, but it was hard to make glass pure and polished enough to be completely see-through.

## LONG-LASTING

Glass is very hard and very resistant to water and other chemicals, so it can last for thousands of years. The oldest glass objects include beads dating back more than 4,000 years. Many early glass objects were made for their beautiful colors, and were used in jewelry. Glass windows appeared around 2,000 years ago, but only in the most important buildings.

# Ceramics

Some special kinds of clay will set as hard as rock if they are baked at very high temperatures. These are known as ceramics, and people have used them for more than 25,000 years to create pots, statues, and tools. The baking process is called firing, and takes place in a special oven called a kiln. Today, ceramics are used everywhere from china plates to spaceship shields.

## CERAMICS IN ART

Ceramics have been used in art for many thousands of years. Early humans discovered that pigments (colored dyes) could be painted on the clay before it was fired. The heat of the kiln bakes the colors onto the clay, so the pattern never washes away.



Spark plug

## CERAMICS IN MACHINES

Ceramics can be molded into very precise shapes when soft, and are very hard and tough when fired. They do not conduct electricity, so are used in power lines and engine spark plugs to make sure electrical current does not flow to the wrong place. However, ceramics are brittle, so they cannot be used in machines where they would crack or splinter.



▲ CERAMIC MOSAIC  
*This sculpture by artist Antoni Gaudi, in Barcelona, Spain, is made from concrete covered in colored ceramic tiles.*



## CERAMICS FOR PROTECTION

Ceramics fired at very high temperatures, up to 2,192°F (1,200°C), can resist enormous temperatures afterward. They are used to line ovens, furnaces, stoves, and kilns. They are also used in spaceships, which have to withstand enormous heat as they reenter Earth's atmosphere. A layer of ceramic tiles and other heatproof materials is used to cover the bottom of the craft so that it does not burn up on its way home.

► **HEAT SHIELD** *The underside of this space shuttle is covered with a shield of more than 24,000 black, heat-resistant ceramic tiles.*



### PROPERTIES

- Long-lasting—resist rain, heat, cold, damp, decay, and rot
- Unreactive—not affected by most chemicals, even strong acids
- Insulating—do not allow electricity to pass through
- Stiff—do not bend under strain (but may crack and splinter)
- Easy to shape—and easy to color for different uses

## CERAMICS AT HOME

Ceramics are smooth, shiny, and easy to clean. They do not burn and they do not react with food and drinks. All this makes them ideal for plates, bowls, mugs, and all kinds of cooking and eating utensils. They are also commonly used for bathroom fixtures, such as toilets, sinks, and baths, because they can be washed with harsh, germ-killing chemicals without being damaged.



## CERAMICS IN THE BODY

Ceramic materials are used to make some artificial body parts, such as teeth and joints. Since ceramics are hard but brittle, there is always the danger that they might split, so false teeth are usually made with additives to help them absorb pressure and strain without cracking.

*Ceramic teeth look and feel similar to natural teeth.*



# Synthetic fibers

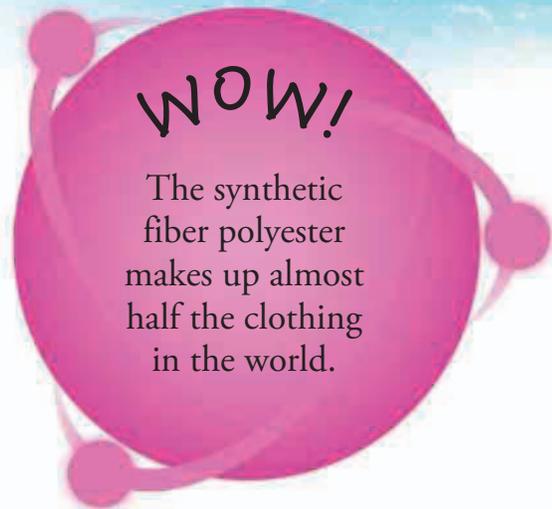
For thousands of years, people have made fabrics and textiles from natural fibers such as cotton from plants, silk from silkworms, and wool from sheep. In the 1890s, two new fabrics, viscose and rayon, were produced by breaking down fibers in wood. The first fully synthetic fiber, entirely made by humans, was nylon in 1935. There are now dozens of synthetic fibers, each with its own combination of strength, thickness, and fluffiness.



## MAKING FIBERS

The first stage is usually to mix various chemicals and squeeze the resulting liquid through tiny holes or spinnerets. Out come long, thin strings that turn solid and become flexible fibers. These are twisted and wound together to make ropes, yarn, and threads, which are woven into textiles, knitted, knotted, and combined in other ways.

◀ **FIRST-STAGE FIBERS** *Bundles of single fibers are drawn together into long, loose strands before further treatment.*



**WOW!**  
The synthetic fiber polyester makes up almost half the clothing in the world.

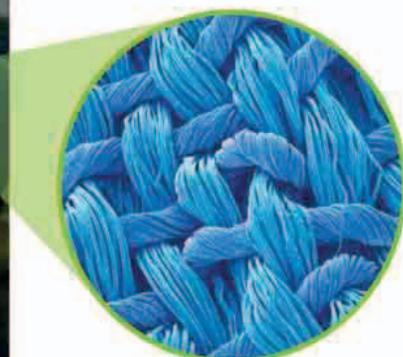
## MICROFIBERS

Synthetic fibers can be made in various thicknesses, from several millimeters to thousands of times thinner.

Microfibers are 100 times narrower than human hairs.

Fabrics made from them are usually soft and flexible. Some are made to soak up water and other fluids, so they are suited to cleaning and polishing.

Others resist water, as in microfiber jackets and similar garments, and types of fleeces.



▲ **WOVEN TOGETHER**  
*A powerful microscope shows how bundles of microfibers are woven over-and-under into a strong, thick fabric.*



## ELASTIC FIBERS

Natural rubber is not suitable for making into thin fibers to be woven into fabrics. However, in 1959 scientists invented a similar synthetic superstretchy material that could be spun into very fine fibers for clothing and other uses. Known as spandex, it is ideal for covering the body while allowing joints and muscles to move easily, without restraint.

### ◀ SMOOTH AND STRETCHY

*Fabrics such as spandex are smooth and stretchy, and are worn by many athletes from swimmers to cyclists.*



## LIGHT AND WATERPROOF

Most modern tents are made from synthetic fabrics, for example nylon and polyester, often coated with other chemicals such as silicone or polyurethane. They do not absorb water or rot, are lightweight, and keep out rain.



Nylon tent

## PRODUCTS AND USES

There are dozens of different kinds of synthetic fibers, some more commonly used than others. The compounds used to make synthetic fibers come from raw materials such as petrochemicals. Each kind has many uses and has one or more common name, such as spandex. These are produced to slightly different qualities by different makers, and combined with other chemicals or fibers to create materials with a variety of trade names, for instance Lycra and Creora for spandex.



◀ **ACRYLIC** *Strong, lightweight, and warm with a wool-like feel, acrylic is used for warm outer garments, as well as furniture and carpets.*



◀ **RAYON** *Known as "artificial silk," rayon fibers are smooth and soft. They absorb heat and repel water, making them ideal for umbrellas.*



◀ **POLYESTER** *Tough and durable, this fabric has many daily uses, such as clothes and blankets, and industrial uses such as conveyor and safety belts.*



◀ **NYLON** *The world's first synthetic fiber, nylon is a strong fiber that has widespread uses from parachutes and tents, to bags and ropes.*

# Composites

A composite material is made from two or more substances, which are usually quite different from each other. The aim is to have the best features of each substance, such as hardness and strength, so that the composite is better overall than its ingredients. Scientists invent new composites almost every week for specialized uses. However, some composites, such as papier-mâché and concrete, are thousands of years old.

## FIBERGLASS

Fiberglass is a composite material made of soft, flexible plastic with very thin strands of glass inside. It is also known as glass-reinforced plastic, or GRP. The glass helps the plastic hold its shape, while the plastic stops the glass from breaking.

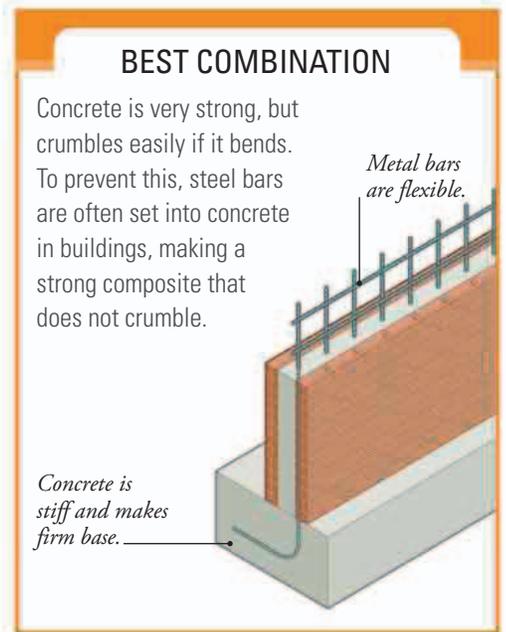
▼ **SPEEDBOATS** *Many speedboats are made of glass-reinforced plastic (GRP). It is waterproof, can be shaped and smoothed, yet can also resist knocks, bends, and twists.*



## CONCRETE

One of the oldest human-made composites, concrete is a mix of cement, sand, small stones, and water. It sets like rock, thanks to a chemical reaction (see p.32). Stones give it a strong overall framework, sand fills the small gaps between them, and cement bonds or glues them all together.

▲ **ROMAN CONCRETE** *The Colosseum in Rome, Italy, was an early concrete structure built almost 2,000 years ago.*



## SUPERSTRONG FABRIC

Some synthetic fibers (see p.68) are immensely strong and tough. Weaving them with other, more flexible fibers makes a composite that is strong but soft. With brand names such as Nomex and Kevlar, these fabrics are made into all kinds of supertough materials, from bulletproof clothing to sword-fencing outfits, ropes, tires, and sails.



WOW!

Kevlar is five times lighter than steel, but can survive five times as much force.



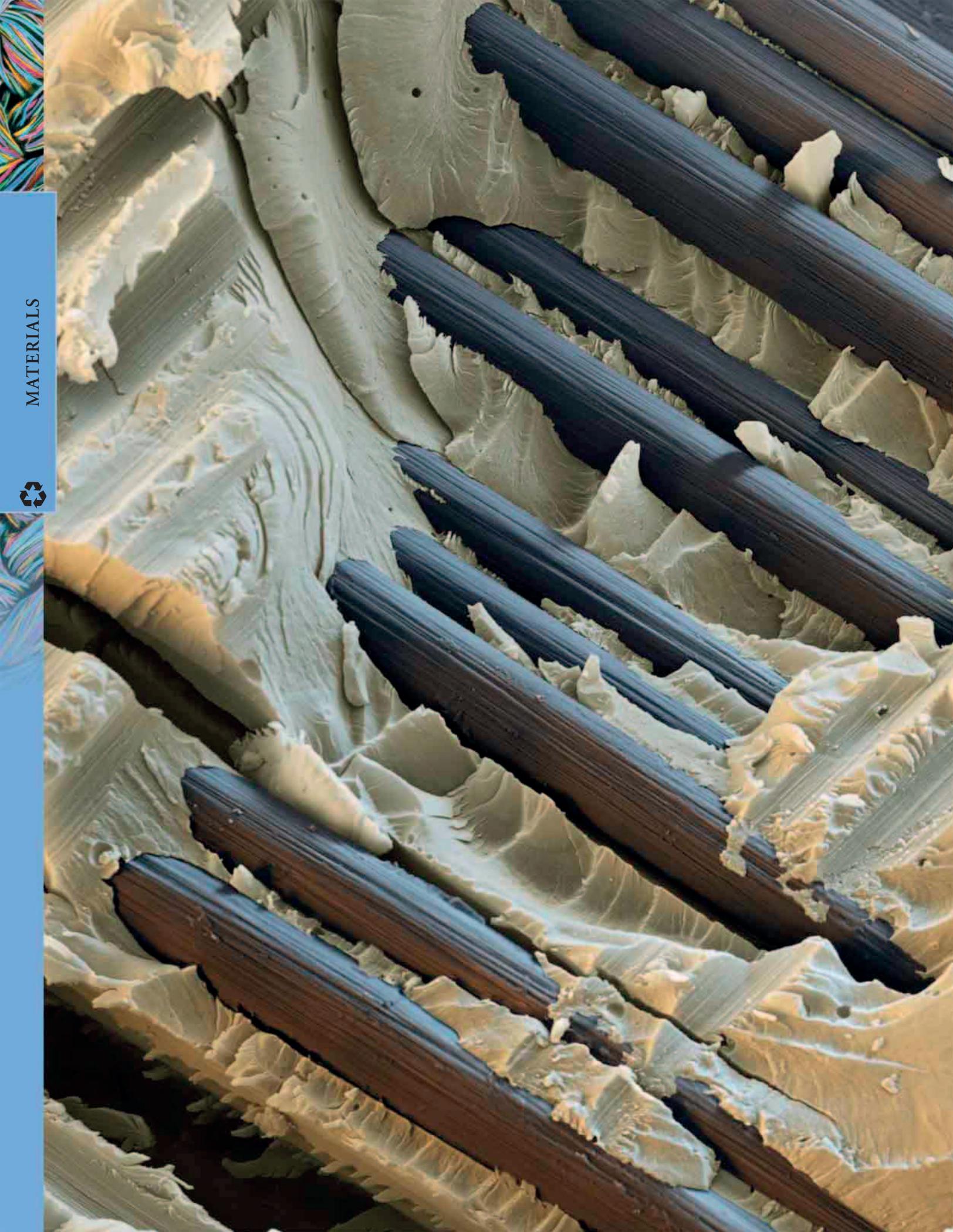
◀ PROTECTIVE GEAR *The protective clothing worn in fencing is made of Kevlar. It protects the fencers, and is light and flexible too.*

## HARDEST COMPOSITES

Some modern tanks and armored vehicles are protected by composites. They often have hard ceramic plates surrounded by layers of metal and stretchy plastics. This “multisandwich” absorbs and spreads the impact of explosions and bullets, so that the people inside remain unharmed.

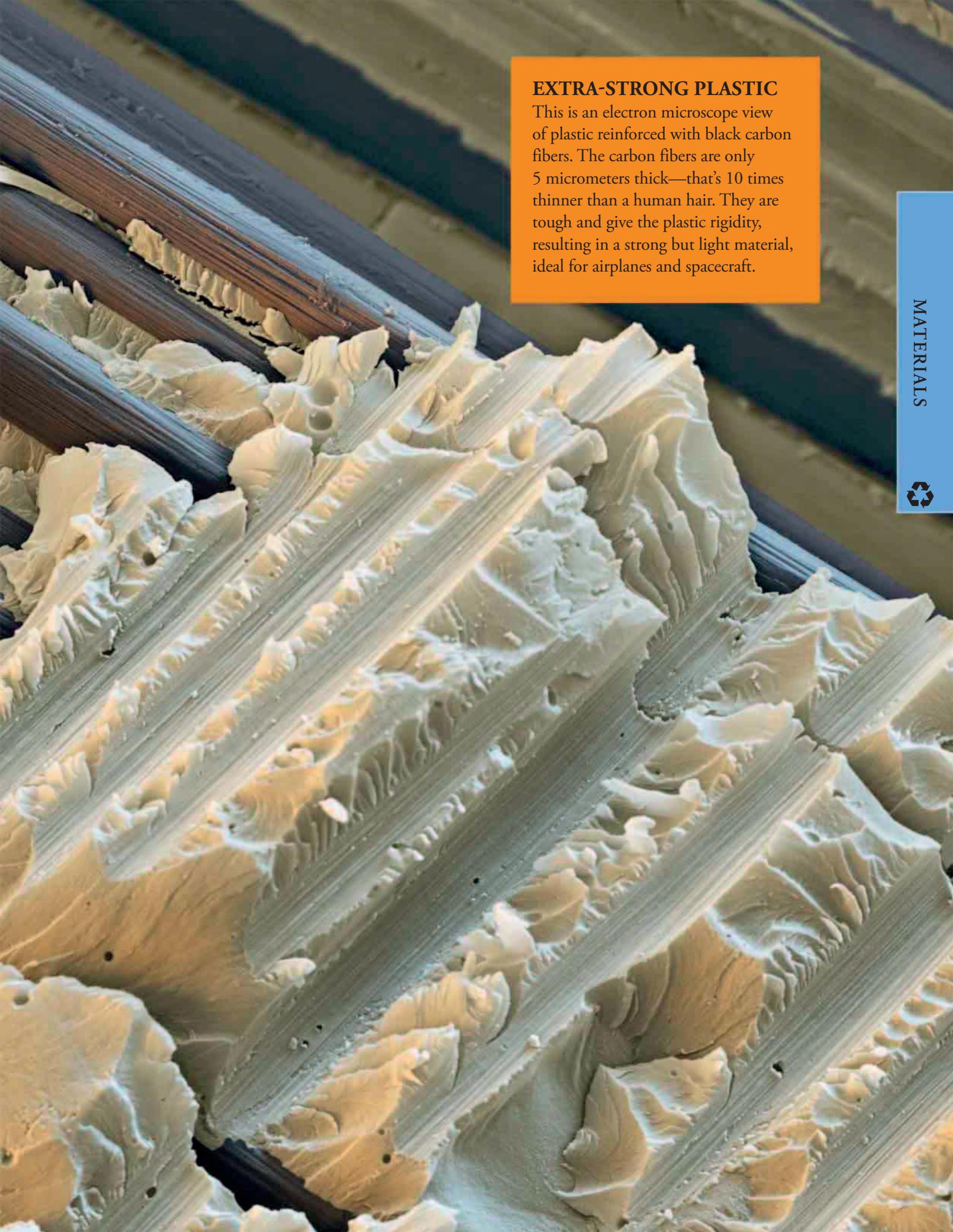
▶ POWER DEFENSE *The 60-ton (54-metric-ton) M1 Abrams tank is protected by layers of composite armor.*





MATERIALS



An electron microscope image showing a cross-section of a composite material. The image displays several parallel, dark, cylindrical carbon fibers embedded within a lighter, textured plastic matrix. The fibers are oriented diagonally across the frame. The plastic matrix has a complex, layered, and somewhat porous appearance, with fine lines and irregular shapes indicating its internal structure. The overall color palette is dominated by shades of grey, white, and black, with some blue highlights from the background.

## EXTRA-STRONG PLASTIC

This is an electron microscope view of plastic reinforced with black carbon fibers. The carbon fibers are only 5 micrometers thick—that's 10 times thinner than a human hair. They are tough and give the plastic rigidity, resulting in a strong but light material, ideal for airplanes and spacecraft.



# Earth's resources

All the materials we use, and the things we make from them, come from the earth. Some are natural and are used in their raw form, such as wood, stone, and ceramics. Others, such as synthetic fibers and human-made plastics, are made by processing natural resources like crude oil and minerals. The energy to make all these products also mainly comes from the earth, as fossil fuels. These resources cannot last forever and we cannot put most of them back.

WOW!

Earth receives more energy from the sun in one hour than everyone in the world uses in one year.

## FOSSIL FUELS

As the most easily-reached sources of coal, gas, and oil are being used up, miners and drill rigs must go to remote mountains, deep oceans, and icebound seas in search of more. At today's rate of use, known coal reserves may run out within 120 years, while oil and gas reserves will last less than 80 years.

▼ OIL PLATFORM  
*Huge exploratory drill platforms search for oil under the seabed.*

## TIMBER

About half of all forests are grown and harvested in a sustainable way for paper, timber, and fuel. But more than half of Earth's tropical rain forests have been cut down in the past 100 years, for rare timber and farmland. Almost none of these tropical forests have been replanted.



▲ CONTINUING USE *In sustainable forests, the timber is removed without too much damage, then new trees are planted.*





Drill pipes inside derrick tower



▲ SALTY TO FRESH Salt can be removed from seawater to make it fresh and clean, but this uses vast amounts of fuel or energy.

## WATER

As Earth's population rises, humans need more clean water for drinking, cooking, and washing. We also use water for growing crops and raising farm animals. Water has to be cleaned and purified before we can use it, which requires energy and resources.



## FARMLAND

Farmers need fertile soil to grow crops and raise animals. Pollution or overfarming (growing too much of the same crop in the same place) can damage the soil, making fertile land a resource that needs to be protected.

### ▲ FARM TERRACES

Leveled strips along a slope, called terraces, help hold water and prevent soil from being washed away.

## ENERGY

Humans around the world need energy to power cities, vehicles, homes, and factories. Energy is another kind of resource. Today, most of it comes from burning fossil fuels, but in the future we will need to find cheaper, less polluting energy sources.



▲ WIND FARMS The wind produces a supply of nonpolluting energy. However, at the moment it can only supply a small amount of the energy we use.

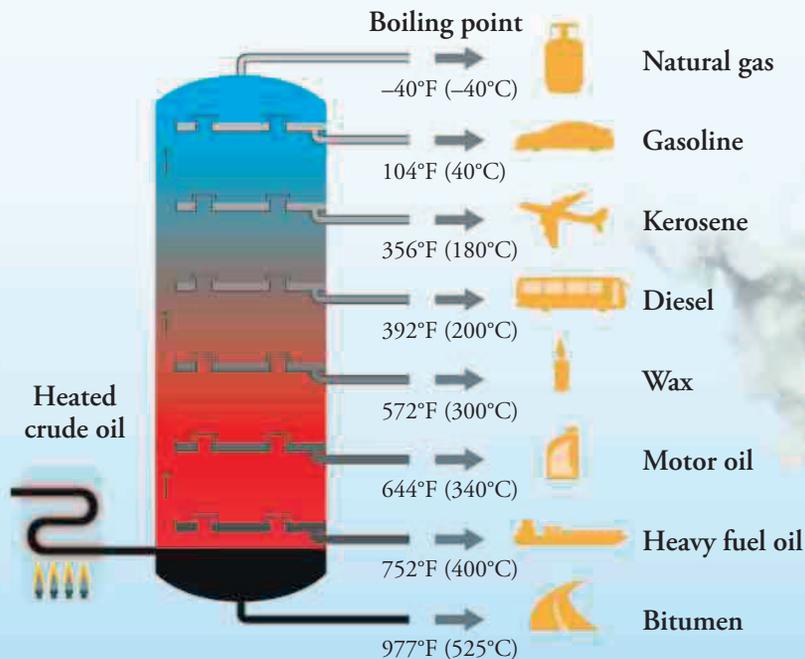


# Industrial materials

Millions of factories around the world take in resources such as energy and raw materials, and churn out chemicals and products, ranging from fertilizers to jumbo jets. One of the main resources is oil, which is used by 90 percent of all the world's industries. Other resources include natural gas, seawater, and minerals.

## INSIDE THE FACTORY

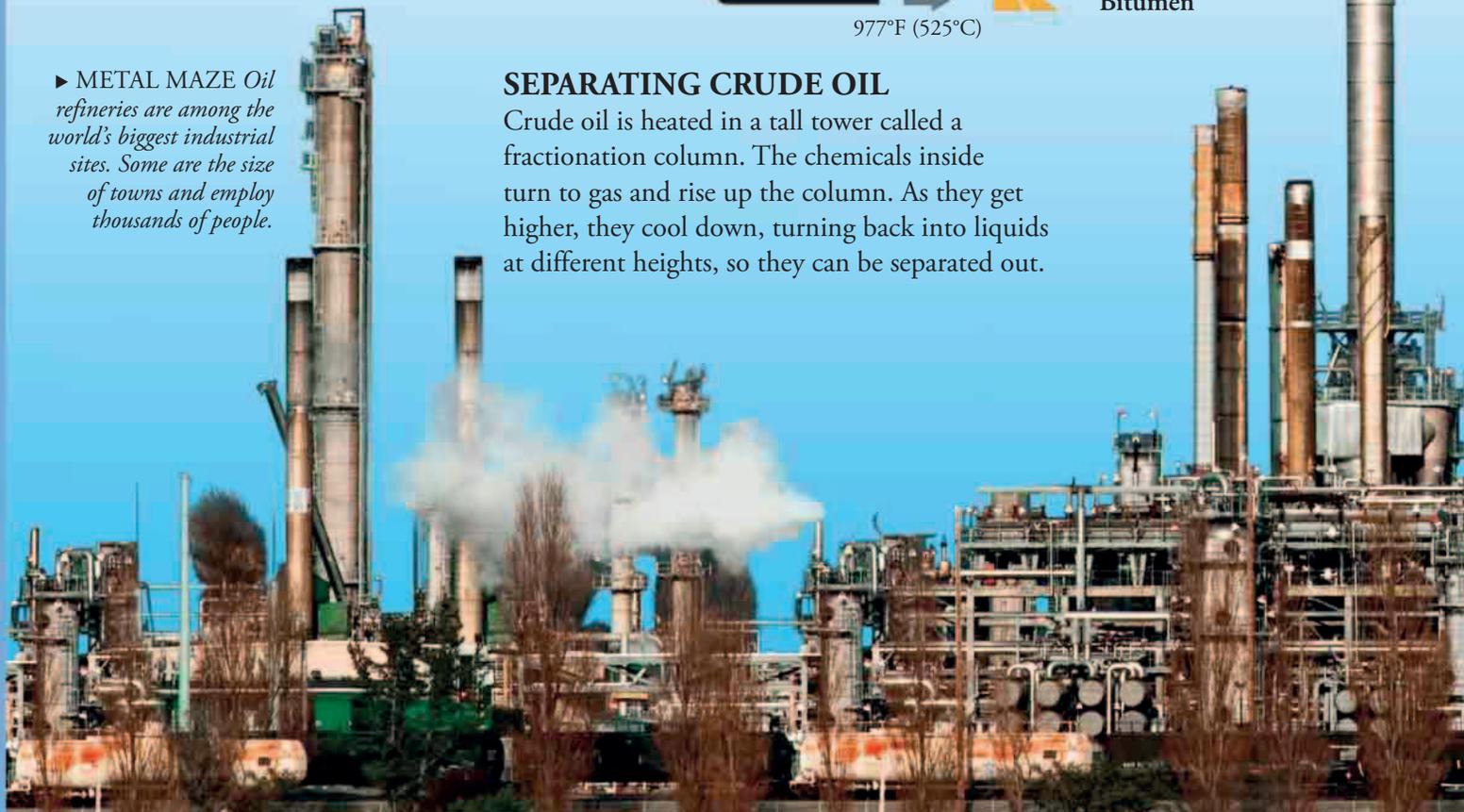
Chemical factories, or plants, start with raw materials, which are mixtures of hundreds of different substances. The raw materials are separated using physical processes such as evaporation and chemical reactions. For instance, an oil refinery receives crude oil, a complex mixture, which it separates into more than 200 different substances. These can then be used for making various products.



► **METAL MAZE** Oil refineries are among the world's biggest industrial sites. Some are the size of towns and employ thousands of people.

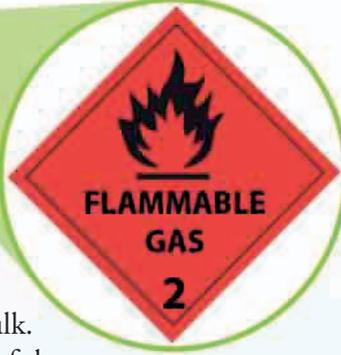
## SEPARATING CRUDE OIL

Crude oil is heated in a tall tower called a fractionation column. The chemicals inside turn to gas and rise up the column. As they get higher, they cool down, turning back into liquids at different heights, so they can be separated out.





▼ **WARNING!**  
*Signs are used on trucks around the world to warn of dangerous materials, such as those that are poisonous or explosive.*



## TRANSPORTATION

Specially designed vessels called tankers are used for transporting chemical products in bulk. Numerous safety rules regulate the transport of these products. Because of the danger of fire or explosion, these trucks carry markings to show what's inside.

► **PERSONAL PROTECTION**  
*Industrial workers wear protective clothing to keep them safe in case of accidents.*



► **AFTERMATH**  
*In 2013, a fire and explosion took place at the West Fertilizer factory in Texas, damaging nearby homes.*



## DANGERS AND DISASTERS

Chemical factories can be dangerous places if things go wrong. Chemicals can leak out, polluting nearby air, soil, and water. Radiation can escape from some facilities, while others might experience fires or even explosions. That's why all factories are carefully controlled to minimize the chances of an accident.

## HEALTH AND SAFETY

Industrial materials and chemicals can be far stronger and much more harmful than those used in homes. Safe practices include storing them in tanks, barrels, or similar secure containers that won't leak, which are clearly marked and kept away from possible causes of heat and fire.



# Recycling

Since Earth's raw materials, energy, and other resources will not last forever, it's essential to make sure they are not wasted. We can do this by repairing, reusing, and recycling. Recycling usually begins by sorting items into separate groups based on their main materials, such as metal, glass, plastic, and paper. Recycling saves not only Earth's resources, but also an immense amount of energy.

## RECYCLING CENTER

To make recycling efficient, different materials must be separated from each other. You can do this when you throw things away, by putting materials to be recycled into separate bins. Plastics are often sorted by experts, since different plastics use different recycling methods, and it can be hard to tell them apart.

▼ **PLASTIC PICKERS** *Workers pick out and sort different kinds of plastics so they can be recycled the right way.*

## LANDFILL

Landfill sites bring problems such as smells, litter, pest animals, and possible pollution. They are costly to cover over and make safe. Some plastics can last forever under the ground without rotting away. Throwing away recyclable materials means they are wasted and cannot be reused.



▲ **AROUND FOR CENTURIES** *Even after landfills are covered with soil and plants, the garbage may cause future problems.*



## PLASTICS

Each type of plastic has its own features (see pp. 62–63). However, its chemical makeup means it must be recycled in a particular way. For some plastics, recycling is not practical with today's technology, and burning them gives off harmful fumes. The solution is to use less plastic and reuse when possible.



▲ **BACK INTO PRODUCTION** *The same glass can go through the recycling process dozens of times. In a landfill, it will last a million years.*

## GLASS

One of the best materials to reuse and recycle is glass (see pp. 64–65). It is hard, smooth, and easily cleaned, so glass jars and bottles are ideal for reuse and filling with other contents. Recycling glass saves more than one-third of the energy and one-half of the raw supplies needed to make new glass, and it can be done many times over.

## RECYCLED PRODUCTS

Glass, metals, and many plastics can be melted down to make new objects that are just as good as nonrecycled ones. Recycled paper is often less smooth than new paper, but is ideal for toilet paper and paper towels. Recycled fabrics can be used to make cleaning rags and dust sheets.

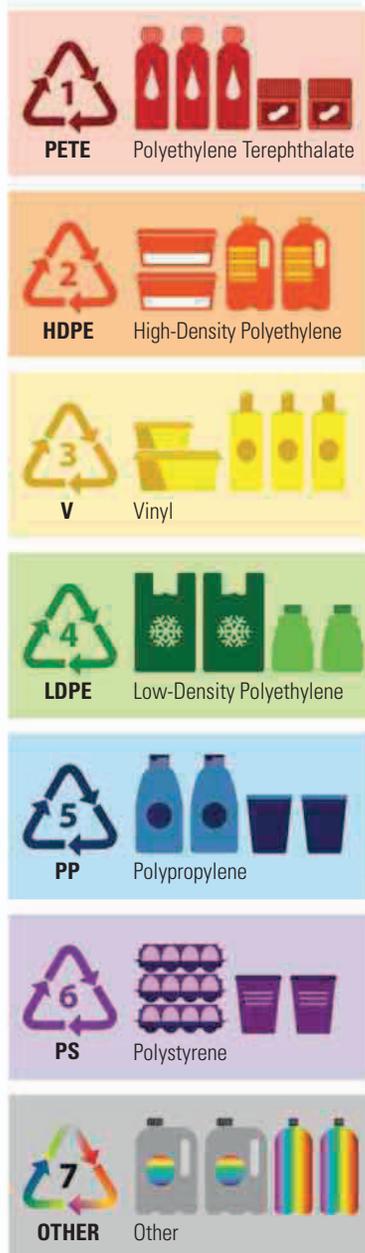


▲ **RECYCLED CHAIR** *Plastics can be melted down and formed into new shapes, from plastic bags to lawn chairs.*

## REUSE AND UPCYCLE

Selling, swapping, or giving away saves even more materials, energy, and landfill space than industrial recycling. There are many ways to reuse, such as swap meets, thrift stores, garage sales, and websites. In “upcycling,” unwanted items are reused to give extra value, for example, using bits of metal from old machinery to create works of art or homemade utensils.

▶ **SORTING FOR REUSE** *Almost any usable item could be wanted by someone, somewhere. Every little bit helps to save Earth's resources, decrease waste, and reduce pollution.*



▲ **PLASTIC BY NUMBERS** *The numbers in the recycling triangle symbols are codes for the type of plastic used in the items.*



# Future materials

As scientists and engineers develop new techniques for combining atoms, more and more materials become available for us to use. Some of the latest designs have amazing properties, from metals that can float on water to armor plating that only turns solid when an impact occurs. These new inventions could transform our lives in years to come.

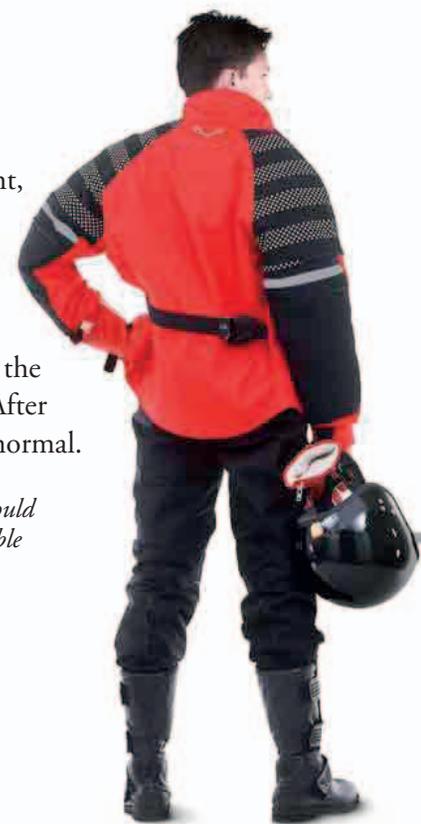
## INTELLIGENT MATERIALS

Smart or intelligent materials can change their properties depending on conditions around them. You might have seen them in glasses that look clear in normal light but darken in bright sunlight. A special form of aluminum has been created that turns see-through when electrical current is passed across it. This could be used to make buildings with windows stronger than glass that can be made opaque at the flick of a switch. Other possibilities include clothing that changes with temperature to keep you warm or cool in any weather.

## ARMORED FABRICS

Future protective gear may feel like ordinary clothes. It will be lightweight, flexible, and waterproof, making it comfortable to wear. However, when knocked or hit, it will instantly stiffen into a tough shell to protect the body beneath and spread the impact harmlessly over a wide area. After the impact, the fabric will return to normal.

► **WELL PROTECTED** *Flexible armor could allow motorcyclists to stay cool and comfortable while riding, yet still keep them safe.*



◀ **SPACE BASE** *A future base on the planet Mars could use smart materials to protect the people inside.*



WOW!

Scientists are working to create a form of concrete that “heals over” cracks, thanks to bacteria living inside it.



## USING ENERGY

Electricity is a very convenient and adaptable form of energy. It is easily transported long distances along wires, and it can be changed into many other forms of energy for our use. At the moment, we rely on fossil fuels to generate most of our electricity, but these cause pollution and will run out in the future. One of the great challenges for future scientists will be finding materials that can store and transport electricity more easily, as well as finding new ways of capturing energy from renewable sources such as the sun or the wind.



### ◀ BATTERY POWER

*As gasoline becomes more expensive, we may rely on electricity to power our cars. New materials may help us build better batteries, which will allow electric cars to travel farther before having to recharge.*



### ◀ SOLAR POWER

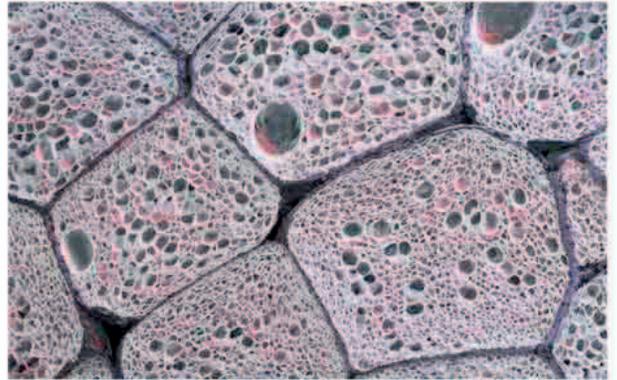
*Energy from the sun is low-cost and causes little pollution. These solar cells trap sunlight and convert it to electricity, but at the moment they are not very efficient. New materials might help us create better solar panels.*

▶ **BENDING DISPLAY** *Flexible touch screens containing electronic circuits might allow your tablet or smartphone to be rolled up and carried in your pocket, or wrapped around your wrist.*



## METAL FOAM

Foamed plastic, containing tiny bubbles of gas, has many uses, such as lightweight packaging and space-filling. Future metal foams could have similar uses, but would be stronger, fire-resistant, and more easily recycled. For instance, metal foam could be put into walls and gently heated by electricity to keep the room warm.



▲ **ALUMINUM FOAM** *This microscope photo shows tiny bubbles in a foam of aluminum metal. This creates a very strong but light substance that could be used in buildings.*

## STRONG BUT FLEXIBLE

Screens are everywhere—on televisions, computers, tablets, and smartphones. At the moment, screens are hard and fragile, but new materials, such as carbon-based graphene, may produce flexible touch screens that can be rolled up or even folded without breaking.





### **SUPERLIGHT SOLID**

This astonishing solid, called SEAgel, is so light that it can sit on soap bubbles without breaking them. It's made from agar, a jellylike substance extracted from seaweed, which is dried and puffed full of gas bubbles. An apple-sized piece of SEAgel weighs the same as a single grain of rice.



# FORCES AND MACHINES



## **BALANCING ACT**

The Millau Viaduct in southern France uses carefully balanced forces to hold 1.6 miles (2.5 km) of road in midair. Tall pillars and extrastrong cables keep the road in place so cars can drive safely across.



A force is a push or a pull. It makes an object speed up or slow down. By building clever machines, human beings can use forces to perform tasks that our own bodies could never manage.



# What are forces?

When fireworks soar through the sky, cars screech to a halt, or flies creep up walls, forces are at work. Forces are the hidden power behind everything on Earth—and far beyond. A force is a push or a pull, sometimes at close range and sometimes from far away. Forces can be tiny or huge. Minuscule forces glue atoms together, while the vast force of gravity hauls the planets around the sun.



## WHAT EFFECT DOES A FORCE HAVE?

We cannot always see forces at work, but they can have spectacular effects. Often a force changes something's shape or makes it move in a new way, though forces can also hold things perfectly still. When the boxer hits this punching bag, the force makes it move, then changes its shape, and finally makes it explode. So even one force can have several different effects.

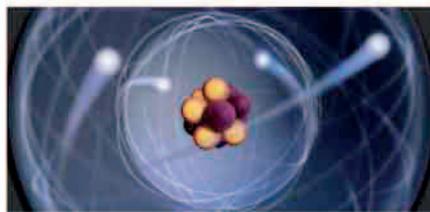
## FORCES AND YOU

There is no escaping forces. Even when you are sitting still or sleeping at night, powerful forces are acting on your body. Forces can help you walk, talk, run, and swim. Inside your body, forces help you breathe, pump blood through your veins, and even make the thoughts that run through your head. Without forces, life would be impossible.



### Gravity

*Gravity is the force that sticks you to the earth's surface, and it also pulls the planets through space.*



### Nuclear force

*Every single atom inside your body is glued together by incredibly strong forces that bind its nucleus (center) tightly together.*



### Weight

*Weight is a measurement of the force of gravity pulling on an object. It can be measured using a scale.*



### Electromagnetism

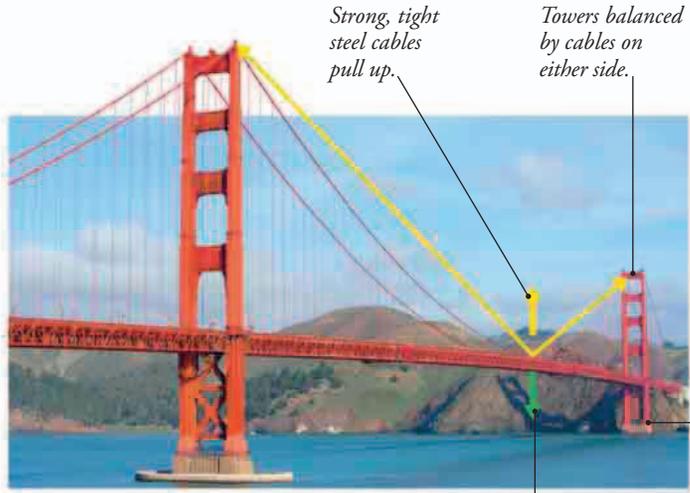
*This force, made by electrons, controls magnetism and electricity, such as the electrical signals that zap through your brain.*

WOW!

The force of Earth's gravity reaches all the way from the center of our planet far into space across the solar system.

**FORCES ACTING TOGETHER**

Forces do not always work alone. Instead, two or more forces can push or pull on the same thing at the same time. When this happens, the forces either add together (making a bigger force) or cancel out (making a smaller one). When forces cancel completely, it looks as though no force is acting at all.



Strong, tight steel cables pull up.

Towers balanced by cables on either side.

Towers reach deep underwater, anchoring bridge to seabed.

Weight of deck pushes down.

▲ **FORCES IN BALANCE** The Golden Gate Bridge in San Francisco does not fall into the water, even though its huge deck (road) is heavy. The weight of the deck pulls down, but the steel cables pull back up. These two forces—weight and tension—cancel out, so the bridge is always safe to use.



▲ **FORCES OUT OF BALANCE** Different-sized forces can act in different directions at the same time. When two wrestlers start to push against each other, they go nowhere since their pushing forces are the same. Soon, one pushes a little harder, making an overall force in that direction so that the pair topples over.



Wind blows sail, tipping boat one way.

Sailor balances boat by leaning the other way.

▲ **FORCES COMBINED** Sometimes, many forces act at once. This boat is being blown over by the wind, but the sailor is leaning out to stop it, and these forces are balanced. The wind is blowing the sail forward, while the rough sea is pushing it backward. These forces are out of balance, so the boat speeds onward.

# Forces and movement

Forces help you walk, and move your mouth when you talk. They blast rockets into space with a roar and blow ships over stormy seas. You could never run or swim without forces. With no force pumping your lungs, you couldn't even breathe. If there were no forces, the world would be a totally still and silent place. Nothing would move and nothing would ever happen.

## HOW FORCES MAKE MOVEMENT

Why does a rocket zoom into the sky when the force from its engine fires below it? An English scientist, Isaac Newton, was the first person to explain how forces make things move. More than 300 years ago, he figured out three simple rules, often called Newton's Laws of Motion. They are among the most important scientific concepts ever discovered.



◀ **NEWTON'S FIRST LAW** *Nothing moves unless a force acts on it. A rocket stays still on the launchpad until the engines fire up. If something is already moving, it keeps moving unless a force stops it.*



◀ **NEWTON'S SECOND LAW** *When a force pushes or pulls on something, it usually gives it extra speed. This is called acceleration. As the engines fire under a rocket, they give it speed that blasts it high into the sky.*

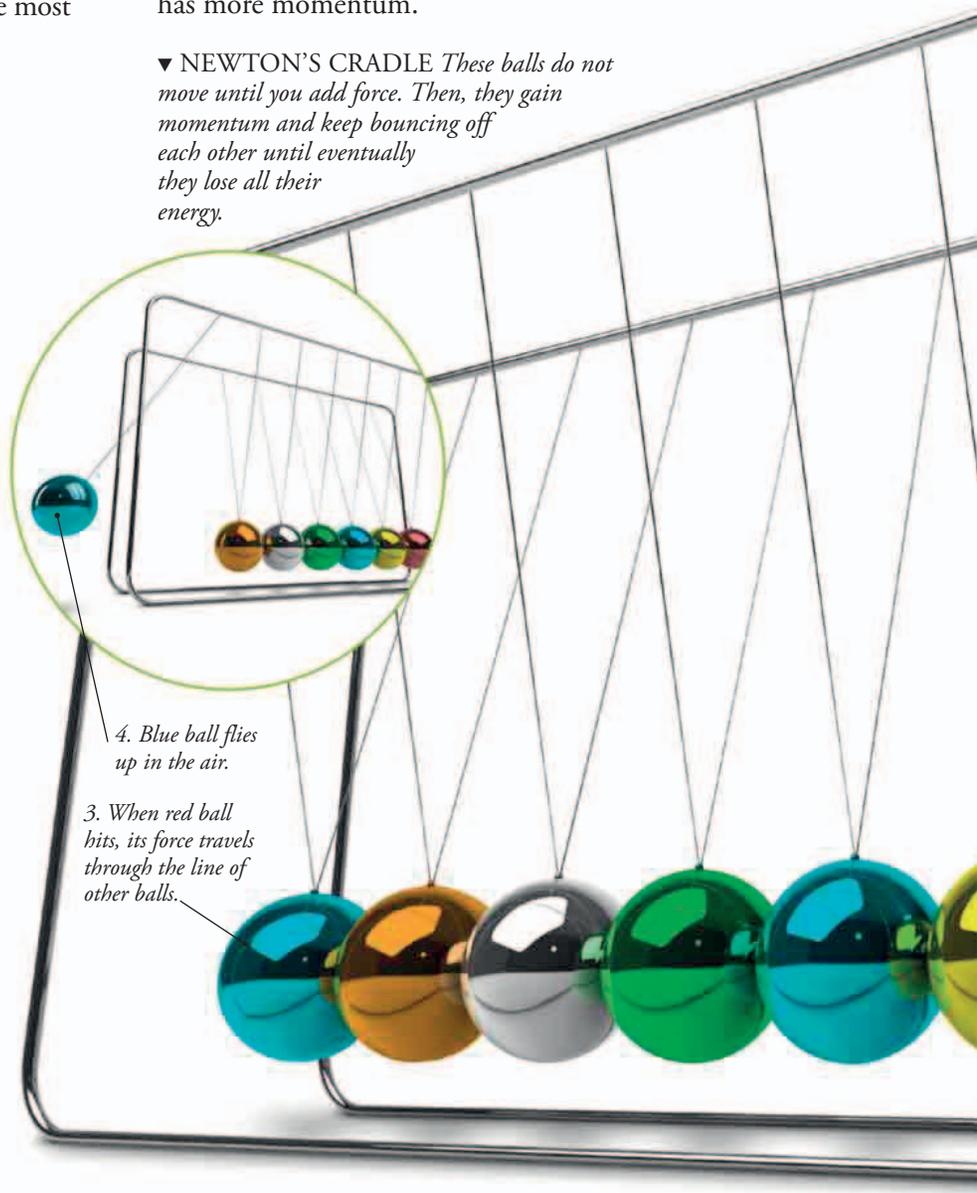


◀ **NEWTON'S THIRD LAW** *When a force pushes, there is always an opposite force of the same size pushing the other way. As the exhaust gas fires down from a rocket, the rocket fires up into the sky.*

## KEEP STILL, KEEP GOING

Heavy things are harder to move because of inertia. This means they do not like to change. A stationary truck is harder to move than a car because of its inertia. A moving object has momentum. The heavier or faster it is, the more momentum it has. A moving truck is harder to stop than a car because it has more momentum.

▼ **NEWTON'S CRADLE** *These balls do not move until you add force. Then, they gain momentum and keep bouncing off each other until eventually they lose all their energy.*



## MEASURING MOTION

Speed, velocity, and acceleration are three different ways of measuring how things move. Speed is how fast something goes, which is how much distance it covers in a certain amount of time. Faster things go farther each second than slower things. Velocity is the speed something has in a certain direction. If it changes direction, its velocity changes even if its speed stays the same. Acceleration is how fast something speeds up or slows down (changes velocity).

**WOW!**

An express train is heavy and travels fast, so it has enormous momentum. It can take five minutes for it to stop from top speed.

Strings allow balls to move freely.

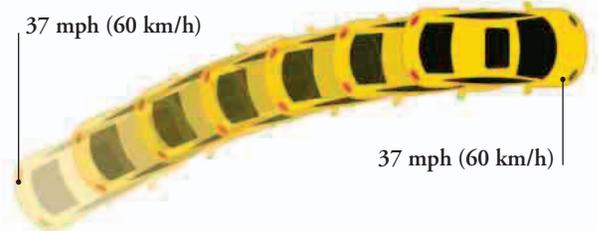
1. Heavy red ball has mass, and lifting it gives it energy.

Line of balls stays still until the force of the red ball hits them.

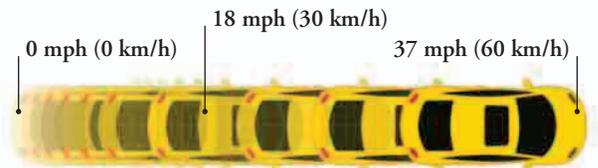
2. Red ball picks up speed, and then crashes into other balls.



▲ **SPEED** This car has a steady speed, so it covers the same distance every second. If it travels for twice as long, it goes twice as far.



▲ **VELOCITY** This car goes at a steady speed but in a curve. Its direction is constantly changing, so its velocity is changing even though its speed stays the same.



▲ **ACCELERATION** This car is accelerating, which means its speed is increasing every second. The longer it travels, the faster it goes. Things accelerate when forces act on them.



## BRAKING FORCE

It takes force to move things—and force to stop them. The quicker you need something to stop, the bigger the force you have to use. Cars are designed to crumple when they crash so that the impact lasts longer. If a car takes twice as long to stop, the people inside feel half as much force on their bodies. That means fewer injuries and a greater chance of surviving.



▲ **CRASH TEST DUMMIES** These dummies are used to test how the force of a crash would affect people inside the car.

# Turning forces

Spinning, wheeling, twisting, turning—when things move in circles, hidden forces are hard at work. Left to themselves, moving things go in straight lines. It takes a force to make something turn in a circle instead. You need a bigger force to turn heavier things, spin them more quickly, or bend them in tighter circles.

## ROUND AND ROUND

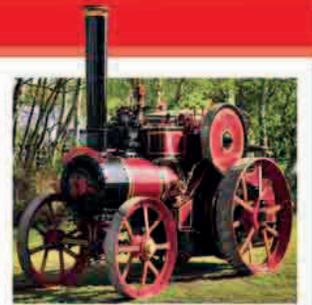
The force that makes things move around in circles is called centripetal (“center-seeking”) force. On this carnival ride, the centripetal force comes from the tight, sturdy ropes, which pull each person around in a different circle. If you cut the ropes, there would be no centripetal force, and the people would fly off in straight lines.

### ► GOING IN CIRCLES

*The more people on the ride, and the heavier they are, the more force the wheel needs to make them spin.*

## STORING SPIN

Giant machines need to store energy so they can run smoothly. This old-fashioned steam tractor uses a huge, heavy flywheel. The engine spins the flywheel, which drives the road wheels. Even if the engine slows down, the flywheel keeps the road wheels turning at a steady speed.



You need force to turn things in circles.

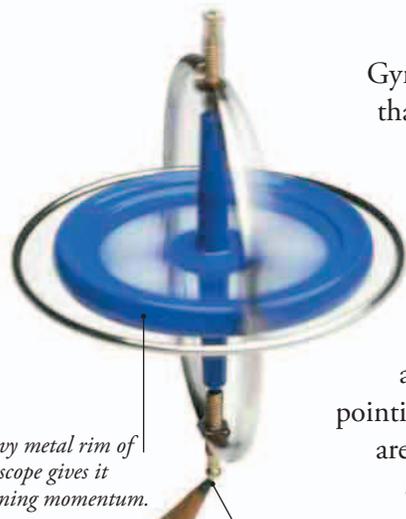


## BALANCING ACT

Your weight seems to be concentrated in your stomach, at a point called your center of gravity. If this is not above your feet, gravity makes you topple over. When you lose your balance, your body spins around your center of gravity as you fall.

### ◀ PERFECT BALANCE

*This gymnast balances because her center of gravity is above her hands. If her feet move, her body will turn and topple over.*



*Heavy metal rim of gyroscope gives it spinning momentum.*

*Gyroscope spins and balances on tiny pencil point.*

## STEADY SPIN

Gyroscopes are spinning wheels that seem to defy gravity. They stay upright even when you push or knock them over.

A heavy wheel spinning inside the gyroscope constantly pulls it upright, so it can balance almost anywhere. Because they keep pointing the same way, gyroscopes are used like compasses to help ships and airplanes navigate.



**WOW!**  
 Standing still on the equator, you are really moving at 1,000 mph (1,600 km/h). Earth turns that fast!

## IN A WHIRL

Hurricanes (also called cyclones or typhoons) spin around like gigantic wheels because forces act inside them. In the eye (middle), air pressure is low, creating the force that spins the hurricane. Air is sucked in from the outside, making fierce winds, and the whole thing whirls around as it moves along.



▶ **SPINNING STORM** *Hurricanes look still from space, but this one is moving at 120 mph (95 km/h)—faster than the top speed of most cars.*

*The outside moves a longer distance than the inside, so it travels faster.*

*As the wheel turns, the inside moves only a short distance.*



## WHEELS AS LEVERS

Wheels work like levers and can increase force or speed. If you turn the hub (center) of a wheel, the rim (edge) spins faster but with less force. If you turn the rim, the hub turns slower but with extra force. That's why faucets sometimes have wheel-shaped knobs to help you turn them on or off.

◀ **LONDON EYE** *This Ferris wheel turns very slowly at the center. But because the wheel is huge, the passenger cars around the edge move more quickly.*



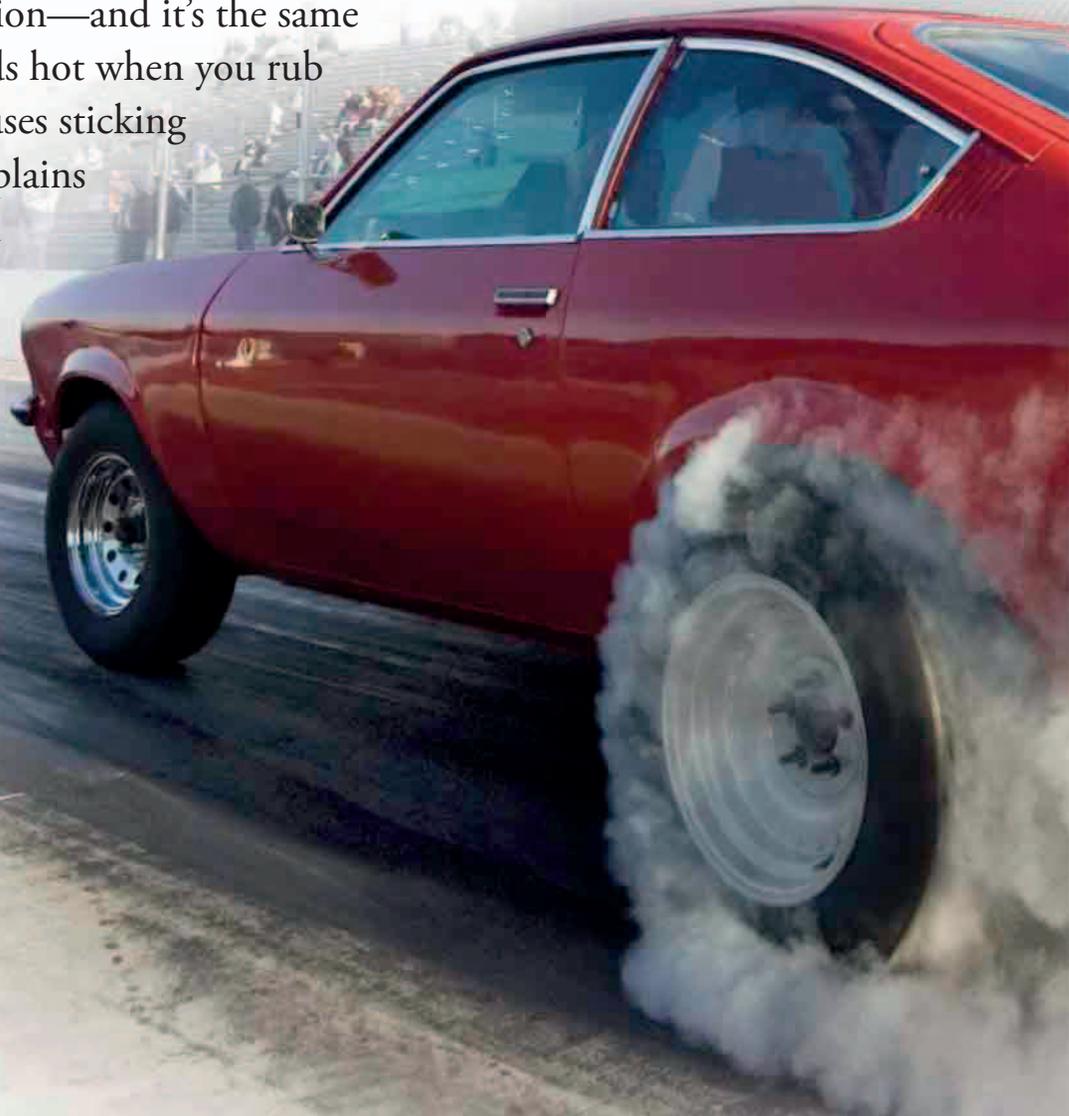
### SWIRLING STORM

Tornados form when a special type of thunderstorm creates spinning forces in the air. The biggest tornados have wind speeds of more than 280 mph (450 km/h), enough to knock down a house. Less powerful is a “landspout.” As seen here, this small swirling storm forms at ground level and gets pulled up into storms above.



# Friction

Every time you walk across the floor, your feet stick to it very slightly. If they didn't, you would fall over. This sticking force is called friction—and it's the same force that makes your hands hot when you rub them together. Friction causes sticking and rubbing, but it also explains slipping and sliding. When there's not much friction, things slide past each other very easily. You slip on ice because there is very little frictional force.



## HANGING IN THERE

Friction can hold things still, even when other forces are pushing or pulling. Lizards can scale rocks by splaying out their toes to create friction on the rough surface. The force of friction is an upward pull, strong enough to balance the lizard's weight pulling down.

◀ **ROCK CLIMBER** *Lizards can climb vertical surfaces because their rough skin creates friction to stop them from falling.*

## TEARING AWAY

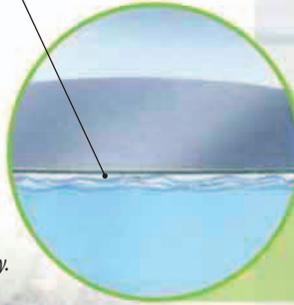
Friction holds things still, but also helps them move. A car speeds along the road because its tires grip the surface. As the wheels turn, the tires push back on the road. The engine's power can then shoot the car forward. Without friction, the wheels would spin, and the car would go nowhere.

**WOW!**

The most slippery thing found in nature is the inside of a carnivorous pitcher plant. Even insects cannot climb out.

*A thin layer of water underneath the surface of the skate makes it slide.*

► **ICE SKATING**  
*The low friction between the skater's blade and the ice allows her to glide smoothly.*



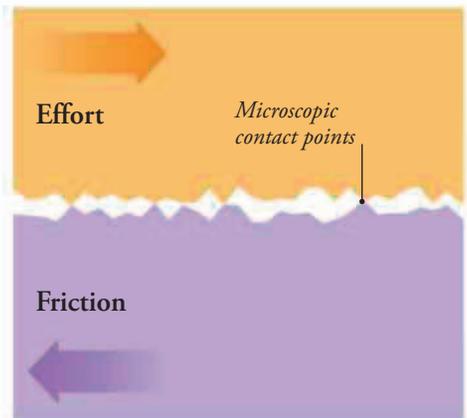
**SMOOTHING THE WAY**

Friction can really slow things down. It can wear out machines by slowly grinding away their moving parts.

Oiling parts makes them slide smoothly past each other, so there is less rubbing. This is called lubrication, and it explains why ice is slippery. When you walk on ice, it melts a tiny bit and the water between your feet and the frozen ground makes you slide, just like oil.

**WHAT MAKES FRICTION?**

Seen under a microscope, even the smoothest things are rough. If two smooth surfaces rub together, atoms on the edge of one catch and snag the atoms on the edge of the other. This snagging is one of the things that causes friction. When atoms are very close, they can attract one another electrically, and that also increases friction. The rougher the surfaces, the more friction they create. If there were no friction, things would keep on moving.



◀ **WHEEL SPIN**

*If a car's engine makes too much force too quickly, or the tires cannot grip, the wheels spin on the road. As the tires rub, friction creates heat and smoke.*



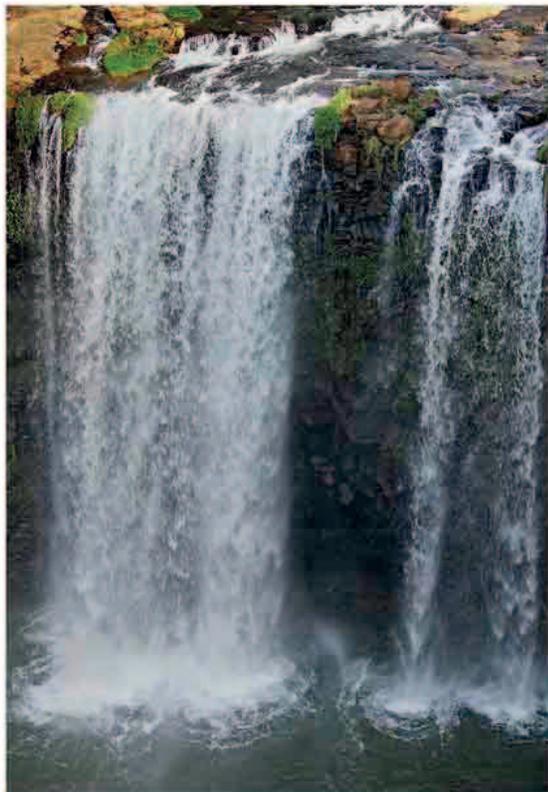
**WHAT A DRAG**

Air might seem empty, but if you move fast enough, you can feel it pushing into you. This is called air resistance or drag, and it's a kind of friction. The faster you go, the harder you have to work against drag. Airplanes, cars, and even cyclists have to use lots of their energy to simply push through the air.

◀ **LEAN MACHINE** *Speed cyclists can go faster by wearing tight-fitting clothes and crouching down to reduce drag.*

# Gravity

Gravity holds the universe together like a giant, invisible spiderweb. Everything around you, the ground beneath your feet, and every single star and planet in space is connected to everything else by this immense tugging force. When you drop something, this same force—gravity—pulls it down toward the earth.



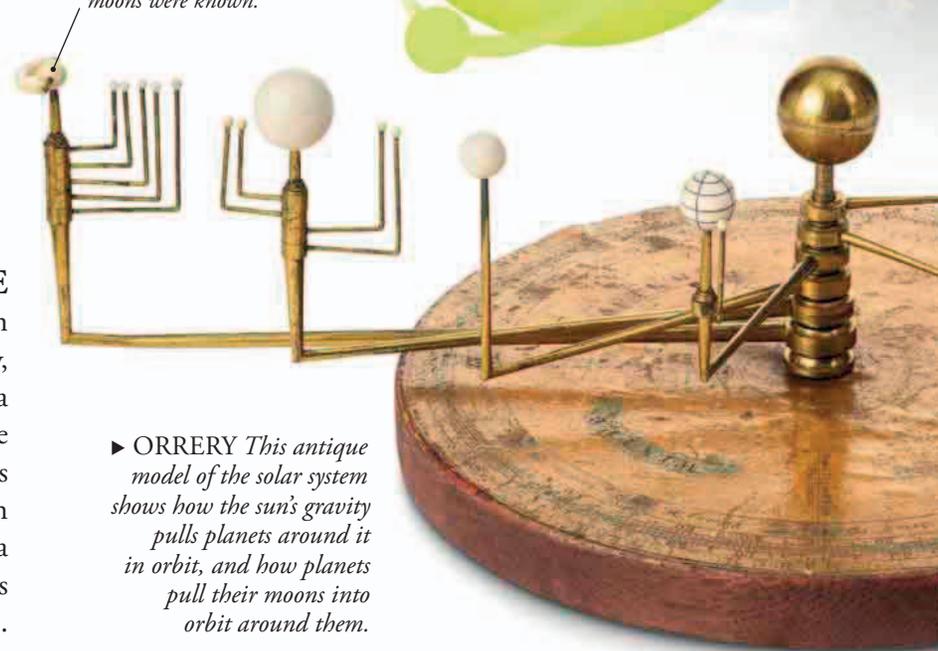
## WHAT IS GRAVITY?

Gravity is the pulling force between every object and every other object in the universe. The closer together two things are, and the heavier they are, the bigger the force of gravity between them. Earth's gravity pulls everything around it toward the center of the planet, keeping us on the ground.

### ◀ FALLING WATER

*The irresistible force of gravity pulls water downhill from mountains all the way to the sea.*

*Saturn has more than 60 moons around it, but when this orrery was made only five moons were known.*



▶ ORRERY *This antique model of the solar system shows how the sun's gravity pulls planets around it in orbit, and how planets pull their moons into orbit around them.*

WOW!  
Tiny things have gravity just like big ones. When an apple falls toward Earth, it also pulls Earth up to meet it by a tiny amount.

## SPIN CYCLE

The planets zoom around the sun in curved paths called orbits. Usually, moving things go in straight lines, but if a force pulls on them, they bend in a curve instead. Gravity from the sun pulls the planets around it in orbits. Because the planets weigh different amounts, each one moves in a different orbit. The orbits look like circles but are really oval shapes (ellipses).

## FREE FALL

When you jump from a plane, gravity tugs you toward the ground, but air pushes against you at the same time. The longer you fall, the faster you go. But you soon reach a speed where the force of gravity pulling down is the same as the force of air pushing up. Then you free fall—move at a steady speed as if you were weightless.



Parachute is ready for safe landing.

Rip-proof nylon is strong enough to survive force of air pushing up.

Air pressure flattens skin against face.

▲ WING SUIT *The extra material in this suit acts like a plane's wing, pushing the skydiver up so he falls more slowly.*

Wrist computer shows flight time and direction.



▲ EARTH *Our planet is big and heavy, so the force of gravity pulling on you is strong. You cannot jump very high or far.*



▲ MOON *The moon is smaller and lighter, so the force of its gravity is weaker. You can jump much higher and farther.*

## MASS AND WEIGHT

Your mass is a measurement of how much “stuff” (matter) you are made of. Your weight measures how much gravity pulls on your mass. Your mass is the same wherever you go, but your weight changes from place to place as the force of gravity changes. On the moon, you weigh about six times less, because the moon is smaller and less massive than Earth, so its gravity pulls less forcefully.

## MAXIMUM GRAVITY

There are spots in space where the force of gravity is so huge that even passing light gets sucked in. These odd places look completely dark, so we call them black holes. Despite their name, they are not empty—they are packed full of mass, giving them immense gravity. If you fell toward a black hole, it would stretch your body thin, like a strand of spaghetti.

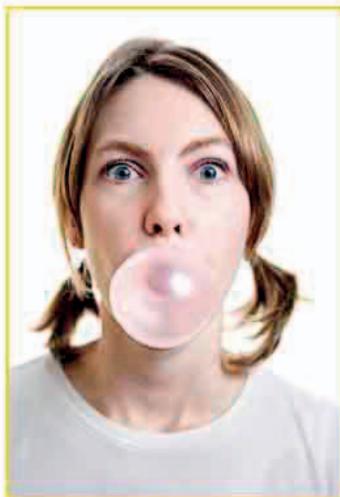


# Bending and stretching

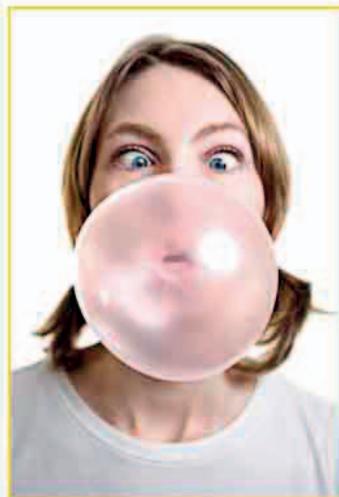
Twisting, bending, squashing, and stretching—all these things happen because of forces. When you squeeze something soft and stretchy, such as a rubber ball, it changes shape. If you stop squeezing, you take the force away, and the ball changes back again. We say the ball is elastic, because it goes back to its original shape.

## STRETCHING SCIENCE

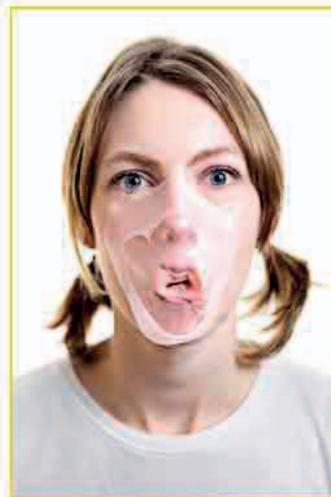
If you apply force to something stretchy, for example by blowing into bubble gum, it changes shape. If you blow twice as hard, it stretches twice as much. Blow too hard and it snaps. This basic rule of stretching is called Hooke's Law, after the scientist Robert Hooke.



▲ **LITTLE FORCE** *Chew the gum to soften it, then blow into it. The blowing force stretches the gum to create a balloon shape.*



▲ **TWICE THE FORCE** *When you blow the gum with twice the original force, the balloon stretches twice as far.*

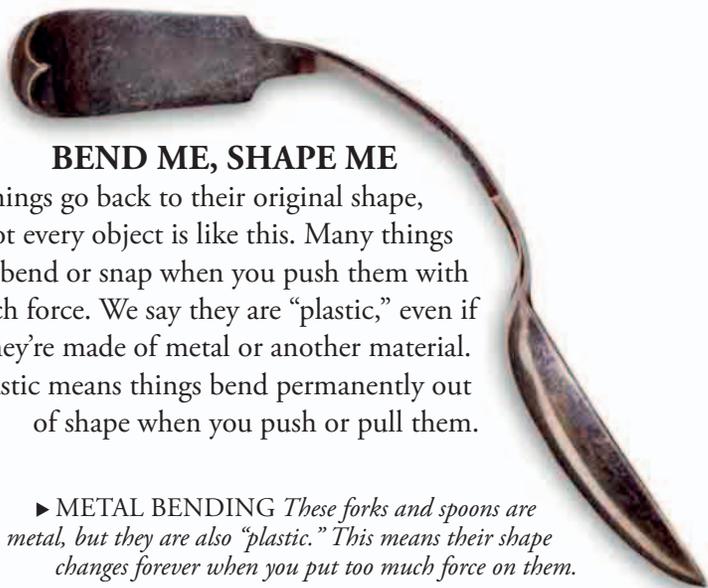


▲ **TOO MUCH FORCE** *If you keep blowing, the gum stretches too far and the balloon bursts.*

## BEND ME, SHAPE ME

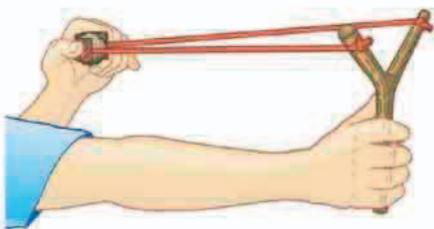
Elastic things go back to their original shape, but not every object is like this. Many things simply bend or snap when you push them with too much force. We say they are “plastic,” even if they’re made of metal or another material. Plastic means things bend permanently out of shape when you push or pull them.

► **METAL BENDING** *These forks and spoons are metal, but they are also “plastic.” This means their shape changes forever when you put too much force on them.*

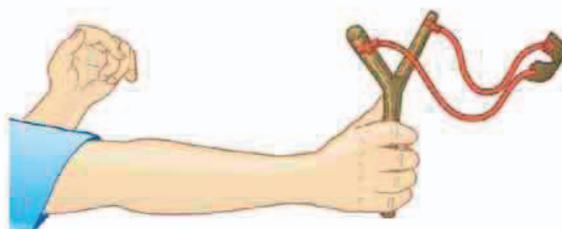


## THE POWER OF STRETCH

Pull back on a slingshot and the force you use stretches the elastic. This stores energy inside it, known as potential energy. When you let go, the elastic returns to its original shape. The stored energy must go somewhere—so it is given to the stone, flinging it through the air.



1. Stretching elastic stores energy.



2. Letting go releases energy.

Stone gains energy originally stored in elastic.

## STRETCHY SKIN

Pinch your skin and let go, and it springs right back again. This is because young skin is very elastic. Older skin is not as elastic, which is why older people have more wrinkles. Antiwrinkle creams work by covering skin in gluey chemicals that stretch it tight. This makes wrinkles disappear—at least for a while.

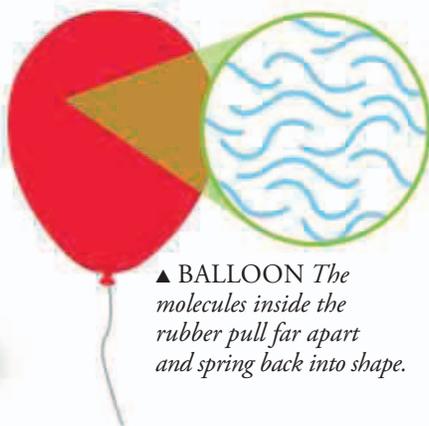


WOW!

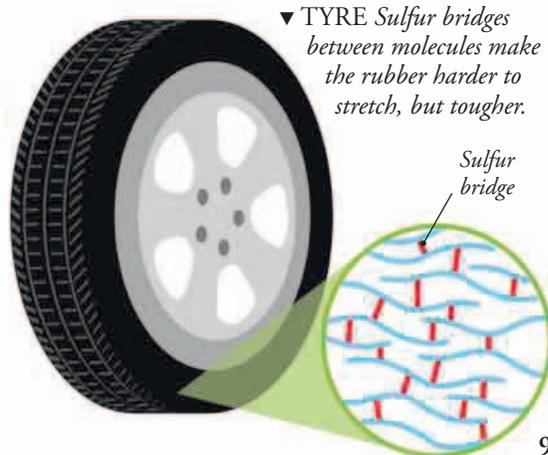
Rubber can be stretched to three times its length. Hydrogels, the world's stretchiest materials, can be pulled to 20 times their original length.

## MAKING RUBBER STRONGER

Rubber comes from trees, and it's white, goeey, and smelly. This pure kind of rubber, called latex, is used to make stretchy things like balloons, but it's not very strong. We can make rubber more useful by cooking it with sulfur. This makes the rubber hard, black, and tough. It's not as stretchy, but it's stronger and lasts longer.



▲ BALLOON The molecules inside the rubber pull far apart and spring back into shape.



▼ TYRE Sulfur bridges between molecules make the rubber harder to stretch, but tougher.

Sulfur bridge



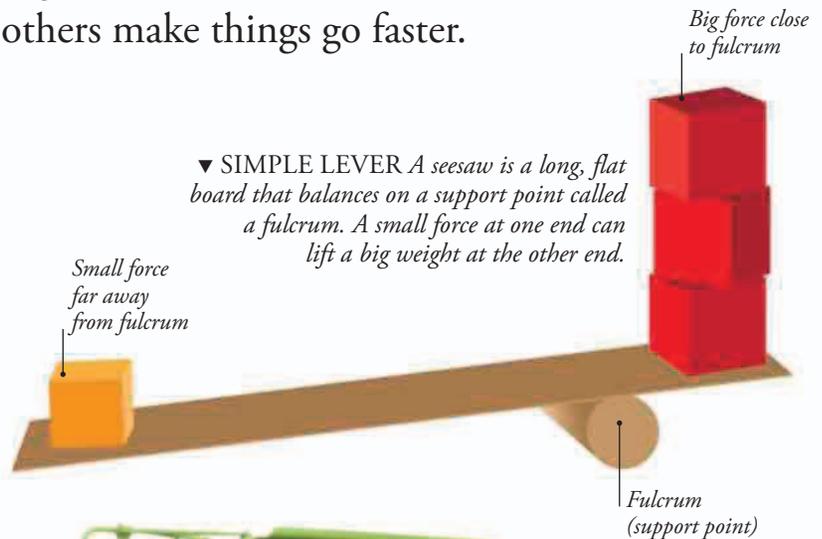
# Simple machines

When a giant rock blocks your path, you need the power of a bulldozer to push it aside. Machines work by turning small forces into big ones. Even complex machines are often made by linking together smaller, simpler devices. These include levers, gears, wheels, and screws. While some machines make forces bigger, others make things go faster.

## MORE FORCE

A lever is a long rod that gives you extra pushing or pulling force. The longer the lever, the more force it gives you. A seesaw is an example of a simple lever. If you sit on the end of a seesaw, you can lift someone much heavier than you are, as long as you sit farther away from the balancing point. Crowbars, hammers, and many other simple tools also work like levers.

▼ **SIMPLE LEVER** A seesaw is a long, flat board that balances on a support point called a fulcrum. A small force at one end can lift a big weight at the other end.



► **MIGHTY MACHINE**  
*This bulldozer's arms use levers to lift heavy loads. Giant tires spread the weight over a large area to stop the bulldozer from sinking in mud.*

**WOW!**

If you had a lever big enough, you could lift the world. But the lever would need to be about 60 quintillion miles long!

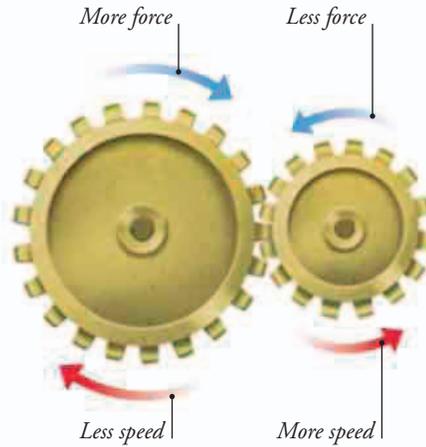


## MORE SPEED

Wheels are like levers that move in circles. If you turn the center of a wheel, the outside edge has to go farther to keep up, so it goes faster. If you turn the outside, the center turns slower and with more force. Wheels can increase force or speed, but not both at the same time.



▲ PENNY-FARTHING BICYCLE  
By pedaling the middle of the large wheel, you make the tire turn quickly, speeding the bicycle along.



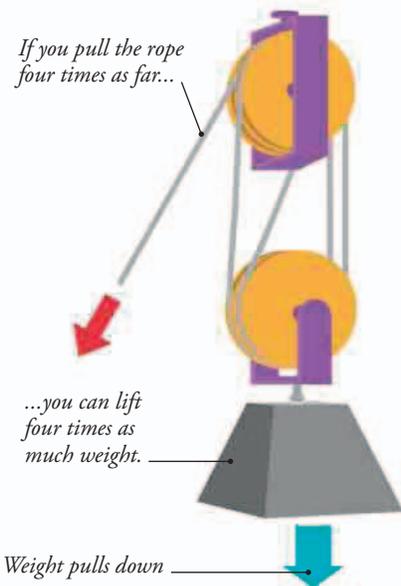
▲ GEARS When a large gear turns a small gear connected to it, the small one spins faster but with less force.

## DIFFERENT SPEEDS

Gears are pairs of wheels that can give a machine extra force or speed. They lock and turn together using teeth around the edges to stop them from slipping. If you use lots of gears, you can make different parts of a machine turn at different speeds, like the hour, minute, and second hands on a clock.

## MORE LIFT

If you want to lift something heavy, you can use a set of wheels and ropes called a pulley. The more times the rope is wrapped around the wheels, the bigger the weight you can lift. But you have to pull the rope farther to lift the weight the same distance.

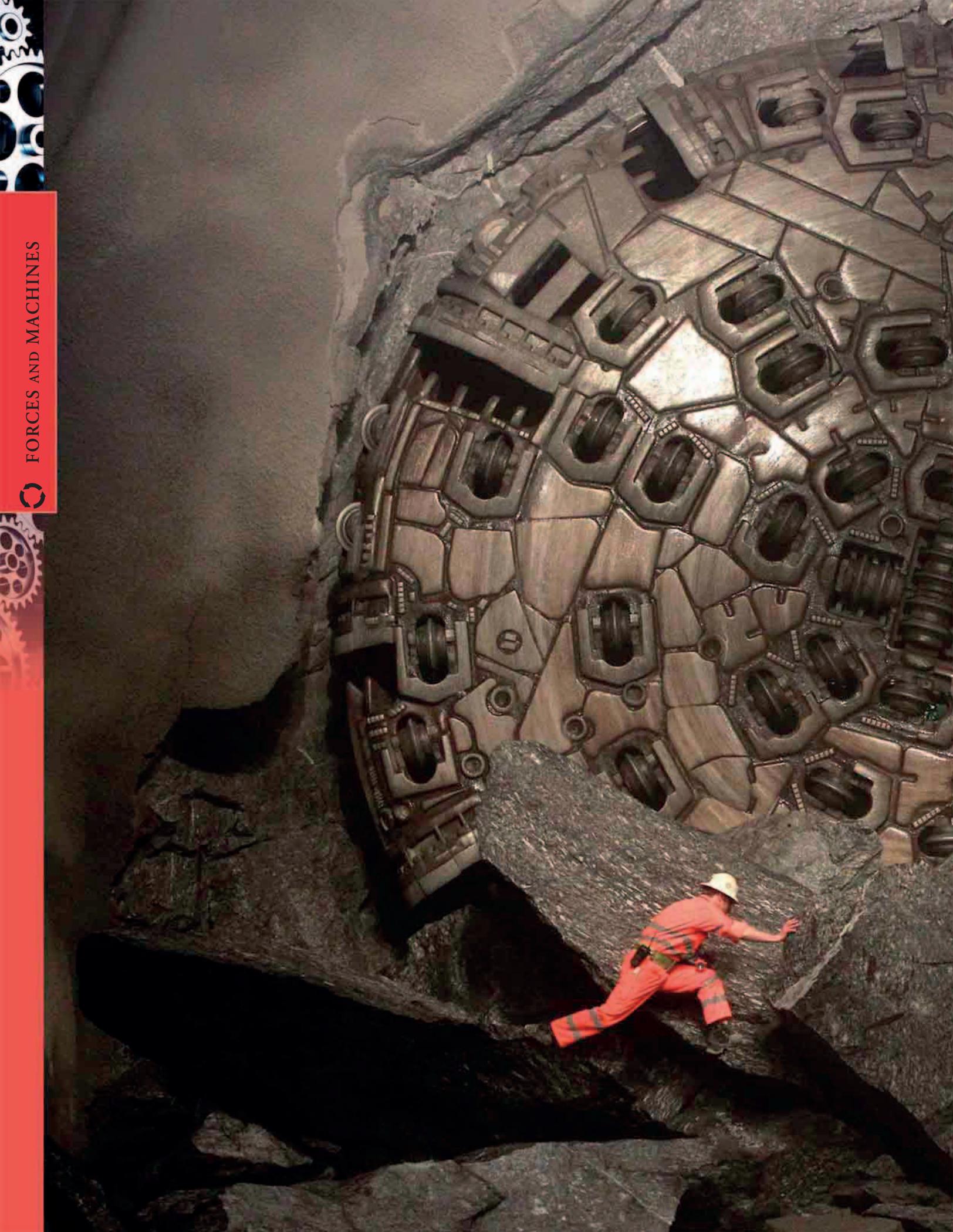


Weight pulls down  
Four-rope pulley

## MORE PUSH

It's tough to lift boxes straight up because you have to work hard against the force of gravity. A ramp makes it easier to move heavy things uphill because you can use less force, though you have to push upward over a longer distance.







## TUNNEL BORER

Giant drilling machines like this one chew their way through rock. Their faces are covered in spinning wheels with teeth that grind away the stone. This borer is being used to build the Gotthard Base railroad tunnel, stretching for 35 miles (57 km) under the mountains in Switzerland.

# Engines and vehicles

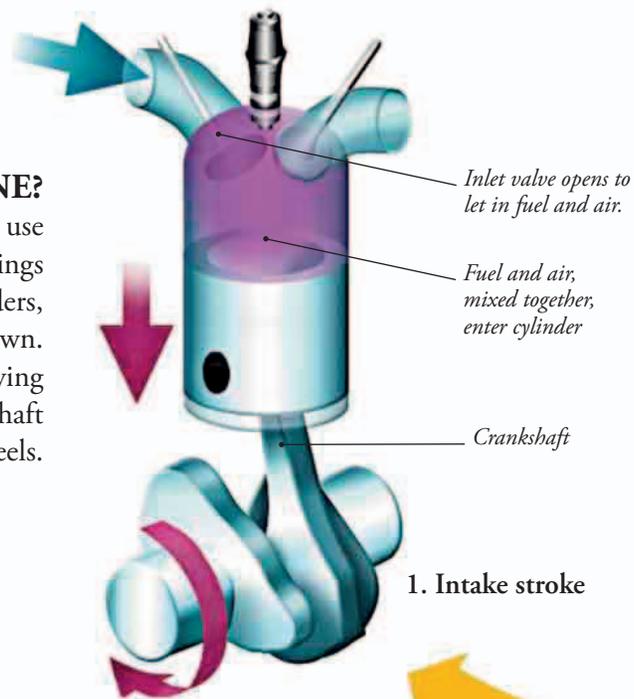
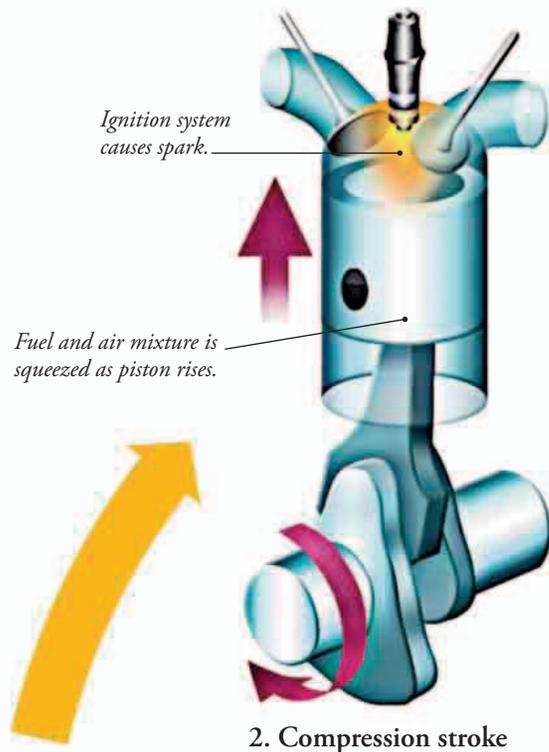
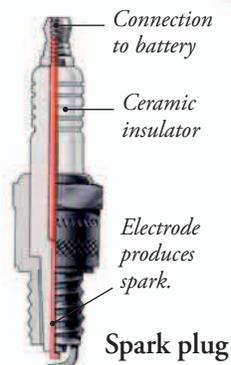
When you see a jet plane sweeping through the sky, or watch a car whizzing past, powerful engines are racing inside them. Most vehicles are powered by engines—machines that burn fuel to let out heat. Even tiny amounts of fuel release huge amounts of energy when they burn. An engine turns this heat energy into kinetic (movement) energy.

## WHAT'S INSIDE AN ENGINE?

Engines take in fuel, burn it to release heat, and use that to make movement. In a car engine, these things happen in sturdy “cooking pots” called cylinders, with pistons at the bottom that pump up and down. As the fuel burns, each piston pumps in turn, driving a rod called the crankshaft. The spinning crankshaft carries the engine’s power to the gears and wheels.

## MAKING A SPARK

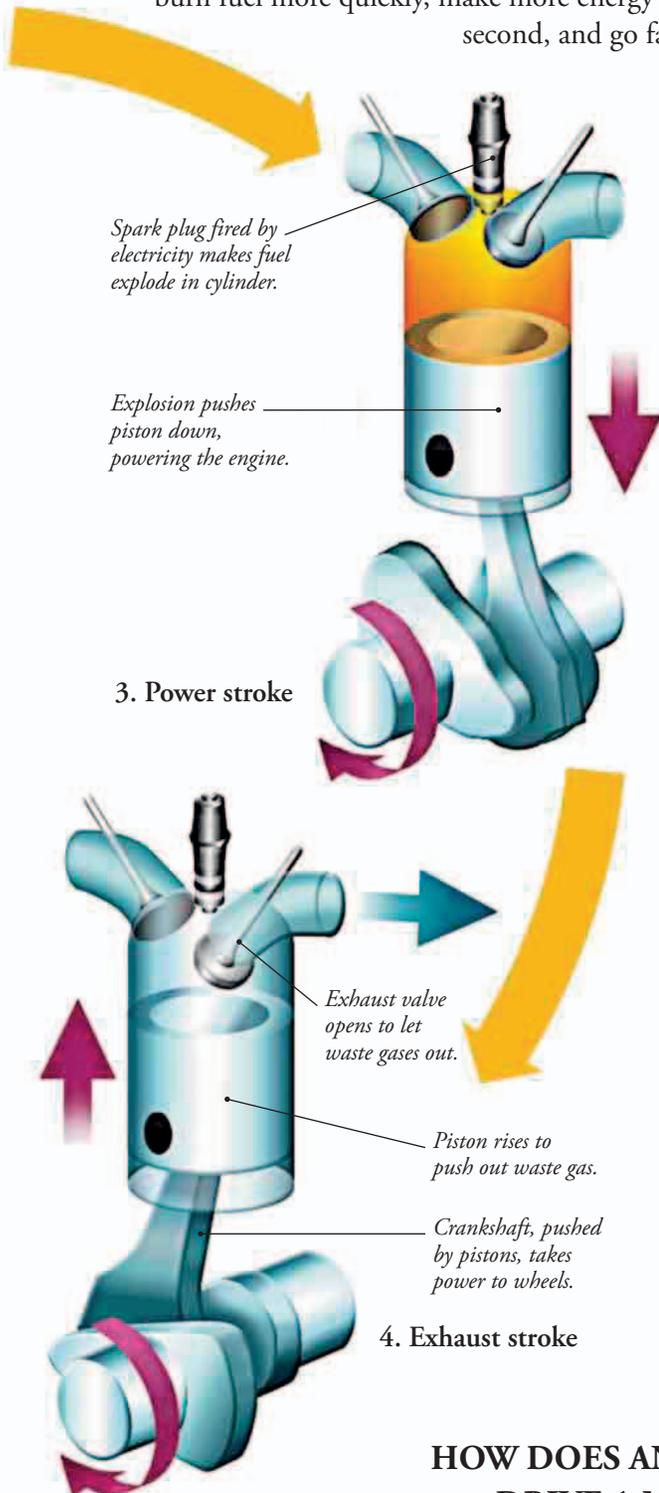
In a gasoline engine, a mixture of fuel and air is squeezed tightly together in the cylinder, then exploded with an electric spark from a spark plug. The explosion as the fuel burns in air powers the engine. Spark plugs work by taking power from a battery and passing it through electrodes. The sparks go off when the pistons have completely squeezed the fuel.



▲ **BURNING FUEL** Car engines repeat four steps (strokes). First, in the intake stroke, mixed air and fuel are sucked in. Second, in the compression stroke, the piston squashes the mixture. Third, in the power stroke, a spark plug makes the fuel burn, expand, and drive the piston. Finally, in the exhaust stroke, the piston pushes waste gases from the cylinder.

## TYPES OF ENGINES

The engines on cars, planes, trains, and rockets all work in different ways. This is mainly because bigger vehicles need to make much more power than smaller ones. They have more powerful engines, so they can burn fuel more quickly, make more energy each second, and go faster.



## HOW DOES AN ENGINE DRIVE A MACHINE?

Jet engines fire exhaust gases backward, which makes planes shoot forward. In cars and trains, the power from the engine is used to turn the wheels. In ships (right) and small planes, the engines turn propellers, pushing air or water to power along.



◀ **CAR ENGINE**  
These run on gasoline or diesel fuel. They are fairly small and light, because cars need to be economical.



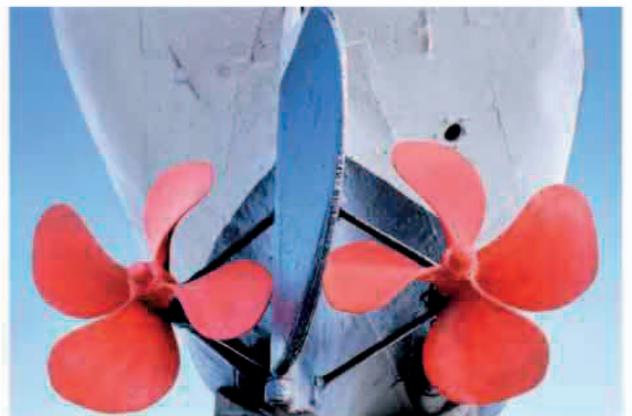
◀ **JET ENGINE** These are much bigger because it takes far more energy to lift a plane and fly it at very high speeds.



◀ **STEAM ENGINE**  
These burn huge amounts of coal to release enough energy to pull many train cars.

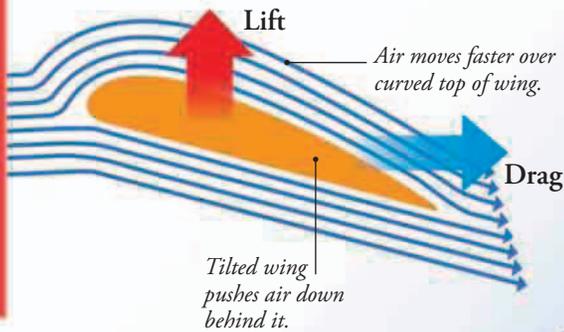


◀ **ROCKET ENGINE**  
These need huge amounts of fuel to escape from Earth. They carry their own oxygen supply because there is no air in space to use for burning fuel.



# Flight

We can run and jump, but we cannot fly. No matter how hard you flap your arms, you can never make enough lifting force to overcome the pull of gravity. A plane can fly, even though it weighs 15,000 times more than you and has 500 heavy people on board. It uses powerful engines to speed forward, so its huge wings can sweep it into the sky.



## HOW DO WINGS WORK?

A plane's engines move it forward, but it's the wings that make it fly. They create lift (an upward force) to overcome its weight. Wings have a curved shape that drives air down behind them, pushing the plane into the air.

## WINGS VERSUS WEIGHT

The heavier a plane is, the bigger the wings it needs. The bigger the wings, the more lifting force they can make. A typical jet plane has wings 230 ft (70 m) wide from tip to tip. That's about 60 times wider than your outstretched arms. A small plane that carries only four people has a wingspan of just 35 ft (10 m).



## WIND TUNNEL TESTING

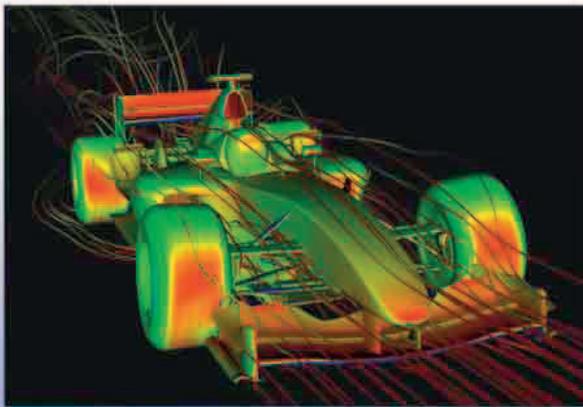
It's dangerous to test a new plane. That's why exact models of planes are tested in wind tunnels. A model is fixed inside the tunnel and a fan blows air past it. This is just like flying a big plane through still air. Engineers study how air moves around the model to improve the real plane.



*Narrow body reduces air resistance.*

*Tailplane keeps the plane level during flight.*

▲ AIRBUS A380 *The world's biggest passenger plane weighs up to 617 tons (560 metric tons)—as much as 100 large elephants. That's why it needs wings 262 ft (80 m) wide.*



▲ **GROUND FORCE** *This wind tunnel test shows how air flowing over a Formula One race car clamps it to the ground.*

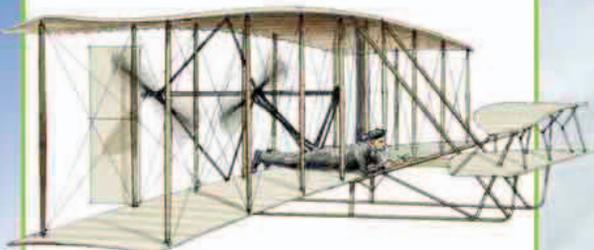
**DON'T TAKE OFF!**  
Race cars go so fast that they could take off, which is dangerous. That's why they have low-down "wings" at the front and high-up ones at the back. They work like a plane's wings in reverse, pushing downward to stick the car to the track.

WOW!

A Formula One race car generates so much downward force at top speed that you could drive it upside down on the ceiling.

### THE WRIGHT WAY

The Wright brothers changed history by making the first powered flight in 1903—and science was the key to their success. They built their own wind tunnel from a wooden box and an old engine, and used it to test 200 different wing designs. They made around 1,000 test flights, carefully recording the results to perfect their flying machine.



The Wright brothers' 1903 Flyer plane

### GLIDING THROUGH AIR

Paragliders use huge parachute wings to lift themselves into the sky. The curved wing, made of very light fabric, is wide enough to generate powerful lift when the wind blows across it. By steering through upward-flowing air columns, the pilot can fly for several hours before gently drifting back to earth.



# Planes and helicopters

Gravity is the enemy of things that fly. Planes and helicopters work hard to fight gravity in two different ways. Planes use their wings to generate a lifting force, but this only works if they fly quickly through the sky. Helicopters need to hover in one place, so ordinary wings are no use to them. Instead, they generate lift using rotors (spinning wings) to pump air down below them.

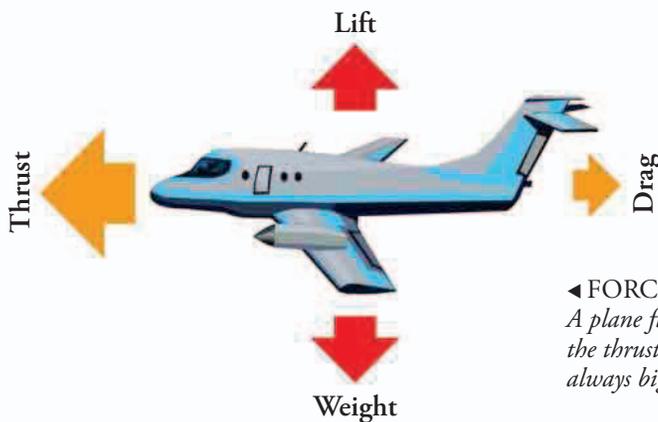


IGOR SIKORSKY

When he was a boy, this ingenious Russian inventor had a dream about flying a strange machine. Forty years later, after moving to America, he built the first practical helicopter.

## POWERING PLANES

Four forces act on a plane as it flies. Thrust from the engines pushes the plane forward, while drag (air resistance) tries to pull it back. Weight (gravity) pulls it down, while lift from the wings pushes it up. During takeoff, the plane generates extra lift to climb into the sky. When it lands, it generates less lift, so gravity brings it back down again.



◀ FORCES ON A PLANE  
*A plane flies forward because the thrust from its engines is always bigger than the drag.*



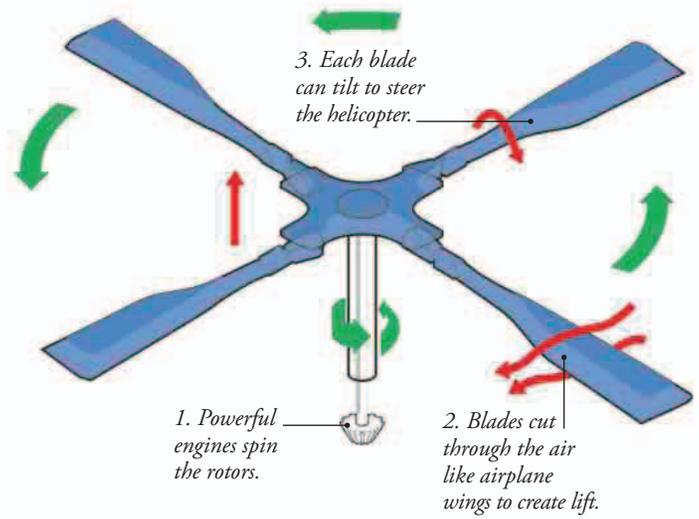
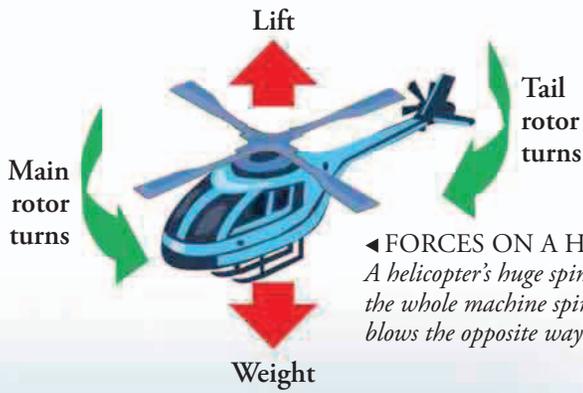
◀ STEERING A PLANE  
*Planes roll left or right by using small moving surfaces on the wings called ailerons. Surfaces on the tail are used to point the aircraft up, down, left, or right.*



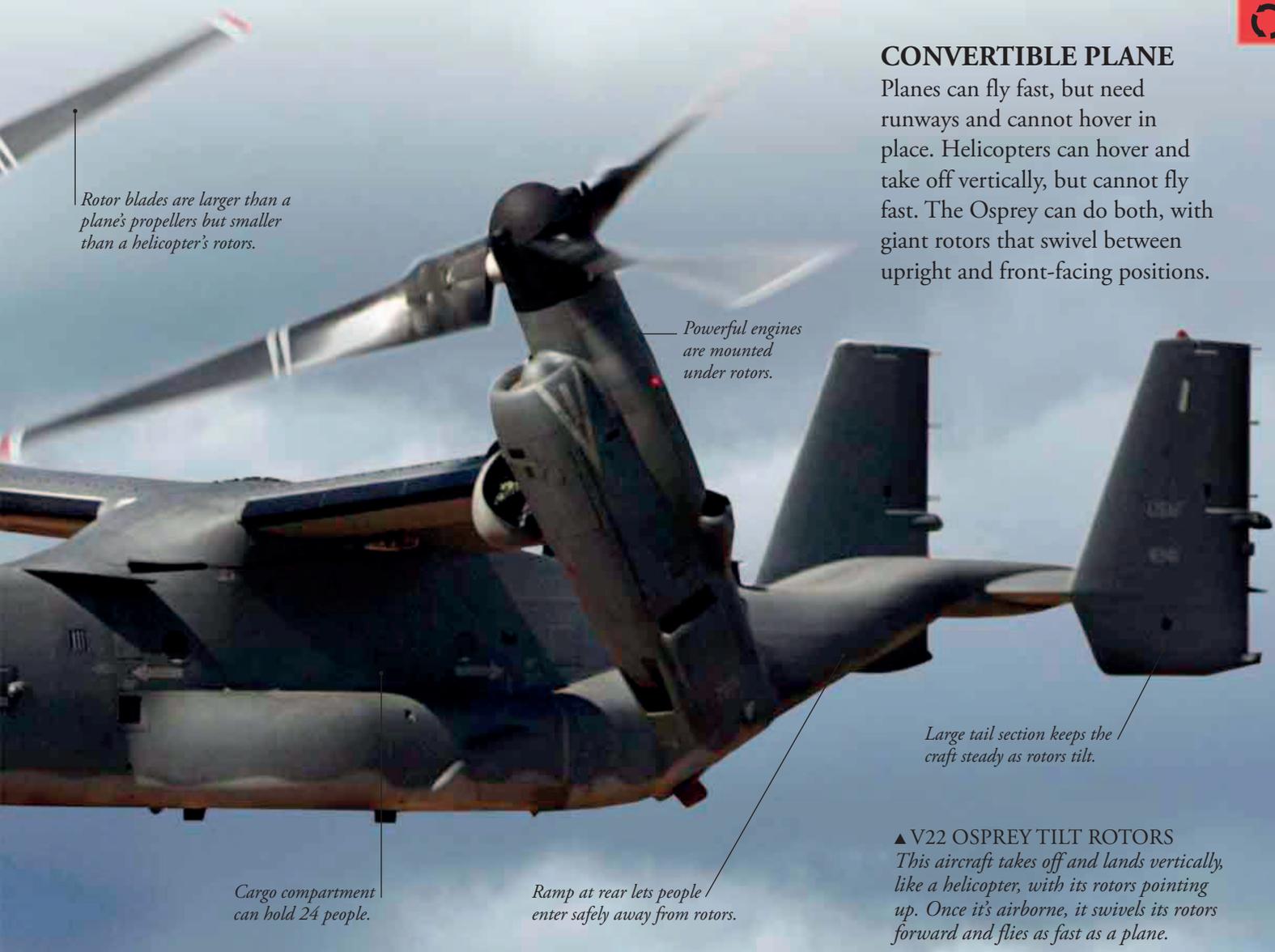
*Probe for refueling in midair*

## HOVERING HELICOPTERS

A helicopter's giant spinning rotor generates enough lift to balance its weight. The pilot can create more or less lift by tilting the blades at different angles. If the lift is more than the weight, the helicopter climbs. If the lift is less than the weight, the helicopter moves slowly down.



▲ STEERING A HELICOPTER  
The rotor blades can tilt as they turn, creating more lift on one side. This steers the helicopter through the air.



## CONVERTIBLE PLANE

Planes can fly fast, but need runways and cannot hover in place. Helicopters can hover and take off vertically, but cannot fly fast. The Osprey can do both, with giant rotors that swivel between upright and front-facing positions.

▲ V22 OSPREY TILT ROTORS  
This aircraft takes off and lands vertically, like a helicopter, with its rotors pointing up. Once it's airborne, it swivels its rotors forward and flies as fast as a plane.

# Rockets and spaceflight

The quickest way to escape the pull of Earth's gravity is to climb into a giant firework—a space rocket—and aim for space. Scientists first dreamed of racing into space in the early 20th century, but it was only in 1961 that rockets became safe enough to carry people. In the future, rockets will work like planes, so more of us will feel the thrill of blasting into space.



## EYES IN SPACE

One of the most common uses for rockets is launching satellites into orbit. These space machines can act as mirrors to bounce telephone and TV signals across the world. Or we can use them as “eyes” in space for making maps of Earth. If we point them out into space, they can take astonishing photos of distant stars we could never capture from Earth.



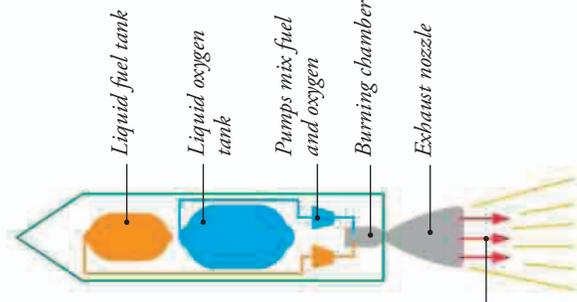
## SPEEDING INTO SPACE

Rockets have to go fast to climb out of Earth's gravity. The speed they need is called escape velocity, and it is about 25,000 mph (40,000 km/h) or 125 times faster than a race car. A rocket needs speed because it takes energy to push against the force of gravity.

A fast rocket has energy to escape; a slow one does not.

## HOW DOES A SPACE ROCKET WORK?

A rocket works like a jet engine on an airplane. It blasts fiery gas backward through a nozzle to make the whole rocket shoot forward. A jet engine makes the gas by burning fuel in oxygen (from the air). There is no air in space, so a rocket has to carry its own oxygen inside a huge tank.



*Hot exhaust gas  
blasts rocket  
upward*

## LIFE IN SPACE

It takes only eight minutes for a rocket to reach space, but it usually takes three days for astronauts to reach their final destination. Space missions can last anywhere from a few weeks to a year or more. While in space, astronauts mostly carry out scientific experiments. But they also have to do everyday things we do here on Earth. They need to sleep, eat, shower, and exercise—all inside a space rocket, in zero gravity (weightlessness). Rockets are carefully designed so these things are safe and easy to do in a very small area.



▲ **SPACE SNOOZE** Astronauts have sleeping bags tied to the wall to keep them from floating away.



▲ **GOING NOWHERE** With no room to go jogging, astronauts have to exercise on a treadmill.

## SPACE PLANES

Rockets are great for shooting things into space, but not so good at bringing them back. When spacecraft return, Earth's gravity makes them go very fast, and friction can burn them up. In the future, rocket planes will zoom into space and come back safely. One day, they might take you on a space vacation.

► **SPACE VISITORS** This aircraft, *SpaceShip Two*, is designed to fly up to the very edge of our atmosphere, to give space tourists a taste of spaceflight.



▲ **BLAST OFF** This 200-ft (60 m) Atlas V rocket is using five boosters to launch the Juno space probe on a mission to Jupiter.

# Wow!

You can cry in space, but there is no gravity to make tears run. They just fill up your eyes instead.



# Under pressure

When things push against each other, they create pressure. Pressure is a measure of how much force pushes against each point on an object's surface. Here on Earth, we are under constant pressure. Although you never notice, there is a thick blanket of about 60 miles (100 km) of air constantly squashing down on you. Air might seem like emptiness, but it still has mass, so gravity pulls it down toward the ground. This makes air pressure, a force spread all over your body.

## WHAT IS PRESSURE?

Pressure is what happens when a force pushes on a surface. More force makes more pressure. When the same force presses over a smaller area, the pressure becomes greater. But if the force is spread over a larger area, the pressure reduces. Sometimes, we don't notice pressure until the force is released.



### ◀ JET PRESSURE

*When firefighters take the cap off a hydrant, the water inside blasts out because it's under high pressure.*



### SPREADING THE LOAD

A person can easily stand on a bed of nails. Their body has weight, which means gravity pulls it down with a lot of force. But when they stand on hundreds of nails, their weight is shared across them all. The pressure on each nail is very small, so they don't get injured.

## PRESS FOR SUCCESS

Life would be impossible without pressure. Blood flows around your body because your heart pumps it with enough pressure to reach your fingers and toes. Water can flow to your home because it is stored high up in reservoirs and tanks. Gravity pulls the water down, giving it pressure that makes it spray from the faucet. Pressure is also used to make many tools work, from vacuum cleaners to pushpins, and car engines to airplanes.



### ▲ PUSHPINS

*A gentle pressure on the wide head creates a lot of pressure on the narrow tip of the pin.*



### ▲ JACKHAMMERS

*High-pressure air flowing through the hose bangs the chisel into the road.*



### ▲ WALKING ON WATER

*Pond-skating insects spread their weight, creating little pressure, so they do not sink.*



Hose supplies oxygen for pilot to breathe.

## WHAT IS AIR PRESSURE?

Air pressure is created by the weight of air above you. If you climb a mountain, there is less air above you, and therefore less air pressure. It is harder for air to get into your body and harder for you to breathe. High in the sky, there is hardly any air pressure, and breathing is almost impossible. Planes have their compartments pressurized by pumps so people inside can breathe normally.

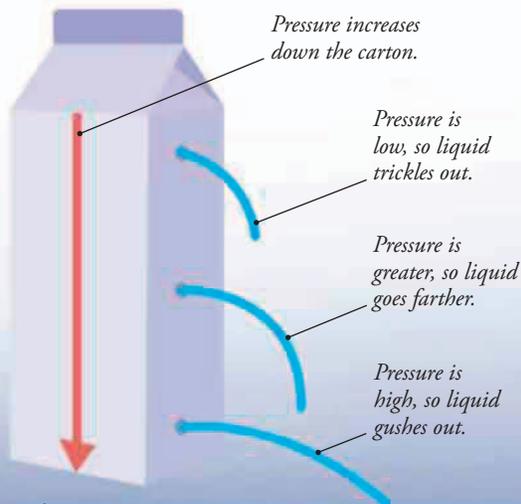
◀ **PRESSURE SUIT** *Fighter pilots feel huge forces. They wear special suits with air pumped into them. This added pressure helps their blood flow normally.*

WOW!

The Mariana Trench is the deepest part of the world's oceans. The water pressure there is 1,000 times higher than the air pressure on land.

## HOW TO MEASURE AIR PRESSURE?

Air pressure changes our weather. Low pressure brings storms and rain. High pressure means sunshine. We can predict the weather using a barometer to measure air pressure. Inside this one is a box filled with air. As the air pressure changes, the box squeezes in and out. This moves the needle around the dial.



Liquid pressure in a carton

Pressure increases down the carton.

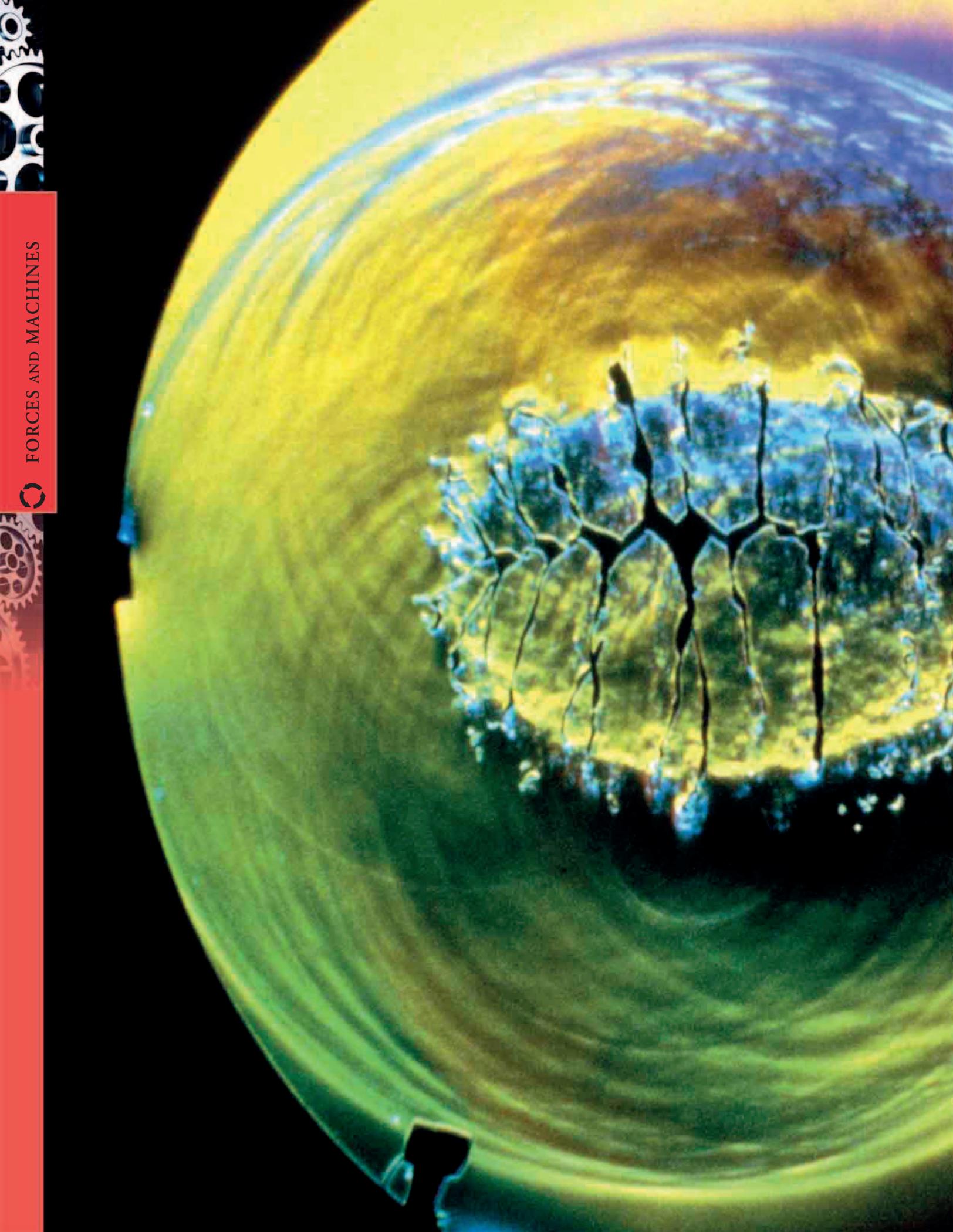
Pressure is low, so liquid trickles out.

Pressure is greater, so liquid goes farther.

Pressure is high, so liquid gushes out.

## HEAVY WATER

The deeper you dive beneath the sea, the more pressure there is. That's because there is more water over your head pushing down. Water is denser than air—the same amount of it weighs more—so water pressure affects things more than air pressure. That's why scuba divers can go down only a short distance, and why submarines need hulls made of strong metal to withstand the pressure. In a milk carton, the liquid near the bottom is squeezed by the weight of the liquid on top.





### **PRESSURE WAVES**

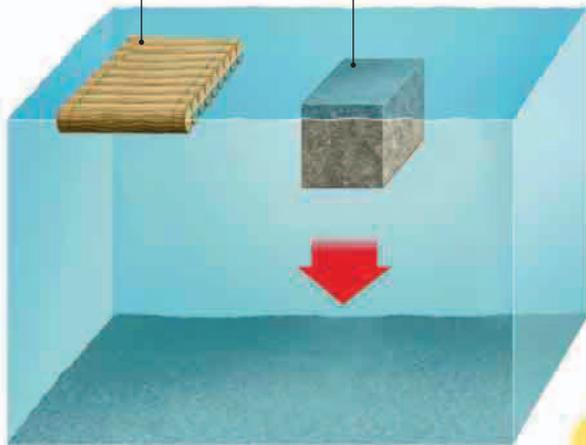
Using a special technique, this photograph captures pressure changes in the air caused by a balloon bursting. The balloon is filled with gas from a canister. The pressure then builds up inside until the rubber weakens and the balloon pops. A shock wave of pressure spreads out, which we hear as a bang.

# Floating and sinking

A blue whale can weigh as much as 20 elephants, yet it has no problem floating in the sea. The giant ships that ferry goods around the world can hold thousands of huge containers without sinking. Things float if they are less dense than the material around them—that is, if a certain volume of the object weighs less than the same volume of its surroundings.

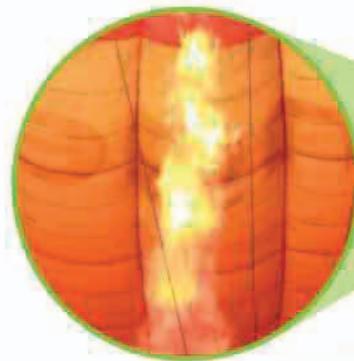
*Weight of wood is less than weight of same volume of water, so wood floats.*

*Weight of stone is more than weight of same volume of water, so stone sinks.*



## WHY DO THINGS SINK?

Gravity pulls things down, even in water. But water pushes upward against things floating in it. If there is enough water pressure beneath something to balance its weight, it floats. Wood is less dense than water. The weight of a block of wood is less than the pressure of the water underneath, so it floats. Stone is more dense than water, so its weight pulls it down in spite of the pressure of the water underneath.



▲ **HOT STUFF** Gas burners heat the air in the balloon. Switching them on or off changes the temperature, making the balloon rise or fall.

## WOW!

In 2005, Indian Vijaypat Singhania reached a record height in a hot-air balloon of 69,000 ft (21,000 m)—twice as high as jets fly!



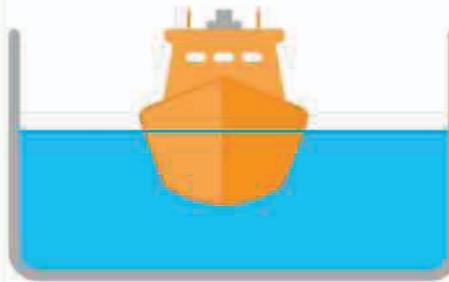
## GOING UP

Heavy things can fly if they can create enough upward force to lift their weight. Before planes were invented, people took to the skies in balloons. These soar into the sky when hot air is pumped inside the huge fabric dome. A balloon full of hot air weighs less than the same balloon full of cold air. It is less dense than the air around it, so it soars into the sky. Big balloons can create enough force to carry people with them.

*Envelope (dome) of balloon is made from long strips of rip-proof nylon.*

## THAT SINKING FEELING

A floating ship sits partly in and partly out of the water. The heavier it is, the deeper it sits—squeezing the water underneath. It stops sinking when the water pressure underneath equals its weight. The squeezed water has to go somewhere, so when a ship is loaded up, it pushes the water aside (displaces it). The amount of water displaced always weighs the same as the ship and its cargo.



A floating ship pushes aside (displaces) its own weight of water.



The volume of water displaced weighs the same as the ship.

## CRAFTY RAFTS

The world's biggest cargo ships carry up to 18,000 vast containers, each as big as a truck. Ships work by spreading their weight over a wide area. Most of a ship is just empty space, so it weighs less than the same volume of water. Although it is incredibly heavy, it still floats.



► **PLIMSOLL LINE** A cargo ship has an upright ruler drawn on the side. As the cargo is loaded, the ship sinks slightly and the water line on the ruler shows if it is safe to travel.

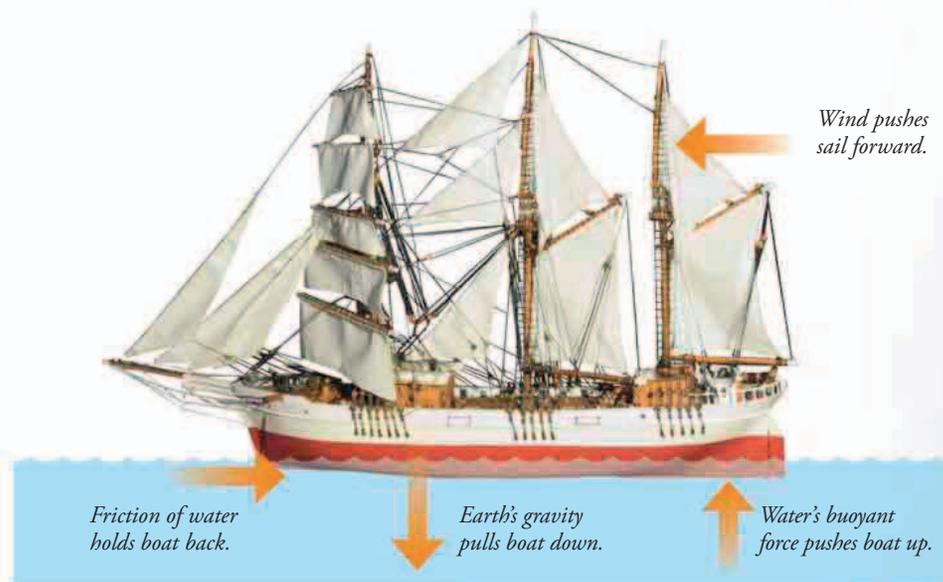


# Boats and submarines

More than two-thirds of Earth's surface is covered by water, so getting around our planet often means traveling by boat. Boats float on the surface of the water using forces such as wind to move across it. Submarines can change their density to float or sink at will.

## HOW DOES A SHIP WORK?

A sailing ship is a mighty machine built for crossing the oceans. It has to survive four huge forces pounding from different directions. The ship's weight, and that of the cargo and crew, push down from above. What stops the ship from sinking is buoyancy—water pressing up from below. Wind buffets the sails, driving the boat from behind, but the rough waves drag against the boat, pushing it back again.



*Wind pushes sail forward.*

*Friction of water holds boat back.*

*Earth's gravity pulls boat down.*

*Water's buoyant force pushes boat up.*

## WATER POWER

Boats do not simply glide across the waves. Their weight makes them sink under the surface a little bit, so they drag in the water as they move. That's why it can take a lot of force to get boats going. The more cargo they carry, the deeper they sink, and the harder it is for them to move. Different types of boats use different sources of power to travel across the waves.



### Sailboats

*Wind pushes the sails to move the boat. By angling the sails, you can travel parallel to or even against the wind.*



### Oar power

*If you pull the oars backward, the boat moves forward. This is Newton's third law of motion (p.88) in action.*



### Jet Skis

*These personal watercraft spray a powerful jet of water behind them. This pushes them forward at very high speeds.*



### Propellers

*Most boats use propellers driven by outboard motors. The propellers pull against the water to drive the boat forward.*



### Hovercraft

*A hovercraft uses fans to lift above the waves on a cushion of air. Another fan blows it forward at high speeds.*



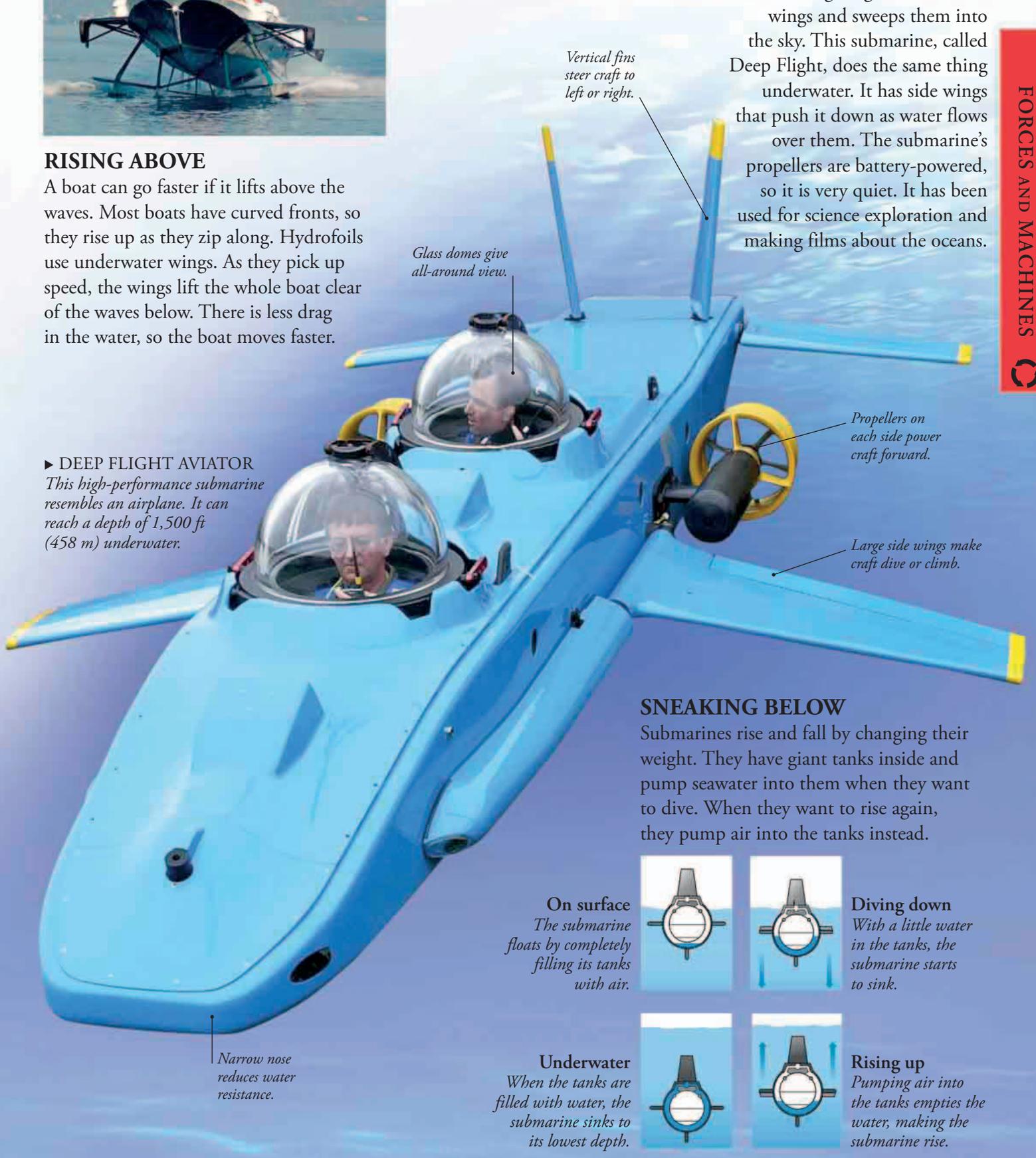
## RISING ABOVE

A boat can go faster if it lifts above the waves. Most boats have curved fronts, so they rise up as they zip along. Hydrofoils use underwater wings. As they pick up speed, the wings lift the whole boat clear of the waves below. There is less drag in the water, so the boat moves faster.

► **DEEP FLIGHT AVIATOR**  
*This high-performance submarine resembles an airplane. It can reach a depth of 1,500 ft (458 m) underwater.*

## FLYING UNDERWATER

Planes can fly because fast-moving air glides over their wings and sweeps them into the sky. This submarine, called Deep Flight, does the same thing underwater. It has side wings that push it down as water flows over them. The submarine's propellers are battery-powered, so it is very quiet. It has been used for science exploration and making films about the oceans.



*Vertical fins steer craft to left or right.*

*Glass domes give all-around view.*

*Propellers on each side power craft forward.*

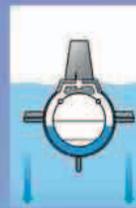
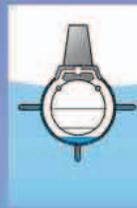
*Large side wings make craft dive or climb.*

*Narrow nose reduces water resistance.*

## SNEAKING BELOW

Submarines rise and fall by changing their weight. They have giant tanks inside and pump seawater into them when they want to dive. When they want to rise again, they pump air into the tanks instead.

**On surface**  
*The submarine floats by completely filling its tanks with air.*



**Diving down**  
*With a little water in the tanks, the submarine starts to sink.*

**Underwater**  
*When the tanks are filled with water, the submarine sinks to its lowest depth.*



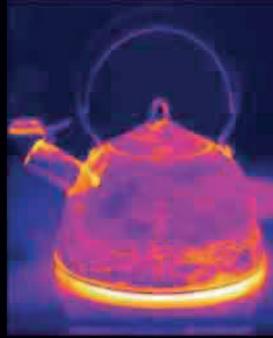
**Rising up**  
*Pumping air into the tanks empties the water, making the submarine rise.*

# ENERGY



## MOVEMENT ENERGY

Everything that moves has energy. These speedy cyclists have lots of kinetic (movement) energy, but their bodies also produce heat energy, and the noise of their tires on the road travels as sound energy.



Energy is what makes things happen. Whenever something moves, gives off heat or light, makes a noise, or creates an electric current, energy is being released.



# What is energy?

Energy is what makes things happen. It's the bang behind a firework and the roar of a race car. It pushes planets around the sun and helps trees reach for the sky. It makes earthquakes that can tear the ground beneath our feet and music that makes us get up and dance. Energy is the hidden power behind everything—including life on Earth and all that happens here.



WOW!

After the Big Bang, the universe was incredibly hot. It took 400,000 years for it to cool enough to form the very first atoms.

## HOW ENERGY WAS BORN

The universe began about 14 billion years ago with a gigantic explosion called the Big Bang. Explosions normally destroy things, but this one created everything we know. It was the beginning of space and the start of time. At first, the universe was made entirely of energy. But, within a fraction of a second after the Big Bang, this energy started turning into particles of matter, then into atoms from which stars and planets were formed.

Big Bang

Energy starts turning into matter.

## WHAT DOES ENERGY DO FOR US?

Everything you do requires energy. All the things you use are made using energy. And everywhere you go, you need energy to get there. It's no wonder that the world uses so much energy. Around 80–90 percent of it comes from fossil fuels such as oil, coal, and gas. We burn them to release the energy locked inside, which we can then use for heating, cooking, or generating electricity. Most of the world's energy is used in three ways—in our homes, for transportation, and in business and industry.



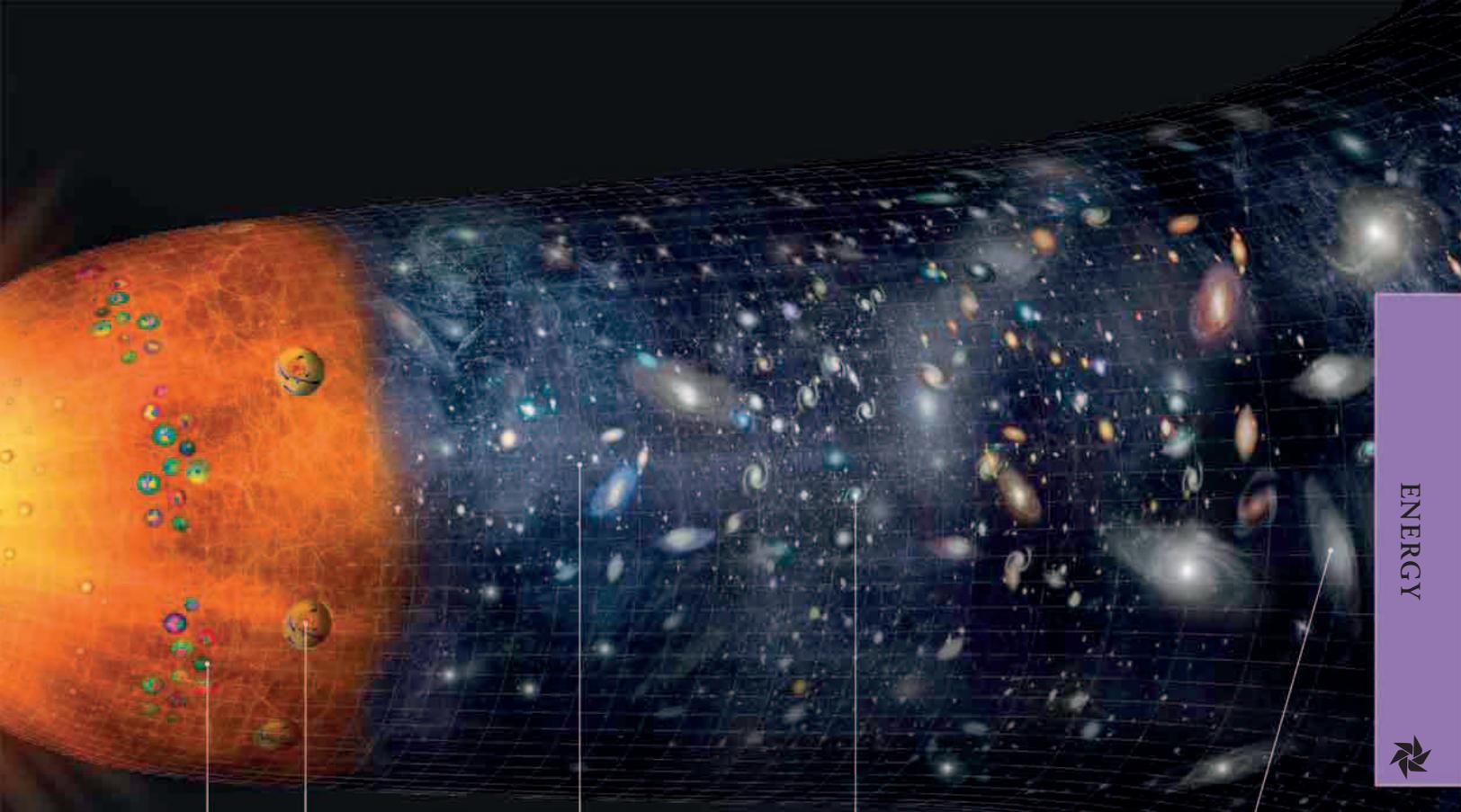
▲ **ENERGY AT HOME**  
*Surprisingly, not much energy is used in people's homes—only about 15 percent. Most of that goes into heating, lighting, cooking, and air-conditioning.*



▲ **ENERGY FOR TRANSPORTATION**  
*About a quarter of all energy is used to power vehicles, such as cars, trucks, and trains. Most vehicles run on fuels made from oil.*



▲ **ENERGY FOR INDUSTRY**  
*Most of the world's energy is used by industry and business. A lot goes to factories, though a growing amount is used in offices.*



1 microsecond:  
Particles form.

400,000 years:  
Atoms form.

300 million years:  
Stars form.

500 million years:  
Galaxies form.

9 billion years: Our  
solar system forms.

▲ **SPACE STORY** *The universe first appeared out of nowhere during the Big Bang. This image shows how it has expanded and changed since then.*



### ENERGY IN YOUR BODY

You are a living machine powered by energy. You load energy into your body by eating food, and use that energy to move, think, sleep, and breathe. Although you might think your muscles do all the hard work, a lot is done by your brain. This small bag of thoughts and feelings uses up to a fifth of all your energy, even while you are asleep and dreaming.

### MATTER AND ENERGY

Everything in the world is either energy or matter—and even matter is a kind of energy. Trees capture the sun's energy in matter by using it to power the growth of their branches and leaves. If you burn wood, you release the trapped energy as heat and light.



▲ **ICEBERG** *Even something still and frozen contains energy. There is about 200 million times more heat energy in a typical iceberg than in a cup of boiling hot coffee, but spread over a much larger volume.*

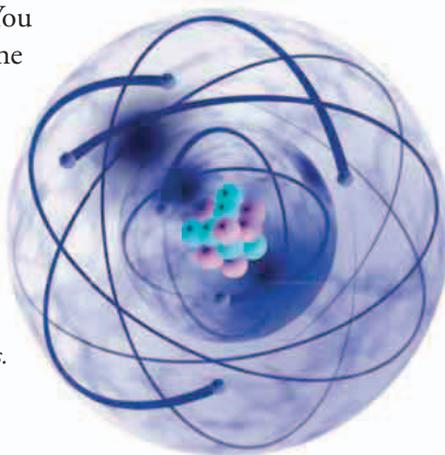
# Types of energy

The world is bursting with energy. Your TV flickers with light, your voice makes sound ripple through the air, and your muscles have energy packed inside them from the food you eat. A spider climbing the wall stores energy by working against the force of gravity. Even this book has energy hiding in its atoms. Everything you can see is either storing energy or using it.

## STORED ENERGY

Stored energy is called potential energy. It's like money in the bank. It is energy we have "saved up" that we can use later. We can store potential energy in different ways by working against forces. If you push a car uphill, your body works against the force of gravity, which is trying to pull the car back down. You lose energy from your muscles, but the car gains potential energy. If you let go, it has the potential (ability) to roll down again.

► **NUCLEAR ENERGY** *The energy stored in the nucleus of an atom is called nuclear energy. We can make atoms release this energy in nuclear power plants.*



▲ **CHEMICAL ENERGY** *When chemicals react together, they can give off energy. Emergency flares use stored chemical energy to make colored smoke, signaling that a boat is in distress.*



◀ **ELASTIC ENERGY** *You need force to change something's shape. Springs, rubber bands, and bows store elastic energy when you stretch them and release that energy when you let go.*



## USING ENERGY

We can use stored (potential) energy to do all kinds of useful things. If you let go of a ball at the top of a hill, it rolls down. The potential energy it had at the top is quickly converted into movement (kinetic energy) as it speeds along. In the same way, the chemical, nuclear, or elastic energy stored inside things can be changed into other kinds of useful energy.



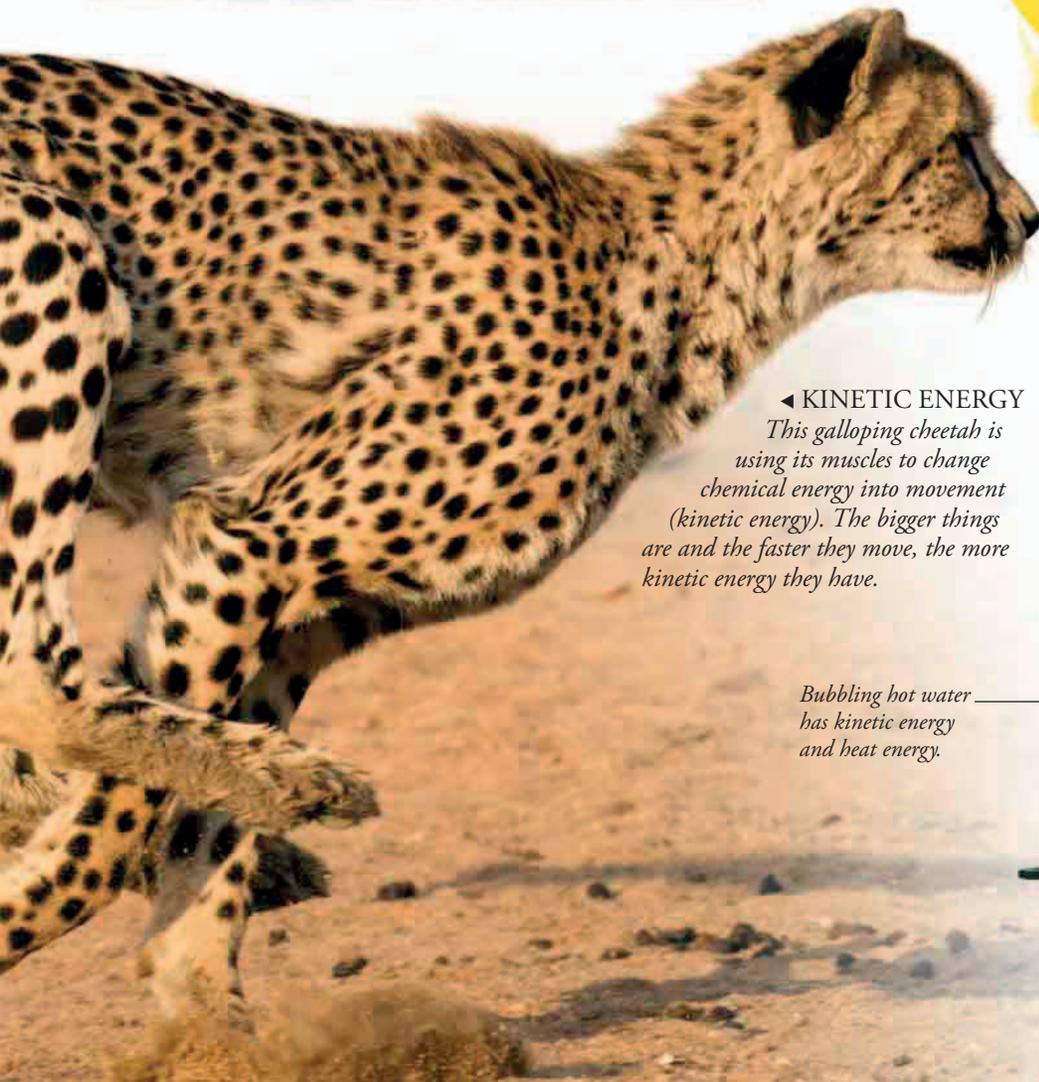
◀ **SOUND ENERGY** *If you bang a drum, your moving hands give it elastic energy. As the stretched drum skin vibrates, it shakes the air and the elastic energy turns into sound energy.*

▶ **LIGHT ENERGY** *This luminous watch glows in the dark because its painted hands give off light. They are turning stored chemical energy into another kind of energy—light.*



WOW!

There is as much energy in the universe today as there was 14 billion years ago when it first came into being.



◀ **KINETIC ENERGY** *This galloping cheetah is using its muscles to change chemical energy into movement (kinetic energy). The bigger things are and the faster they move, the more kinetic energy they have.*

*Bubbling hot water has kinetic energy and heat energy.*



◀ **HEAT ENERGY** *Hot things have energy because the atoms inside are crashing into one another. The hotter they are, the faster the atoms move, and the more they collide.*



# Potential and kinetic energy

Our hectic world is powered by energy—nothing can happen without it. But where do the things that rush around us get their energy from? Things that are moving have kinetic energy, which they have to get from somewhere. Often, they make it from their own stored-up energy, which is called potential energy.

WOW!

The world's fastest roller coaster, Formula Rossa, in the United Arab Emirates, speeds people along at up to 150 mph (240 km/h).

## RIDING THE ROLLER COASTER

A roller coaster starts high in the air and swoops up and down as it twists and turns. This thrilling ride is also a very clever energy-converting machine. When the cars are high in the air, they have a lot of potential energy. That is stored energy, ready and waiting to do things. As the cars clatter down the track, they convert some of this stored energy into kinetic energy.

That is the energy things have when they move.

► ENERGY RIDE  
*The more people there are on the ride, the more potential energy it takes to lift them into the air.*

## HOW A ROLLER COASTER CONVERTS ENERGY

High above the ground, the roller coaster has potential energy since Earth's gravity pulls down on it. When the car rolls downhill, it converts some of this potential energy into movement (kinetic energy). But the car slowly loses its energy due to friction (rubbing against the track) and air resistance. It stops when its energy is gone.

*At the start of the ride, the car has maximum potential energy.*

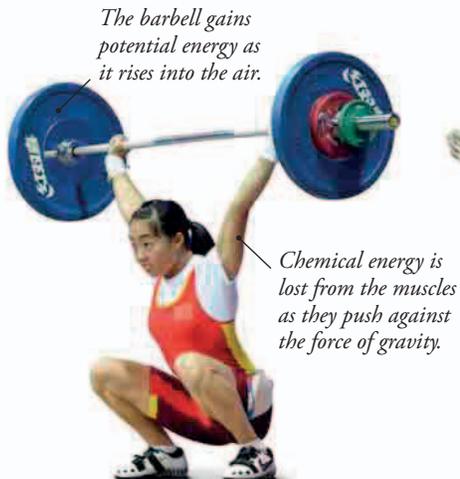
*The car goes fastest in dips, where the potential energy turns into kinetic energy.*

*The car is always losing energy to friction and drag, so it cannot climb as high.*

*The car comes to a stop when it has no more energy left to push it along.*

## WHAT HAPPENS TO THE ENERGY?

We cannot make energy appear or disappear like magic, but we can change its form. When this weight lifter lifts her barbell, her muscles use up stored potential energy. Her body loses energy as she lifts, and the barbell gains potential energy. When she drops the barbell to the ground, its potential energy turns into kinetic energy. As the barbell hits the floor, its kinetic energy turns into other types of energy—noise and elastic energy as it bounces up and down.



**POTENTIAL ENERGY** *The weight lifter uses stored energy from food to give the barbell potential energy.*



**KINETIC ENERGY** *The falling barbell speeds up as potential energy is turned into kinetic energy.*

*Kinetic energy is lost to the ground as the barbell bounces off.*



Roller coasters use science to make you scream.



# Energy spectrum

Light is energy we can see. But it is only one small part of a whole spectrum of energy rays that stream across the universe. There are many types of energy similar to light that are invisible to us. Like light, these are made from waves of electricity and magnetism, racing around at high speeds. We call these different energy waves the electromagnetic spectrum.



**NOW!**

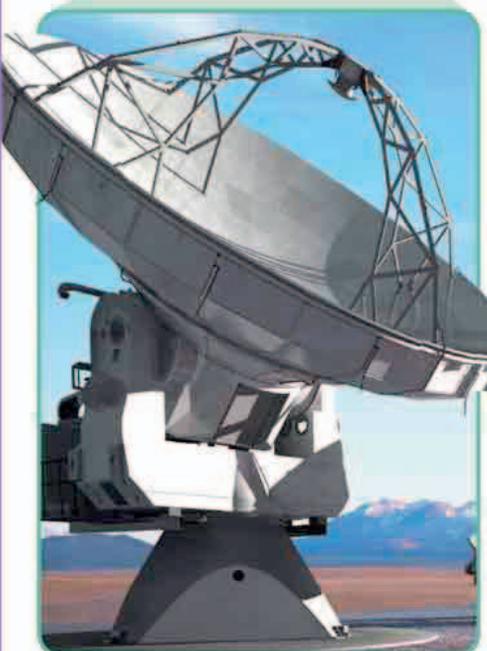
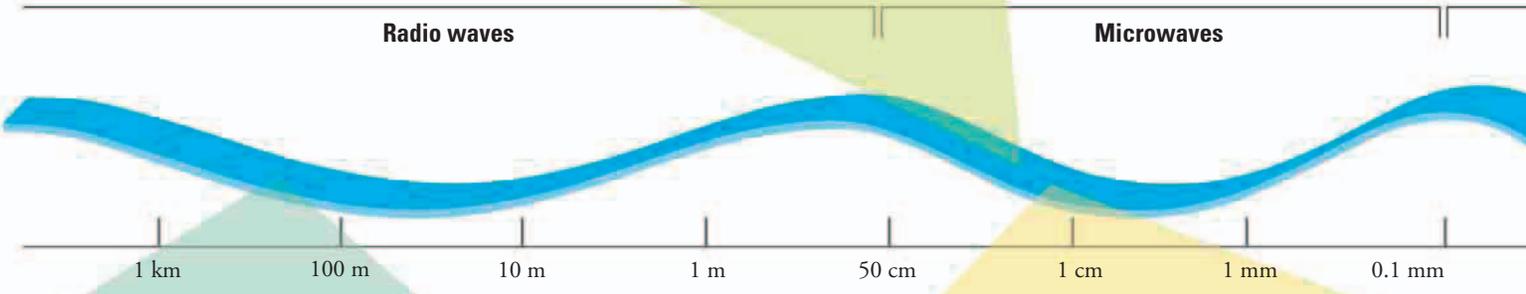
Bees and butterflies can see colors we cannot. Their eyes can detect ultraviolet radiation that is invisible to us.

## ON THE WAVELENGTH

If you could take electromagnetic waves and stretch or squeeze them to make them longer or shorter, you could make any type of electromagnetism. The waves that carry radio and TV broadcasts are longer than a football field, while those that make gamma rays are much smaller than atoms.



◀ **MICROWAVES** *Microwave radiation is absorbed by water, where it turns into heat energy. Microwave ovens use this energy to heat up food.*



◀ **RADIO WAVES** *TV and radio programs race through the sky, riding on very long electromagnetic waves called radio waves. We can see distant light rays using a telescope, but to detect radio waves we need a metal antenna or a dish-shaped radio telescope like this.*



▲ **CELL PHONE TOWERS** *Cell phones use bursts of electromagnetic radiation to send messages. They use similar wavelengths to microwave ovens, but use much less energy. The signals are picked up by towers like this one.*



## ENERGY RAYS

The night sky gleams with stars—explosions of energy blasting through space. Much of the electromagnetic energy that surrounds us started off in space. Some of it, called cosmic microwave background, was originally produced during the Big Bang almost 14 billion years ago. It is the oldest light in the universe.

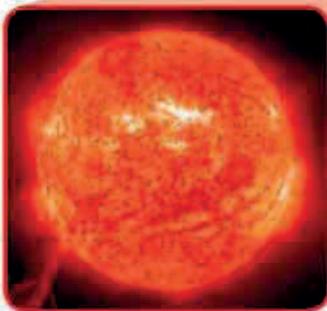
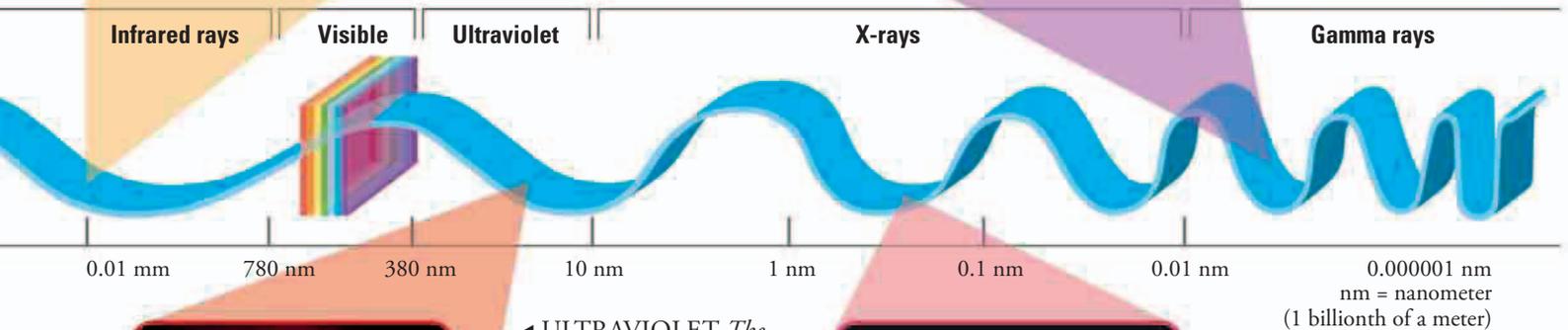
► **LIGHT-YEARS** Stars are vast distances away, measured in light-years. A light-year is how far light travels in one year: 6 trillion miles (9.5 trillion km).



◀ **INFRARED RAYS** The heat you can feel beaming from things is a kind of invisible “hot light” called infrared radiation. Like light, it travels instantly and in straight lines.



◀ **GAMMA RAYS** Some atoms give off powerful and dangerous radiation called gamma rays. They are the most energetic form of electromagnetic radiation and they can travel all the way across the universe.



◀ **ULTRAVIOLET** The sun pumps out light we cannot see, including harmful ultraviolet light that can cause sunburns and skin cancer. Sunscreens stop this harmful radiation from reaching your skin.



◀ **X-RAYS** Light cannot get through skin or bone. More energetic X-rays get through skin but not bone. They can make “shadow” pictures of our skeletons that show broken bones and some illnesses.

**THE SPEED OF LIGHT**  
Electromagnetic waves (including light) are the fastest things in the universe. They travel 186,000 miles (300,000 km) per second—quick enough to whip around the world 450 times in a minute.

JOURNEY	DISTANCE	TIME FOR LIGHT TO TRAVEL
From this book to you	30 cm	1 nanosecond (billionth of a second)
Around the Earth	40,000 km	0.134 seconds
The moon to Earth	384,000 km	1.3 seconds
The sun to Earth	150 million km	8 minutes 20 seconds
Nearest star to Earth	40 trillion km	4.2 years
Distance across our galaxy	950 quadrillion km	100,000 years



## STARDUST

Electromagnetic radiation from distant stars speeds through empty space. Some of it reaches Earth as visible light, while some travels in wavelengths we cannot see. This image shows infrared radiation from the North America Nebula, a huge cloud of stardust about 1,500 light-years away.





# Heat

Atoms are constantly jiggling around with energy. We call this heat energy. The more heat something has, the faster its atoms move. Even the coldest objects have some heat energy since their atoms are always moving around. If we could stop the atoms from moving, we could make an object completely cold. We call this temperature “absolute zero,” though no one has ever managed to cool anything down that much. The sun is probably the hottest thing you can imagine. If you could peek inside, you would see it exploding with heat.

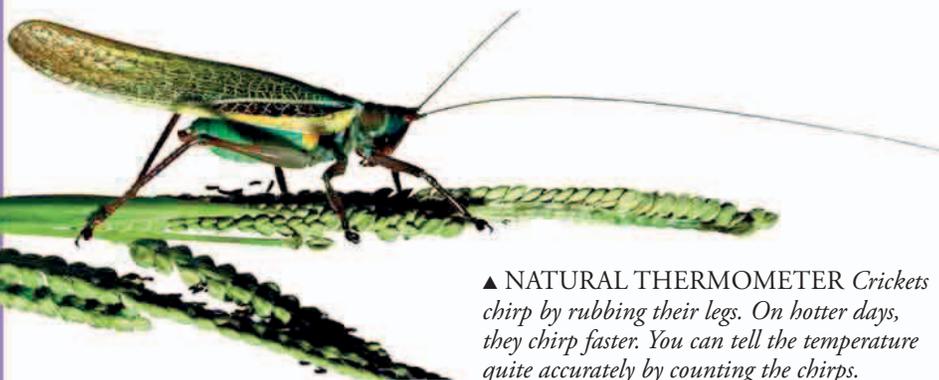
## MEASURING HEAT

The temperature of an object tells us how hot or cold it is. We can use this to tell whether food is properly cooked, if a person is suffering from a fever, or if a car engine is overheating. These days, we have electronic thermometers that can measure temperature for us quickly and accurately, but in the past humans relied on changes in nature to measure temperature.



### ▲ ELECTRONIC THERMOMETER

*Temperature changes how materials conduct electricity. The hotter they are, the more easily electricity flows through them. This thermometer measures temperature by measuring the electricity flow.*



▲ NATURAL THERMOMETER *Crickets chirp by rubbing their legs. On hotter days, they chirp faster. You can tell the temperature quite accurately by counting the chirps.*

# WOW!

The center of the sun is about 10,000 times hotter than the temperature of melting steel.

## TEMPERATURE SCALES

We can use different scales to measure temperature. In 1724, German scientist Daniel Fahrenheit invented the Fahrenheit scale (°F). He set 0°F as the lowest temperature he could create in his laboratory, and 100°F as human body heat. Today, scientists use the Celsius scale (°C), with 0°C representing the freezing point of water and 100°C its boiling point.

Core of the sun  
27 million °F  
(15 million °C)



Hot car brakes  
950°F (500°C)



Human body  
98.6°F (37°C)



Ice cubes  
32°F (0°C)



North Pole  
-40°F (-40°C)



## HEAT CHANGES THINGS

Heat is a type of potential energy—it is stored energy that has the power to change things in surprising ways. If you heat ice, it will turn into water, and then steam. The energy you add causes a spectacular change, turning a solid into a gas that looks nothing like the ice you started out with. Heat changes different substances in different ways. It can cook things, burn them, or melt them.



▲ **EVAPORATING** Heating liquids makes part of them turn to gas and disappear, cooling the liquid left behind. This is evaporation. Sweating works by evaporation. Our bodies cool when sweat evaporates from our skin.



▲ **FREEZING** Most things shrink and become harder when you remove heat. Frozen food gets hard, while flowers cooled to low temperatures shatter like glass.



▲ **BURNING** Heat things with oxygen and you can start a dramatic chemical reaction called combustion (burning). Flames are made when the vapor (gas) given off by a burning object catches fire.

► **MELTING** Things that do not burn can melt instead. Melting means turning from a solid into a liquid. Water melts at 32°F (0°C), but bronze melts at 1,650°F (900°C).

Molten bronze glows orange or yellow when some of its heat energy turns into light.



Insulated glove stops heat from burning the person's hand.

Sand is a good insulator that protects the surrounding surface from heat.



# Heat transfer

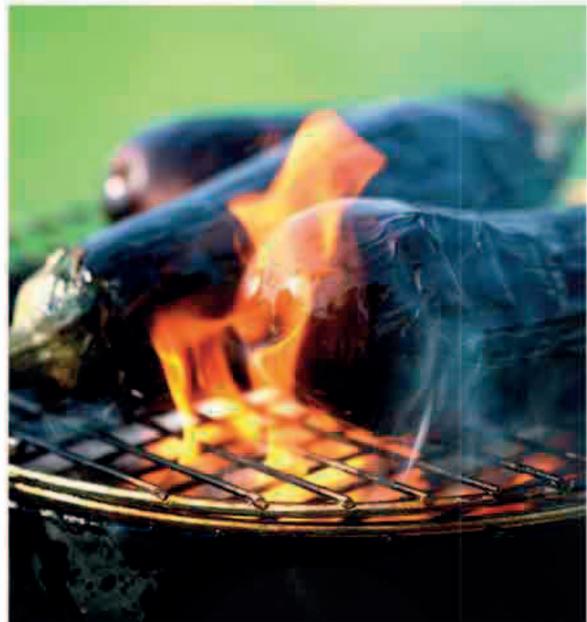
Coffee always gets cold and ice cream always melts. Hot things cool down and cool things warm up because heat is constantly on the move. Although heat transfer is sometimes a nuisance, it can help us do many things. A refrigerator removes heat from food to keep it cool and fresh, while an oven heats the same food up to cook it. Heat transfer dries our clothes, indoors or out, and keeps our homes cozy in the depths of winter.

## WHY DOES HEAT MOVE?

Heat moves when things are at different temperatures. It always moves from hotter to colder things, never the other way around. In winter, you are hotter than the air around you. Heat flows out from your body, and it is hard to stay warm. On summer days, heat flows into your body, and it is hard to keep cool.

WOW!

Nothing can get colder than  $-459^{\circ}\text{F}$  ( $-273^{\circ}\text{C}$ ). Scientists call this temperature “absolute zero.”



▲ ON THE GRILL *Cooking food transfers heat into it. This kills germs, making food safe to eat. Cooking also makes food easier for us to digest.*

## HOW DOES HEAT MOVE?

Heat moves in three different ways. If you touch something hot, you can feel the heat moving into your body. This is heat conduction, and it happens whenever hot things come into contact with cooler ones. If you lean over a radiator, you can feel hot air rising. This is called convection, and it is the main way heat travels through liquids and gases. Heat can also beam straight through the air or empty space. This is called heat radiation.



▲ CONDUCTION  
*When a saucepan sits on a stove, heat transfers from the stove to the pan by conduction.*



▲ CONVECTION  
*Hot liquids rise above cooler ones. Heating this purple dye makes it float in the water.*



▲ RADIATION  
*A hot lamp beams heat through the air in all directions, just as the sun fires heat through space.*



## KEEPING WARM

The best way to keep warm is to stop heat from escaping. This is called heat insulation. We wear layers of clothes in winter because they trap air between them. This reduces heat conduction, convection, and radiation from our bodies so we stay warmer. Animals do the same with thick layers of blubber and fur. The feathers on a penguin's coat trap air just like the layers of clothes we wear.

◀ **SNUGGLING SCIENCE**  
*When a baby penguin cuddles up to its mother, heat conduction keeps it warm and cozy.*



*Tightly screwed lid stops convection.*

*Vacuum (empty gap) stops convection and conduction.*

*Metal inner bottle stops radiation.*

*Thin plastic stand stops conduction.*



## HOW A THERMOS WORKS

A hot drink stays hotter much longer if you put it in a thermos. Inside, there is a glass or metal bottle surrounded by a vacuum (empty space with no air inside) and plastic to stop heat from getting out so quickly. Thermoses also keep heat from getting in, so you can use them to keep cold drinks cool as well.



## DRYING WITH HEAT

Laundry dries when the water inside it evaporates. We can dry laundry outside using conduction, convection, and radiation. If we lay it on warm ground, it dries by conduction.

If we hang it in the air, convection plays a part. When the sun shines on laundry, radiation warms the cloth and the water inside, helping the water evaporate.

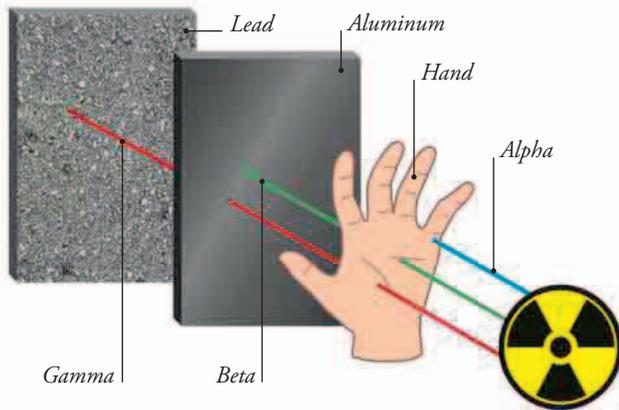


# Radioactivity and nuclear power

You can fit a million atoms on the head of a pin. Each one of these tiny bits of matter has the power to make a massive amount of energy. We can release this energy by smashing an atom apart or crashing two atoms together. Some atoms split all by themselves, giving off a kind of energy called radioactivity, which can be dangerous but very useful.

## WHAT IS RADIOACTIVITY?

Some atoms are unstable and break up to make more stable ones. When they split, they give off radioactivity. This can be chunks of atoms called alpha particles, flying neutrons called beta particles, or waves of energy known as gamma rays.



◀ **PENETRATING POWER** Alpha particles can be blocked by your hand. Beta particles are stopped by aluminum. It takes lead to stop gamma rays.

1. Hydrogen atoms fired in.

1. Neutron fired at high speed.

2. Uranium atom splits apart when neutron hits it.

3. Big atom splits into smaller atoms and releases more neutrons.

## WHY DO ATOMS CONTAIN ENERGY?

Suppose you had all the parts to build an atom—a big pile of protons, neutrons, and electrons. You could squeeze them together, but you would need to use massive force and energy to do so. If they stayed together, the energy you used would be locked inside the atom as potential energy. This is the energy that gets released when an atom smashes apart.

▲ **NUCLEAR FUSION** Energy is also produced when small hydrogen atoms crash together to make bigger helium ones. This is called nuclear fusion because the atoms join together (fuse).

◀ **NUCLEAR FISSION** We can make energy by smashing big uranium atoms apart. Fission (splitting atoms) releases more neutrons, which smash more atoms in a chain reaction.

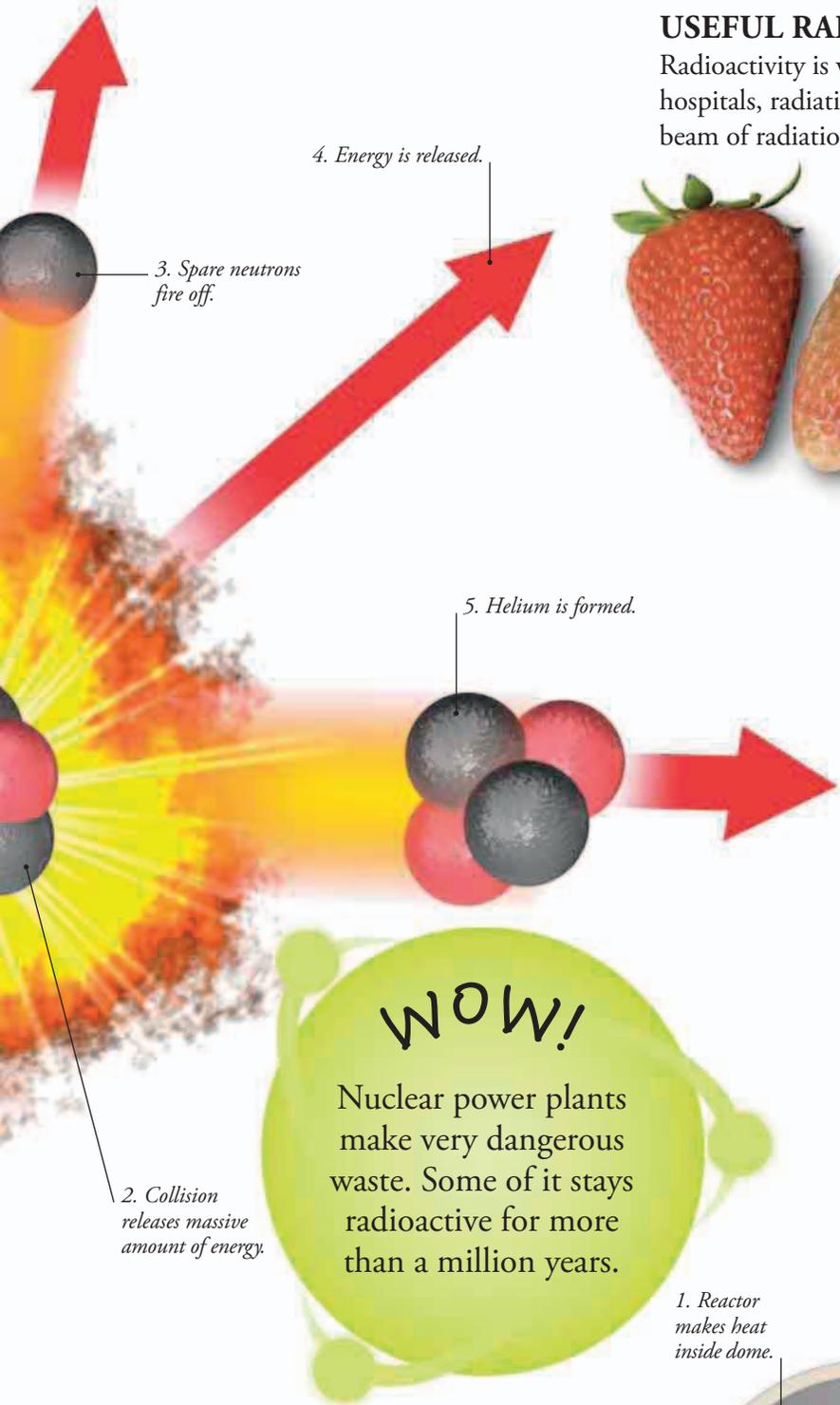
4. Neutrons split other atoms.

**USEFUL RADIOACTIVITY**

Radioactivity is very dangerous, but it can also be very helpful. In hospitals, radiation treatment is sometimes used to treat cancer. A beam of radiation is fired at tumors (harmful growths in the body) to kill them and stop them from spreading. Food is sometimes treated in a similar way so it lasts longer in stores.

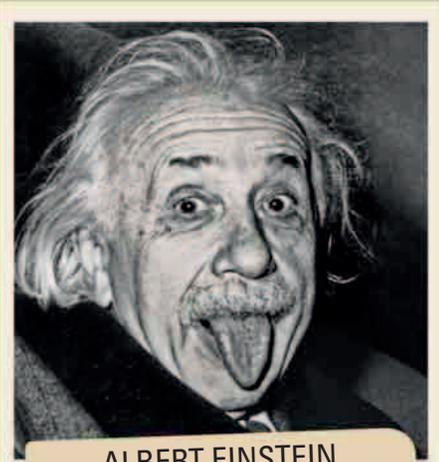


◀ **FOOD PRESERVATION** Food can be blasted with radiation to kill germs so it lasts longer. Some people argue against this because radiation can also destroy minerals and vitamins.



**WOW!**

Nuclear power plants make very dangerous waste. Some of it stays radioactive for more than a million years.

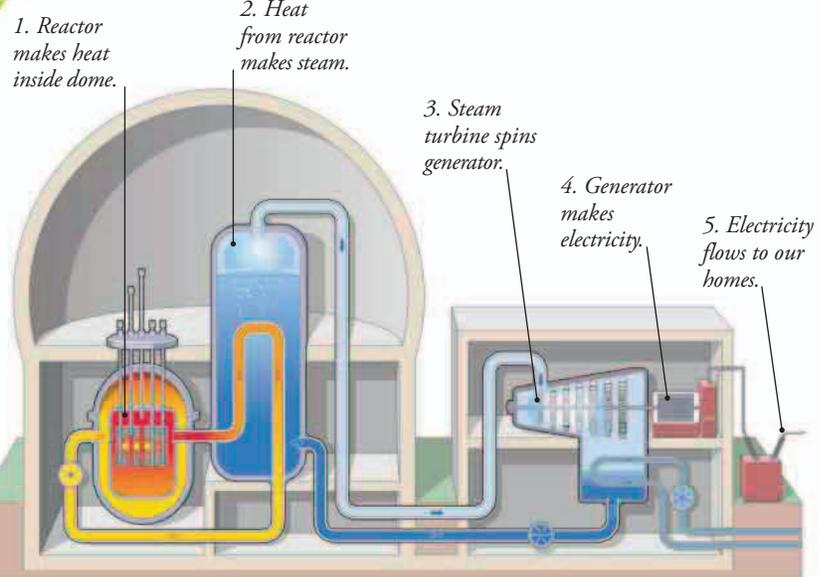


**ALBERT EINSTEIN**

German-born scientist Albert Einstein discovered that a tiny amount of matter can change into a huge amount of energy. This is the basic idea that makes a nuclear power plant work. It also explains why a nuclear bomb causes a massive explosion and a huge amount of damage.

**HOW NUCLEAR POWER WORKS**

Nuclear reactions release a lot of energy. We can use a nuclear reactor to turn this energy into useful electricity. Instead of burning fuel like an ordinary power plant, a nuclear reactor uses energy from splitting atoms.



▶ **NUCLEAR REACTOR** Heat is made in the dome-shaped nuclear reactor. This produces steam that turns the generator, making electricity that powers our homes.

# Energy conversion

Energy lasts forever. It cannot be created or destroyed. But it can turn from one form into another. Every single burst of energy that beams down to Earth from the sun has to go somewhere. All energy can change into other forms. It keeps changing, until it eventually becomes waste heat that we can no longer use.

## ENERGY IN MOTION

Almost all our energy comes from the sun. When sunlight hits the Earth, it makes plants grow, which feeds animals, including humans. Packed full of food, animals have the energy to do all kinds of things. Even the simplest things an animal does (such as thinking or sleeping) can use up a lot of energy.

▲ **SUNLIGHT** *Almost all the energy we use on Earth comes from the sun. A little bit of it also comes from heat made deep inside the earth.*

▼ **GROWING PLANTS** *Plants are living "machines" that catch sunlight and store it. They do this using photosynthesis, a process that turns light into chemical energy.*

► **FOOD** *Wild animals can spend more than 12 hours a day eating. Humans don't eat as much because we can select the most energy-rich food, and cook it to give us maximum energy.*

WOW!

Cars waste about 80 percent of the energy they get from gasoline. Only 20 percent of the energy moves you down the road.

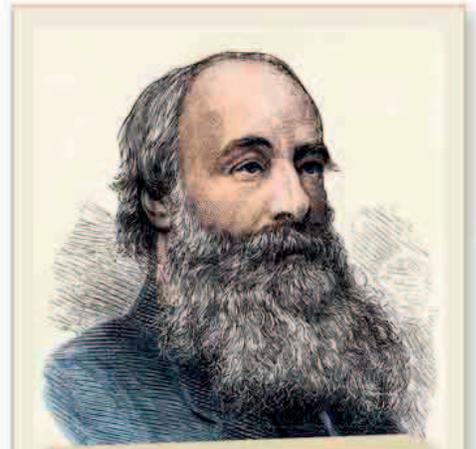




▲ **EATING** *Your body digests food to extract energy and nutrients. Excess energy is stored as fat.*

## ENERGY IN, ENERGY OUT

When something loses energy, that energy has to go somewhere. When you feel hungry, it means you have used up the energy you took in from food. Some of it has kept you warm. More has been used by your brain for thinking. You have used some moving around. If you add up all the energy your body uses in different ways, it comes to the same amount as the energy in the food you eat to start with.



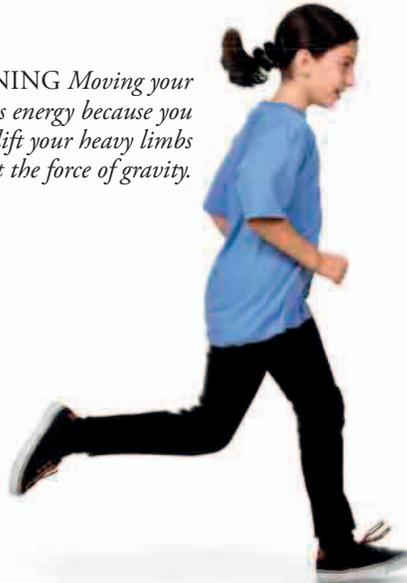
**JAMES JOULE**

British scientist James Joule showed how energy can change from one form to another. In 1845, he proved that when something loses energy, another thing must gain the same amount of energy. This is called the "conservation of energy," and it is one of the most important scientific laws.

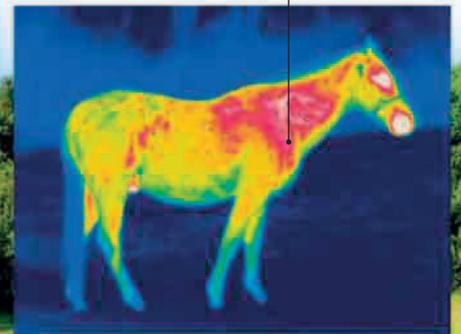


▲ **RESTING** *Doing nothing takes energy because your body still has to think and keep warm. Even while resting, your body is busy on the inside.*

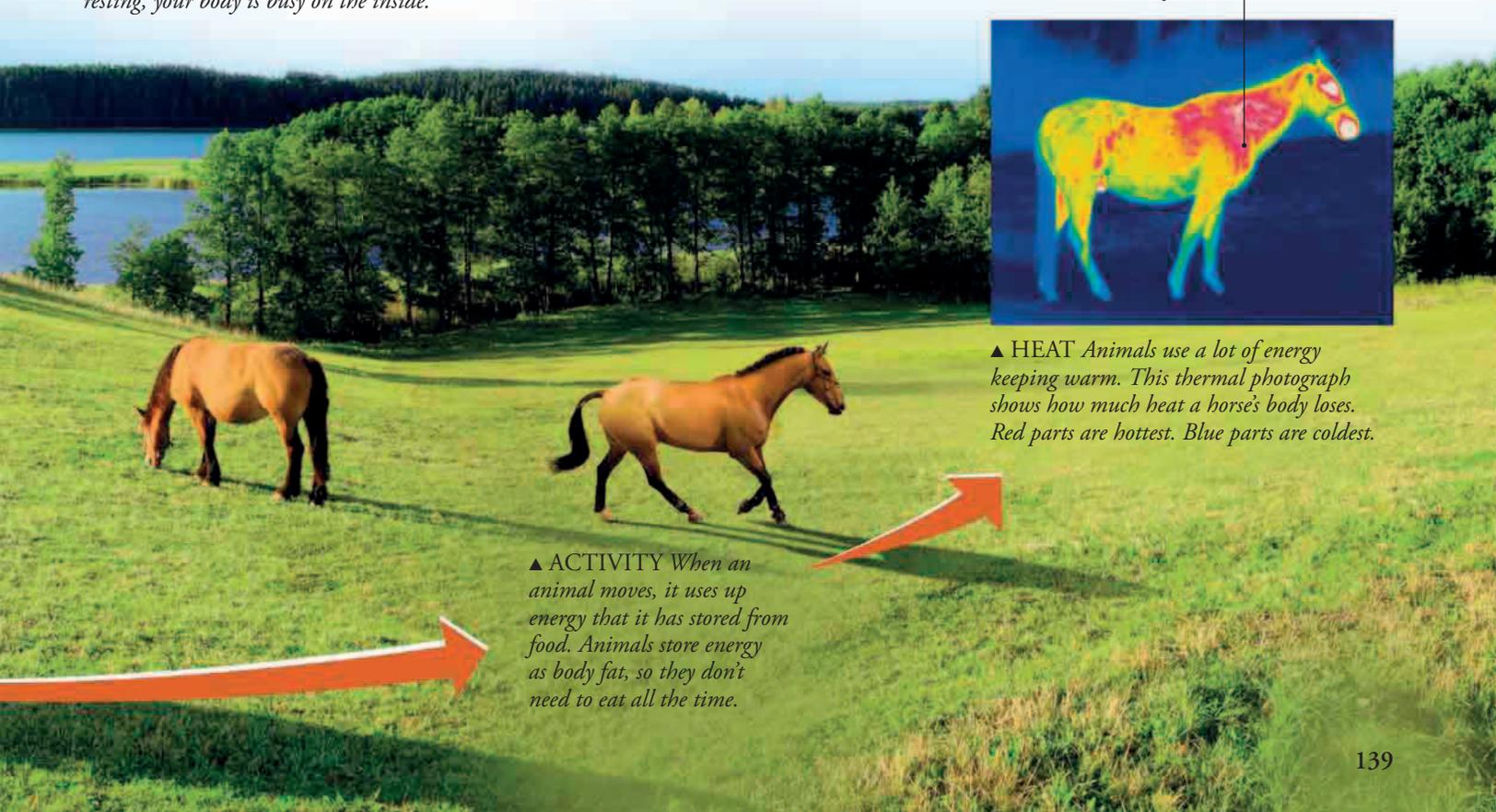
▶ **RUNNING** *Moving your muscles takes energy because you have to lift your heavy limbs against the force of gravity.*



*The heart is the hottest part of a horse.*



▲ **HEAT** *Animals use a lot of energy keeping warm. This thermal photograph shows how much heat a horse's body loses. Red parts are hottest. Blue parts are coldest.*



▲ **ACTIVITY** *When an animal moves, it uses up energy that it has stored from food. Animals store energy as body fat, so they don't need to eat all the time.*

# Waves

When winds roar across the oceans, the water whips into towering waves that ripple around the world until they crash onto the shore. Waves are how energy travels from place to place. Waves on the ocean are formed when energy from the wind is transferred to the water. Earthquakes also create giant waves, which can shake the surface of the land and create towering tsunamis out at sea.

WOW!

An ocean wave crashing on a beach in front of you may have traveled more than 9,000 miles (15,000 km) across the ocean.

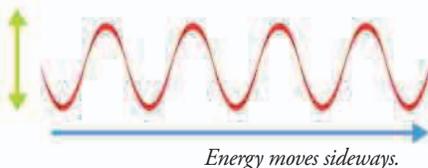
## RIDING ON WAVES

Surfers can zoom across the ocean because waves are packed full of energy. The higher and faster the wave, the more energy it carries. A typical wave carries enough energy per yard of its width to power up to 1,000 large light bulbs. Waves break and release their energy when they hit the shallow water near the shore.

### ENERGY IN MOTION

Although ocean waves seem to move the water, the ocean does not go anywhere. In fact, the water just moves up and down. As it does so, energy passes sideways into the neighboring water molecules. You can see the same effect with a friend by holding on to the ends of a piece of string. If one of you shakes the string, waves of energy will pass all along it.

*Water moves up and down.*



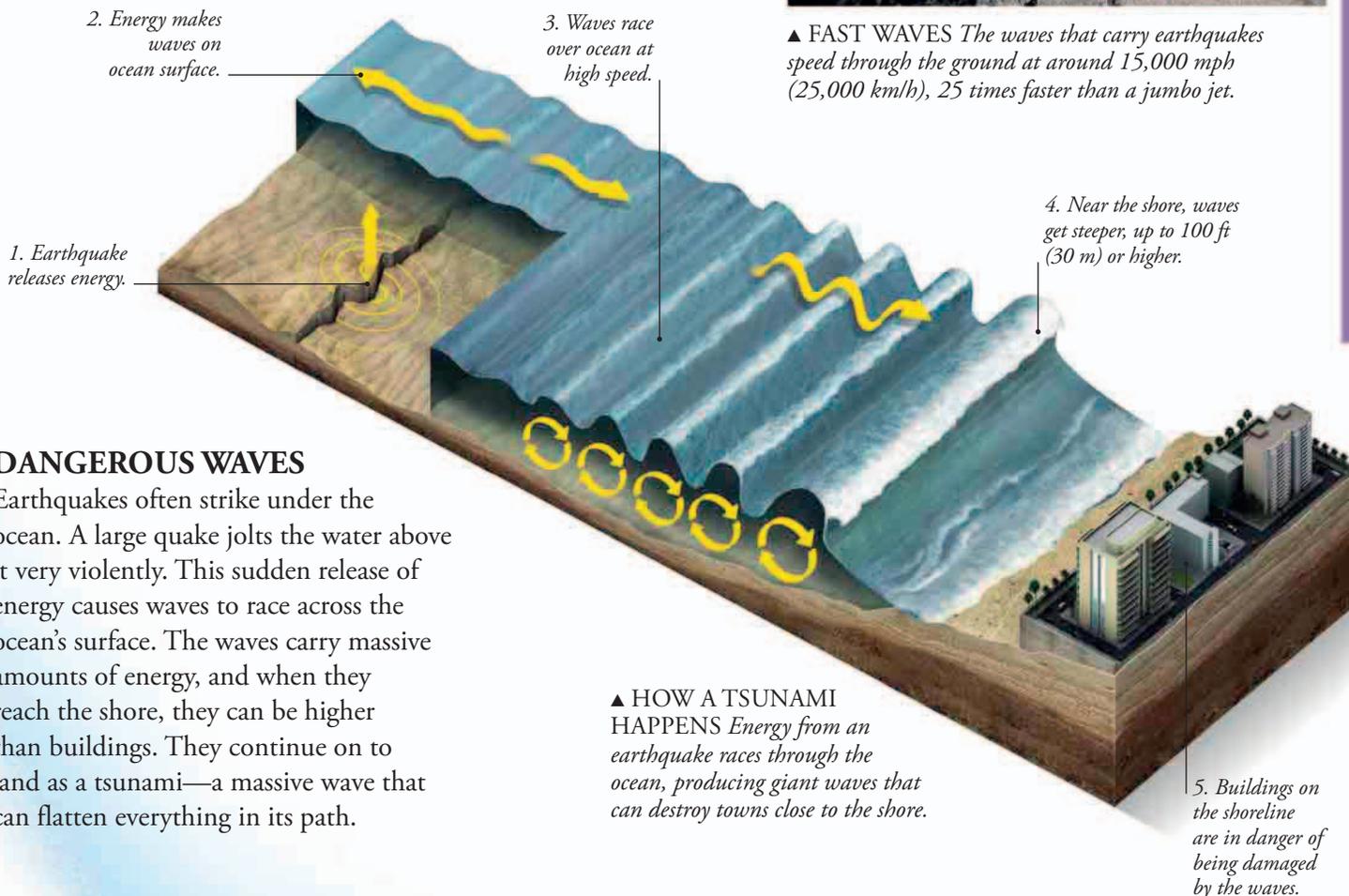
*Energy moves sideways.*

**How waves carry energy**



## EPIC EARTHQUAKES

Earthquakes are waves that shake the ground beneath our feet. Earth's landmasses are built on giant rocky plates that grind slowly past one another. Sometimes they jolt up and down, causing a massive release of energy at cracks called faults. This energy races through Earth as a high-speed wave, producing an earthquake on the surface.

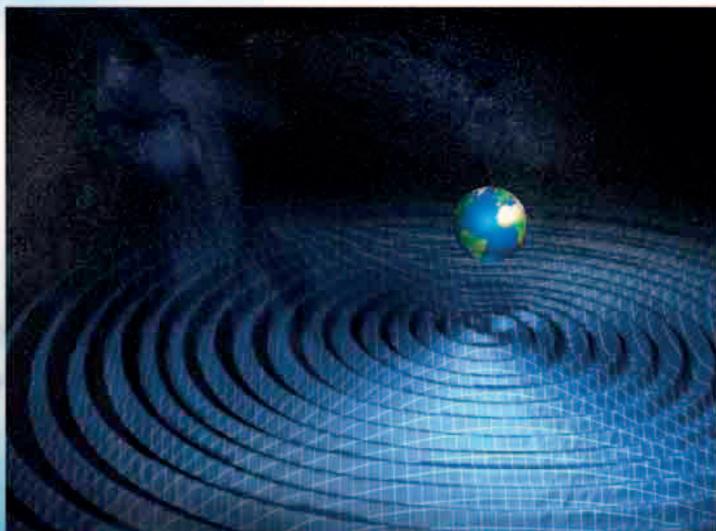


▲ **FAST WAVES** The waves that carry earthquakes speed through the ground at around 15,000 mph (25,000 km/h), 25 times faster than a jumbo jet.

▲ **HOW A TSUNAMI HAPPENS** Energy from an earthquake races through the ocean, producing giant waves that can destroy towns close to the shore.

## DANGEROUS WAVES

Earthquakes often strike under the ocean. A large quake jolts the water above it very violently. This sudden release of energy causes waves to race across the ocean's surface. The waves carry massive amounts of energy, and when they reach the shore, they can be higher than buildings. They continue on to land as a tsunami—a massive wave that can flatten everything in its path.



## WAVES IN SPACE

In addition to physical waves, there are also waves of force and energy pulsing through the universe. Some scientists believe that gravity makes waves that ripple through space and time, like waves on the ocean. Bigger objects, such as massive black holes, make bigger waves. As gravitational waves travel, they spread out and get weaker, which makes them very hard to detect.

◀ **GRAVITATIONAL WAVES** Scientists are trying to find evidence that gravitational waves are racing through space. Although they have built sensitive wave detectors, no such waves have yet been found.



# Sound

Close your eyes and listen to the world. You can recognize almost all the things you hear because they each have their own distinctive sound. Sounds are unique because they are all made in slightly different ways, but all sounds have one thing in common: They are created when something vibrates (shakes back and forth), sending waves of energy into our ears.

ENERGY

## GOOD VIBRATIONS

We make music with instruments that vibrate. Our voices are instruments too, singing when air vibrates inside our throats. The sound of a person talking, singing, or playing music is easy to listen to. Our ears pick up the sounds and our brains turn them into thoughts and feelings.

◀ **MUSIC TO OUR EARS** *The bow makes the strings of a violin vibrate, moving air inside the case that we hear as music.*



## LOUDNESS

Sounds travel as waves of vibration. The bigger the waves, the more energy they carry. When they arrive at your ears, louder sounds push harder against your eardrums. From rustling leaves to jet engines screaming past, our ears can “measure” an amazing range of quiet and loud sounds.

## BAD VIBRATIONS

Machines and engines have moving parts that grind and shake, making noise (sounds we do not want to listen to). Music is made from sound waves of varying pitch, arranged in a pleasant way. Noise is simply random sound, often at a single pitch.

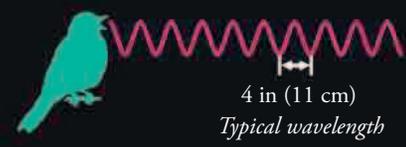
### ◀ **NOISE POLLUTION**

*Loud noise can damage your hearing. Workers usually wear earplugs to prevent sound waves from entering their ears.*

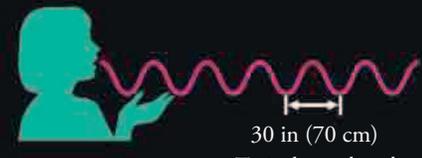


WOW!

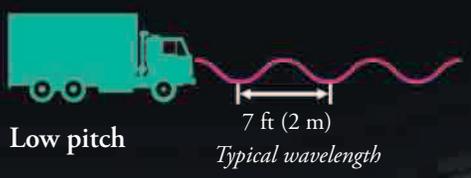
A space rocket taking off makes more noise than 10 million rock bands performing together.



High pitch



Medium pitch



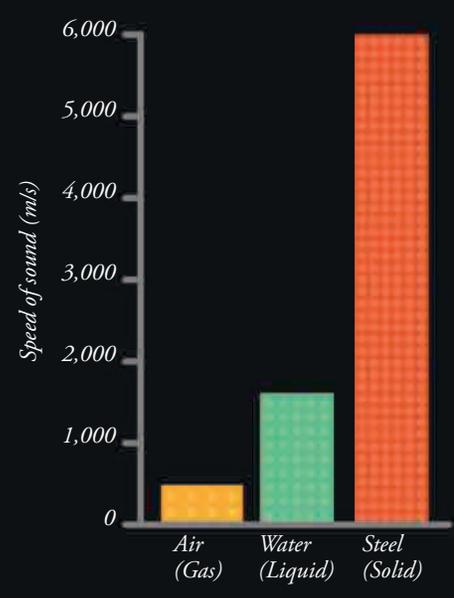
Low pitch

### PITCH

The sound something makes changes if it vibrates quicker or slower. When an object vibrates quickly, we hear high-pitched sounds. Low-pitched sounds come from things that vibrate more slowly. Most vibrating things make a mixture of many different sound waves. Every source makes a unique mixture—and that's why even two people's voices can sound very different.

### ▲ SPEAKING VOLUMES

The glowing light-emitting diode (LED) bars on a music player show the loudness of the sounds it plays. The more bars that light up, the louder the sound.



### SPEED OF SOUND

Sound cannot exist in a vacuum—the vibrations that carry it need something to travel through. Surprisingly, sound travels much faster in solids than in liquids or gases.



◀ WHALE TALK Whales communicate with one another by making low-pitched sounds in water. Their sounds can travel across entire oceans.

## SONIC BOOM

As a plane flies, the noise of its engines speeds out in all directions. If the plane moves faster than the speed of sound, it starts to overtake the sound waves in front of it. A shock wave forms, spreading out in a cone behind the aircraft and creating a loud noise called a sonic boom.





ENERGY



# Music

When waves of energy vibrate inside your ears, you might feel like singing or dancing. We call this music. It is a special kind of sound that we enjoy listening to because it has the power to make us feel happy or sad. Music is made by instruments that shake the air so the sound rushes toward us. Most instruments make a range of sound frequencies, so they can play a musical tune.

**WOW!**  
The oldest instrument ever discovered is a simple flute made from a vulture's wing bone. It was made 35,000 years ago.

ENERGY



## HOW INSTRUMENTS WORK

Musical instruments make sound by moving the air back and forth all around them. The faster they vibrate, the faster they shake the air and the higher the musical notes we hear. Most instruments are designed so they can vibrate at slightly different speeds, making many different notes. A guitar has six strings, but you can press them in different places to make dozens of different notes.

► **BOTTLE ORGAN** *You can build an organ by filling bottles with different amounts of water. When you blow into a bottle, the air inside vibrates, making a musical note. The fuller bottles make higher notes, while the ones with less water produce lower notes.*



## STARS OF THE ORCHESTRA

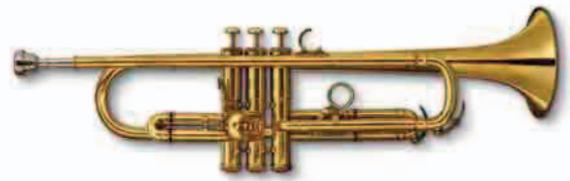
We can create an infinite number of melodies by combining different sounds from different instruments. Although each instrument makes sound waves, they all work slightly differently. Bigger instruments tend to make lower and louder notes than small ones. Instruments with more keys, strings, or holes can make a wider range of notes. Playing many instruments together in an orchestra makes even more interesting effects.



▲ **WOODWIND** *Air vibrates inside a pipe when you blow across the end. The holes change the sound waves and the pitch of the notes they make.*



▲ **PERCUSSION** *Banging a drum makes its tight elastic skin vibrate. The tighter or smaller the drum, the higher the pitch of the notes it makes.*



▲ **BRASS** *Air vibrates in the metal pipes of this trumpet to make sounds. Switches called valves are used to change the notes.*



▶ **STRING** *A stretched string makes a note when you pluck it. Longer strings make lower notes than shorter ones.*



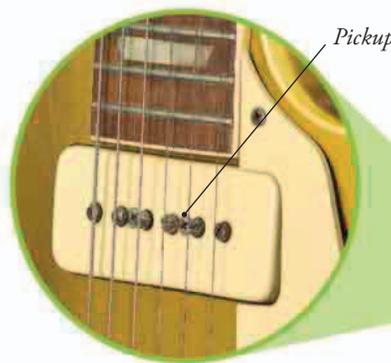
▲ **SYNTHESIZER** *Electronic keyboards can copy the sounds of any orchestral instrument. They can also make futuristic sounds that no traditional instrument could ever play.*

## ELECTRIC SOUNDS

It takes energy to produce sound, so making loud sounds for a long time is hard work. That's one reason why we have electric instruments. They use electricity to help us make loud sounds for long periods of time. Electric instruments also make very different sounds from traditional acoustic (nonelectric) instruments.

### HOW DO ELECTRIC GUITARS WORK?

Ordinary acoustic guitars have strings that you pluck. When the strings move, they vibrate air inside the wooden case and this makes the sound. Electric guitars have metal strings with pickups (wire-wrapped magnets) underneath. When the strings vibrate, they make electric currents flow through the pickups. If a guitar is connected to an amplifier and loudspeaker, these currents are boosted in volume to make loud music.



Pickup

▲ **GUITAR PICKUPS** *Each string on an electric guitar has a pickup underneath it, made from magnets and coils of wire. The pickups make tiny electric currents when the strings move above them.*

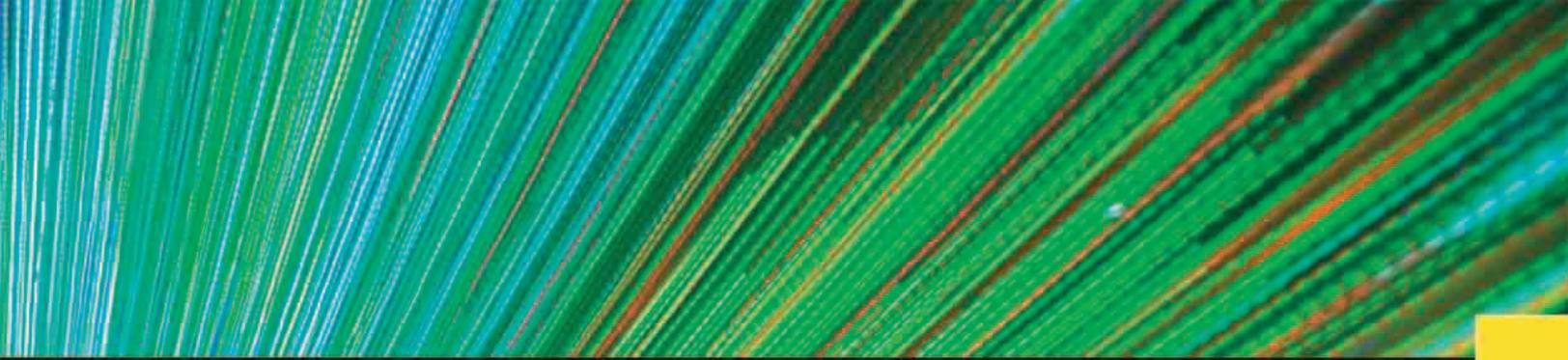




# LIGHT

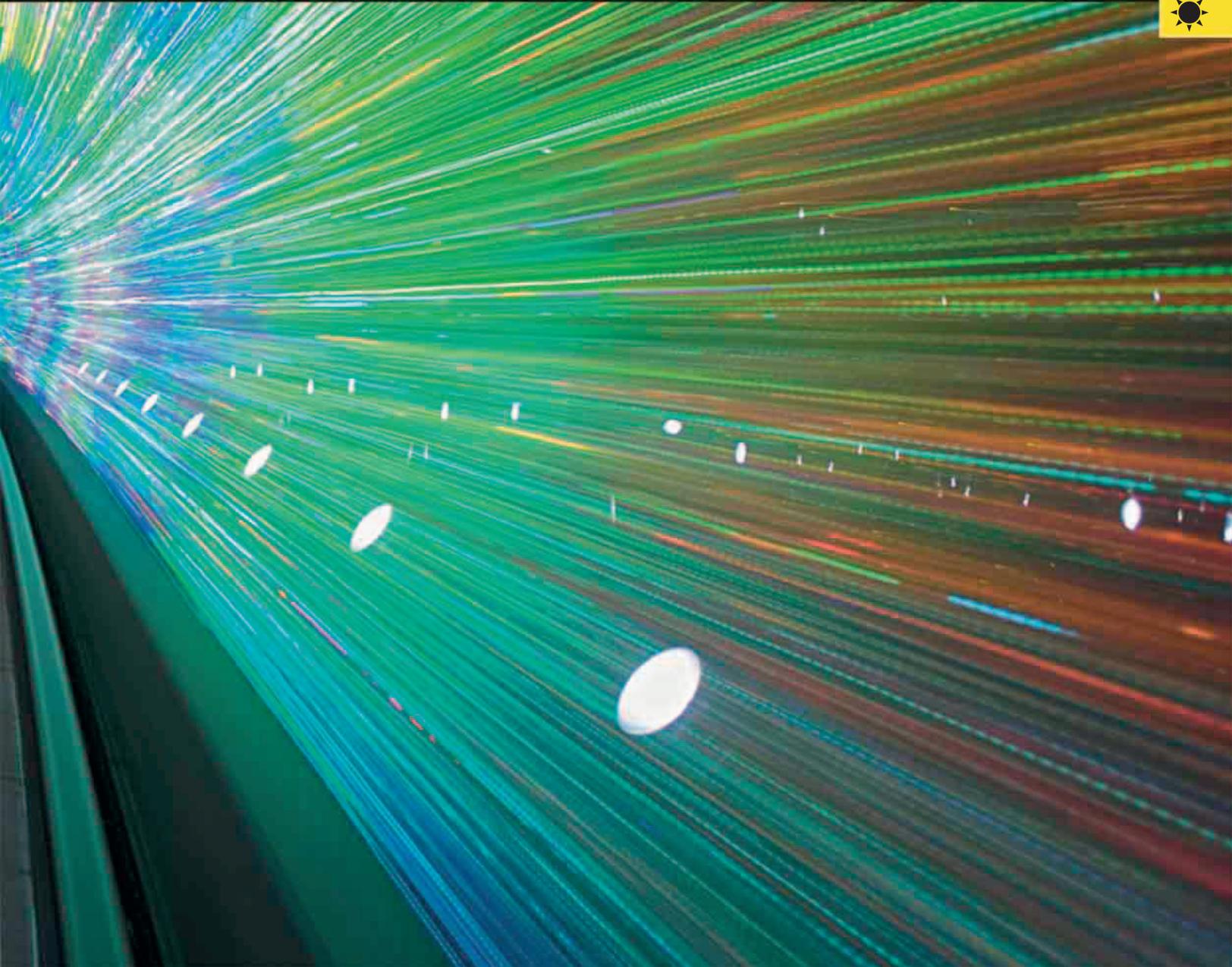
## LIGHT DISPLAY

This train tunnel in Shanghai, China, is lined with colorful patterns, created by shining laser light beams onto the walls. These lights were photographed using a special effect to make them blur into streaks.



Light is energy radiating through space. This includes everything we see. From blazing sunlight to the tiny glow of a firefly, light brings life and color to the things around us.

LIGHT

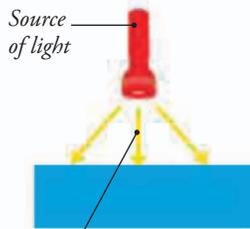


# Light and shadows

Light is the energy that shows us the world. People are daytime animals, and we live in a world of bright light and color. Many animals prefer the dark and thrive when the sun goes down. In between light and dark, there is a dusky world filled with shadows.

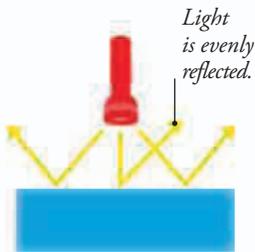
## SEEING CLEARLY

We see things because light bounces off them and into our eyes. White things reflect most light, while dark things soak up the light and do not reflect much. In darkness, seeing things is very hard because little light reflects into our eyes.



Light beam gets absorbed.

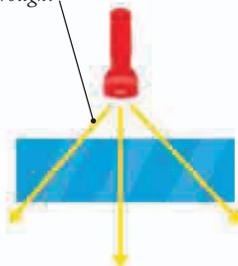
◀ **OPAQUE OBJECTS**  
*Light cannot pass through a dull, opaque object. Some light gets absorbed and the rest reflects back into our eyes.*



◀ **SHINY OBJECTS**  
*No light is absorbed by a mirror. Instead, all the light reflects straight back again.*



Most light passes through.



◀ **TRANSPARENT OBJECTS**  
*See-through things let most light pass through. But some light reflects back; if it didn't, we would not be able to see them.*



## LIGHT SOURCES

Light does not magically appear out of thin air—it has to be made using another kind of energy. A candle makes light by burning wax. The sun makes its light when atoms smash together inside it, releasing huge amounts of nuclear energy.



## SHADOWS

Light rays shoot in straight lines, and when something gets in their way, they cannot pass. A pattern of darkness forms behind the object, called a shadow. The dark middle of a shadow is the umbra. The lighter part around the edge is the penumbra.

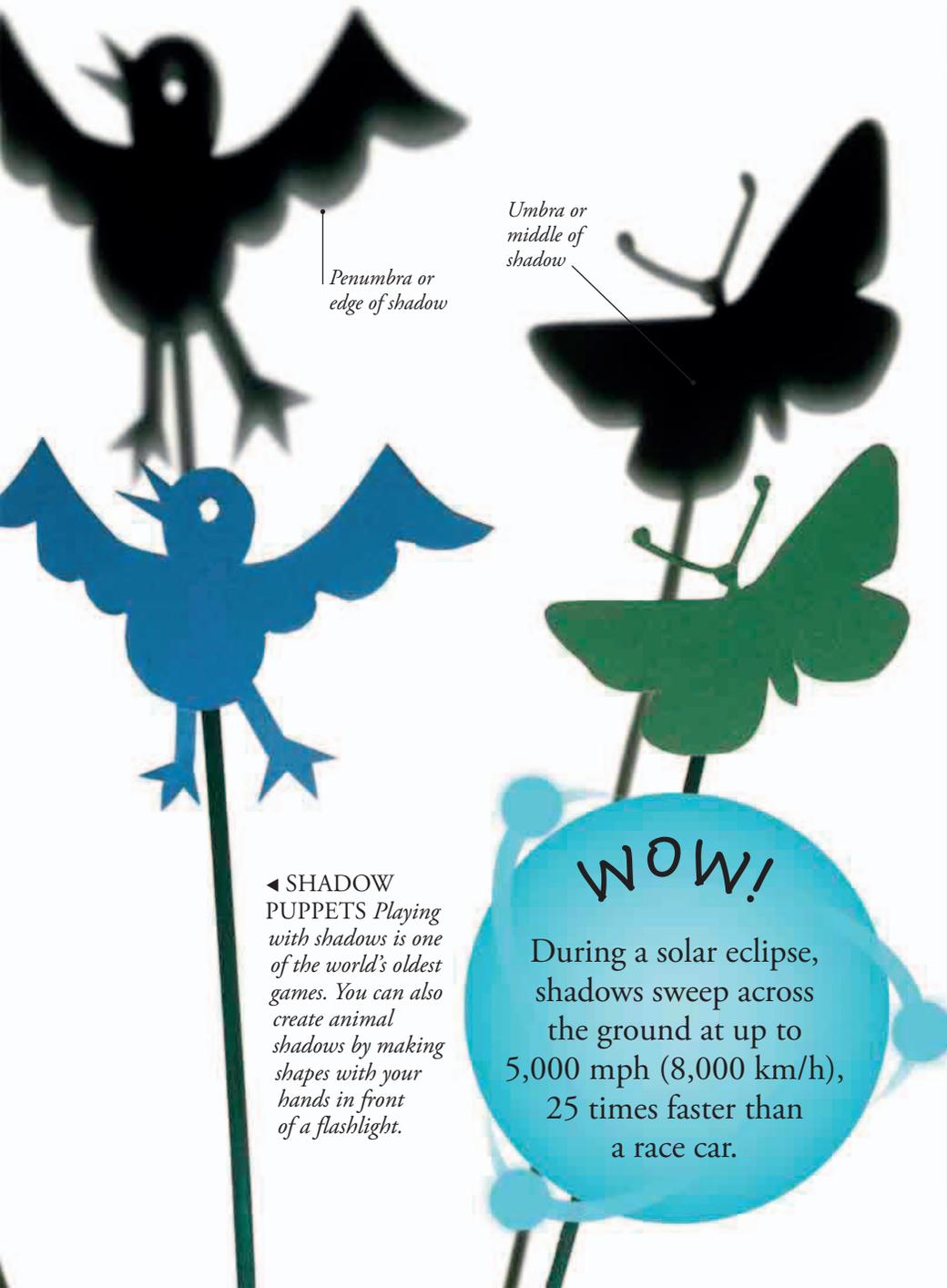


## TIME FOR SHADOWS

People have been telling time using shadows for more than 5,000 years. As the sun sweeps around the sky, it casts shadows on the ground. The shadow of a stick moves clockwise in a circle. At noon, it always points exactly north (in countries north of the equator) or south (in countries south of the equator).

### ▶ TELLING TIME

*Most sundials use a gnomon (tilted pointer). The gnomon and dial must be carefully lined up with a compass to tell time correctly.*



*Penumbra or edge of shadow*

*Umbra or middle of shadow*

◀ **SHADOW PUPPETS** *Playing with shadows is one of the world's oldest games. You can also create animal shadows by making shapes with your hands in front of a flashlight.*

**WOW!**

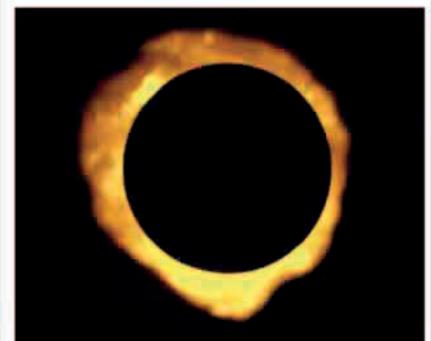
During a solar eclipse, shadows sweep across the ground at up to 5,000 mph (8,000 km/h), 25 times faster than a race car.

## SHADOWS IN SPACE

The sun shines like a giant flashlight in space, but we can only see it if nothing gets in the way. Sometimes, the moon passes directly in front of the sun, casting a shadow over Earth. This phenomenon is called an eclipse.



▲ **SOLAR ECLIPSE BEGINS** *As the moon inches slowly across the sun, it starts to block out the light.*



▲ **TOTAL ECLIPSE** *When the moon is completely in front of the sun, it makes a sparkle of light called the diamond ring.*



# Color

Rainbows paint the sky with color—but what exactly is color? Things around us seem to have color because they reflect light into our eyes in different ways. The colors we see are made by light waves of different sizes (wavelengths and frequencies). Recognizing different colors helps our eyes and brains pick out objects to understand the world more clearly.

LIGHT

## LIGHT OF MANY COLORS

White light is actually a mixture of all the other colors. We know this because white light splits into colors when you shine it through a wedge of glass called a prism (see pp.154–55). Raindrops and pieces of plastic also split white light into its colors in the same way.

► **RAINBOW** *When light from the sun passes through raindrops, it bends by different amounts, splitting into different colors. Violet bends the most, so it is always on the inside of a rainbow.*

**WOW!**

You might think a rainbow has only seven colors. In fact, there are an infinite number of colors between red and violet.

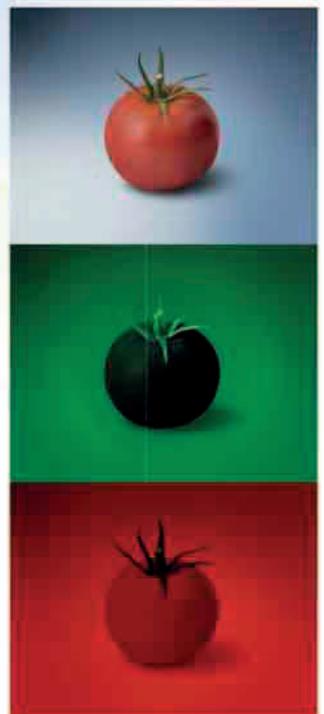
## CHANGING COLORS

Daylight is made from white light. A tomato looks red because it reflects the red part of white light into our eyes and absorbs (soaks up) the other colors. If you change the color of the light shining on it, you change the light that is reflected and absorbed. This makes the tomato look different and strange.

► **WHITE LIGHT**  
*The tomato absorbs green, blue, and all other colors and reflects red into our eyes, making it look red.*

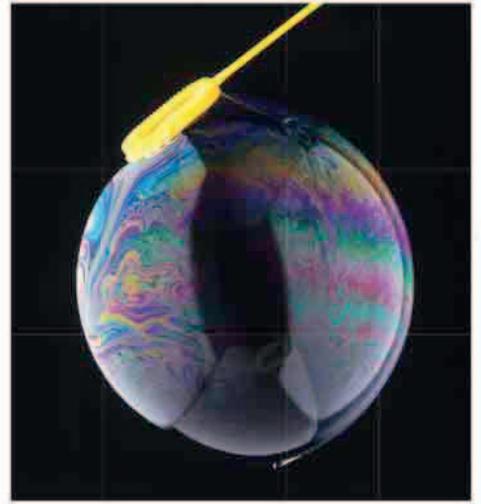
► **GREEN LIGHT**  
*The tomato absorbs green light, so it turns black. The stalk reflects green light, so it still looks green.*

► **RED LIGHT**  
*The tomato reflects red light and so does the white background. The green stalk absorbs red light, so it appears black.*



## SOAPY SWIRLS

Have you ever noticed colorful patterns swimming in soap bubbles? Light rays reflect off both the top and bottom of the thin soap film (wrapped around the bubble). These separate rays meet and merge together. This makes colors that change according to how thick the soap is. As the thickness of the film is constantly changing, the colors slowly change too.



▲ **BLOWING BUBBLES** *The film gets thinner as you blow on it, which makes the colors change from purple (where it is thickest) to yellow and clear (where it is thinnest).*



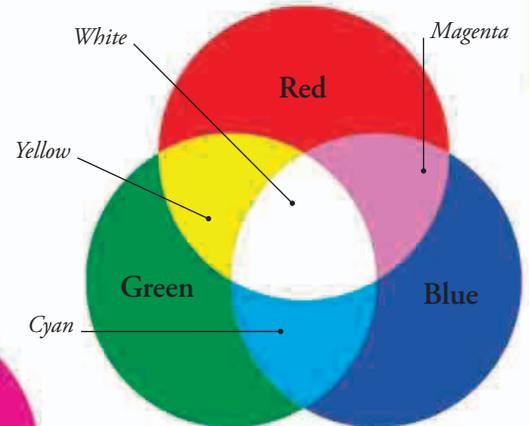
## HEAT MAKES COLOR

Hot things glow red, yellow, or white hot because heat makes the atoms inside give off light. The hotter something is, the more the atoms are “excited” and the more light they give off. When something is white hot, it has so much energy that its atoms are giving off all the different colors of light at once.

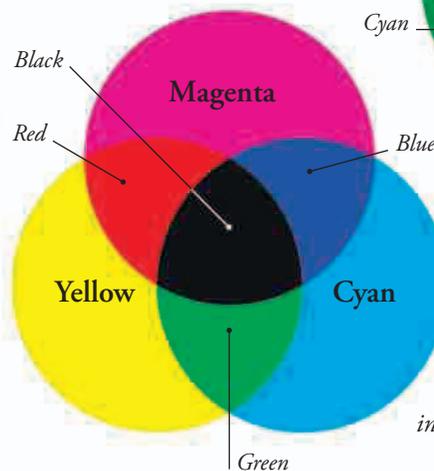
◀ **HOT STUFF** *Hot things give off energy you can see (light) as well as energy you can feel (heat).*

## MIXING LIGHTS, MIXING INKS

Colors can change when light rays mix. If you shine red, green, and blue flashlights together, their light combines to make white light. If you mix red, green, and blue ink on a page, they absorb all the light that falls on them, so the page looks black.



▲ **MIXING LIGHTS** *Red, green, and blue lights add together on the way to your eyes. All three together produce white light.*



◀ **MIXING INKS** *Different colored inks absorb different wavelengths of light. By mixing them together, we create ink that absorbs all colors, so it looks black.*



## PIGMENTS AND PAINTS

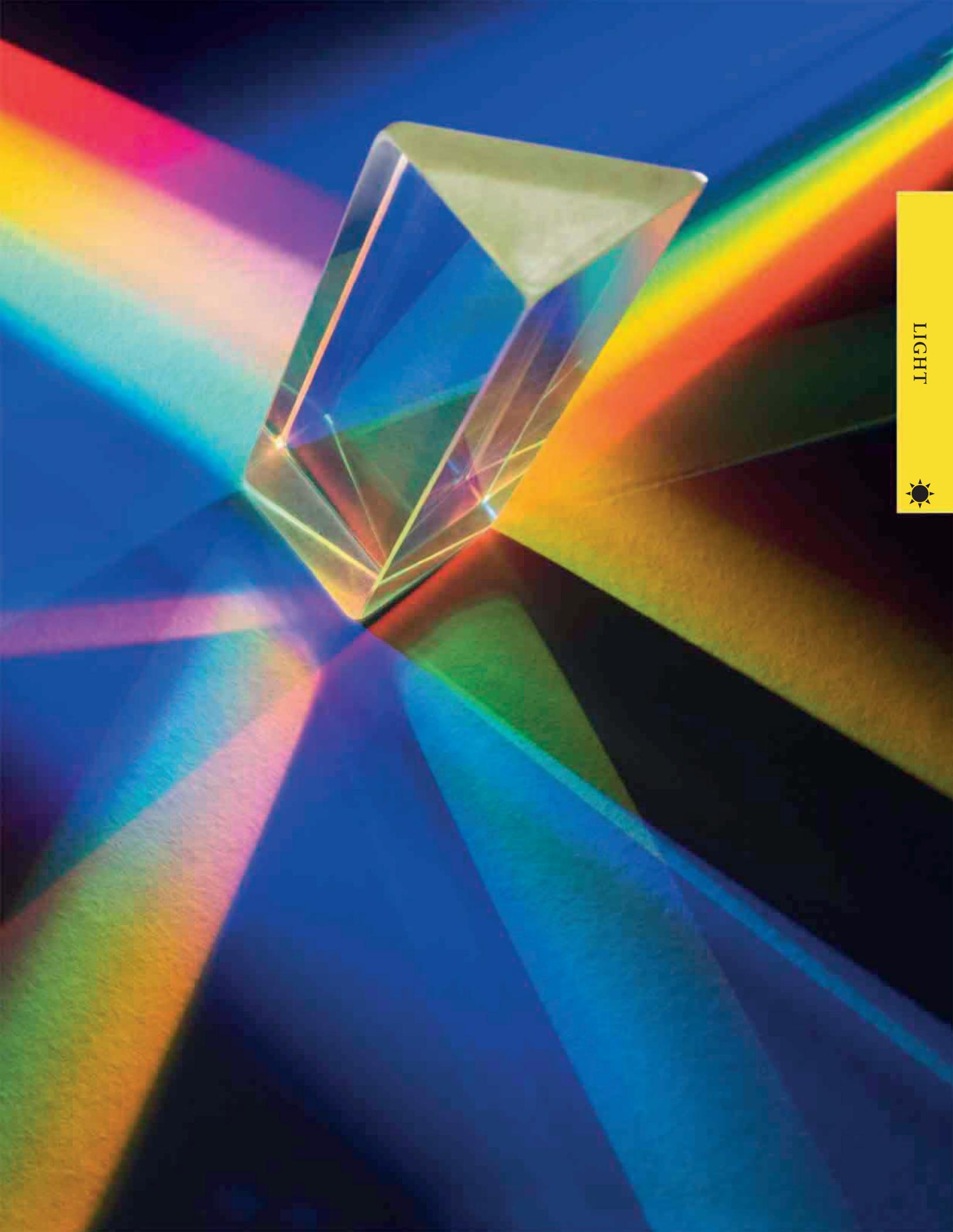
Pigments are the chemicals that give paints their vibrant colors, and most are made from salts (compounds) of metals. Titanium dioxide, found in sand, is used to make a brilliant white color, while iron oxide makes paints that are red or brown. Green paint is made from chromium oxide.





### **SPLITTING LIGHT**

Our eyes see different wavelengths of light as different colors. White light is actually many wavelengths mixed together. When light passes through a prism, it changes direction (refracts). Different wavelengths refract by different amounts, splitting white light into a rainbow of colors.



LIGHT



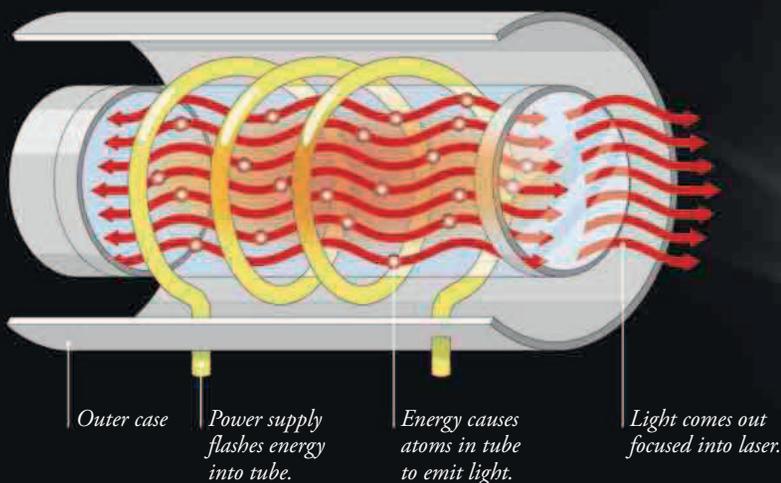
# Lasers

Lasers are light beams that fire out from a tube packed with energized atoms. Often used in light shows, lasers are also the power behind CD and DVD players, some computer printers, and holograms, which make ghostly images dance before your eyes. Powerful lasers can leap miles into the sky and even slice through metal.



## HOW DOES A LASER WORK?

Lasers are concentrated beams of light. A laser works by flashing light into a special tube. As the atoms inside the tube soak up the light energy, they start to give off light themselves and cause other nearby atoms to give off light too. The rays of light all line up inside the tube and shine out in a single concentrated beam.



## READING AND WRITING WITH LIGHT

When you learned to read, you might have moved your fingers under the words to keep your place. Laser beams read music and movies from CDs and DVDs in a similar way. Inside the player, the CD or DVD spins at high speed. Just like a tiny finger, a laser beam scans across the disc and reads information from bumps on the surface.



## LEAPING LASERS

Lasers make more powerful light than flashlights, so they shine much farther. In a flashlight beam, the light waves are jumbled up, so they tend to cancel one another out. They quickly soak into the air and do not go far. In a laser beam, the light waves all line up, so they are brighter and can travel farther.

► **LIFELIKE**  
*Colorful holograms bring science to life in a museum in Paris.*



## HOLOGRAMS

Photographs are flat images that always look the same. Holograms are like 3-D photos that look different from every angle. They are made by bouncing lasers off objects to capture more information, which is displayed inside plastic or glass. Holograms have been used to make life-size 3-D pictures of actors that can stand on stage. They are also used to stop people from copying credit cards and paper money.

◀ **LASER SHOW** *The light from lasers is so concentrated it almost looks like a solid object.*

**WOW!**

The world's biggest laser is made from 192 laser beams and makes as much power as 10 billion light bulbs.



# Reflection and mirrors

Mirrors play throw and catch with light. They catch light from in front of them and throw it back the way it came. Mirrors are made from thin metal sheets inside glass, but many other surfaces reflect light as well. A smooth lake mirrors the sky above it, and you can often see your face in shiny shoes or a polished spoon.

## MIRROR SHAPES

Light rays stream in straight lines, so a flat and smooth (plane) mirror reflects things much as they are. The reflected image looks like the original because the incoming rays bounce back in parallel lines.

However, a mirror that curves inward (concave) makes things look bigger, while one that curves outward (convex) can make them look smaller.



### ▲ PLANE MIRROR

*Light rays bounce back in parallel lines, so your reflection looks like you do. It seems reversed, left to right, so writing looks like gibberish.*



### ▲ CONCAVE MIRROR

*These are bent ("caved") inward and sometimes flip things upside down. They make things look bigger, so they are often used for shaving and bathroom mirrors.*



### ▲ CONVEX MIRROR

*These are bent outward and make things look smaller and further away. They are used in cars' side mirrors so drivers can see a wider view.*

WOW!

The giant mirror in the Hubble Space Telescope took five years to grind and polish.



## HEAT MIRRORS

Mirrors reflect heat as well as light. Hot objects give off infrared radiation, which is like invisible, hot light. When infrared hits a mirror, it reflects straight back again. You can test this effect for yourself by wrapping some silver foil around your arm. It feels warm because your body heat is being reflected back.



▲ **HEAT BLANKET** *Clothes keep you warm by trapping air that insulates your body. This metal blanket keeps you warm by reflecting body heat.*

Each hexagon in the mirror weighs about 46 lb (20 kg).

## ANIMAL MAGIC

Cats are like walking mirrors. They can see at night because they have special reflecting surfaces (miniature mirrors) behind their eyes. These catch incoming light and bounce it back out through their eyes again. The light passes through their eyes twice, and this gives them double the chance to see dim objects. That's why a cat's eyes shine at night or in dim light.



LIGHT



## MEGA MIRRORS

Some telescopes need giant mirrors, but if a mirror becomes too big, it bends and buckles. To get around this, the biggest and best space telescopes use mirrors split into dozens of honeycomb-like segments. Bolted onto a framework, very close to one another, they work together like a single giant mirror.

◀ **SEEING STARS** *The James Webb Telescope, which will replace NASA's Hubble Space Telescope, is being made from 18 giant hexagonal mirrors.*

# Refraction and lenses

Lenses play tricks with light, bending it so it seems to come from a different place. The science behind this “magic” is called refraction, and it can make things look bigger than they really are. Lenses are the power behind microscopes and telescopes, which bring the world nearer. Working the opposite way, powerful lighthouse lenses can sweep beams of light far into the night.



## REFRACTION IN ACTION

Straight things often look strange when they stand in water—and refraction is to blame. When light moves from water to air, it changes speed and bends in a new direction. This can make something underwater appear to be in a different place.

◀ **BENT PENS** *Light from the lower halves of these pens is shifted by refraction, so they seem to be in the wrong place.*

## HOW A LENS WORKS

A drop of water can work just like a lens. Place some clear plastic on a newspaper, drop some water on top, and you'll find that it slightly magnifies the words underneath. A magnifying glass works the same way, but makes the words much bigger because it uses thicker plastic that can bend the light more.



◀ **WATER LENS**  
*The water drop on this leaf bends light rays coming out. Like a lens, it makes the veins of the leaf look bigger.*

WOW!

The world's biggest camera lens is 6 ft (1.9 m) long, weighs 220 lb (100 kg), and can magnify things up to 1,000 times.

## SEEING THE LIGHT

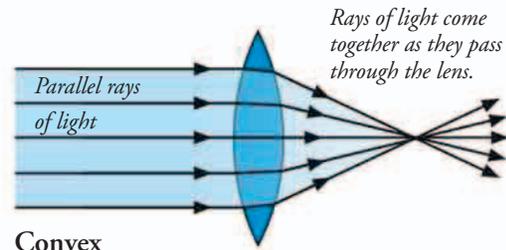
If you want to throw a beam of light far out to sea, you need a powerful lens. A normal lens this big would be too heavy, so lighthouses use Fresnel lenses instead. With a surface made of sharp steps, they are much thinner and lighter. Each step bends the light slightly more, making a powerful, parallel beam. Fresnel lenses are also used in car headlights.

▼ **FRESNEL LENS** *This lighthouse uses a bright gas lamp behind a huge Fresnel lens. The lens spins on an electric turntable that sweeps its beam across the sea.*

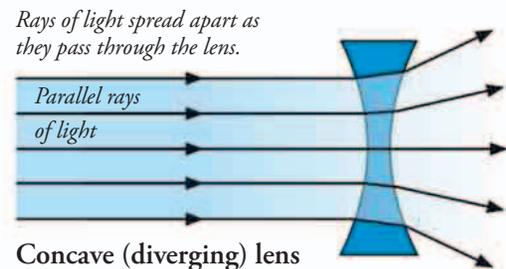


## THICK AND THIN LENSES

Different-shaped lenses bend light in different ways. Lenses that are thick in the middle and thin at the edges make light rays converge (come together) at a point. Magnifying glasses, binoculars, and glasses for nearsighted people use convex (converging) lenses. Lenses of the opposite shape—thin in the middle and thick at the edges—make light rays diverge (spread out). Film projectors use concave (diverging) lenses.



**Convex (converging) lens**



**Concave (diverging) lens**



## WHAT MAKES A MIRAGE?

Stare at a road on a hot day and you might see water in the distance. Move closer and there is no water there—it is a mirage. What you can see is light from the sky bent down into your eyes by layers of hot and cold air. The air bends light like a lens.



▲ **JUST DESERT** *The wobbling pattern in the distance is a mirage—a reflection of the sky in the hot desert air.*

# Telescopes and microscopes

Turn your eyes to the sky and you will see stars so far away that their light has taken millions of years to reach you. Telescopes make these pinpoints of light bigger, showing us a vast universe beyond Earth that we have barely explored. Back on our own world, there is another, tiny universe too small to see with the naked eye. Microscopes help us zoom in on this secret world.

## HOW DOES A TELESCOPE WORK?

A telescope is a long tube with lenses at each end. The lenses catch light rays coming from a faraway object, and bend them so they appear to come from much closer. This makes the object look bigger. Large, powerful lenses can bend light more and make bigger images. Unfortunately, large lenses are heavy and expensive, and they can distort images. That's why most large telescopes use mirrors to make their images instead.



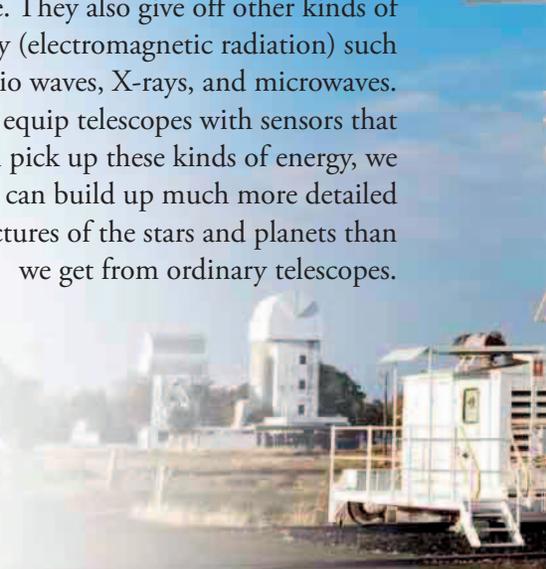
## GIANT TELESCOPES

The farther you want to see, the bigger the telescope you need. Linking two telescopes makes a combined telescope that is more than twice as powerful. The Large Binocular Telescope in Arizona (above) does this with two side-by-side mirror telescopes, each 28 ft (8.4 m) wide.



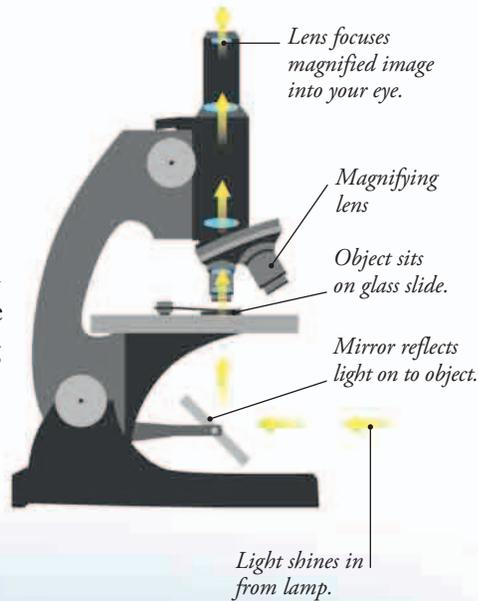
## SEEING WITHOUT LIGHT

Distant stars don't just beam out light we can see. They also give off other kinds of energy (electromagnetic radiation) such as radio waves, X-rays, and microwaves. If we equip telescopes with sensors that can pick up these kinds of energy, we can build up much more detailed pictures of the stars and planets than we get from ordinary telescopes.



## HOW DOES A MICROSCOPE WORK?

Like a telescope, a microscope is a tube with mirrors and lenses inside. It catches the light rays given off by tiny things and spreads them apart, so they look bigger and our eyes can see them more clearly. A microscope works the same way as a magnifying glass, but uses extra lenses to make a more magnified image.



## GIANT MICROSCOPES

Just as there are huge telescopes, there are also huge microscopes. The Diamond Light Source near Oxford, England, is one of the world's biggest. It whirls electrons around a giant ring to make powerful beams of radiation. These are finer than light waves, so they can see things in more detail.



### ▲ DIAMOND SYNCHROTRON

Electrons race around a ring of magnets inside this doughnut-shaped building at just under the speed of light. That makes them fire out beams of light 10 billion times brighter than the sun.



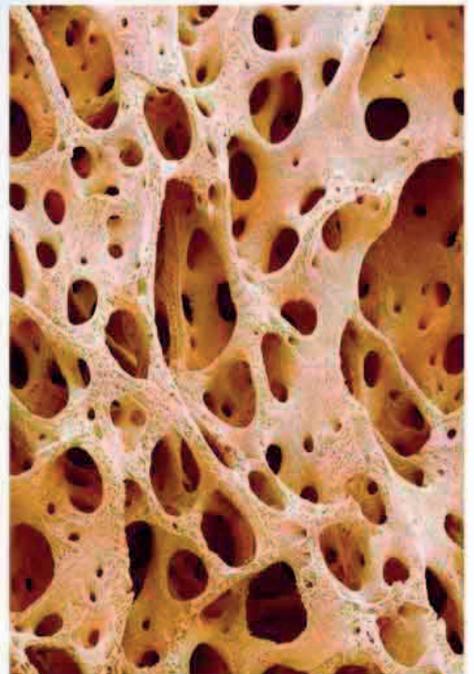
This huge radio telescope, called the Telescope Compact Array, is located in New South Wales, Australia. It has six dish-shaped antennae like this one, each 72 ft (22 m) in diameter.

## MICROSCOPES WITHOUT LIGHT

Light travels in small packets, like microscopic cannonballs. If we want to see tiny things, these “balls” of light are too big. For extra seeing power, we can use electron microscopes that fire beams of electrons instead. Electrons are smaller than light, so electron microscopes can see smaller things, magnifying them up to 2 million times.

### ► BARE BONES

Bones look strong and solid on the outside, but an electron microscope can zoom in to show the spongy structure inside.





LIGHT





### **LASER-GUIDED TELESCOPE**

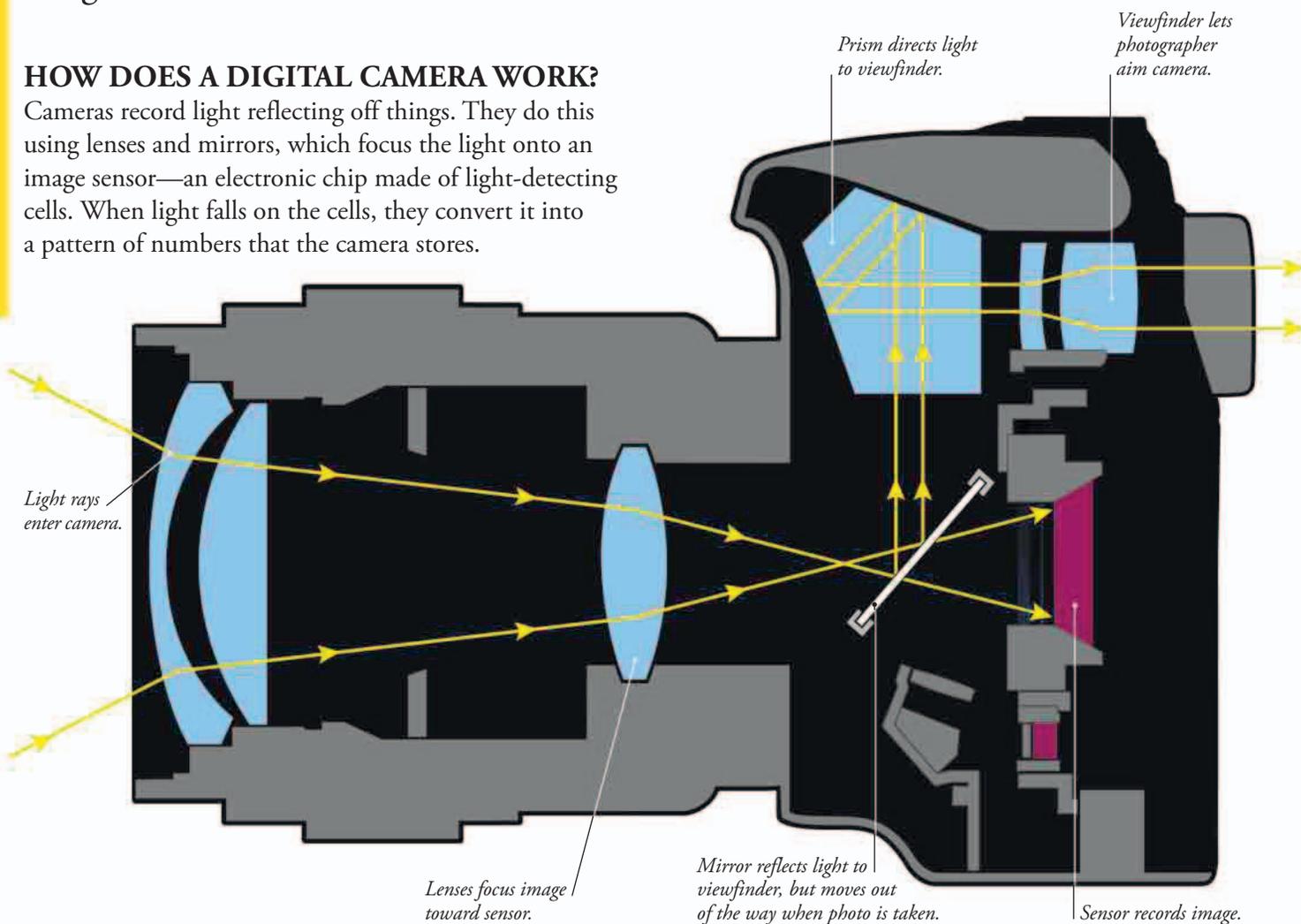
This is one of the four telescopes that make up the Very Large Telescope—one of the world's most powerful stargazers. It uses laser beams to help it aim at distant stars and planets. It is located high in the Atacama Desert in Chile, where the air is thin and clear, and the stars are easier to see.

# Cameras

We see things because light bounces off them and into our eyes, where our brains recognize them. Cameras are like artificial eyes. They can record patterns of light as images and store them for us to look at later. They use lenses to take in light from a wide area and focus it on a small recorder.

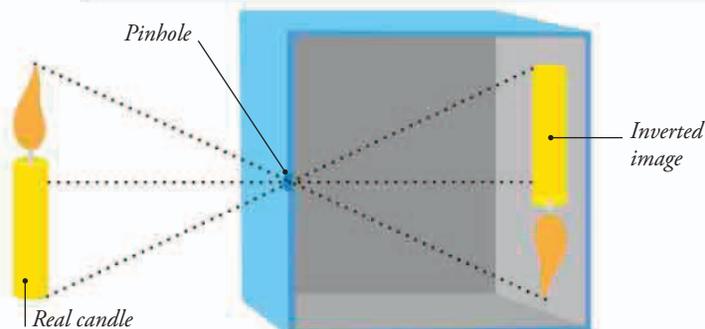
## HOW DOES A DIGITAL CAMERA WORK?

Cameras record light reflecting off things. They do this using lenses and mirrors, which focus the light onto an image sensor—an electronic chip made of light-detecting cells. When light falls on the cells, they convert it into a pattern of numbers that the camera stores.



## PINHOLE CAMERAS

Modern cameras are based on an older invention called the pinhole camera. This is a sealed box with a tiny hole on one side. As light streams through, it makes an upside-down image on the back wall of the box. You can even project an image on the wall of a room by making a tiny hole in the blinds. Pinhole cameras were invented in ancient China, but the first person to understand how they worked was Islamic scientist Alhazen, around 1,000 years ago.



## EARLY PHOTOGRAPHS

Photography was born in 1727 when a German scientist named Johann Schulze found that chemicals containing silver looked different after light shone on them. A century later, photographers were able to capture the first images of the world around them.



► **CAUGHT ON FILM**  
*Frenchman Louis Daguerre made the first practical photographs in 1831. He used silver-coated plates to make detailed pictures called daguerreotypes. This one is thought to be the first photograph of a living person.*



## EXTREME PHOTOGRAPHY

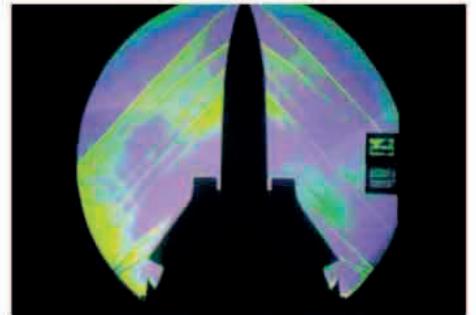
Ordinary snapshots capture the world as we see it, but our eyes cannot see everything. They aren't fast enough to catch things that happen very quickly, or sharp enough to notice very tiny changes. Special photographic techniques can take astonishing pictures that our eyes alone could never see.



▲ **SLOW MOTION** *Cameras can slow things down that happen too fast for our eyes to see. This photo shows what really happens when a balloon full of water bursts.*



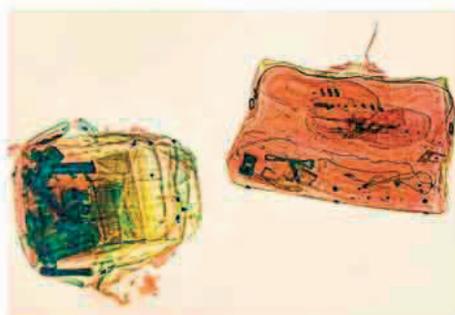
▲ **MACRO** *Powerful lenses can zoom in on the details of microscopic things. Macro lenses make large, detailed close-ups of very small objects, such as these seeds.*



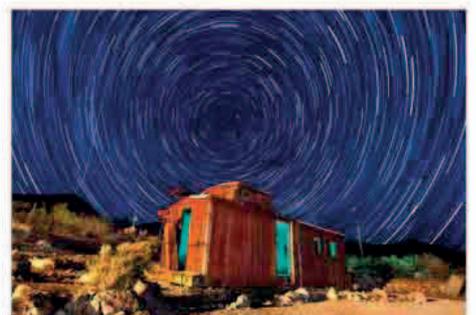
▲ **SCHLIEREN** *Schlieren photos use colored lines to reveal invisible air moving around things. They are used to design more efficient shapes for airplanes and spacecraft.*



▲ **MICROGRAPH** *A photograph taken under a microscope is called a micrograph. With an electron microscope, we can make lifelike 3-D micrographs, such as this photo of algae.*



▲ **X-RAY** *X-rays pass straight through soft materials such as fabric and skin, so they can show the ghostly details inside things, like the contents of these bags.*



▲ **LONG EXPOSURE** *Photos taken over a long time show moving lights as lines. These circles are trails made by stars circling the sky.*

LIGHT



WOW!

Some cameras can take a photo in just 1/8,000th of a second—much faster than the eye can blink.

# Moving pictures

What's it like to be a pirate at sea, to live in the future, or to rocket into space? Movies use tricks of light to show us these exciting stories. A movie is made from many still photographs that flash in front of our eyes very quickly. Our brains merge them together to make realistic moving pictures.

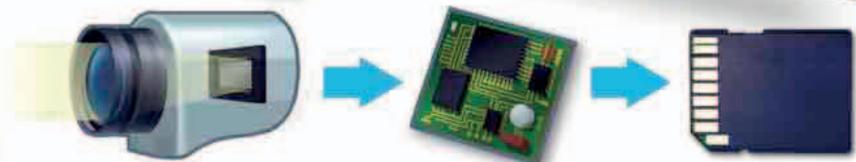
## MOVIEMAKER

An ordinary camera captures one picture at a time. A movie camera takes many pictures, one after another. Old cameras store their pictures on a reel of plastic film. Modern cameras save pictures on memory chips like the ones used in computers.

- ▶ **CAMCORDER** *This portable movie-making machine stores pictures on a memory card. You can watch your movie on the screen and copy it to your computer as well.*



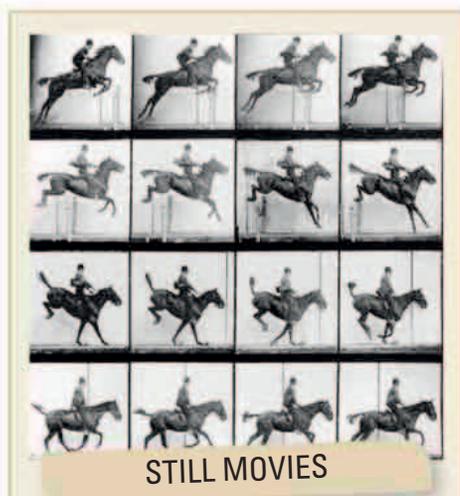
Camera takes 60 pictures every second, and records sound.



1. Camera lens captures light from object.

2. Microchip in camera turns light to numbers.

3. Memory card in camera stores numbers.

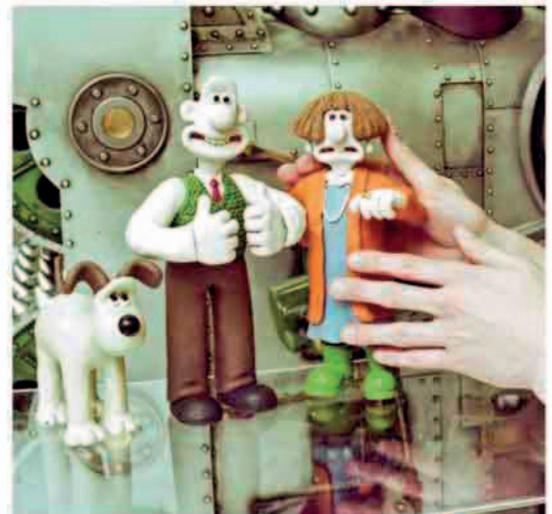


Movies were invented when people found out how to take quick photos, one after another. Often, the photos were printed on a strip. British photographer Eadweard Muybridge made many film strips, including these galloping horses recorded in 1878.

## HANDS-ON MOVIES

Stop-motion is a way of making movies using small models. The models are photographed, then bent into a new position and photographed again. Each second of animation requires 12 photographs, or "frames."

- ▶ **CLAY CHARACTERS** *These characters from the movie A Close Shave (1995) are made of modeling clay, but seem to move on screen.*



## COMPUTER ANIMATION

How can you make a car laugh or a panda dance? You cannot film things that do not exist, but you can draw them on a computer screen and use computer software to turn them into moving pictures. This is called computer-generated imagery (CGI).



◀ **DIGITAL ACTORS** *These characters from Kung Fu Panda (2008) were created and animated on computers.*

WOW!

A full-length stop-motion movie contains up to a million separately photographed frames.

## FLYING IN PLACE

Computer screens create moving pictures in the same way as movies, by flashing lots of still images very quickly. When pilots learn to fly airplanes, they sit in fake cockpits with computer screens all around the walls. As the pilot moves the controls, the view changes as if the airplane were flying.

▼ **HAPPY LANDING** *A pilot practices landing an Airbus A330 plane in a flight simulator in Berlin, Germany. Every detail of the cockpit is copied exactly from a real airplane.*



# Communicating with light

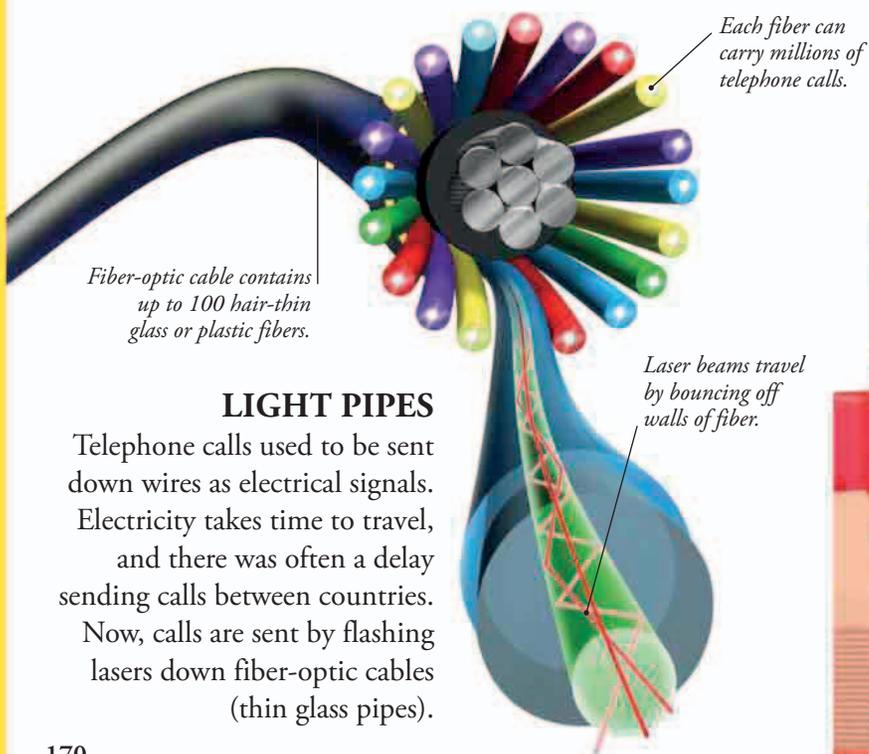
It takes about seven hours to fly from London to New York City. A beam of light can make the same journey more than 50,000 times in less than a second. Nothing travels faster than light, which is why this sparkling form of energy is the perfect way to send messages.

LIGHT



## INSTANT LIGHT

You will see the flash of lightning seconds before you hear the crash of thunder. The sound and the light set off together, but the light travels almost a million times faster than the sound. Light is almost instantaneous. That's why we use light for most forms of communication.



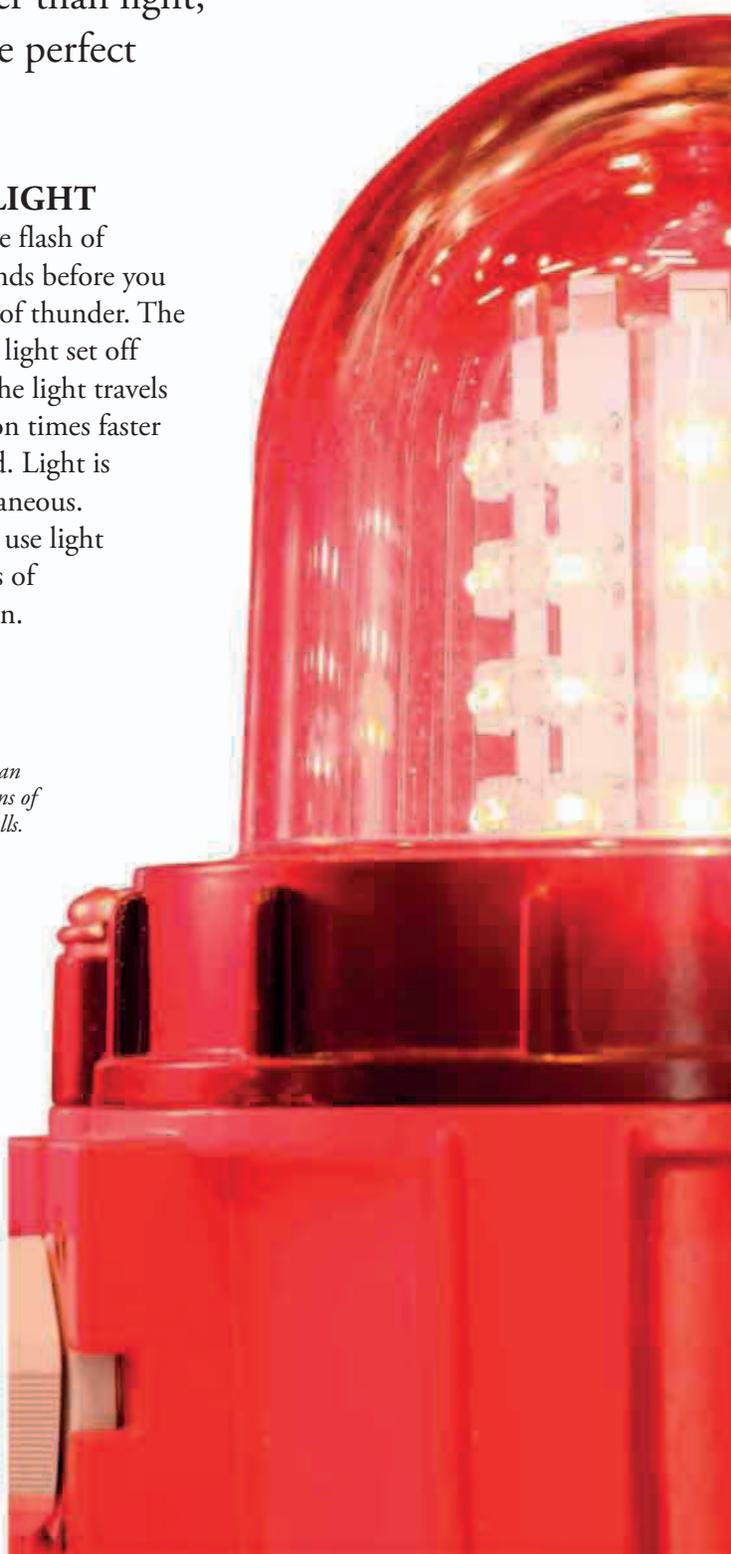
*Fiber-optic cable contains up to 100 hair-thin glass or plastic fibers.*

*Each fiber can carry millions of telephone calls.*

*Laser beams travel by bouncing off walls of fiber.*

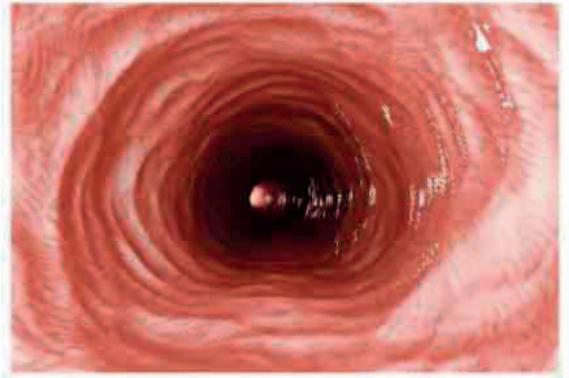
## LIGHT PIPES

Telephone calls used to be sent down wires as electrical signals. Electricity takes time to travel, and there was often a delay sending calls between countries. Now, calls are sent by flashing lasers down fiber-optic cables (thin glass pipes).



## JOURNEY INTO YOUR BODY

It can be hard for a doctor to see why someone is sick if the problem is hidden deep inside their body. Endoscopes solve this problem. They are cameras with long, flexible fiber-optic cables attached. The cable is poked inside the patient, and light shines down it. The light then reflects up a second cable, sending back a clear picture that the doctor can see.



▲ **DOWN THE TUBES** *Your esophagus (the tube from your throat to stomach) looks like this through an endoscope.*

## SIGNALING WITH LIGHT

Light is the oldest way of communicating. Before telephones or the Internet, people sent messages between towns by lighting huge fires (beacons). Before radio, armies could send signals by reflecting the sun off mirrors. Although this might seem slow, these signals race to your eyes at the speed of light.

◀ **EMERGENCY LIGHT** *This signaling light uses dozens of small light-emitting diodes (LEDs) to make a single powerful beam.*



WOW!

A beam of light can leap the 90 million miles (150 million km) from the sun to Earth in just over 8 minutes.

LIGHT



## GLOWING CREATURES

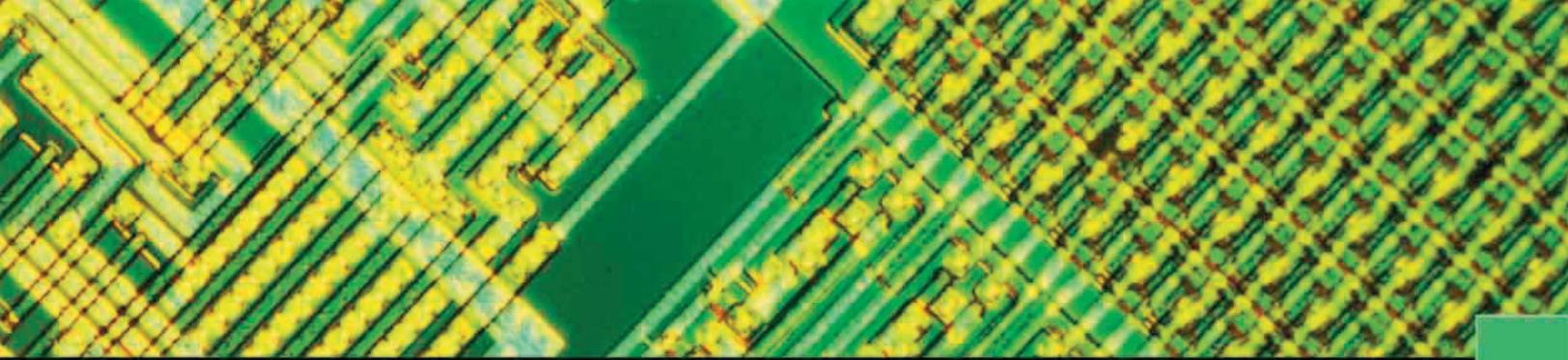
Sound might be important to humans, but for the rest of the natural world light and color are much more important forms of communication. Some animals can create light inside their bodies to scare away predators. Fireflies glow in the dark to attract a mate. Squid can change color to show their mood.

▲ **FLASHING FISH** *Jellyfish are bioluminescent. They make flashes of blue light inside their bodies to scare off predators.*

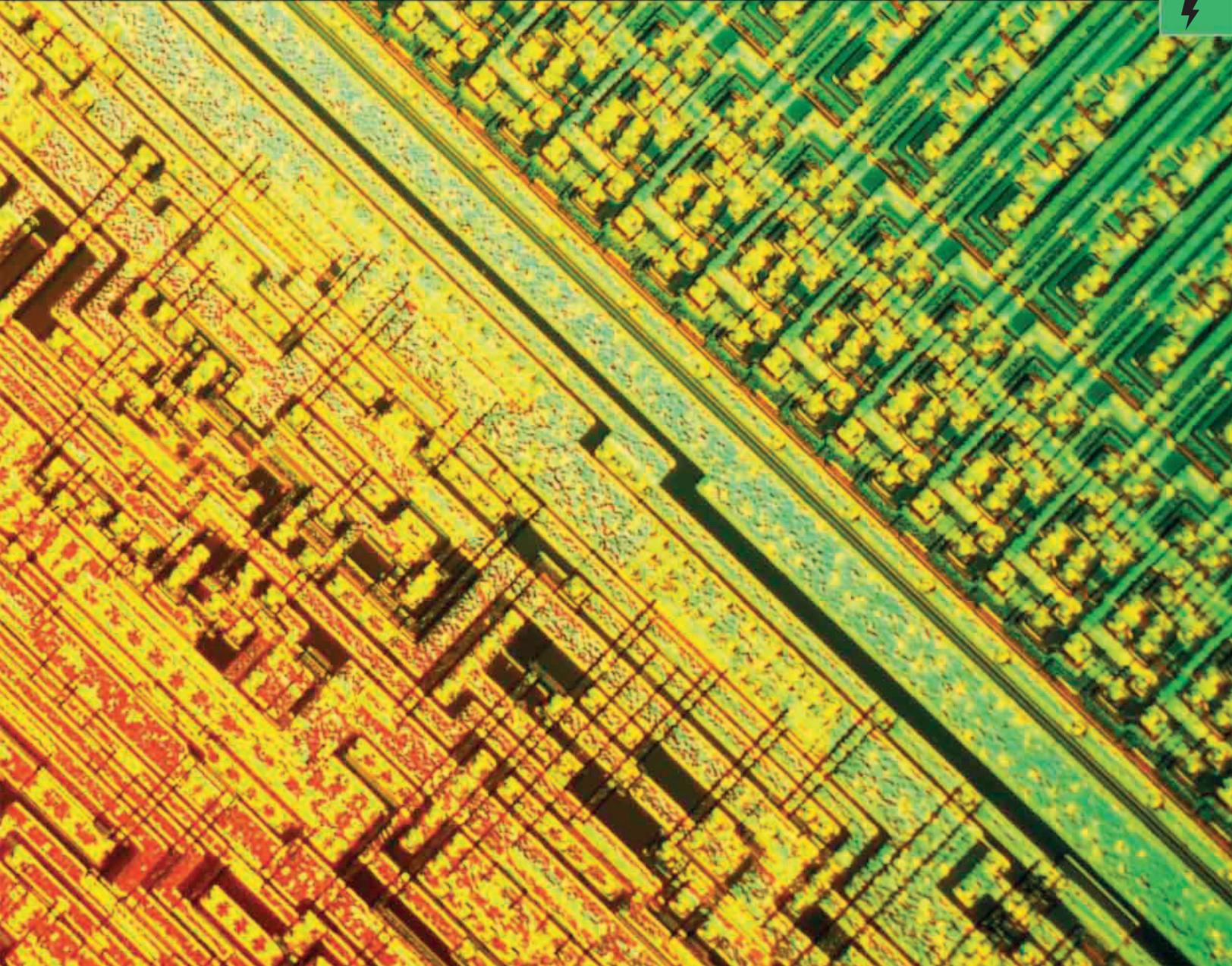
# ELECTRICITY AND MAGNETISM

## **MAGNIFIED MICROCHIP**

Computer chips use electricity to record information and perform mathematical calculations. They do this by using millions of tiny switches, which are so small they can only be seen under a microscope.



Electricity floods your home with light, while magnetism can pick up cars or stick things to your refrigerator. Working together, they can create amazing tools, from motors to supercomputers.



# Electricity

Everything electrical is powered by tiny electrons, the particles that whirl around atoms. In ancient times, no one really understood electricity or how it could be used. Now, we know electricity is created when electrons gather together or zip from place to place. Electricity can help us do all kinds of things, from powering trains to catching criminals.

## WHAT IS ELECTRICITY?

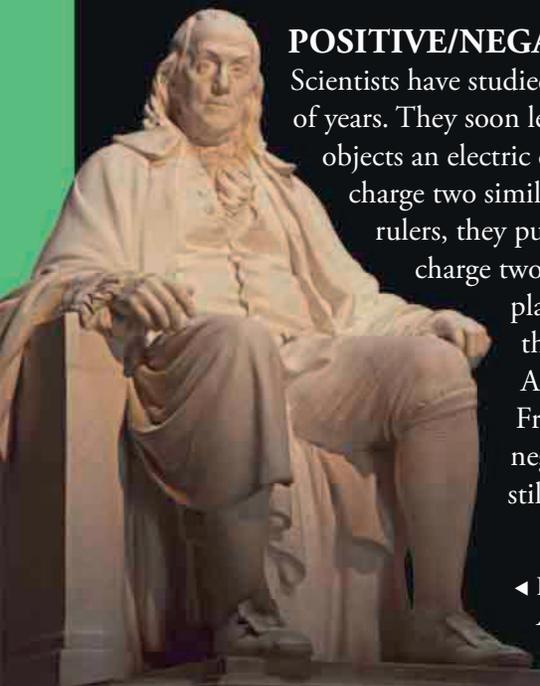
Electricity is energy caused by electrons. When electrons gather in one place, they make static electricity (the kind that crackles in your sweater when you take it off). When electrons move around, they make current electricity. This is what powers things like vacuum cleaners and flashlights.

► **LEAPING LIGHTNING** *During a storm, clouds rub through the sky, and build up static electricity. When the clouds have too much charge to hold on to, they release it through lightning bolts (current electricity), which crash down to the earth.*

## POSITIVE/NEGATIVE

Scientists have studied electricity for hundreds of years. They soon learned that you could give some objects an electric charge by rubbing them. If you charge two similar objects, such as two plastic rulers, they push away from each other. If you charge two different objects, such as a plastic ruler and a glass ruler, they pull toward each other. American scientist Benjamin Franklin called this positive and negative electrical charge, and we still use those labels today.

◀ **BENJAMIN FRANKLIN** *This American scientist studied electricity in the 18th century and made several important discoveries.*



Lightning branches out like a tree as the electricity in a cloud tries to find the quickest way down to earth.

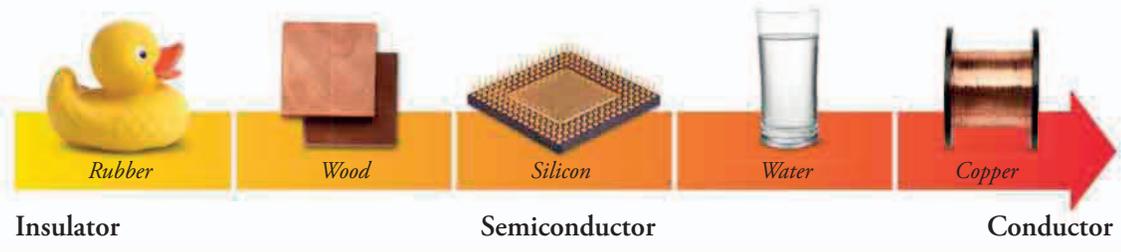


### FLOATING TRAINS

Scientists have discovered that some substances conduct electricity perfectly. None of the electrical energy is lost passing through them. These are called superconductors, and they can be used to create incredibly strong magnets. The world's fastest trains use these powerful magnets to float above the surface of the track, so there is no friction to slow them down.

### CONDUCTORS AND INSULATORS

We use copper to make electrical wires because metals such as copper carry electricity very well. They are good conductors, which means electricity can go through them easily. Other materials, such as rubber and plastic, stop electricity from going through. These are called insulators. Electrical wires are made of good conductors, but often have insulators wrapped around them to protect us from electric shocks. Semiconductors are substances that can conduct or block electricity at different times, making them useful in electronics.



Dusting powder with a very fine brush reveals hidden fingerprints without destroying them.



**WOW!**

There is enough electric power in a lightning bolt to boil water for 50,000 cups of coffee.

### ELECTRIC FINGERPRINTS

When criminals leave fingerprints, they also leave electricity. Fingerprints contain proteins that have a positive electric charge. Detectives can find prints by sprinkling them with gold dust, which has a negative electric charge. The opposite charges attract, the gold sticks to the proteins, and the hidden fingerprints become visible.

► **DUSTING FOR PRINTS** *Forensic scientists (people who apply scientific knowledge to solve crimes) use the power of static electricity to find fingerprints hidden on everyday objects.*

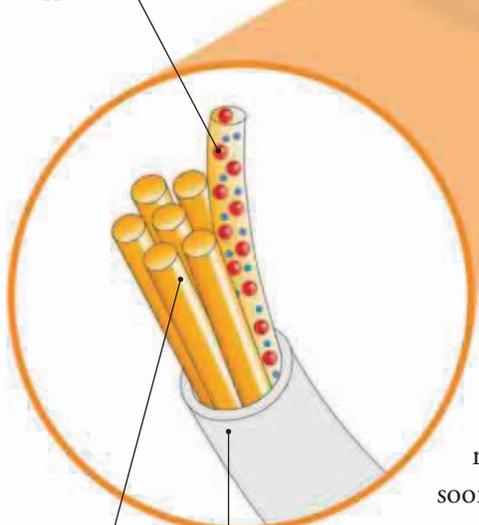
# Circuits and current

To make electricity do useful things, we have to push it around a loop. This is a circuit—the secret power behind everything electrical in your home. The looping electricity is called a current, and the force that pushes it is a voltage. Sometimes the voltage is made by a battery, but in our homes it also comes through sockets carrying electricity from power plants.

## GO WITH THE FLOW

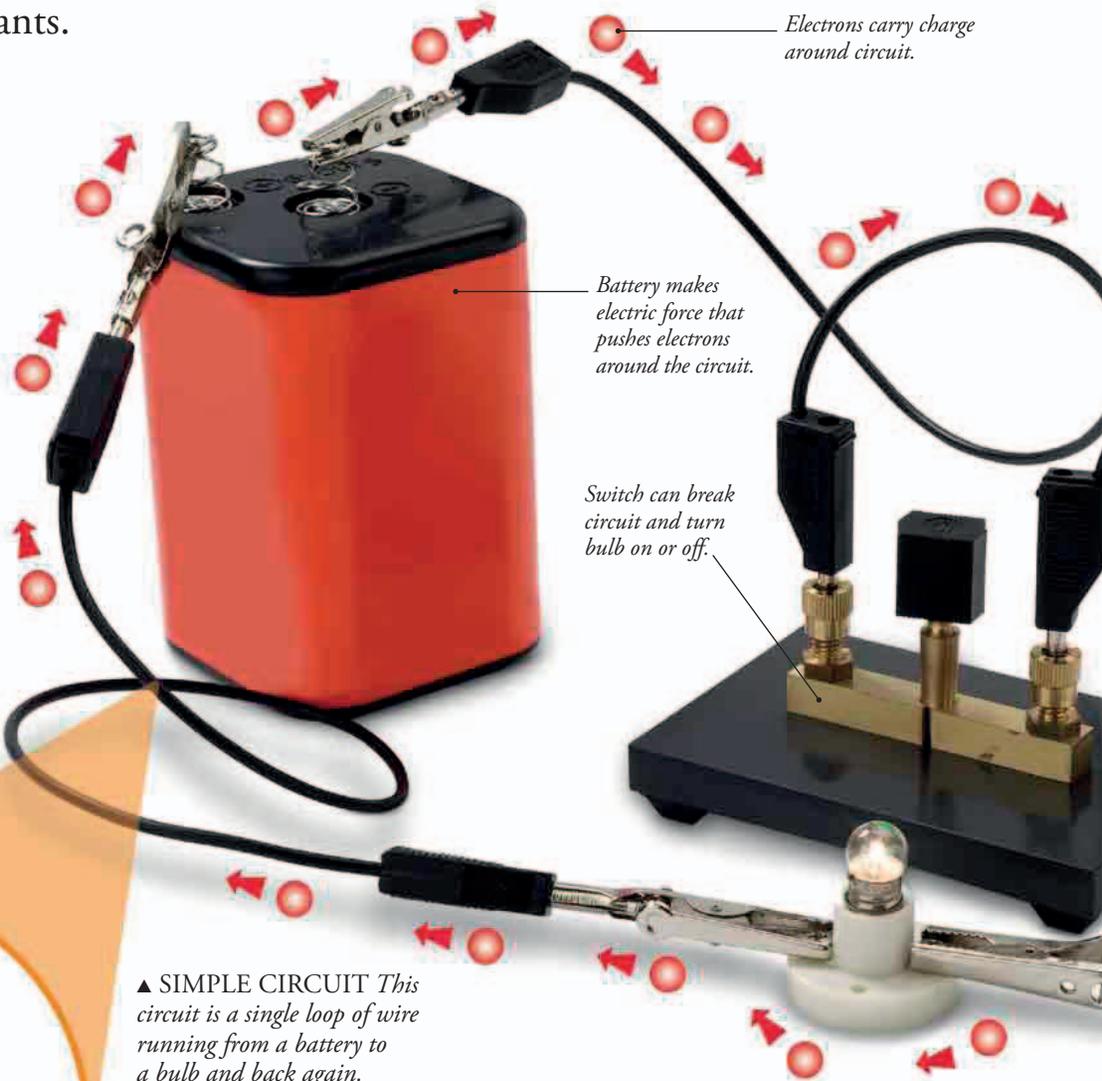
Electric things work when current flows through their circuits. A current is really a flow of electrons, zipping down a wire like water flowing down a pipe. The main purpose of a circuit is to transport energy. The energy flows from a battery (or other power source), around the wire, to a device such as a light bulb or electric motor.

*Electric current is carried by electrons flowing through copper wire.*



*Multiple copper wires inside cable*

*Rubber insulation stops electricity from passing to surrounding objects.*



*Electrons carry charge around circuit.*

*Battery makes electric force that pushes electrons around the circuit.*

*Switch can break circuit and turn bulb on or off.*

▲ **SIMPLE CIRCUIT** *This circuit is a single loop of wire running from a battery to a bulb and back again.*

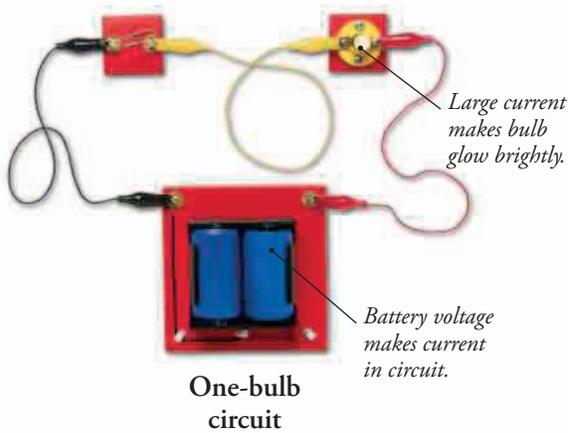
## INSTANT ELECTRICITY

The power plant that supplies your home might be far away, but your lights come on as soon as you flip a switch. There is no waiting for electricity. It's like turning on a faucet—the pipes are already full, so water comes out at once. In the same way, wires in your home are already full of electrons that flow through instantly.

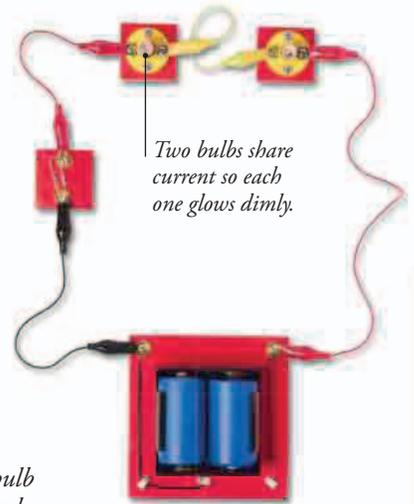


## VOLTAGE AND CURRENT

Voltage pushes current around a circuit. The bigger the voltage, the bigger the current. Electric things that work harder need higher voltages and currents. An electric stove needs a much bigger voltage and current than a cell phone. Similarly, a phone needs more voltage and current than a flashlight.



**One-bulb circuit**

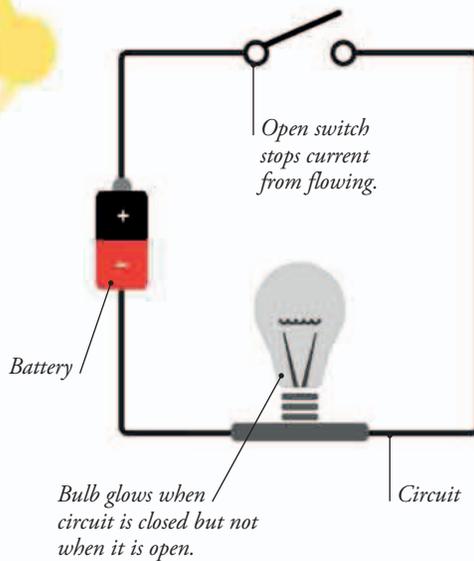
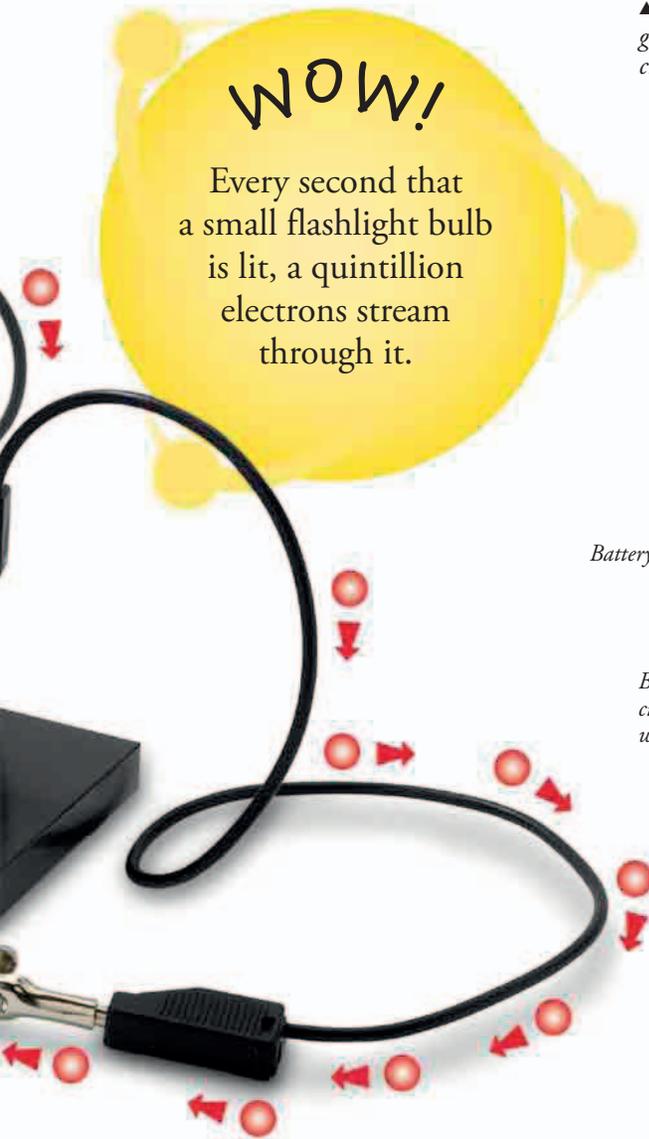


**Two-bulb circuit**

▲ **CURRENT FLOW** In the first circuit, the bulb glows brightly as it gets more current. In the second circuit, the two bulbs share the current and are dimmer.

**WOW!**

Every second that a small flashlight bulb is lit, a quintillion electrons stream through it.

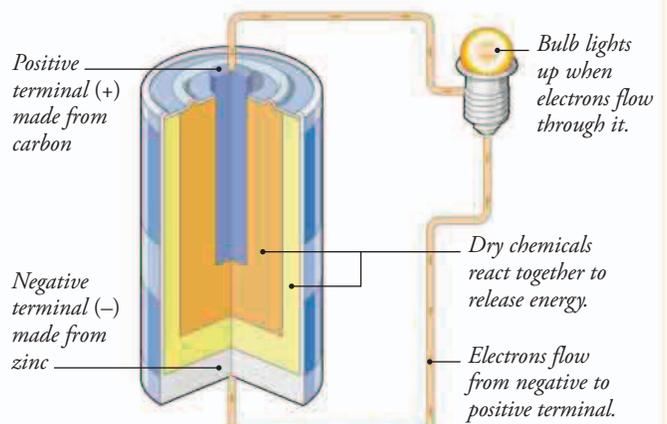


## SWITCHES

You don't want your teapot boiling all day long or your television blaring out at night. Switches help us turn circuits on and off when we need to. They work just like bridges, allowing current across when they are closed and stopping it from flowing when they are open.

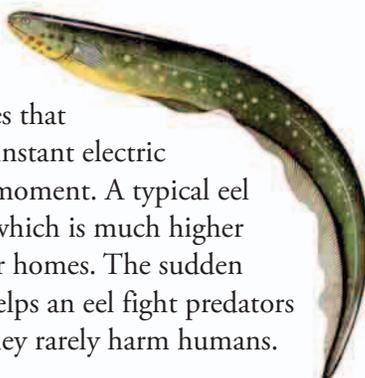
## BATTERIES

Batteries are like miniature power plants you can carry around. Inside, they are packed full of chemicals. When you connect batteries to a circuit, the chemicals react together and make electricity. A battery will keep making electricity for as long as the chemicals last.



## ELECTRIC EEL

Electric eels are like batteries that can swim—they can make instant electric current, though only for a moment. A typical eel can make up to 600 volts, which is much higher than the voltage used in our homes. The sudden crack of an electric shock helps an eel fight predators and stun its prey, though they rarely harm humans.



# Static electricity

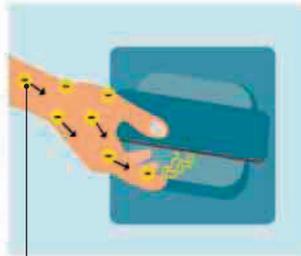
Whenever you see lightning leaping to the earth, you are watching a sudden zap of static electricity. This is the kind of electricity that happens when many electrons gather in one place. No one has yet managed to figure out how to capture lightning, but static electricity has plenty of other uses. It can power photocopiers and printers, and scrub black smoke from chimneys.



1. As you rub on a car seat, electrons flow from the seat to your body.



2. The electrons cling to your clothes and body, even when you get out of the car.



3. When you touch the metallic handle, the electrons can flow into it, giving you a shock.

## SHOCKING STUFF

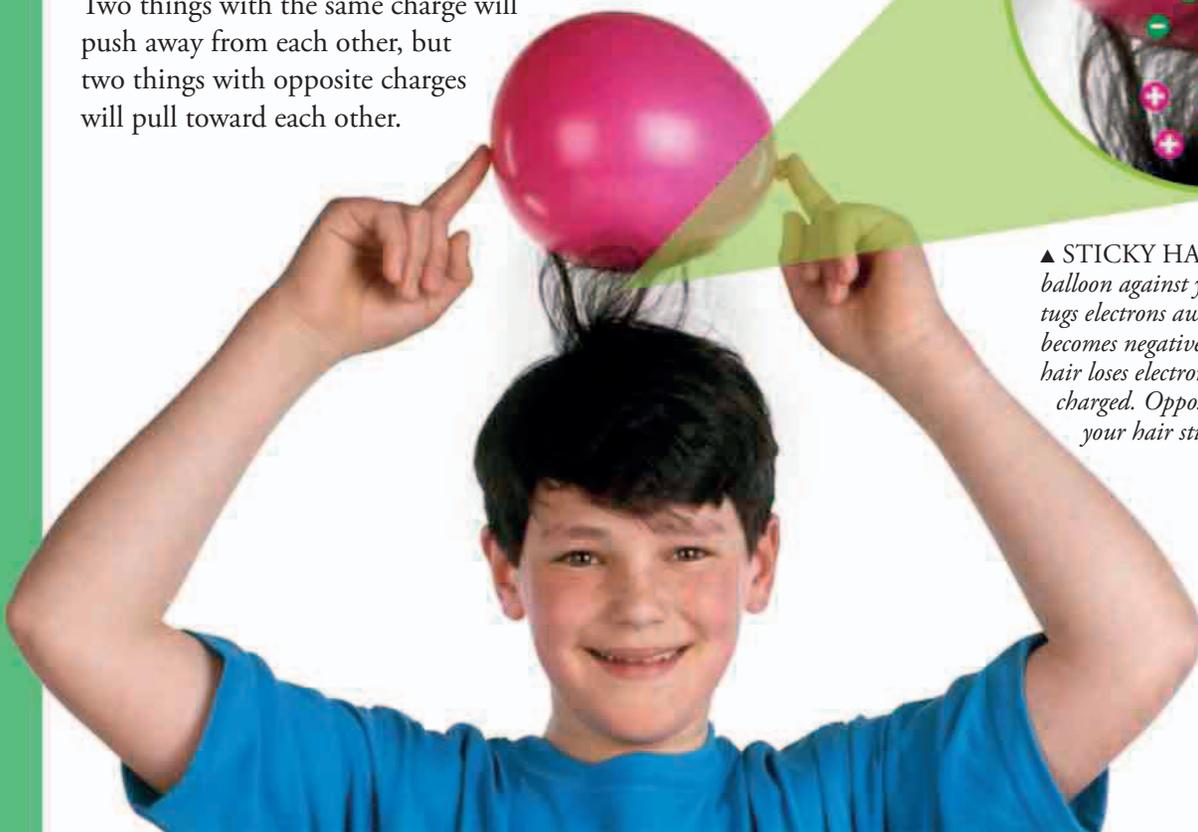
Have you ever gotten a tiny shock when you touched a door handle? It happens because your body builds up static as it rubs against things. The static stays on you until you touch something metal. Then it moves from your body, through the metal, to the earth—giving you a shock.

## HAIR-RAISING

Electrons are little particles of negative electric charge. Some substances can take on more electrons by rubbing against things. Taking on more electrons makes them negatively charged, while the object that loses electrons becomes positively charged. Charged objects can create forces. Two things with the same charge will push away from each other, but two things with opposite charges will pull toward each other.



▲ **STICKY HAIR** When you rub the balloon against your hair, the rubber tugs electrons away, so the balloon becomes negatively charged. Since your hair loses electrons, it becomes positively charged. Opposite charges attract, so your hair sticks to the balloon.



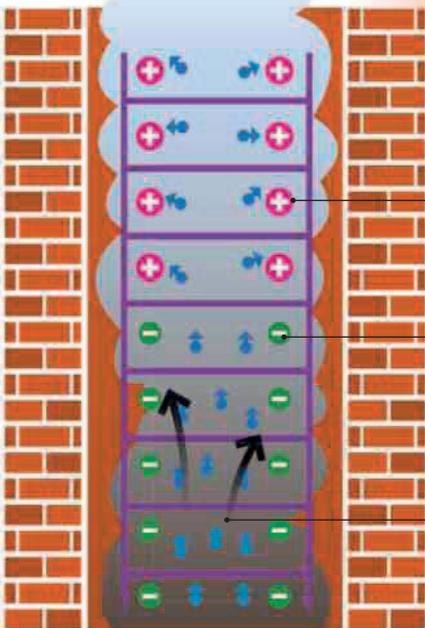
## CAN YOU SEE ELECTRICITY?

Magnets make invisible patterns around them, called magnetic fields. When static electricity builds up, it makes a similar pattern called an electric field. If you rub a balloon to give it a static charge, an electric field forms around it. If you put tiny pieces of paper nearby, they are inside the balloon's electric field, so they get "sucked" toward it by force and stick to it.

► **BLOOD TEST** *Electric fields can be used to test people's blood for diseases. Doctors put the blood on a special microscope slide and dip an electric wire into it. The wire creates an electric field that draws patterns in the blood. The colors show if the patient is healthy or ill.*

*Electric field separates colorful chemicals out from the blood.*

*Clean white smoke comes out of chimney.*

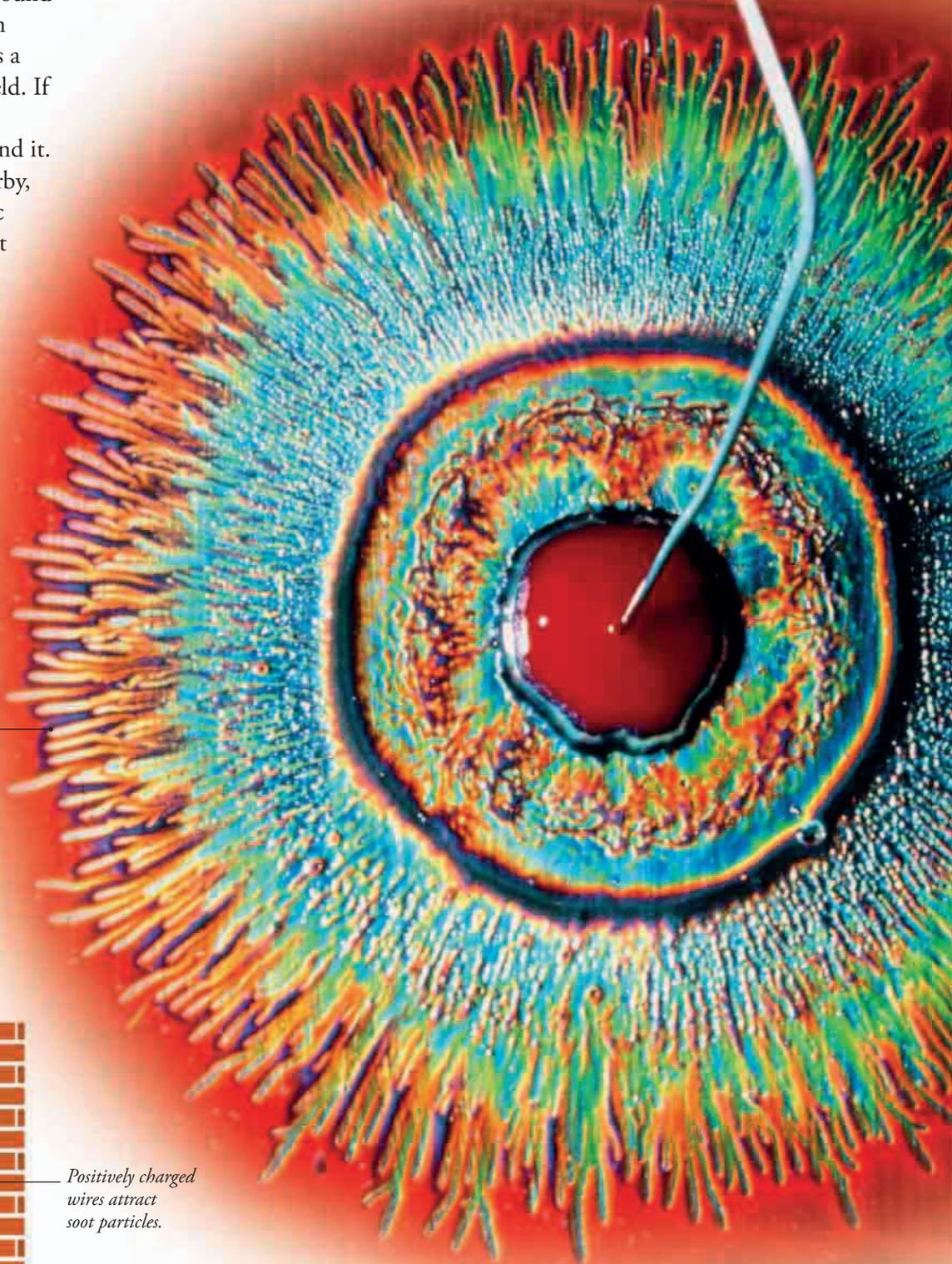


*Positively charged wires attract soot particles.*

*Electric wires give soot a negative charge.*

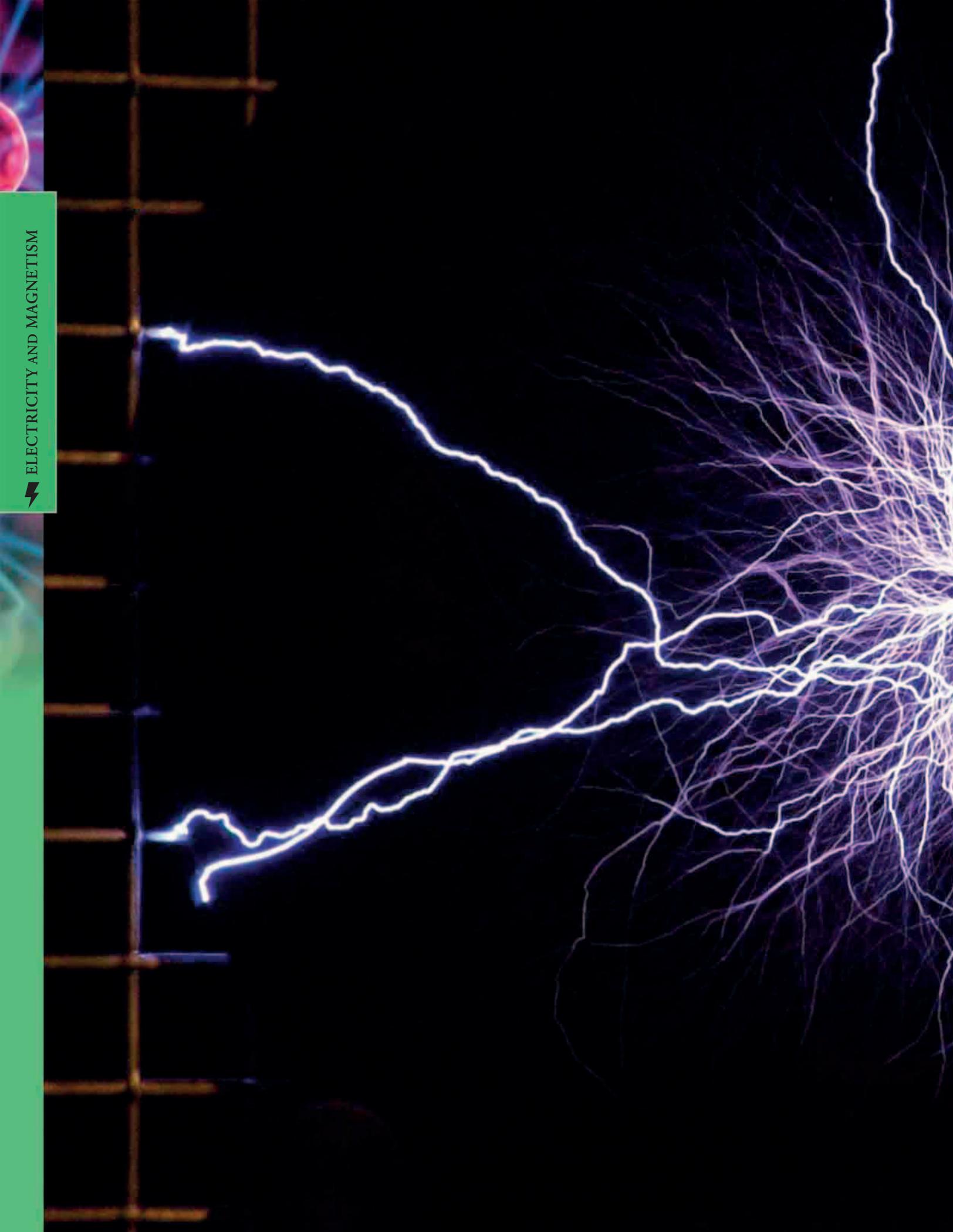
*Black smoke enters bottom of chimney.*

*Wire carries electric current.*

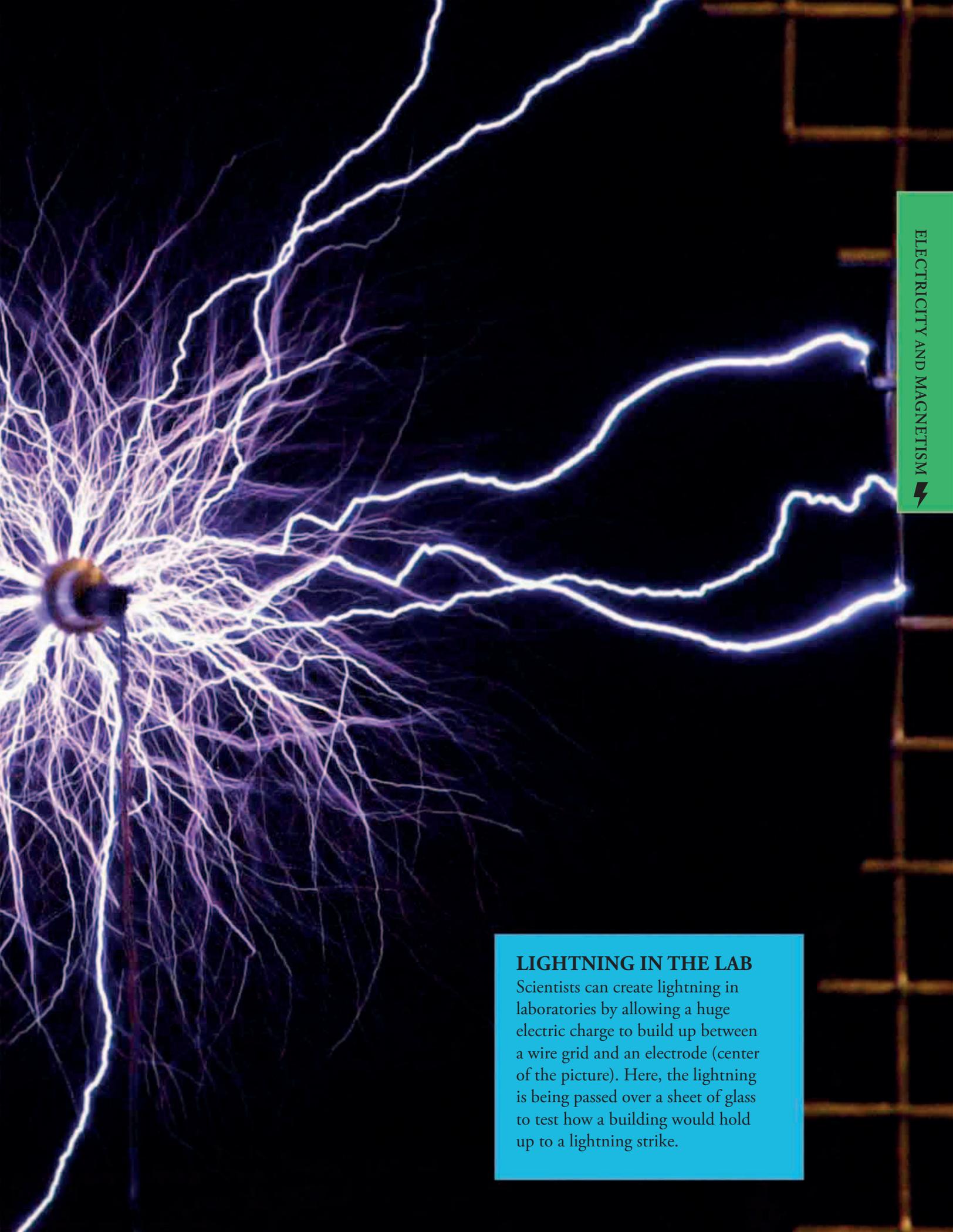


## SMOKE SCRUBBERS

Static electricity can be used to clean filthy smoke in chimneys. The smoke flows over electric wires, so the soot particles inside it pick up a negative electrical charge. Higher up in the chimney, there are more wires with an opposite, positive electrical charge. The negative soot particles cling to these positive wires, cleaning the dirt from the smoke.



⚡ ELECTRICITY AND MAGNETISM

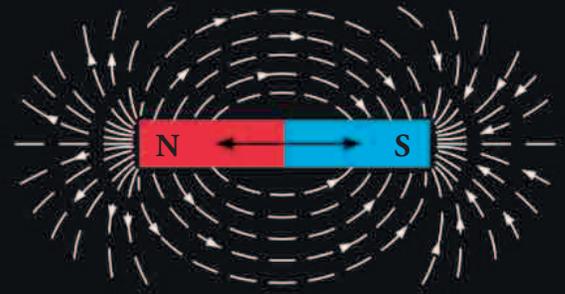


### **LIGHTNING IN THE LAB**

Scientists can create lightning in laboratories by allowing a huge electric charge to build up between a wire grid and an electrode (center of the picture). Here, the lightning is being passed over a sheet of glass to test how a building would hold up to a lightning strike.

# Magnetism

Magnetism is a hidden force, caused by electrons inside the atoms from which all things are made. You stick to the ground partly because you are a little bit magnetic, and Earth is like a giant magnet. You don't notice the magnetism between Earth and your body because gravity is stronger. For small things, magnetism can be much stronger than gravity—that's why magnets cling to your refrigerator.

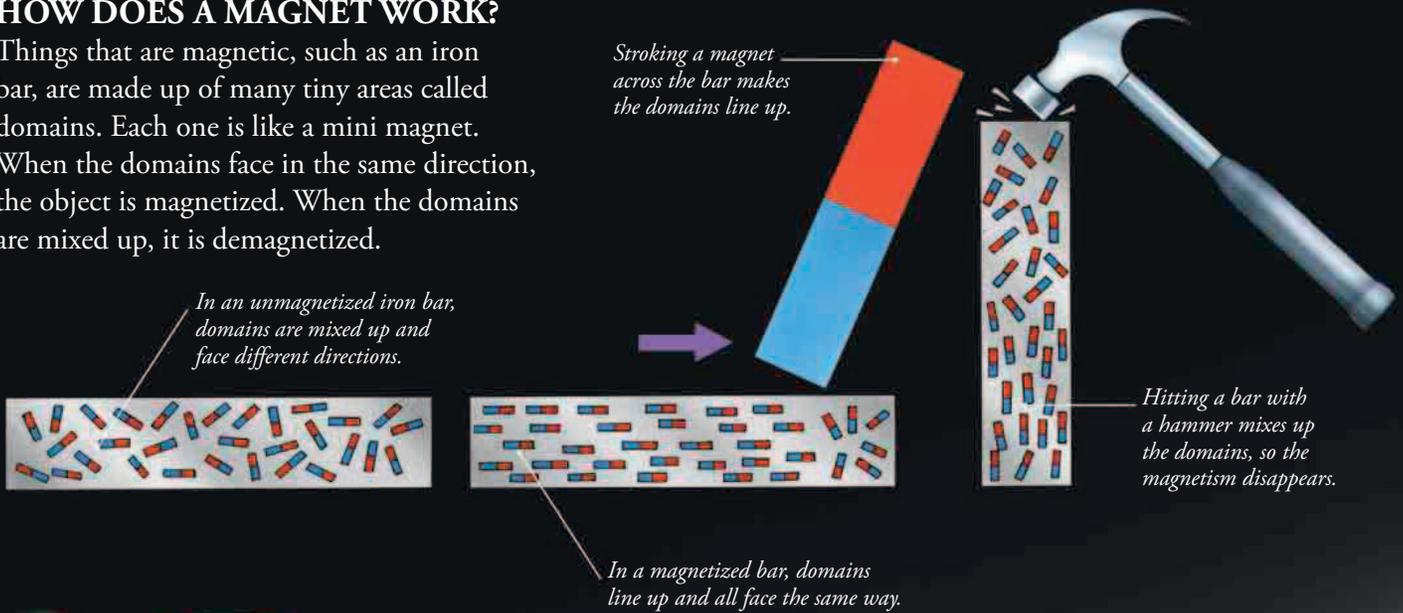


## MAGNETIC FIELD PATTERNS

Magnets have two ends—a north pole (N) and a south pole (S). A magnetic field (invisible pattern of magnetism) curves from north to south. Put a nail in this field and it is pulled toward the magnet.

## HOW DOES A MAGNET WORK?

Things that are magnetic, such as an iron bar, are made up of many tiny areas called domains. Each one is like a mini magnet. When the domains face in the same direction, the object is magnetized. When the domains are mixed up, it is demagnetized.



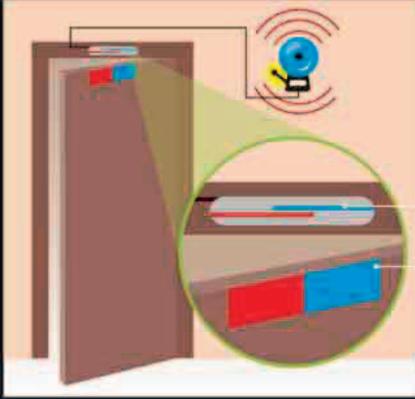
WOW!

Some bacteria are magnetic. Scientists have used magnets to steer these bacteria around to build microscopic walls.

▼ **NORTHERN LIGHTS** *These strange green patterns swirl in the sky close to the North Pole. They happen when particles shooting from the sun are pulled by Earth's magnetism, crashing into our atmosphere to make light.*

## MAGNETIC SWITCHES

Magnets can catch burglars. A magnet sits on the door, and a magnetic switch sits on the frame. When the door closes, the magnet pushes apart two contacts in the switch. When the door opens, the switch moves away from the magnet and the contacts spring together. This completes a circuit and the alarm rings.



*Magnetic contacts in the switch are pushed apart when the door is closed.*

*When the magnet moves away, the contacts spring back together.*

## EARTH THE MAGNET

Molten matter swirling inside Earth's core creates a magnetic field all around us. It's as though there is a huge but very weak magnet hiding inside our planet.

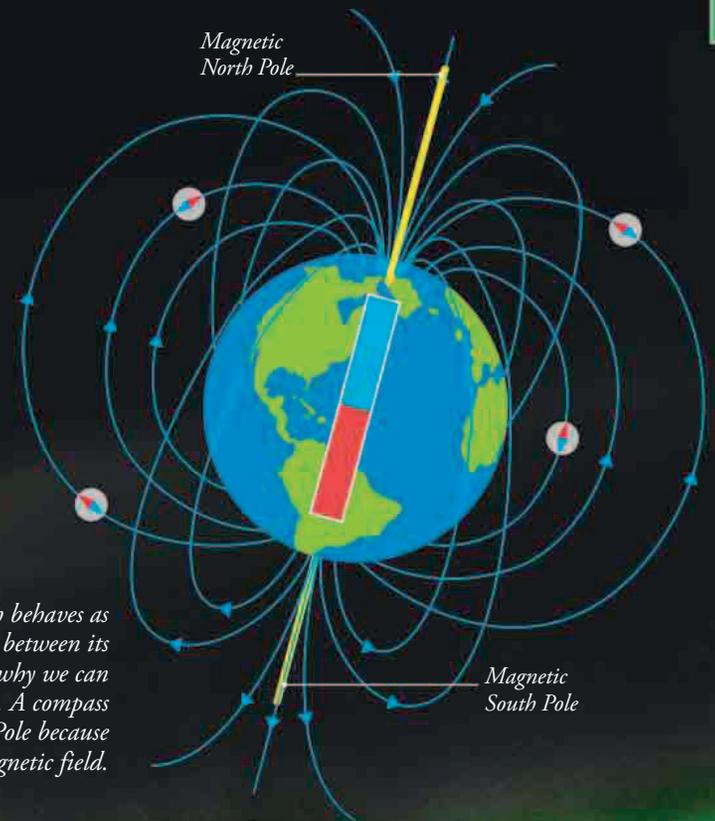
► **FINDING YOUR WAY** *Earth behaves as if there is a giant invisible magnet between its North and South Poles. That's why we can find our way using a compass. A compass points toward Earth's North Pole because it is attracted by Earth's magnetic field.*

## HOW STRONG IS THAT MAGNET?

Magnets come in all sizes. We can make magnets out of ceramics or metal, like the ones you find on your refrigerator. We can also create powerful magnets using electricity (see pp.184–185). Our bodies contain tiny amounts of iron, so we work like very weak magnets. The Earth is a giant magnet, but its magnetism is spread out through the whole planet. The strongest magnetic forces occur inside atoms, but only over very tiny distances.

Magnet strengths compared to an ordinary bar magnet.

OBJECT	STRENGTH
Electromagnet	500
Ceramic magnet	2
Bar magnet	1
Human body	1/50 million

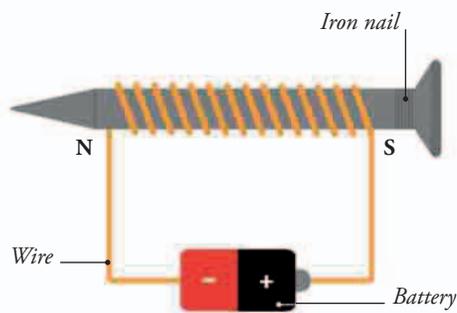


# Electromagnetism

When your doorbell rings, the noise you hear is made by a quick burst of magnetism and electricity. Many people think electricity and magnetism are separate things, but really they are like two sides of the same coin. We call this electromagnetism, and it has important uses in our daily lives.

## HOW DO YOU MAKE AN ELECTROMAGNET?

When electric current flows down a wire, it makes invisible magnetism all around it. If you bend the wire into a spiral and wrap it around a nail, the nail becomes an electrically powered magnet—an electromagnet. Other electromagnets work just like this but on a larger scale.



▲ **SIMPLE ELECTROMAGNET**  
You can make an electromagnet by wrapping plastic-coated wire around a nail and attaching it to a small battery.

## WHAT IS ELECTROMAGNETISM?

Both electricity and magnetism are made by the electrons inside atoms. When electricity changes, it makes magnetism.

When magnetism changes, it makes electricity. To make magnetism powerful enough to lift things, you need many coils of electric wire and a big electric current.

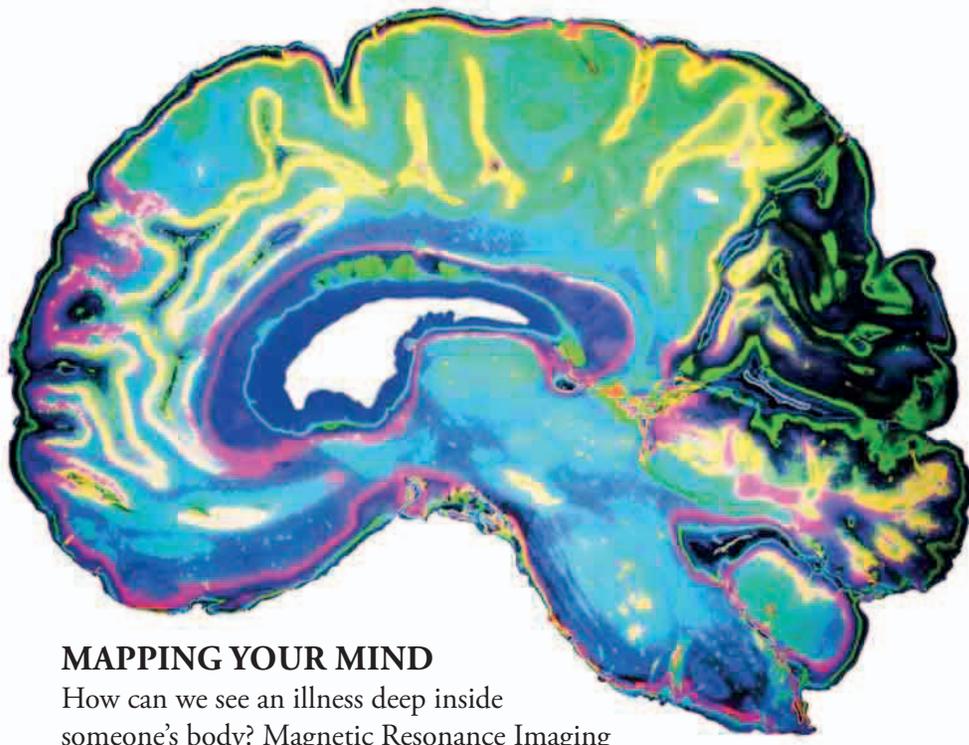
► **JUNKYARD SWING** *This giant crane lifts metal with an electromagnet. When the electricity is turned on, the metal sticks. When it's turned off, the metal falls away.*

WOW!

A tiny refrigerator magnet is 20 times more powerful than the magnetism made by our huge planet Earth.

Electromagnet attracts magnetic metal parts when current is switched on.

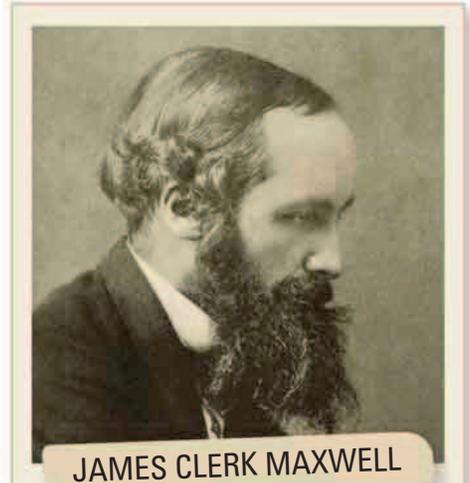




### MAPPING YOUR MIND

How can we see an illness deep inside someone's body? Magnetic Resonance Imaging (MRI) scanners use electromagnets to excite the body's atoms. This makes them form magnetic patterns that a computer can see and draw on a screen. Doctors can examine these scans to pinpoint diseases and save lives.

▲ BRAIN SCAN *This is what the cross section of a person's brain looks like through an MRI scanner.*



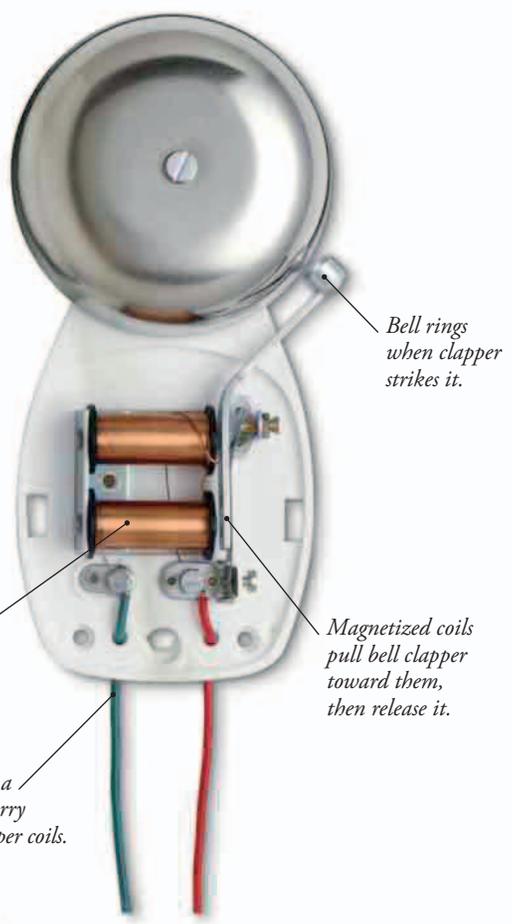
JAMES CLERK MAXWELL

Electromagnetism was always there, waiting to be discovered. The first person to understand it properly was Scottish scientist James Clerk Maxwell. In 1865, he wrote four simple rules explaining how electricity could produce magnetism and vice versa.

### YOUR ELECTROMAGNETIC HOME

There are dozens of electromagnets in your home. They're in your doorbell and your telephone. They're in your radio and television, and in the loudspeakers and microphones in your stereo. You can also find them in low-energy light bulbs, battery chargers, and burglar alarms. In fact, they are all around you.

► ELECTRIC DOORBELL *Two orange coils of copper wire turn into electromagnets when electricity flows through them. They pull on the clapper that rings your bell.*

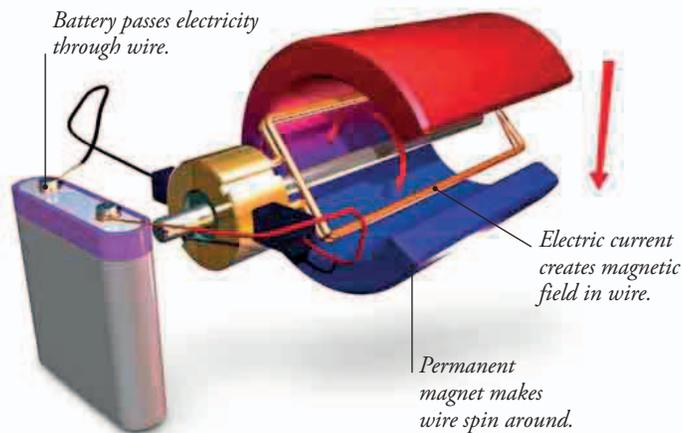


# Electric motors and generators

When electrons pass through a wire, they can power anything from a toy car to a huge train. Electric motors hold the secret to this trick—they turn electrical energy into kinetic energy (pp.128–129). Machines called generators work in the opposite way from motors. They turn kinetic energy into electricity. All of the electricity we use comes from generators.

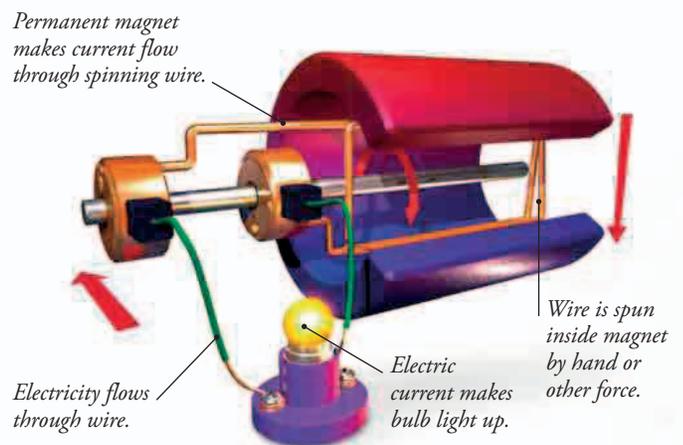
## WHAT IS AN ELECTRIC MOTOR?

An electric motor is a loop of wire sitting inside a piece of magnetic metal (a permanent magnet). When the wire is connected to an electricity supply, a magnetic field forms around it. Force from the permanent magnet pushes against the magnetized wire, spinning it around.



## WHAT IS A GENERATOR?

Electricity generators are almost identical to motors but work in exactly the opposite way. If you spin a piece of wire inside a magnet, electricity flows through it. The longer you spin the wire, the more electricity you can make.



## LINEAR MOTOR

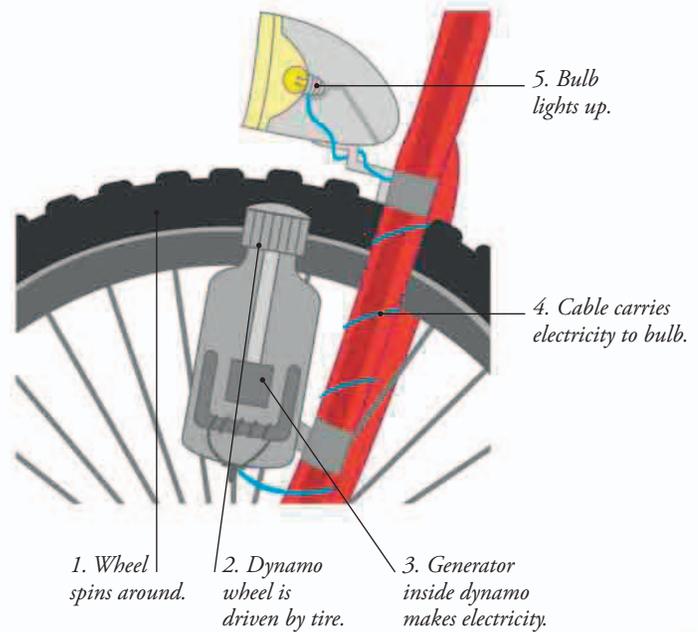
Electric motors make things turn in circles, so they are perfect for powering washing machines or food processors. Some machines need to go in straight lines, not circles, so they use a linear motor instead. This is like a normal motor cut open and laid out flat. One part of the motor slides past the other, gliding down a long, straight track.



► **ROCKET LAUNCHER** *In the future, linear motors could fire rockets into space. This test shows a small model rocket on a linear motor track.*

## PEDAL POWER

Bicycle dynamos are like miniature power plants strapped to your bike. As you cycle along, your tire presses against a tiny wheel on the dynamo, spinning it around. Inside the dynamo, there is a small electricity generator. This makes enough electric current to feed the bulb in your headlight.



## PUMPING OUT POWER

Hydroelectric power plants use the force of a rushing river to make electricity. The river is blocked by a vast concrete dam, then slowly allowed to escape through a pipe at the bottom. The pipe fires the river water at a windmill-like propeller, called a water turbine. The turbine spins a huge generator and produces vast amounts of electricity.

▼ **WATER POWER** *The Hoover Dam in the United States uses 11 giant water turbines and generators to make as much electricity as a large coal or nuclear power station.*

**WOW!**

The Hoover Dam, on the Colorado River between Arizona and Nevada, can make as much power as half a million bicycle dynamos.



# Using electricity

In ancient times, people had to burn substances such as wood or coal to get heat and light energy for cooking and keeping warm. In our modern homes, we can just flip a switch to release electrical energy whenever we need it. Our homes are buzzing with electricity. Running through the walls and the ceiling, hidden wires conduct power to every room.

## HOW DOES AN ELECTRIC LIGHT WORK?

Old-fashioned light bulbs create light by making heat. They squeeze a large electric current through a narrow, twisted wire called a filament. As the current flows, the filament gets so hot that it glows brightly and gives off light. This wastes a lot of energy as heat. More modern lights save energy by using cold, fluorescent tubes and light-emitting diodes (LEDs).



◀ **FILAMENT LIGHT** *The filament is made of hard tungsten metal. It is covered by a glass bulb filled with argon gas to stop it from burning, so it lasts longer.*



*White phosphor coating turns energy into visible light.*

*Tube is filled with mercury vapor.*

*Electrons release energy when they hit mercury vapor.*

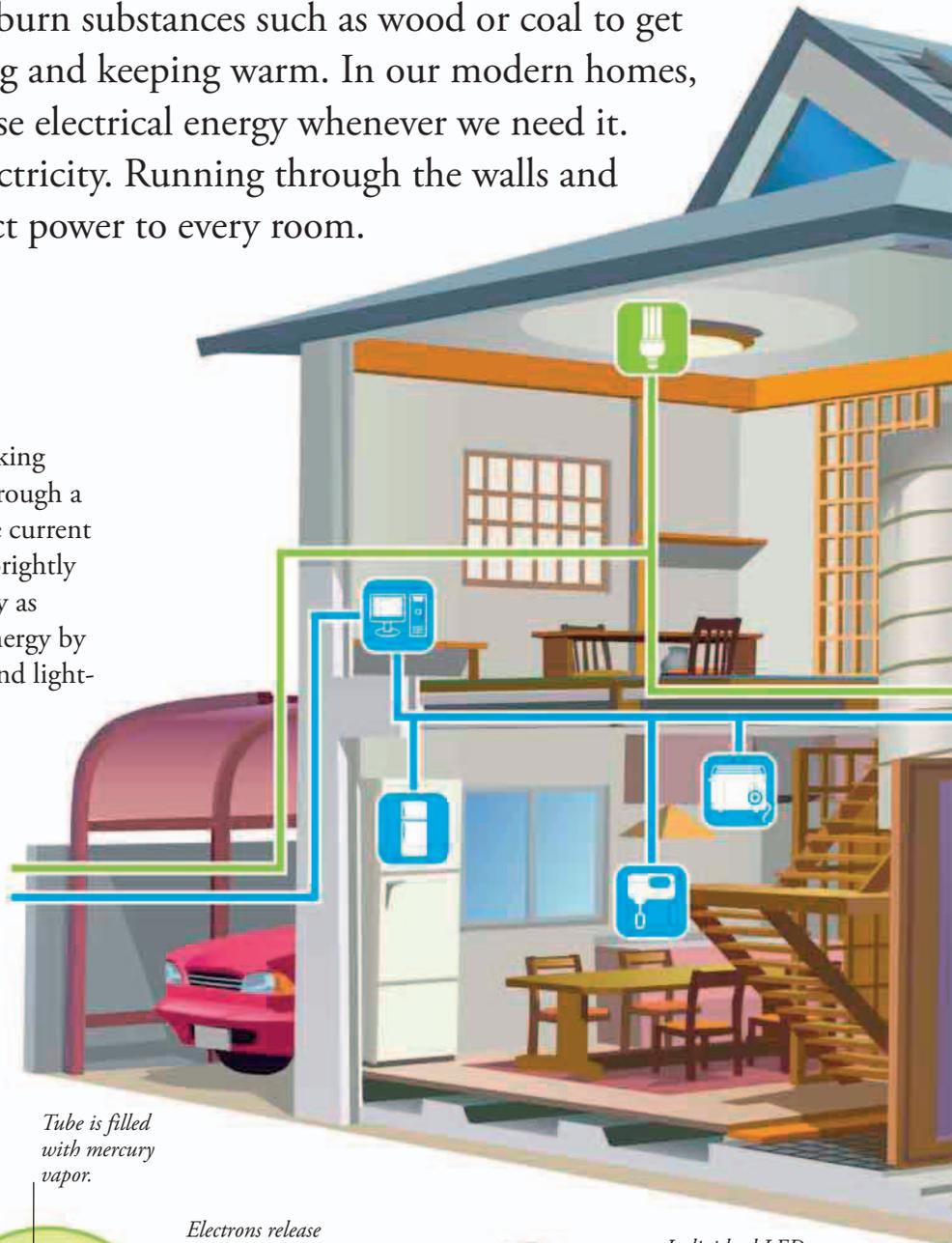
*Electrode fires electrons through the tube.*

◀ **COMPACT FLUORESCENT LAMP (CFL)** *These bulbs use four times less energy than filament bulbs and last 10 times longer. They work by firing electrons through a tube filled with mercury vapor to make light.*



*Individual LED in plastic case*

▲ **LIGHT-EMITTING DIODE (LED)** *These use half as much energy as CFL bulbs and last twice as long. LEDs pass electrons through crystals to make light.*



## MAKING HEAT WITH ELECTRICITY

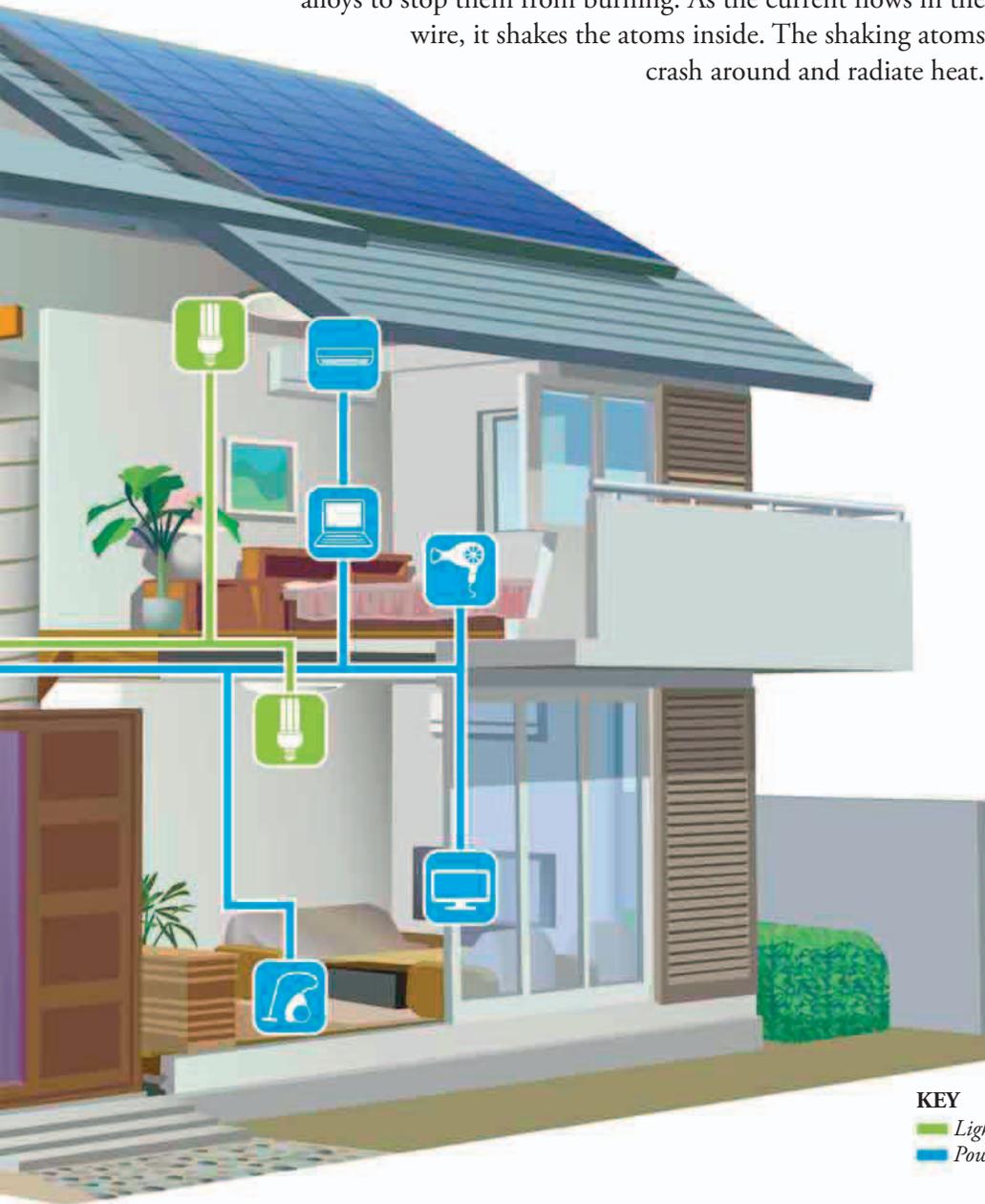
When electricity flows through wires, it produces heat. Heating elements are wires designed to get as hot as possible when electricity passes through them, and are used in devices such as toasters and hair dryers. They are made from special alloys to stop them from burning. As the current flows in the wire, it shakes the atoms inside. The shaking atoms crash around and radiate heat.



▲ **INSIDE A TOASTER** *The heating elements in a toaster get hot as electricity passes through them. They radiate heat toward the bread, turning it into toast.*

## WIRED FOR POWER

You live inside giant electric circuits. Every room in your home has wires running above, below, and around it. Homes often have many separate circuits. A high-powered circuit carries a large electric current to the stove. A separate lighting circuit powers all the lights, and a power circuit carries current to all other appliances.



◀ **HOUSEHOLD WIRING** *Separate circuits power different appliances in your home. Each circuit is protected by a separate fuse (safety switch). If one circuit fails, the others keep working.*

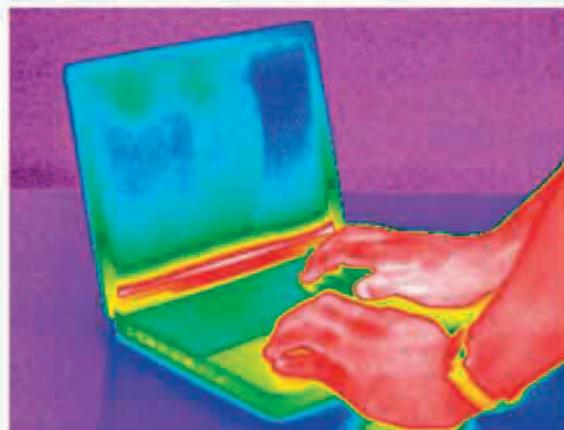
### KEY

- Lighting circuit
- Power circuit

## WHY DO COMPUTERS GET HOT?

Computers work by using electronic circuits to shuffle numbers around. Although they have few moving parts, they still get hot. Every time a computer chip changes a number, it has to use electrical energy to do it. This releases a tiny bit of heat. Even the simplest job a computer does changes millions of numbers, so the heat quickly mounts up.

► **HOT LAPTOP** *This color photograph shows the temperature of a laptop. The hottest part (red) is the processor. The coolest part (blue) is the screen.*

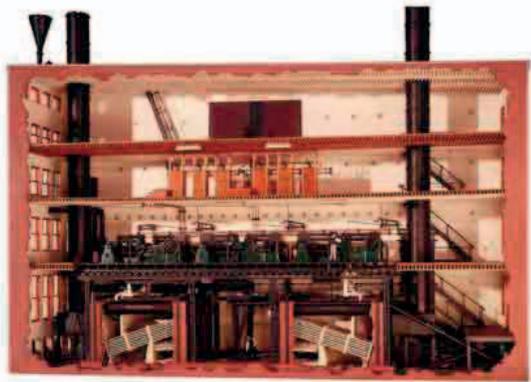


# Electricity supply

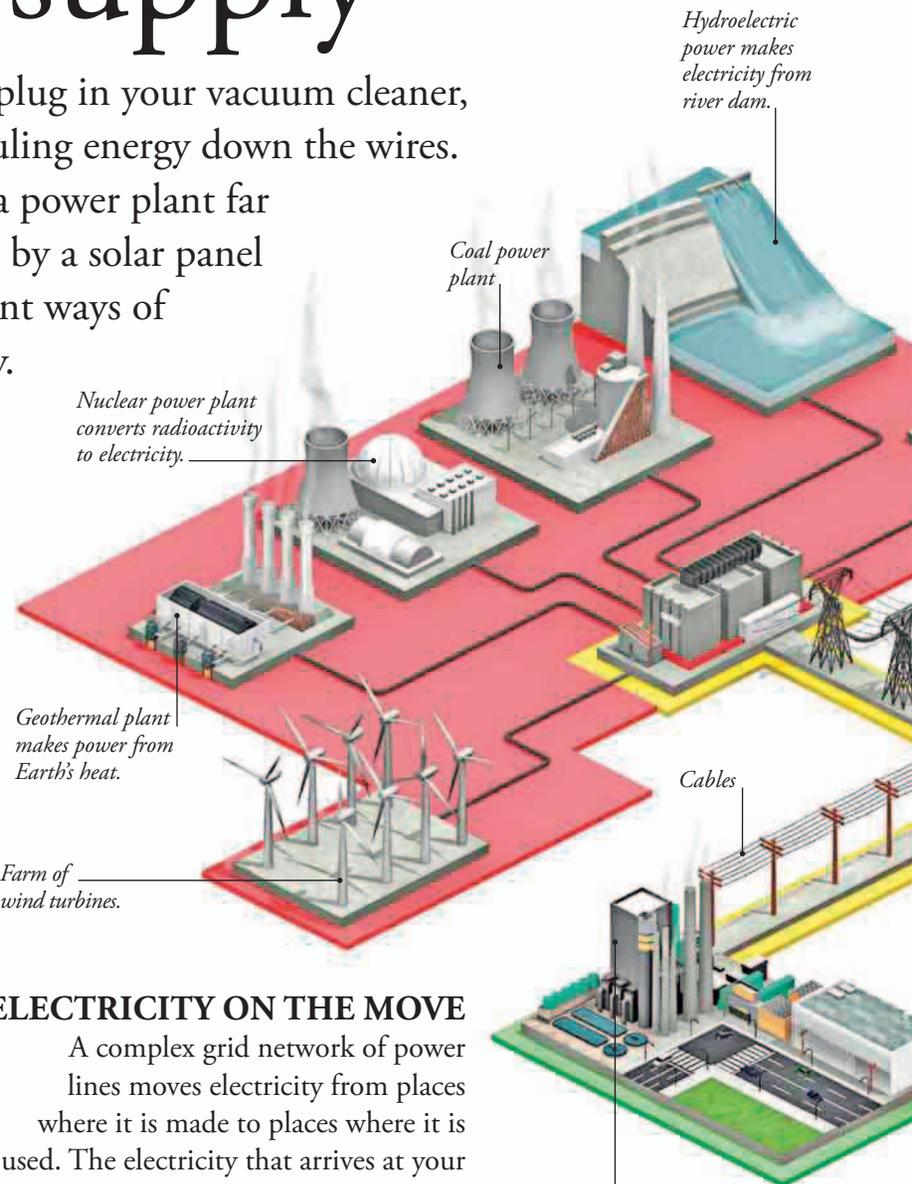
Every time you switch on a lamp or plug in your vacuum cleaner, electrons charge into your home, hauling energy down the wires. That energy might have come from a power plant far away, or it could have been absorbed by a solar panel on your roof. There are many different ways of making, storing, and using electricity.

## POWER PIONEER

Before household electricity was invented, if people wanted heat in their homes, they had to burn wood or coal. If they wanted light, they needed candles or oil lamps. In 1882, American inventor Thomas Edison (1847–1931) opened the world's first true power plant in Manhattan. Although it only supplied 59 homes at first, it proved the value of electricity and changed the world.



▲ PEARL STREET Edison's power plant filled two large buildings on Pearl Street in Manhattan. Coal was burned in furnaces on the ground floor, powering six electricity generators on the first floor.



Hydroelectric power makes electricity from river dam.

Coal power plant

Nuclear power plant converts radioactivity to electricity.

Geothermal plant makes power from Earth's heat.

Farm of wind turbines.

Cables

## ELECTRICITY ON THE MOVE

A complex grid network of power lines moves electricity from places where it is made to places where it is used. The electricity that arrives at your home is exactly the same, whether it has come from coal, wind, or sunlight.

There are many different ways of making electricity, and we can use it for many different purposes.

Large factories use as much power as a small town.

## VOLTAGE CHANGE

Voltage is the force that pushes electricity down wires. High voltage is better for transferring electricity over long distances, because it uses less energy. In the home, we use lower voltages because they are safer, but things that use high power, such as air conditioners and refrigerators, usually need high voltages as well. Batteries give out low power with smaller and safer voltages.



Lightning bolt  
100 million volts



Transmission tower  
500,000 volts



Electric train cables  
20,000 volts

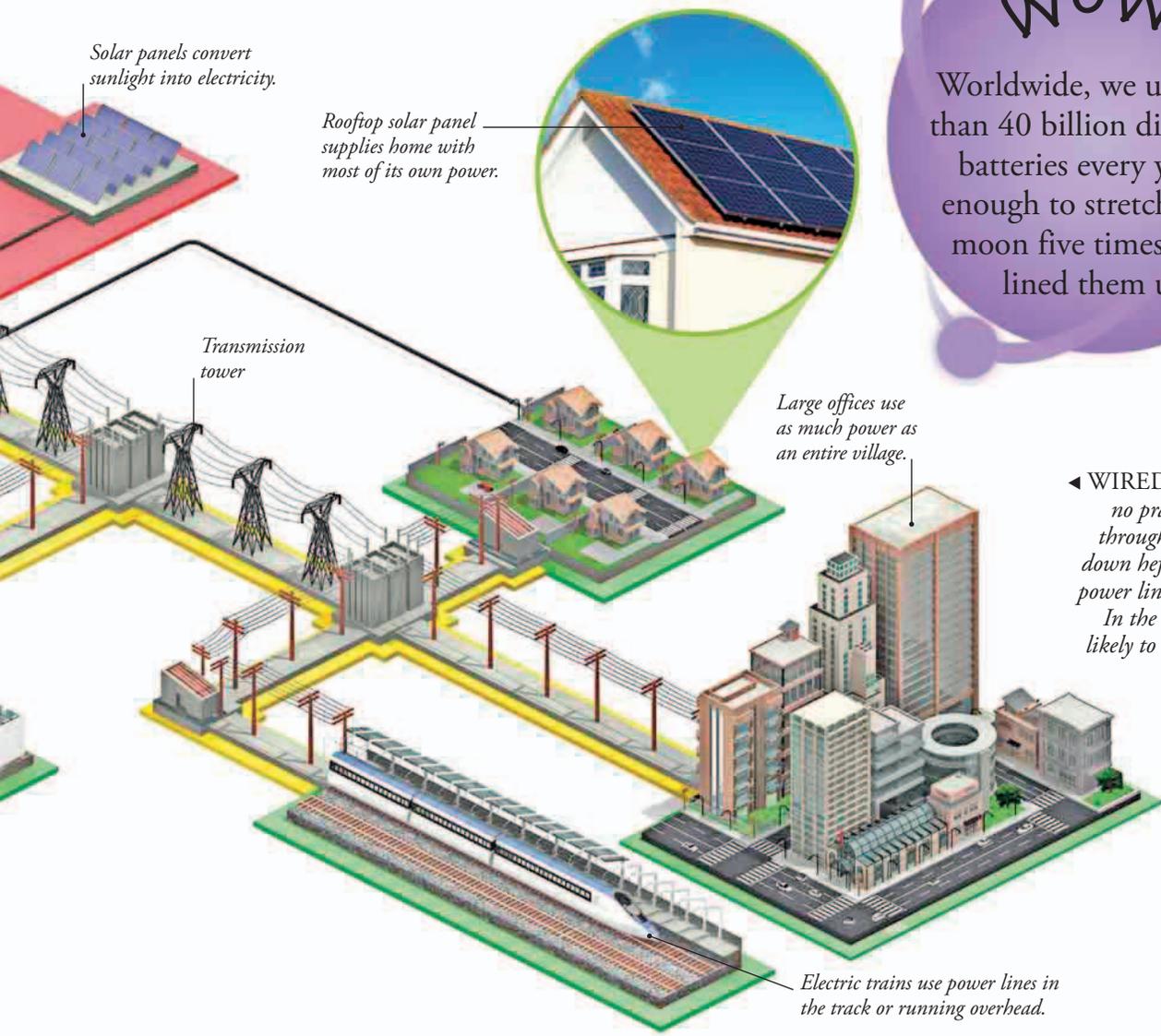


### STORING ELECTRICITY

Many devices, such as cell phones, have batteries that can store electricity, so we can use them when we are away from home. Rechargeable batteries take in electricity from the household supply whenever they are plugged in, storing it as potential energy. They release this energy as electricity when the phone is used.

**WOW!**

Worldwide, we use more than 40 billion disposable batteries every year—enough to stretch to the moon five times if you lined them up.



◀ **WIRED FOR POWER** *There is no practical way to beam power through the air, so it has to travel down hefty cables instead. In cities, power lines often run underground. In the countryside, they are more likely to hang from poles or towers.*



Electric eel  
600 volts



Electricity in homes  
110–240 volts



Laptop charger  
20 volts



Flashlight bulb  
1.5 volts

# Energy sources

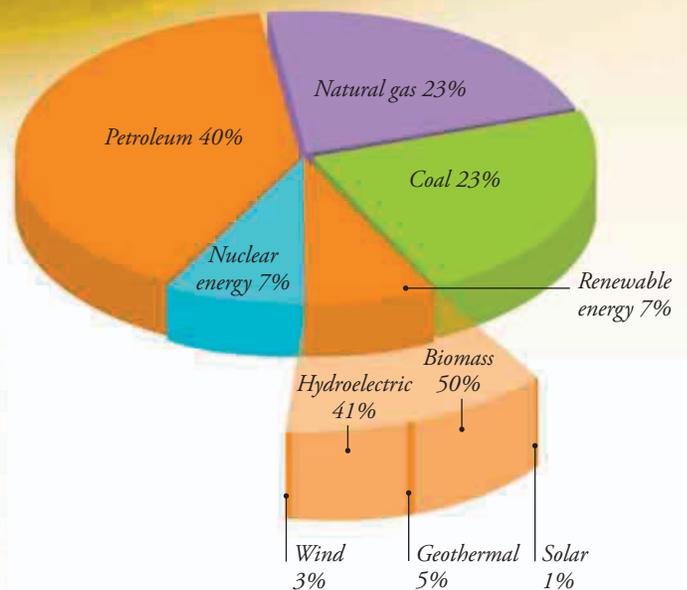
A billion cars, six billion cell phones, a billion televisions—it's no wonder Earth's seven billion people use vast amounts of energy. Most of this energy is beamed down to us from the sun. Some has been stored inside the earth for millions of years as fossil fuels, which we can burn to make power. Because this causes environmental problems, people are now turning to cleaner, "greener" forms of energy, such as wind and solar power.

## NATURE'S POWER SOURCE

Energy from the sun powers most of the activity on our planet, from plants and animals to wind and weather. Deep inside the sun, tiny atoms smash together and fire off energy. About 93 million miles (150 million km) away, here on Earth, sunlight makes plants burst to life, feeding animals, including people. A single second of the sun's fiery energy could power everything that happens on Earth for a million years.

## POWER FOR HUMANS

Humans use energy to power machines such as cars, computers, and factories. About 80–90 percent of our energy comes from fossil fuels: petroleum (oil), coal, and natural gas. Most renewable energy comes from hydroelectricity (river dams) and biomass (plants burned to make power). Only a tiny fraction comes from solar and wind power.



▲ **COAL MINING** Coal is extracted from deep underground with the help of big machines that drill and blast the surface of the Earth.

## BURIED FUELS

Oil, coal, and gas are made from fossils. When plants and sea creatures die, their remains get buried, squashed down, and cooked by Earth's heat. After many millions of years, this creates fossil fuels that we can dig out or pipe to the surface.



## NUCLEAR ENERGY

When small atoms smash together or big ones break apart, they release energy trapped inside. This comes from the nucleus (center) of the atoms, so it is called nuclear energy. Nuclear power plants can make lots of electricity, but they also create dangerous waste.

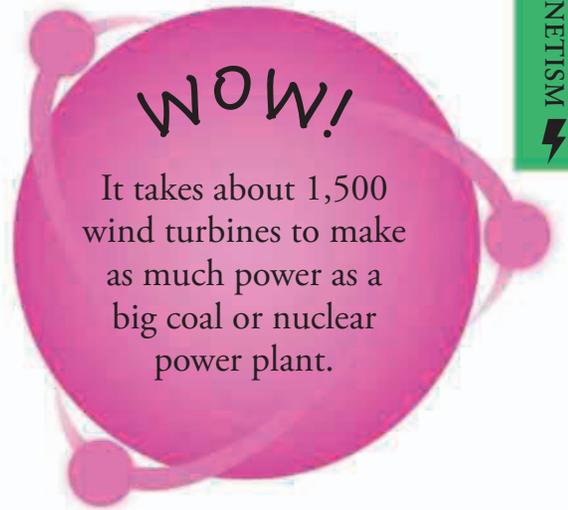
► **NUCLEAR POWER** *Nuclear plants require vast amounts of cooling water, so they are often built close to the sea.*



◀ **SOLAR PANELS** *These sun collectors make electricity when light falls on them. The light pushes electrons through a circuit, making the electricity flow.*

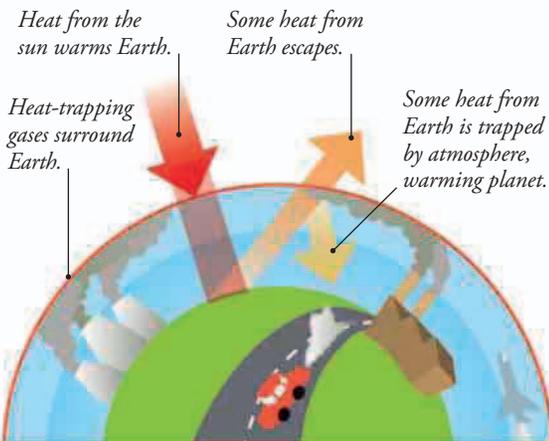
## ENDLESS ENERGY

Energy that we can make forever, without burning fossil fuels, is called renewable energy. Solar power, wind power, biomass, and energy from rivers and oceans are all renewable. Very little of the energy we use is renewable at the moment, but in the future more of our energy will need to be made this way as fossil fuels become scarce.

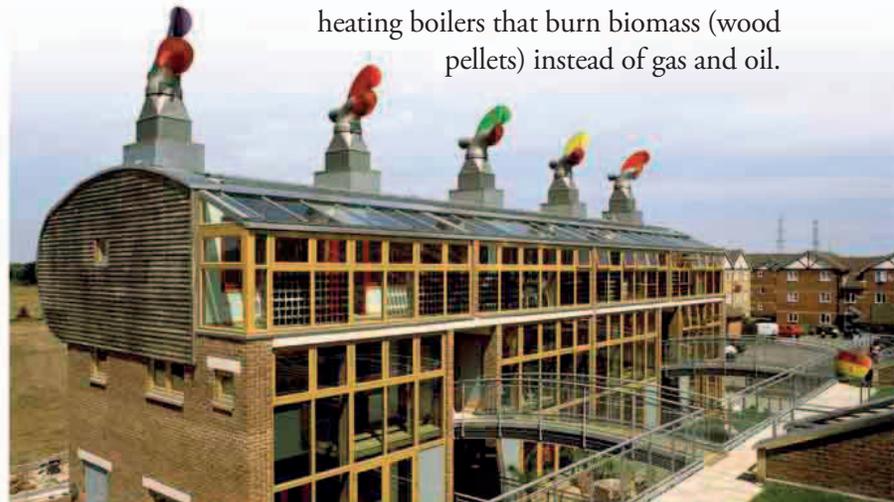


## CLIMATE CHANGE

Burning fossil fuels release a gas called carbon dioxide. This is building up around Earth, trapping heat and warming our planet. As Earth gets hotter, its climate is changing, and the seas are slowly rising. These changes will make it harder for millions of people to feed themselves and live safely.



▼ **ECO HOMES** *The BedZED building in London, England, has wind cowls on the roof so it can keep cool without air conditioning.*



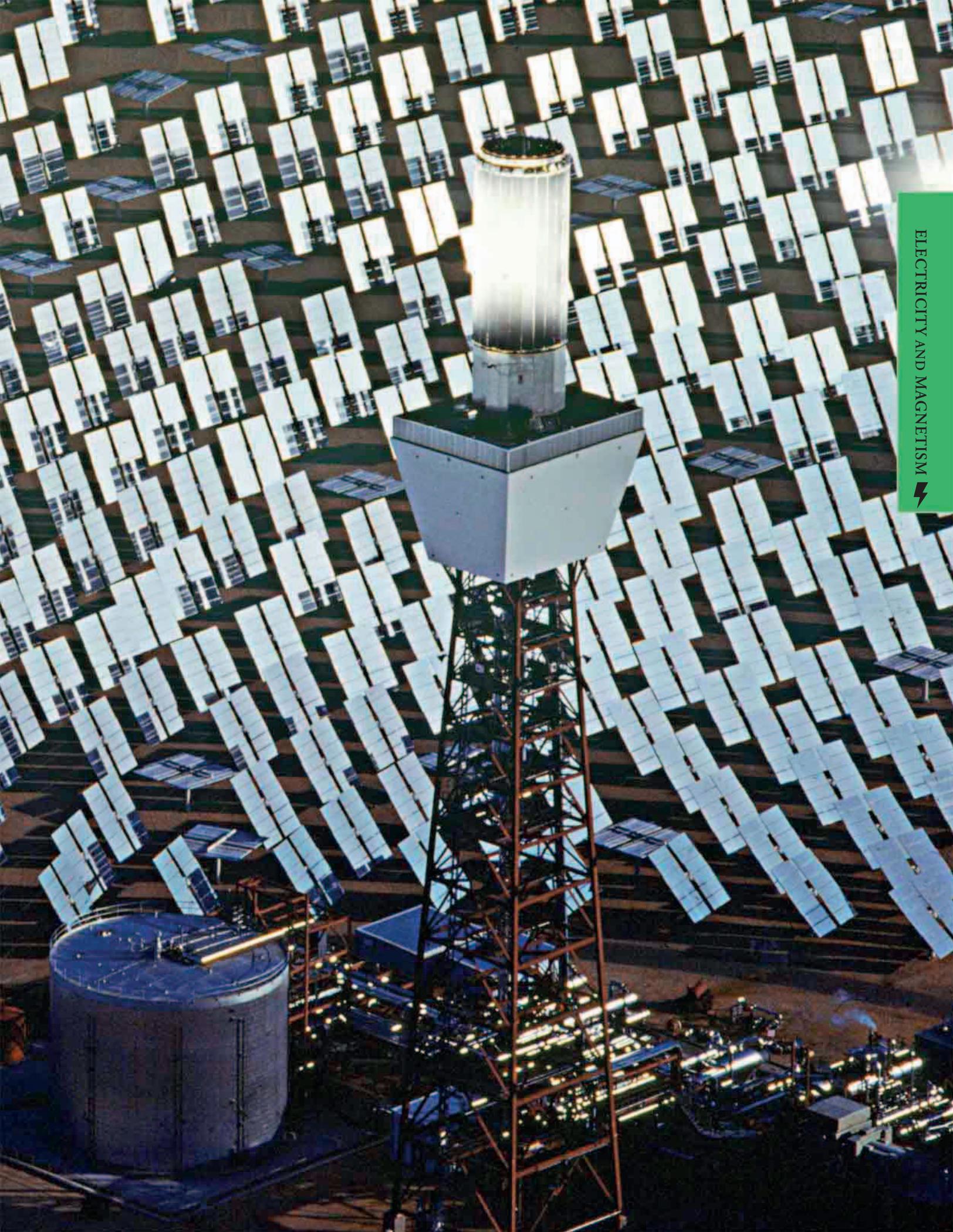
## MAKE YOUR OWN POWER

Ordinary power plants waste up to two-thirds of the fuel they burn. Homes that make their own power can be more efficient. Many homes now have solar panels or miniature wind turbines on their roofs. Others use heating boilers that burn biomass (wood pellets) instead of gas and oil.



### **SOLAR POWER PLANT**

The sun's energy could replace polluting fossil fuels as an electricity source, if we could only find efficient ways to capture it. This solar power plant in California used hundreds of mirrors to focus sunlight on a central tower, which made intense heat and generated electricity.



ELECTRICITY AND MAGNETISM



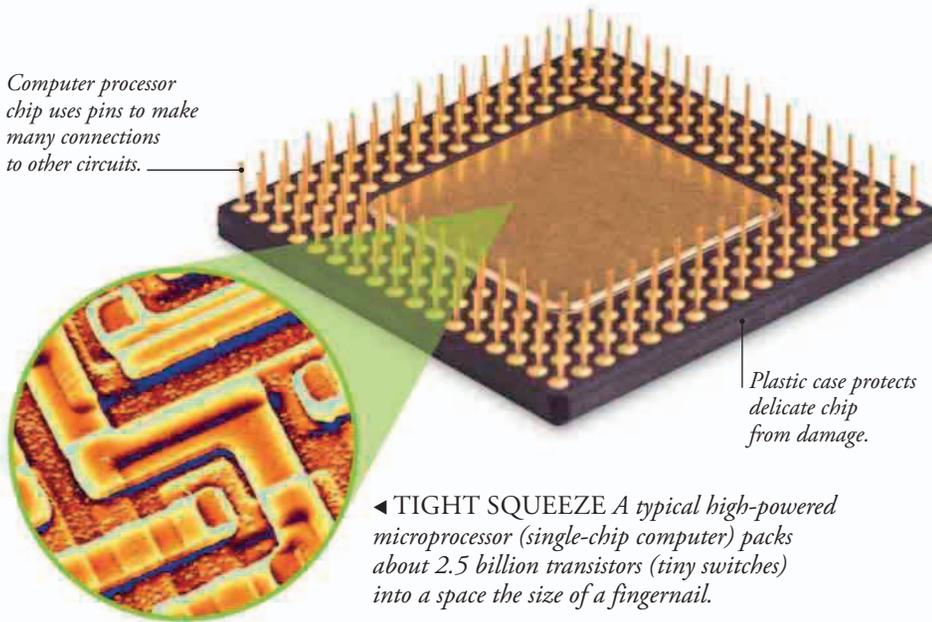
# Electronics

Electronics is a kind of “thinking” electricity. While we use electricity to power things such as lights and motors, we use electronics to control electrical things. Although electricity uses lots of current to deliver a large amount of energy, electronics uses only tiny amounts. Electronic circuits use lots of tiny switches to change the flow of electrons. Some electronic parts are so sensitive they can move just a single electron.

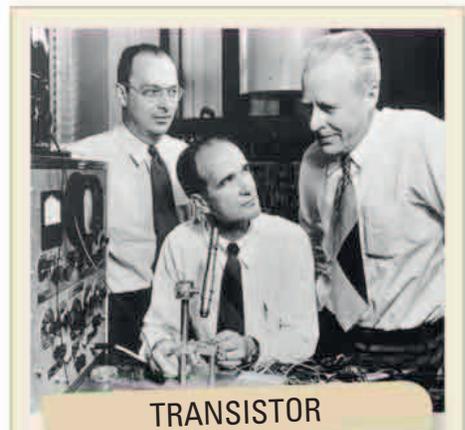
## ALL-IN-ONE CHIP

Electronic gadgets, such as cell phones, have complex circuits inside them. Each circuit is made from thousands, millions, or even billions of separate parts. Since they would normally take up a lot of room, engineers had to find ways of squeezing these parts into a smaller space. This led to the invention of the integrated circuit, or microchip—a flat, fingernail-sized circuit with electrical parts made in miniature form.

Computer processor chip uses pins to make many connections to other circuits.



◀ **TIGHT SQUEEZE** A typical high-powered microprocessor (single-chip computer) packs about 2.5 billion transistors (tiny switches) into a space the size of a fingernail.



## TRANSISTOR

American scientists John Bardeen, William Shockley, and Walter Brattain invented the transistor in 1947. A transistor is the king of electronic parts—the most important one by far. It is a simple, miniature on/off switch that can also make an electric current much bigger. If you connect lots of transistors together, you can build computer circuits that make decisions and remember things.

## ELECTRONIC BUILDING BLOCKS

Electronic circuits are made by connecting small parts called components. Each one does a different job, and they all work as a team. A typical electronic circuit in a transistor radio would have a few dozen components. The processor chip in a computer could have billions.



▲ **DIODES**  
Diodes make electricity flow in only one direction. They are used for picking up signals in radios.



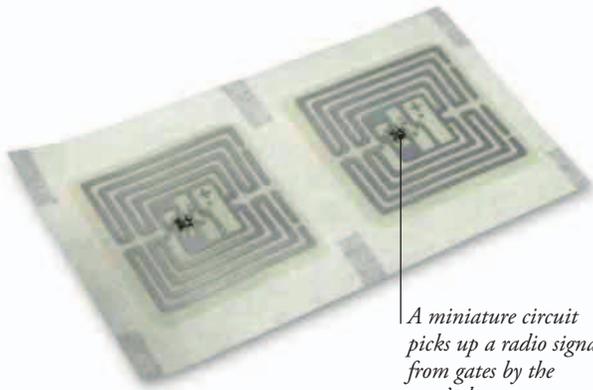
▲ **LEDs**  
Glowing lights on electronic gadgets are made from tiny, colored light-emitting diodes (LEDs).



▲ **TRANSISTORS**  
Transistors switch currents or make them bigger. They were first used to make sounds louder in hearing aids.

## HIDDEN CHIPS

Stores hide microchips inside items to stop people from stealing them. The chips pick up radio signals from plastic gates standing on either side of the store entrance. When an item is bought, the sales assistant switches off the chip so it passes through the gates harmlessly. If something is stolen, the chip sends a signal to the gates and sounds the alarm.



*A miniature circuit picks up a radio signal from gates by the store's doorway.*

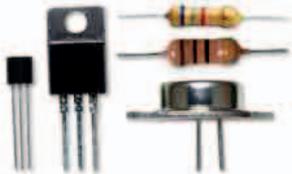
▲ **SECRET CIRCUIT** This antishopping chip is called a radio-frequency identification (RFID) tag. It has an electronic circuit hidden inside.

*Flexible Organic LED (OLED) displays can bend into new shapes without breaking.*



## FLEXIBLE GADGETS

The first radios and TVs were huge, heavy, and gobbled up power. The first computers filled entire rooms. Today's electronic gadgets are small and light—we can easily carry phones in our pockets. Tomorrow's gadgets will be even more user-friendly. They will be made from very light plastic circuits with flexible displays, known as Organic LEDs (OLEDs). In the future, your phone could wrap around your wrist like a watch.



▲ **RESISTORS**  
A resistor makes an electric current smaller. Dimmer switches use resistors to turn down lights.



▲ **CAPACITORS**  
A capacitor stores electricity, like a battery without chemicals. The flash on a camera uses a large capacitor.

**WOW!**

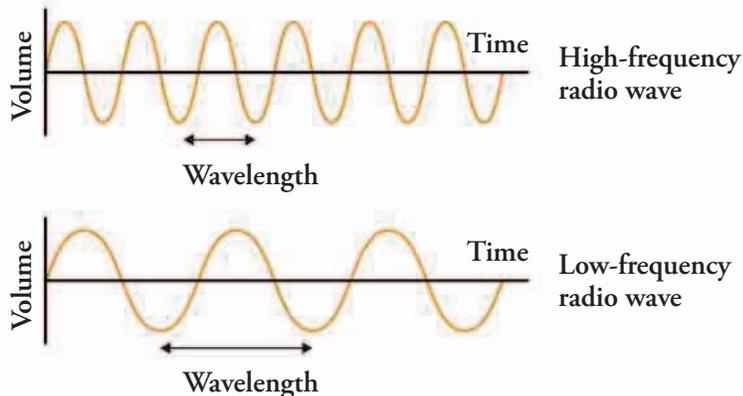
You could fit more than 2 million tiny transistors on the period at the end of this sentence.

# Radio and television

A television can conjure up people from history or show you what is happening right now on the other side of the world. This might seem like magic, but it is science in action. A TV set grabs invisible signals shooting down cables or through the air, and converts them into pictures you can see. Radio does exactly the same thing but with voices and music.

## WHAT IS A RADIO WAVE?

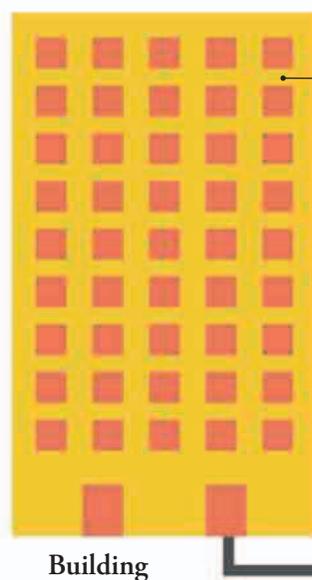
Radio and TV signals beam through the air as waves of energy. These radio waves are invisible, yet they can pass through buildings. They travel as fast as light waves, so they can speed seven times around the world in a single second. If you could see a radio wave, it would have a snakelike pattern of ups and downs.



▲ **RADIO WAVE** Radio and TV signals travel in waves of different frequency. The frequency is how many times the wave goes up and down each second. You can pick up different channels by tuning to different frequencies.

## RADIO BY NUMBERS

Modern radio stations use digital signals to transmit sounds. The transmitter breaks the signal from a radio station into tiny chunks. Each chunk is turned into a number and beamed through the air many times. A digital radio picks up the chunks and turns them back into waves you can hear. This makes a clear sound with no static.



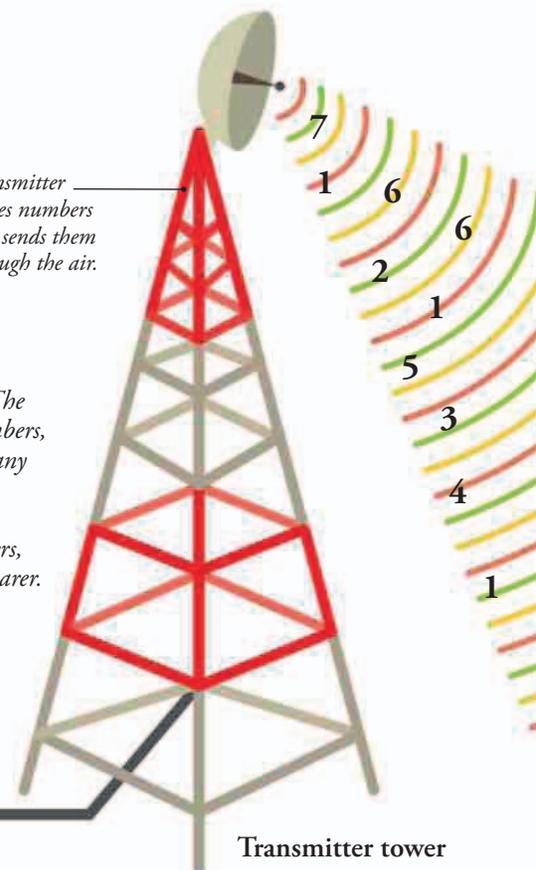
Building

Radio station turns signal into numbers.

► **DIGITAL RADIO** The signal is turned into numbers, copied, and broadcast many times. Your digital radio has a greater chance of picking up all the numbers, so the program sounds clearer.

1 2 3 4 5 6 7

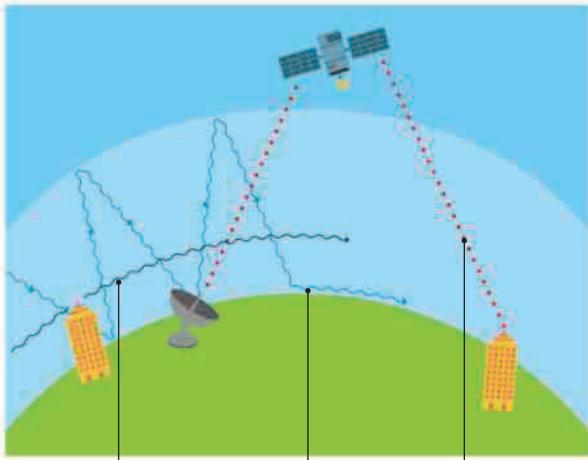
Transmitter copies numbers and sends them through the air.



Transmitter tower

WOW!

By bouncing signals from satellites, we can send TV and radio transmissions to anywhere in the world.



Ordinary ground wave follows curve of Earth.

Waves can go farther by bouncing off ionosphere.

Waves can go even farther by reflecting off satellites.

## STREAMING SIGNALS

Radio waves travel in straight lines, so you might think they would shoot into space and disappear. In fact, radio signals can bounce all the way around our curved planet. Some crawl across the ground. Others go farther by bouncing off part of the atmosphere called the ionosphere. This works best at night, which is why you can hear distant radio stations better in the evening. Space satellites help signals go even farther by bouncing them like mirrors in the sky.

Early TVs could only show pictures in black and white.

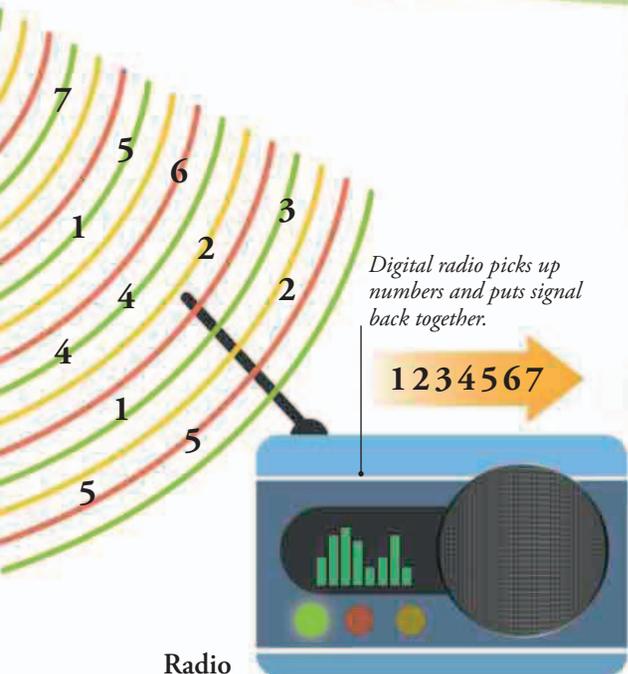
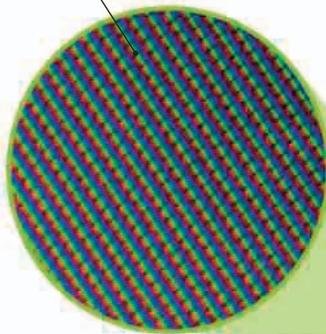


## HOW TV MAKES HISTORY

Television helps us mark important moments in history. Thanks to satellites, we can watch amazing events as they happen (“live”) anywhere in the world. By storing TV pictures as videos, we can keep these moments forever. Recording history like this was impossible before TV was invented.

▲ MOON LANDING When astronauts reached the moon in 1969, up to a billion people followed the event on radio and TV.

Each part of a TV picture is built from tiny red, blue, and green dots called pixels.



Digital radio picks up numbers and puts signal back together.

1 2 3 4 5 6 7



◀ COLOR SCREEN Digital televisions receive signals made up of streams of numbers and turn them into pictures and sound.

## HOW TELEVISION WORKS

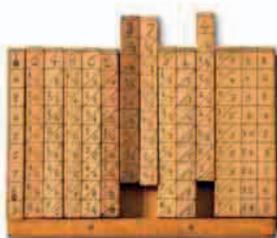
Television works just like radio except the waves traveling through the air carry pictures as well as sounds. When the signal streams into your home, your television splits it in two. Part of it makes the picture and the other part makes the sound. By sending their signals as numbers, just like digital radio, TV stations can send lots of channels at once, giving us a greater selection of things to watch.

# Computers

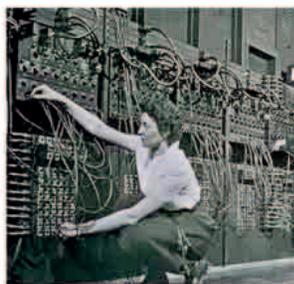
Most animals think with their brains, but people also think with electronic brains—computers. A hundred years ago, there were no electronic computers anywhere in the world. Today, there are more computers than people. They hum away on office desks and control robots in factories. In our homes, they power everything from phones and TVs to washing machines and microwaves.

## HISTORY OF COMPUTERS

No single person invented the computer. The idea took shape gradually, starting with the abacus, a simple counting frame made of beads, invented about 4,500 years ago. Although modern computers do much more complicated tasks, they are still really just counting machines.



▲ **NAPIER'S BONES** *The first computers used moving rods, levers, or gears. This simple wooden multiplier was created by Scottish inventor John Napier in 1617.*



▲ **ENIAC** *The world's first electronic computer was invented in 1946. It was as big and heavy as a truck, but less powerful than a modern cell phone.*



▲ **APPLE MACINTOSH** *This machine appeared in 1984. With a friendly, picture-based screen, it was designed for people who had never used a computer before.*

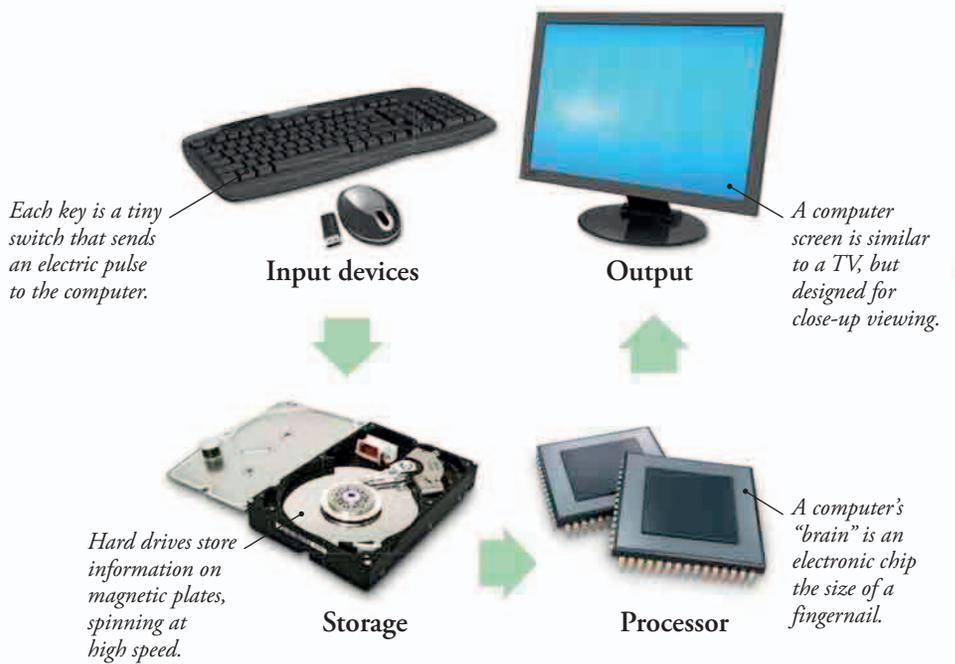
► **TABLET** *Larger computers use keyboards and mice, but tablets do not need them. Instead of typing words or dragging your mouse, you simply touch the screen with your finger.*

*A sensitive surface hidden inside the touch screen uses electricity to detect your finger.*



## HOW DOES A COMPUTER WORK?

From editing vacation photos to playing music videos, everything computers do happens in four steps. First, we feed in (input) some information, often with a keyboard or mouse. Next, the computer stores that information in its memory. Then, it works on the information with its processor chips, performing millions of calculations each second. Finally, we get the results (output) on the screen.



**WOW!**

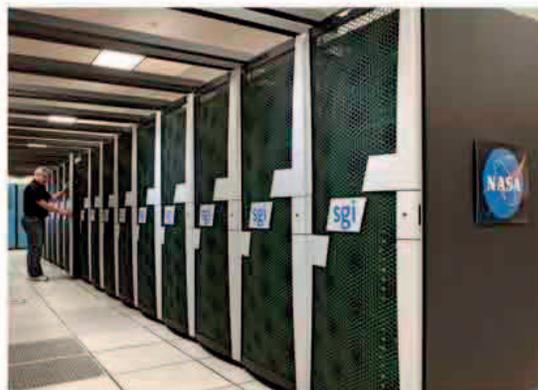
Today's supercomputers are about 300 trillion times faster than the 1940s ENIAC.

## EYES ON THE ROAD

People can't always reach for a computer to look up the facts and figures they need. Heads-up displays project useful information before your eyes. Drivers can have maps or information from the dashboard beamed onto their windshield so they don't have to look away from the road.



▼ **MORE SPEED** NASA's Pleiades supercomputer has 112,896 processors stacked in 185 racks, and is used for space and weather research.



*The electronic parts in a tablet computer are on very flat circuits, not much thicker than cardboard.*

## SUPERCOMPUTERS

Forecasting the weather is a tricky scientific problem that would take an ordinary computer years to tackle. Supercomputers work millions of times faster. They are made by connecting hundreds of thousands of ordinary computer chips together. A problem is broken up into tiny pieces and each chip handles one small piece. This is much quicker than trying to tackle the problem all together, in one big piece.

# Cell phones

If you could see a cell phone call, it would look like waves of energy spreading out from the phone to a tower or satellite. That's because cell phones connect together with radio waves traveling at the speed of light. They don't need wires, so we can use them anywhere in the world, from the top of Mount Everest to the middle of the Sahara Desert.



## HISTORY CALLING

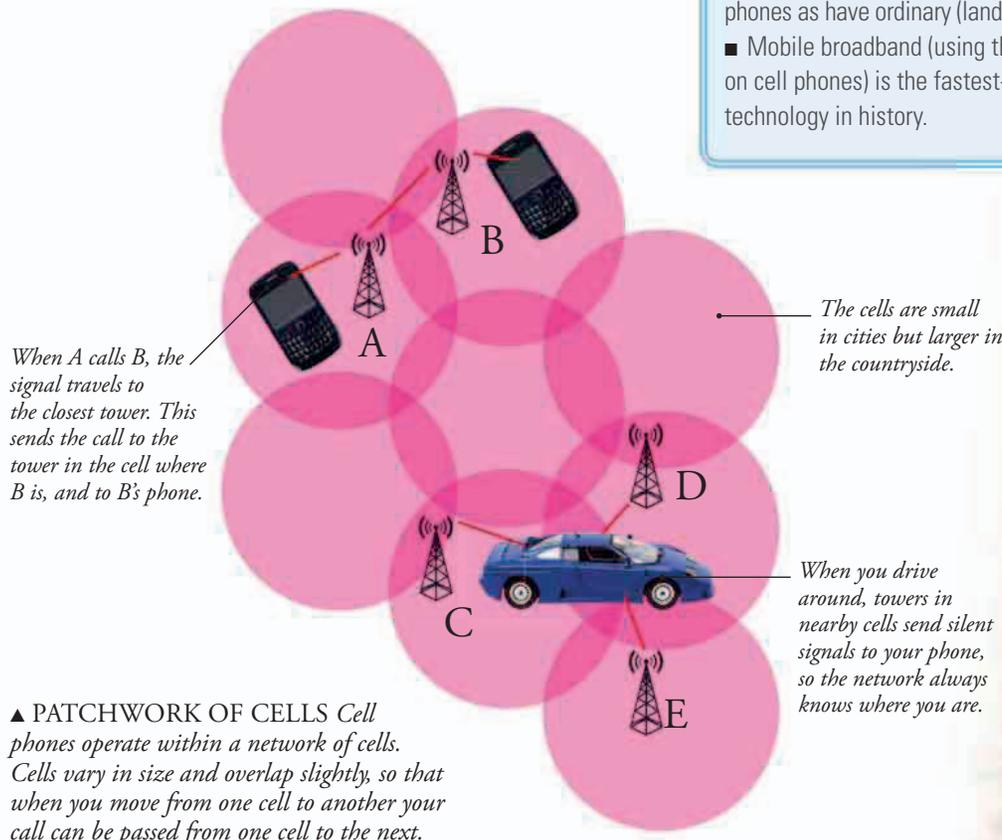
Cell phones were invented by American engineer Martin Cooper in 1973, but it was another 10 years before they went on sale. The first cell phone you could buy was the Motorola DynaTAC, which cost \$3,995. It was six times heavier than a modern phone, and its huge battery lasted only an hour.

## HOW CELL PHONES WORK

Cell phones make calls by sending signals through the air using radio waves. Wireless phone networks divide regions into much smaller zones called cells. Each cell contains its own phone tower (sending and receiving antenna). The signals from a phone travel via the closest tower, which beams them on through the telephone network to their destination.

### FAST FACTS

- There are 3.4 billion cell phone users worldwide.
- Five times as many people have cell phones as have ordinary (landline) phones.
- Mobile broadband (using the Internet on cell phones) is the fastest-growing technology in history.

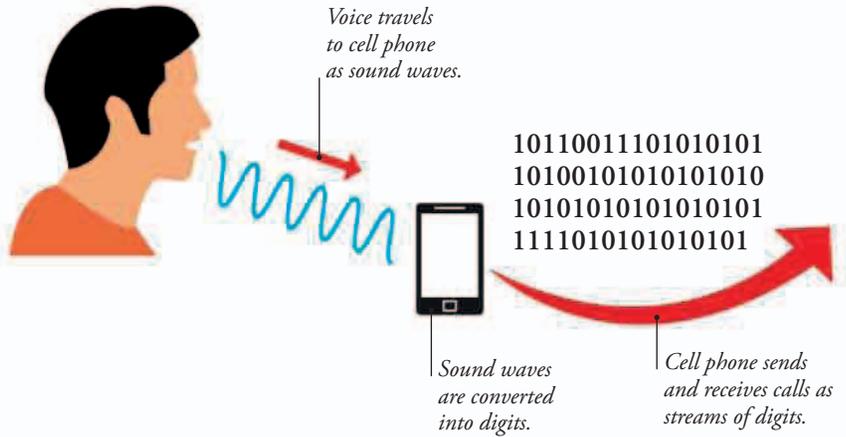


▲ **PATCHWORK OF CELLS** Cell phones operate within a network of cells. Cells vary in size and overlap slightly, so that when you move from one cell to another your call can be passed from one cell to the next.

## CALLING BY NUMBERS

When you speak, your voice vibrates through the air as sound waves. When you talk into a cell phone, it converts the sound of your voice into numbers (digits).

This kind of digital information is easier and safer to send over networks, and travels more clearly with less background noise.



WOW!

The world's first cell phone was as big as a brick and weighed 28 lb (13 kg)—100 times more than a modern phone.

## WIRELESS WORLD

Cell phones have really changed the world. It's much too expensive to lay giant telephone cables across huge continents such as Africa and Asia.

Fortunately, cell phones can work anywhere, without wires. Thanks to cell phones, people can enjoy the Internet and stay in touch with their friends even in areas without telephone cables.

### ◀ CALLING FROM ANYWHERE

*Cell phones can make calls wherever they can pick up a signal from a tower or overhead satellite—even a remote desert. The closer they are to the tower, the more reliable the call.*



# The Internet

You can send messages to your friends at the click of a button, even if they live on the other side of the world. This is possible thanks to the Internet, a giant network that links the world's computers. The Internet is also the power behind the World Wide Web, a digital library made from over a trillion pages that anyone can tap into anytime, anywhere.

## HOW DOES THE INTERNET WORK?

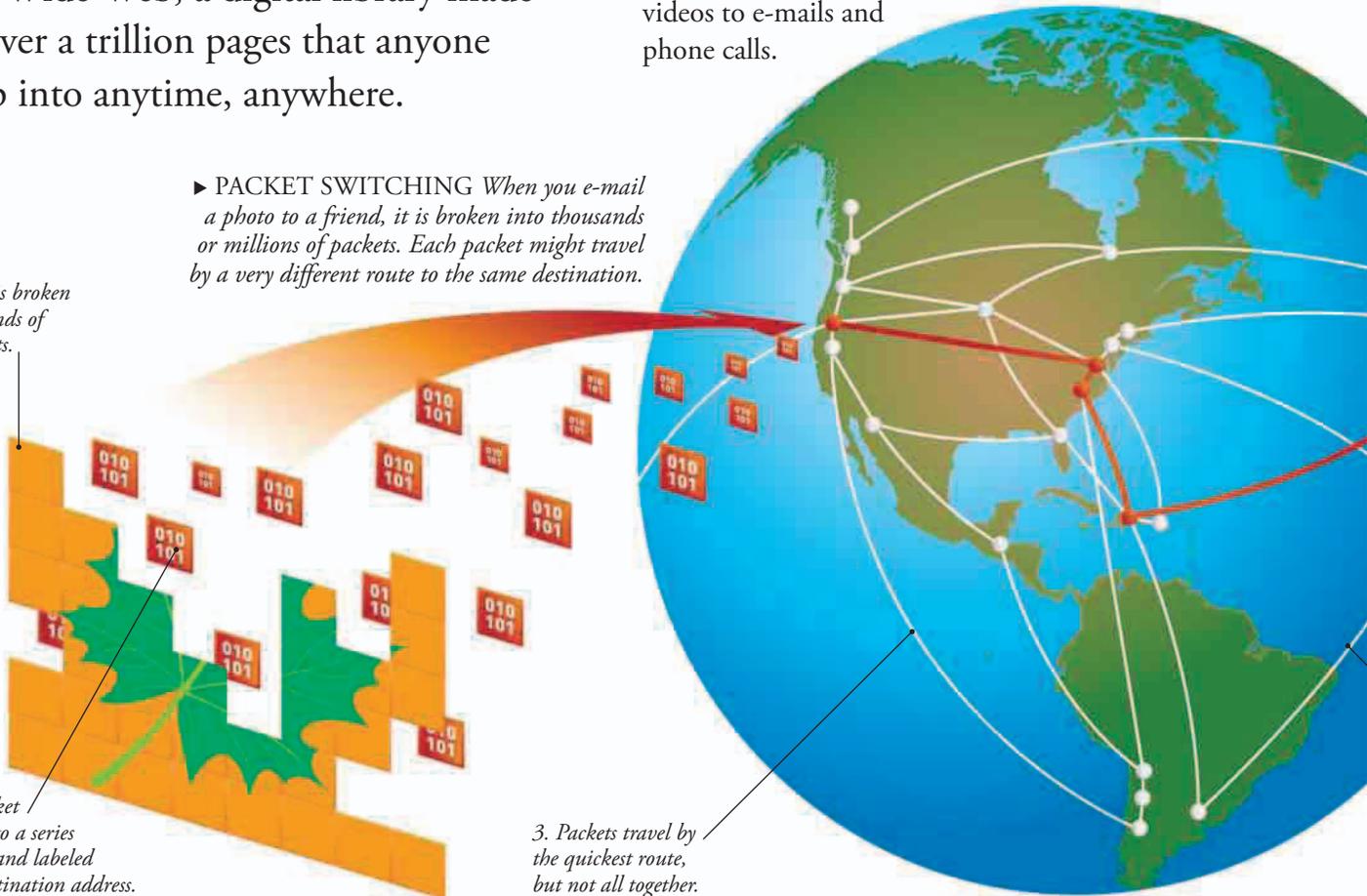
Just as there are many ways to travel between two places on Earth, there are many ways to send information between two computers. The Internet uses this idea to transport data (computer information) very efficiently. The data is split into packets (tiny pieces), which travel separately so they reach their destination faster. Any information can be sent over the Internet, from photos and videos to e-mails and phone calls.

► **PACKET SWITCHING** When you e-mail a photo to a friend, it is broken into thousands or millions of packets. Each packet might travel by a very different route to the same destination.

1. A photo is broken into thousands of small packets.

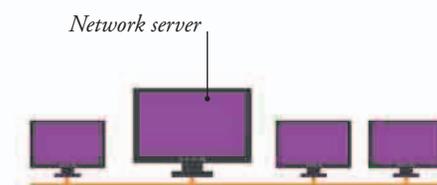
2. Each packet is turned into a series of numbers and labeled with the destination address.

3. Packets travel by the quickest route, but not all together.

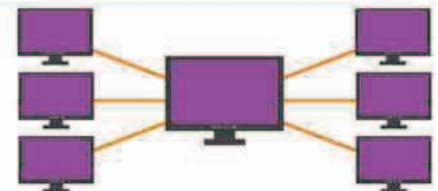


## COMPUTER NETWORK

The Internet is a computer network that spans the world, but there are smaller networks too. A network at home may connect several computers to a printer. This is called a LAN (Local Area Network). In offices, there are bigger LANs, in which dozens of computers are connected. Each LAN usually has one place where it connects to the outside Internet, through a secure connection.



▲ **LINE NETWORK** Each computer is connected to the others in a simple chain. The network server controls the network.

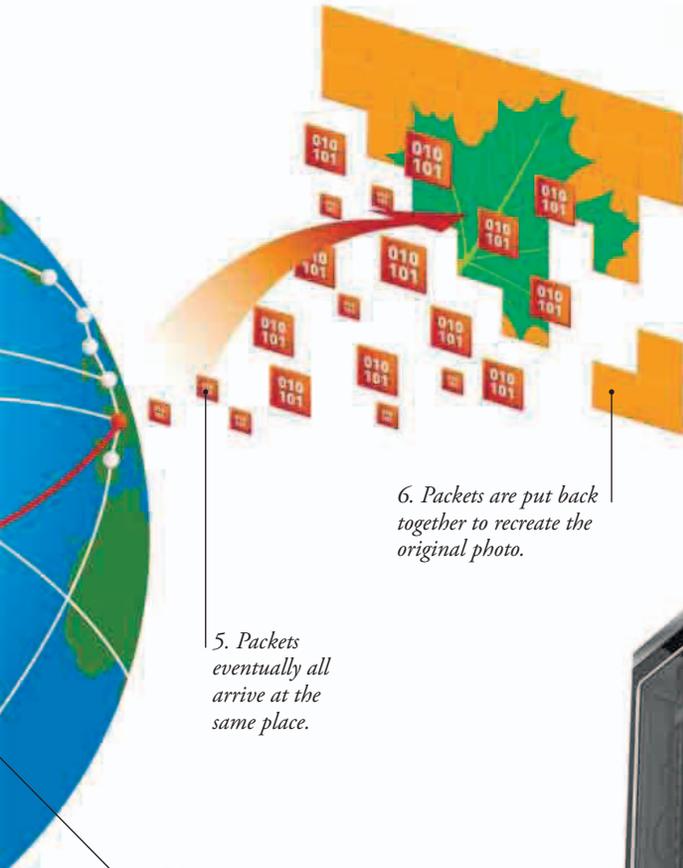
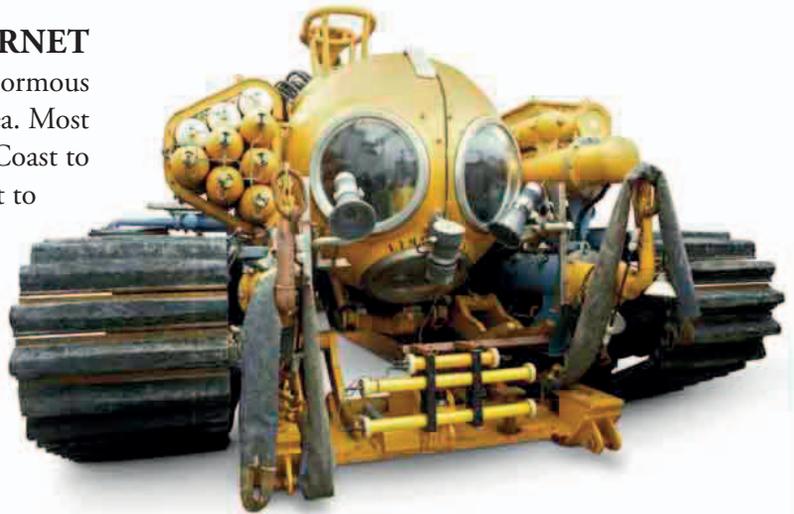


▲ **STAR NETWORK** All the computers on this network branch out from the server in the middle, which controls them.

## UNDERWATER INTERNET

The Internet links about 200 countries with enormous cables, almost 250 of which stretch under the sea. Most run from the United States, some from the East Coast to Britain and Europe, and others from the West Coast to China, Japan, and other Asian countries.

► **CABLE CRAWLER** Most Internet cables are lowered from reels behind giant ships. Some are laid by submarines like this, which crawl along the seabed.



5. Packets eventually all arrive at the same place.

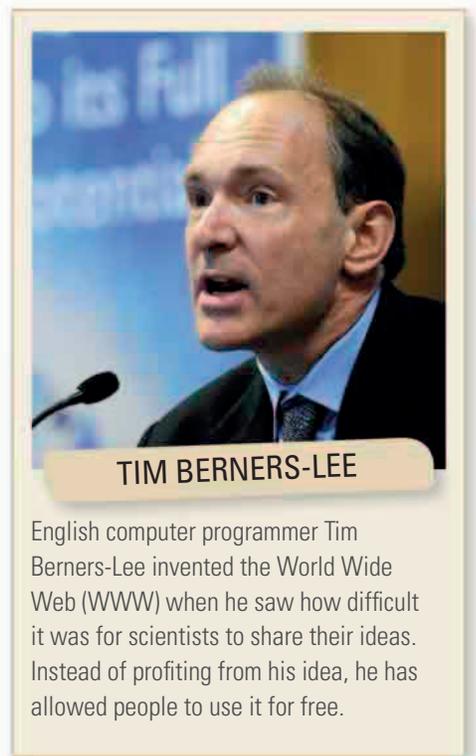
4. If any route is blocked, packets can go a different way.

6. Packets are put back together to recreate the original photo.

Servers are made from individual computers slotted into racks in large cabinets.



▲ **WEB SERVER** Websites operate from large computers called web servers, many times more powerful than home computers.

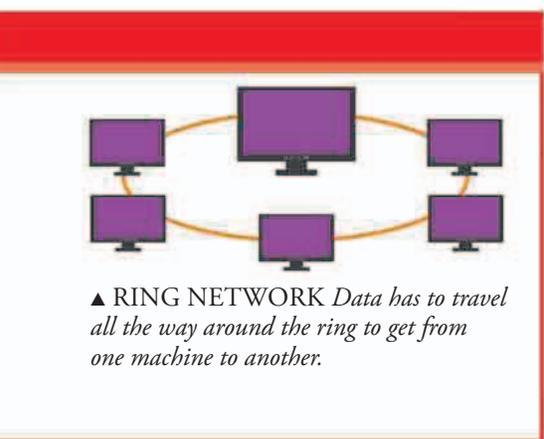


TIM BERNERS-LEE

English computer programmer Tim Berners-Lee invented the World Wide Web (WWW) when he saw how difficult it was for scientists to share their ideas. Instead of profiting from his idea, he has allowed people to use it for free.

## WORLD WIDE WEB

Knowledge used to be locked in libraries. Now you can read it from your computer on a giant library called the World Wide Web. Most web pages are stored in a simple format called HTML, which all computers recognize. Computers send and receive HTML pages using a method called HTTP. Simply speaking, the web works because all the computers connected to it speak the same language of HTML and HTTP.



▲ **RING NETWORK** Data has to travel all the way around the ring to get from one machine to another.

# Robots

As technology advances, more and more robotic machines are being invented to do jobs for us. Powered by electricity, they never get tired. Robots probably built your car, cut and stitched your clothes from the fabric, and put together many of the things you use every day.

## WHAT IS A ROBOT?

A robot is a machine that can learn to do different jobs. Controlled by a computer “brain,” it is built from levers and wheels, and operated by electric motors. Some robots look like people, but most are just mechanical arms with tools attached.



▲ **FACTORY FLOOR** *Factory robots work 24 hours a day doing the same job without making a mistake. Robots can easily be reprogrammed to do new things.*



Grabber arm can lift objects.

Camera sends images back to the operator.

WOW!

There are 1.5 million factory robots currently at work worldwide. Forty percent of them are used to build cars.

## EMERGENCY ROBOTS

Robots can be sent on emergency missions that are too dangerous for people. Robots are now being developed that will be able to rescue victims from earthquakes and other disasters. One day, these robots will be able to dig through rubble, put out fires, and even drive cars.

◀ **REMOTE CONTROL** *Most robots do not control themselves. This bomb disposal robot, called Hobo, is operated from a distance by a person who uses the small camera on top to see what the robot is doing.*





## THINKING MACHINES

Humans learn how to do new things by thinking about the way they have done things before. This is called intelligence, and it includes learning from your past mistakes. In the future, computers and robots will be artificially intelligent—as skilled at thinking as humans.

▲ **GRAND MASTER**  
Computers are now smart enough to beat humans at games. In May 1997, IBM's *Deep Blue* supercomputer beat Russian world chess champion Gary Kasparov. In 2011, another IBM computer won the television quiz show *Jeopardy!*

## ROBOTS LIKE HUMANS

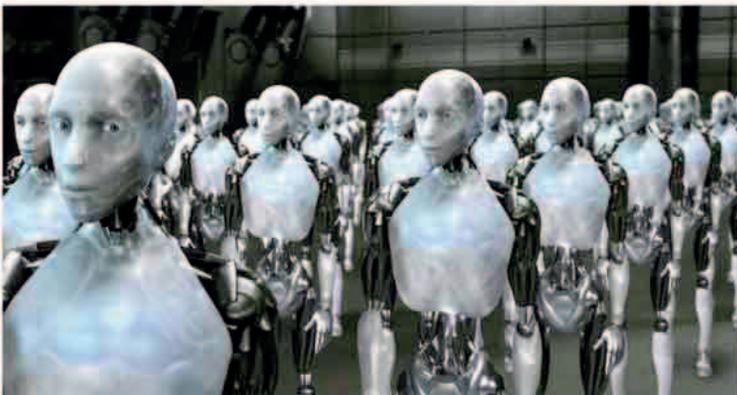
Robots need to work with humans, and scientists are always looking for ways to make them more like us.

The latest robots even look like friendly humans.

In the future, humans and robots might even merge. People can already have replacement robotic body parts, and, in time, our entire bodies might be replaced with robotic ones.

## OUR ROBOT FUTURE?

If robots get too smart, they might want to control themselves instead of listening to us. American author Isaac Asimov suggested three laws that robots must obey: Robots must not hurt people, they must always obey human orders, and they must protect themselves unless that involves harming people.



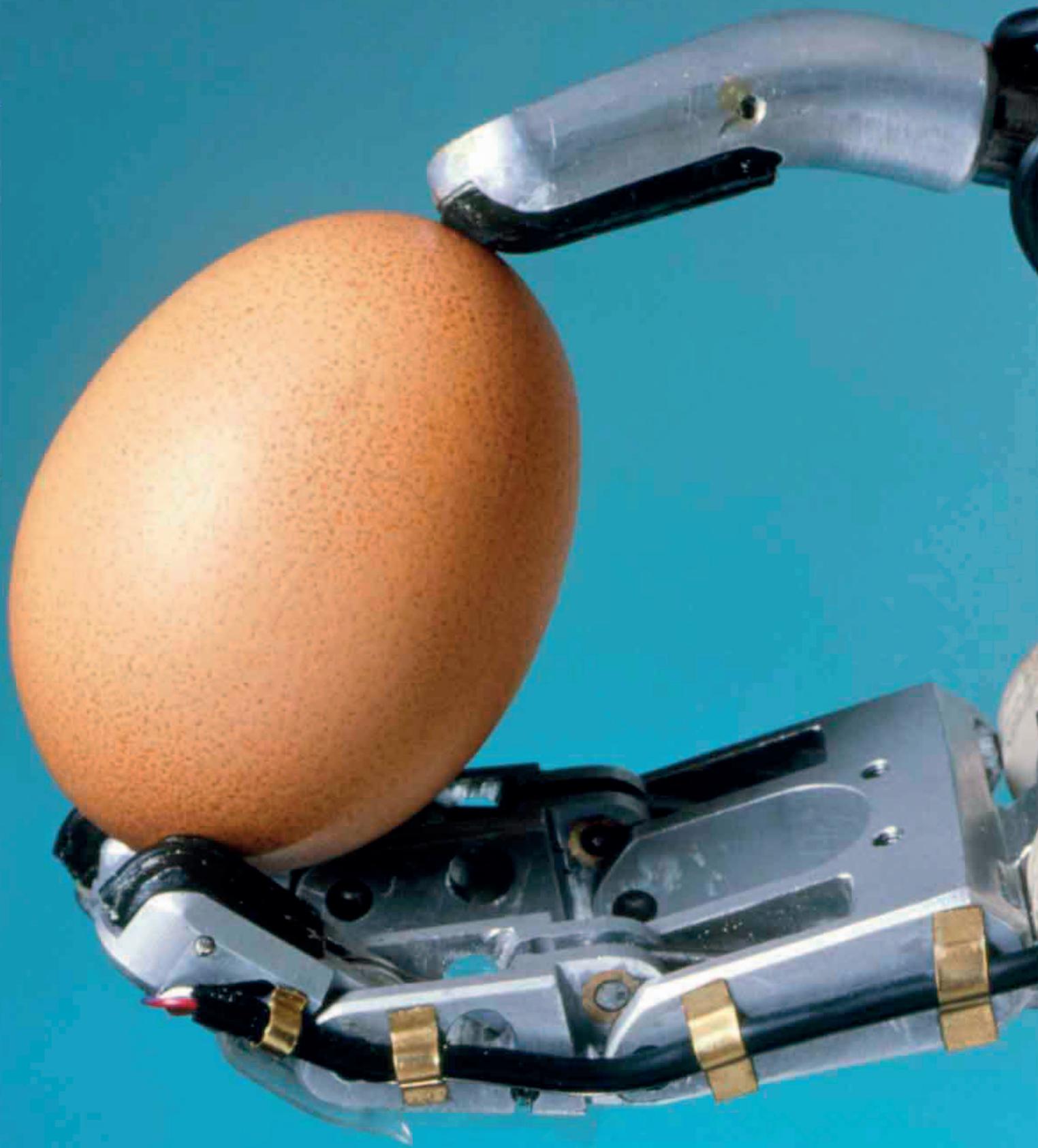
▲ **I, ROBOT** This 2004 science fiction movie is about a future world where most things are done by robots. It is based on a 1950 book of short stories written by Isaac Asimov.

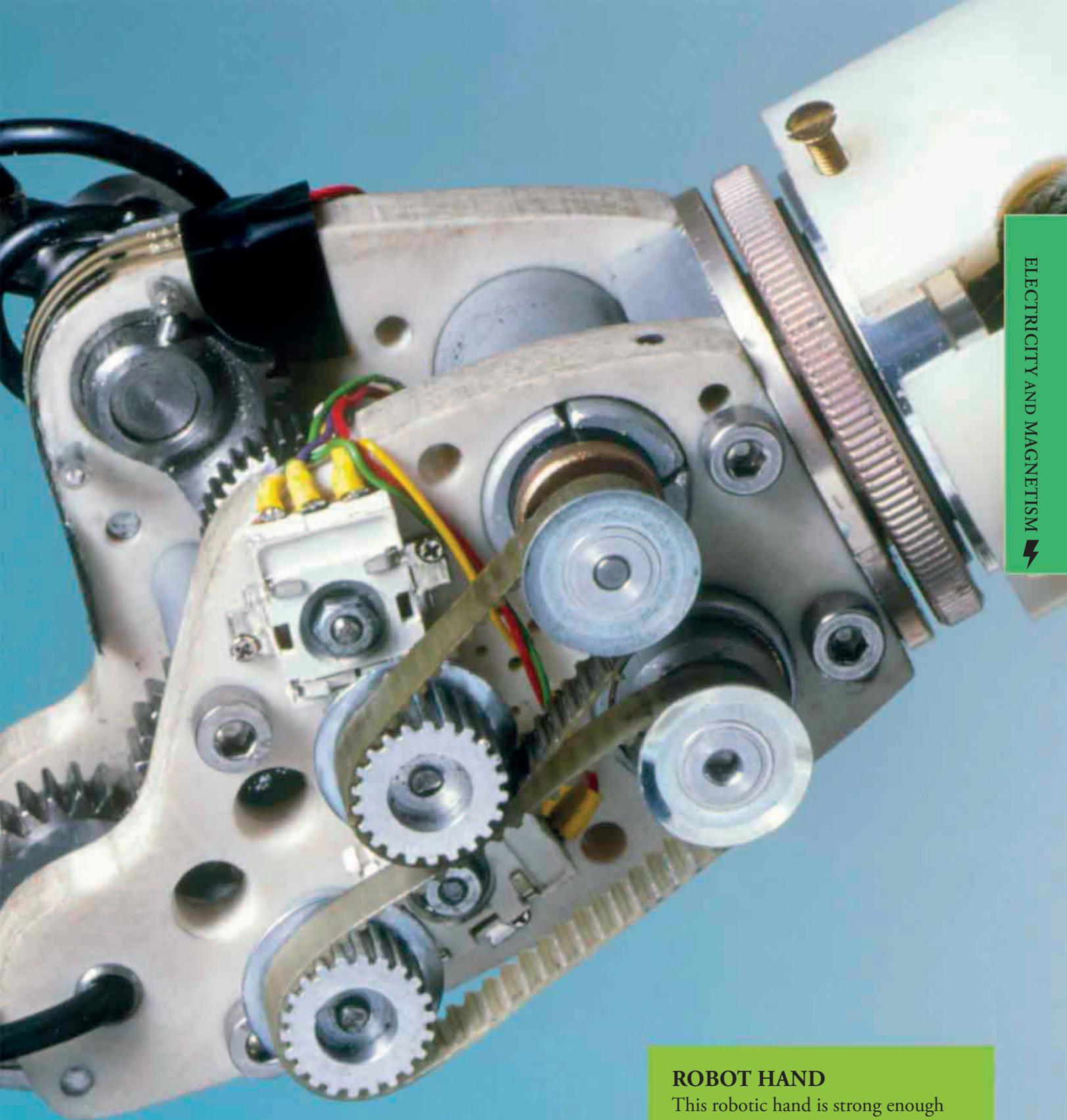


Eight electric motors in face produce anger, surprise, and other expressions.

Thirty electric motors in body help Miim walk realistically and even dance.

▲ **ROBOT OR PERSON?** “Miim” (official name HRP-4C) is a friendly Japanese robot that can speak, sing, and model clothes on a catwalk. Robots made to look like humans are called androids.





## ROBOT HAND

This robotic hand is strong enough to pick up heavy objects, but delicate enough to hold an egg without breaking it. It was designed for people who have lost a hand. The robot replacement can turn and grip, and has sensors on the fingers to make sure it doesn't squeeze too hard.

# Future technology

The new ideas and inventions of today could transform everyday life in the future. Electric vehicles gliding down the street, tiny robots zooming through our blood, endless energy captured from atoms—all this new technology could arrive in our lifetime. People have been making amazing inventions since the beginning of history. For thousands of years, technology has helped us make the world a better place.



## HELPING HANDS

In the future, computers and machines will be with us all the time. We might wear glasses that tell us where we are so we never get lost, or clothes that transform depending on the temperature so we never get too hot or too cold.

◀ **GOOGLE GLASS** *These futuristic goggles project information onto a miniature computer screen right in front of your eyes.*

## BUILDING WITH ATOMS

The only materials we have today are ones we can find buried underground or ones we design for ourselves in laboratories. Someday soon, we'll be able to make any material we want by building it out of atoms and molecules. This is called nanotechnology.

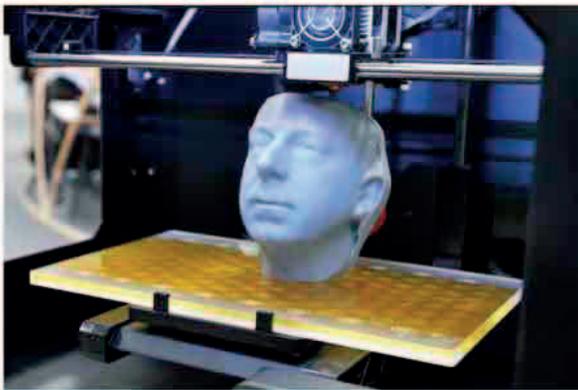
▼ **NANOBOTS** *It's hard to cure serious illnesses without risky surgery. In the future, we could swallow nanotechnology robots to repair our bodies from the inside.*



## CLEAN, GREEN MACHINES

There is only one planet Earth, so we must take care of it. We need to use energy more wisely and create less pollution. One way to do this is to stop powering cars, ships, and planes with fossil fuels and use more electricity-powered vehicles. Electric vehicles are much “greener” because we can make the electricity using clean solar, wind, or water power.

► **SOLAR BOAT** *Instead of a diesel engine, this boat is powered by giant solar panels fixed to its roof. They drive an electric motor that spins the propellers.*



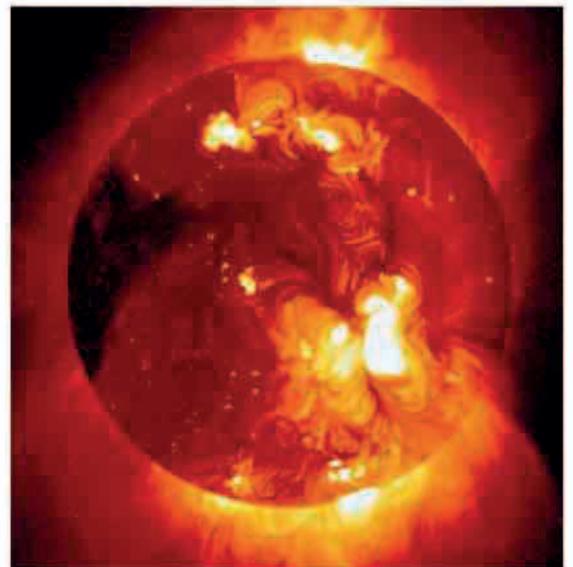
▲ **GETTING AHEAD** *This 3-D printer is making a model of someone's head by slowly printing layers of melted plastic on top of one another.*

## MAKE IT YOURSELF

You can buy all kinds of things in stores, but they might not be exactly the size, shape, or color you want. What if you could make any object you wanted, whenever you wanted? That's what a 3-D printer does. It works like an ordinary computer printer except that, instead of using ink, it sprays soft plastic onto a board to build up a 3-D object.

## ENERGY FOREVER

In 30 years, the world could be using 50 percent more energy. Where will we find it? Nuclear fusion (smashing atoms together) could be one way of making clean energy without harming the planet. This is the process by which energy is created inside the sun. If we could build safe nuclear fusion plants on Earth, we could have clean energy forever.



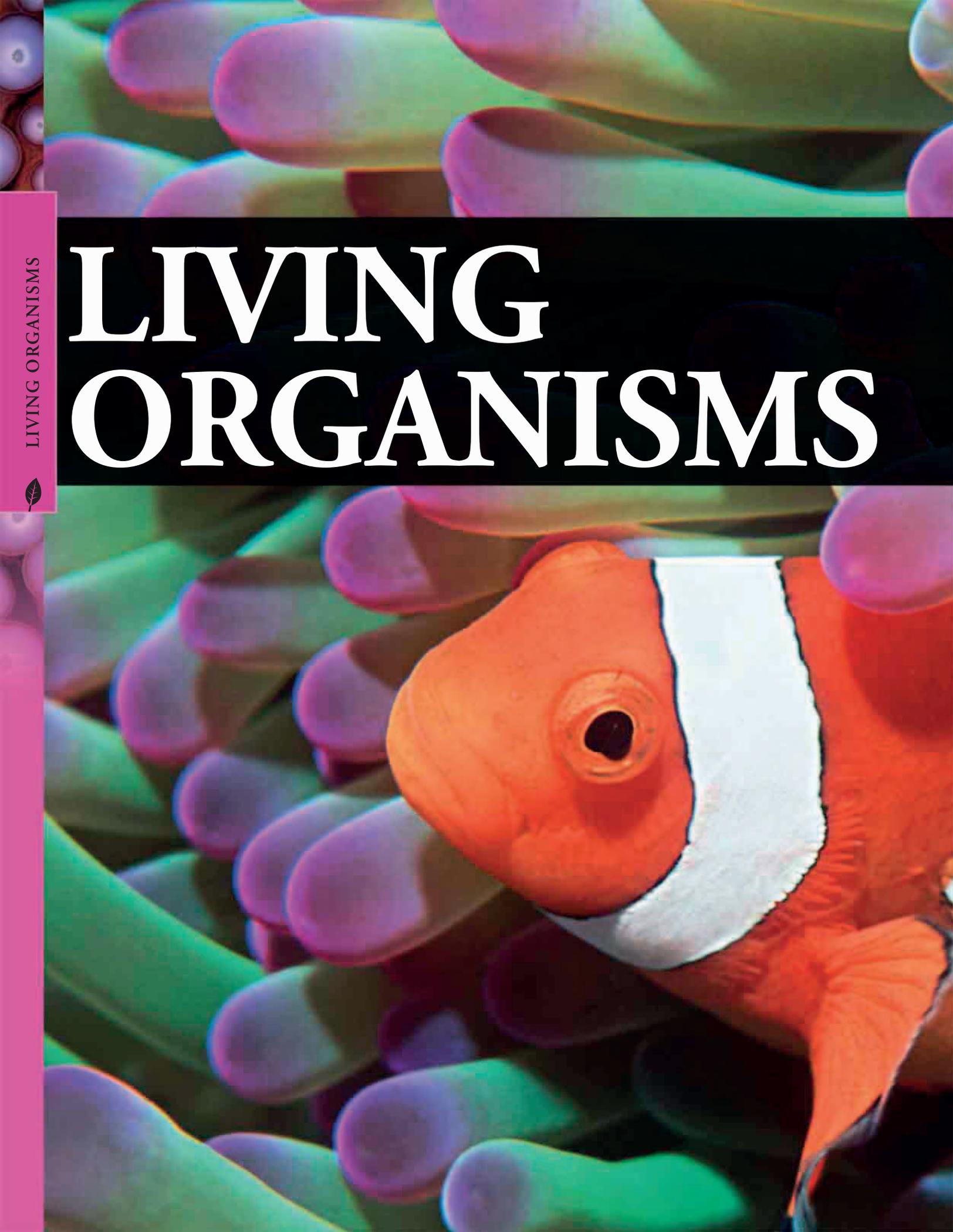
▲ **SUN'S ENERGY** *Nuclear fusion inside the sun releases vast quantities of energy into space.*

WOW!

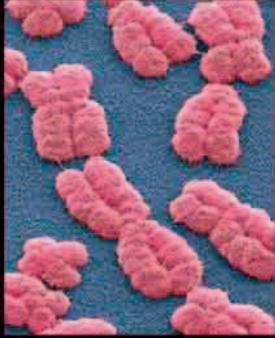
More than half a million new inventions are patented (registered) each year in the United States alone.

*Tiny microchip "brain" programs nanobot to kill germs.*





# LIVING ORGANISMS



Our planet is full of living things, from tiny germs to giant trees, deep-sea fish to high-flying birds. Biology is the science of how living things work.



### LIVING PARTNERS

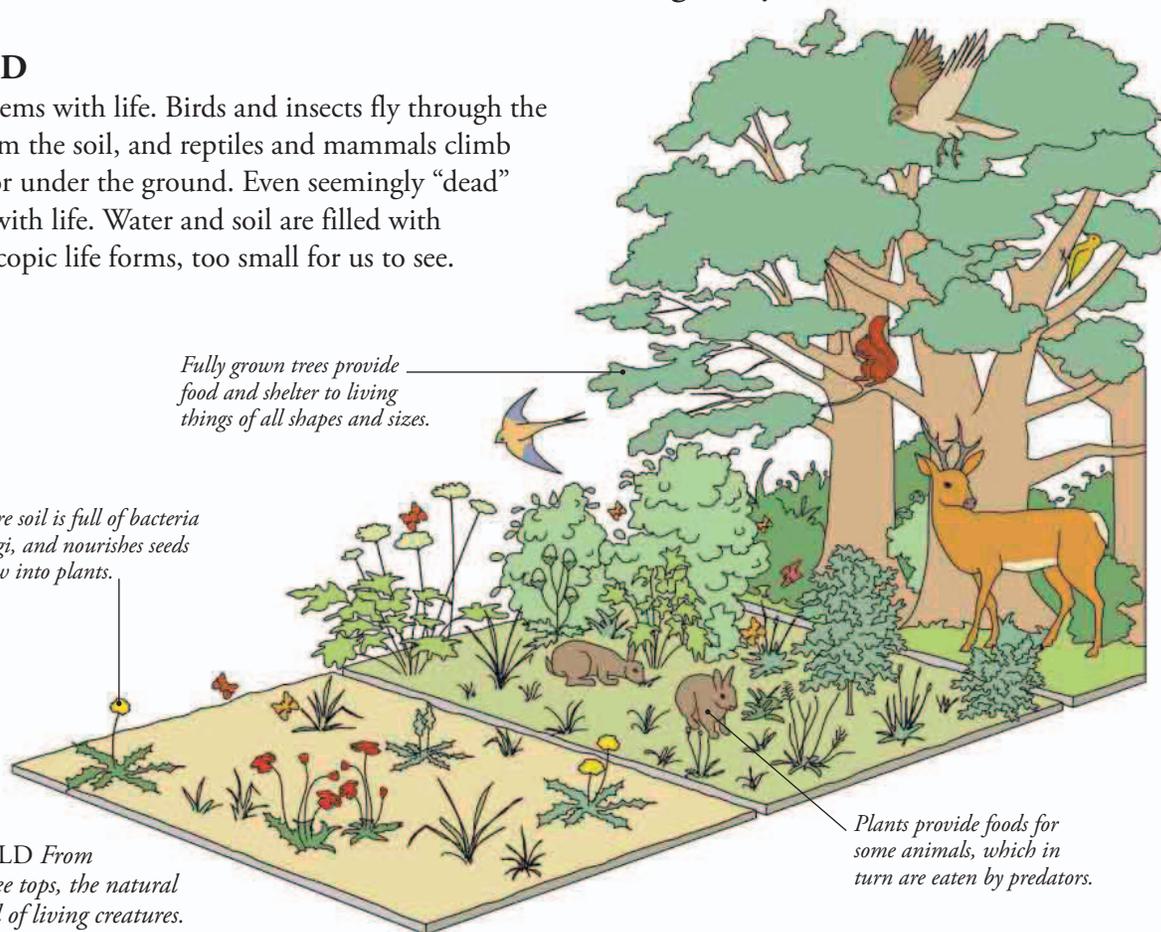
Sometimes two different species of living creatures form a partnership, known as symbiosis. This poisonous anemone protects the clownfish from attackers. In return, the fish keeps the anemone clean.

# Life on Earth

Almost every corner of planet Earth has life. Even tall mountains and frozen polar seas are home to amazingly tough animals and simple plants. But living things flourish best where it's warm and damp or wet—so tropical rain forests and coral reefs are filled with a dazzling array of life.

## LIFE ALL AROUND

The world around us teems with life. Birds and insects fly through the air, plants spring up from the soil, and reptiles and mammals climb the trees and crawl on or under the ground. Even seemingly “dead” matter is often packed with life. Water and soil are filled with vast numbers of microscopic life forms, too small for us to see.



Fully grown trees provide food and shelter to living things of all shapes and sizes.

Even bare soil is full of bacteria and fungi, and nourishes seeds that grow into plants.

Plants provide foods for some animals, which in turn are eaten by predators.

► **LIVING WORLD** From lowlands to high tree tops, the natural world is packed full of living creatures.

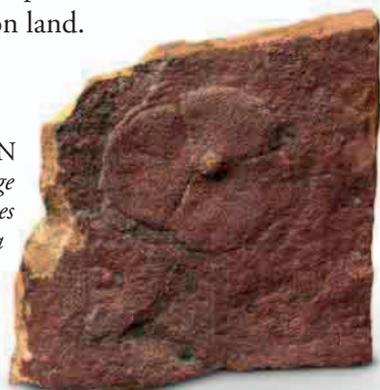
## EARLIEST LIFE

Fossils are the remains of once-living things preserved in rocks. They show there were small, simple forms of life in the sea more than 3 billion years ago.

By 400 million years ago, plants and then animals appeared on land.

### ► FOSSIL IMPRESSION

Fossil imprints of strange soft-bodied creatures in the rocks of Ediacara Hills, South Australia, date back more than 550 million years. Many have no living relatives.

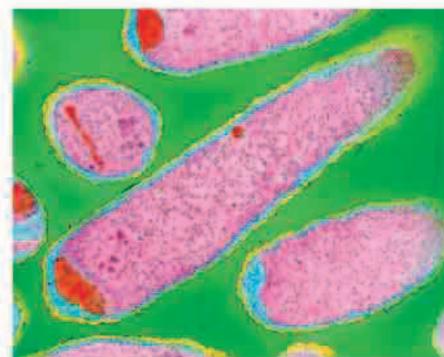


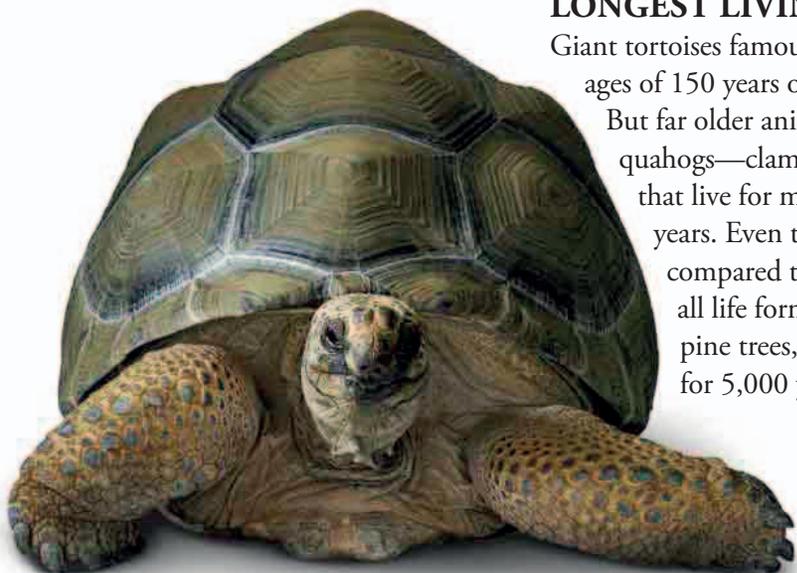
## SIMPLEST LIFE FORMS

The simplest life forms are known as prokaryotes. They are made up of only a single tiny cell, which can break down chemicals around it to obtain energy. To breed, they usually split into two identical clones.

### ► BACTERIA

One of the two groups of prokaryotes, bacteria were some of the first living creatures to appear on Earth.



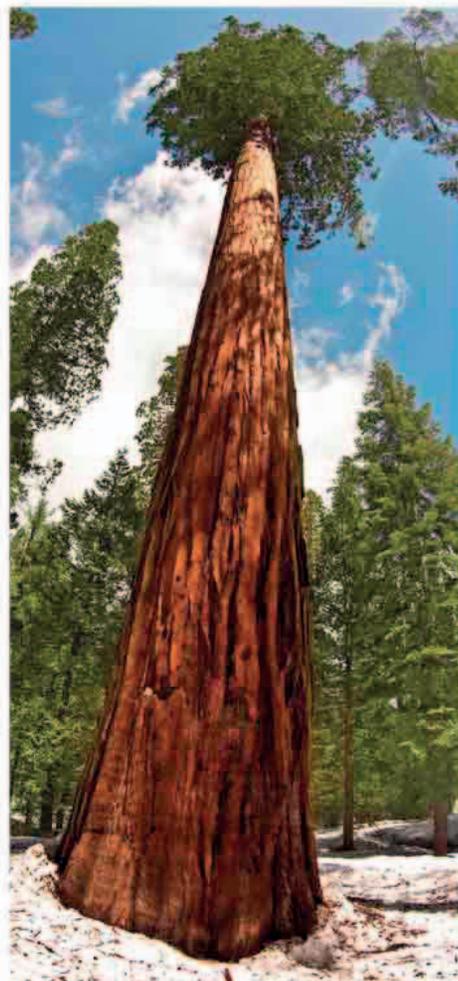


▲ **LONG-LASTING** *Some giant tortoises have been measured at 180 years of age. Others are claimed to be more than 220 years old.*

## LONGEST LIVING

Giant tortoises famously reach great ages of 150 years old or more.

But far older animals are ocean quahogs—clamlike shellfish that live for more than 500 years. Even these are young compared to the oldest of all life forms—bristlecone pine trees, which can live for 5,000 years.



▲ **FOREST GIANTS** *These giant redwoods are the heaviest living things, but their relatives, the coast redwoods, are taller, at up to 377 ft (115 m).*

## BIGGER THAN ALL

At 279 ft (85 m) high and 2,204 tons (2,000 metric tons) in weight, giant redwood trees are the biggest living things on Earth. Among animals, the blue whale is the largest—larger than even the great dinosaurs of long ago. The blue whale is 98 ft (30 m) long and weighs almost 220 tons (200 metric tons).

WOW!

Tardigrades are microorganisms, about 0.02 in (0.5 mm) long. They can survive extreme conditions—even outer space.

## IN LARGE NUMBERS

Except for worms and bugs such as flies, one of the most numerous wild animals is the red-billed quelea of Africa. However, among domesticated animals, chickens beat them, with a world population of over 20 billion—that's three chickens for every human.



◀ **FLYING FLOCK** *There are about 1.5 billion red-billed queleas in the world. They are called "feathered locusts" because they eat so many farm crops.*

## IS IT EVEN ALIVE?

The lithops plant has leaves that look just like pebbles. Their shape, size, and color makes them resemble small stones in their natural surroundings. They hardly grow or change at all, sometimes for years, earning the name "living stones." Then, suddenly, the plant produces new leaves or flowers.



▶ **LIVING STONES** *Lithops blend in with stones as a means of protection, so animals rarely notice and eat them.*

# Classifying life

There are millions of different types of living things on Earth. To understand how they relate to each other, scientists arrange them into groups. This is called classification. Some groups are easy to identify—for example, all mammals feed their young on milk—but others are more complicated.

## GROUPING ORGANISMS

Scientists sort all living things into species. Organisms that can breed with each other are said to be the same species. Lions are a species, and so are humans. Species are grouped into larger and larger groups called families, orders, and classes. The biggest groups are called kingdoms, which are separated by how the organisms within them obtain the energy they need to live.

WOW!

Scientists estimate that there are as many as 9 million species of life on Earth. More than 6 million of these are yet to be discovered.

### MICROLIFE

Some living things are so tiny, they can be seen only through a microscope. Each one is often made of a single unit, or cell. These single-celled life forms are neither plants nor animals. Some gain their energy from sunlight, as plants do, while others “eat” other organisms.



Paramecium are single-celled organisms found in freshwater.

### FUNGI

Most fungi feed on dead or dying plants and animals, by making them rot or decay. They then soak up nutrients and energy from the rotten food by absorbing them into their cells. We mostly see fungi when they grow as molds, mushrooms, and toadstools.



Toadstools are fungi with a round cap on a short stem.

### PLANTS

A plant gets its energy from the sun. Substances in its body, usually in the green leaves, catch the energy in sunlight and use it to make sugars. The plant also takes in water and nutrients from the soil, and uses the sugar energy to grow.



African daisies are colorful flowers that flourish in sunlight.

### INVERTEBRATES

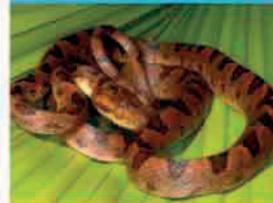
Animals get their energy by eating food, usually plants or other animals. Invertebrates are animals without backbones, such as worms, snails, insects, spiders, crabs, and starfish. They are mostly small but incredibly numerous.



Ladybugs are a type of insect, the biggest group of invertebrates.

### VERTEBRATES

Animals with inner skeletons and backbones are called vertebrates. Fish, amphibians, reptiles, birds, and mammals (including humans) are all vertebrates. They are usually larger than invertebrates, but exist in smaller numbers.



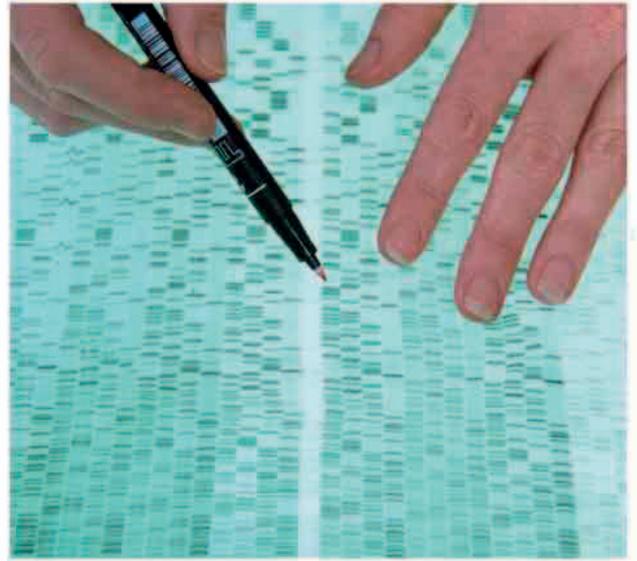
Snakes, such as this northern cat-eyed snake, are reptiles.

## FINDING RELATIVES

Humans have been working to classify living things for thousands of years. The earliest classifications were based on recognizing similar features in plants and animals, such as the way they feed their young, or the way their limbs are formed. Today, our understanding of genetics and evolution allows us to look at the DNA of living creatures to figure out which ones have developed from the same kinds of ancestors.



▲ **SIMILAR SHAPES** *The rhinoceros (left) and the tapir (right) have similarly shaped bones in their feet. This and other similarities show that they are part of the same order (called “odd-toed ungulates”).*



▲ **RELATIVE DNA** *By comparing the DNA of different species, scientists can look for links to creatures that lived long ago. This allows them to figure out how different things evolved, and how they are related.*



▶ **VELVET WORM** *These creatures creep across the floors of tropical forests, where they prey on insects.*

Stubby, leglike appendages

## HARD TO CLASSIFY

Nearly all worms lack legs. But velvet worms have many pairs of stubby legs, as well as a bendy body like a worm or caterpillar. These creatures live in tropical forests and catch prey, such as insects, by squirting them with slime. Experts are not sure which other animals are their closest relatives. They are classified in their own group, Onychophora.

## RULE BREAKERS

Some living things have evolved very differently from others in the same group, sometimes taking up a different way of life. Plants such as the Venus flytrap, sundew, and pitcher plant get most of their energy from light, but they also “eat” small creatures by trapping and dissolving their bodies. The tiny animals that make coral reefs can absorb energy from sunlight, as plants do, by partnering with microorganisms living inside them.



▲ **VENUS FLYTRAP** *Unlike most plants, this species can “eat” insects. Its leaves snap shut to trap wandering flies inside.*



▲ **CORAL POLYPS** *These polyps manage to gain energy from sunlight, as plants do, thanks to microorganisms living inside them.*



# DNA and genes

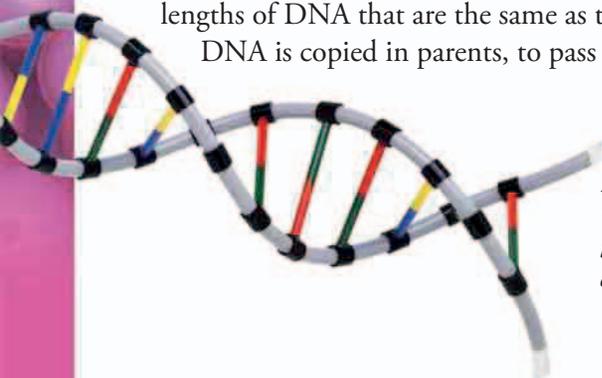
Animals start life as a single tiny cell called a zygote that slowly grows into a full-sized body. The instructions for how this happens are contained in the form of chemicals called deoxyribonucleic acid (DNA). Adults produce young, and pass their DNA on to them. This means offspring look similar to their parents.

WOW!

About half the genes in a human being are the same as the ones in a banana.

## WHAT IS DNA?

DNA is a long, thin molecule that can be found in almost every cell in your body. Each length resembles a ladder twisted like a corkscrew, known as a double helix. DNA can copy itself by dividing into halves. Each half then copies itself, resulting in two lengths of DNA that are the same as the original. This is how DNA is copied in parents, to pass on to their offspring.



◀ TWISTED LADDER  
*To divide in half, DNA splits lengthwise—midway across each “rung” of the ladder.*

## GENES

Each gene is a piece of DNA that carries information to make a protein, and proteins are the building blocks of bodies. Together, our genes decide the size, shape, and color of our bodies, as well as how each organ works, such as a muscle that pulls, an eye that detects light, and a stomach that digests food.

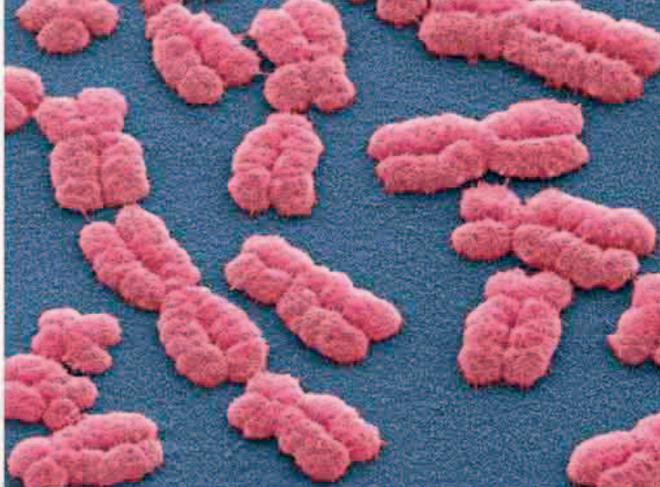


▲ GENES FOR EVERY BODY PART *Cats’ genes have instructions to make all parts, including eyes, ears, claws, and different colors of fur.*



## CHROMOSOMES

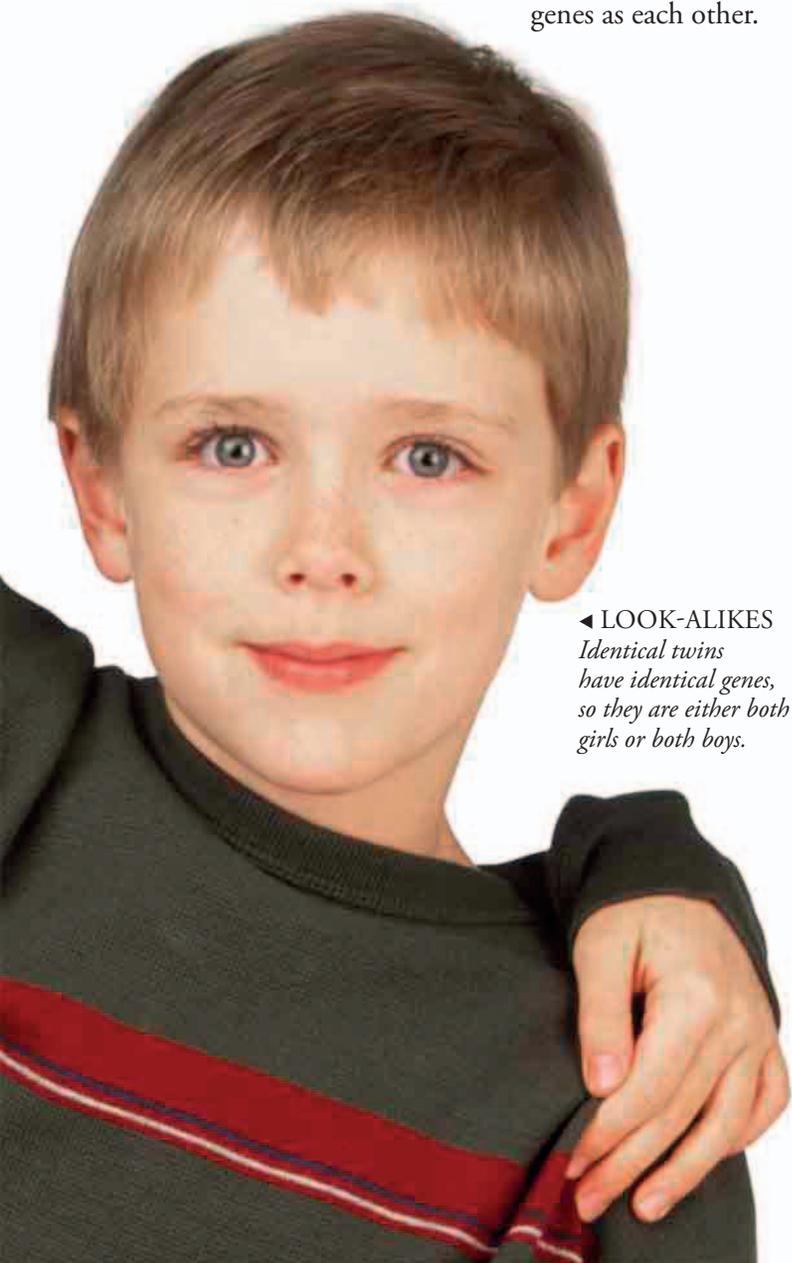
Information in DNA is carried by the order of the various chemical parts along the “rungs” of its ladder. In each living thing, the DNA comes in separate lengths called chromosomes. A human body has two sets of 23 chromosomes, one set from each parent. A pigeon has two sets of 40, and a mosquito has two sets of three.



► **X SHAPE** *When the length of DNA in a chromosome folds and coils up, it forms an X shape. These are human chromosomes seen under a microscope.*

## SAME BUT DIFFERENT

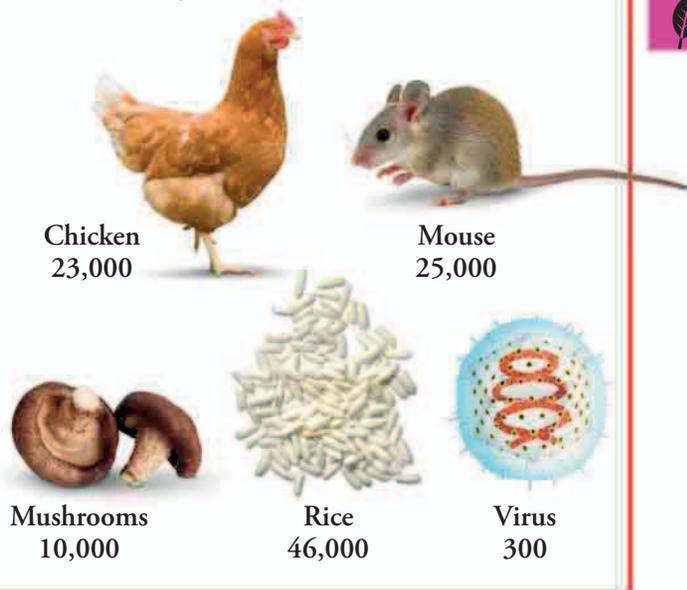
The way that genes are passed on means that each offspring receives a slightly different combination of genes than its parents and siblings. So sisters and brothers resemble each other and their parents, but each individual has slightly different features. That is, except for identical twins, who have exactly the same genes as each other.



◀ **LOOK-ALIKES**  
*Identical twins have identical genes, so they are either both girls or both boys.*

## HOW MANY GENES?

Different species of living things have different numbers of genes. However, bigger ones do not always have more. Some tiny plants and creatures have huge numbers, while some big animals and trees have fewer. A human has around 20,000 genes.

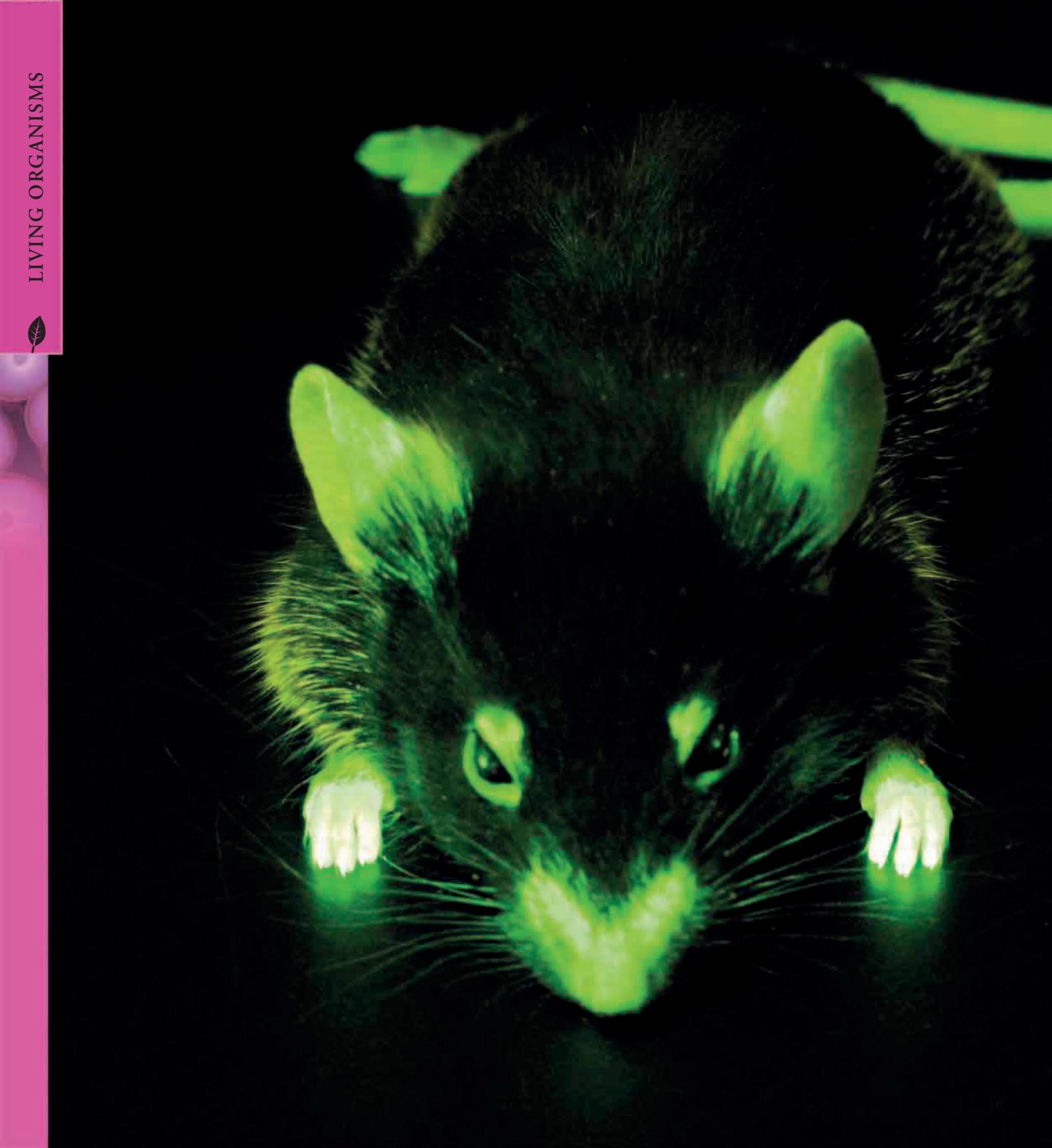


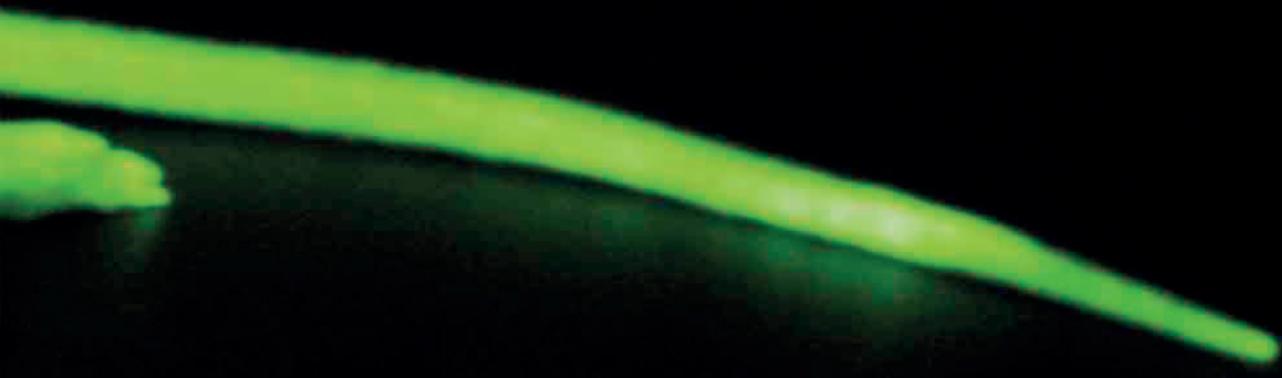
## UNUSUAL GENES

Sometimes, genes change because DNA does not copy itself exactly. The changed gene may make an animal or plant look and work differently. For example, if the genes for the color of skin, fur, or feathers do not work properly, the result is a mainly white animal called an albino.

► **WHITE BIRD**  
*This albino hummingbird has unusual genes, giving it white feathers but pink legs and a pink beak.*







### **THE POWER OF GENETICS**

By adding genes from one organism to the DNA of another, we can change the chemicals produced inside its body. This mouse has had jellyfish genes added to its DNA, so its skin glows in the dark. Other experiments have created crops that are resistant to disease, or that produce tastier fruit.

# Evolution

Species of animals and plants change because of genetic variations that occur with each group of offspring. Organisms born with more advantageous features will be more likely to survive. These features are passed on to future generations in a process known as natural selection. Over millions of years, this has allowed primitive life forms to develop into complex animals and plants.

## ADAPTATION

Each animal or plant has features or adaptations to help it stay alive. Desert creatures cope with extreme heat and little water, while polar animals use extra fur, feathers, or fat to stay warm. This also means that most living things can survive only in their own habitat, so parrots cannot live on icebergs, and penguins cannot live in tropical forests.

► ADAPTED TO THE DESERT *The Bactrian camel has many adaptations to cope with the lack of water, intense summer heat, and severe winter cold in its Asian desert home.*

*Hump of fat stores energy.*

*Long eyelashes keep out sand.*

*Thick fur keeps out cold in winter.*

*Wide hooves spread weight on soft sand or snow.*

WOW!

Out of every 1,000 species that have ever lived on Earth, 999 have become extinct.



## EXTINCTION

Over thousands or millions of years, as new species appear or evolve, others gradually die out, or become extinct. This happens because some species cannot evolve fast enough and alter their adaptations to cope with the changing environment and new species around them. This has happened for billions of years, ever since life first appeared on Earth.



▲ **WOOLLY MAMMOTH** *This mammoth evolved to survive Ice Age conditions, but after that it could not survive the warming climate or protect itself from being hunted.*

## SURVIVAL TACTICS

Living things have many kinds of adaptations that help them survive, such as big teeth and claws in predators, and long legs in prey for running away fast. Many creatures are camouflaged—that is, they are colored so that they blend into their surroundings. This makes them harder to see, so they can hide from predators or sneak up on prey.



▲ **GREEN ON GREEN** *The green iguana lizard is the same color as the leaves of its forest home. This camouflage works best if it stays still when enemies are near.*

## EVOLVING TOGETHER

Living creatures evolve (adapt) to cope with their surroundings, and with other organisms living alongside them. Sometimes, very different organisms can look very similar because they have adapted to live in the same environment—for example, whales and dolphins are mammals, but their bodies are shaped like fish to help them move through the water easily. Some species have evolved to live in partnership with each other, while others have taken on the colors of dangerous creatures so that predators avoid them.



Dolphin



Shark

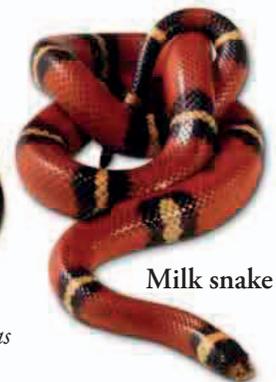
◀ **LOOK SIMILAR** *The dolphin is a mammal and the shark is a fish. But they have evolved to have similar streamlined body shapes to swim at high speed in water. This is known as convergent evolution.*



◀ **INTERDEPENDENCE** *Yucca moth caterpillars eat the seeds of the yucca plant. In return, the moth carries yucca pollen so the seeds can develop. This is called coevolution.*



Coral snake



Milk snake

▲ **LOOK DANGEROUS** *The milk snake has no venom, but it has evolved to look like the venomous coral snake. This is called mimicry.*



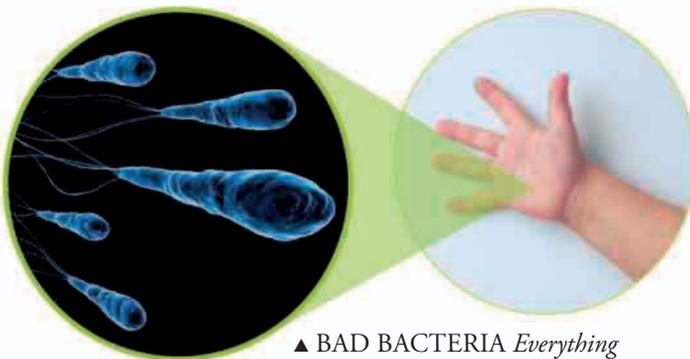
# Simple life forms

All living things are made of tiny parts called cells, which are so small they can only be seen through a microscope. The human body has more than 100 trillion cells (see p.260). But many forms of life have just one cell each. Some get energy from light (as plants do). Others are like animals and eat even smaller things. Still others do both.

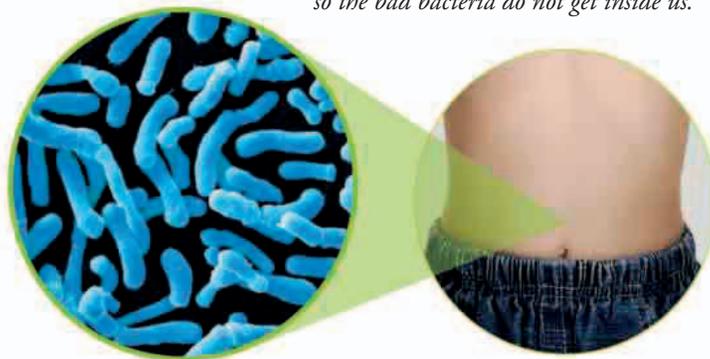
## BACTERIA

Bacteria are simple cells with few parts inside. They are so tiny that about 100,000 bacteria would fit in this “o.” Bacteria live by the trillions almost everywhere—in soil and water, on rocks, walls, and floors, under icebergs, in boiling-hot springs, and on and inside living things.

Some bacteria cause illness and make up one of the groups of harmful life forms we call germs. Some bacteria are helpful to humans and can protect us from illness. Others are used to make food such as yogurt and cheese.



▲ **BAD BACTERIA** *Everything we touch contains many kinds of bacteria. Washing our hands helps get rid of them so the bad bacteria do not get inside us.*



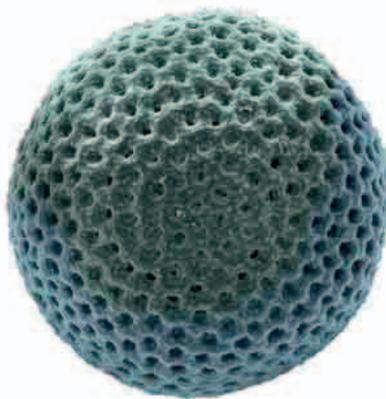
▲ **GOOD BACTERIA** *There are millions of helpful bacteria inside our guts. They can destroy harmful bacteria and help digest our food.*

## MANY DIFFERENT TYPES

There are more than 100 main groups of single-celled living things. Diatoms are like miniplants that live in any water, from damp gutters to the open ocean. Forams mostly live in the sea and catch bits of food using long tentacles. Flagellates swim along by waving long, thin parts known as flagella.



▲ **DIATOMS** *These make cases around themselves out of silica, the mineral of sand, in amazing shapes such as balls, pyramids, and boxes.*



▲ **FORAMS** *A foraminiferan builds a shell, or test, with small holes for its tentacles. The test lasts after the foram inside dies.*



▲ **FLAGELLATES** *Some flagellates collect energy from sunlight; others feed on tiny prey. They thrash their flagella to and fro like long whips to move around.*

## INSIDE THE CELL

Single-celled organisms can be divided into two different types based on their cell structures. Some, such as bacteria, have just a few separate parts inside the cell, and no blob-shaped nucleus or control center. These organisms belong to the group of single-celled organisms known as prokaryotes. Other single-celled creatures, called eukaryotes, do have a nucleus.

**Flagella**  
Long and thin, spin around to help bacterium move

**Pili** Short "hairs" that help bacterium contact others for breeding

**DNA** One long length of genetic material carrying genes

► **INSIDE A BACTERIUM**  
This sausage-shaped bacterium is shown about 10,000 times larger than life. Bacteria have many other shapes, from balls and rods to hooks and corkscrews.

**Cell wall** Thick outer container to protect the insides

**Cell membrane** Controls what goes in and out of bacterium



## GERMS AND DISEASE

More than 2,000 kinds of single-celled living things produce illness in humans. Bites of certain mosquitoes spread a microbe called plasmodium that causes the serious fever malaria. Bacteria in bad food or dirty water multiply in the gut to cause vomiting and diarrhea, as in cholera or typhoid. Single-celled fungi cause itchy redness in nail infection and athlete's foot. Viruses that are spread by sneezes and coughs produce colds, flu, and measles.



**Plasmodium:**  
Malaria



**Bacteria:**  
Cholera



**Fungus:**  
Nail infection



**Virus:**  
Cold, flu



LIVING ORGANISMS





### GRAND PRISMATIC SPRING

This lake in Yellowstone Park gets its amazing colors from tiny bacteria. The lake sits above a volcano. Magma (hot rock from beneath the earth's crust) bubbles up below the lake. This heats the water and brings up minerals, creating the perfect environment for bacteria to thrive.

# Fungi

A fungus gets its energy and nutrients from other living things—or, more often, dead ones. The fungus makes substances called enzymes that ooze out of it, into the dead bodies of plants or animals. These enzymes break down the body into nutrients that the fungus can absorb for food.



## FUNGAL NETWORK

A fungus feeds using long, threadlike parts called hyphae. These grow through the soil, into and around dead plants and animals of all kinds. The hyphae form a network called a mycelium. They cause decay and rotting, and take in the nutrients.

◀ **WHITE THREADS** *These pale threads, hyphae, form a weblike net in the soil.*

## FUNGAL SPORES

A fungus breeds by making tiny, seedlike spores. To do this, the fungus grows upward through the soil and produces a part above the surface, which is the fruiting body—usually called a mushroom or toadstool. This makes millions of spores that float away in the wind to grow elsewhere.



◀ **PUFFING SPORES** *The puffball is a ball-shaped fruiting body that blows out tiny spores, which look like dust.*

## TASTY AND DEADLY

There are many different kinds of mushrooms and toadstools. Some are tasty and safe to eat.

But others are poisonous and can cause serious illness, sometimes even death. There is no simple way to see the difference, and only experts can tell which wild mushrooms are safe and which are dangerous.



◀ **DELICIOUS** *Fungi such as button mushrooms are sold in markets. They are safe and tasty to eat.*

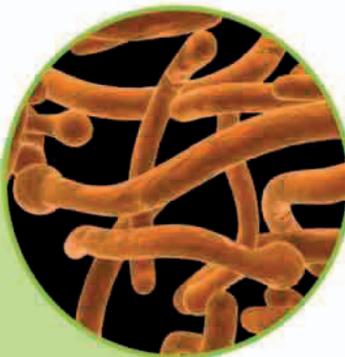


## USEFUL FUNGI

Fungi grow on rotten food, which can be dangerous to us if we eat it. But they also have many uses. In nature, they help turn plant and animal remains back into useful soil. We also use a kind of fungus called yeast to make fresh bread and to brew beer.



◀ **BREAKDOWN**  
*When fungi grow on something, they begin to break it down. We say it has gone moldy or rotten.*



▲ **BUILDUP** *Yeasts are microscopic fungi. They produce gas bubbles that make bread rise.*

## COMPOST HEAP

Fungi are nature's recyclers. In a compost heap, many kinds of fungi rot down bits of plants—for example, leaves, shoots, flowers, cuttings, and leftover food such as vegetable peelings. After weeks or months, the result is brown, crumbly, and nutrient-rich, and ready to be added back into the soil.



*Well-rotted  
compost*

## BRACKET FUNGI

Some fungi grow on the sides of trees and other wood, forming round ledges like curved shelves. These are bracket fungi. They send their stringlike hyphae into the tree's wood to get nutrients. After a while, bracket fungi may cause the tree to sicken and die. Some brackets grow so large and hard that people can stand on them.

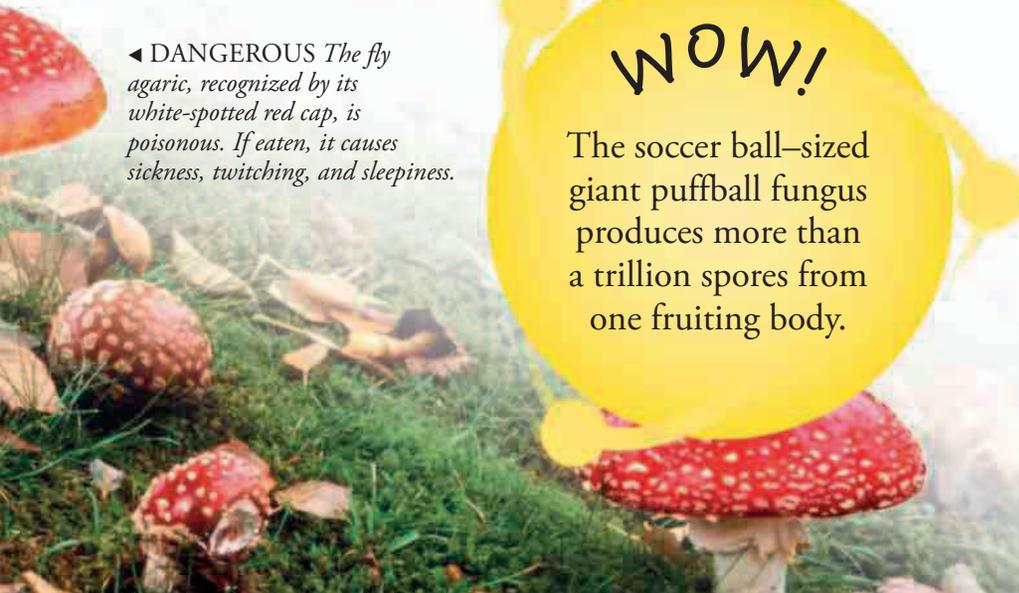


▲ **SCARLET BRACKET** *This bracket fungus from Australia and New Zealand ranges from brown to red-pink. It grows on living trees and dead stumps.*

◀ **DANGEROUS** *The fly agaric, recognized by its white-spotted red cap, is poisonous. If eaten, it causes sickness, twitching, and sleepiness.*

**WOW!**

The soccer ball-sized giant puffball fungus produces more than a trillion spores from one fruiting body.



# Plants

Like other major groups of living things, plants are usually identified by how they get their energy—by using sunlight to build up complex substances from simple ones (see p.232). Most plants are green, but some have red or yellow leaves and other parts.

## TYPES OF PLANTS

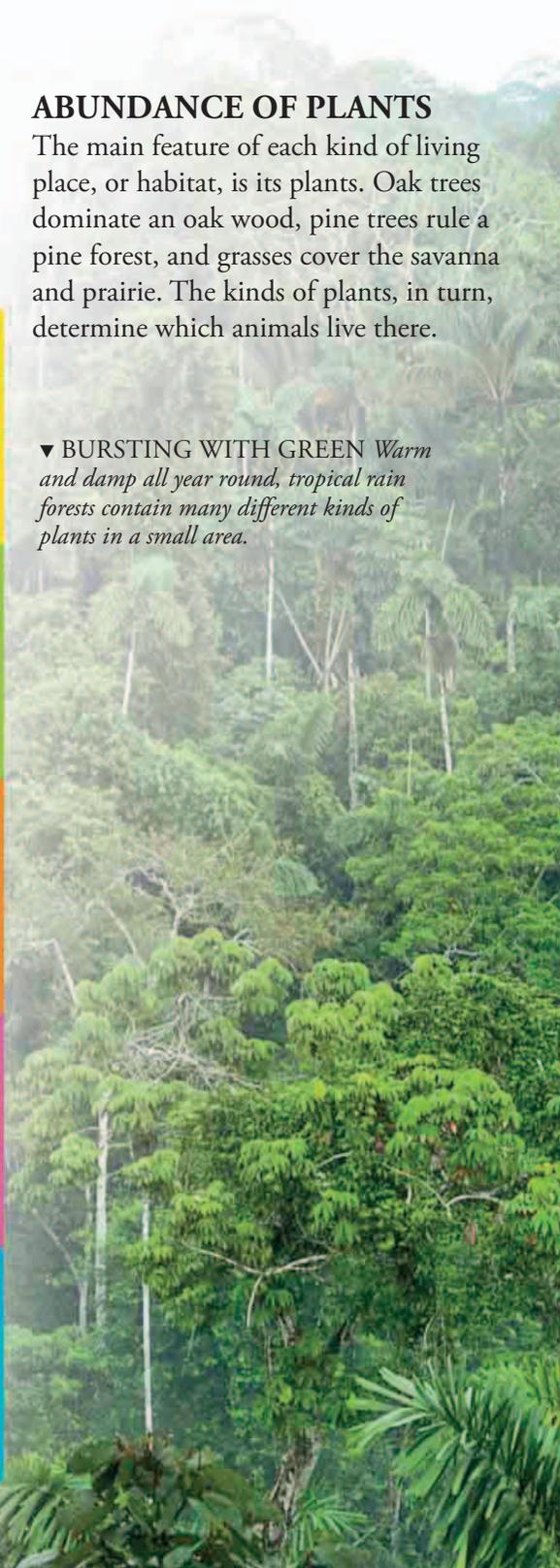
Most plants are made of the same vital parts—roots, stems, and leaves. The main subgroups of plants are divided by the way they breed or reproduce, and by which special parts they have.

<b>ALGAE AND SEaweEDS</b>	Some experts do not classify these as true plants. They range from tiny—just a few cells—to giant seaweeds as big as trees.	
<b>MOSSES</b>	Most mosses are small, with simple leaves on short stems, and no proper roots. They breed using spores (see p.234).	
<b>FERNS</b>	A typical fern has tubes in its stems that end in leaflike fronds, and roots to take in water and nutrients, but no flowers.	
<b>CONIFERS</b>	Nearly all conifers have needlelike leaves that they keep all year round. They make their seeds in woody cones.	
<b>FLOWERING PLANTS AND TREES</b>	The biggest plant group, these are the most complex plants, with flowers that produce seeds, often in fruit.	

## ABUNDANCE OF PLANTS

The main feature of each kind of living place, or habitat, is its plants. Oak trees dominate an oak wood, pine trees rule a pine forest, and grasses cover the savanna and prairie. The kinds of plants, in turn, determine which animals live there.

▼ **BURSTING WITH GREEN** *Warm and damp all year round, tropical rain forests contain many different kinds of plants in a small area.*

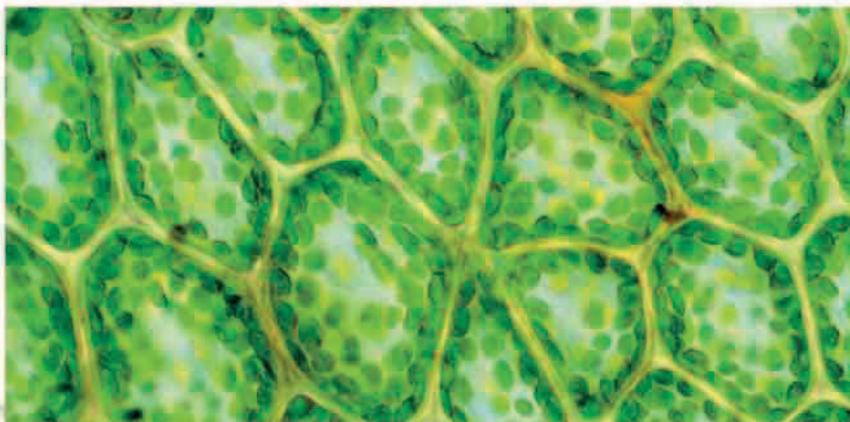




## PLANT CELLS

Under the microscope, plant cells differ from animal cells. A typical plant cell has a thick, stiff outer covering called the cell wall. It also has baglike, liquid-filled parts inside known as vacuoles, and several tiny chloroplasts, which make the plants green and help them produce food.

► **WALLED PATTERN** *Leaf cells are separated by thick cell walls. Each leaf cell has many small green blobs called chloroplasts.*



WOW!

The total weight of all the Earth's plants is 1,000 times more than the total weight of all the animals.

## PLANTS AS FOOD

Nearly all animal life depends on plants, directly or indirectly—herbivores eat the plants, carnivores eat the herbivores, and scavengers feed on dying and dead plant matter. Humans rely on plants too, grown in farms, orchards, and greenhouses.



### ◀ TALLEST HERBIVORE

*The giraffe can reach leaves up to 23 ft (7 m) high—higher than any other ground-based herbivore.*

## PLANT DEFENSES

Plants have many ways to defend themselves against herbivorous animals. They develop horrible-tasting or poisonous substances, stinging hairs, sharp thorns and spines, and hard casings, as in nuts. Animals soon learn from their parents or their own experience to avoid these types of plants. Other plants simply grow very fast to keep up with being eaten.



▲ **POISONS** *The red color of the poisonous baneberries is a warning that animals learn to avoid.*



▲ **STINGS** *The stinging nettle plant has small hairs on the leaves and stem that break off to release an irritant fluid.*



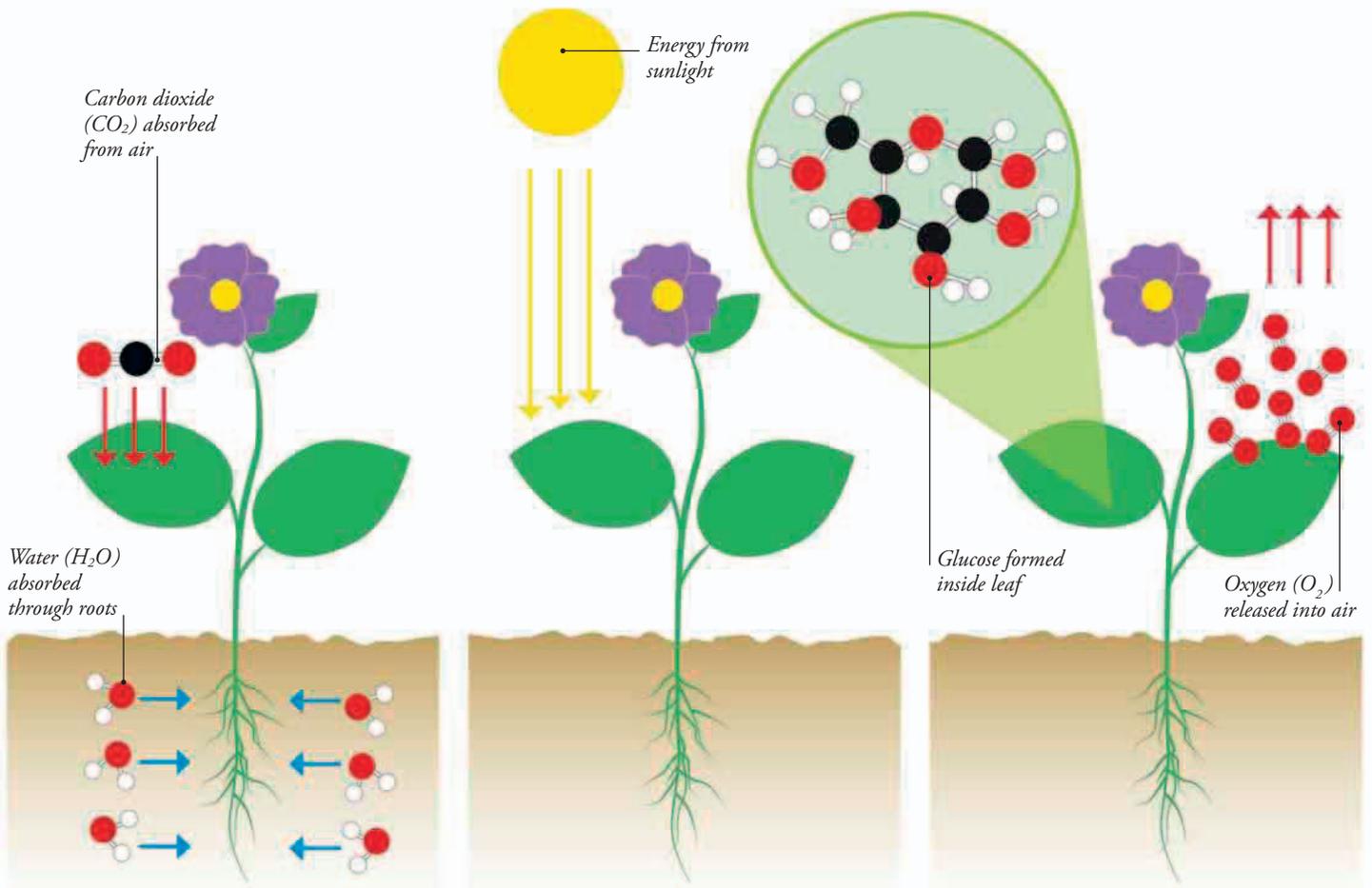
▲ **SPINES** *In a cactus, the leaves have been modified into sharp spines that protect the green stem.*

# Photosynthesis

Plants make their own food through a process called photosynthesis, which means “making with light.” A plant catches the energy in light rays and converts it into chemical energy in sugars. The plant then uses these high-energy sugars to live, develop, and create flowers and seeds that will grow into new plants.

## IN AND OUT

In photosynthesis, the energy from sunlight is used to join carbon dioxide (CO<sub>2</sub>) from the air with water taken in by the plant, usually through its roots from the soil. The result is sugars, or carbohydrates, which spread around the plant dissolved in a fluid, called sap. This process also releases oxygen into the air.



▲ **WATER AND CARBON DIOXIDE** Plants take in carbon dioxide (CO<sub>2</sub>) from the air, and water (H<sub>2</sub>O) from the soil.

▲ **SUNLIGHT** Light, a form of energy, is taken in by leaves. Mainly red and blue colors are absorbed, leaving green to be reflected and give leaves their color.

▲ **GLUCOSE AND OXYGEN** The reaction produces a simple sugar called glucose, and releases oxygen.



## WHERE PHOTOSYNTHESIS HAPPENS

The microscopic cells of a leaf have dozens, sometimes hundreds, of flat disk- or sausage-shaped parts inside known as chloroplasts. These have thin layers of a green pigment called chlorophyll. This pigment helps the plant's leaves trap energy from the sun.

◀ **CHLOROPLASTS** *Each chloroplast is less than 0.01 mm long, with many thin layers inside. A typical leaf cell contains up to 100 chloroplasts.*

# WOW!

Tropical rain forests produce nearly 40 percent of the world's oxygen through photosynthesis.

## LIGHT AND DARK

Plants need light to grow. If a plant does not have enough light, it may grow fast for a while, trying to get above anything nearby that causes shade. But if light is still lacking, eventually it dies.

▶ **NOT ENOUGH** *Compared to the plants grown in normal light on the left, the plants on the right have grown in too little light. They are pale and try to grow too fast.*



## NOT ALL GREEN

The main plant colored pigment, chlorophyll, is green. But a range of other plant pigments also carry out photosynthesis. They include orange or yellow carotenoids (as in carrots), red or yellow betalains, and red, purple, or blue anthocyanins.

### ▶ PIGMENT FOR COLOR

*The flowering plant Solenostemon "Black Prince" has dark purple leaves because of pigments called anthocyanins.*



## NO PHOTOSYNTHESIS

Some plants are not green and do not carry out photosynthesis. They are parasites, stealing nourishment from others. This almost-white plant, called Indian pipe, is a parasite on fungi and trees. Indian pipe is usually found on the remains of dead plants.



Parasitic Indian pipe

# Plant life cycles

Plants have many different ways of breeding. Some simply grow new, smaller plants from parts of their bodies. Others break off leaves, stems, or shoots that grow into new plants. Simple plants, such as mosses and ferns, make tiny, dustlike particles—spores—that grow into new plants. Flowering plants develop flowers that make seeds, which are contained in fruit.

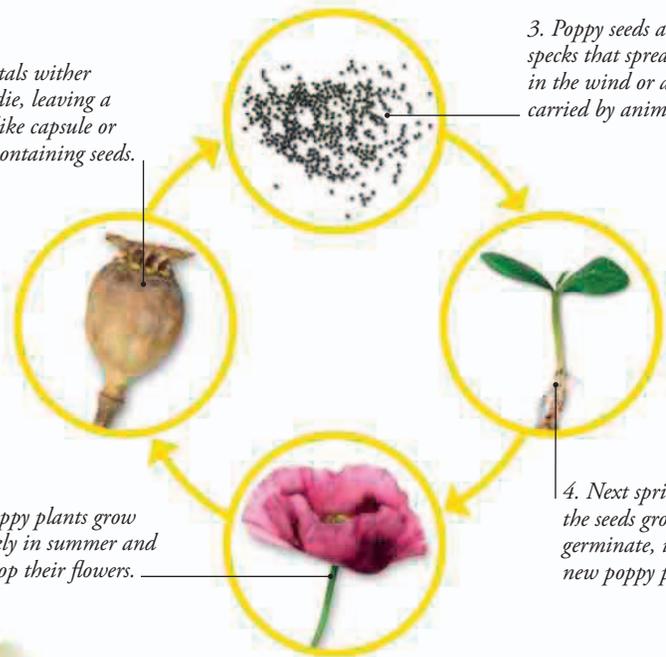
## ONE YEAR OR MANY?

Some plants have a one-year life cycle. They produce flowers that develop seeds. The adult plant dies, but next year the seed grows into a new adult plant and the cycle begins again. Other plants, such as trees, live for hundreds of years.

► **ANNUAL CYCLE** *Plants that have a generation every year, such as poppies, are called annuals. Those which survive many years are called perennials.*

2. *Petals wither and die, leaving a flasklike capsule or pod containing seeds.*

3. *Poppy seeds are tiny specks that spread easily in the wind or are carried by animals.*

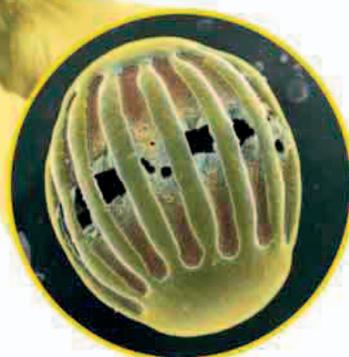


*A flower's bright colors and sweet smell attract insects.*

*Pollen sticks to insects and birds and is carried to new flowers.*

## FLOWERS

The flower, or bloom, is a plant's breeding part. A typical flower has several fanlike petals around a central set of male and female parts. The male parts make pollen; the female ones have unripe seeds. Pollen must reach the female parts so the seeds can ripen.



◀ **POLLEN GRAIN**  
*Bees carry pollen in sacs on their legs. Pollen looks like dust to the naked eye, but under a microscope it has different shapes, such as parachutes, balls, or baskets.*



## THE FOUR SEASONS

Many perennial plants change with the seasons of the year, especially bushes, shrubs, and trees. A deciduous tree (one that sheds leaves annually) blossoms, or flowers, in early spring. Fresh new leaves appear in late spring and early summer. It then starts losing its leaves, usually in fall, when they turn brown, wither, and fall off. In winter, the branches are bare.



Tree blossoms in spring.



Leaves appear in summer.



Browned leaves come off in fall.



Tree is left bare in winter.

## SEEDS AND SPORES

Some plants, such as mosses, liverworts, ferns, and horsetails, grow from spores rather than seeds.

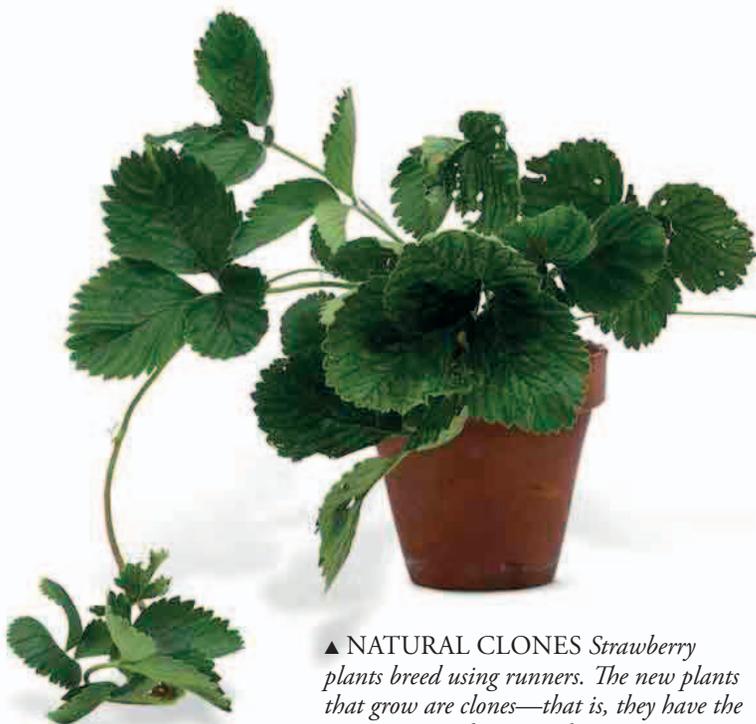
Unlike a seed, a spore has no stores of food for its early growth, or germination. Spores are usually very tiny and blow easily in the wind, then germinate if they find a suitable patch of bare, nourishing soil.



► **FERN BUTTONS** *Ferns, such as this goldfoot fern, grow spores in brown "buttons," called sori, on the underside of the fronds (leaves).*

## GROWING WITHOUT SEEDS

Some plants can create exact copies of themselves without using seeds or fruit. Instead, they send out a special shoot called a runner, or stolon. A new plant grows at the end of the runner, and takes root in the nearest available soil.



▲ **NATURAL CLONES** *Strawberry plants breed using runners. The new plants that grow are clones—that is, they have the same genes as the original.*

*New plants can send out their own runners to grow more clones.*

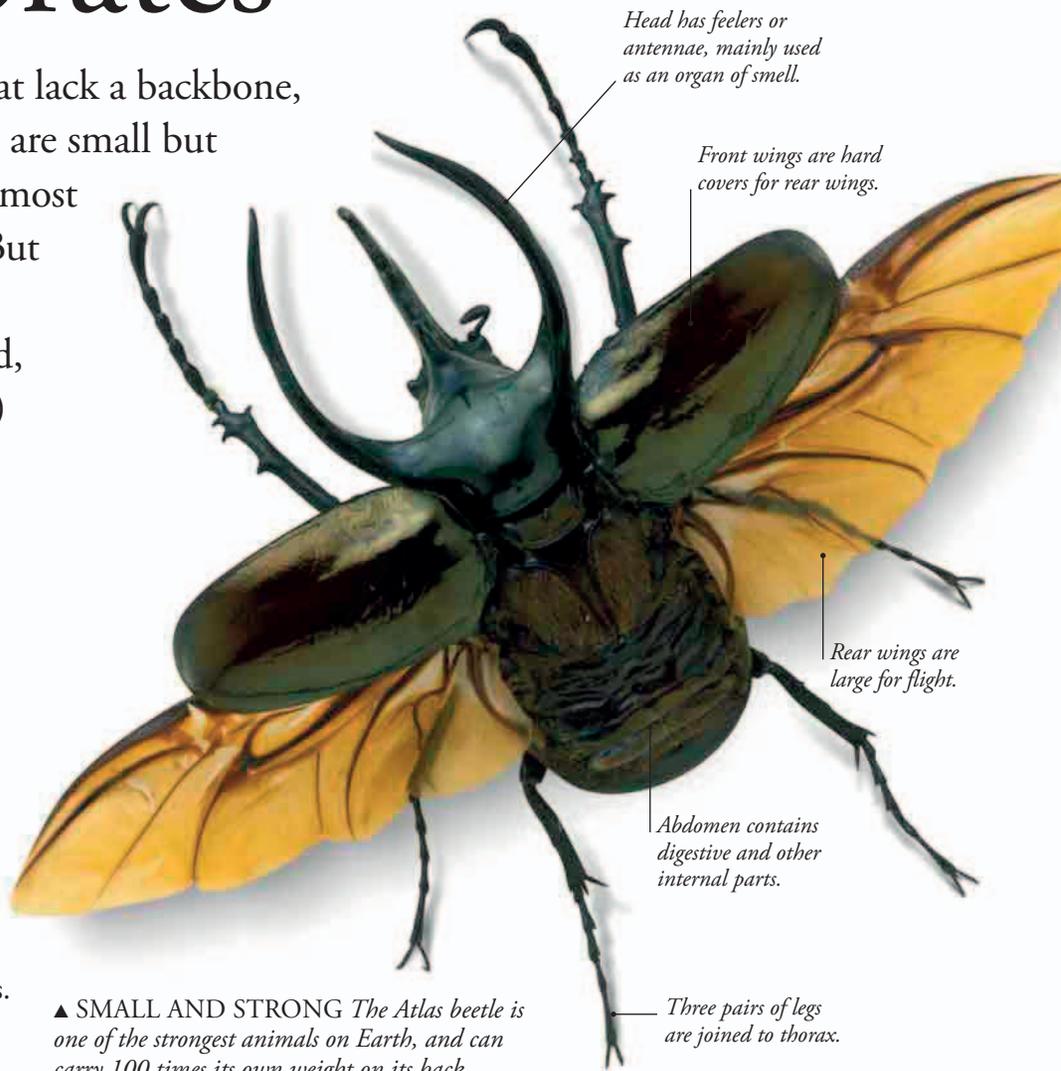


# Invertebrates

Invertebrates are animals that lack a backbone, or spine. Most invertebrates are small but very common, thriving in almost every habitat in the world. But a few are huge—the biggest is the deep-sea colossal squid, which grows to 46 ft (14 m) long and weighs half a ton.

## NO BACKBONE

Insects are the biggest group of invertebrates. An adult insect has six legs, usually two or four wings, and a body divided into three main parts—head, thorax, and abdomen. An outer skeleton, called the exoskeleton, covers and protects its entire body. Within the insects, beetles are the largest subgroup—there are more than 300,000 known species of beetles.



Head has feelers or antennae, mainly used as an organ of smell.

Front wings are hard covers for rear wings.

Rear wings are large for flight.

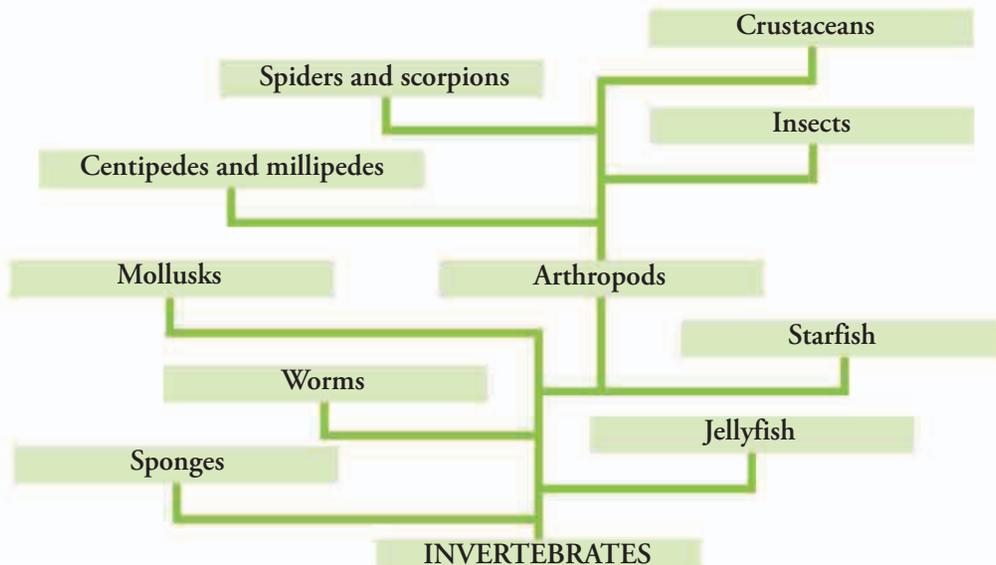
Abdomen contains digestive and other internal parts.

Three pairs of legs are joined to thorax.

▲ **SMALL AND STRONG** *The Atlas beetle is one of the strongest animals on Earth, and can carry 100 times its own weight on its back.*

## TYPES OF INVERTEBRATES

This tree diagram shows the main groups of invertebrates and how they are related to one another. Sponges and jellyfish are mostly simple creatures without a brain or heart. Starfish are animals with a body that is radial—like a wheel with spokes (other creatures have left and right sides). The arthropods or “joint-legs” include many familiar invertebrates from both land and water. They include insects, arachnids (spiders and scorpions), and crustaceans such as crabs.



## SPONGES

Sponges have a basic body structure with no defined organs—they filter water to get nutrients. Most are spongy, while some, such as glass sponges, have a hard supporting structure.



Stove-pipe sponge

## MOLLUSKS

Mollusks include shelled animals such as clams, mussels, and limpets. Most live in the sea, but some, such as snails, live on land. The octopus is also a mollusk.



Garden snail

## JELLYFISH

Jellyfish, corals, and anemones are members of a group called cnidaria. They have special stinging organs called cnidocytes, which release venom when touched or triggered.



Jellyfish

## INSECTS

One of the most diverse animal groups, insects have six legs and two sensory antennae. Bugs, butterflies, bees, and beetles are all insects.



Desert locust

## STARFISH

Starfish, sea cucumbers, and sea urchins make up the group called echinoderms. Many of these can regenerate their tissues if damaged—for instance, some starfish can regrow lost arms.



Starfish

## SPIDERS AND SCORPIONS

Spiders and scorpions, part of the group called arachnids, have eight legs and sharp mouthparts. Some spiders spin elaborate webs to catch prey.



Red-kneed tarantula

## WORMS

There are many different groups of worms—flatworms, roundworms, and segmented worms. Each group of worms has thousands of different species within it.



Earthworm

## CRUSTACEANS

Most crustaceans, including lobsters, barnacles, and crabs, live in water. They often have hard outer shells to protect their bodies.



Lobster

## CENTIPEDES AND MILLIPEDES

Centipedes and millipedes have long bodies divided into many segments. Centipedes have one pair of legs per segment, and millipedes have two pairs per segment. Their bodies are covered in a tough but flexible exoskeleton.



Giant tiger centipede



## **FIREFLY**

These amazing insects can produce light from their bodies. Special chemicals inside them create a yellow or green glow in a process called “bioluminescence.” The bugs use this light to attract mates. They can use a steady glow or flashing lights to signal to each other.



# Vertebrates

Most of the world's large animals, from sharks to humans, are vertebrates. Their common feature is a strong framework inside the body, called a skeleton. This is based on a vertebral column—also known as a backbone, or spine.

## SKELETON AND VERTEBRAE

A backbone is a long row of smaller bones called vertebrae, joined like links in a chain. At the front end are the bones of the skull. In most vertebrates, the bones at the rear end become smaller and narrower, forming the tail. Limbs such as fish fins, bird wings, and animal legs are attached to the vertebral column. The number of vertebral bones varies from fewer than 10 in frogs to more than 700 in the deep-sea snipe eel.

**WOW!**

Only about 4 percent of animal species are vertebrates. The rest are invertebrates.

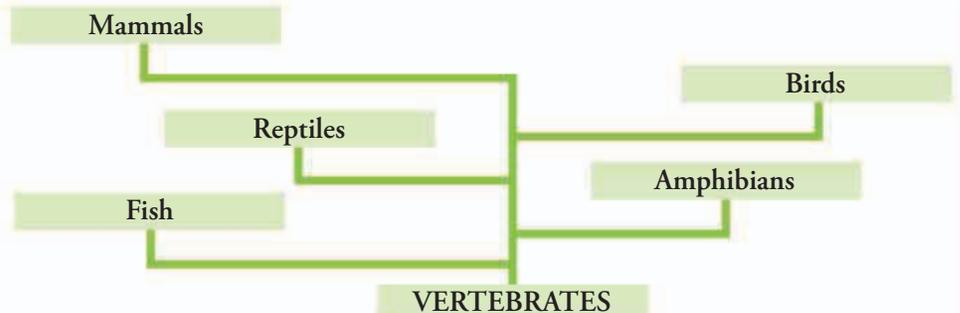


▲ **SUPPORT SYSTEM** *The backbone, or vertebral column, usually runs along the middle of the body. This is the vertebral column of a giant salamander (right), the largest of the amphibian vertebrate group.*



## TYPES OF VERTEBRATES

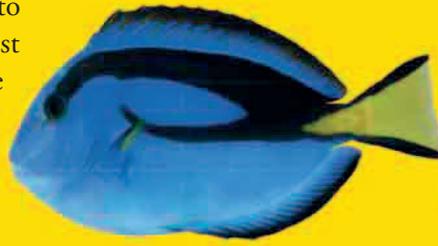
This tree diagram shows how the main vertebrate groups are related to one another. The earliest vertebrates were jawless fish, more than 500 million years ago. Other fish groups then appeared. Some lobe-finned fish developed legs and became the first land vertebrates, called amphibians. From these came the reptiles, including dinosaurs. One dinosaur group developed into birds, while another reptile group gave rise to mammals.





## FISH

Fish are cold-blooded—they cannot make their own body heat. They use fins to move, gills to breathe, and most are covered in scales. There are jawless fish such as lampreys, cartilaginous fish such as sharks and rays, and bony fish such as salmon and cod.



Regal tang



*Usually lay eggs to reproduce*



*Live underwater*



*Absorb oxygen from the water using gills*



*Swim with the help of fins and a tail*



*Most are cold-blooded*

## AMPHIBIANS

Amphibians are cold-blooded and have moist skin. Most lay eggs in water. These hatch into larvae, called tadpoles, that change shape (metamorphose) as they grow into adults. Amphibians include those with tails, such as newts and salamanders, and those without tails, such as frogs and toads.



Poison dart frog



*Usually lay eggs to reproduce*



*Have moist skin and may die if they dry out*



*Many can survive in water and on land*



*Some hatch as tadpoles and change shape to become adults*



*Are cold-blooded*

## REPTILES

Reptiles are cold-blooded. Most have scales for protection. Most lay eggs, but some give birth to babies. Reptiles include turtles, terrapins, and tortoises; lizards and snakes; and crocodiles, alligators, and caimans.



Savanna monitor lizard



*Most lay eggs to reproduce*



*Have dry, scaly skin*



*Most are meat eaters*



*Most live in warmer climates*



*Are cold-blooded*

## BIRDS

Birds are warm-blooded (making their own body heat). They have wings, feathers, and a beak, and most fly. Birds lay hard-shelled eggs and care for their baby chicks. There are more than 30 groups, from huge ostriches to tiny hummingbirds, fierce eagles, and all kinds of perching birds.



Pigeon



*Lay eggs to reproduce*



*Have beaks instead of teeth*



*Are covered in feathers*



*Have wings and most can fly*



*Are warm-blooded*

## MAMMALS

Mammals are warm-blooded. They have hair or fur for warmth and protection. A few, such as echidnas and platypuses, lay eggs; the rest give birth to babies. The females produce milk to feed the young. The wide variety of mammals form more than 30 groups.



Black panther



*Almost all give birth to live young*



*Feed their young on milk*



*Most have hair or fur*



*Are warm-blooded*



*Include human beings*

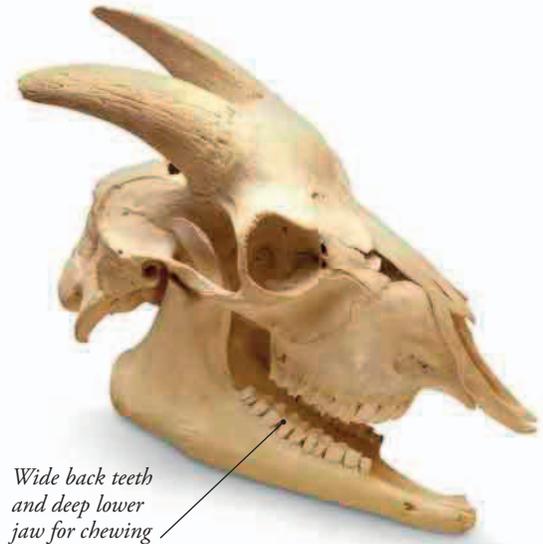
# Energy from food

Different animals get their energy from different kinds of food. Some are fierce hunters with sharp teeth and pointed claws. Others munch plants for most of the day. Leeches and bugs such as fleas suck blood, while some beetle grubs chew solid wood and earthworms eat soil.

## HERBIVORES AND CARNIVORES

A herbivore is a creature that obtains all or most of its food from plants. Some herbivores, such as caterpillars, eat only one kind of plant, while others, such as elephants, eat shoots, flowers, fruits, and leaves of a wide variety of plants.

A carnivore gets all or most of its food from eating other animals. Carnivores have special body parts, such as sharp teeth and claws, to catch and chew food.



Wide back teeth and deep lower jaw for chewing

▲ **HERBIVORE ADAPTATIONS** A goat has wide-topped back teeth—premolars and molars—that crush and grind tough plants, to get as many nutrients as possible from them.



Canine teeth to catch and kill prey

Incisor teeth to nibble meat from bone

▲ **CARNIVORE ADAPTATIONS** The fox has long, pointed front teeth, called canines, and sharp back teeth to slice up flesh and bone.

◀ **FOOD FOR YOUNG** Young carnivores may not be able to catch prey for themselves. Their parents bring them a share of their own meals.



## OMNIVORES

An omnivore eats a mixture of plants and animals. Many omnivores change their diet with the seasons, depending on what is available. For example, bears mostly live on fruits and berries, but will eat meat when it is available.



▲ **WIDE DIET** *The raccoon eats all kinds of food, from bugs, mice, and eggs to seeds, flowers, fruits, and human leftovers, so it can live almost everywhere.*

## PARASITES

A living thing that gets food or shelter from another—its host—and harms this host in the process is called a parasite. Some parasites suck blood or other body fluids from outside. Others, such as tapeworms and flukes, live inside the host's body.



▲ **BLOODSUCKER** *Fleas infest mammals and birds, sucking blood through their sharp, piercing mouthparts.*

## DETRITIVORES

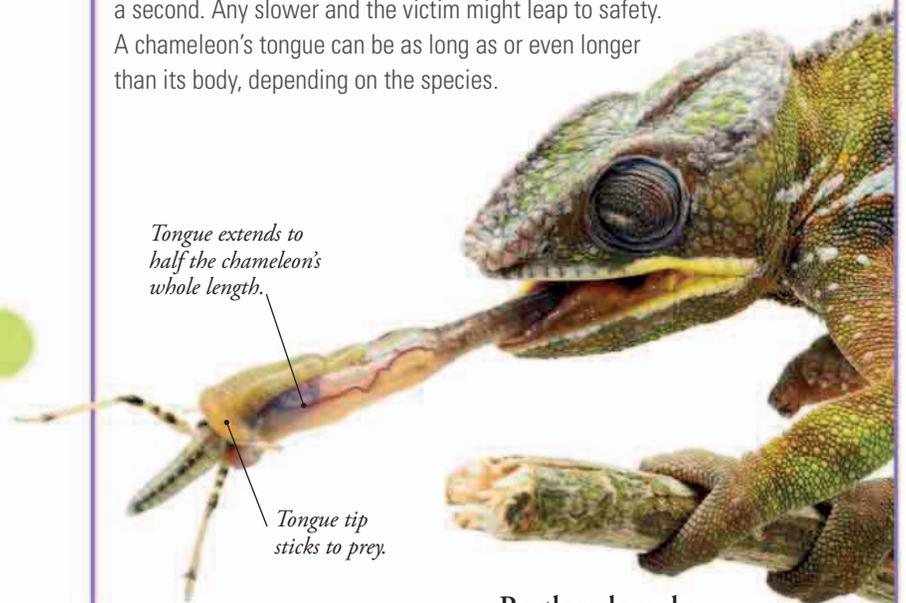
Detritivores feed on detritus—general bits and pieces of dead animals and plants, such as old leaves, decaying fruit, animal droppings, and rotting eggs. They help recycle nutrients that other creatures waste.



▲ **DEAD AND DECAYED** *Pill bugs feed mainly on rotting vegetation, bacteria, fungi, and animal remains. They rarely eat living plants.*

## FASTEST FEEDERS

Some animals capture their food in less than the blink of an eye. The chameleon lizard flicks out its long, stretchy tongue, grabs a grasshopper on its sticky tip, and pulls it into its mouth—all in less than 1/10th of a second. Any slower and the victim might leap to safety. A chameleon's tongue can be as long as or even longer than its body, depending on the species.



Panther chameleon

WOW!

The creature with the biggest appetite is a moth caterpillar that eats 20 times its own body weight each day.



# Predators and prey

In nature's constant battle for survival, predators, or hunters, must catch their food (prey). Meanwhile, prey try to avoid becoming victims by defending themselves. Usually, there is a balance—sometimes predators kill, sometimes prey escape.

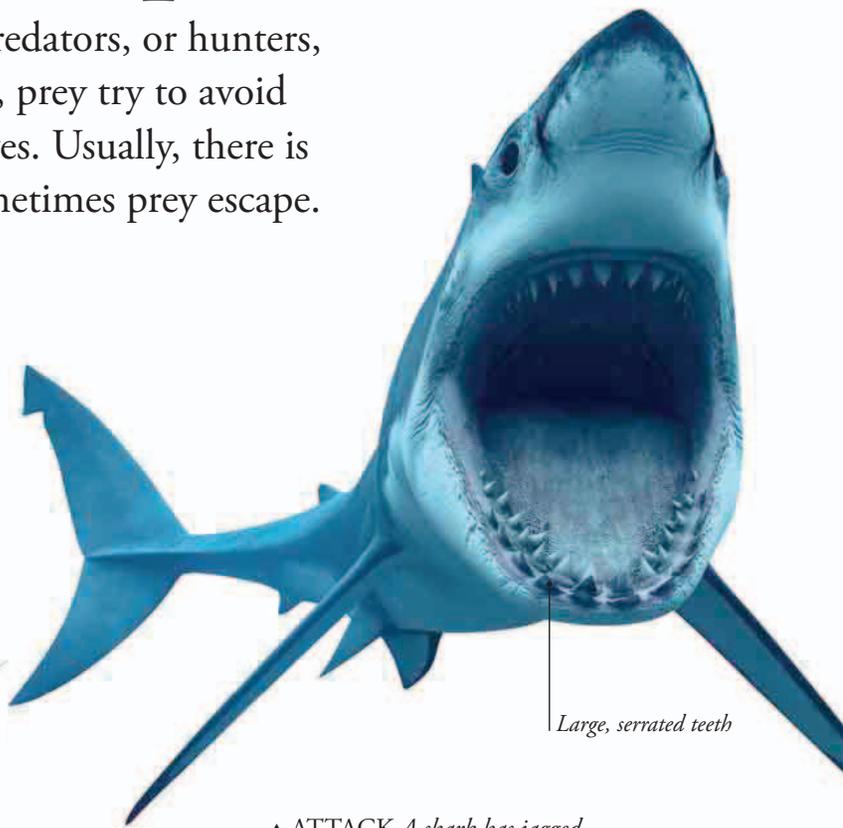
## PHYSICAL WEAPONS

Predators use weapons such as sharp teeth to grab, kill, and cut up their victims. Some have fangs—long, thin teeth—that may inject venom. Pincers can grab prey to crush or slice them. Prey also have weapons, but for self-defense, such as long spines, hard shells, tough scales, and thick skin.

Spiny quills



► **DEFENSE** *A porcupine may run at a predator and jab in its spines, called quills, which pull out of the porcupine's skin and stick into the attacker.*



Large, serrated teeth

▲ **ATTACK** *A shark has jagged, saw-edged teeth, jaws that open very wide, and strong muscles to snap them shut with incredible power.*

## SPEED

Predators such as leopards, tigers, and lions are fast runners and use a burst of incredible speed to catch a meal. However, their prey are almost as speedy, and also able to dart and weave suddenly to and fro, to dodge the attack.

▼ **ATTACK AND DEFENSE** *Animals can use speed to chase their prey as well as to escape from their predators.*



## USING COLOR

► **WARNING COLORS** are bright patterns, such as red and black, yellow and black, and green and black, showing that a creature is poisonous, or bad to eat. This shield bug uses bright red-and-black stripes as warning colors.



► **CAMOUFLAGE** is looking like the surroundings, to blend in and be less noticeable. It is used by both predators and prey. This crab spider is camouflaged with the same yellow color as the flower to help it ambush its prey.



## CHEMICAL WEAPONS

Venoms are toxic substances that are jabbed or stabbed into another creature using fangs, stingers, and similar sharp body parts. A venom causes harm, pain, paralysis (being unable to move), and even death.



► **ATTACK** Using its tail stinger, a scorpion may jab venom into prey, which it grabs with its large pincers.

► **DEFENSE** The bombardier beetle squirts two substances from its rear end that mix to produce a stinging, irritating spray against enemies.



## GROUP SIZE

Compared to one predator alone, a group or pack of predators can bring down more and bigger prey. Similarly, a group of prey, such as a herd or flock, has safety in numbers. There are many eyes, ears, and noses to detect approaching hunters and give the alarm, allowing most of the group to escape.



▲ **ATTACK** A wolf pack can kill a victim as large as an adult deer, which is many times bigger than one wolf. But the meal must then be shared, so there may not be much for each wolf.



▲ **DEFENSE** Caribou are very fast and graze in large herds, where they are always alert to danger.





### **HIDING IN THE WEEDS**

These ghost pipefish are cleverly camouflaged to look just like seaweed. To keep up their disguise, they drift along in the water almost without moving, with their noses down. They even bend their bodies in the current like real weeds. This behavior helps keep them safe from predators.

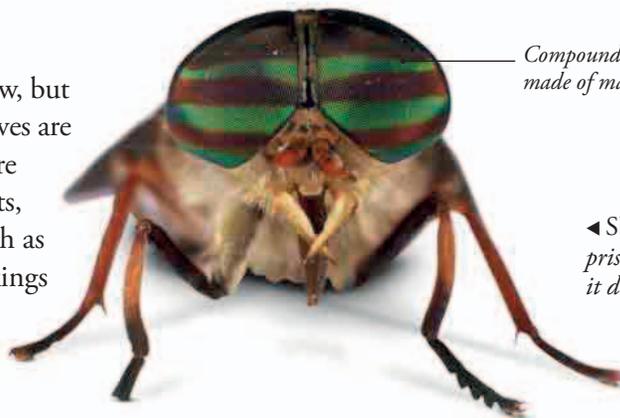


# Senses

The human body's main five senses are sight, hearing, smell, taste, and touch. Many animals have these senses too. Some have fewer, such as underground burrowers or deep-sea dwellers that need no eyes because there is no light there. Other creatures have much stronger senses than ours, and some even have extra senses, such as the ability to detect electricity.

## SIGHT

Our eyes see all the colors of the rainbow, but not all light-type energy. Ultraviolet waves are shorter than ordinary light waves and are seen by various animals including insects, fish, and some birds and mammals, such as caribou. Some flowers have petal markings that show up in ultraviolet light and guide insects to their sugary nectar.



Compound eyes are made of many lenses.

◀ SUPERVISION A horsefly's prislake compound eyes help it detect motion.

## TASTE

Most vertebrates have tongues—muscular organs in their mouths—which they use to manipulate food. Mammals' tongues are covered in tiny sensors called taste buds, which can identify chemicals that are dissolved in saliva. This helps them recognize what is in their food, and to avoid eating anything rotten or contaminated. Other vertebrates such as fish and reptiles have fewer taste buds, and rely on other senses to identify safe foods.

▶ TONGUE POWER *Tongues are not just for tasting; they also help animals eat. Lions' rough tongues scrape tiny scraps of meat from the remains of their prey.*



## SMELL

Compared to a human's nose, a dog's long nose has more room for many millions more smell detectors. For certain scents, this makes a dog's sense of smell more than 100,000 times better than our own.

▲ BIG NOSE *Some breeds of dogs have more than 200 million microscopic smell detectors inside their noses, compared to about 5 million in a human's.*



## TOUCH

Many animals have sense receptors in their skin so they can feel what is around them. Humans can detect gentle touch, hard pressure, heat and cold, and pain through their skin. Other animals, such as cats, have extrasensitive whiskers that can pick up the slightest pressure.

► **STAR-NOSED MOLE** *This furry creature tracks underground prey using its sense of touch. The tiny “fingers” on its nose are extremely sensitive.*



## HEARING

Bats fly and find their way even in complete darkness, using sounds. They send out very high-pitched, or ultrasonic, clicks and squeaks. These bounce or echo off nearby objects. The bat hears the returning echoes and figures out the object’s size, shape, distance, and direction, in a process known as echolocation.



▲ **BIG EARS** *A bat sends out ultrasonic signals from its nose and mouth, and the huge ears hear the faint echoes.*

WOW!

In clear Arctic air, a polar bear can detect the smell of a dead seal or whale 3 miles (5 km) away.

## EXTRA SENSES

Human beings rely on five main senses to take in information about the world around them. Other animals, however, can recognize information that passes us by, such as tiny changes in the temperature or pressure of the air around them, or detect magnetic or electrical fields in their surroundings.



▲ **HEAT SENSE** *Pit vipers have bowl-shaped, heat-detecting parts called pit organs, one under each eye. The pits receive heat or infrared rays from a warm object, such as a bird or mammal, and tell the snake its direction, distance, and size.*



▲ **ELECTRICAL SENSE** *Living bodies make small electrical pulses that spread out through water. The hammerhead shark is especially good at sensing electricity. It does this with the help of tiny pits covering its snout and the underside of its head.*

# Communication

The natural world is busy with all kinds of animals sending messages and signals to each other. They use sight, sound, smell, taste, and touch—often all together. Some messages are simple and understood by many creatures. A hiss or growl says, “If you come near, I’ll attack!” Other communications are less obvious and can only be understood by animals of the same kind.

WOW!

The deep moans of a whale’s song can be heard more than 621 miles (1,000 km) away.

## BODY LANGUAGE

The way a creature stands or sits, and the positions of its head, limbs, tail, ears, and other body parts, are all forms of communication. Sometimes the differences between gestures may seem small to us—for example, a slight lowering of the tail—but others of the same species know what they mean. Facial expressions are especially important in mammals, where the slight movement of lips or eyebrows shows a different mood.

◀ **MOUTH WIDE OPEN** *An adult male mandrill yawns by opening its mouth fully to reveal its canines. This is a warning to rival groups or predators.*



## DEFENDING TERRITORY

Some animals have a territory where they live, feed, and breed. They defend the territory by showing off to and chasing away others. Animals also display and even fight to be in charge of a group such as a herd, and to scare away rivals at breeding time.



▲ GET OUT! *Male impalas stamp, snort, and shake heads to scare off invaders in their territory. If this fails, a battle follows.*

## MATING DISPLAY

Most creatures have a way of attracting a mate for breeding. Usually it is the male who puts on the display, for example by dancing and calling. He shows the female that he is fit and healthy, and as a father he will pass on these features to their offspring.



▲ RED BALLOON *The male frigate bird blows up his scarlet throat patch like a balloon to impress the female.*

## WARNING SIGNALS

Defense messages usually involve an animal making itself look bigger and more frightening to an enemy.

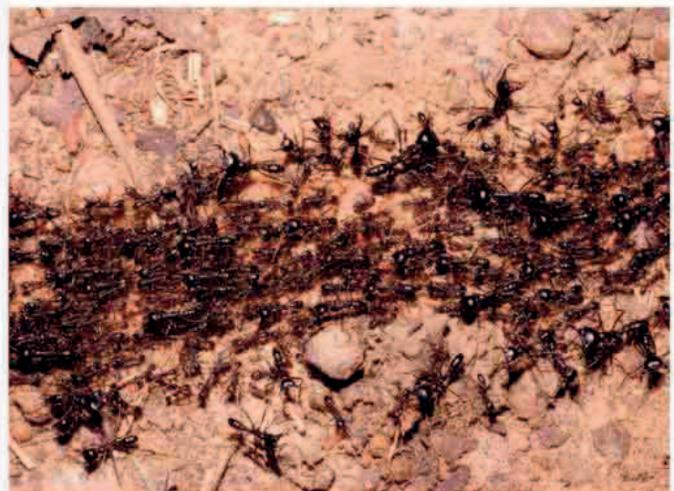
Mammals make their fur stand on end and birds fluff out their feathers. Often, the animal opens its mouth, jumps around, and makes noises to scare the predator.



▲ LOOK BIGGER *The frilled lizard opens out its frill of skin, shows its teeth, and hisses to communicate that it will fight back if attacked.*

## SHARING INFORMATION

Social animals live together with their own kind in groups or colonies. There are many forms of communication among group members, for instance about the location of food, getting ready to move on, or approaching danger. Ants communicate by touch and scents. They give off different scents, or pheromones, for food, attack, defense, and danger.



A large group of army ants working together



# Living together

Creatures that live with others of their kind are known as social animals. They sometimes live together in one big home, called a colony. Living together offers many benefits, such as being able to share food and protect each other from predators. Different animals form different kinds of group to give them the best chance of survival.



## TOGETHER FOR LIFE

Several kinds of mammals and birds mate for life. This means choosing and then staying with the same breeding partner for as long as the two survive. Each year, the pair renew their close bond and use their combined experience and knowledge to raise their family.

◀ **PERMANENT PAIR** *Scarlet macaws can stay together for more than 40 years. When one dies, the other may take years to find a new partner.*

WOW!

Army ants live and move around in huge colonies, but they do not build permanent nests. They cling together in large clusters to rest.

## BATTLE FOR MATES

When breeding time arrives in the animal kingdom, males may hold contests to attract the best or most partners. The males show off their health and readiness to mate. The biggest battles are between male elephants, who head-butt and clash tusks, sometimes causing deep wounds.

## ▼ SHAKING THE GROUND

*Male elephants spread their ears, trumpet, stamp, and shove to decide which one gets to breed.*



### SMALL GROUPS

Social groups of 10 to 20 are common among smaller animals. In a group of meerkats, also known as a mob or gang, only one pair—the alpha female and male—produce young. Some less important females babysit and feed the offspring, while others contribute to the group by watching for danger, communicating about food sources, and sounding alarm calls.



▶ **WATCHING OUT** *Adult meerkats often climb to a higher point to spot potential predators. If a predator is detected, they warn the rest of the group.*



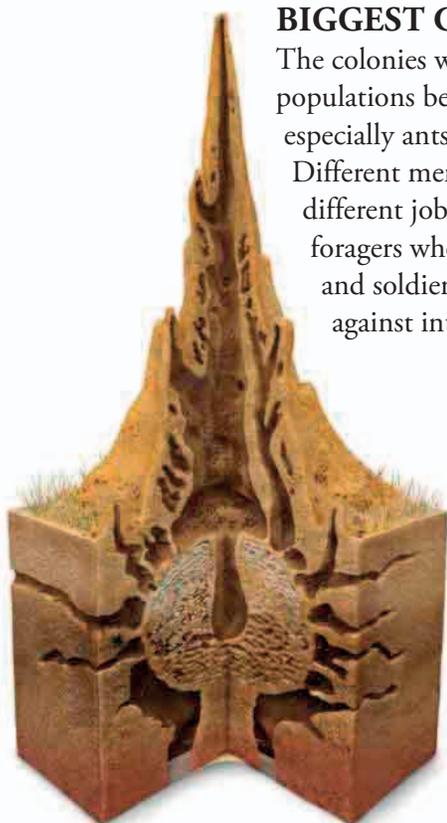
### BIG GROUPS

The biggest animal groups include bird flocks of tens of thousands, fish shoals of hundreds of thousands, and swarms of locusts containing many millions. These vast gatherings may travel to find food, or to breed, or simply stay together to discourage predators.

◀ **AIR TRAFFIC** *While they feed in smaller groups by day, starlings gather at dusk into groups of thousands, sometimes even millions.*

### BIGGEST COLONIES

The colonies with the biggest populations belong to insects, especially ants and termites. Different members have different jobs, such as foragers who gather food, and soldiers who defend against intruders.



◀ **INSECT CITY** *A tall termite mound is home to more than 7 million individuals, living in tunnels and chambers underneath the ground.*

### BEING SOCIAL

The most complex mammal societies include dolphins, whales, lemurs, monkeys, apes, and elephants. They have many ways of communicating complex information (see p.250) about who is in charge, food sharing, friendships, rivalries, and mating. As young chimps play and rest together, they learn hundreds of signals and messages.



Young chimps watch adults to learn new behavior.

# Migration and hibernation

Many regions of the world have a warm season each year with plenty of food and good living conditions, followed by a cold season when survival is much more difficult. There are two main ways of staying alive through the difficult times—stay or go. That is, stay and enter hibernation or torpor, or leave by migration.

## MIGRATION

Migration is a long-distance journey, usually made around the same time each year along a regular route. Most animals migrate away from a cold place to where it is warmer, then back again, each year. A huge variety of creatures migrate, from worms, lobsters, and insects to fish, birds, and mammals.

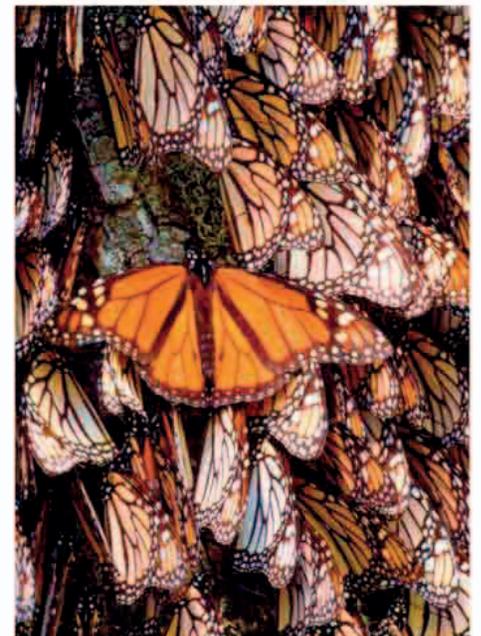


► **LONG-DISTANCE SWIMMERS** *Atlantic salmon travel from freshwater streams to the Atlantic Ocean for food. After a few years, they return to the fresh waters to lay eggs.*



► **FLYING FAR** *The tiny ruby-throated hummingbird flies between the Northeast US and Central America to escape the cold weather. Some of them take an almost nonstop journey of 620 miles (1,000 km).*

◀ **ON THE HOOF** *Caribou, or reindeer, travel to where their food is available. In summer, they trek north to find seasonal plants to eat. In winter, they travel back south where it is warmer.*



▲ **MONARCH ROOST** *Monarch butterflies fly up to 3,000 miles (4,800 km) from their summer feeding grounds to their winter roosts.*



## HIBERNATION

Hibernation is a form of inactivity in which animals enter deep sleep to survive the harsh winters. Warm-blooded animals, mainly mammals, hibernate by hiding away and lowering their body temperatures by up to 50°F (30°C). Breathing, heartbeat, and other body processes become very slow to save energy.



▲ **IN A CAVE** Bats cluster in groups to hibernate in caves, where the temperature is cold but it rarely freezes.

## TOO COLD TO MOVE

Cold-blooded animals, such as reptiles, fish, and insects, do not truly hibernate. Since they cannot make warmth in their bodies, they become so cool in winter that their muscles can no longer work. This inactive condition is called torpor, and usually lasts for a shorter period than hibernation. Some insects may even freeze solid, then thaw out and continue living when it warms up in spring.

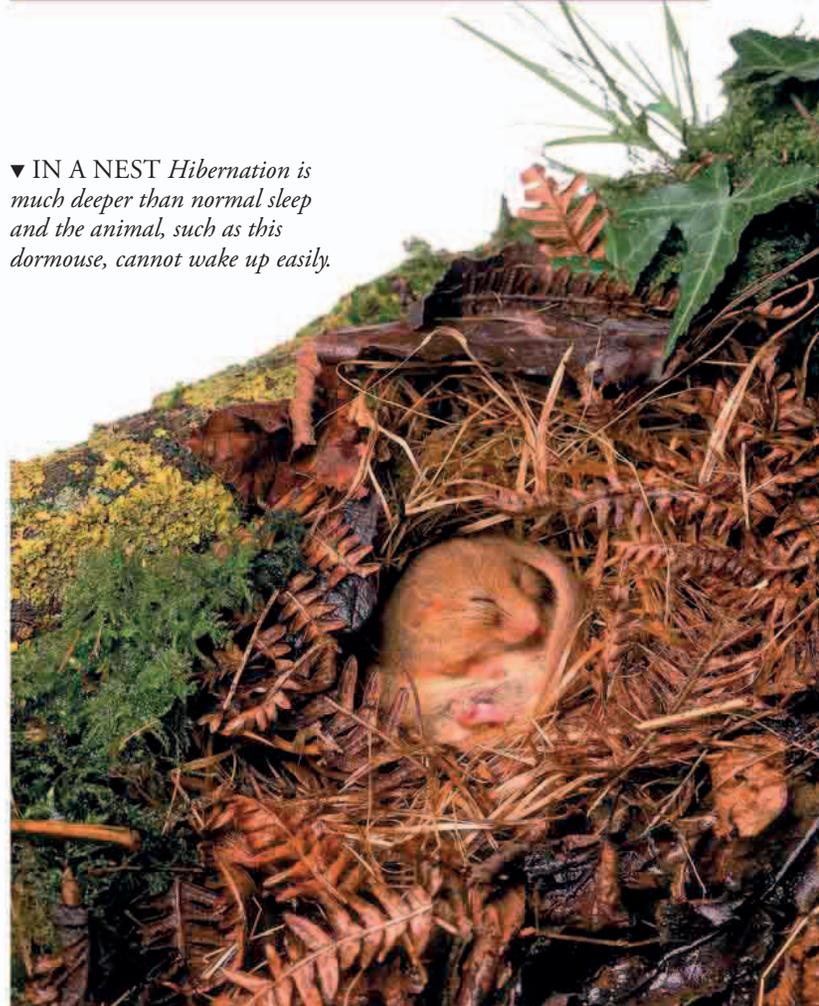


◀ **GARTER SNAKES** These snakes go into torpor in large numbers in common dens during the winter.



◀ **WOOLLY BEAR CATERPILLAR** These caterpillars survive the extreme cold of the Arctic by letting their bodies freeze.

▼ **IN A NEST** Hibernation is much deeper than normal sleep and the animal, such as this dormouse, cannot wake up easily.



# Habitats and ecosystems

A habitat is a particular kind of place or environment where something lives. Together, all the living things in each habitat are known as a community. These are plants and animals including herbivores, carnivores, and detritivores (see pp.242–243). An ecosystem describes the ways in which these living things interact—for example, who eats what in the food chain.

## MAJOR HABITATS

Physical conditions such as the hardness of rock or saltiness of water, the land's height or the water's depth, and the yearly climate and seasons all greatly affect which plants and animals live in a habitat. Warmth, moisture, deep soil, and lack of wind all encourage life. Hard rock, extreme temperatures, and lack of water make survival more difficult.

**Savannas** *These regions have very hot, dry seasons followed by short rainy seasons every year.*

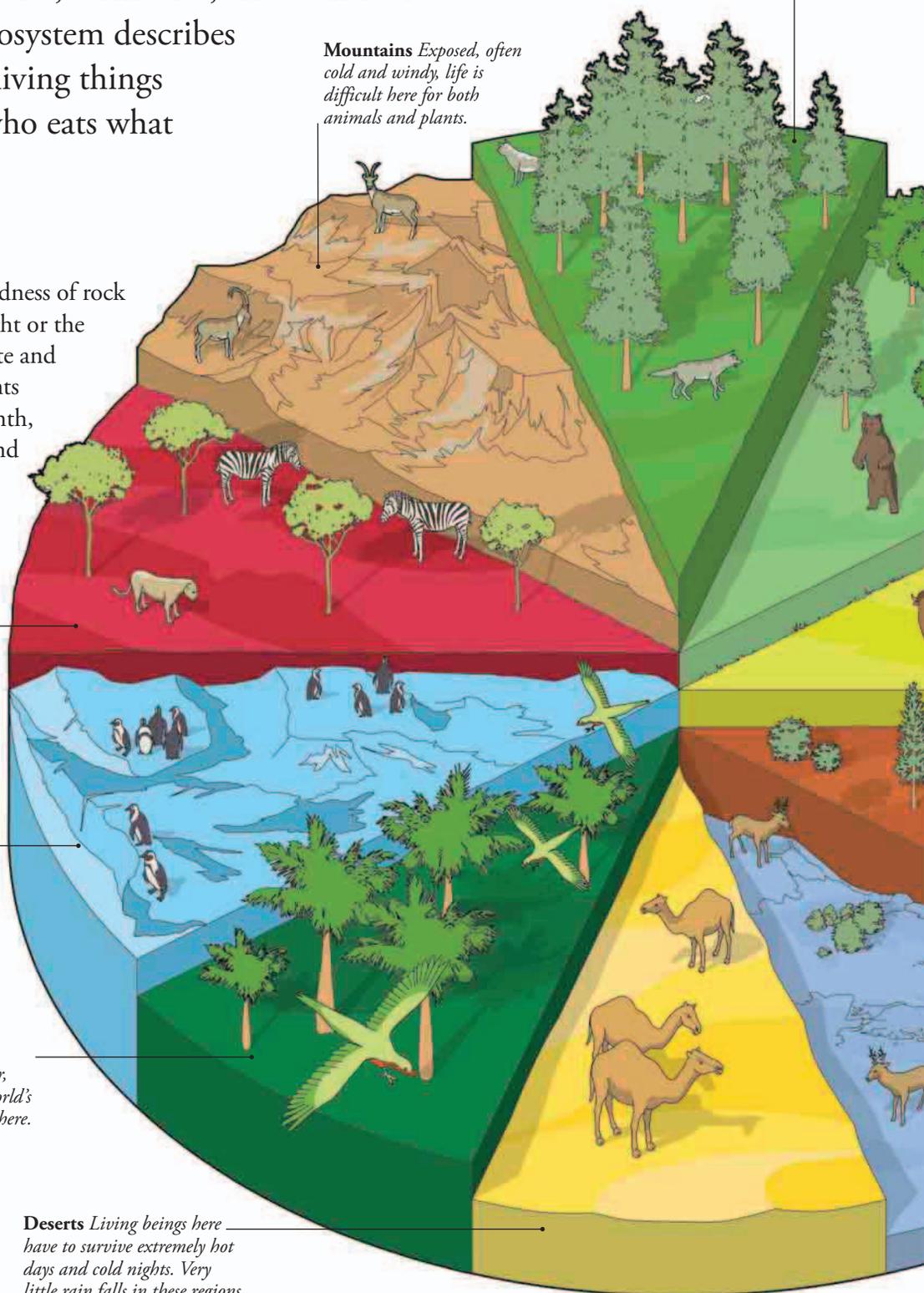
**Polar ice** *Frozen for most of the year, these icy regions are the coldest places on Earth.*

**Tropical rain forests** *Warm and moist all year, more than half of the world's animals and plants live here.*

**Deserts** *Living beings here have to survive extremely hot days and cold nights. Very little rain falls in these regions.*

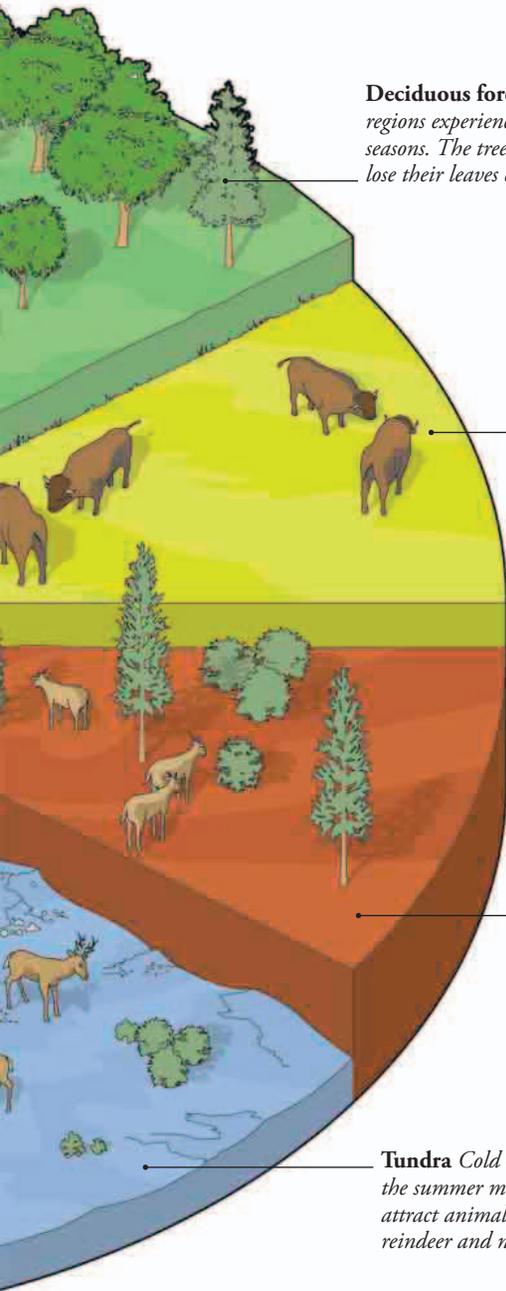
**Coniferous forests** *Covered with coniferous trees, these regions have warm summers and cold winters.*

**Mountains** *Exposed, often cold and windy, life is difficult here for both animals and plants.*



WOW!

The coldest habitat is the Antarctic ice cap, where emperor penguins cope with temperatures of  $-58^{\circ}\text{F}$  ( $-50^{\circ}\text{C}$ ).



**Deciduous forests** These regions experience four distinct seasons. The trees grow and lose their leaves every year.

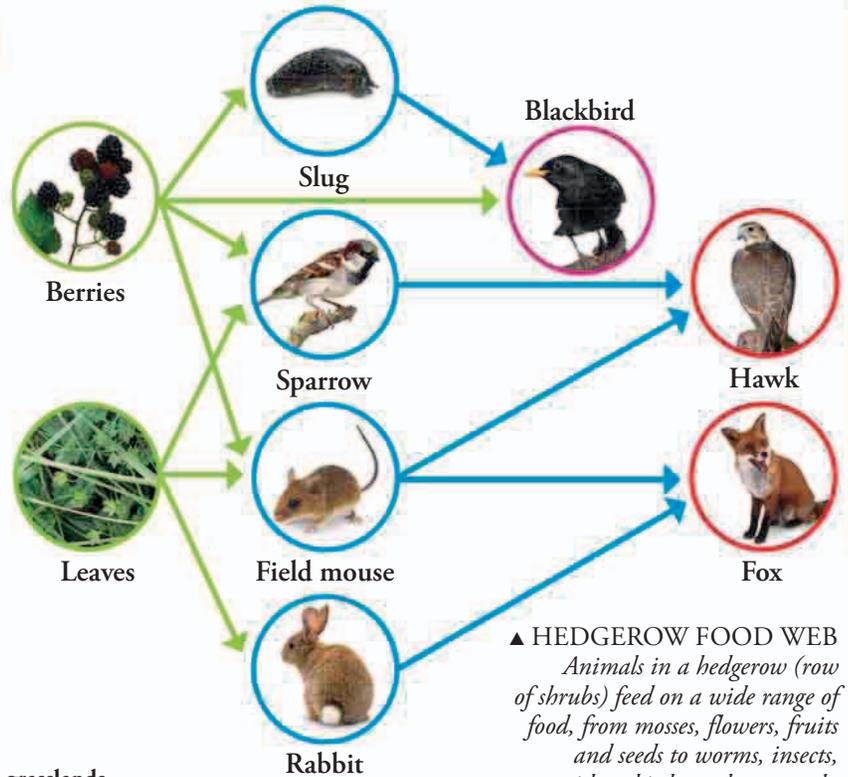
**Temperate grasslands** These dry, grassy lands support grazing herds such as bison, donkeys, or kangaroos.

**Mediterranean** Filled with scrub vegetation, these regions have hot, dry summers, and much milder, wetter winters.

**Tundra** Cold and treeless, the summer months attract animals such as reindeer and nesting birds.

## FOOD CHAINS AND WEBS

Food chains show examples of who eats what in a particular habitat. Each chain starts with a plant, then a herbivorous animal, a carnivore, and ends with a top carnivore—an animal that few others prey on. In most habitats, animals have varied diets, so food chains link together into larger food webs.



▲ **HEDGEROW FOOD WEB**  
Animals in a hedgerow (row of shrubs) feed on a wide range of food, from mosses, flowers, fruits and seeds to worms, insects, spiders, birds, and mammals.

## BIODIVERSITY

The more different kinds of living things there are in a habitat, the greater its biodiversity. Tropical forests and coral reefs are the most biodiverse, with hundreds, even thousands, of species in each small area. Polar regions, deserts, and the deep-sea bed are much less biodiverse.



▲ **MOST VARIED** A coral reef has a huge range of species living in minihabitats such as rocky caves and burrows.



# Ecology and conservation

Ecology is the study of how living things fit together in their surroundings. For example, what are the predators of a certain animal? Which herbivores eat a plant's fruit and spread its seeds? What kinds of nest sites do animals need? Sadly, more wild places are destroyed every year. Knowing their ecology helps us figure out how we can save or conserve them for the future.

## MAIN THREATS TO WILDLIFE

- Habitat loss, such as logging, burning, and clearance for human use
- Global warming, especially affecting coral reefs by killing polyps
- Pollution, such as oil slicks, pesticide sprays, and industrial waste
- Poaching and hunting for food and trophies, such as tiger bones and rhino horns
- Diseases, such as chytrid fungus killing amphibians
- Invasive species replacing native ones



Habitat destruction through deforestation



Coral death due to global warming



Imported species kill off native wildlife

## WILD LAND TO FARMLAND

Massive areas of grasslands and other natural habitats are taken over each year for farming—to grow crops and raise cows, sheep, and other domestic animals. The wild animals who lived there are forced into smaller areas and die from lack of food, disease, and other problems of overcrowding.

▼ **NOWHERE TO GO** *As people fence off more African grasslands to grow crops, natural grazers such as wildebeests and zebras can no longer follow their age-old migrations (the regular movement of animals from one place to another).*





## THE NEED TO KNOW

Gathering knowledge about different ecosystems helps identify the best way to save species and habitats. This is especially important for animals that travel widely, such as birds, whales, and turtles. Knowing the places they visit and the risks they face leads to a conservation plan for how best to keep them alive.

◀ **KEEPING TRACK** *This hawksbill turtle has a small tracking device attached that records where it swims to feed, rest, mate, and lay eggs.*

WOW!

One in five mammal species, and one in three amphibians, are on the official lists of threatened animals.

## CAPTIVE BREEDING

Breeding creatures in wildlife parks and zoos can help save a very rare species from dying out. It also raises people's awareness of the need for conservation. The aim in the long term is to release the animals back into their safe wild habitat.

▶ **SOMEWHERE TO LIVE** *Baby giant pandas are born in breeding centers because their natural habitat is endangered.*



## CONSERVATION CAMPAIGNS

Saving big, spectacular wild animals, such as gorillas and dolphins, depends on preserving their habitats—which also saves all the other creatures and plants living there. Governments and many organizations work to protect important habitats.

▶ **SAVED** *Mountain gorillas live in only a few small highland areas of central Africa. With huge conservation efforts, their numbers have increased in recent years.*



▲ **LOST** *The rare Chinese river dolphin, also known as baiji, suffered from pollution, overfishing, lack of food, and other hazards. In 2010, it was declared extinct.*



# The human body

The human body has more than 1,000 parts—including bones, muscles, and other organs—all working together every second of every day. The body is fueled by food substances, especially starches, sugars, and fats. These combine with oxygen, taken in by the lungs, to release energy that keeps the body warm and powers its movements and processes.

## UNDER THE SKIN

The body's main parts, such as the skin, brain, eyes, heart, and stomach, are called organs. Each contains millions of busy cells. The organs fit closely together and are always working—the heart beats, the lungs breathe, the intestines process food, and the muscles move our body.

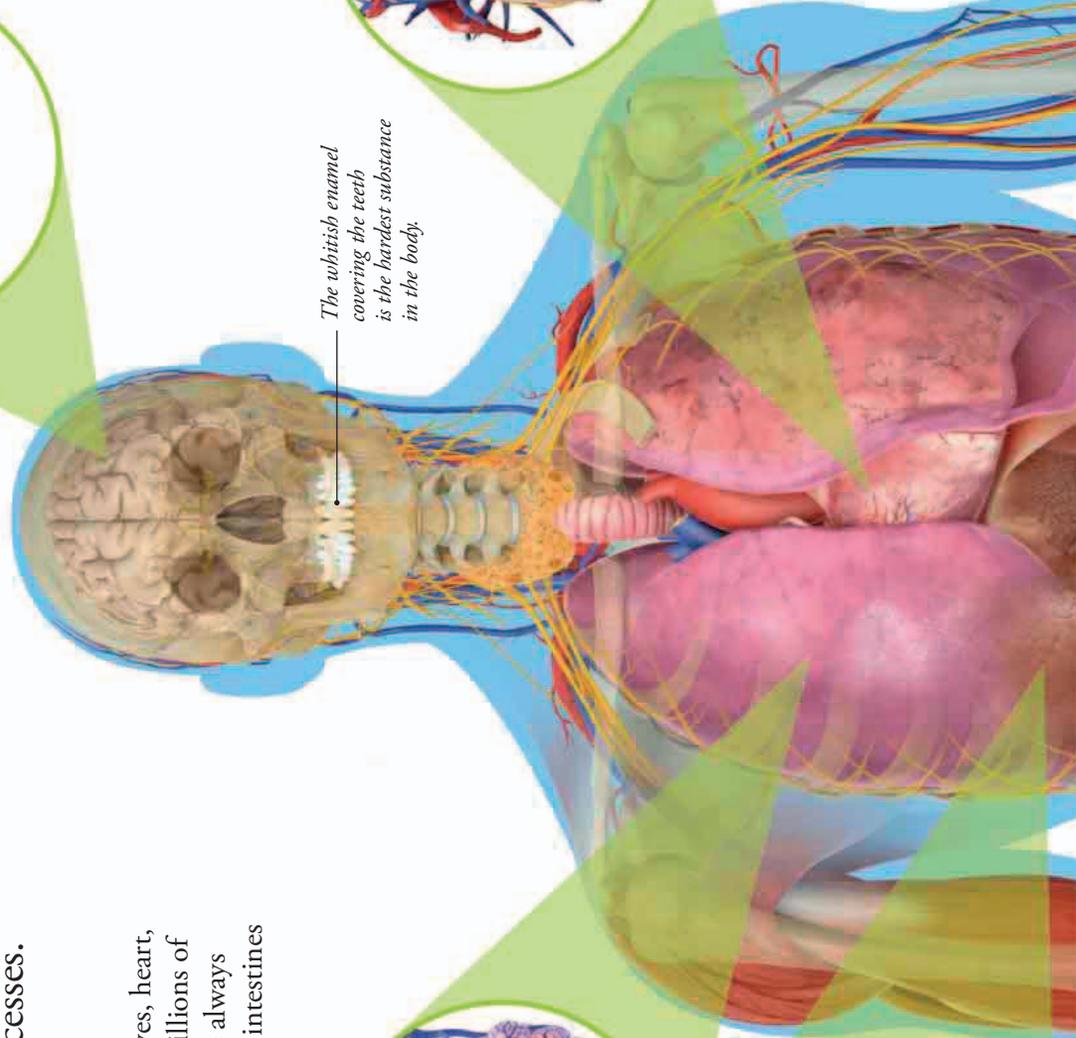
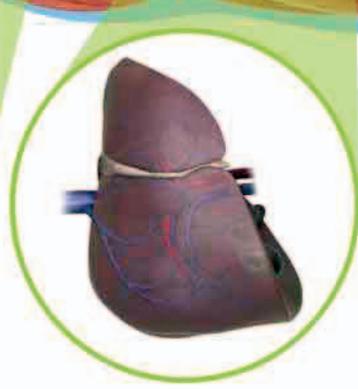
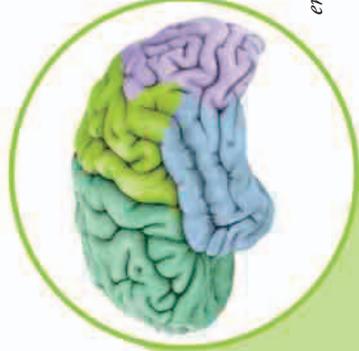
► **LUNGS** Deep in the lungs are millions of bubblelike alveoli, which take in oxygen from the air and get rid of carbon dioxide.

► **LIVER** The largest inner organ, the liver takes substances from digested food and alters them. It stores some and releases others into the blood.

◄ **BRAIN** Filling the top half of the head, the brain controls movements and is the place for thoughts, emotions, and memories.

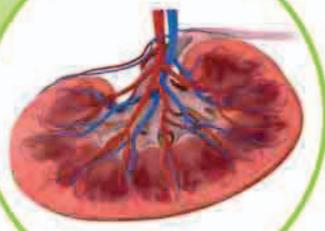
The whitish enamel covering the teeth is the hardest substance in the body.

▲ **HEART** Beating once every second or more, the muscular heart sends blood out through blood vessels (tubes) that reach every body part.





► **KIDNEYS**  
*All the body's blood flows through the kidneys every three minutes, where wastes are removed to form urine.*



◀ **STOMACH**  
*As the stomach enlarges with swallowed food, it makes powerful acids and other chemicals to digest the food into a pulp.*



▲ **MUSCLE**  
*There are more than 620 major muscles in the human body. Each one pulls to move the parts attached to it, usually bones.*



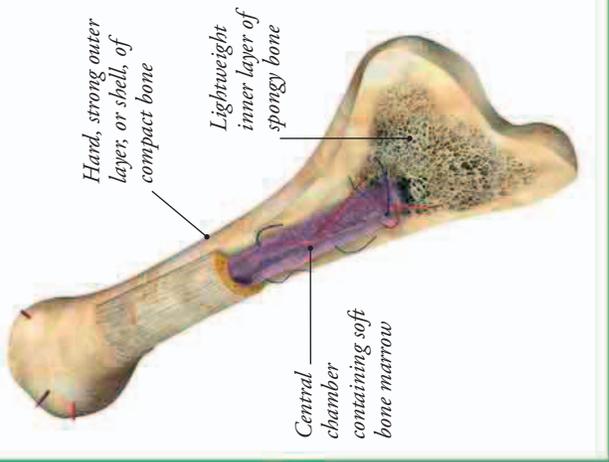
*The small intestine is 20 ft (6 m) long. It receives partially digested food from the stomach, completes digestion, and takes the nutrients into the blood.*

*Nerves carry control signals to every part of the body.*

**Wow!**  
 Every second, more than 3 million body cells die—and 3 million new ones form.

**BONES**

All 206 bones form a strong but movable framework called the skeleton. Like other parts, bones have nerves and blood vessels and are very much alive. Some bones have soft marrow inside, which stores fat for energy and makes new cells for the blood.

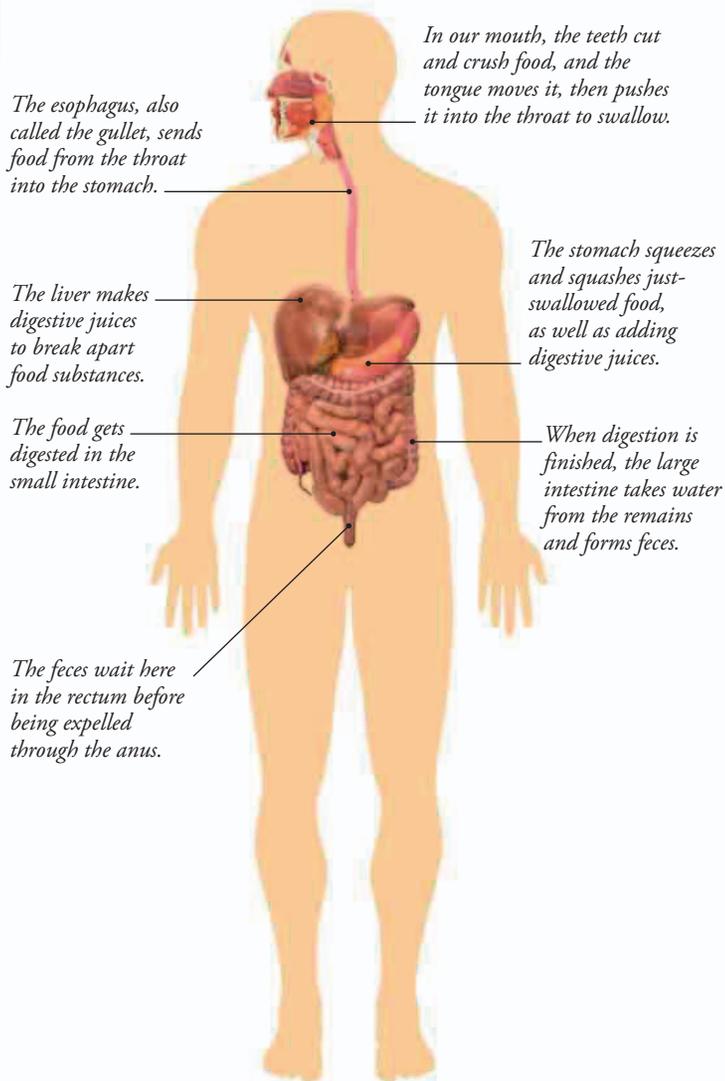


# Body systems

The body's main organs and tissues work together in groups called systems. Each individual system carries out an important task to keep the whole body alive and healthy. For example, the bones and joints form the skeletal system for support, and the muscular system keeps the heart beating and the body moving.

## DIGESTIVE SYSTEM

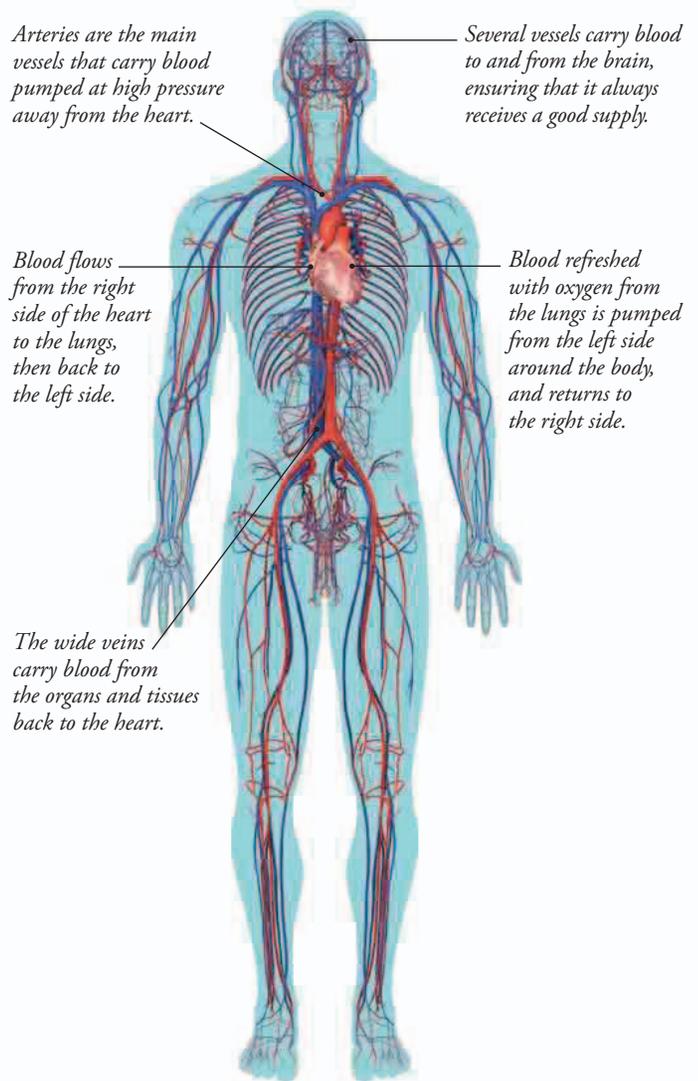
This system starts in the mouth, as teeth chop up and chew food, then mix it with saliva (spit) so that it is moist and easily swallowed. At the other end, leftovers of digested food come out of the opening at the anus.



▲ **WHERE DIGESTION HAPPENS** *The main organs of the digestive system form one long passageway, the gut. They fill most of the lower half, or abdomen, of the torso.*

## CIRCULATORY SYSTEM

The three main parts of this system are the muscular pump of the heart, the network of blood vessels, and the blood that passes through them. Blood delivers oxygen, energy, and nutrients, and collects wastes for disposal.

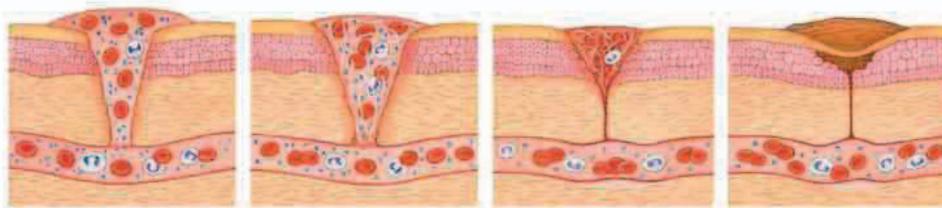


▲ **BODYWIDE NETWORK** *Blood vessels branch out into every body part. Added together end-to-end, they would stretch more than 62,000 miles (100,000 km).*



## SKIN REPAIR

When your skin is cut, blood is always ready to repair it. Special proteins in blood form a tangle of threads, or fibers, that trap blood cells. At the same time, tiny cells in the blood called platelets come together and become sticky. These two processes help form a clot, which hardens and stops bleeding.



1. Blood leaks from a fresh cut.

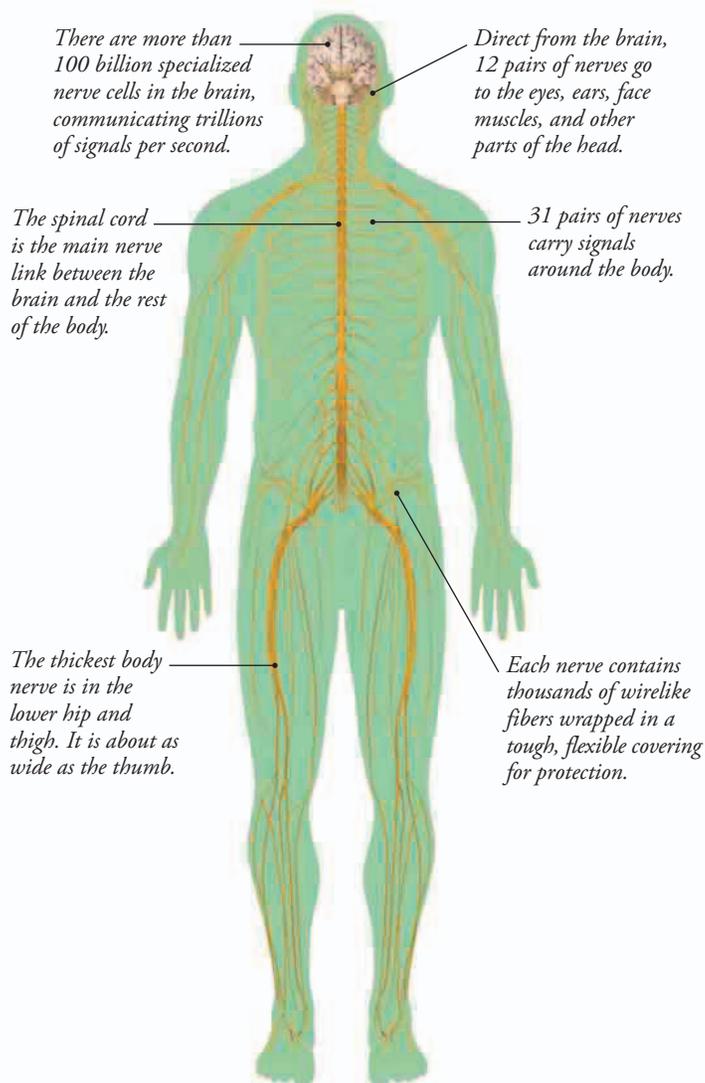
2. Fibers in blood trap blood cells to form clot.

3. Clot stops leak and begins to harden.

4. Clot solidifies into scab and protects new skin beneath.

## NERVOUS SYSTEM

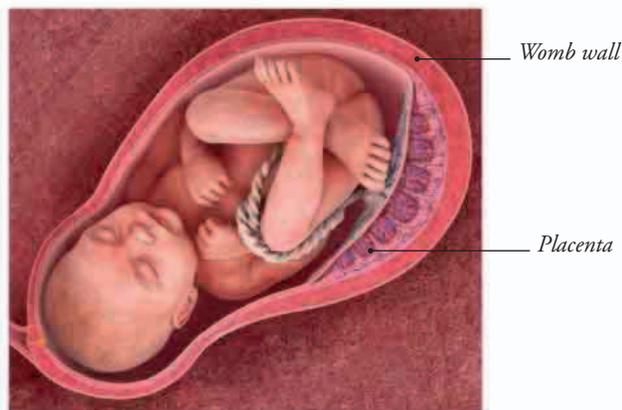
The brain is linked by nerves to every corner of the body. Some nerves carry messages to the brain from the eyes, ears, and other senses. Other nerves take messages from the brain to the muscles, to control movements.



▲ INFORMATION WEB Nerves send and receive messages in the form of tiny pulses of electricity, thousands every second, some traveling more than 328 ft (100 m) per second.

## REPRODUCTIVE SYSTEM

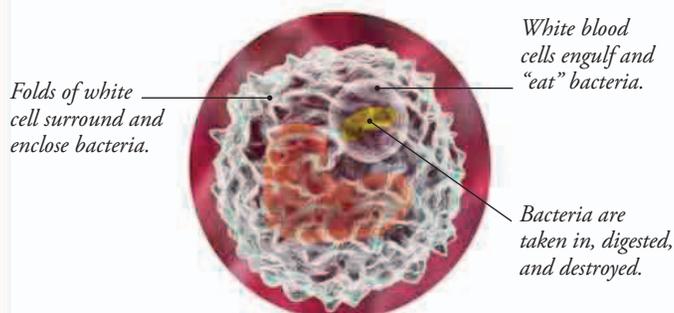
The female reproductive system makes tiny egg cells, and the male system produces even smaller sperm cells. When a sperm and egg join, the resulting fertilized egg develops in the womb inside the female body. Nine months later, a baby is ready to be born.



▲ IN THE WOMB The placenta helps transfer oxygen and nutrients from the mother's blood to the baby's.

## BODY DEFENSES

The body contains more than 50 billion white cells. Most are in the blood, but they also squeeze out into the gaps between other cells and tissues. The white cells defend the body by attacking any invaders and other dangers, from microscopic germs to parasitic worms.



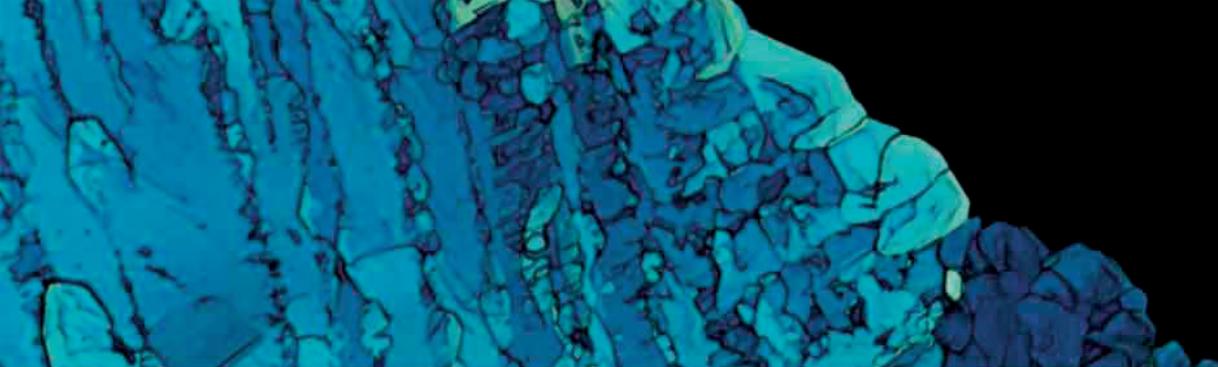
White blood cell destroying bacteria



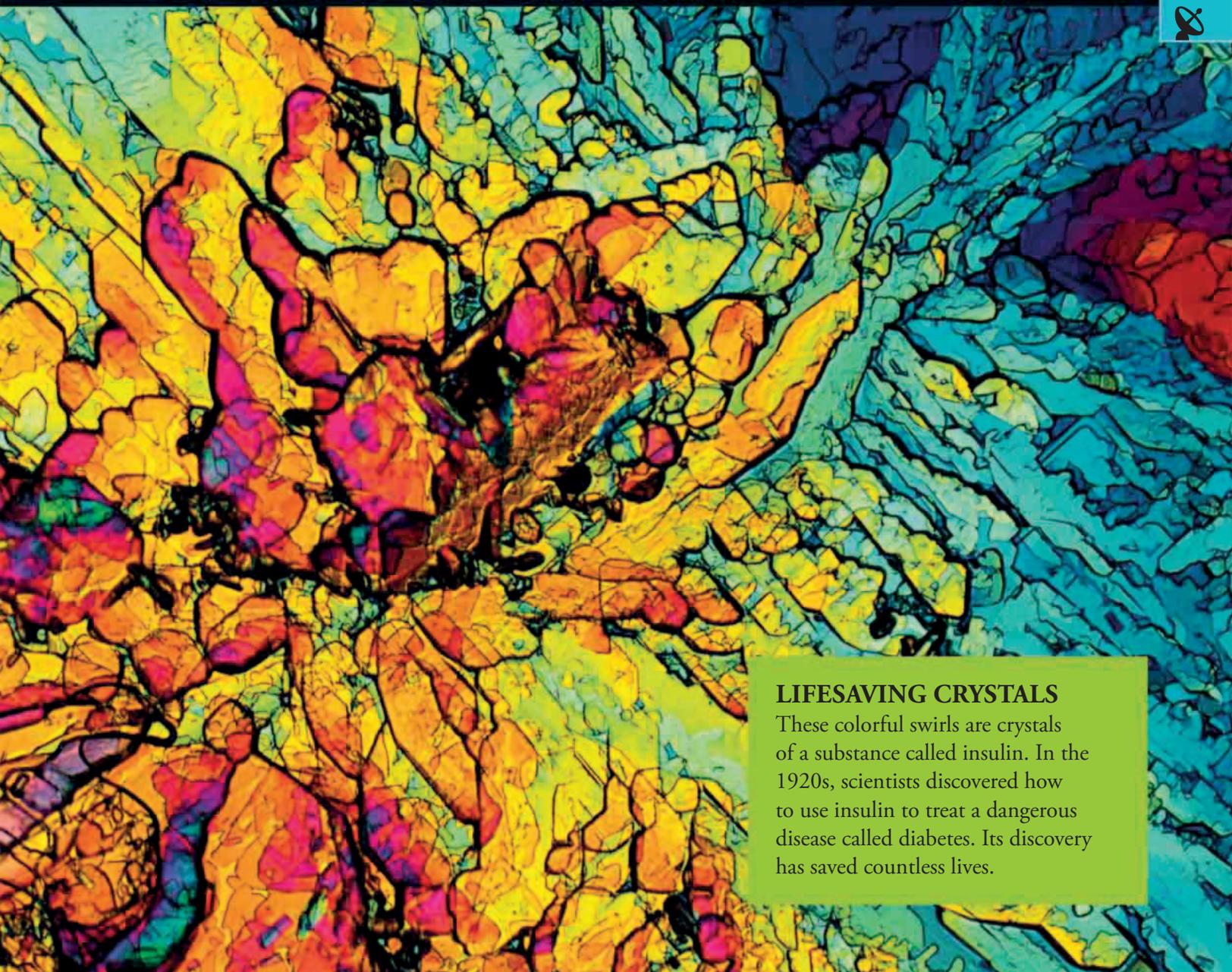
GREAT DISCOVERIES

# GREAT DISCOVERIES





For thousands of years, scientists have tried to understand how the world works. Their amazing discoveries—some made by accident—have transformed the way we live.



### LIFESAVING CRYSTALS

These colorful swirls are crystals of a substance called insulin. In the 1920s, scientists discovered how to use insulin to treat a dangerous disease called diabetes. Its discovery has saved countless lives.

# Progress in science

The earliest humans knew very little about the world. But they did know that some berries were tasty while some were poisonous, and that some rocks could be used to make fire or tools. As civilization advanced, people learned to use these observations to come up with new ideas. Later, they learned to test these ideas and use the results to bring about new technologies. Science is a continuous learning process—the more we learn, the more ways we can make our lives better.

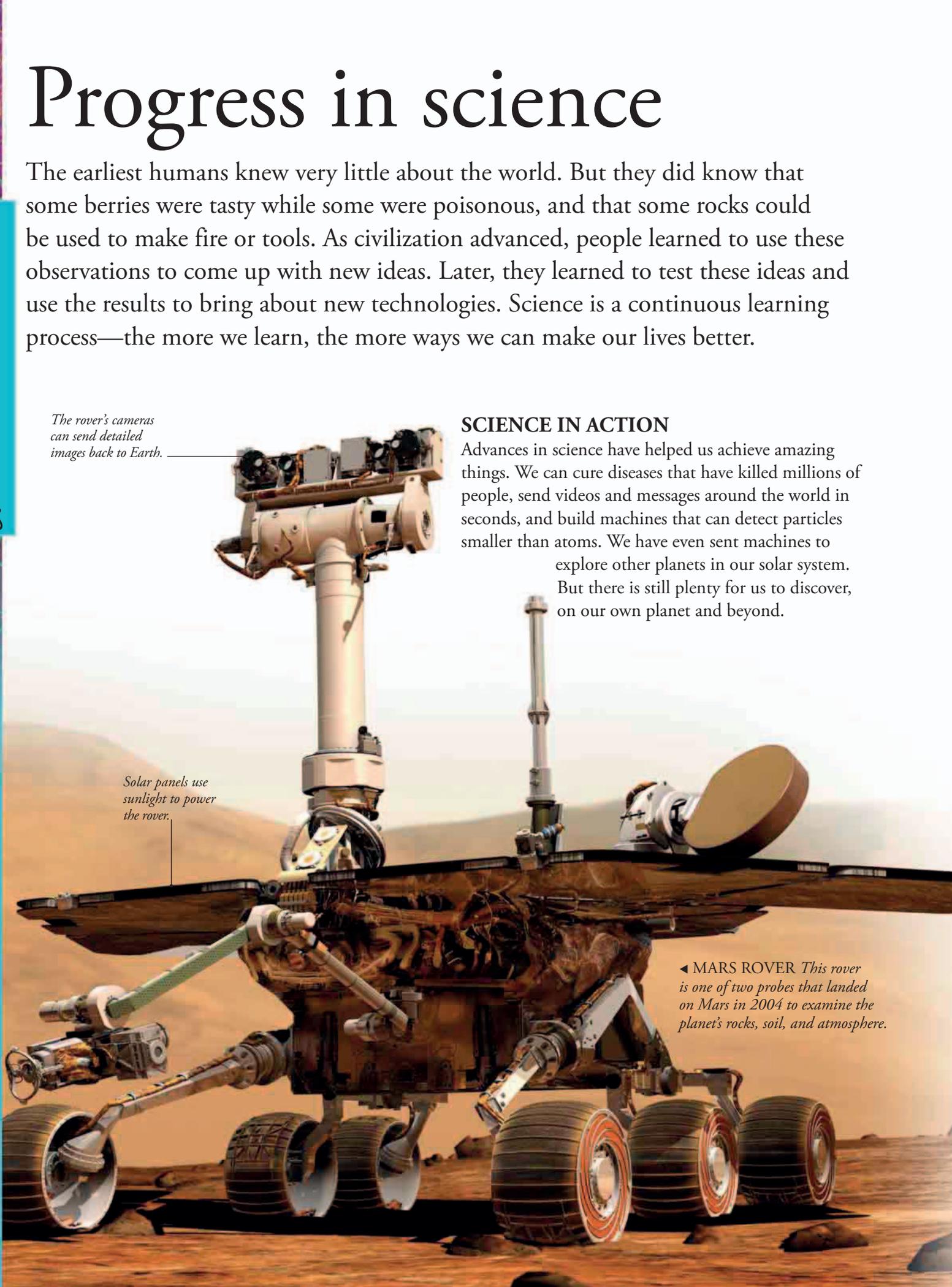
*The rover's cameras can send detailed images back to Earth.*

## SCIENCE IN ACTION

Advances in science have helped us achieve amazing things. We can cure diseases that have killed millions of people, send videos and messages around the world in seconds, and build machines that can detect particles smaller than atoms. We have even sent machines to explore other planets in our solar system. But there is still plenty for us to discover, on our own planet and beyond.

*Solar panels use sunlight to power the rover.*

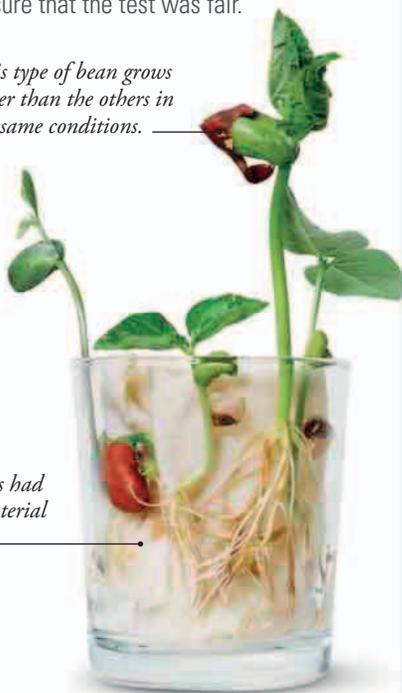
◀ **MARS ROVER** *This rover is one of two probes that landed on Mars in 2004 to examine the planet's rocks, soil, and atmosphere.*



### A FAIR TEST

The most important tool in science is the experiment. Scientists use these special tests to see whether their ideas are correct. For an accurate test, every possible influence must be controlled, so that we can be sure any changes are due to the test and not other factors. The experiment below tests how quickly different types of beans grow. Only the type of bean was changed. The plants were all given the same time to grow, and the same amount of light and food, to ensure that the test was fair.

*This type of bean grows faster than the others in the same conditions.*



*All the beans had the same material to grow in.*

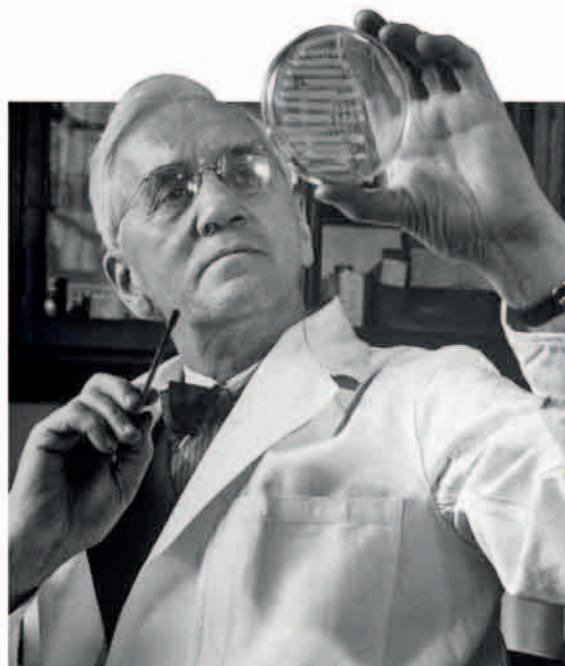
### THE SCIENTIFIC METHOD

Scientists work by observing events in the world around them (known as phenomena). They then ask a question—why or how does this happen? Then they come up with a hypothesis, or an idea, that answers that question. Finally, they conduct an experiment that tests their hypothesis. If the experiment is a success, the hypothesis is accepted as true. If not, the hypothesis is rejected, and the scientist looks for a new explanation.



### ACCIDENTAL DISCOVERIES

Sometimes accidents or luck lead people to new ideas and new techniques. One example is the discovery of antibiotics—drugs used to kill bacteria that cause diseases. The first antibiotic, penicillin, was accidentally discovered when a scientist allowed mold to grow in a dish of bacteria he was growing for other experiments. He noticed that the area around the mold was free of bacteria—the mold was producing a substance that killed off the germs.



◀ **VULCANIZATION** Charles Goodyear invented a new technique for hardening rubber when he accidentally spilled some samples onto a hot stove.

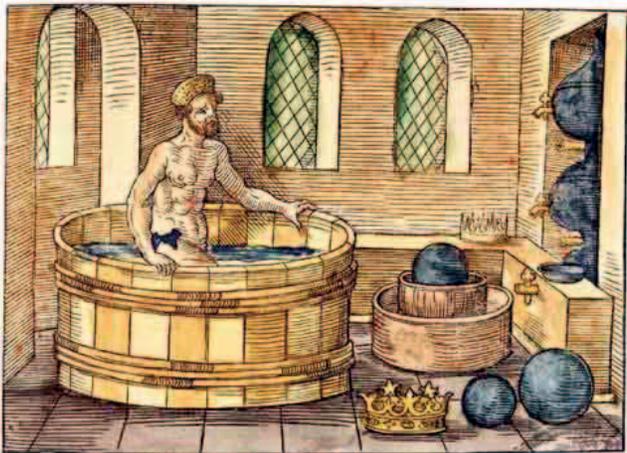
▲ **PENICILLIN** This powerful germ-killing bug was accidentally discovered by the Scottish scientist Alexander Fleming in 1928.

# Ancient science

We take for granted many tools we use today, but all of them—even the very simplest—had to be invented somewhere. People from ancient civilizations across the world discovered and wrote down some of the earliest scientific ideas, passing them down to us today. Their inventions gave later scientists the basis for new ways of thinking. They also laid down rules for how to think about science and math that are still used to this day.

## EUREKA!

The ancient Greeks began to come up with scientific processes in the 5th century BCE. One early scientist, Archimedes, was challenged to find out whether a gold crown was all gold or just lead covered in gold leaf. According to legend, he discovered the solution when he sat down in his bath, slopping water over the edge. This gave him the idea of immersing the crown in water to calculate its volume. He leaped from his bathtub shouting, “Eureka!” (meaning “I have found it!”).



▲ **BATHTIME BRAINSTORM** *This medieval drawing shows Archimedes in his bathtub with gold crowns and iron weights nearby.*



## WATCHING THE SKIES

Ancient civilizations were often interested in the sun, moon, and stars. They noticed that the sun was highest in the sky at the same time every day—noon—but sunrise and sunset were at different times each day. This gave rise to the idea of seasons. They noticed that the moon changed shape in a regular pattern lasting 28 days, giving us the idea of months. And they tracked the motion of stars, watching how they moved through the sky at different times of year, and even picking out the other planets in our solar system.

▼ **AZTEC SUN STONE** *The Aztecs of what is now Mexico mapped out their calendar of the year on this decorated stone.*

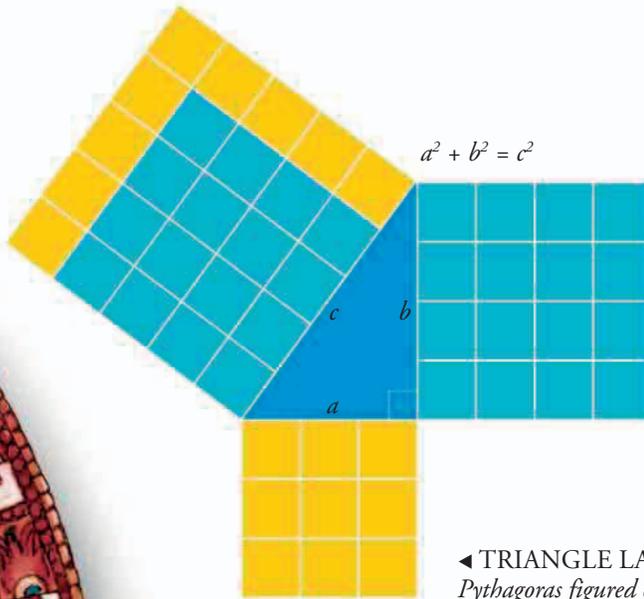


Eight dragon heads point in different directions.



Dragon facing the direction of the earthquake drops ball into toad's mouth.

$$a^2 + b^2 = c^2$$



◀ **TRIANGLE LAW** *The Greek philosopher Pythagoras figured out that, for any triangle with a right angle, the square of side a and the square of side b would equal the square of side c.*

## NUMBERS AND MATH

In addition to observing nature, early scientists began to work with shapes and numbers—the beginnings of mathematics. The works of the Greek philosopher Euclid, written around 300 BCE, were used to teach math across Europe for more than 1,000 years. Another Greek, Eratosthenes, calculated the distance around the earth almost perfectly, 1,700 years before modern scientists.

## BUILDING SHAPES

Ancient civilizations used their knowledge of materials and geometry to create astonishing buildings. The ancient Egyptians and Babylonians used right angles to build pyramids, while the Romans discovered how to build self-supporting arches. Many of these buildings were constructed so strongly that they are still standing today.



▲ **ROMAN ARCHES** *This amazing structure in France, called Pont du Garde, was built by the Romans to carry water.*

## SCIENTIFIC INSTRUMENTS

With new ideas about science came new machines and instruments. Some of these were built to help with difficult tasks, such as cranes, ramps, and levers for building. Others were built to help with scientific studies—from the earliest clocks, which used the position of the sun to measure time, to devices for figuring out where an earthquake was taking place.

◀ **EARTHQUAKE DETECTOR** *Around 100 CE, Chinese scientist Zhang Heng created the first seismograph—an instrument used to locate the direction of earth tremors.*



# Islamic science

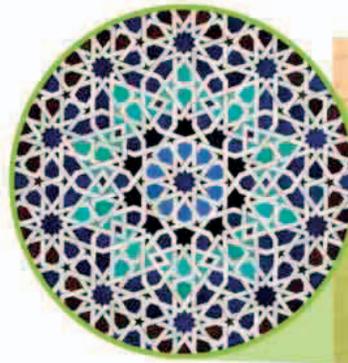
By the 7th century CE, the ancient civilizations had started to fall apart. New empires sprang up around the world and began to explore their own scientific ideas, often inspired by the discoveries of older cultures. One of the largest empires was formed as Islamic peoples spread across Asia. They valued scientific study and, between the 8th and 12th centuries CE, made great advances in astronomy, mathematics, and medicine.



▲ **THE BOOK OF OPTICS** *Ibn al-Haytham's ideas about light spread across Europe and Asia. This medieval edition of The Book of Optics shows how Ibn al-Haytham's ideas were used to explain refraction and reflection.*

## LIGHT IDEAS

Many of the great advances in science came as Islamic scholars improved on the ideas of ancient Greek philosophers and scientists. Two Greeks, Aristotle and Euclid, had different ideas about how our eyes see. Aristotle believed that light shone out of objects and into our eyes, while Euclid believed that our eyes beamed out rays to help us see. The Islamic scholar Ibn al-Haytham used observations and experiments to prove that Aristotle was right.



## THE SCIENCE OF SHAPES

Islamic cultures at this time often decorated their buildings with colorful ceramic tiles. Mathematicians used ancient ideas of geometry (the mathematics of shapes and angles) to plan out complex patterns of shapes that fit together perfectly so there were no gaps between the tiles. The mathematics of interlocking (perfectly fitting) shapes is called tessellation.

► **TESSELLATING TILES** *These tiles in Morocco fit together perfectly in a neat mathematical pattern.*



**PREDICTING THE STARS**

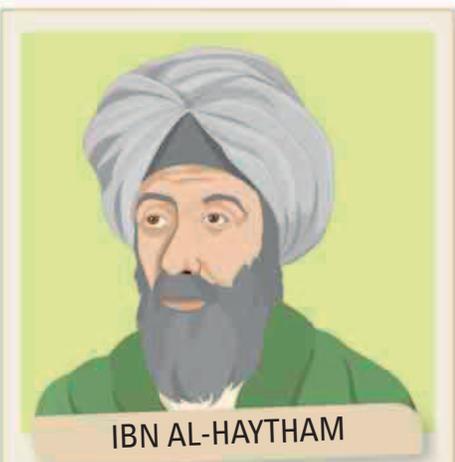
Islamic scholars made great advances in astronomy—the study of the stars. Arab astronomer al-Battānī (858–929) worked out the length of the solar year, which is how long it takes for the Earth to travel around the sun. He also helped generate tables of numbers to predict where the sun, moon, and planets could be seen in the sky at different times of year. Other scholars, like al-Zarqālī (1029–1087), built instruments called astrolabes to help map out the positions of stars in the sky.



◀ **ASTROLABE** *These instruments map the movements of the sun, moon, planets, and stars.*

**MATH MASTER**

Great developments in mathematics were made during the Islamic Age. The one we use every day is the numbers 0–9. A scholar named al-Khwārizmī (780–850) adapted a system of numbers used in India to create Arabic numerals (shown below). It spread across Asia and Europe to form the numbers we use to this day. He also made use of algebra—a way of using equations to find out mathematical answers.



**IBN AL-HAYTHAM**

Ibn al-Haytham (965–1040), also known as Alhazen, is often called the world’s first scientist. He made careful observations to test his ideas, making sure that all the other conditions of his experiment remained the same so that no other influences could disrupt his results.

**CURING THE SICK**

Ancient medicine was often closer to magic than science.

Islamic scientists such as ibn Sīnā (980–1037) tried to make the study of medicine more scientific. They made careful lists of the symptoms of illnesses, and experimented with different cures to find out which ones worked and which were based on superstition. They also tried out different mixtures of herbs in different amounts to create medicines that were effective and safe to use.

▶ **MEDICAL MANUAL** *The Canon of Medicine by ibn Sīnā was a huge encyclopedia of medicine, which was used across Europe and Asia for hundreds of years.*



# Planets and pendulums

The 16th century ushered in a scientific revolution in Europe. A wave of new ideas spread across the continent, taking the discoveries of ancient Greek, Roman, and Islamic scholars and using them to create new fields of exploration and research. These discoveries changed the way people looked at the world, providing a basis for inventions such as machines and electricity, which make modern life possible.

## ASTRONOMY AND SPACE

One of the most important scientists of the new age was an Italian named Galileo Galilei. A student of mathematics, Galileo went on to develop his own ideas, and was able to build telescopes that could see farther and more clearly than before. His writings made him unpopular with powerful members of the Catholic Church, who felt that his new ideas challenged their authority, and he was arrested and imprisoned.

▼ SEEING THE STARS *Using his improved telescope, Galileo was the first person to record that the planet Venus changes shape in the sky, just like the moon.*

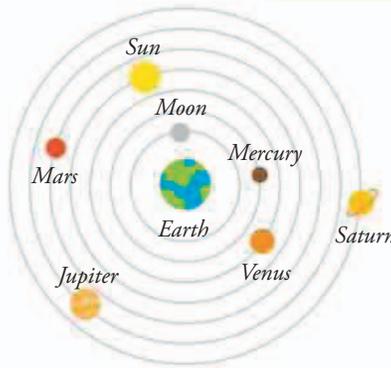
WOW!

Galileo was able to estimate the heights of mountains on the moon by measuring the lengths of their shadows.

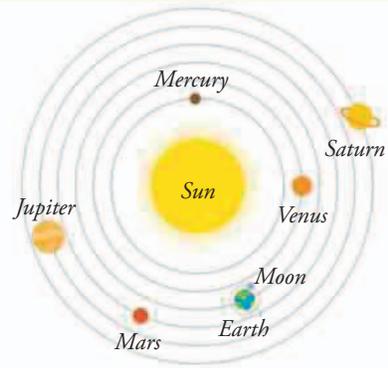


## SOLAR SYSTEM AND PLANET ORBITS

The ancient Greeks believed that the earth was at the center of the universe, and the sun and all the stars orbited around it. A Polish astronomer named Nicolaus Copernicus, who studied in Italy in the early 16th century, challenged this view. His measurements of the movements of the sun and planets led him to believe that the earth orbited the sun. He also correctly positioned all of the known planets at the time and explained why the seasons occurred. His theories were backed up by Galileo's studies in astronomy around 30 years later.



▲ **EARTH AT CENTER** *In earlier times, it was believed that the Earth sat at the center of the universe, and the sun and planets orbited around it.*



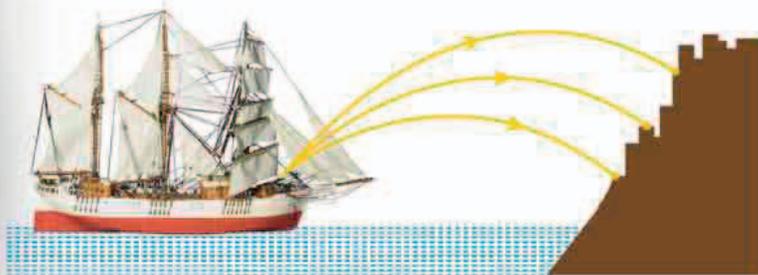
▲ **SUN AT CENTER** *Copernicus figured out that the Earth and the other planets orbit the sun. He also said that the Earth spins on its axis, and the moon orbits around the Earth.*



▲ **TOWER TESTS** *Legend has it that Galileo began his experiments on pendulums by swinging the chandeliers in the famous Cathedral of Pisa, Italy.*

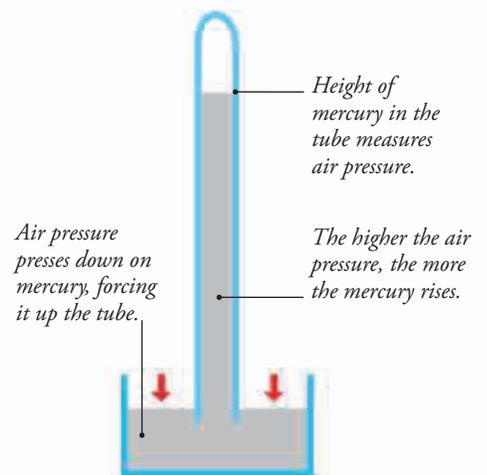
## THE BEST AIM

Another area in which Galileo made important discoveries was the mathematics of trajectories, or how objects fly through the air when gravity pulls on them. A ball fired from a cannon flies in a steady curve called a parabola, moving up with the force of the cannon shot, then curving back down to earth as gravity acts on it. Galileo figured out how changing the angle of the cannon changes the distance the cannonball flies when it is fired.



## THE PENDULUM'S SWING

Galileo also studied the mechanics of movement, especially the way things fall or swing on a rope. He watched a pendulum swinging and noticed that it always crossed its middle point in time with his heartbeat, no matter how far it swung. Galileo concluded that a pendulum always takes the same time to complete a cycle—swinging from one side to the other. Later scientists used this principle to build the first pendulum clocks.



## AIR PRESSURE

Galileo's writings influenced many scientists. Evangelista Torricelli, born in Italy in 1608, read many of Galileo's works and used them to develop his own ideas. He is most famous today for inventing the barometer (above), a machine that measures air pressure using a column of mercury. This device can be used to predict changes in the weather.



# Gravity and rainbows

In the late 1600s, another wave of scientific discoveries spread across the world. This was known as the Enlightenment, and it combined scientific thinking with new ideas, philosophy, and politics. One of the most famous scientists of this period was the English Isaac Newton, whose ideas about light, gravity, and motion are still used by scientists and engineers to this day.



## DISTANT ATTRACTION

Newton was fascinated by the movements of the planets. A German astronomer named Johannes Kepler had already figured out that the planets orbit the sun in oval shapes, called ellipses. Newton realized that these orbits were controlled by an invisible force—gravity—that pulled the planets towards the sun. Newton also figured out that gravity must pull between all objects, but that larger objects, such as the sun, pull with more force than smaller objects. Finally, he showed that the force of gravity gets weaker as objects get farther apart.

◀ **MOON'S ORBIT** *Newton's laws of gravity explain how the moon orbits around the Earth, and the Earth in turn orbits around the sun.*

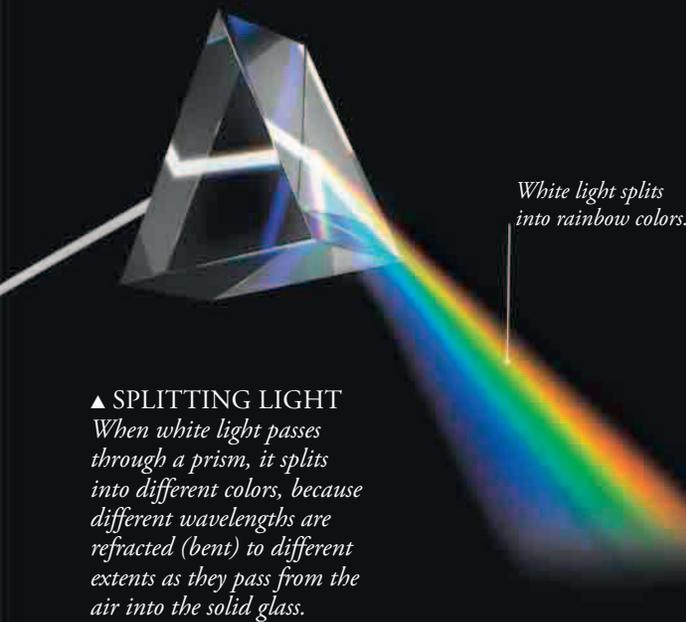
WOW!

Newton said he came up with his theory of gravity after watching an apple fall from a tree.



## COLORS OF LIGHT

Newton was also very interested in how light travels between objects. He did experiments into refraction (or the way light changes direction when it passes through a solid object), such as a glass prism. He noticed that colored light stayed the same color when it passed through a prism, while white light was split into rainbow patterns. This led him to the idea that different colors are created by different kinds of light (what we now know as different wavelengths). He used his understanding of the movement of light to suggest improvements to telescopes and microscopes.



▲ **SPLITTING LIGHT**  
When white light passes through a prism, it splits into different colors, because different wavelengths are refracted (bent) to different extents as they pass from the air into the solid glass.

► **CALCULATING CURVES** Calculus lets us work out the area under a curve, and how steep the curve is in different places. This graph shows how fast a motorcycle is going at different times. We can use calculus to find out how far it has traveled, and how quickly it speeds up and slows down.



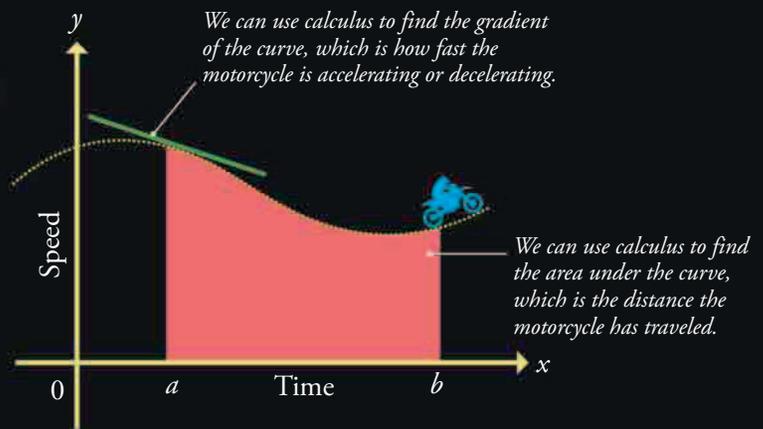
## ACTION, REACTION

Newton's three Laws of Motion (see pp. 88–89) are the basis for much of modern mechanics and engineering. The first law says that a stationary object will stay stationary, and a moving one will stay moving, unless a force acts on it. The second law states that the greater the force that acts on an object, the faster it moves. The third law says that any force applied to an object creates an equal force in the opposite direction.

◀ **LAWS OF MOTION** Newton's laws explain how a cricket ball moves in one direction until it hits the bat. The ball changes direction when force from the bat is applied to it, and the bat bounces back when the ball hits it.

## A NEW KIND OF MATH

Before the 1680s, nobody had discovered how to work out the area under a curved line. Two mathematicians, Newton and a German, Gottfried Wilhelm Leibniz, came up with a new type of mathematics called calculus, which made all kinds of new calculations possible.



## RARE VISITORS

Comets are balls of ice and rock that orbit around the sun. Their orbits take them far out into space, so they are rarely seen from Earth. Thanks to Newton and other astronomers, it became possible to work out the shape of a comet's orbit and predict when it would next appear. In 1705, British astronomer Edmond Halley figured out that a certain comet should appear every 75 years, with the next sighting due in 1758. He died before the day arrived, but the comet appeared as he predicted, and has been known as Halley's Comet ever since.

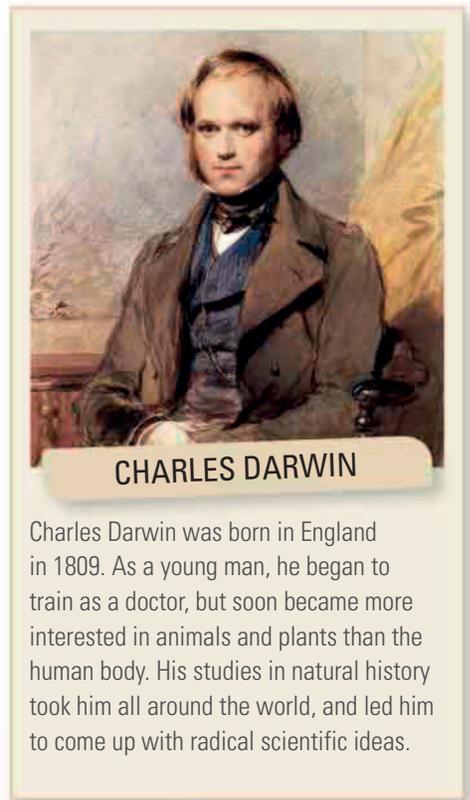


Halley's Comet



# Evolution and adaptation

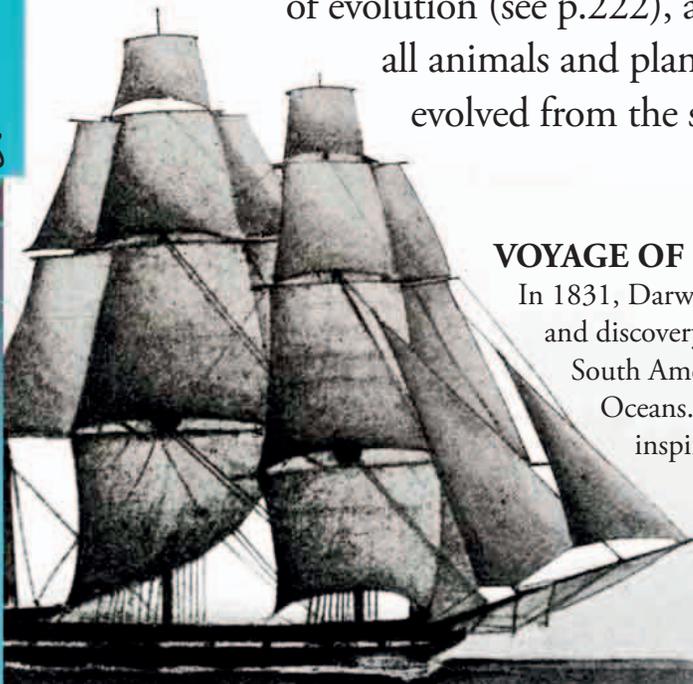
In the 19th century, English naturalist Charles Darwin came up with one of the most important scientific ideas in history. He realized that living things could change across generations, and only the most successful passed their genes on to their children. His theory paved the way for our idea of evolution (see p.222), and showed that all animals and plants, even humans, evolved from the simplest life forms.



## VOYAGE OF DISCOVERY

In 1831, Darwin joined the crew of HMS *Beagle* on a voyage of exploration and discovery. Over the course of five years, they traveled from England to South America and Australia, crossing the Atlantic, Pacific, and Indian Oceans. The things he saw on this journey provided Darwin with the inspiration for some of his most important ideas.

◀ 1831 DARWIN SETS SAIL *The Beagle was sent to map the coasts of the lands of the Southern Hemisphere. Darwin went along as a naturalist, to study local wildlife and bring back samples.*



1830

1831

1832

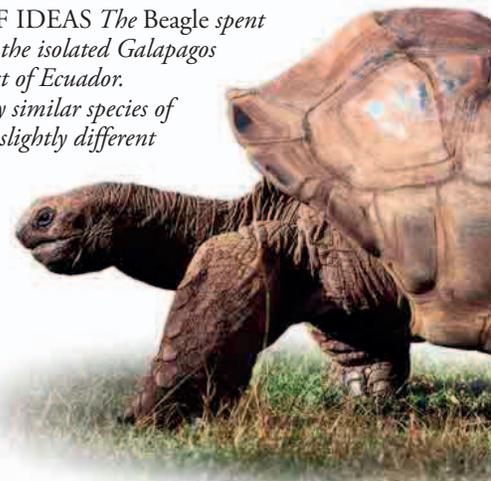
1835

1840



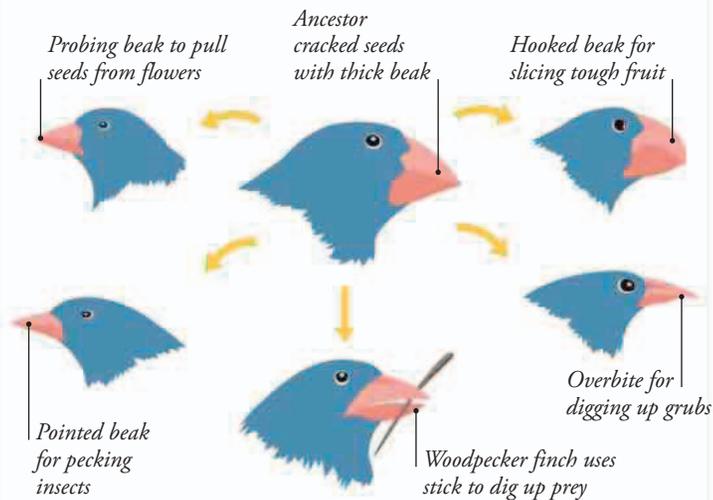
◀ 1832 MAMMOTH MAMMAL *Upon arriving in Brazil, Darwin was shown the fossilized remains of a large mammal. He identified it as Megatherium, a creature that died out many thousands of years ago, and noted how similar it was to the sloths still living in South America.*

▶ 1835 ISLANDS OF IDEAS *The Beagle spent several weeks exploring the isolated Galapagos Islands off the west coast of Ecuador. Darwin noted that very similar species of birds and tortoises had slightly different body shapes on the different islands. This supported his idea that species change over generations to cope with different conditions.*



## DARWIN'S FINCHES

During his time in the Galapagos Islands, Darwin observed groups of birds with the same appearance but very different beaks. He came to the conclusion that since these islands were far from the mainland and hard for birds to get to, one species of finch had reached them in the distant past. It had evolved into several distinct species, each with a beak specially designed for eating the food on its particular island.



◀ 1848 ALLIES AT HOME *After returning to England, Darwin published some of his findings, but continued working on his grand theory in secret. In 1848, another English naturalist, Alfred Russel Wallace, began working on a theory very similar to Darwin's. Together, the two men presented their ideas to other naturalists in 1858.*



▲ 1859 WORD GETS OUT *Darwin's grand theory was finally published in a book called On the Origin of Species. It immediately caused a great uproar, since many people were unwilling to believe that humans shared ancestors with apes. Cartoons such as this one poked fun at Darwin and his theory of evolution. Despite these attacks, Darwin's ideas quickly spread, changing the way we look at life on Earth forever.*



1848



1850



1855



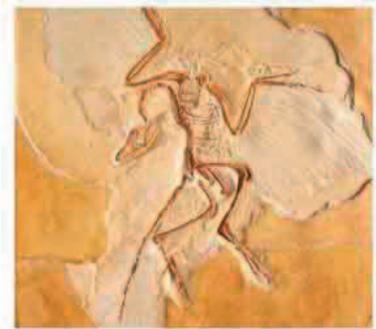
1859



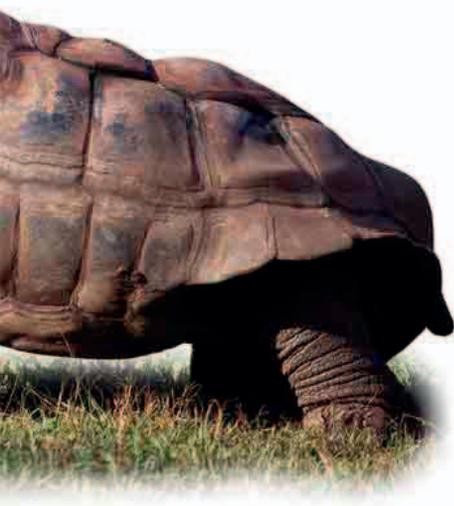
1860

## DARWIN'S SUPPORTERS

Many scientists at the time agreed with Darwin's ideas, and used them to help with their own research. Thomas Huxley was one of them. He studied fossils to look for links between prehistoric forms of life and species living today. One of his most famous discoveries was that an extinct winged animal called *Archaeopteryx* had a skeleton very similar to small dinosaurs, but was feathered like a modern bird. He took this as proof that birds had evolved from dinosaurs.



Fossil of *Archaeopteryx*



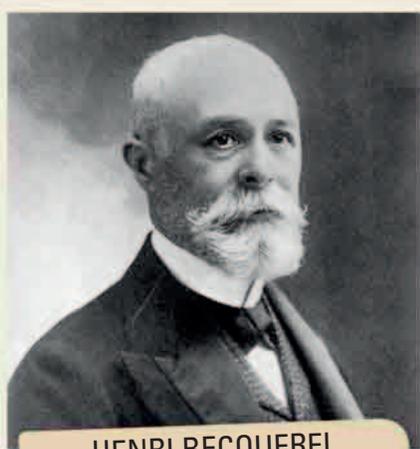
# Invisible rays

Toward the end of the 19th century, scientists began to develop delicate instruments for detecting energy signals. They also began to use electricity in their experiments. The result was a series of exciting discoveries, from X-rays (invisible light that can pass right through solid objects) to radioactivity (tiny particles that shoot out of atoms). Together, they opened up a whole new world of scientific ideas, full of invisible types of energy that nobody had ever dreamed existed.

## MARIE CURIE

The discovery of radioactivity opened up important areas of scientific research. Some of the earliest and most famous discoveries were made by Marie Curie, a Polish-born scientist working in France. She and her husband, Pierre Curie, discovered two new radioactive elements, polonium and radium, in 1898. After Pierre's death in 1906, Marie worked out new methods for extracting pure radium from its ore, and was the first person to study the metal in detail.

► **MARIE CURIE AT WORK** *This picture shows Curie in her laboratory at the University of Paris, France, where she was the first woman professor.*



**HENRI BECQUEREL**

French scientist Henri Becquerel discovered radioactivity by accident in 1896, when he left samples of radioactive uranium next to photographic plates. He noticed that the plates showed dark patches where the uranium had been.





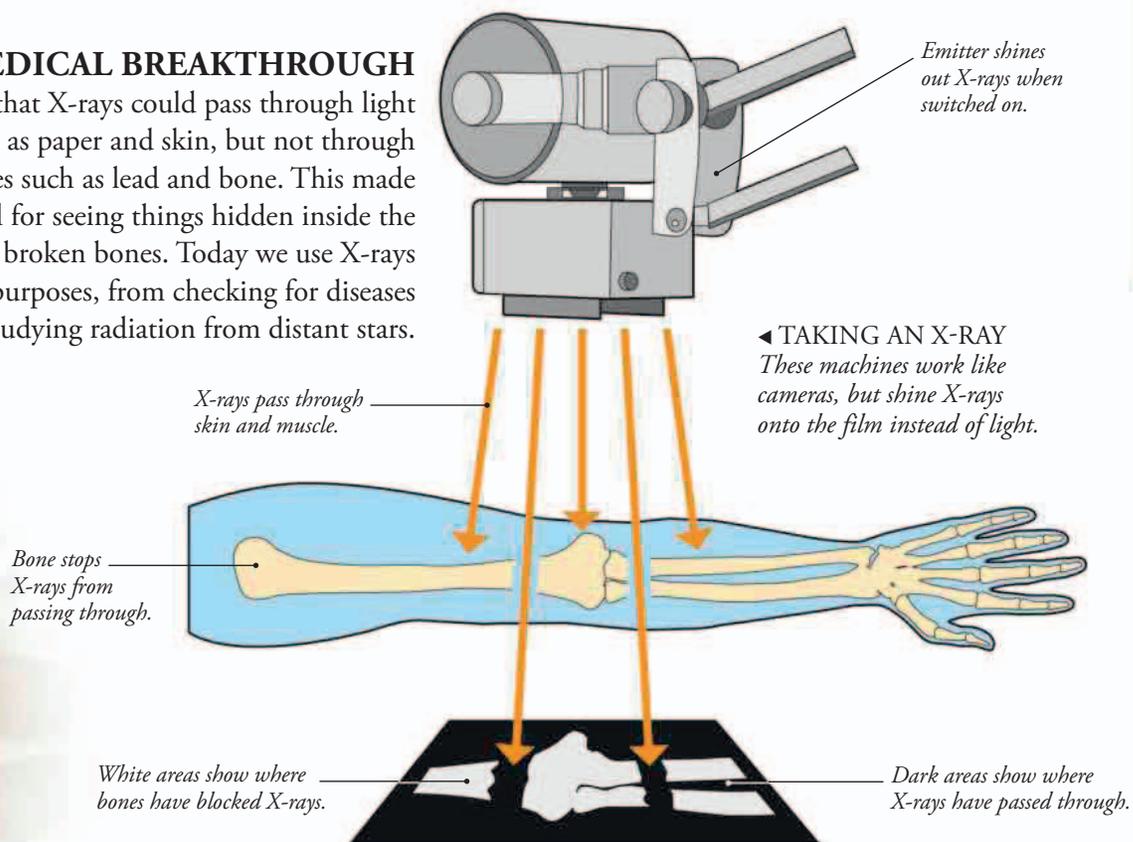
## DISCOVERING X-RAYS

X-rays were discovered in 1895 by a German physicist named William Röntgen. He was investigating the light produced by passing electricity through a vacuum tube. He noticed that, even with a cardboard screen covering the tube, some radiation could still be detected. He named this radiation X-rays, after the scientific term for something unknown, X.

◀ **THE FIRST X-RAY** *Röntgen took the first X-ray photograph, showing the bones of his wife's hand and her wedding ring.*

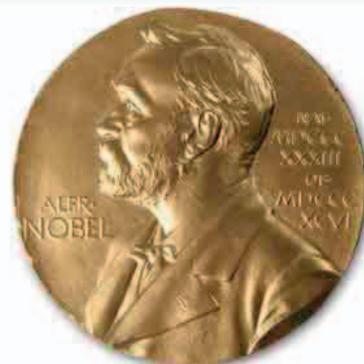
## MEDICAL BREAKTHROUGH

Röntgen realized that X-rays could pass through light materials such as paper and skin, but not through denser substances such as lead and bone. This made them very useful for seeing things hidden inside the body, for example broken bones. Today we use X-rays for many different purposes, from checking for diseases inside the body, to studying radiation from distant stars.



## NOBEL PRIZE

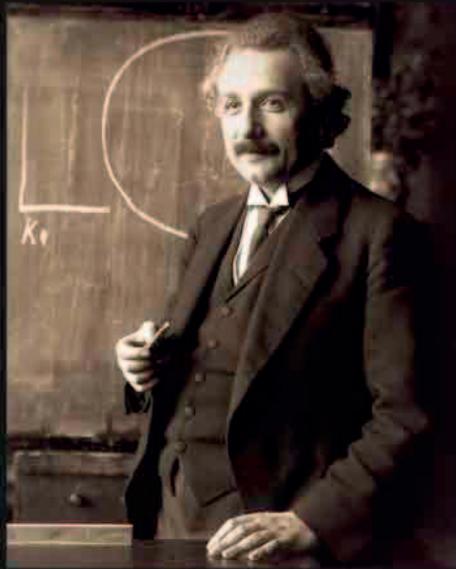
Swedish inventor Alfred Nobel set up the Nobel Prize in 1895. He wanted the prestigious awards to be given each year to the people who had made the greatest advances in science, literature, and peace. They are still some of the world's most prestigious prizes. Marie Curie is the only person in history to have been awarded two Nobel prizes in two different sciences—one for physics in 1903, for her contribution to research on radioactivity, and one for chemistry in 1911, for discovering the elements polonium and radium.



Nobel Prize medal

# It's all relative

One of the most famous scientists of all time, German physicist Albert Einstein transformed the way we think about the universe. At the beginning of the 20th century, his new ideas about math and physics made scientists across the world think differently about time, energy, and matter. His ideas were so far ahead of his time that we are still working on them today, and he became so famous that his name has been used to mean “genius” ever since.



## ALBERT EINSTEIN

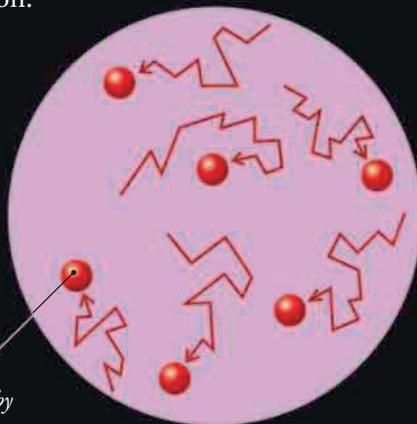
Einstein grew up in Germany and Switzerland. His first job was as a clerk in the Swiss patent office, where he read many scientific papers on topics such as electromagnetism. He began to write his own scientific papers in his spare time. In 1905, at the age of just 26, he published four articles that were read by scientists around the world. The papers investigated the structure of atoms, the movement of electrons, and the relationship between matter and energy. He soon became famous, and won the 1921 Nobel Prize for physics.

◀ **GENIUS AT WORK** *Einstein moved to the United States in 1933, and worked at Princeton University for more than 20 years.*

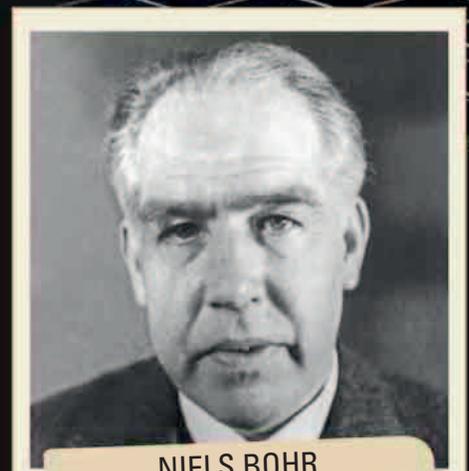
## BROWNIAN MOTION

In 1827, a Scottish botanist named Robert Brown noticed that grains of pollen floating in water seemed to jump around when viewed under a microscope. In 1905, Albert Einstein provided an explanation.

Water is a liquid, made up of water molecules that can move freely. The pollen grains are jostled around by the water molecules, which bump into them and push them around. Einstein used this as proof of the existence of atoms and molecules.



*Grains of pollen dance around as they are pushed by free-moving water molecules.*



**NIELS BOHR**

Danish physicist Niels Bohr worked on some of the same problems as Einstein at around the same time. Bohr figured out that electrons orbit atoms at set distances called shells, and that they can move from a closer orbit to one farther away if given energy.



## SPACE AND TIME

A fast object seems to move slowly if you are moving fast as well. It can even seem to move backward if you overtake it. Einstein showed that this is not true of light, which always moves away from you at light speed, no matter how fast you travel. This creates an effect known as “time dilation,” which means that time slows down for things that travel very quickly. Einstein figured out that time is in fact just another dimension, like the three dimensions of space.

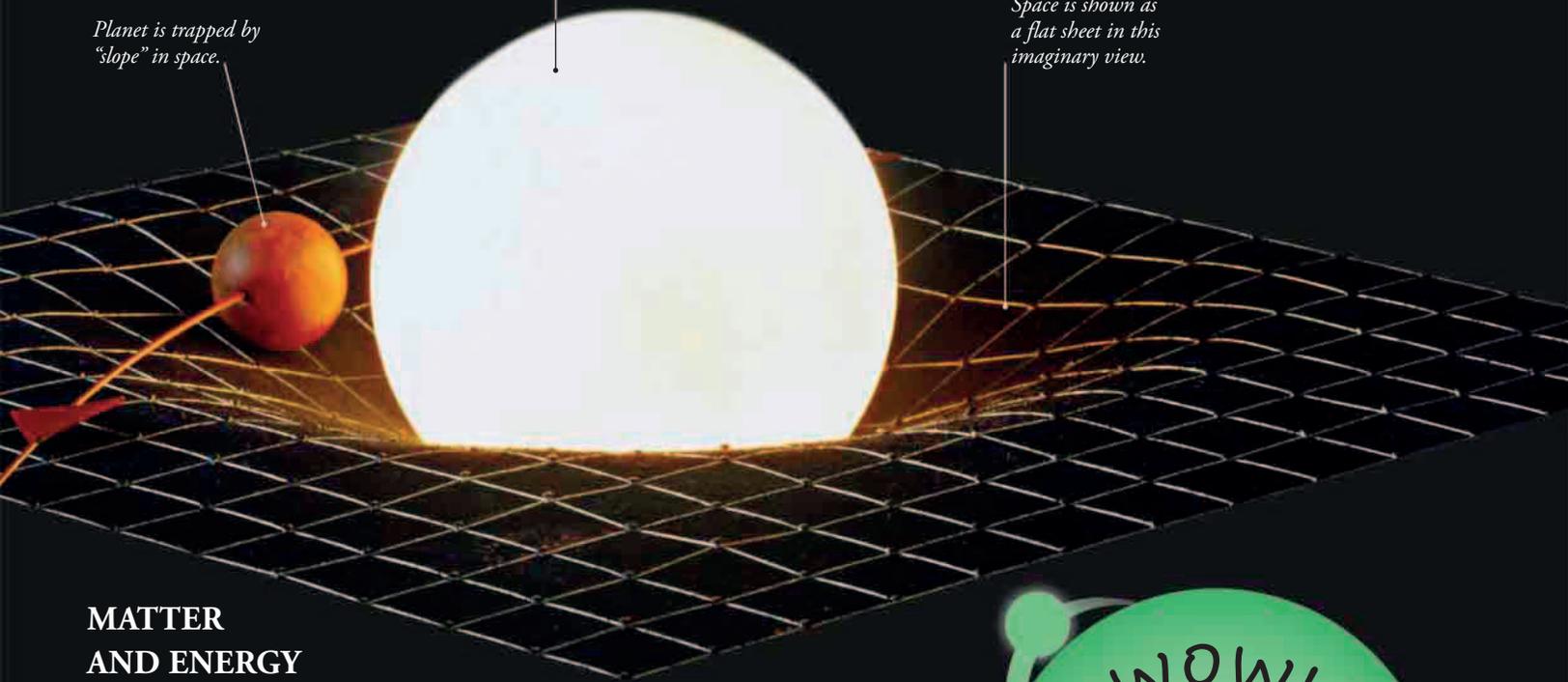


▲ **RELATIVITY** GPS satellites rely on very accurate clocks to help people on the ground find out where they are. Because the satellites are moving very quickly in orbit, time runs slightly more slowly for them than for clocks on Earth, so computers are used to correct the signals and keep the system accurate.

Planet is trapped by “slope” in space.

Sun distorts space, creating a “gravity well.”

Space is shown as a flat sheet in this imaginary view.



## MATTER AND ENERGY

As things travel faster, they gain more energy. Einstein calculated that as an object gains energy, it also gets heavier, although it takes a huge amount of energy to cause a small increase in mass. His famous equation for this is  $E = mc^2$ —that is, energy is equal to mass times the speed of light squared (a very big number). From this, Einstein was able to prove that matter can be converted to energy, and vice versa. In fact, matter and energy can be seen as two sides of the same coin.

### ▲ BENDING SPACE

According to Einstein, large bodies of mass and energy, such as our sun, bend space and time around them, like weights sitting on a rubber sheet. Smaller objects are pulled into orbit around them by the “slope” they create.

WOW!

After his death, Einstein’s brain was taken away for research, without permission, by a doctor at his hospital.

# Inside the atom

Until the 20th century, atoms were always thought to be the smallest things in the universe—so small they could never be broken down into anything else. We now know that atoms are made up of even tinier particles—protons, neutrons, and electrons. These discoveries came about thanks to experiments carried out in the 1900s by scientists such as Ernest Rutherford and his colleagues.

## ERNEST RUTHERFORD

Born in New Zealand in 1871, Ernest Rutherford studied in England, where he became a famous professor of physics and chemistry. In 1908, Rutherford successfully proved that radioactivity was the result of atoms breaking apart—something that had always been considered impossible. In addition to making important discoveries, he also taught other physicists, such as the Danish scientist Neils Bohr, who developed Rutherford's ideas. As a result, Rutherford is often known as the “father of nuclear physics.”



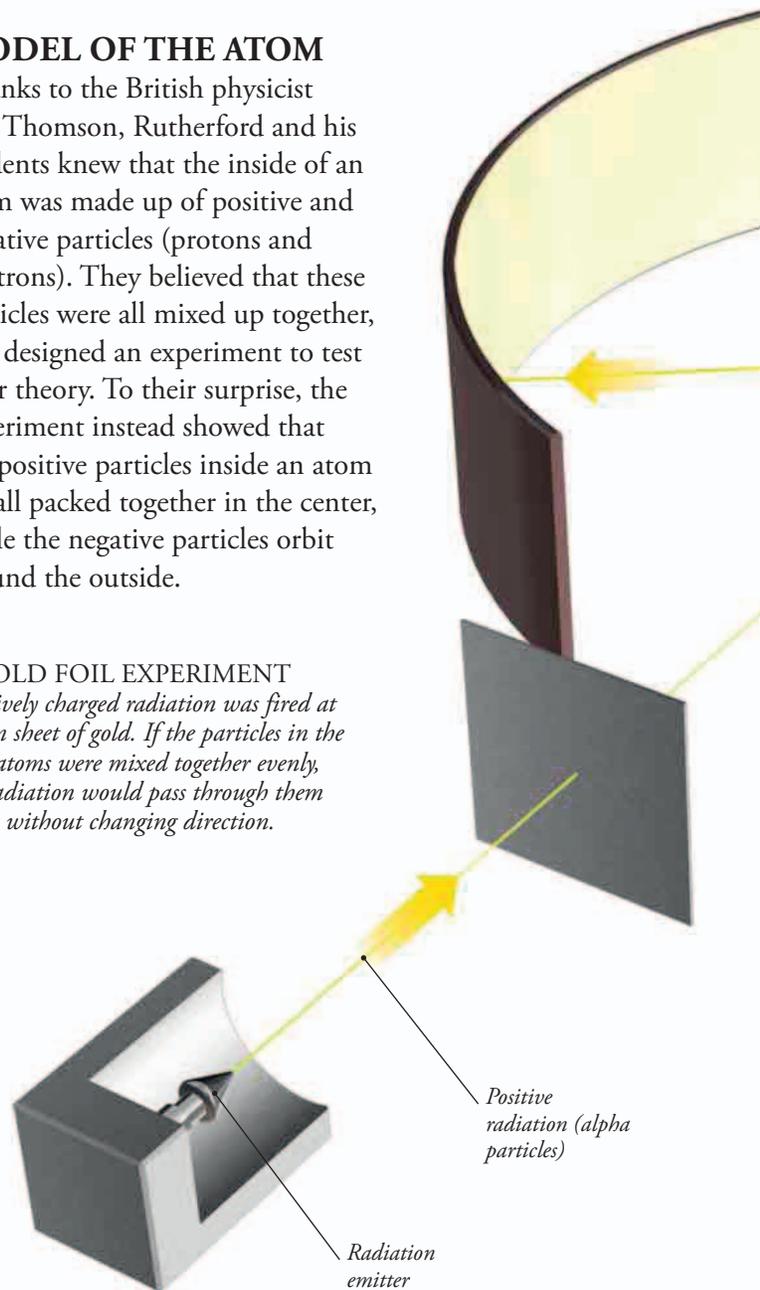
▲ **LIFETIME IN RESEARCH** Ernest Rutherford worked and taught physics at Manchester University in England. He won the Nobel Prize for physics in 1908.

## MODEL OF THE ATOM

Thanks to the British physicist J. J. Thomson, Rutherford and his students knew that the inside of an atom was made up of positive and negative particles (protons and electrons). They believed that these particles were all mixed up together, and designed an experiment to test their theory. To their surprise, the experiment instead showed that the positive particles inside an atom are all packed together in the center, while the negative particles orbit around the outside.

### ► GOLD FOIL EXPERIMENT

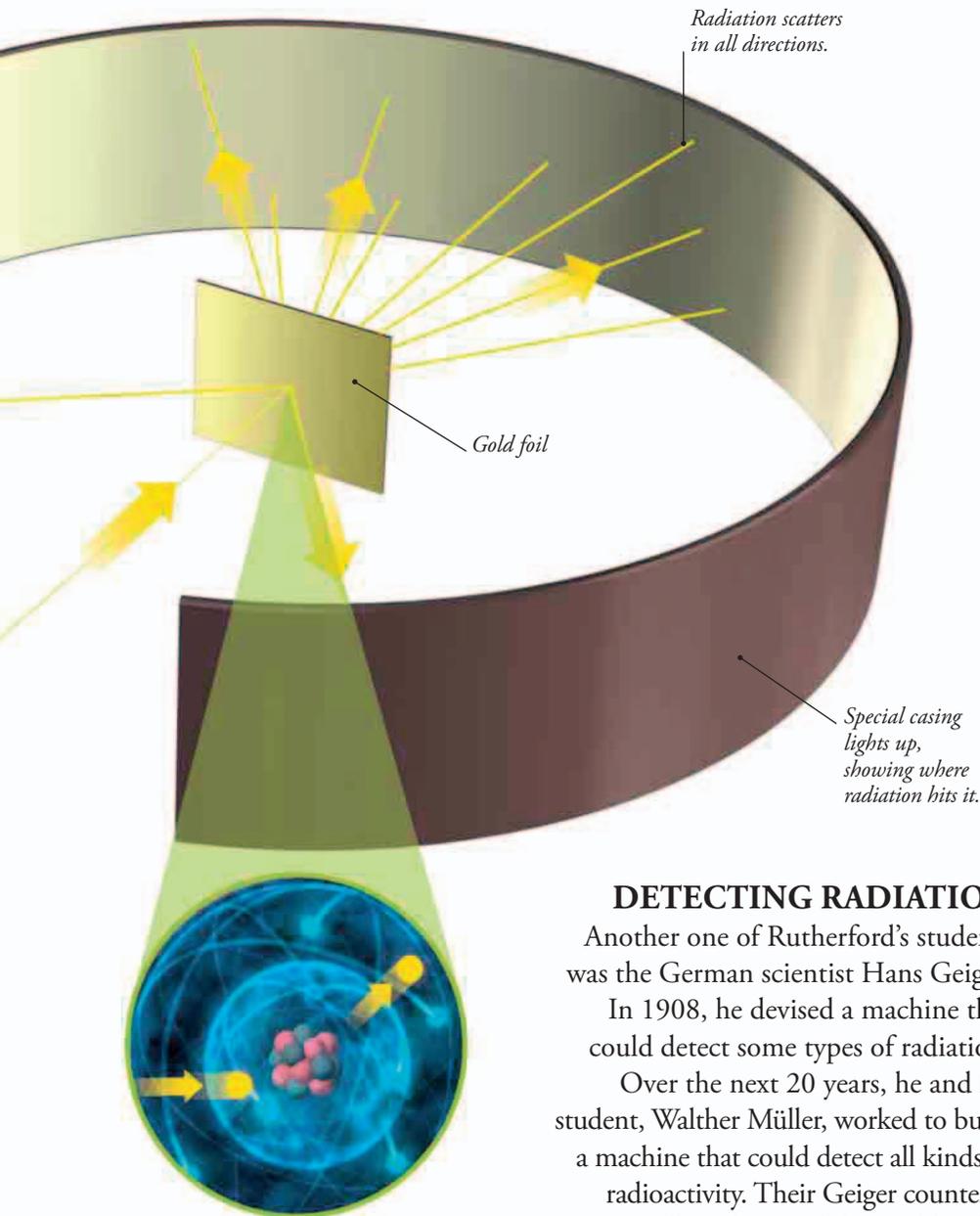
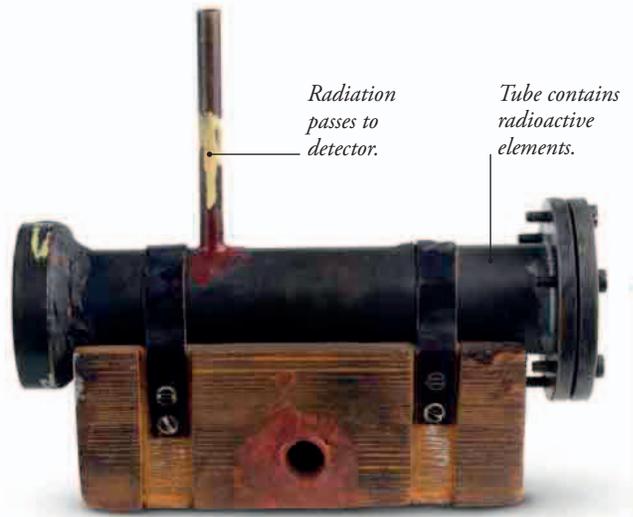
*Positively charged radiation was fired at a thin sheet of gold. If the particles in the gold atoms were mixed together evenly, the radiation would pass through them easily without changing direction.*



## ANOTHER PARTICLE

Rutherford and his colleagues had proven the existence of protons and electrons, but they also knew that atoms were too heavy to be made up of just those particles. Rutherford came up with the idea of a third particle, called a neutron, with no electrical charge. It sits inside the nucleus of the atom, next to the protons. His idea remained a theory until 1932, when James Chadwick, a British physicist at the University of Cambridge in England, built a neutron detector to prove the existence of this third kind of particle.

► **NEUTRON DETECTOR** *Chadwick used two different radioactive elements, polonium and radium, to create a device that emitted neutrons.*



▲ **NUCLEUS** *The radiation was scattered in all directions. This showed that the positive parts of an atom are in the center (nucleus), while the negative parts orbit around it, like planets around the sun.*

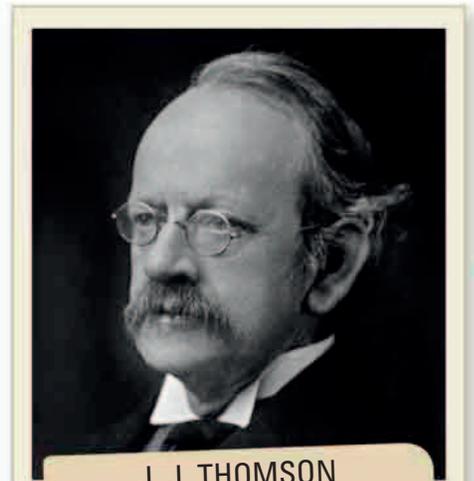
## DETECTING RADIATION

Another one of Rutherford's students was the German scientist Hans Geiger.

In 1908, he devised a machine that could detect some types of radiation.

Over the next 20 years, he and his student, Walther Müller, worked to build a machine that could detect all kinds of radioactivity. Their Geiger counter is still used around the world today.

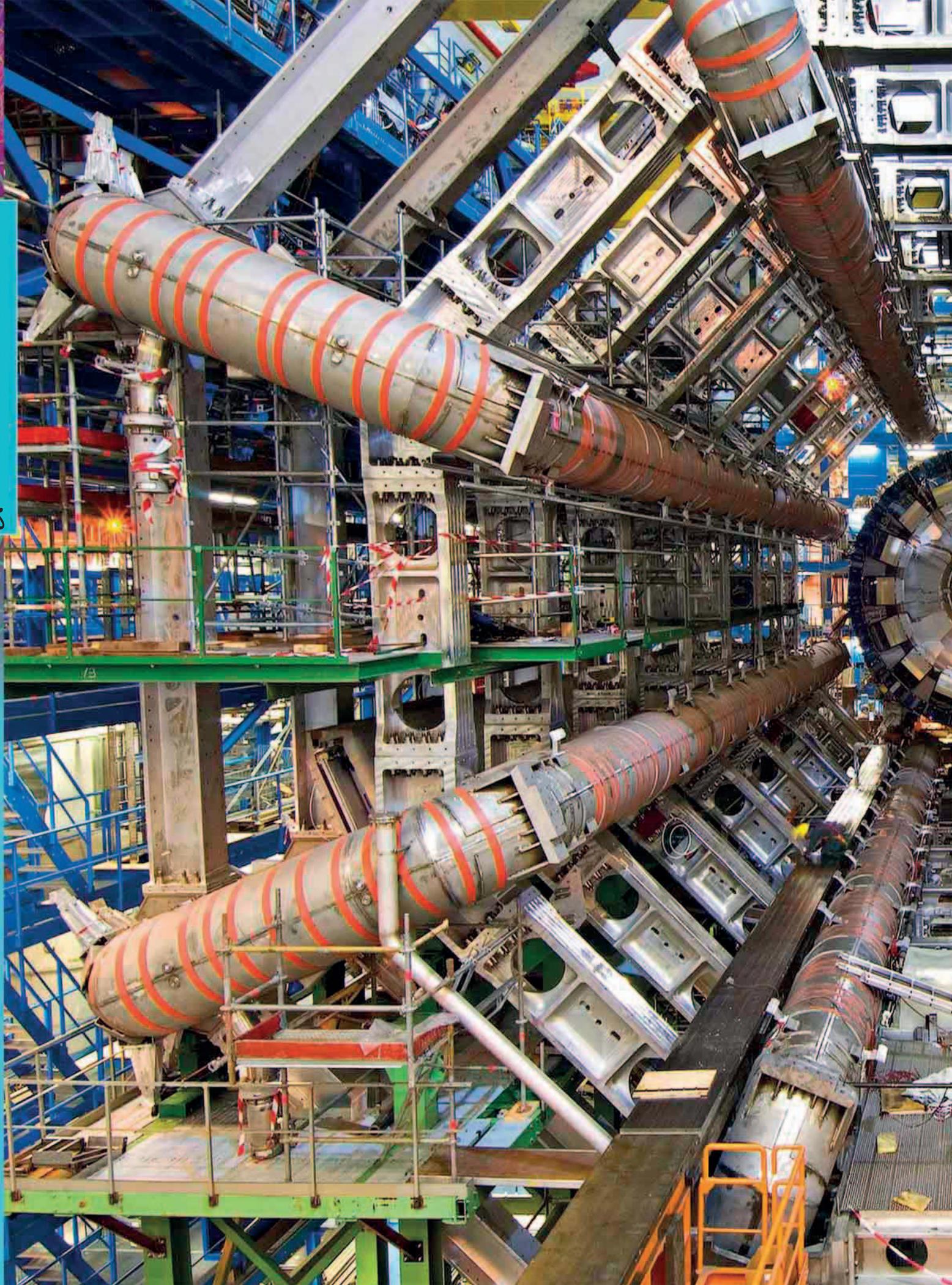
► **GEIGER COUNTER** *This device is used across the world, for example to check for radioactive contamination in crops.*



J. J. THOMSON

In 1897, Thomson became the first person to prove that atoms can be split into smaller particles. He passed electrons through a cathode ray tube, and discovered that magnets and static electricity caused the electrons to change direction. This showed that the electrons were tiny particles rather than waves of energy.







## ATOM SMASHER

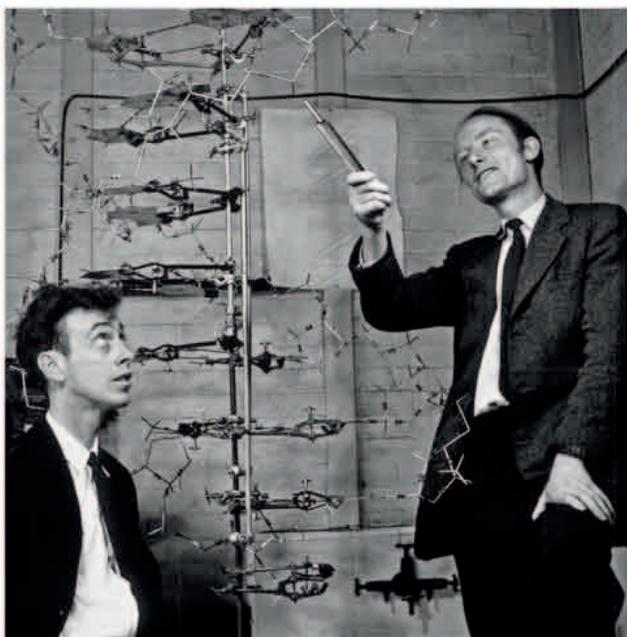
The Large Hadron Collider uses powerful magnets to speed pieces of atoms around a circular track 17 miles (27 km) long. The pieces smash into each other at close to the speed of light, splitting into tiny particles. Scientists can study these particles to find out more about the universe.

# The secret of life

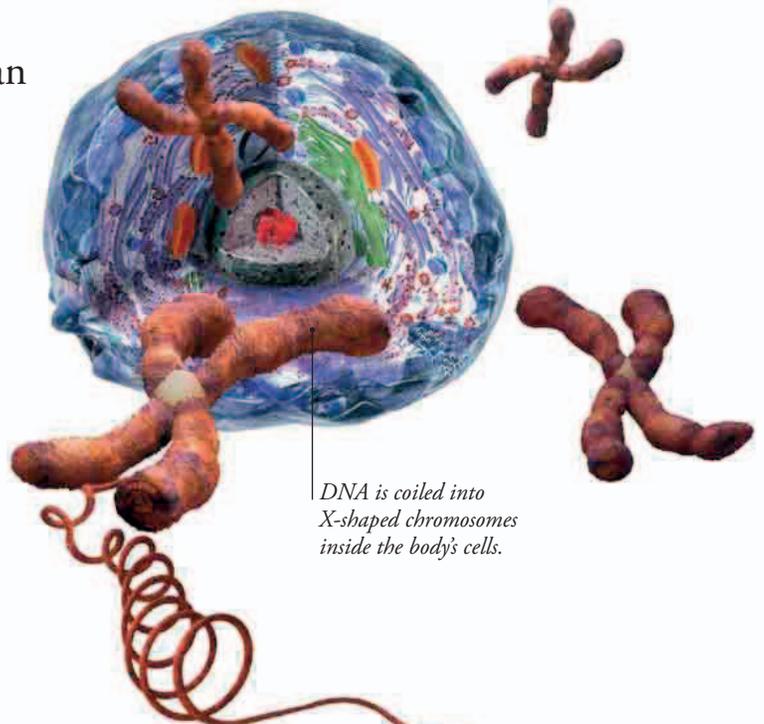
How can something as complex as a human body grow from a single cell? The answer lies in deoxyribonucleic acid (DNA), a special kind of molecule hidden inside almost all the cells in your body. These long strings contain all the information needed to grow a human being. DNA was discovered in the 1940s, but nobody understood how it could carry genetic code. It was only in 1953 that scientists discovered its unique structure—a special spiral with information stored in its coils.

## CRACKING THE CODE

Francis Crick and James Watson were researchers at the University of Cambridge in England. Their research showed that DNA molecules are shaped in a two-part spiral (called a double helix), enabling them to carry a huge amount of information in a small space.



▲ SPIRAL MODEL Watson (left) and Crick built a model of a DNA molecule in their laboratory in Cambridge, which they used to demonstrate their theory.



DNA is coiled into X-shaped chromosomes inside the body's cells.



◀ DNA These incredibly long molecules are hidden inside every cell of your body. Each one contains all the information needed for your body to grow.

**WOW!**

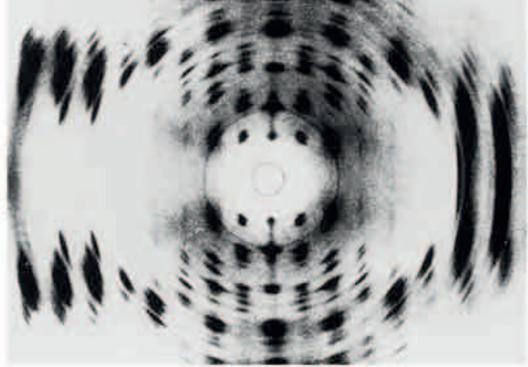
Your genetic code is made up of about 3.2 billion pairs of building blocks called proteins that are stored in your DNA.





**X-RAY PICTURES**

Watson and Crick's discovery was made possible by the work of Rosalind Franklin. She and her colleague, Maurice Wilkins, used a new technique called X-ray crystallography to create the first clear images of DNA in 1952. These images gave Watson and Crick vital clues about the molecule's shape and structure.



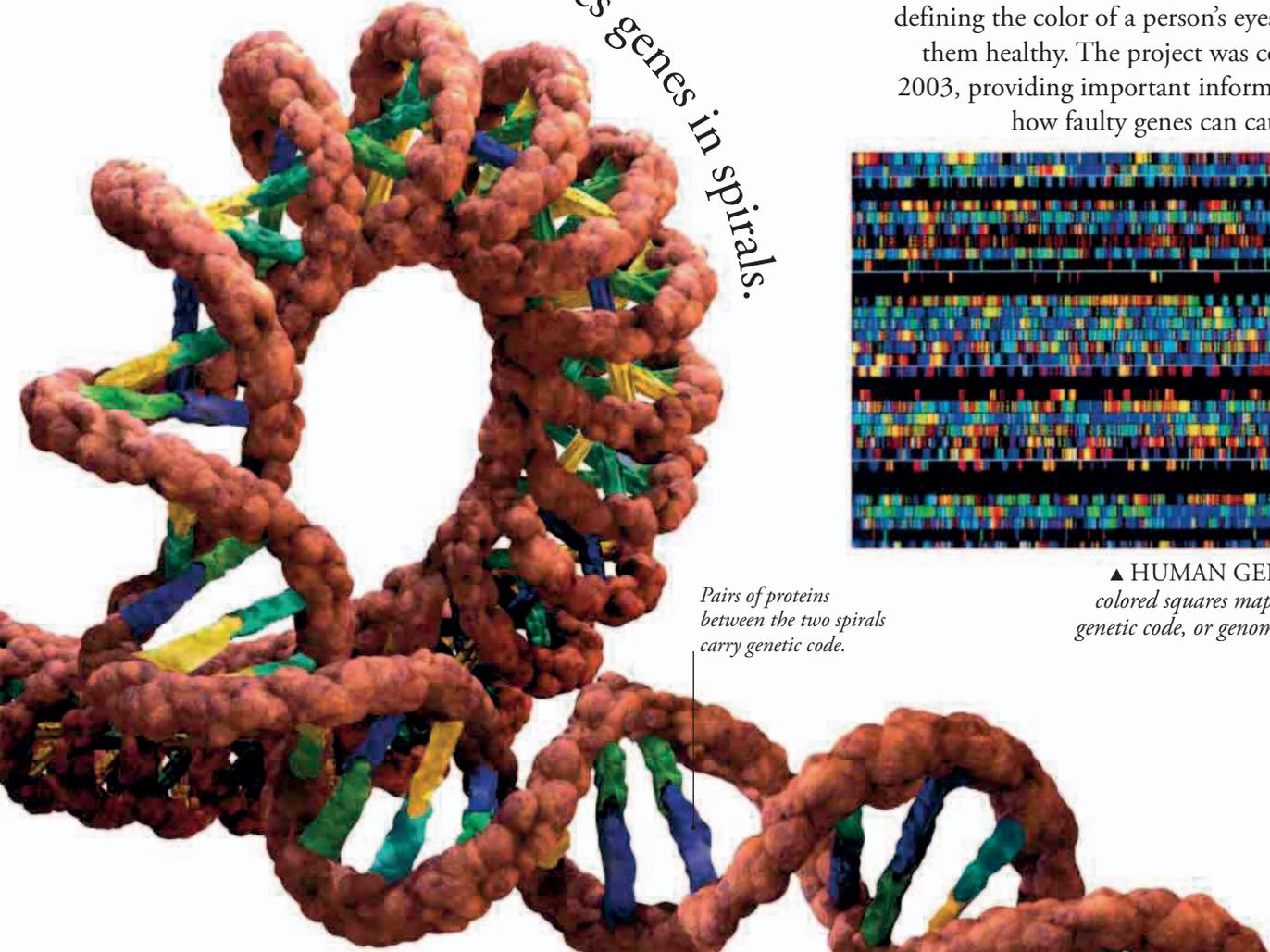
◀ **MICROSCOPE VIEW**  
*Franklin produced images like this by reflecting X-rays off DNA molecules.*

▲ **PAVING THE WAY** *English scientist Rosalind Franklin produced the first clear images of DNA molecules, and identified some of the elements in them.*

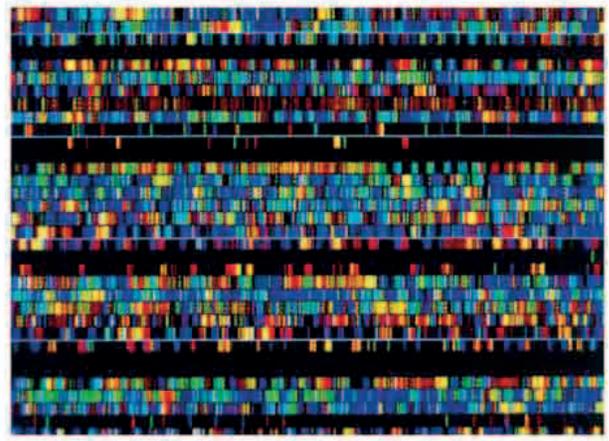
**MAPPING THE GENES**

In 1990, a project was launched to study every gene in a human being's genetic code. The idea was to figure out what each gene was for, from defining the color of a person's eyes to keeping them healthy. The project was completed in 2003, providing important information about how faulty genes can cause diseases.

DNA stores genes in spirals.



*Pairs of proteins between the two spirals carry genetic code.*



▲ **HUMAN GENOME** *These colored squares map out the entire genetic code, or genome, of a person.*

# Great inventions

Inventions power progress—the never-ending quest to improve our world. Although some inventions occur by accident, most happen when science becomes technology. Science is the journey of discovery that reveals the wonder of the world, while technology means using science to solve human problems.

GREAT DISCOVERIES



▼ **2 MILLION YEARS AGO STONE TOOLS** *The earliest stone tools were invented about 2 million years ago. These multipurpose flint axes were held with one hand.*

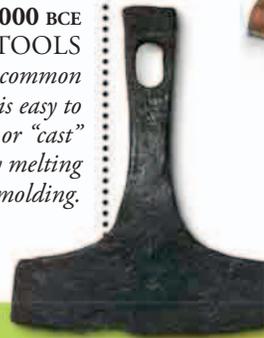
► **c.5000 BCE WRITING** *The Sumerians invented writing by pressing marks in clay tablets, so people could record crop harvests, taxes, and early business deals.*



▼ **3000 BCE BRONZE TOOLS** *A strong alloy (mixture) of copper and tin, bronze was easy to shape into tools, and was rustproof and very hard wearing.*



► **2000 BCE IRON TOOLS** *Iron, a common metal, is easy to hammer or “cast” into shape by melting and molding.*

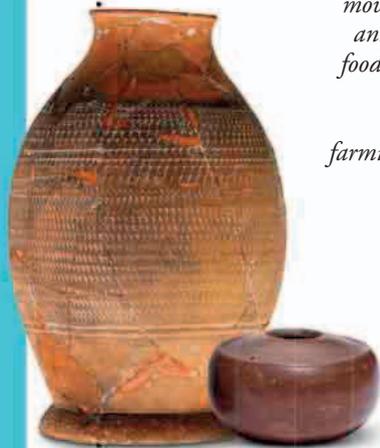


15,000 BCE

7500 BCE

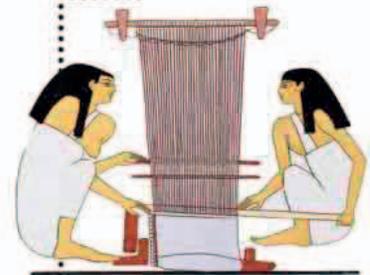
5000 BCE

2500 BCE



▲ **20,000 BCE POTTERY** *One of the oldest known handicrafts, pottery was invented when people discovered how to dig soft clay from the ground and “fire” it to make it hard.*

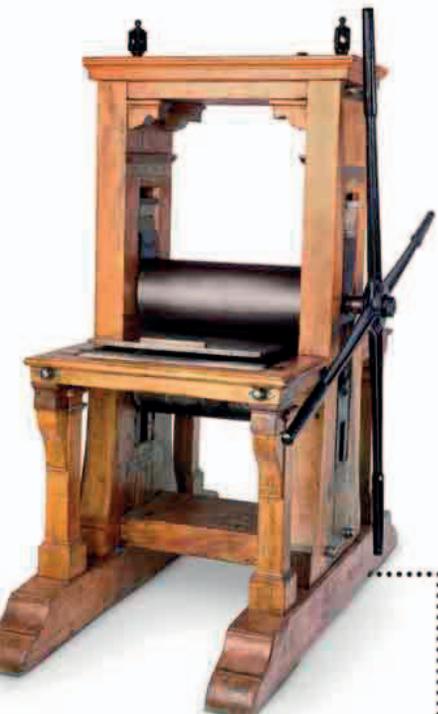
▼ **8000 BCE FARMING** *Early tribes moved around, hunting animals and gathering food. Modern life began when people settled, growing crops and farming animals instead.*



▲ **3000 BCE COTTON FABRIC** *The first clothes date from around 5,000 years ago. Cotton fabric was first made in the Indus Valley.*

▼ **5000 BCE PLOW** *The first crops were planted with picks and digging sticks. Plows, pulled by animals, meant one person could work much more land.*





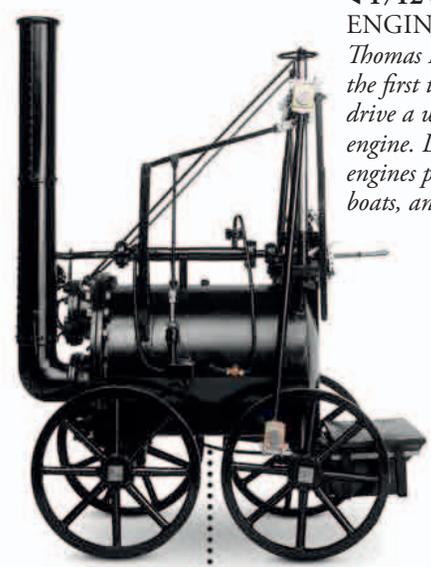
▲ 1430s PRINTING PRESS  
After Johannes Gutenberg invented modern printing, books could be copied by the thousands. Before that, each volume had to be copied by hand.



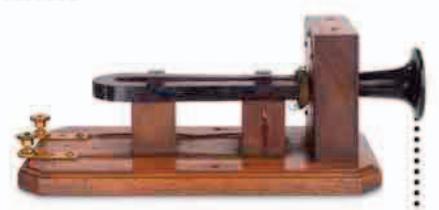
▲ 1700s FACTORY  
The first factories used water and animal power to spin and weave textiles such as wool and cotton. Later ones were powered by steam.



▲ 1608 TELESCOPE  
Dutch spectacle-maker Hans Lippershey invented the telescope. Galileo Galilei improved it so he could watch the stars and planets.



◀ 1712 STEAM ENGINE  
Englishman Thomas Newcomen was the first to use steam to drive a water-pumping engine. Later, steam engines powered trains, boats, and cars.



▲ 1876 TELEPHONE  
American scientist Alexander Graham Bell's telephone enabled people to talk over long distances for the first time.

100 CE

1500

1800



▲ 1280 EYEGLASSES  
English scientist Roger Bacon first came up with the idea of using a magnifying glass to help with reading.

▼ 105 BCE PAPER  
Chinese inventor Ts'ai Lun made the first paper. Without its invention, printing would never have been possible.



▼ 1590 MICROSCOPE  
Microscopes were key to the development of biology. They helped scientists discover cells, which power living things.

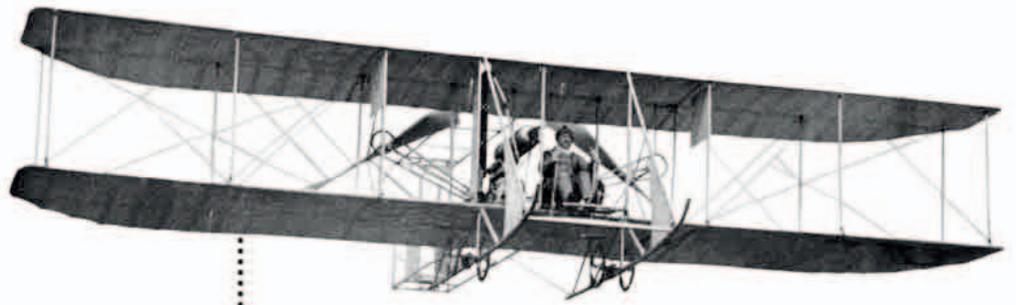


▼ 1761 PORTABLE CLOCK  
Clocks were difficult to transport until the invention of accurate, portable watches for use on ships.

▼ 1878 LIGHT BULB  
People had to make light by burning gas flames or by using candles until US inventor Thomas Edison perfected the electric light bulb.



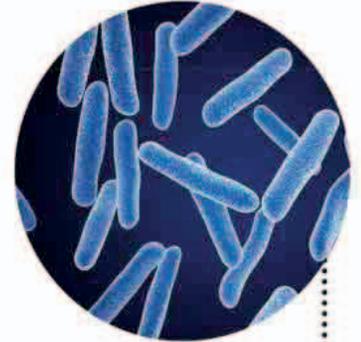
▼ **1880s MOTION PICTURES** French scientist Étienne-Jules Marey invented the movie camera. A decade later, Auguste and Louis Lumière showed the first public films.



▲ **1903 AIRPLANE** Two American brothers, Wilbur and Orville Wright, invented the airplane when they added a gasoline-powered engine to a giant glider.



▲ **1928 ANTIBIOTICS** Scottish biologist Alexander Fleming helped save millions of lives when he discovered penicillin, the first antibiotic drug.



▲ **1931 ELECTRON MICROSCOPE** Germans Max Knoll and Ernst Ruska built the first microscope that could see ultrasmall things.

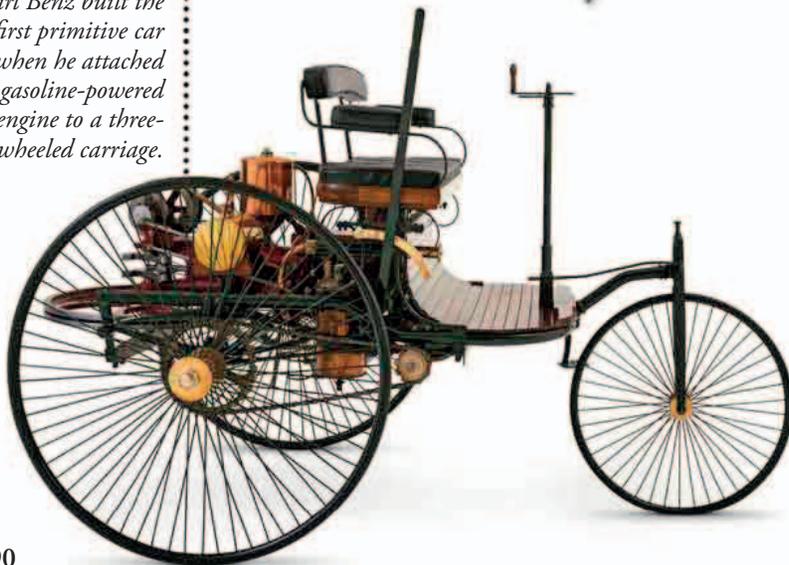
1880

1900

► **1890 RADIO BROADCASTS** Although Italian Guglielmo Marconi did not invent radio, he demonstrated how it could send messages around the world.



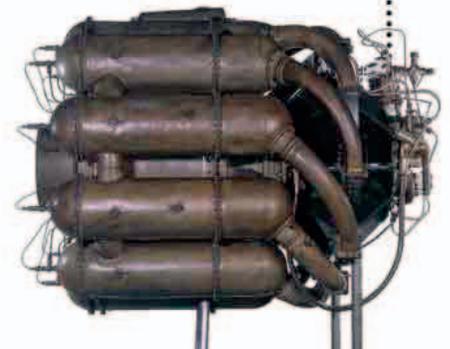
▼ **1885 CAR** German engineer Karl Benz built the first primitive car when he attached a gasoline-powered engine to a three-wheeled carriage.



► **1926 TELEVISION** Scottish inventor John Logie Baird used radio waves to send pictures, giving the first demonstration of television.



▼ **1937 JET ENGINE** English inventor Frank Whittle developed a faster engine that could push airplanes forward using a hot jet of burning gas.





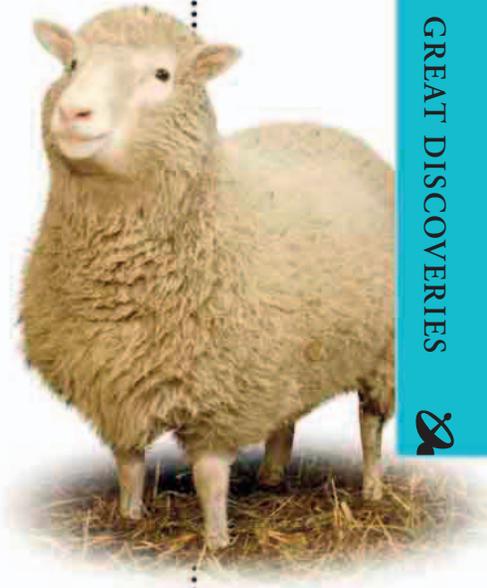
▲ **1969 MAN ON THE MOON** American astronauts Neil Armstrong and Edwin “Buzz” Aldrin became the first people to walk on the moon.

◀ **1973 CELL PHONES** Radio telephones date back to the 1920s, but the first cell phone call was not made until 1973, by Martin Cooper of the Motorola corporation.



▼ **1996 CLONED SHEEP** Dolly the sheep became world famous as the first animal “made” by cloning—copying genetic material in a laboratory.

▼ **1974 INTERNET** Americans Vinton Cerf and Bob Kahn invented a way of sending packets of information between different computers.



1950

1970

2005



▲ **1957 SPACE SATELLITE** The Soviet Union started the space race by launching Sputnik 1, the first artificial satellite.

▼ **1977 PERSONAL COMPUTERS** Early computers filled entire rooms. Smaller versions, such as the Apple II and Commodore PET (below), brought portable computer power to people’s homes.



▲ **1982 ARTIFICIAL HEART** Dr. Robert Jarvik developed the first mechanical heart in 1982. Made from plastic and aluminum, it was powered by air pressure.



▲ **2004 SMARTPHONE** Computers and cell phones merged together when smartphones were invented. Their touch screens work as both displays and keyboards.

# Glossary

**Acceleration** The change in the velocity (speed and direction) of a moving object.

**Air pressure** The force made by air molecules pushing against a surface or container.

**Alloy** A material made by mixing a metal with small amounts of other metals or nonmetals. Alloys are stronger, harder, or more useful than the metal they are based on.

**Android** A type of robot that looks and behaves like a human being.

**Astronomy** The study of objects in space, including stars, planets, and galaxies.

**Atom** The smallest possible part of a chemical element. Atoms are made of protons, neutrons, and electrons.

**Atomic mass** The total number of protons and neutrons that an atom contains.

**Atomic number** The number of protons an atom contains.

**Barometer** A scientific instrument that measures air pressure. Some barometers also show simple weather forecasts.

**Battery** A portable electricity supply that stores electric charge using chemicals.

**Big Bang** A powerful explosion from which our universe was created about 14 billion years ago.

**Boiling point** The temperature at which a liquid starts to change into a gas.

**Buoyancy** The upward force on an object in a liquid, caused by the water pressure underneath it. Buoyancy pushes against the object's weight and tends to make it float.

**Camouflage** A surface pattern, body shape, or color that living things use to hide themselves from predators.

**Carbohydrate** A chemical compound, found in starchy foods such as rice, potatoes, and bread, which gives us energy. Carbohydrates are made from carbon, hydrogen, and oxygen.

**Carnivore** An animal that eats the meat of other animals. Plants that eat insects are also sometimes called carnivores.

**Cell** The basic unit from which all living organisms are made.

**Centigrade** A temperature scale based on the melting point of ice (0°C) and the boiling point of water (100°C), with 100 equal divisions, called degrees, in between them.

**Chemical** A substance made from elements or compounds, which are made from atoms and molecules.

**Chlorophyll** A green chemical found in plants. With the help of sunlight, chlorophyll helps plants turn water and carbon dioxide into food through photosynthesis.

**Chloroplast** A part of a plant cell that contains chlorophyll.

**Chromosome** A structure in the nucleus of a cell, made from coiled DNA strands, that carries genetic information.

► **HUDDLE UP** *Animals living in extremely cold habitats stay together to keep warm. Huddling allows the conduction of heat, in this case from the mother to the baby penguin.*

**Circuit** A path that electricity flows around. All electrical and electronic things have circuits inside them.

**Climate change** Long-term changes in Earth's weather patterns. These changes can result from orbital cycles, global environmental variations, and, in recent times, human activity.

**Clone** An organism that has exactly the same genetic material as its parent.

**Cold-blooded** An animal whose body temperature changes to match the temperature of their surroundings.

**Colony** A group of organisms of the same species that live together to support and protect one another.

**Combustion** A chemical reaction in which a fuel, such as wood or coal, burns with oxygen from the air to release heat energy.

**Compound** A chemical made by combining the atoms of two or more different elements.



**Compound eyes** The eyes in creatures such as flies, made from thousands of separate light-detecting units called ommatidia.

**Concave lens** A lens in which one or both outer edges curve (“cave”) inward. Concave lenses tend to make light spread out, or diverge, so they are also called diverging lenses.

**Condensation** The process by which a gas or vapor turns into a liquid when the temperature falls or the pressure rises.

**Conduction** The flow of electricity or heat through a material.

**Convection** The process by which heat spreads through a liquid or gas as warmer material floats to the surface.

**Convex lens** A lens in which one or both of the outer edges curves outward. Convex lenses tend to make light focus on a point, or converge, so they are also called converging lenses.

**Diode** An electronic component that allows an electric current to flow through a circuit in only one direction.

**DNA** Deoxyribonucleic acid. The chemical inside chromosomes that lets parents pass genetic information on to their offspring.

**Ecosystem** A community of living plants and animals, and nonliving things such as air or water, that occupy the same habitat and interact with one another.

**Elasticity** A property of a material that allows it to stretch or bend when you push or pull it, and then return to its original shape and length.

**Electricity** A type of energy caused by electrons inside atoms. Static electricity is made by electrons building up in one place, while current electricity happens when electrons move around.

▲ **HOW BIG?** *Our universe is incredibly huge. It includes planets, stars, galaxies, and dust clouds. The Earth is a tiny dot in this vast space.*

**Electrode** An electrical contact, made from a conductor, that connects the main part of a circuit to something outside it, such as the chemicals in a battery.

**Electromagnet** A coil of wire that makes temporary magnetism when electricity flows through it.

**Electron** A tiny particle with a negative electric charge that occupies the empty outer space around an atom’s nucleus. Moving electrons can carry heat or electricity and make magnetism.

**Electronics** A way of using small, very precise amounts of electricity to carry information, such as TV pictures or computer data, or to control electric appliances.

**Element** A basic building block of matter made from identical atoms.

**Energy** A property of an object that allows it to do something now or in the future. Different types of energy include kinetic energy (movement energy) and potential energy (stored energy).

**Engine** A device that burns fuel and oxygen to release stored heat energy that can power a machine.

**Enzyme** A catalyst that living things use to make chemical reactions happen more quickly inside them.

**Evaporation** The process by which a liquid turns into a vapor when the temperature rises or pressure falls.

**Exoskeleton** A hard skeleton on the outside of an insect or crustacean that protects the body inside.

**Extinct** A species that has completely died out, so no members of it are still alive anywhere on Earth.

**Fahrenheit** A temperature scale with the melting point of ice at 32°F and the boiling point of water at 212°F, originally proposed by German physicist Daniel Fahrenheit.

**Filament** A thin coil of wire that glows as electricity flows through it. A filament makes the light in an electric lamp.

**Force** A pushing or pulling action that changes an object's speed, direction of movement, or shape.

**Fossil** The remains of a plant or animal preserved inside a rock.

**Fossil fuel** A fuel made mostly from carbon and hydrogen that can be burned with oxygen to release heat energy. Coal, oil, and gas are fossil fuels.

**Freezing point** The temperature at which a liquid turns into a solid.

**Frequency** A measurement of how often a wave of energy moves up and down. Waves with a higher frequency move up and down faster.

**Friction** The rubbing force between two things that move past each other. Friction slows things down and generates heat.

**Galaxy** A large group of stars, dust, and gas held together by the force of gravity. We live in a galaxy called the Milky Way.

**Gear** One of a pair of wheels of different sizes, with teeth cut into their edges, that turn together to increase the speed or force of a machine.

**Genome** The complete collection of genetic information inside a living thing.

**Global warming** A very gradual rise in the average temperature of Earth's atmosphere and oceans, thought to be caused by people burning fossil fuels.

**Gravity** The pulling force between every mass in the universe and every other mass.

**Habitat** The place where a plant or an animal normally lives.

**Herbivore** An animal that eats plants.

**Ice Age** A period of history when Earth's atmosphere and oceans were much cooler and more of the planet was covered by glaciers and ice sheets.

**Infrared** A type of electromagnetic radiation that carries energy in invisible beams from hot objects.

**Laser** Light Amplification by Stimulated Emission of Radiation. A very powerful beam of light made by exciting atoms inside a tube.

**Lens** A curved, transparent piece of plastic or glass that can bend light rays to make something look bigger, smaller, closer, or farther away.

**Lever** A rod balanced on a pivot that can increase the size of a pushing, pulling, or turning force. Crowbars, bottle openers, and seesaws all work as levers.

**Light-emitting diode (LED)** A small electronic component that converts electricity into light without making heat.

**Light-year** The distance light travels in a year. One light-year is about 6 trillion miles (9.5 trillion km).

**Magnetic field** The invisible pattern of force that stretches out around a magnet.

**Mass** The amount of matter that an object contains.

**Matter** The material which everything around us is made from. Matter includes solids, liquids, and gases, and both living and nonliving things.

**Melting point** The temperature at which a solid turns into a liquid.

**Metamorphosis** The process by which a living thing changes into a different form, such as when a caterpillar changes into a butterfly.

**Microchip** A miniature circuit made from thousands, millions, or even billions of separate electronic components. The components are so small that the chip is usually no bigger than a fingernail.

**Microscope** A scientific instrument that uses lenses and mirrors to make small objects appear much larger.

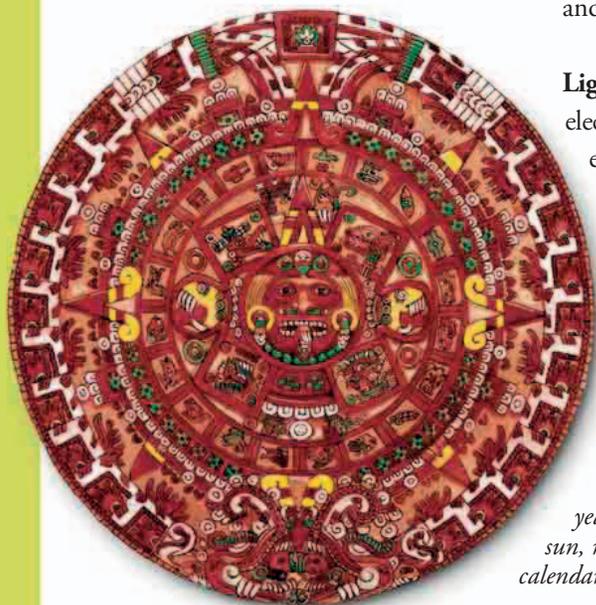
**Molecule** A substance made from two or more atoms bonded (joined tightly) together. The atoms in a molecule might be the same or different.

**Motor** A machine that uses electricity and magnetism to produce spinning movement or sometimes movement in a straight line.

**Nanotechnology** A way of building tiny materials by joining together individual atoms or molecules.

**Natural selection** The process by which a species evolves through time by passing on useful improvements to the next generation.

**Neutron** A particle inside the nucleus of an atom that has a neutral electric charge.



◀ **EARLY CALENDARS**  
Ancient civilizations often determined seasons, months, and years based on the movements of the sun, moon, and stars. This Aztec calendar was based on the sun's cycles.



▲ **LIGHT TRAVEL** A fiber-optic cable is created from thin strands of optical fiber, which are made of plastic or glass. These cables are used to quickly transfer information such as sound, pictures, or computer code, in the form of light.

**Nuclear fission** A process in which large atoms break into smaller ones, giving off large amounts of energy.

**Nuclear fusion** A process in which small atoms, such as hydrogen, join together to make larger ones, such as helium, and give off large amounts of energy. The sun is powered by nuclear fusion.

**Nucleus** The central part of an atom made from protons and neutrons.

**Omnivore** An animal that feeds on both plants and animals.

**Organic compound** A compound made from carbon and other elements.

**Parasite** An organism that lives off another (usually much larger) organism.

**pH** A measurement that tells us whether an acid or base is strong or weak.

**Photosynthesis** The process by which growing plants use sunlight, water, and carbon dioxide to make food.

**Polymer** An organic molecule made from many identical units (monomers) joined together. Plastics are examples of polymers.

**Predator** An animal that hunts other animals for food.

**Pressure** The force pushing on a surface. The bigger the force or the smaller the area it acts on, the higher the pressure.

**Prey** An animal hunted or eaten by a predator.

**Proton** A particle inside the nucleus of an atom that has a positive electric charge.

**Radiation** 1: A burst of particles or energy released by an unstable atom. 2: A process by which heat transfers through air or empty space. 3: An electromagnetic wave.

**Reflection** The way light, sound, or other types of energy bounce back from a surface.

**Refraction** The way light bends and changes direction when it passes from one material into another.

**Renewable energy** A type of energy that will not run out, generated from sources such as wind, waves, and sunlight.

**Resistor** An electronic component that reduces the electric current flowing through a circuit.

**Satellite** An object in space that travels around another in a path called an orbit. Artificial satellites placed into Earth's orbit by humans take photographs, transmit data, and help us navigate.

► **EXPLORING SPACE** *The first space shuttle was launched in 1981. This is the space shuttle Endeavour at NASA's Kennedy Space Center in Florida, launched in 2009.*

**Species** A group of similar organisms that can breed with one another to produce offspring.

**Transistor** An electronic component that can make electric currents bigger or switch them on and off. Transistors are the basic components in computer memory and microchips.

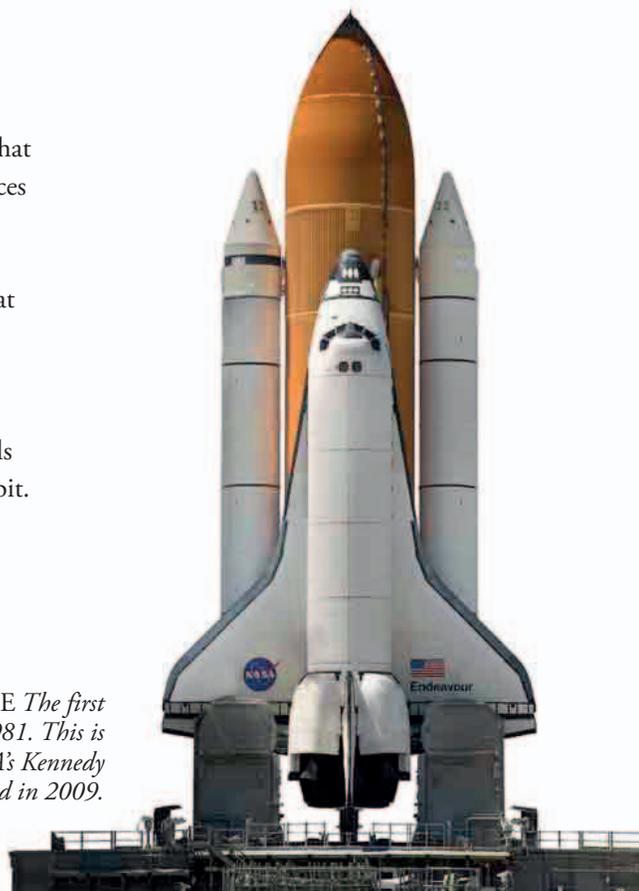
**Transmitter** A device that turns electricity into radio waves and broadcasts them through air or space.

**Ultrasound** A type of high-frequency sound that humans cannot hear. Ultrasound is used for medical scanning and testing materials.

**Vacuum** An empty space that contains no air or other matter.

**Warm-blooded** An animal whose body temperature stays almost constant even if its surroundings grow hotter or colder. Humans and birds are warm-blooded.

**Wavelength** The distance between the peaks of a wave.



# Index

## A

abdomen 236  
absolute zero 133  
acceleration 89  
acetylene 21  
acid 13, 30–31  
acrylic 69  
additive (plastic) 62  
agar 82  
air 52–53  
air pressure 53, 91,  
112–113, 273  
air resistance (drag) 95,  
108, 126  
air bag 33  
Airbus A380 106–107  
aircraft 38, 51, 108–109,  
290 *see also* spacecraft  
flight 106–107  
material for 73  
sonic boom 145  
airplane *see* aircraft  
airship 42, 43  
*see also* hot-air balloon  
al-Battānī 271  
al-Haytham, ibn (Alhazen)  
270, 271  
al-Khwārizmī 271  
albino 219  
algae 230  
algebra 271  
alkali metal 24, 38  
alkaline earth metal 39  
alloy 27, 37  
alpha particle 136  
aluminum 38  
amethyst quartz 14–15  
amphibian 240, 241

ancient civilization 268–269  
anemone 212–213  
anesthetic 21  
animation (film) 168, 169  
annual plant 234  
ant 251, 253  
antibiotic 267, 290  
anus 262  
arachnid 236, 237  
Archimedes 268  
Aristotle 270  
armor 71, 80  
*see also* protective clothing  
arsenic 39  
arthropod 236  
artificial body part 67, 209  
artificial intelligence 207  
astrolabe 271  
astronaut 111  
astronomy 271, 272  
Atlas V rocket 110–111  
atom 6–7, 10–11, 12–13,  
14, 15, 18, 20, 22  
in carbon 55, 57  
discovery of 280,  
282–283  
and friction 95  
heat 132, 153  
Large Hadron Collider 285  
and light 153, 156, 192

nanotechnology 210  
nuclear power 136  
in table of elements  
24–25  
attack (self-defense)  
244–245, 246–247, 251  
Aztec civilization 268–269

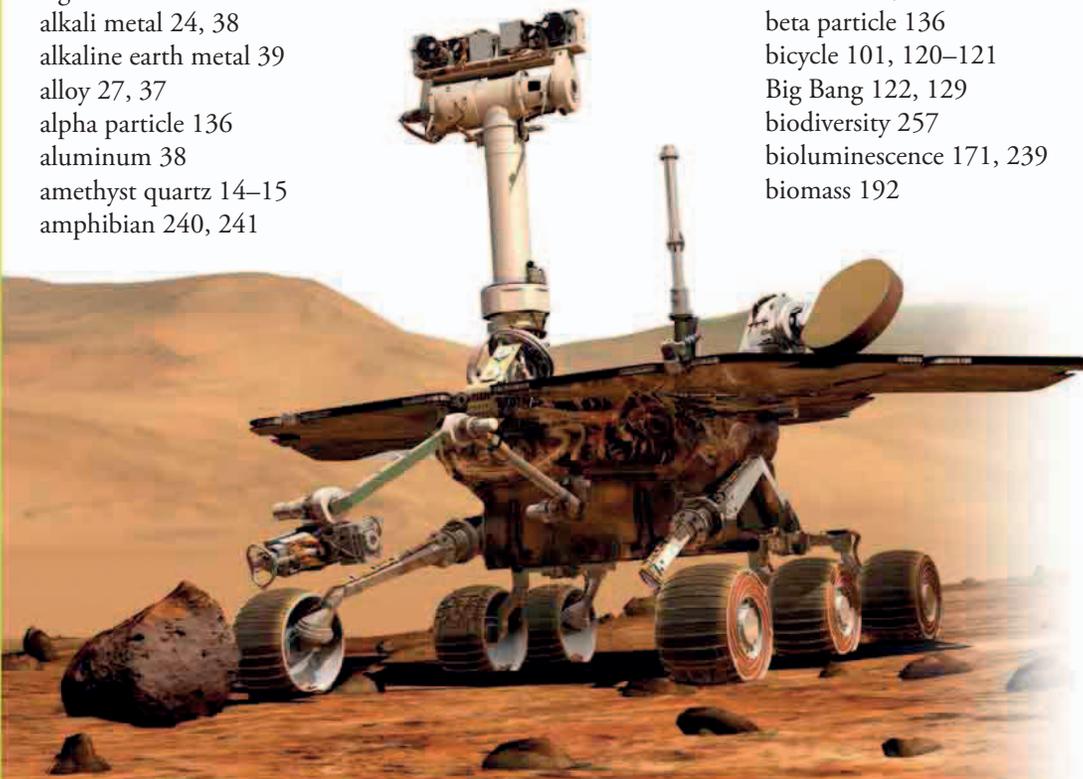
## B

backbone (spine) 240, 236  
bacteria 31, 214, 224–225,  
227, 263  
antibiotics 267  
baking soda 13  
balance 91  
balloon 99, 114–115  
air bag 33  
airship 42, 43  
blimp 21  
hot-air balloon 116–117  
static electricity 178–179  
barometer 113, 273  
base 30–31  
bat (mammal) 249, 255  
battery 81, 176, 177, 191  
vehicle 30, 104  
beacon 171  
Becquerel, Henri 278  
beetle 236  
bend (force) 98–99  
Berners-Lee, Tim 205  
beta particle 136  
bicycle 101, 120–121  
Big Bang 122, 129  
biodiversity 257  
bioluminescence 171, 239  
biomass 192

bioplastic 62  
bird 219, 241  
communication 251  
evolution 277  
migration 254  
sight 248  
birth 241  
bitumen 19  
black hole 97  
blimp 21  
blood 260, 261, 262, 263  
bloodsucker *see* parasite  
blue whale 215  
boat *see* ship  
body language 250  
Bohr, Niels 280, 282  
boiling point 23  
bone 163, 240, 261  
spine 240, 263  
borer (machine) 102–103  
brain 260, 263  
scan 185  
breed 216, 252, 259  
animal mating display 251  
plant 234  
bridge 87  
bronze 37  
Brown, Robert 280  
bubble 153  
bubble gum 98  
buoyancy *see* flotation  
burning 45, 133  
chemical reaction  
(combustion) 33  
fuel 104, 110, 193  
gas 21  
hydrogen 42–43  
butterfly 254

## C

cable 84, 191, 205  
fiber-optic 170, 171  
caffeine 13  
calcium 39  
calculus 275  
calendar, Aztec 268–269  
camcorder 168  
camel 222  
camera 166–167, 290  
camcorder 168  
endoscope 171  
lens 160



- camouflage 223, 245, 246–247  
cancer 137  
candle wax 23  
capacitor 197  
car 94–95, 290  
  battery 30  
  engine 105  
  racing 55, 107  
carbohydrate 57  
carbon 13, 54–55, 56–57  
carbon dating 54  
carbon dioxide 56–57, 193  
  photosynthesis 232  
carbon fiber 55, 72–73  
cardboard 60  
caribou 248, 254  
carnivore 231, 242, 257  
  carnivorous plant 217  
cat, eyes 159  
catapult 99  
caterpillar 255  
CD 156  
cell (organism) 224–225, 231, 233  
  DNA in 218–219, 286  
  human body 261, 263  
cell phone 128, 191, 202–203, 291  
Celsius scale 132  
cement 32  
centipede 237  
centripetal force 90  
ceramic 66–67, 270  
  pottery 288  
CFC (chlorofluorocarbon) 45  
CGI (computer generated imagery) 169  
Chadwick, James 283  
chalk 13  
chemical element 24–25  
chemical energy 124  
chemical plant 76–77  
chemical reaction 24, 32–33, 34–35  
  *see also* reaction, nuclear  
  combustion 33, 133  
  neutralization 31  
chicken 215  
China, ancient 269  
chlorine 41  
chlorofluorocarbon (CFC) 45  
chlorophyll 233  
chloroplast 233  
chocolate 22, 23  
chromatography 27  
chromosome 219  
circuit  
  electronic 176–177, 183, 196  
  power 188–189  
circulatory system 262  
citric acid 30  
classification, of life 216–217  
climate change 193  
clock 151, 289  
clone 214, 235, 291  
cloud 47  
  stardust 8, 130–131  
cnidaria 237  
coevolution 223  
coal 33  
  mining 54–55  
  power 74, 190, 192  
  steam engine 105  
cold-blooded animal 241, 255  
colony 251, 252  
color 152–153, 154, 275 *see also* pigment  
  animal 245  
combustion 33  
comet 275  
communication  
  in animals 250–251  
  with light 170–171  
community *see* habitat  
component, electronic 196–197  
composite material 70–71  
compost 229  
compound 12–13, 39, 41, 50  
  organic 56, 57  
compressed gas 51  
computer 169, 189, 200–201, 291  
  chip 172  
  Internet 203, 204–205, 291  
concave 158, 161  
concentration 28  
concrete 70  
conduction 134, 135,  
conductor (metal) 36, 175  
conifer 230  
conservation 258–259  
construction material 60  
convection 134, 135  
convergent evolution 223  
convex 158, 161  
cooling metal 37  
Copernicus, Nicolaus 273  
copper 36  
coral reef 257  
crane (machine) 184–185  
crankshaft 104  
Crick, Frances 286, 287  
crime prevention 175, 183, 197  
crude oil (petroleum) 19, 62, 76, 192  
crustacean 236, 237  
cryogenic storage 50  
crystal 15, 16–17  
  insulin 264–265  
  salt 12  
  snowflake 48–49  
Curie, Marie 278, 279  
current, electric 66, 176–177, 184, 186, 188–189  
cycle 101, 120–121  
cylinder 104
- D**  
Darwin, Charles 276, 277  
decay 56, 229, 243  
Deep Flight aviator 119  
defense (animal) 244–245, 246–247, 251  
defense (plant) 231  
deforming (solid) 15  
deoxyribonucleic acid (DNA) 217, 218–219, 221, 286–287  
deposition 23  
desert 256  
detritivore 243  
diabetes 265  
diatom 224  
diet *see* food  
digestive system 262  
digger 100–101  
digital camera 166  
digital signal 198, 203  
dilution 28  
dinosaur 240, 277  
diode 196  
disease 137, 225, 258, 265, 267  
  faulty gene 287  
  medical test for 129, 179, 185, 278–279, 287  
dissolve 28  
DNA 217, 218–219, 221, 286–287  
dog 248
- doorbell 185  
“double helix” 218, 286  
  *see also* DNA  
drag (air resistance) 95, 108, 126  
drill 102–103  
dry ice 13  
DVD 157  
dynamite 32  
dynamo (generator) 187
- E**  
Earth 45, 52, 53, 151, 273  
  *see also* gravity  
  climate change 193  
  magnetism 183  
  resources 74–75  
  water on 46, 47  
earthquake 141, 269  
echinoderm 237  
eclipse 151  
ecology 258–259  
ecosystem 256–257, 259  
  *see also* habitat  
Edison, Thomas 190, 287  
eel 177  
egg 241, 263  
Einstein, Albert 137, 280–281  
elastic 98, 99  
  energy 124  
  force 98, 99  
  synthetic fiber 69  
electric motor 186–187  
electric musical instrument 147  
electric shock 177, 178  
electric signal 170  
electrical sense 249  
electrode 181  
electromagnetic radiation 130, 162  
electromagnetic spectrum 128–129  
electromagnetism 86, 184–185





- electron 10–11, 12, 174, 176  
 discovery of 280, 282, 283  
 electron microscope 11,  
 72–73, 163, 167, 290  
 magnetism 182  
 static electricity 178  
 electronics 196–197  
 circuit 176–177, 183, 196  
 element, chemical 24–25  
 elephant 252–253, 253  
 emulsion (liquid) 18  
 endoscope 170  
 engine 94, 104–105  
 jet 290  
 rocket 110  
 steam 90, 289  
 Enlightenment, The 274–275  
 enzyme 228  
 Euclid 269, 270  
 eukaryote 225  
 evaporation 133  
 evolution 217, 222–223,  
 276–277  
 exoskeleton 236  
 experiment, scientific 221,  
 267, 278  
 with atoms 282–283  
 Newton's 275  
 explosion 34–35, 43, 77  
*see also* chemical reaction  
 Big Bang 122, 129  
 engine 104  
 explosive 51  
 extinction 223  
 eye 159, 248
- F**  
 fabric 288  
 armored 80  
 synthetic fiber 68–69, 71  
 factory 76–77  
 Fahrenheit scale 132  
 family 252–253  
 classification 216  
 pack animal 245  
 twins 218–219  
 fang 244  
 farming 258, 288  
 soil for 50, 75  
 fern 230  
 fertilization (reproduction)  
 263  
 fiber 15  
 carbon 55  
 synthetic 68–69, 71  
 fiber-optic cable 170, 171  
 fiberglass 70  
 fibrous solid 15  
 filament 188  
 filtration 27, 46  
 purification 75  
 fingerprint 175  
 firefly 238–239  
 fish 212–213, 241, 246–247  
 breathing 44  
 migration 254  
 sense 248  
 fission reaction 136  
 flagellum 224  
 flask 135  
 flexible material 81, 197
- flight 106–107, 110–111  
*see also* aircraft, airship,  
 spacecraft  
 flotation 21, 116–117  
 of hydrogen 42  
 of ice 46  
 mixture 27  
 ships 118  
 trains 175  
 flowering plant 230, 234, 248  
 fluorine 41  
 foam 81  
 food 216, 231, 248, 262  
 acid in 30  
 chain 257  
 cooking 134  
 energy from 138–139,  
 242–243  
 preservation 137, 229  
 prey 244–245  
 foram 224  
 forest 256–257  
 fossil 214, 276, 277  
 fossil fuel 54, 74, 81, 122,  
 192–193 *see also* coal,  
 gas, oil  
 organic chemistry 56–57  
 fractionation column 76  
 francium 25  
 Franklin, Benjamin 174  
 Franklin, Rosalind 287  
 freezing 133  
 frequency 198  
 Fresnel lens 161  
 friction 94–95, 126  
 fuel 43, 104  
 fungus 216, 228–229  
 fusion reaction 136–137
- G**  
 gadget *see* electronics  
 Galapagos Islands 276, 277  
 Galileo Galilei 272, 273  
 gamma rays 128, 129, 136  
 gas 8, 20–21, 22, 23, 41  
 air 52–53  
 chemical reaction 32  
 as energy source (natural  
 gas) 74, 76, 192  
 from engines 105, 110  
 hydrogen 42–43  
 nitrogen 50–51  
 noble 24, 25, 41, 52  
 oxygen 44–45  
 water vapor 47  
 gear 101  
 Geiger, Hans 283
- generator 186–187  
 genetics 217, 218–219,  
 221, 286–287  
 in bacteria 225  
 cloning 291  
 geometry 270  
 germ 224, 225, 267  
 geyser 8–9  
 gill 44, 241  
 glass 64–65  
 recycling 79  
 glider 107  
 global warming 258  
 glucose 232  
 gold 36  
 Google Glass 210  
 graphene 81  
 graphene aerogel 14  
 grassland 257  
 gravitational wave 141  
 gravity 86, 91, 96–97, 141  
 discovery of 274  
 and flight 108, 110–111  
 and flotation 116  
 with trajectory 273  
 Greece, ancient 268, 269, 270  
 “green” energy 211 *see also*  
 renewable energy  
 grid (electricity) 190–191  
 GRP (glass-reinforced  
 plastic) 70  
 Guggenheim Museum 58–59  
 guitar 147  
 gypsum 16–17  
 gyroscope 91
- H**  
 habitat 256–257, 258, 259  
 Halley, Edmond 275  
 halogen 41  
 hearing 249  
 heart 260  
 heat 125, 132–133,  
 134–135, 139  
 boiling and melting  
 22–23  
 blanket 159  
 from chemical reaction  
 32, 33  
 and color 153  
 household 188–189  
 and reflection 159  
 sense 249  
 heat-proof material 67  
 helicopter 108–109  
 helium 21  
 herbivore 231, 242, 257



- hibernation 254–255  
 Hindenburg disaster 43  
 hologram 157  
 Hooke's Law 98  
 hot-air balloon 116–117  
 hovercraft 118  
 HTML 205  
 human body 44, 132, 224,  
 260–261, 262–263  
*see also* robot  
 energy 123, 127  
 evolution of 277  
 genes 218–219, 286–287  
 hunting 258  
 hurricane 91  
 Huxley, Thomas 277  
 hydraulic pressure 18  
 hydroelectric power  
 187, 192  
 hydrofoil 119  
 hydrogen 42–43  
 hypha 228  
 hypothesis 267
- I**  
 ibn Sīnā 271  
 ice 46, 49, 95  
 iceberg 123  
 indicator 30  
 inertia 88  
 infrared rays 129, 249  
 insect 236, 237, 248  
 instrument, musical 142,  
 146–147  
 instrument, scientific 269  
 insulation 135, 175  
 insulin 264–265  
 integrated circuit (microchip)  
 39, 172–173, 196  
 intelligent material 80  
 Internet 203, 204–205, 291  
 intestine 261, 262  
 invention 288–291  
 invertebrate 216,  
 236–237  
 iodine 41  
 ionosphere 199  
 iron 24, 32  
 Islam, ancient 270–271
- J**  
 jawless fish 240, 241  
 jellyfish 171, 221, 236, 237  
 jet engine 105, 110, 290  
 jet pressure 112  
 Jet Ski 118  
 Joule, James 139
- K**  
 Kepler, Johannes 274  
 kidney 261  
 kiln 66  
 kinetic energy 104, 125,  
 126–127, 186  
 kingdom (classification) 216
- L**  
 ladybug 216  
 laminated glass 65  
 landfill site 78  
 landspout 92  
 language *see* communication  
 Large Hadron Collider  
 284–285  
 laser 148–149, 156–157, 165  
 Laws of Motion (Newton's)  
 88, 275  
 lead 23, 38  
 leaf 216, 230–231, 232–233  
 LED (light-emitting diode)  
 143, 171, 196  
 lens 160–161, 166 *see also*  
 microscope, telescope  
 lever 91, 100  
 lift (force) 106, 107  
 light, speed of 129  
 light bulb 188, 289  
 lightning 170, 174–175,  
 180–181  
 linear motor 186  
 liquid 8, 18–19, 22, 23  
 hydrogen 43  
 nitrogen 50  
 oxygen 45  
 lithops 215  
 liver 260, 262  
 lizard 94  
 long-exposure photography 167  
 lubrication 95  
 lunar eclipse 151  
 lung 260
- M**  
 macro photography 167  
 magma 227  
 magnet 27, 179,  
 182–183, 184  
*see also* electromagnetism  
 in electric guitars 147  
 in electric motors 186  
 in Large Hadron  
 Collider 285  
 for trains 175  
 Magnetic Resonance  
 Imaging (MRI) 185  
 mammal 240, 241, 248, 276  
 communication 250, 251  
 hibernation 247  
 society 252, 253  
 man-made plastic 62  
 marrow 261 *see also* bone  
 Mars Rover 266  
 mass 97, 281  
 mathematics 269, 271, 275  
 mating display 238–239,  
 251, 252  
 Maxwell, James Clerk 185  
 medical testing 171, 179,  
 185 *see also* disease  
 discoveries in 278–279  
 by Islamic scientists 271  
 Mediterranean (habitat) 257  
 meerkat 253  
 melting 22–23, 37, 133  
 mercury 19  
 metal 14, 24–25, 36–37,  
 38–39  
 bending 98  
 foam 81  
 liquid 19  
 magnetic 184, 186  
 and static electricity 178  
 metalloid 39  
 mice 220–221  
 microlife 216  
 single-cell organism  
 224, 225  
 microchip 39, 172–173, 196  
 microfiber 68  
 micrograph photography 167  
 microorganism *see* bacteria,  
 single-cell organism
- microscope 162–163, 289  
 electron microscope  
 11, 72–73, 163,  
 167, 290  
 microwave 128  
 migration 254–255  
 milk 18, 31, 241  
 Millau Viaduct 84–85  
 millipede 237  
 mimicry, for survival 223  
 mine 54–55, 192  
 mirage 161  
 mirror 65, 158–159  
 camera 166  
 microscope and telescope  
 162, 163  
 solar power plant 194  
 mixture 26–27  
 mold 229  
 molecule 12–13, 14, 15,  
 18, 20, 32  
 discovery of 280  
 DNA 218–219,  
 286–287  
 nanotechnology 210  
 in solution 28  
 mollusk 237  
 momentum 88  
 moon 151, 268, 272, 274  
 eclipse 151  
 and gravity 96, 97  
 landing 199, 291  
 moss 230  
 motion 88–89, 104  
 motion pictures  
 168–169, 290  
 mountain 256  
 MRI scan 185  
 muscle 261  
 mushroom 228  
*see also* fungi  
 musical instrument 142,  
 146–147





- N**  
 nanotechnology 210  
 natural selection 222  
 nebula 8, 130–131  
 negative electric charge 11,  
 12, 174, 175, 282–283  
 battery 177  
 static electricity 178, 179  
 neon light 41  
 nerve 261, 263  
 nervous system 263  
 nest 255  
 neutralizing 31  
 neutron 10, 11, 136  
 detector 283  
 Newton, Isaac 88, 274, 275  
 nitrogen 50–51, 52  
 Nobel, Alfred 279  
 noble gas 24, 25, 41, 52  
 noise pollution 142  
 North Pole (magnetism) 182  
 Northern Lights 182–183  
 nose 248, 249  
 nuclear force 86  
 nuclear power 124,  
 136–137, 193  
 fusion 211  
 reactor 137  
 nucleus 10–11, 193, 283  
 cell 225  
 nylon 68, 69
- O**  
 ocean, wave 140  
 oil 29  
 cooking 23  
 crude oil 62  
 drilling for 74–75  
 refinery 76  
 OLED 197  
 omnivore 243  
 Onychophora 217  
 orbit (planets) 96, 273, 274  
 orchestra 147  
 order (classification) 216  
 ore 37  
 organ 260  
 organic chemistry 56–57  
 oxygen 13, 21, 44–45, 54  
 in air 24, 52 *see also*  
 chemical reaction  
 and hydrogen 43  
 lung 260  
 in photosynthesis 232  
 ozone 45
- P**  
 pack animal 245  
 packet switching 204  
 paper 79, 289  
 parabola 273  
 paraglider 107  
 parasite 233, 243, 263
- pedal 187  
 pendulum 273  
 penguin 135  
 penicillin 267  
 perennial plant 235  
 periodic table of elements  
 24–25  
 petroleum (crude oil) 19,  
 62, 76, 192  
 pH scale 30  
 phenomenon 267  
 phosphorus 41  
 photography 167  
*see also* camera  
 photosynthesis 232–233  
 pickup (electric guitar) 147  
 pigment 29, 37, 153  
*see also* color  
 in material 64, 66  
 plant (chlorophyll) 233  
 pincer 244  
 pinhole camera 166  
 piston 104  
 pitch (sound) 143  
 pitch (tar) 19, 267  
 plane *see* aircraft  
 planet 122, 272–273, 274  
 exploration of 266  
 gravity 96  
 plant 138, 216,  
 230–231, 257  
 life cycle of 234–235  
 plastic 62–63, 72–73, 98  
 composite 70, 71  
 flexible 197  
 recycling 78, 79  
 platelet 263  
 poisonous animal 213,  
 228, 245  
 polar ice 256  
 pollen 234  
 pollution 29, 42, 81,  
 211, 258  
 noise 142  
 polyester 68, 69  
 polymer 63  
 polyp 217  
 poor metal 38  
 porcupine 244  
 positive electric charge 11,  
 12, 174, 175, 282–283  
 battery 177  
 static electricity 178, 179  
 potential energy 124, 125,  
 126–127, 133  
 pottery 288  
 ceramic 66–67, 270
- power plant 190–191  
 precious stone 9  
 predator 223, 244–245  
 pressure (force) 18, 20,  
 112–113  
 air 53, 91, 113, 273  
 suit 113  
 wave 114–115  
 prey 244–245  
 printing press 289  
 prism 152, 154–155, 275  
 prokaryote 214, 225  
 propeller 105, 118  
 property, of material 60–61  
 ceramic 67  
 glass 65  
 plastic 63  
 protective clothing 71, 77,  
 80, 159  
 protein, DNA 218  
 proton 10, 11, 282, 283  
 table of elements 25  
 pulley 101  
 purification 75  
 filtration 27, 46  
 Pythagoras 269
- Q**  
 quelea 215
- R**  
 radiation 128, 129, 130,  
 134, 135, 137  
 discovery of 279, 283  
 radioactivity 136–137  
 radio 198–199, 290  
 radio wave 128, 198, 199, 202  
 radioactivity 136–137  
*see also* radiation  
 radium 278  
 rain forest 256  
 rainbow 152 *see also* color  
 ramp 101  
 rayon 68, 69  
 reaction, chemical 24,  
 32–33, 34–35  
 combustion 33, 133  
 neutralization 31  
 reaction, nuclear 137  
 recycling 63, 78–79  
 decay 56, 229, 243  
 reflection 65, 158–159, 166  
 refraction 154, 160–161,  
 162, 275  
 refrigeration 23  
 cryogenic storage 50  
 relativity 281



- remote control 206  
renewable energy 81, 192, 193  
  hydroelectric power  
  43, 187  
  solar power 191,  
  194–195, 211  
  wind power 52, 75, 211  
reproductive system 263  
reptile 240, 241  
resistor 197  
rhinoceros 217  
rhodium 37  
robot 206–207, 208–209  
rocket *see* spacecraft  
roller coaster 126, 126–127  
Rome, ancient 269  
Röntgen, William 278  
rotor 108, 109  
rubber 99  
Rutherford, Ernest 282, 283
- S**
- safety glass 65  
sail 87, 118  
salamander 240  
salt (sodium chloride) 12  
satellite 110, 199, 291  
savanna 256  
schlieren photography 167  
Schulze, Johann 167  
scorpion 236, 237  
screen, electronic 168, 169,  
  199, 200, 201  
  heat in 189  
  material for 81  
scuba equipment 44  
SEAgel 82–83  
season 234, 268  
seaweed 82, 230, 246  
seed 234, 235  
seesaw 100  
self-defense 244–245,  
  246–247, 251  
semiconductor 39  
sense 248–249  
separation (mixtures) 27  
shadow 150–151  
shark 244, 249  
shelled animal  
  *see* mollusk  
ship 87, 118–119, 211  
  *see also* airship  
  flotation 117  
  material 70–71  
  propeller 105, 118  
shockwave 145  
sight 150, 248
- signal  
  cell phone 128, 202  
  for communication  
  170–171, 239, 251, 253  
  radio and television  
  198–199  
single-cell organism 216,  
  224, 225  
sinking 116–117, 118  
skeleton 216, 240, 261  
  *see also* bone  
skin 99, 249, 260, 263  
skydiver 97  
sleep *see* hibernation  
slow motion 167  
smart material 80  
smell 248  
smog 53  
snake 216, 249, 255  
snowflake 48–49  
social animal 245, 251, 252  
sodium 11, 12, 24  
soil 50, 75  
solar eclipse 151  
solar power 81, 191, 192, 193,  
  194–195, 211  
solar system 96, 273  
  *see also* planet, sun  
solid 8, 14–15  
  melting 22–23, 37, 133  
  in solution 28, 29  
solution (liquid) 27, 28–29  
solvent 28–29  
sonic boom 145  
sound 53, 142–143,  
  146, 203  
  musical instrument  
  142, 146–147  
  sound energy 125  
  speed of 143  
  wave 145, 147, 203  
South Pole (magnetism) 182  
spacecraft 43, 88,  
  110–111, 186  
  engine 105  
  material for 67, 73  
spark plug 66, 104  
species 216, 217  
spectacle 289  
speed 89, 101, 244  
  of light 129, 160  
  of sound 143  
  wind 92  
sperm 263  
spider 236, 237  
spine (porcupine) 244  
spine (skeleton) 240, 263
- sponge 236, 237  
spore 228, 235  
squid 236  
stainless steel 36  
stardust 8, 130–131  
starfish 236, 237  
state, of matter 8, 22–23,  
  46 *see also* gas, liquid, solid  
static electricity 174, 178–179  
steam engine 90, 105, 289  
stomach 261, 262  
storage (electricity) 191  
storage (potential energy)  
  124, 125, 126–127, 133  
storm 91, 92  
  lightning 170, 174–175,  
  180–181  
stretch (force) 98–99  
subatomic particle 10  
  *see also* electron,  
  neutron, proton  
sublimation 23  
submarine 118–119  
sugar 232  
sulfur 32, 40  
sun 129, 138, 192, 211, 273  
  as calendar 151, 268,  
  269, 271  
  gravity 96, 274  
  photosynthesis 232  
  solar eclipse 151  
  solar power 81,  
  191, 192, 193,  
  194–195, 211  
  temperature 132  
sundial 151  
supercomputer 201  
suspension (mixture) 27  
switch 172, 177, 183  
symbiosis 213  
synthetic fiber 68–69, 71  
synthetic plastic 62
- T**
- tablet 200  
tadpole 241  
tail 240  
tanker, oil 77
- tapir 217  
tardigrade 215  
taste 248  
teeth 242, 244, 260  
telephone 170, 289  
  cell phone 128, 191,  
  202–203, 291  
telescope 159, 162–163,  
  164–165, 272, 289  
  radio telescope 128  
television 198–199, 290  
temperature 132  
termite 253  
thermometer 132  
Thomson, J.J. 282, 283  
thorax 236  
thunderstorm 92, 170,  
  174–175, 180–181  
timber 74 *see also* wood  
time 151  
tire 51  
titanium 36  
toadstool *see* fungus  
tongue 243, 248  
tornado 92–93  
torpor 255  
Torricelli, Evangelista 273  
tortoise 215  
touch 249  
train 175  
  steam engine 90,  
  105, 289  
trajectory 273  
transistor 196  
transition metal 38  
transmitter 198  
transparent plastic 63  
tree 215  
tsunami 141  
tundra 257  
tunnel 102–103, 148–149  
twins 218–219  
  *see also* DNA



- U**  
 ultraviolet 129, 248  
 universal indicator 30  
 universe 122, 273  
   Big Bang 129  
   gravity 141  
   Large Hadron Collider 284–285  
   solar system 96, 273  
   *see also* sun, planets  
 “upcycling” 79 *see also* recycling
- V**  
 V22 Osprey 109  
 vapor, water 49  
 vehicle 104–105 *see also*  
   aircraft, car, ship, spacecraft  
   bicycle 101, 120–121  
   train 175  
   steam engine 90, 105, 289  
 velocity 89, 110  
 velvet worm 217  
 venomous animal 245  
   *see also* poisonous animal  
 Venus flytrap 217  
 vertebrate 216, 240–241  
 Very Large Telescope 164–165  
 vibration, sound 53, 142–143
- viscose 68  
 viscosity 19  
 vision (sight) 150, 248  
 volcano 227  
 voltage 176, 177, 190–191  
 vulcanization 267
- W**  
 Wallace, Alfred Russel 277  
 warm-blooded animal 241, 255  
 warning (self-defense) 244–245, 246–247, 251  
 water 23, 31, 44, 46–47, 75, 118  
   and heat 135  
   light in 160  
   photosynthesis 232  
   power (hydroelectric) 43, 187, 192  
   pressure 113, 116, 117  
   as solvent 28, 29  
   vapor 22, 49, 52  
   waterfall 96  
   wave 140–141  
 Watson, James 286, 287  
 wave  
   ocean 140–141  
   radio 128, 198, 199, 202  
   sound 143, 145, 147, 203  
   ultraviolet 129, 248  
 wavelength 154, 198  
 weather system 91, 92  
   cloud 47  
   lightning 170, 174–175, 180–181  
 weight 86, 97  
 welding 21  
 whale 215  
 wheel 91, 94–95, 101, 103  
 white cell 263  
 wind  
   as force 91, 118, 140  
   musical instrument 147  
   power 52, 75, 192–193, 211  
   speed 92  
   tunnel 106, 107  
 windshield 65, 201  
 wing (invertebrate) 236  
 wing (vehicle) 106–107, 108, 119  
 womb 263  
 wood 14, 116  
   as energy source 193  
   as material 61  
   musical instrument 147
- World Wide Web 204, 205  
 worm 217, 237  
 Wright brothers 107, 290
- X**  
 xenon 24  
 X-rays 129  
   discovery of 278–279, 287  
   and photography 167
- Y**  
 yeast 229  
 Yellowstone Park 226–227  
 yttrium 25

# Acknowledgments

## Smithsonian Institution:

Andrew Johnston, Geographer, Center for Earth and Planetary Studies, National Air and Space Museum

## Smithsonian Enterprises:

Carol Le Blanc, Senior Vice President, Consumer Products and Education; Brigid Ferraro, Vice President, Consumer Products and Education; Ellen Nanney, Licensing Manager; Kealy Wilson, Product Development Manager

DK would like to thank David Burnie for consultancy advice, Joanna Shock for proofreading, Elizabeth Wise for the index, Olivia Stanford and Lizzie Davey for editorial assistance, Surya Sarangi and Sakshi Saluja for picture research assistance, and Mrinal Duggal for illustrations.

The publisher would like to thank the following for their kind permission to reproduce their photographs:

(Key: a-above; b-below/bottom; c-center; f-far; l-left; r-right; t-top)

**2–3 Dreamstime.com:** Brett Critchley.

**4 Dorling Kindersley:** NASA (cr).

**Dreamstime.com:** Corepics Vof (crb).

**5 123RF.com:** Roman Gorielov (cb/

Paints). **Corbis:** Mediscan (crb/Bacteria).

**Dorling Kindersley:** Malcolm Coulson

(cr); The Royal British Columbia

Museum, Victoria, Canada (cra/

Mammoth); The Senckenberg Nature

Museum, Frankfurt (br). **Dreamstime.**

**com:** Anikasalsera (c); Felix Mizionnikov

(ca/Amusement Park Ride); Ben Heys

(cb/Water Drop); Štěpán Kápl (cb/Solar

Power); Anthony Bolan (tr/Pixel Pattern).

**Getty Images:** Jacom Stephens / E+ (tc).

**NASA:** JPL-Caltech (ca/Nebula). **Science**

**Photo Library:** Alfred Benjamin (bc); Dr.

Charles Mazel / Visuals Unlimited, inc

(cra/Mouse); Pasioka (crb/Micrograph).

**6–7 Corbis:** Dan McCoy - Rainbow /

Science Faction. **6–57 Science Photo**

**Library:** Frans Lanting, Mint Images

(sidebar). **7 Corbis:** Martin Rietze /

Westend61 (ca). **Dorling Kindersley:**

The Natural History Museum, London

(cla/nugget). **Dreamstime.com:** Diego

Cervo (cla). **8 Dreamstime.com:**

Snapgalleria (c). **NASA:** ESA / ASU / J.

Hester (tr). **8–9 Corbis:** Pat O’Hara.

**9 Dorling Kindersley:** The Natural

History Museum, London (tl); The

Science Museum, London (br). **Getty**

**Images:** Photodisc / John William

Banagan (cr). **11 Science Photo Library:**

Prof. Erwin Mueller (b). **12–13 Science**

**Photo Library:** Pasioka. **13 Dreamtime.**

**com:** Dbjohnston (tc); Sergei Primakov

(c). **14 Corbis:** Long Wei / epa (bl).

**Dreamstime.com:** Jianghongyan (bc).

**Pearson Asset Library:** Trevor Clifford /

Pearson Education Ltd (br). **15 Alamy**

**Images:** Jim West (tr). **16–17 Science**

**Photo Library:** Javier Trueba / MSE

**18 Getty Images:** Roberto la Forgia /

Flickr (bl). **18–19 Science Photo**

**Library:** Paul Rapson. **19 Dreamtime.**

**com:** Marcel Clemens (cra). **20 Alamy**

**Images:** ImageDJ (bl). **20–21**

**Dreamstime.com:** Hel080808 (t). **21**

**Corbis:** Olaf Döring / imagebroker (clb).

**Fotolia:** reflektastudios (br). **24**

**Dreamstime.com:** Artem Gorohov (bl);

Eimantas Buzas (br). **Pearson Asset**

**Library:** Coleman Yuen / Pearson

Education Ltd (clb). **25 Corbis:**

Theodore Gray, / Visuals Unlimited (br).

**Science Photo Library:** (bc). **27**

**Dreamstime.com:** Jörg Beuge (c).

**Pearson Asset Library:** Cheuk-king Lo /

Pearson Education Ltd (bc); Joey Chan /

Pearson Education Ltd (bl); Gareth

Boden / Pearson Education Ltd (bc/jar).

**Science Photo Library:** Charles D.

Winters (clb). **28 Dreamstime.com:**

Diego Cervo (l). **29 Corbis:** Christopher

Berkey / epa (br). **Dreamstime.com:**

Denise Peillon (cl). **Science Photo**

**Library:** Charles D. Winters (tl). **30**

**Pearson Asset Library:** Studio 8 /

Pearson Education Ltd (cb).

**31 Dreamstime.com:** Valentyn Volkov

(c). **Science Photo Library:** Ted Kinsman

(tr). **32 Dreamstime.com:** Christina

Richards (cl). **33 Dreamstime.com:**

Lkordela (cra). **Getty Images:** fStop

Images – Caspar Benson / Brand X

Pictures (br). **34–35 Science Photo**

**Library:** Ria Novosti. **36 Dreamtime.**

**com:** Rudy Umans (clb). **37 Dorling**

**Kindersley:** The University Museum of Archaeology and Anthropology, Cambridge (bl/bowl); The Natural History Museum, London (ftr); The Museum of London (bl/cup, bl/spear-tip). **Dreamstime.com:** Daniel Nagy (crb); Somyot Pattana (tr). **Science Photo Library:** Martyn F. Chillmaid (c). **38–39 Dorling Kindersley:** The March Field Air Museum, California (bl). **39 Alamy Images:** Dave Marsden (cr); Thomas Jackson (tl). **Dreamstime.com:** Olivier Le Queinec (br). **40–41 Corbis:** Martin Rietze / Westend61 (bl). **41 Dreamstime.com:** Mr. Smith Chetanachan (cra); Stocksnapper (cla); Showface (cra/paste). **42 Science Photo Library:** Charles D. Winters (bl, bc). **42–43 NASA.** **43 Getty Images:** Archive Holdings Inc. / Hulton Archive (br). **45 Corbis:** NASA (tr). **Dreamstime.com:** Andra Cerar (c); Uladzimir Chaberkus (b). **46 Pearson Asset Library:** Oxford Designers & Illustrators Ltd. / Pearson Education Ltd (cl). **46–47 Dreamstime.com:** James Steidl. **47 Dreamstime.com:** Happyshoot (cla). **NASA's Earth Observatory:** (br). **48–49 Science Photo Library:** Eye of Science. **50 Dreamstime.com:** Vit Kovalcik (cl). **50–51 123RF.com:** Kristian Kirk Mailand (b). **51 Dorling Kindersley:** The Science Museum, London (tc). **Dreamstime.com:** Andrey Burmakin (tr); Dmitry Kalinovsky (cr). **Getty Images:** Steve Craft (cla). **52 Dreamstime.com:** Piotr Wawrzyniuk (cl); Sean Nel (c). **53 Alamy Images:** Extreme Sports Photo (tr). **Dreamstime.com:** Kenny1 (cl). **54 Science Photo Library:** James King-Holmes (c). **54–55 Dreamstime.com:** Zbynek Burival (b). **55 Alamy Images:** (tl). **Corbis:** Barnie Rabbit / Demotix (cla). **Dorling Kindersley:** The Natural History Museum, London (tc). **57 Alamy Images:** Big Pants Productions (cr). **Dreamstime.com:** Molekuul (tc). **58–59 Corbis:** Mark Mawson / Robert Harding World Imagery. **58–83 Science Photo Library:** (sidebar). **59 Dreamstime.com:** Fotosenmeer (cla). **Science Photo Library:** Eye of Science (ca); Susumu Nishinaga (fcla). **60 Alamy Images:** John Bentley. **61 Dorling Kindersley:** Rough Guides (tr); The Science Museum, London (cl). **62 Dreamstime.com:** Fotosenmeer (cl). **Pearson Asset Library:** Gareth Boden / Pearson Education Ltd (br). **62–63 Dreamstime.com:** Viktor Prymachenko (c). **63 123RF.com:** Anna Bizoń (tr). **Science Photo Library:** Philippe Psaila (br). **64 Dreamstime.com:** Paul Mckinnon (bl). **64–65 Dreamstime.com:** Ragoarts (c). **65 Dreamstime.com:** Pikkystock (bl). **Getty Images:** Olada / E+ (tl). **66–67 Dreamstime.com:** Roland Nagy (bl). **67 Dreamstime.com:** Jorg Hackemann (tr). **Pearson Asset Library:** Joey Chan / Pearson Education Ltd (br). **68 Dorling Kindersley:** Master Ropemakers (cl). **Dreamstime.com:** Daniel Krylov (bc). **Science Photo Library:** Susumu Nishinaga (br). **68–69 Dreamstime.com:**

Photographerlondon (t). **69 Dreamstime.com:** Dmitrii Kiselev (crb). **70 Pearson Asset Library:** Pearson Education Ltd (tr). **70–71 Dreamstime.com:** Anthony Aneese Totah Jr (b). **71 Corbis:** George Hall (cr). **Dreamstime.com:** Victor5490 (cla). **Science Photo Library:** Sinclair Stammers (tc). **72–73 Science Photo Library:** Eye of Science. **74 Dorling Kindersley:** Lucy Claxton (bl). **74–75 Dreamstime.com:** Trondur (c). **75 Dreamstime.com:** Deorext (cra); Shao Weiwei (tl). **76–77 Dreamstime.com:** Charlieb34 (b). **77 Alamy Images:** Justin Kase szixz (tl). **Corbis:** POOL / Reuters (cra). **Dreamstime.com:** Endostock (cl). **78 Dreamstime.com:** Photographerlondon (cra). **78–79 Getty Images:** Tim Sloan / AFP (bl). **79 Dreamstime.com:** Aleksandr Kiriak (cla); Chiyacat (cl). **Pearson Asset Library:** Jon Barlow / Pearson Education Ltd (br). **80 Dreamstime.com:** Corepics Vof (bl). **81 Corbis:** JIANAN YU / Reuters (cl). **Dreamstime.com:** Eduard Bonnin Turina (b). **Science Photo Library:** Eye of Science (cra). **82–83 Science Photo Library:** Lawrence Livermore National Laboratory. **84–85 Corbis:** Jean-Pierre Lescourret. **84–119 Getty Images:** KTSDESIGN / Science Photo Library (sidebar). **85 Dorling Kindersley:** NASA (ca). **Getty Images:** Jacom Stephens / E+ (fcla); Rick Neves / Flickr (cla). **86 Dreamstime.com:** Worradirek Muksub (bc). **Getty Images:** Ray Massey (cla). **NASA:** NASA / JPL (clb). **Science Photo Library:** Janie Airey (bl). **86–87 Dreamstime.com:** Ukrphoto. **87 Dorling Kindersley:** Rough Guides (tl). **88–89 Dreamstime.com:** Kasiastock. **88 NASA:** Bill Ingalls (bl). **89 Courtesy Mercedes-Benz Cars, Daimler AG:** Mercedes (br). **90–91 Dreamstime.com:** Felix Mizionnikov. **90 Dreamstime.com:** Bob Brookfield (cra). **91 NASA:** MODIS Rapid Response Team at NASA GSFC (crb). **92–93 Corbis:** Jim Reed / Jim Reed Photography - Severe &. **94–95 Getty Images:** Jacom Stephens / E+. **95 Dreamstime.com:** Radu Razvan Gheorghe (bl). **96–97 Dorling Kindersley:** Whipple Museum of History of Science, Cambridge (b). **Getty Images:** Rick Neves / Flickr. **97 Science Photo Library:** Mark Garlick (br). **98 Getty Images:** Ryan Lane / E+ (c). **99 Getty Images:** Alexandru Magurean / E+ (cra). **Pearson Asset Library:** Oxford Designers & Illustrators Ltd. / Pearson Education Ltd (t). **101 Getty Images:** Brand X Pictures / Stockbyte (br). **102–103 Corbis:** ARND WIEGMANN / Reuters. **105 Dorling Kindersley:** NASA (crb). **Dreamstime.com:** Corepics Vof (cra); Sdbower (cr); Yury Shirokov (br). **106 NASA:** (clb). **106–107 Dreamstime.com:** Olga Besnard. **107 Courtesy of BMW Sauber F1 Team:** (t). **Dorling Kindersley:** Rough Guides (br). **108 Getty Images:** Keystone-France / Gamma-Keystone (tr). **108–109 U.S. Air Force.** **110–111 NASA:** Pat Corkery, United Launch Alliance (t). **110 NASA:** (b). **111 Getty Images:** Bloomberg (cr).

**NASA:** (cl, clb). **112 Dreamstime.com:** Karenkh (clb); Massimiliano Leban (cr); Lastdays1 (bc). **112–113 Getty Images:** Tyler Stableford / Iconica (t). **114–115 Science Photo Library:** Dr. Gary Settles. **116 Dreamstime.com:** Creativedoxfoto (cr). **116–117 Corbis:** José Fuste Raga. **117 Corbis:** STRINGER / EGYPT / Reuters (crb). **Dreamstime.com:** Yuangeng (br). **118 Dorling Kindersley:** Search and Rescue Hovercraft, Richmond, British Columbia (br). **119 Dreamstime.com:** Rhombur (tl). **Fotolia:** Strezhnev Pavel (water). **Getty Images:** Justin Sullivan / Stringer. **120–121 Getty Images:** Keren Su. **120–147 Science Photo Library:** Pasielka (sidebar). **121 Dreamstime.com:** Epicstock (cla); Oksana Belodaro (fcla). **Science Photo Library:** GIPhotoStock (ca). **122 Dreamstime.com:** Peter Wollinga (br). **123 Pearson Asset Library:** Studio 8 / Pearson Education Ltd (clb). **124 Corbis:** Pauline St. Denis (bl). **Dreamstime.com:** Per Björkdahl (cra). **124–125 Dreamstime.com:** Stu Porter. **125 Dorling Kindersley:** The Science Museum, London (br). **Dreamstime.com:** Fireflyphoto; Oksana Belodaro (cla). **126–127 Dreamstime.com:** Brett Critchley. **127 Getty Images:** Mark Lalston (tr, tc). **128 Dorling Kindersley:** Ruth Jenkinson (c). **Dreamstime.com:** Chasmac (br). **ESO:** ALMA (ESO / NAOJ / NRAO) / L. Calçada (ESO) / H. Heyer (ESO) / H. Zodet (ESO) (bl). **129 Dreamstime.com:** James Knopf (crb). **ESO:** ESO (tr). **NASA:** SOHO - EIT Consortium, ESA (clb). **Science Photo Library:** GIPhotoStock (cla). **130–131 NASA:** JPL-Caltech. **133 Dorling Kindersley:** Bergen County, NJ, Law and Public Safety Institute (tr). **Dreamstime.com:** Jamie Roach (tl). **Getty Images:** Kerstin Klaassen / Photographer's Choice RF (tc). **134 Dreamstime.com:** Birgit Reitz-hofmann (br). **135 Dreamstime.com:** Anikasalsera (br). **Getty Images:** Keith Szafranski / E+ (l). **136 Pearson Asset Library:** Terry Leung / Pearson Education Ltd (cl). **137 Alamy Images:** Keystone Pictures USA (cra). **Dreamstime.com:** Voyagerix (tc). **138–139 Getty Images:** konradlew / E+ (b). **139 Dreamstime.com:** Valeriy Novikov (cla). **139 Alamy Images:** North Wind Picture Archives (tr). **Pearson Asset Library:** Studio 8 / Pearson Education Ltd (cl). **Science Photo Library:** Edward Kinsman (clb). **140 Dreamstime.com:** Epicstock. **141 Dreamstime.com:** Tom Wang (tr). **Science Photo Library:** Henning Dalhoff (bl). **142 Dreamstime.com:** Dmitry Kalinovsky (bl). **142–143 Dreamstime.com:** Mikado767. **143 Dreamstime.com:** Corey A. Ford (bc). **144–145 Alamy Images:** Conspectus. **147 Alamy Images:** Judith Collins (ca). **Dorling Kindersley:** The National Music Museum (tr, cra, cb, br). **148–149**

**Corbis:** Paul Souders. **148–171 Corbis:** John Rensten (sidebar). **149 Corbis:** Tetra Images (ca). **Getty Images:** Anders Blomqvist / Lonely Planet Images (cla). **150 Dreamstime.com:** Alexstar (bl); Suljo (tr). **151 Getty Images:** Anders Blomqvist / Lonely Planet Images (tr); Space Frontiers / Photodisc (cr); Steven Puetzer (br). **152–153 Corbis:** Chris Selby / age fotostock Spain S.L. **153 123RF.com:** Roman Gorielov (b). **PunchStock:** Corbis (cla). **154–155 Corbis:** Tetra Images. **156–157 Dreamstime.com:** Tamas Bedecs. **157 Science Photo Library:** Philippe Plailly (tr). **158 Dreamstime.com:** Lulya (cla). **Pearson Asset Library:** Jon Barlow / Pearson Education Ltd (clb). **158–159 NASA:** MSFC / David Higginbotham / Emmett Given. **159 Alamy Images:** Harriet Cummings (tc). **160 Dreamstime.com:** Ben Heys (bl). **160–161 Dreamstime.com:** Hywit Dimyadi. **161 Dreamstime.com:** An driukas76 (br). **162 NASA:** Large Binocular Telescope Observatory (tr). **162–163 Dreamstime.com:** Carol Buchanan. **163 Corbis:** Peter Ginter / Science Faction (tr). **Science Photo Library:** Susumu Nishinaga (br). **164–165 ESO:** G. Hüdopohl. **167 123RF.com:** Klemen Mistic (bc). **Corbis:** (tr, ca). **Dorling Kindersley:** Barrie Watts (cb). **Dreamstime.com:** (br); Francois Loubser (clb). **NASA AMES Research Centre:** W.T. system F-14D model Schlieren test (crb). **168 Alamy Images:** Jeff Morgan 06 (br). **Dreamstime.com:** Steve2009 (cra). **Getty Images:** Eadward Muybridge / The Bridgeman Art Library (bl). **169 Corbis:** Norbert Michalke / imagebroker (b). **Rex Features:** Moviestore Collection (t). **170 Dreamstime.com:** Sergey Galushko / Galdzer (cla). **170–171 Dreamstime.com:** Nikkytok. **171 Getty Images:** Science Picture Co / Collection Mix: Subjects (tr). **172–173 Science Photo Library:** Astrid Aand Hanns-Frieder Michler. **172–211 Dreamstime.com:** Creasencso (sidebar). **173 Dreamstime.com:** Brett Critchley (cla). **NASA:** ISS Crew Earth Observations experiment and Image Science & Analysis Laboratory, Johnson Space Center (fcla). **SuperStock:** Mick Roessler (ca). **174–175 Fotolia:**



Stephen Coburn. **174 Dorling Kindersley:** Demetrio Carrasco (bl). **175 Corbis:** Imaginechina (tr). **Dorling Kindersley:** The Science Museum, London (cb). **176–177 Pearson Asset Library:** Trevor Clifford / Pearson Education Ltd. **176 Pearson Asset Library:** Jules Selmes / Pearson Education Ltd (br). **179 Science Photo Library:** Alfred Benjamin (tr). **180–181 Corbis:** Armin Weigel / dpa. **182–183 NASA:** ISS Crew Earth Observations experiment and Image Science & Analysis Laboratory, Johnson Space Center. **184–185 SuperStock:** Mick Roessler. **185 Dreamstime.com:** Katie Nesling (tl). **186 NASA:** (br). **187 Dreamstime.com:** Harris Shiffman (b). **188–189 Alamy Images:** Ryuichi Gamo / Aflo Photo Agency. **188 Dreamstime.com:** Hpphoto (br). **189 Dreamstime.com:** Brett Critchley (tr). **Science Photo Library:** Tony Mcconnell (br). **190 Dreamstime.com:** Artaniss8 (bc). **Getty Images:** Science & Society Picture Library (clb). **Pearson Asset Library:** Jules Selmes / Pearson Education Ltd (br); Terry Leung / Pearson Education Ltd (fbr). **191 Corbis:** Arman Zhenikeyev (tl). **Dreamstime.com:** Derek Tenhue (ca); Yourthstock (bl); Vitalyedush (bc). **192 Fotolia:** claffra (bl). **NASA:** (t). **193 Corbis:** Raf Makda / VIEW (br). **Dreamstime.com:** Ron Chapple (tr); Štěpán Kápl (ca). **194–195 Corbis:** Georg Gerster / age fotostock Spain S.L. **196 Dorling Kindersley:** The Science Museum, London (c, br). **Getty Images:** Hulton Archive / Stringer (cr). **Science Photo Library:** Pasička (clb). **197 Dreamstime.com:** Albert Lozano (tl); Peter Sobolev (c). **Pearson Asset Library:** Gareth Boden / Pearson Education Ltd (bl). **199 Dreamstime.com:** Anthony Bolan (clb); Grzym (cb). **Getty Images:** CBS Photo Archive (cra). **200 123RF.com:** Anatolii Babii (bl). **Corbis:** (cr).

**Dorling Kindersley:** Whipple Museum of History of Science, Cambridge (c). **Dreamstime.com:** Alexander Kirch (fcr); Dave Bredeson (b). **201 Fotolia:** Alexandr Mituic (cra); Maxim Kazmin (tc, tr). **Getty Images:** Coney Jay / Stone (cr). **NASA:** Dominic Hart (bc). **Pearson Asset Library:** Tsz-shan Kwok / Pearson Education Asia Ltd (ca). **202 Corbis:** Ted Soqui (tr). **202–203 Corbis:** René Mattes / Hemis (b). **205 Fotolia:** Sashkin (bc). **Getty Images:** AFP / Stringer (cr). **Science Photo Library:** Laurent Douek / look at sciences (tr). **206 Dorling Kindersley:** Kate Howey and Elgan Loane of Kentree Ltd, Ireland (bl). **Dreamstime.com:** Dikiy (cra). **207 Alamy Images:** AF archive (bl). **Getty Images:** Stan Honda / AFP (tl); Yoshikazu Tsuno / AFP (r). **208–209 Science Photo Library:** James King-Holmes. **210 Alamy Images:** dpa picture alliance (cl). **210–211 Dreamstime.com:** Glazyu (b). **211 Brand X Pictures:** The Stocktrek Corp / Alamy (br). **Corbis:** Fabrizio Bensch / Reuters (cl). **212–213 Science Photo Library:** Georgette Douwma. **212–263 Science Photo Library:** Gerry Bishop, Visuals Unlimited (sidebar). **213 Dorling Kindersley:** Malcolm Coulson (cla / Mushroom). **Dreamstime.com:** Linncurrie (ca). **Science Photo Library:** Power and Syred (cla). **214 Dorling Kindersley:** The Hunterian Museum (University of Glasgow) (bl). **Science Photo Library:** Dr Kari Lounatmaa (br). **215 Dreamstime.com:** Linncurrie (bl); Mwicks (tr). **216 Alamy Images:** D. Hurst (br/Ladybug). **Getty Images:** Volker Otten (bl). **217 Corbis:** Michael & Patricia Fogden (c). **Dorling Kindersley:** Rough Guides (ca). **Dreamstime.com:** Johannes Gerhardus Swanepoel (cla); Swalters316 (bc). **Science Photo Library:** Andrew J. Martinez (br); Simon Fraser (tr). **219 Dreamstime.com:** Steve Byland (br); Theo Malings (cra). **Pearson Asset Library:** Cheuk-king Lo / Pearson Education Ltd (crb). **Science Photo Library:** Power and Syred (tr). **220–221 Science Photo Library:** Dr. Charles Mazel / Visuals Unlimited, inc. **222 Alamy Images:** Nurlan Kalchinov (b). **223 Corbis:** Michael & Patricia Fogden (cr). **Dorling Kindersley:** The Royal British Columbia Museum, Victoria, Canada (tl). **Dreamstime.com:** Kcmatt (bc). **224 Corbis:** Mediscan (c).

**Dreamstime.com:** Sebastian Kaulitzki (ca); Zurijeta (cr). **Science Photo Library:** Clouds Hill Imaging Ltd. (bc). **225 Dreamstime.com:** Alexander Zhiltsov (bc/mosquito); Lisa F. Young (bc); Patricia Hofmeester (br). **Pearson Asset Library:** Trevor Clifford / Pearson Education Ltd (fbr). **226–227 Getty Images:** Philippe Bourseiller. **228–229 Dorling Kindersley:** Malcolm Coulson (bl). **228 Corbis:** Michael & Patricia Fogden (cra). **Science Photo Library:**

Dr. Jeremy Burgess (cl). **229 Dreamstime.com:** Mark Eaton (cla); Sebastian Kaulitzki (tc). **Getty Images:** Peter Walton Photography (br). **Science Photo Library:** David Scharf (tr). **230 123RF.com:** Daniel Poloha (ca). **Dorling Kindersley:** Rough Guides (c). **230–231 Dorling Kindersley:** Rough Guides (c). **231 Corbis:** DLILLC (c). **Science Photo Library:** John Durham (tr). **233 Getty Images:** Chris Cheadle / All Canada Photos (br); Dr. Kari Lounatmaa (tl); Nigel Catlin (cr). **234 Dorling Kindersley:** The EMU Unit of the Natural History Museum, London (br). **235 Getty Images:** David Sieren / Visuals Unlimited (cra). **237 Alamy Images:** Melba Photo Agency (cl). **238–239 Alamy Images:** Phil Degginger. **240 Dorling Kindersley:** The Booth Museum of Natural History, Brighton (cr). **Science Photo Library:** Dante Fenolio (crb). **242 Dorling Kindersley:** The Natural History Museum, London (crb). **244 Corbis:** Denis Scott (cra); Ocean (b). **245 Corbis:** Jim Brandenburg / Minden Pictures (bl); Staffan Widstrand (br). **naturepl.com:** Nature Production (cr). **Science Photo Library:** B. G. Thomson (tr); Claude Nuridsany & Marie Perennou (tl). **246–247 Science Photo Library:** Scubazoo. **248 Science Photo Library:** Frans Lanting, Mint Images (cr). **249 Alamy Images:** Zeeshan Mirza / ephotocorp (bl). **Corbis:** Ken Catania / Visuals Unlimited (tr). **Dreamstime.com:** Frhojdzys (br). **250 Corbis:** Thomas Kitchin Victoria Hurst / Design Pics. **251 Alamy Images:** Premaphotos (br). **Getty Images:** Heinrich von den Berg / Gallo Images (tl); Michael Nolan / Robert Harding World Imagery (bl). **252 Corbis:** Paul Souders (cla). **Science Photo Library:** (b). **253 Alamy Images:** David Tipling (cl). **Fotolia:** frank11 (tr). **Science Photo Library:** Frans Lanting, Mint Images (br). **254 Alamy Images:** Art Wolfe / Cultura RM (br). **Corbis:** Michio Hoshino / Minden Pictures (cl). **Getty Images:** Keith Ringland / Oxford Scientific (bc). **254–255 Corbis:** Wave. **255 Getty Images:** David Parsons / E+ (bl); Norbert Rosing / National Geographic (tr); Visuals Unlimited, Inc. / Louise Murray (cr). **257 Alamy Images:** Mark Conlin (br). **Dorling Kindersley:** The National Birds of Prey Centre, Gloucestershire (cra). **Fotolia:** Stefan Andronache (ca). **258 Alamy Images:** Malcolm Schuyf (fcr). **Getty Images:** Rainer von Brandis / E+ (cr). **258–259 Dorling Kindersley:** Rough Guides (b). **259 Corbis:** Alex Hofford / epa (crb); Joe McDonald (cb). **Getty Images:** Reinhard Dirscherl / WaterFrame (tl); STR / Stringer / AFP (cra). **264–265 Science Photo Library:** Pasička. **264–291 Science Photo Library:** Calor & Mike Werner / Visuals Unlimited, Inc. (sidebar). **265 Getty Images:** Science & Society Picture Library (cla). **Science Photo Library:** Science Source (ca). **266 NASA.** **267 Getty Images:** Alfred Eisenstaedt / Time & Life Pictures (br). **Pearson Asset Library:** Tudor

Photography / Pearson Education Ltd (bl). **268 Getty Images:** Universal Images Group (bl). **269 Getty Images:** Science & Society Picture Library (bl). **270–271 Getty Images:** Science & Society Picture Library. **270 Dreamstime.com:** Alessandro0770 (br). **Science Photo Library:** New York Public Library (cl). **271 Science Photo Library:** National Library of Medicine (br). **272 Getty Images:** Universal Images Group. **274 Dorling Kindersley:** NASA / digitaleye / Jamie Marshall. **275 Dreamstime.com:** Mopic (cl). **NASA:** (br). **Pearson Asset Library:** Silverpin Design Company Ltd. / Pearson Education Ltd (tc). **276 Alamy Images:** The Natural History Museum (cl). **Dorling Kindersley:** The Natural History Museum, London (bl). **Getty Images:** De Agostini Picture Library (tr). **277 Corbis:** (clb); Thomas Nast (cra). **Dorling Kindersley:** The Senckenberg Nature Museum, Frankfurt (br). **278 Getty Images:** Culture Club / Hulton Archive (bl). **278–279 Science Photo Library:** Science Source. **279 Alamy Images:** Peter van Evert (br). **Getty Images:** Science & Society Picture Library (tl). **280 Alamy Images:** GL Archive (cl). **Getty Images:** Keystone-France / Gamma-Keystone (br). **281 Dreamstime.com:** Aleksandr Volodin (tr). **282 Science Photo Library:** Prof. Peter Fowler (bl). **283 Dreamstime.com:** Wellphotos (br). **Getty Images:** Science & Society Picture Library (tr). **Science Photo Library:** Library of Congress (cr). **284–285 Science Photo Library:** Maximilien Brice, CERN. **286 Science Photo Library:** A. Barrington Brown (bl). **287 Science Photo Library:** James King-Holmes (crb); Science Source (tl, tc). **288 Corbis:** Frederic Cailliaud / Stapleton Collection (crb). **Dorling Kindersley:** The Trustees of the British Museum (ca, clb, bc); The Museum of London (cl); The Statens Historiska Museum, Stockholm (cr); The University Museum of Archaeology and Anthropology, Cambridge (fclb). **288–289 Alamy Images:** Feng Yu (bc). **289 Dorling Kindersley:** Whipple Museum of the History of Science, University of Cambridge (ca); Calcografia Nacional, Madrid (tl); The Science Museum, London (tr, cr, cb, br); Saxon Village Crafts, Battle, East Sussex (clb). **Getty Images:** Print Collector / Hulton Archive (tc). **290 Corbis:** Bettmann (t); Mediscan (ca). **Dorling Kindersley:** The Science Museum, London (cb, br); The National Motor Museum, Beaulieu (bl). **Dreamstime.com:** Andrey Sukhachev / Nchuprin (cra). **291 Corbis:** Ira Nychman / Sygma (crb); Najlah Feanny (cra). **Dreamstime.com:** Mishoo (ca); Solarseven (br). **NASA:** (tl). **292 Getty Images:** Keith Szafranski / E+ (bl). **293 ESO:** ESO (t). **295 NASA:** Bill Ingalls (bl).

All other images © Dorling Kindersley  
For further information see:  
www.dkimages.com