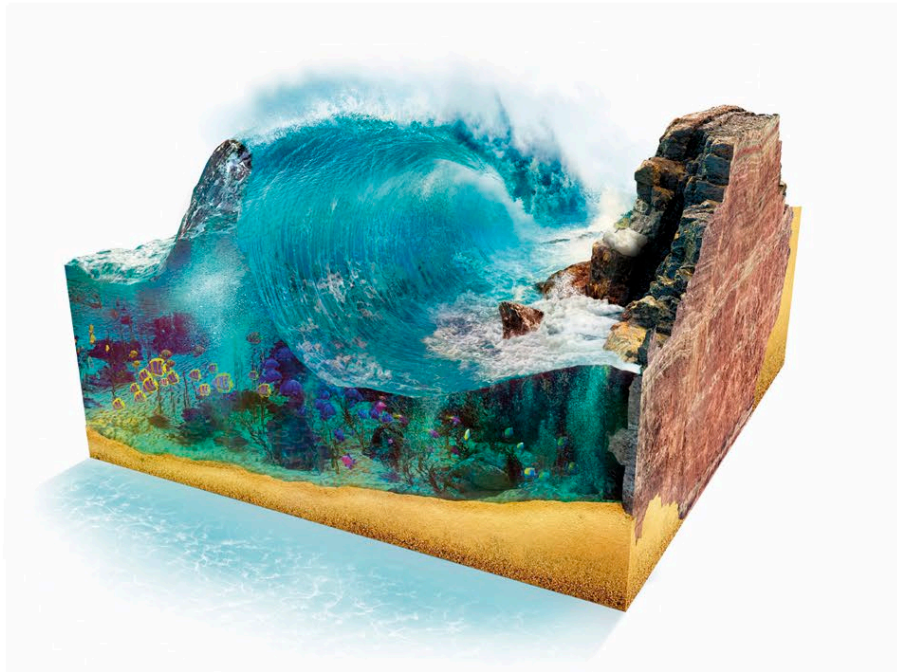
DK SMITHSONIAN

SCIENCE!

SCIENCE AS YOU'VE NEVER SEEN IT BEFORE



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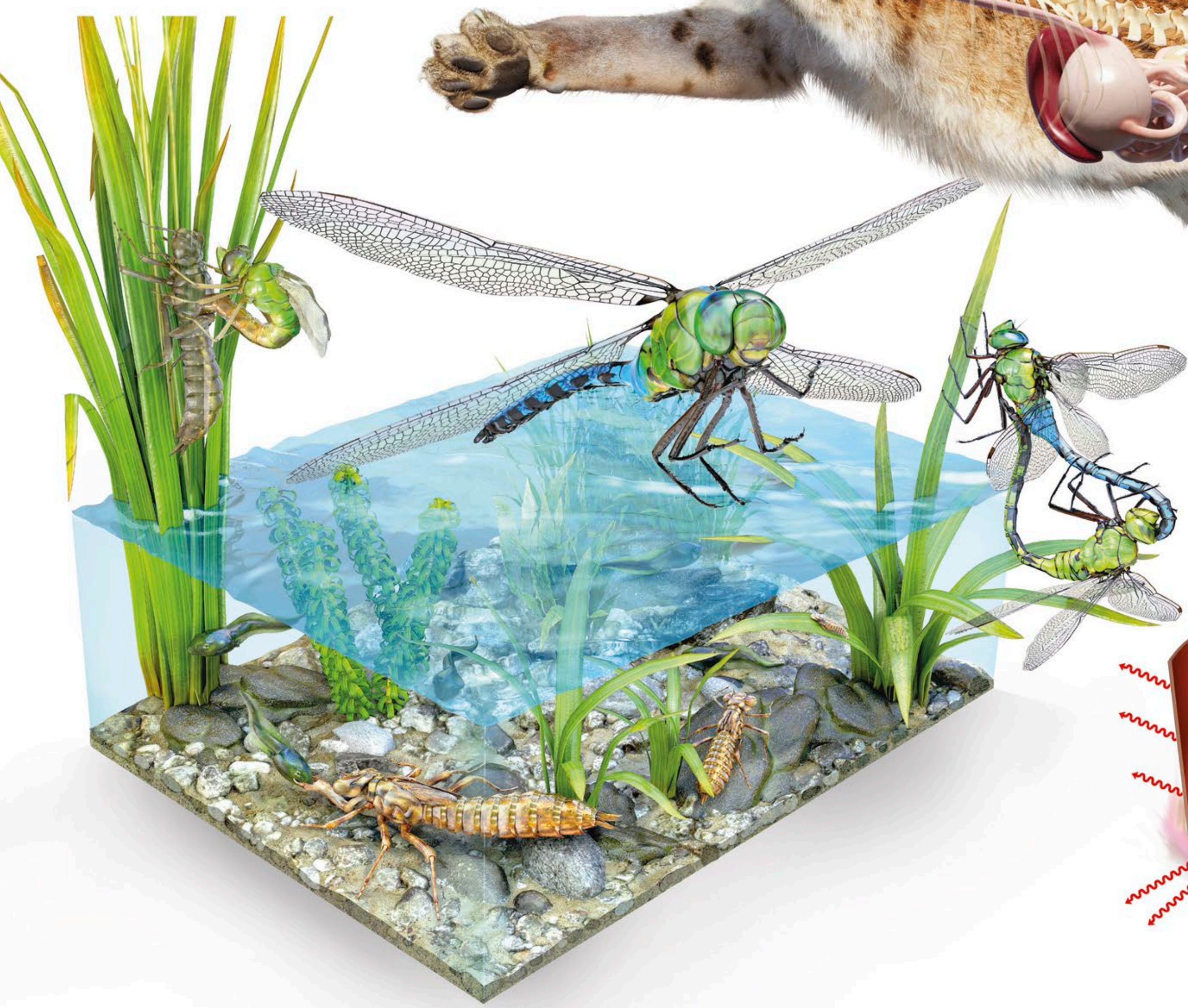

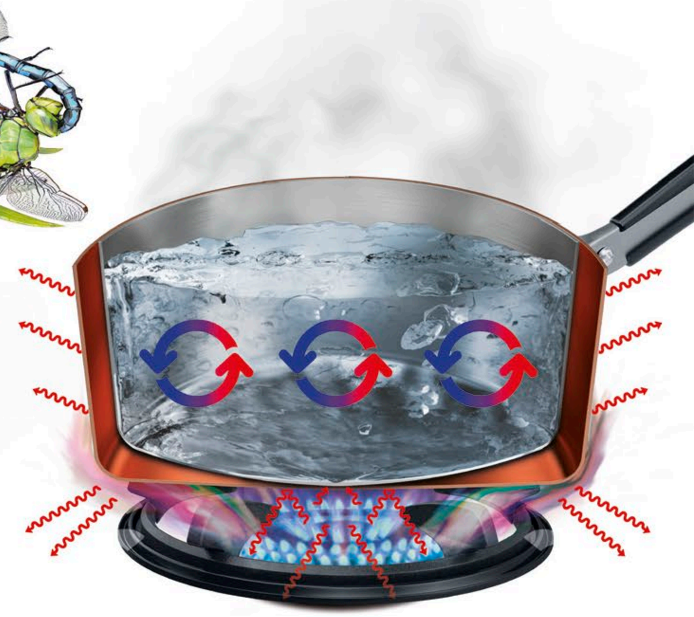

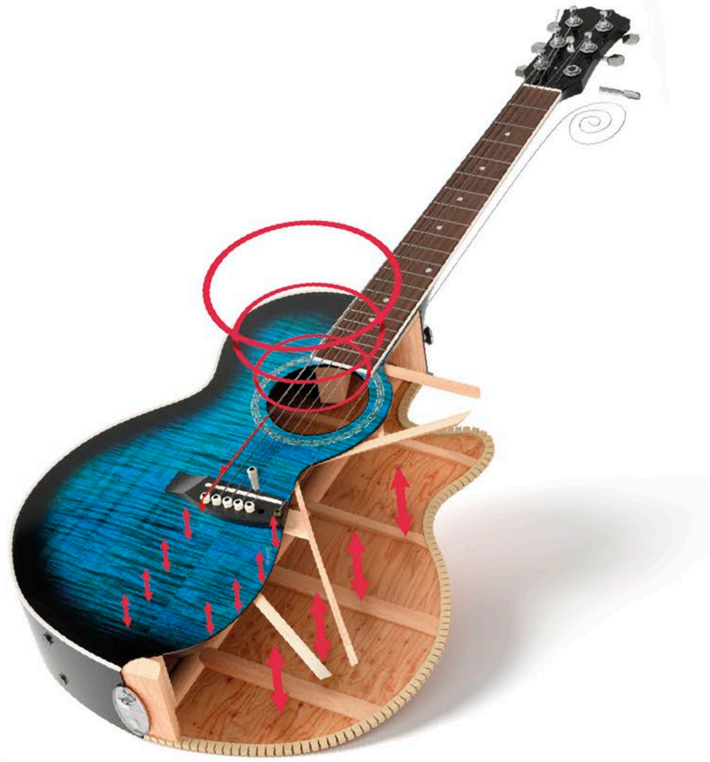

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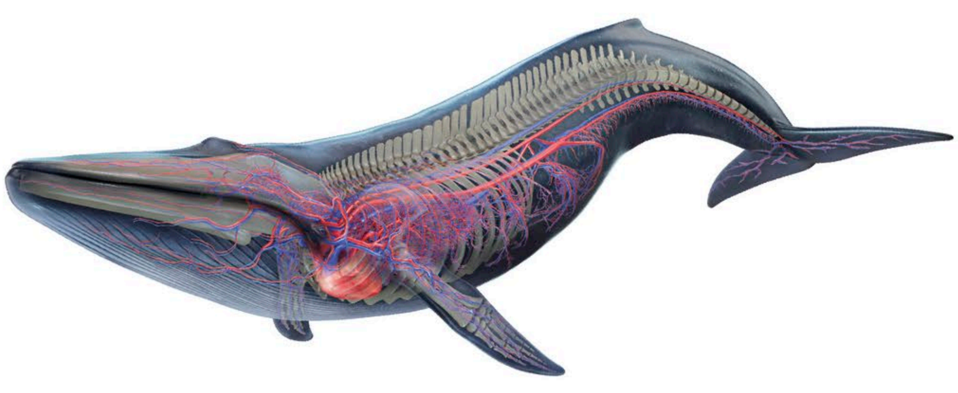

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Smithsonian

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Established in 1846, the Smithsonian is the world's largest museum and research complex, dedicated to public education, national service, and scholarship in the arts, sciences, and history. It includes 19 museums and galleries and the National Zoological Park. The total number of artifacts, works of art, and specimens in the Smithsonian's collection is estimated at 154 million.

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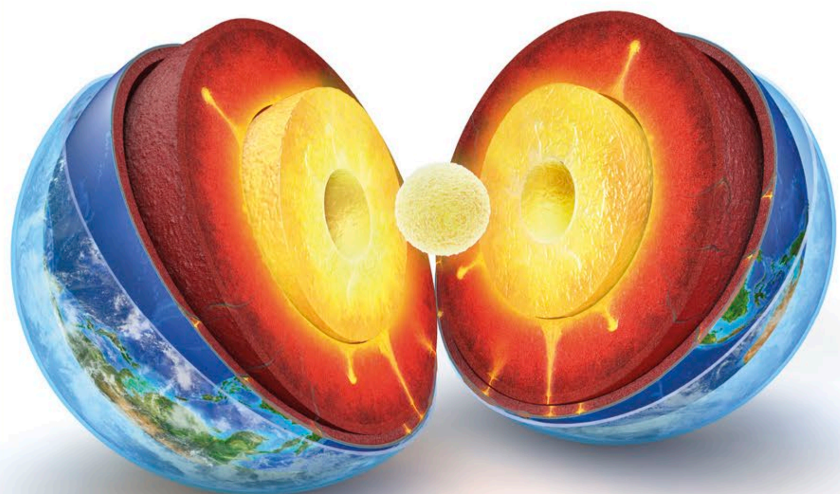
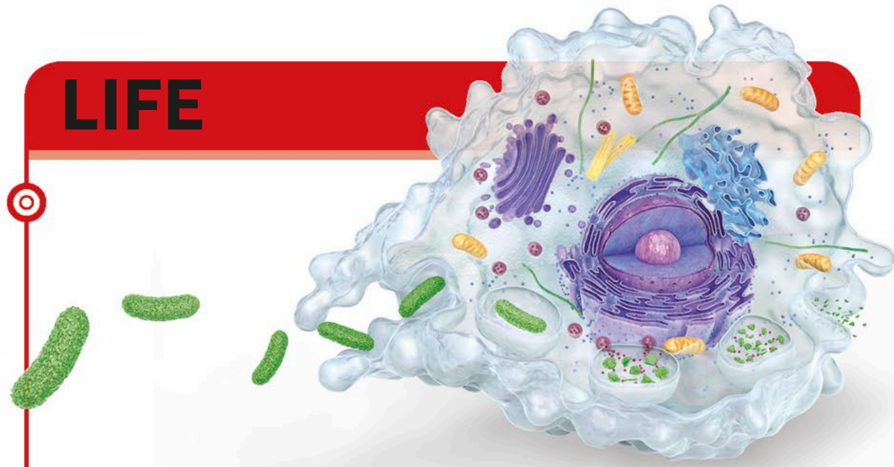


LIFE



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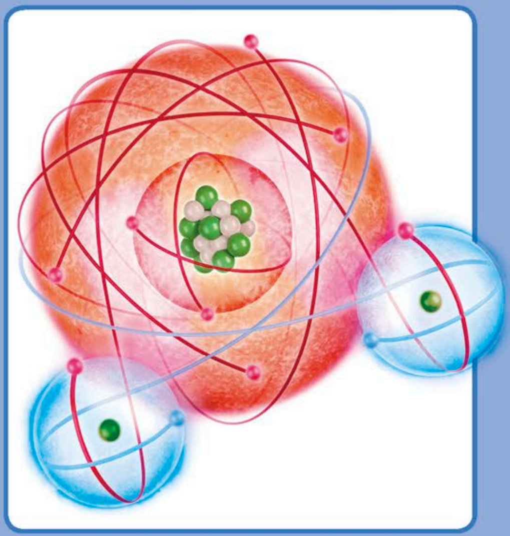
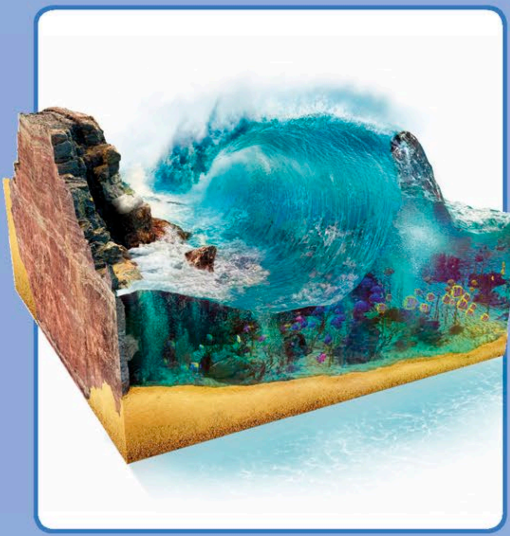




MATTER

The ground beneath your feet, the air around you, and the stars in the sky are made of matter. You are made of matter, too. All matter is made of minute particles called atoms, which join together in countless ways to form an astonishing variety of substances.

1855 The **bunsen burner** is invented by German scientist **Robert Bunsen.**

Discovering matter

Thousands of years of questioning, experimentation, and research have led to our understanding of matter as we know it today.

Following the earliest explorations of matter by our prehistoric ancestors, Greek philosophers were among the first people to attempt to classify matter and explain its behavior. Over time, scientists found more sophisticated ways of analyzing different types of matter and discovered many of the elements. The Industrial Revolution saw the invention of new synthetic materials using these elements, while greater understanding of the structure of atoms led to significant advances in medicine. New substances and materials with particularly useful properties are still being discovered and invented to this day.

Timeline of discoveries

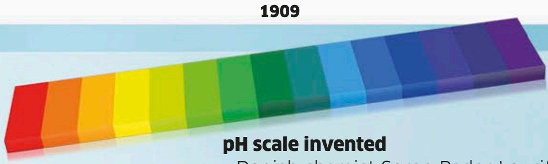
From prehistory to the present day, people have sought to understand how matter behaves and to classify different types. Over the years, this has led to the discovery of new matter and materials.

MODERN TIMES

Modern chemistry

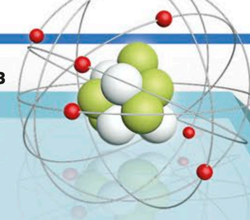
Advances in technology allowed chemists and other scientists to invent new materials by reproducing natural materials synthetically or rearranging atoms through nanotechnology.

1890 – 1945



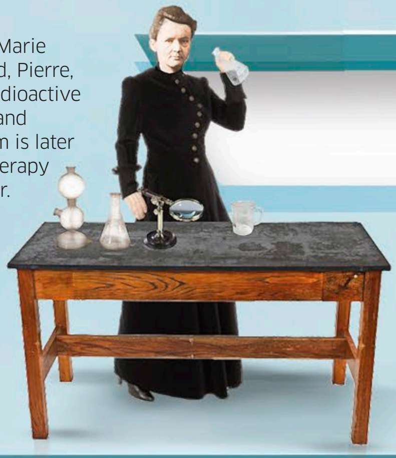
1909

pH scale invented
Danish chemist Søren Peder Lauritz Sørensen invents the pH scale, which is used to judge whether a substance is an acid, neutral, or base.



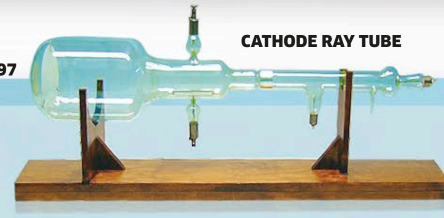
1913

Electron shells
The Danish scientist Niels Bohr proposes a model of the atom that shows how electrons occupy shells and orbit around the nucleus.



1898

New elements
Polish-French scientist Marie Curie and her husband, Pierre, discover two new radioactive elements, radium and polonium. Radium is later used in radiotherapy to treat cancer.



CATHODE RAY TUBE

1897

Discovery of electrons
English scientist J. J. Thomson discovers electrons using a cathode ray tube. This is the first step toward understanding the structure of atoms.

The Atomic Age

The discovery of radioactivity led to a better understanding of what lies inside an atom, and more research into subatomic particles. This knowledge was put to use in medicine and health care.

1772 / 1774

Discovery of oxygen
Swedish chemist Carl Scheele builds a contraption to capture oxygen by heating various compounds together. English scientist Joseph Priestley also discovers oxygen by showing that a candle can't burn without it.

SCHEELE'S OXYGEN APPARATUS

1789

Antoine Lavoisier
French chemist Antoine Lavoisier publishes *Elements of Chemistry*, which lists the 33 known elements divided into four types: gases, metals, non-metals, and earths.

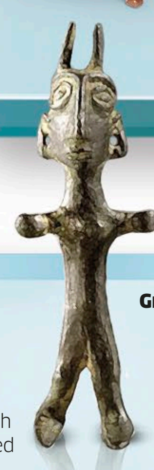
BEFORE 500 CE

Prehistory to antiquity

The earliest discoveries of how matter behaves were made not by scientists, but by prehistoric ancestors trying to survive. During antiquity, philosophers spent a lot of time trying to work out what matter is.

790,000 BCE

Making fire
Our ancestors learn to make fire using combustion (although they don't know that at the time).



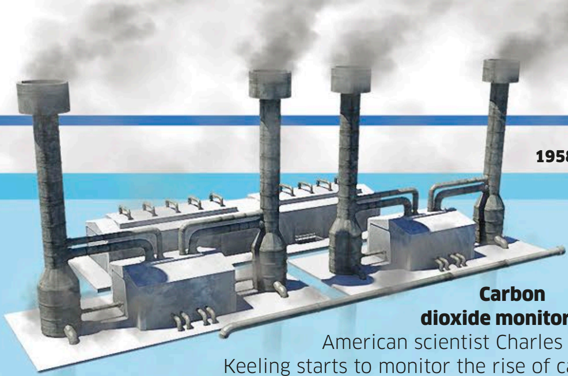
3200 BCE

Copper and bronze
Smelting of copper (extracting it from its ore through heat) is discovered. Bronze (copper smelted with tin) is first produced in 3200 BCE.

420 BCE

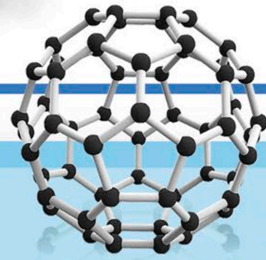
Greek philosophers
Empedocles suggests that everything is made of four elements: air, earth, fire, and water. Democritus suggests that all matter consists of atoms.

1661 Robert Boyle's *The Sceptical Chymist* develops a **theory of atoms**.



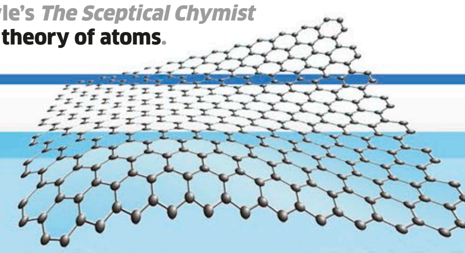
1958

Carbon dioxide monitoring
American scientist Charles David Keeling starts to monitor the rise of carbon dioxide in the atmosphere. His Keeling Curve graph is still used to study climate change.



1985

Buckyball discovery
Scientists at Rice University in Houston discover a new form of carbon called buckminsterfullerene, or buckyball.



2004

World's thinnest material
Graphene (a layer of carbon atoms just one atom thick) is produced at the University of Manchester, UK. It is the world's thinnest material, but 200 times stronger than steel.

1945 – PRESENT

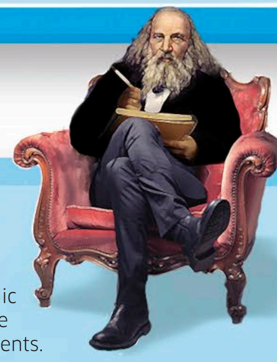
1890–1945

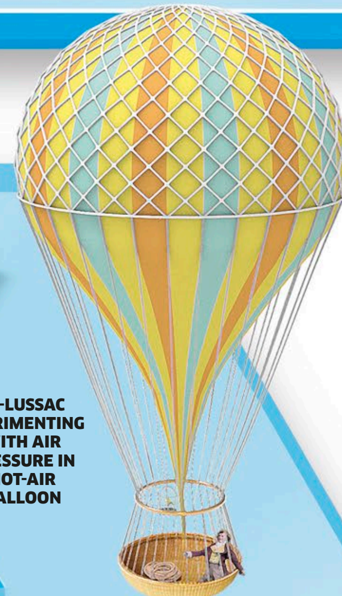
1870

Synthetic materials
The first synthetic materials made from cellulose are invented: celluloid (moldable plastic) in 1870 and viscose rayon in 1890.

1869

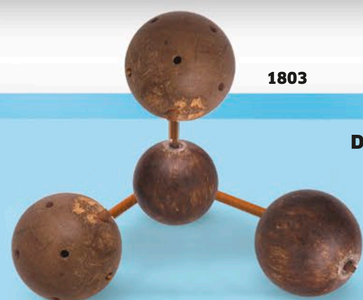
Mendeleev's periodic table
Russian chemist Dmitri Mendeleev arranges the 59 known elements into groups based on their atomic mass and properties. This periodic table enables him to predict the discovery of three more elements.





19TH CENTURY

Industrial Revolution
Driven by the thirst for modernization, chemists identified more elements and invented ways to use them in medicine, in creating new materials, and in advanced industrial technologies.



1803

Dalton's atomic theory
English chemist John Dalton argues that all matter is composed of atoms and atoms of the same element are identical. He compiles a list of elements based on their atomic mass, then known as atomic weight.

1805

Structure of water
French chemist Joseph Louis Gay-Lussac experiments with gases and pressure and finds that water is made up of two parts hydrogen and one part oxygen.

1800 – 1890

17TH CENTURY

Age of Discovery
The Renaissance brought both rediscovery of antique knowledge and a quest for fresh ideas. Scientists began to test, experiment, and document their ideas, publishing their findings and working hard to classify matter.

1527

Salts, sulfurs, and mercuries
Swiss chemist Theophrastus von Hohenheim works out a new classification for chemicals, based on salts, sulfurs, and mercuries.

1600 – 1800

MIDDLE AGES

Middle Ages
In Asia and the Islamic world, alchemists experimented to find the elixir of life and to make gold. By the late Middle Ages, European alchemists were working toward the same goal.

855 CE

Gunpowder
While they are looking for the elixir of life, Chinese alchemists accidentally invent gunpowder by mixing saltpeter with sulfur and charcoal.

900

Classifying elements
Arab physician Al-Razi divides elements into spirits, metals, and minerals depending on how they react with heat.

500 CE – 1600

WHAT IS MATTER?

The air around you, the water you drink, the food you eat, your own body, the stars, and the planets—all of these things are matter. There is clearly a huge variety of different types of matter, but it is all made of tiny particles called atoms, far too small to see. About ninety different kinds of atom join together in many combinations to make all the matter in the universe.

PARTICLES OF MATTER

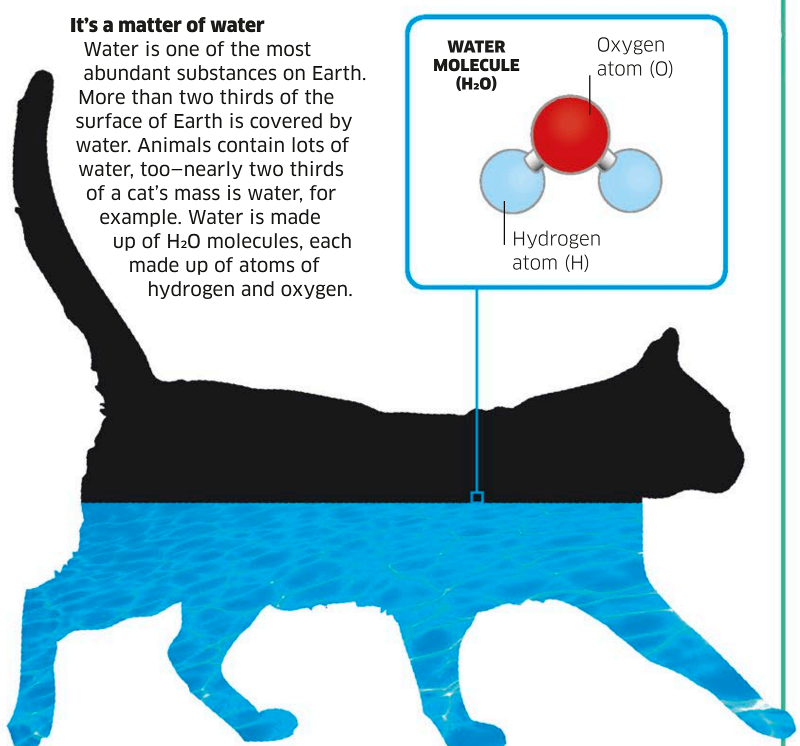
Matter is made of atoms—but in many substances, those atoms are combined in groups called molecules, and in some they exist as ions: atoms that carry an electric charge. Both atoms and ions can bond together to form compounds.

Atoms and molecules

An atom is incredibly small: you would need a line of 100,000 of them to cover the width of a human hair. Tiny though they are, atoms are made of even smaller particles: protons, neutrons, and electrons. Different kinds of atom have different numbers of these particles. Atoms often join, or bond, in groups called molecules. A molecule can contain atoms of the same kind or of different kinds.

It's a matter of water

Water is one of the most abundant substances on Earth. More than two thirds of the surface of Earth is covered by water. Animals contain lots of water, too—nearly two thirds of a cat's mass is water, for example. Water is made up of H_2O molecules, each made up of atoms of hydrogen and oxygen.



ELEMENTS, COMPOUNDS, AND MIXTURES

Everything around us is matter, but it is a bit more complex than that. Elements can exist on their own, but usually bond together chemically with other elements to form compounds or appear in mixtures (substances in which the "ingredients" are not chemically bonded, but simply mixed together). A mixture can consist of two or more elements, an element and a compound, or two or more separate compounds.

What's what?

Everything can be sorted into different categories of matter, depending on whether it is a pure substance or a mixture of different substances. This diagram shows the main types.

Cut diamond

Pure substances
Matter is pure if it is made of just one kind of substance. That substance can be an element or a compound. Diamond, a form of the element carbon, is a pure substance. So is salt (sodium chloride), a compound of the elements sodium and chlorine.

Elements
An element, such as gold, is a pure substance, made of only one kind of atom. Iron, aluminum, oxygen, carbon, and chlorine are other examples of elements. All elements have different properties, and are sorted into a chart called the periodic table (see pp.28–29).

Compounds
A compound is a pure substance that consists of atoms of different elements bonded together. In any particular compound, the ratio of the different kinds of atoms is always the same. In salt there are equal numbers of sodium and chlorine atoms (1:1), while water contains twice as many hydrogen as oxygen atoms (2:1).

Stainless steel—an alloy of iron, carbon, and chromium—is a homogeneous mixture.

Homogeneous mixtures
In a homogeneous mixture, particles of different substances are mixed evenly, so the mixture has the same composition throughout. They can be solid (steel), liquid (honey), or gas (air).

Solutions
All homogeneous mixtures are solutions, but the most familiar are those where a solid has been dissolved in a liquid. An example is salt water—in which the salt breaks down into ions that mix evenly among the water molecules. In sugary drinks, the sugar is also dissolved—no grains of sugar float around in the solution.

The air in a balloon is a homogeneous mixture of several gases, mostly the elements nitrogen and oxygen.

Matter
Matter can be solid, liquid, or gas. Most of the matter around you, from planets to animals, is composed of mixtures of different substances. Only a few substances exist naturally in completely pure form.

A frog is made of compounds and mixtures.

An ice cream is an impure substance—a mixture of many different ingredients.

A sandwich is a mixture of several substances.

Impure substances
If a substance is impure, it means that something has been mixed into it. For example, pure water consists of only hydrogen and oxygen. But tap water contains minerals, too, which makes it an impure substance. All mixtures are impure substances.

Mixtures
There are many different kinds of mixtures, depending on what substances are in the mix and how evenly they mix. The substances in a mixture are not bound together chemically, and can be separated. Rocks are solid mixtures of different minerals that have been pressed or heated together.

A leaf is a very complex uneven mixture.

Muddy water is a suspension: it may look evenly mixed at first, but the larger mud particles soon separate out.

Heterogeneous mixtures
In a heterogeneous mixture, particles of different substances are mixed unevenly. Examples are concrete (a mixture of sand, cement, and stone) and sand on a beach, which consists of tiny odd-sized particles of eroded rock, sea shells, and glass fragments.

Suspensions
Suspensions are liquids that contain small particles that do not dissolve. If they are shaken, they can appear evenly mixed for a short time, but then the particles separate out and you can see them with your naked eye.

Colloids
A colloid looks like an even mixture, but no particles have been completely dissolved. Milk, for example, consists of water and fat. The fat does not dissolve in water, but floats around in minute blobs that you cannot see without a microscope. A cloud is a colloid of tiny water droplets mixed in air.

STATES OF MATTER

Most substances exist as solids, liquids, or gases—or as mixtures of these three states of matter. The particles of which they are made (the atoms, molecules, or ions) are in constant motion. The particles of a solid vibrate but are held in place—that's why a solid is rigid and keeps its shape. In a liquid, the particles are still attracted to each other, but can move over each other, making it fluid. In a gas, the particles have broken free from each other, and move around at high speed.

Changing states of matter

With changes in temperature, and sometimes in pressure, one state can change into another. If it is warm, a solid ice cube melts into liquid water. If you boil the water, it turns into gaseous steam. When steam cools down, it turns back into a liquid, such as the tiny droplets of mist forming on a bathroom window. Only some substances, including candle wax, exist in all three states.

Liquid
In the heat of the flame, the wax melts, and the molecules can move over each other and flow.

Gases
Near the wick, the temperature is high enough to vaporize the liquid wax, forming a gas of molecules that can react with the air. This keeps the flame burning.

Solid
Solid wax is made of molecules held together. Each wax molecule is made of carbon and hydrogen atoms.

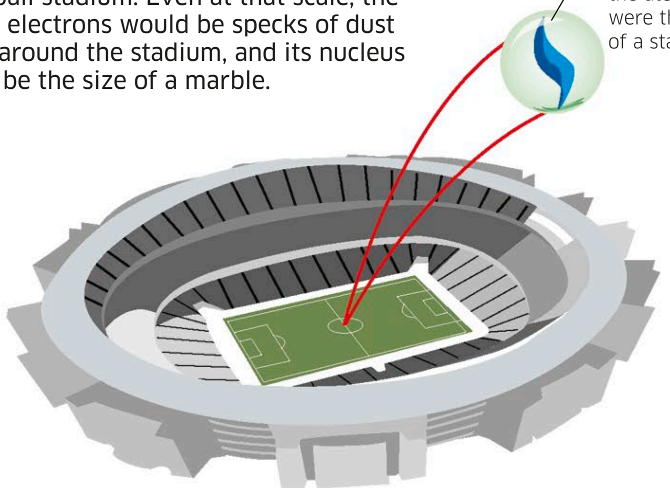
Plasma, the fourth state of matter

When gas heats up to a very high temperature, electrons break free from their atoms. The gas is now a mixture of positively charged ions and negatively charged electrons: a plasma. A lightning bolt is a tube of plasma because of the extremely high temperature inside it. In space, most of the gas that makes up the sun, and other stars in our universe, is so hot it is plasma.

The name atom comes from the Greek *atomos*, which **means “uncuttable,”** first used by the **ancient Greek philosopher Democritus**.

Atomic proportions

You would have to enlarge an atom to a trillion times its size to make it as big as a football stadium. Even at that scale, the atom’s electrons would be specks of dust flying around the stadium, and its nucleus would be the size of a marble.



Atoms

You, and all the things around you, are made of tiny particles called atoms—particles so minuscule that even a small grain of sand is made up of trillions of them.

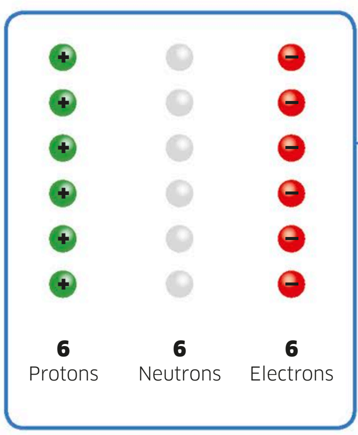
Atoms were once thought to be the smallest possible parts of matter, impossible to split into anything smaller. But they are actually made of even smaller particles called protons, neutrons, and electrons. Atoms join, or bond, in many different ways to make every different kind of material. A pure substance, consisting of only one type of atom, is called an element. Some familiar elements include gold, iron, carbon, neon, and oxygen. To find out more about the elements, see pp.28–41.

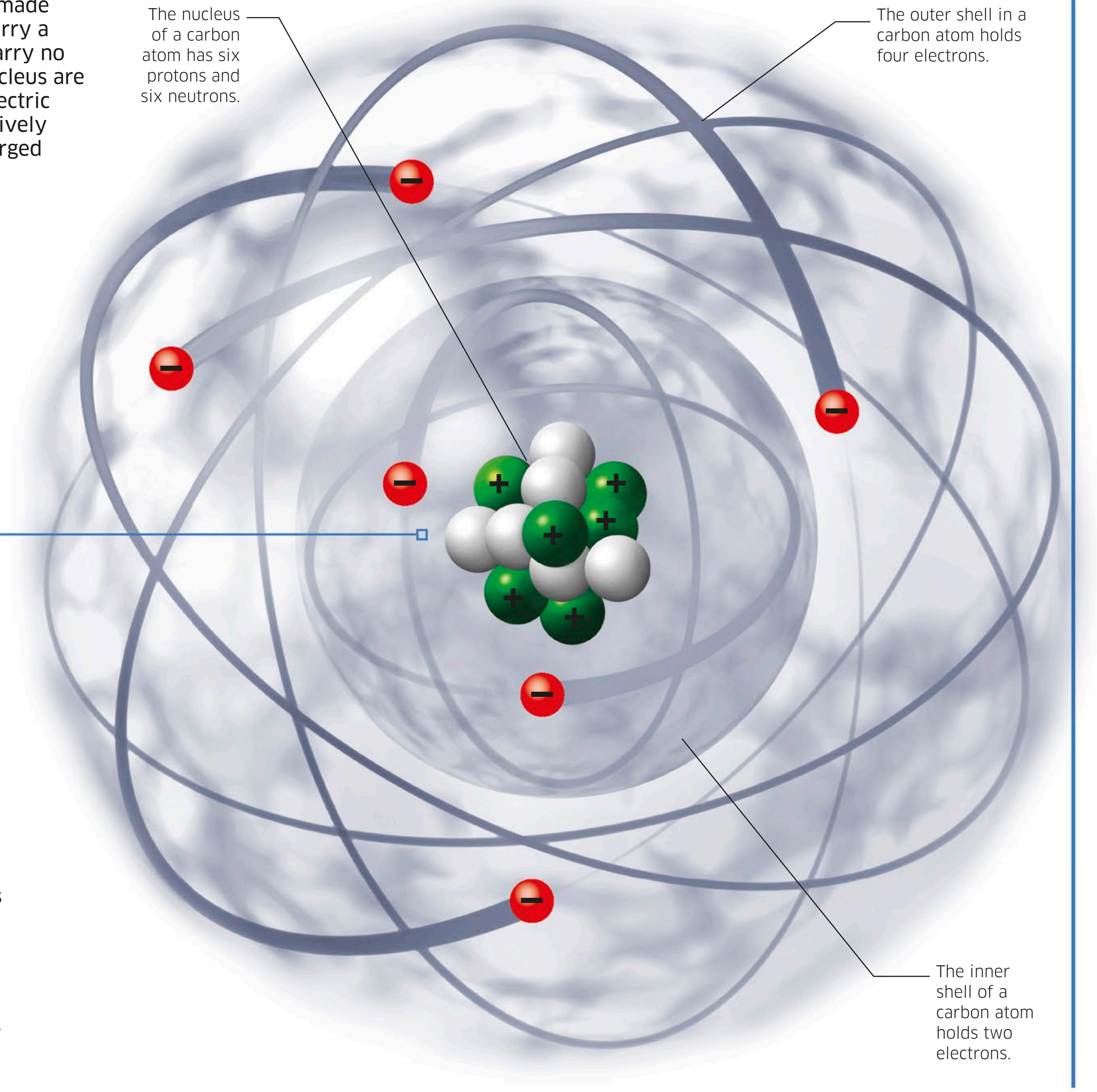
Atomic structure

The nucleus at the center of an atom is made of protons and neutrons. The protons carry a positive electric charge. The neutrons carry no charge—they are neutral. Around the nucleus are the electrons, which carry a negative electric charge. It is the force between the positively charged protons and the negatively charged electrons that holds an atom together.

Particles of an atom

Every atom of an element has the same number of electrons as it has protons, but the number of neutrons can be different. Below are the particles of one atom of the element carbon.





Carbon atom

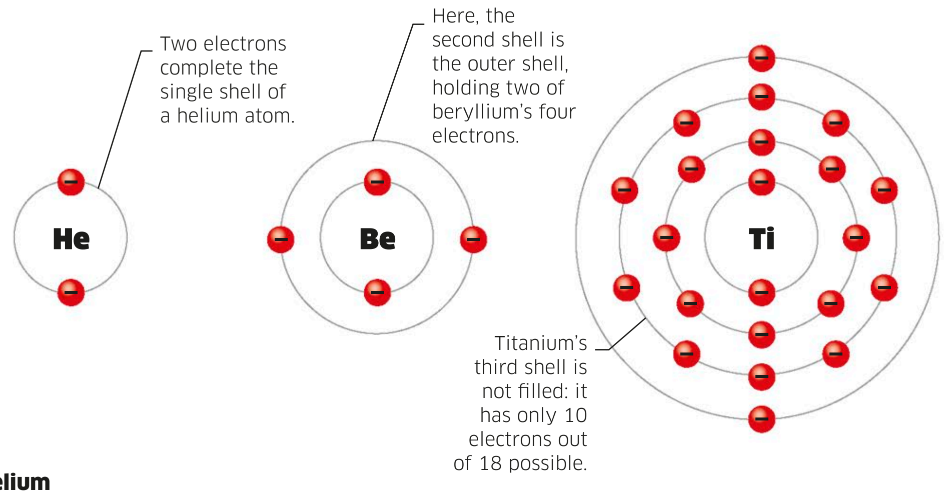
The number of protons in an atom’s nucleus is called the atomic number. This defines what an element is like: each element has a different atomic number, as shown in the periodic table (see pp.28–29). For the element carbon, shown here, the atomic number is 6. An atom’s number of electrons is also equal to its atomic number.

Atoms of the **element helium** are **the smallest** of all **atoms**.

1803 The year **schoolteacher John Dalton** presented his **theory** about **what atoms are** and what they do.

Electrons and electron shells

An atom's electrons are arranged around the nucleus in shells. Each shell can hold a certain number of electrons before it is full: the inner shell can hold 2, the next shell 8, the third one 18, and so on. The heaviest atoms, with large numbers of electrons, have seven shells. Atoms that don't have full outer shells are unstable. They seek to share, or exchange, electrons with other atoms to form chemical compounds. This process is known as a chemical reaction. Atoms with a filled outer shell are stable, and therefore very unreactive.



Helium
The gas helium has the atomic number 2. All its atoms have two electrons, which is the maximum number the first shell can hold. With a full outer shell, helium atoms are very unreactive.

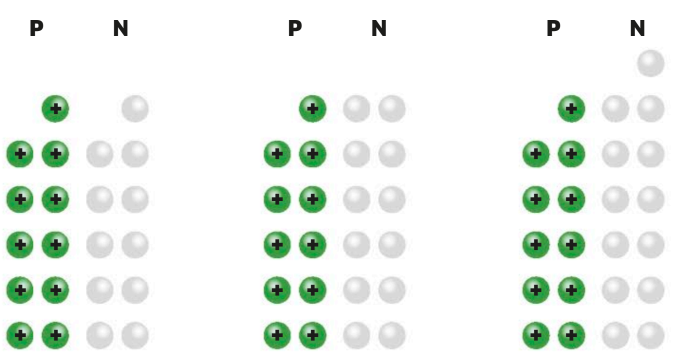
Beryllium
The second shell of an atom can hold up to eight electrons. The metal beryllium (atomic number 4) has a filled inner shell, but only two electrons in its outer shell, making it quite reactive.

Titanium
The metal titanium (atomic number 22) has four shells. It has two electrons in its outer shell, even though the third shell is not full. It is quite common for metals to have unfilled inner shells.

Atomic mass and isotopes

The mass of an atom is worked out by counting the particles of which it is made. Protons and neutrons are more than 1,800 times heavier than electrons, so scientists only take into account those heavier particles, and not the electrons. All atoms of a particular element have the same number of protons, but there are different versions of the atoms, called isotopes, that have different numbers of neutrons. The relative atomic mass of an element is the average of the different masses of all its atoms.

Isotopes of sodium
All atoms of the element sodium (atomic number 11) have 11 protons, and nearly all have 12 neutrons. So the relative atomic mass is very close to 23, but not exactly.



Sodium-22
The sodium isotope with 11 neutrons in its atoms has a mass of 22.

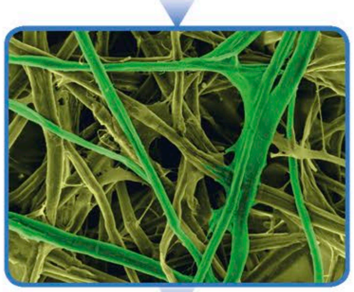
Sodium-23
Sodium-23, the most common sodium isotope, has 11 protons and 12 neutrons.

Sodium-24
This sodium isotope has a mass of 24: 11 protons and 13 neutrons.

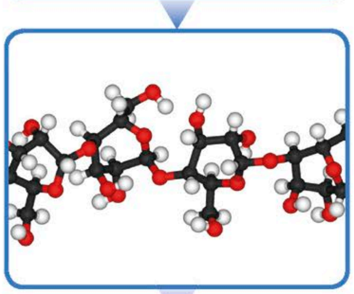
Atoms and matter

It is difficult to imagine how atoms make the world around you. Everyday objects don't look as if they consist of tiny round bits joined together: they look continuous. It can help to zoom in closer and closer to an everyday material, such as paper, to get the idea.

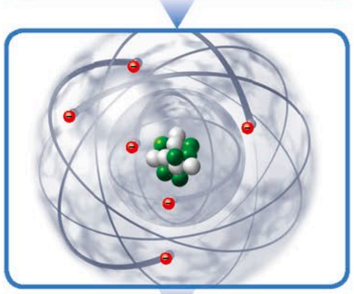
Paper
Paper is made almost entirely of a material called cellulose, which is produced inside plant cells, usually from trees. Cellulose is hard-wearing and can absorb inks and paints.



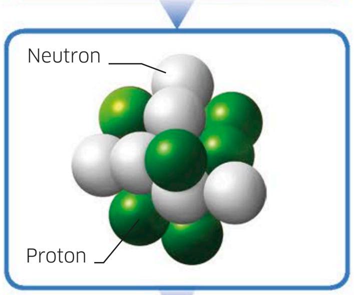
Cellulose fiber
Cellulose forms tiny fibers, each about one thousandth of a millimeter in diameter. The fibers join together, making paper strong and flexible.



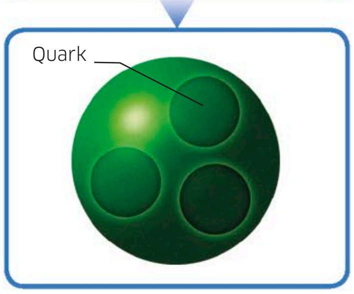
Cellulose molecule
Each cellulose fiber is made of thousands of molecules. A cellulose molecule is a few millionths of a millimeter wide. It is made of atoms of different elements: carbon (black), oxygen (red), and hydrogen (white).



Carbon atom
A typical cellulose molecule contains a few thousand carbon atoms. Each carbon atom has six electrons that form bonds with atoms of the other two elements.



Nucleus
Most of the carbon atom is empty space. Right at the center, about one trillionth of a millimeter across, is the nucleus, made of six protons and six neutrons.

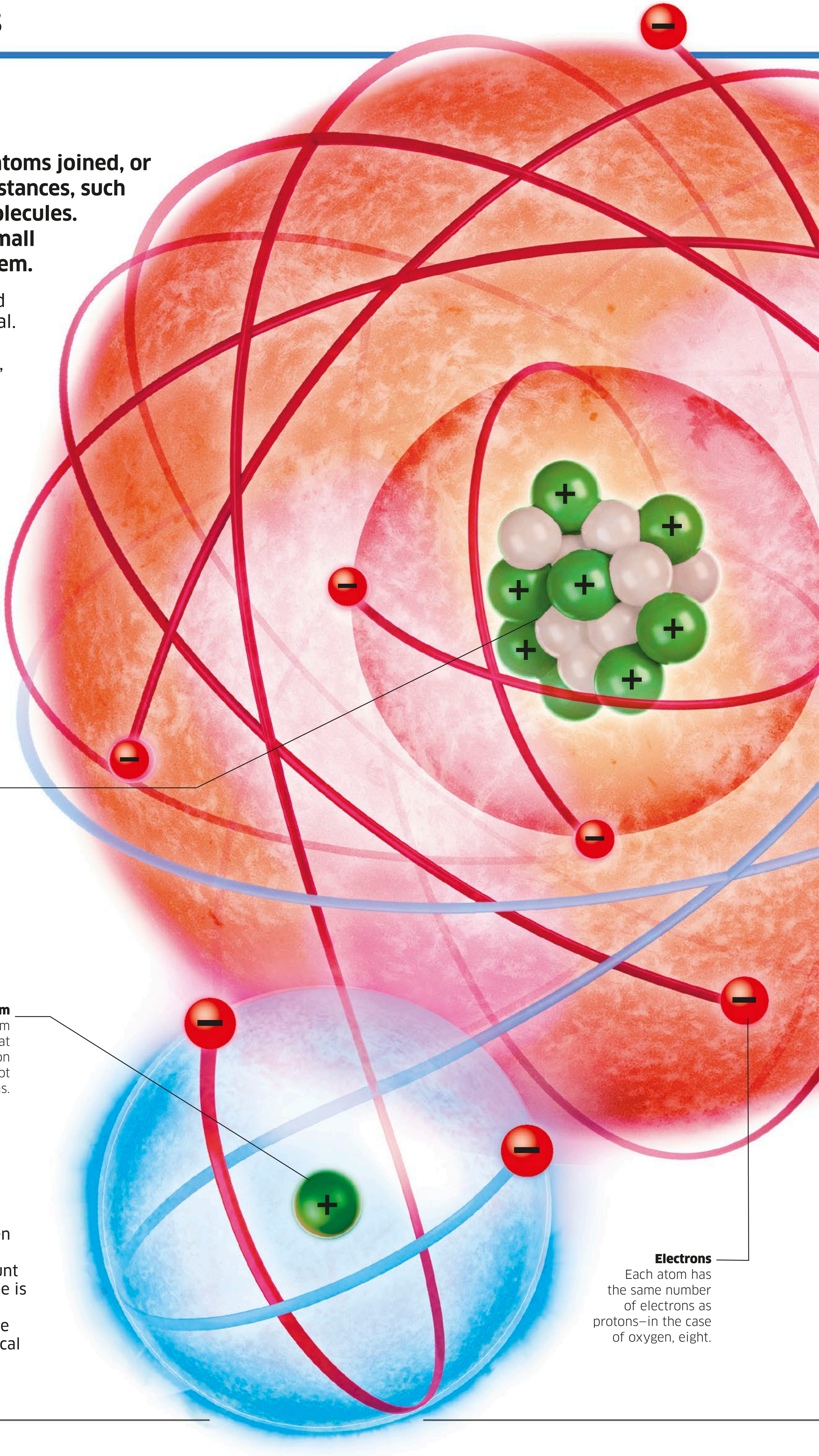


Quarks
Each particle in the nucleus is made of even smaller particles, called quarks. Each proton—and each neutron—is made of three quarks, held together by particles called gluons.

Molecules

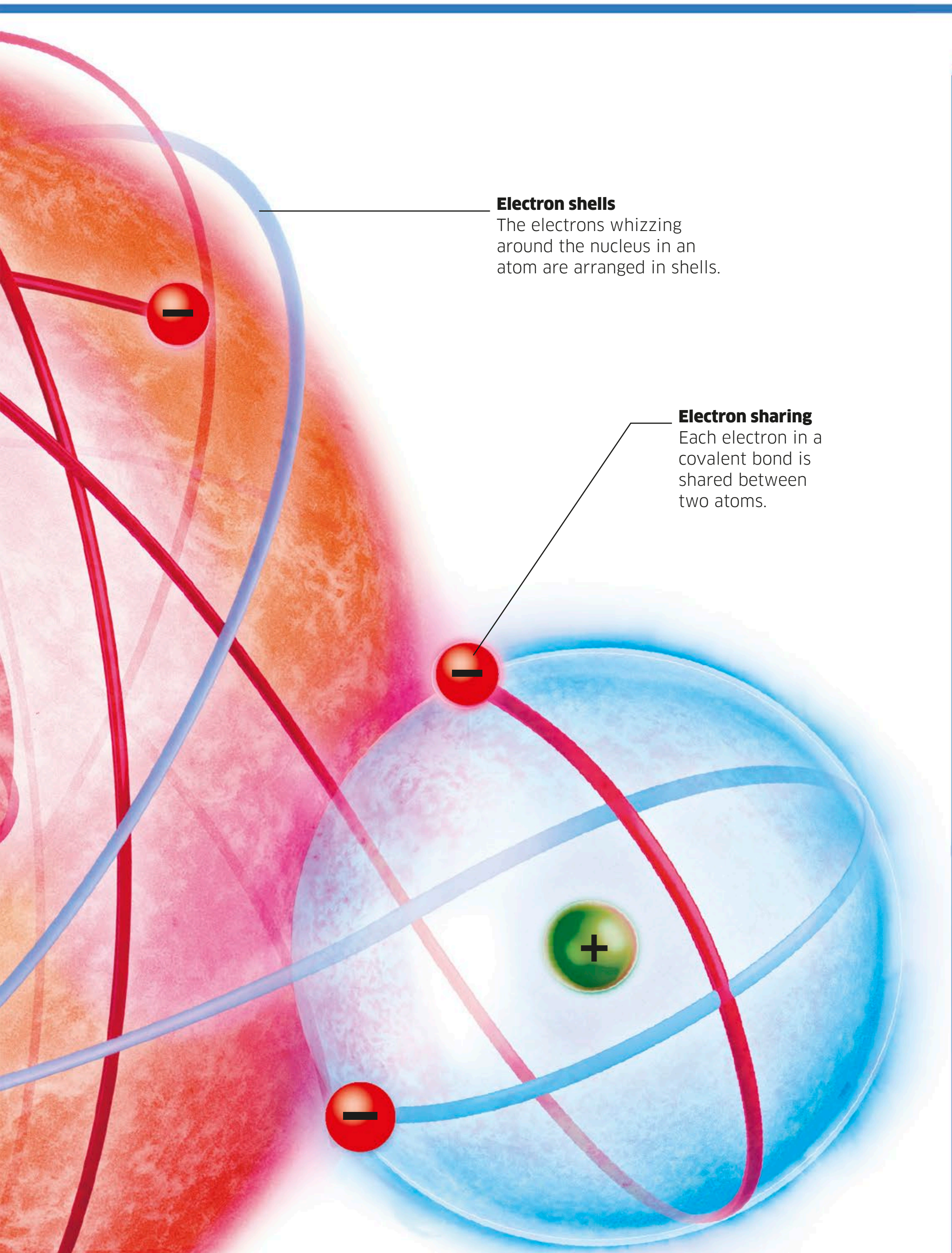
A molecule consists of two or more atoms joined, or bonded, together. Many familiar substances, such as sugar or water, are made up of molecules. Molecules are so small that even a small drop of water contains trillions of them.

All the molecules of a particular compound (chemically bonded substance) are identical. Each one has the same number of atoms, from at least two elements (see pp.28–29), combined in the same way. The bonds that hold molecules together form during chemical reactions but they can be broken as atoms react with other atoms and rearrange to form new molecules. It is not only compounds that can exist as molecules. Many elements exist as molecules, too, but all the atoms that make up these molecules are identical, such as the pair of oxygen atoms that make up pure oxygen (O_2).



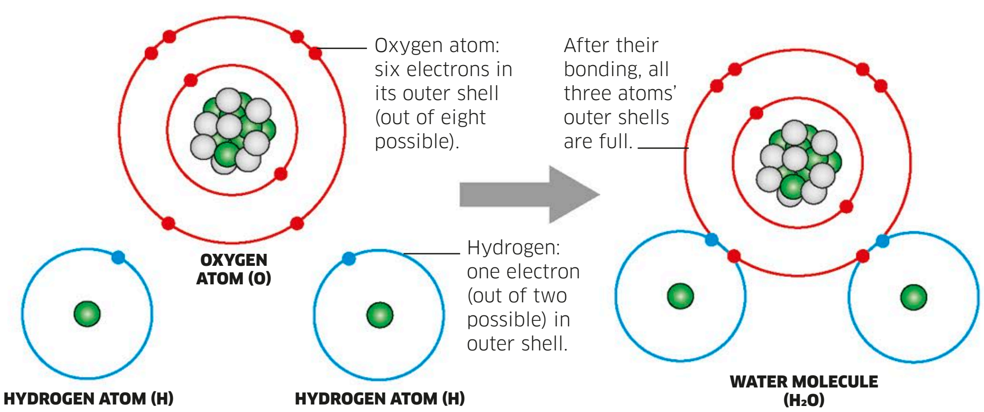
Water molecule

Imagine dividing a drop of water in half, and then in half again. If you could keep doing this, you would eventually end up with the smallest amount of water: a water molecule. Every water molecule is made up of one oxygen atom and two hydrogen atoms. The atoms are held together as a molecule because they share electrons, in a type of chemical bond called a covalent bond (see also p.16).



What keeps a molecule together?

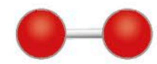
Atoms in a molecule are held together by covalent bonds. These form when atoms share electrons. In every atom, the electrons are grouped around the nucleus in shells. Each shell has a certain number of atoms it can hold before it is full. Atoms are most stable when their outer shell is full, and sharing electrons is one way to achieve this.



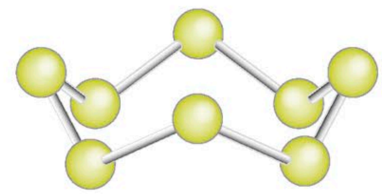
Elements and compounds

Most elements are made up of single atoms, but some are made of molecules of two or more identical atoms. When two elements react, their molecules form a new compound.

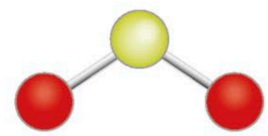
Oxygen
The gas oxygen (O_2) is made of molecules, each containing two oxygen atoms.



Sulfur
Pure sulfur (S), a solid, normally exists as molecules of eight sulfur atoms bonded together.

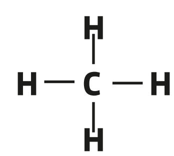


Sulfur dioxide (SO_2)
When sulfur and oxygen molecules react, their bonds break to make new bonds and a new substance forms.

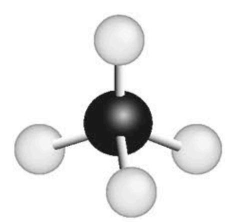


Representing molecules

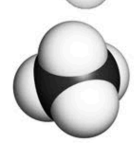
Scientists have different ways of representing molecules to understand how chemical reactions happen. Here, a molecule of the gas compound methane (CH_4), made of one carbon atom and four hydrogen atoms, is shown in three ways.



Lewis structure
The simplest way to represent a molecule is to use the chemical symbols (letters) and lines for covalent bonds.



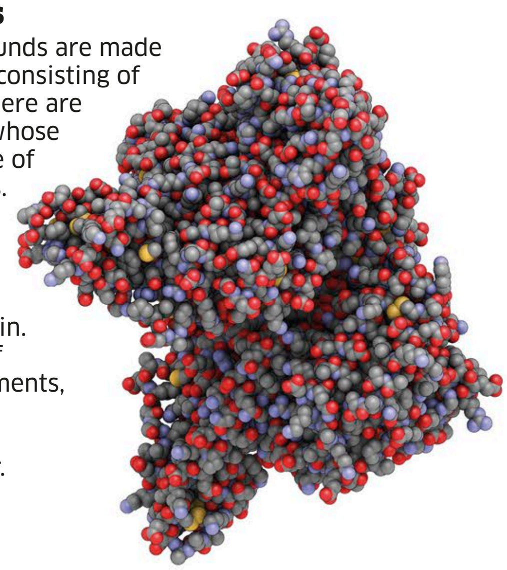
Ball and stick
Showing the atoms as balls and the bonds as sticks gives a three-dimensional representation of a molecule.



Space filling
This method is used when the space and shape of merged atoms in a molecule are more important to show than bonds.

Macromolecules

While some compounds are made of small molecules consisting of just a few atoms, there are many compounds whose molecules are made of thousands of atoms. This molecular model shows a single molecule of a protein found in blood, called albumin. It contains atoms of many different elements, including oxygen, carbon, hydrogen, nitrogen, and sulfur.



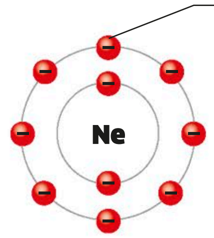
Bonding

Matter is made of atoms. Most of them are joined, or bonded, together. The bonds that hold atoms together are formed by the outermost parts of each atom: the electrons in the atom's outer shell.

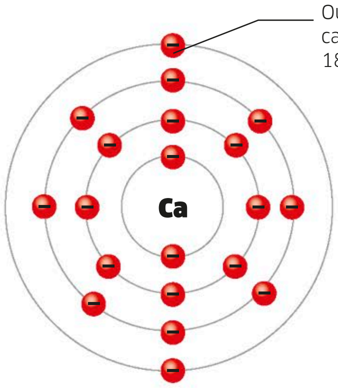
There are three main types of bonding: ionic, covalent, and metallic. An ionic bond forms when electrons from one atom transfer to another, so that the atoms become electrically charged and stick together. A covalent bond forms when electrons are shared between two or more atoms. In a metal, the electrons are shared freely between many metal atoms. All chemical reactions involve bonds breaking and forming.

To bond or not to bond

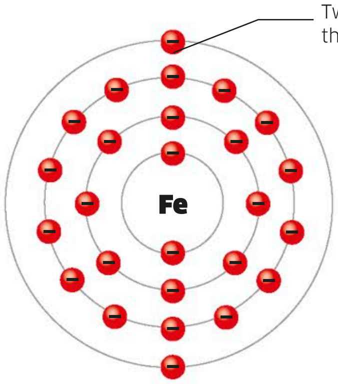
The number of electrons an atom has depends upon how many protons are in its nucleus. This number is different for each element (see p.28). The electrons are arranged in "shells," and it is the electrons in the outermost shell that take part in bonding. An atom is stable when the outermost shell is full (see p.13). The atoms of some elements have outermost shells that are already full—they do not form bonds easily. But most atoms can easily lose or gain electrons, or share them with other atoms, to attain a full outer shell. These atoms do form bonds and take part in chemical reactions.



Neon atom
All atoms of the element neon have two shells. The outermost shell is full, with eight electrons, so neon does not form bonds.



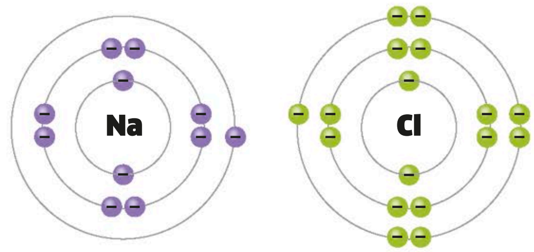
Calcium atom
The outer shell of a calcium atom is nowhere near full; calcium can easily lose its two outermost electrons, and readily forms bonds.



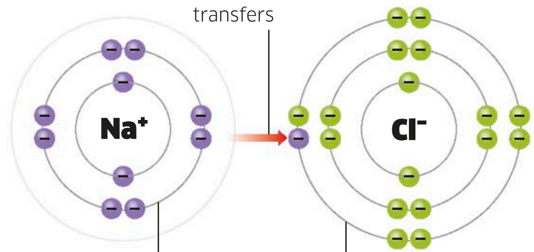
Iron atom
Iron can lose its two outermost electrons, but the next shell down is also unfilled. This means that iron (and most other transition metals) can form all three types of bond—ionic, covalent, and metallic.

Ionic bonding

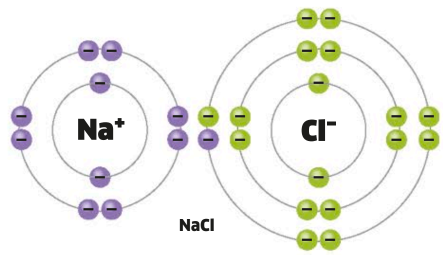
Many solids are made of ions: atoms, or groups of atoms, that carry an electric charge because they have either more or fewer negative electrons than positive protons. Ions form when atoms (or groups of atoms) lose or gain electrons in order to attain full outer electron shells. Electrical attraction between positive ions (+) and negative ions (-) causes the ions to stick together, forming a crystal.



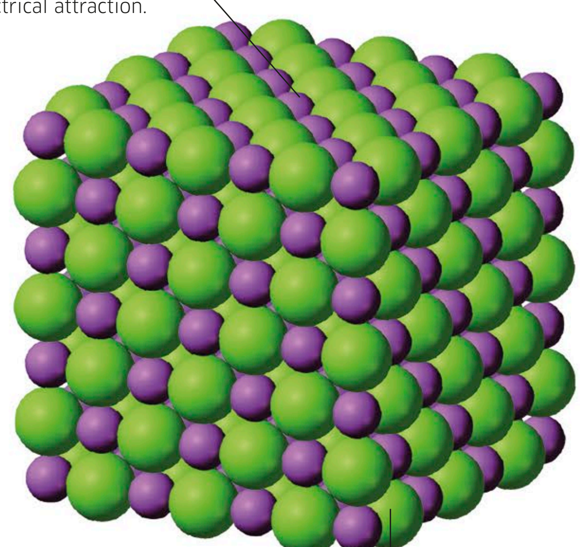
Two atoms
Neither sodium (Na) nor chlorine (Cl) atoms have filled outer shells. Sodium will easily give up its outermost electron.



Electron transfer
Chlorine readily accepts the electron, so now both atoms have filled outer shells. They have become electrically charged and are now ions.



Electrical attraction
The positive sodium ion and the negative chlorine ion are attracted to each other. They have become a compound called sodium chloride (NaCl).

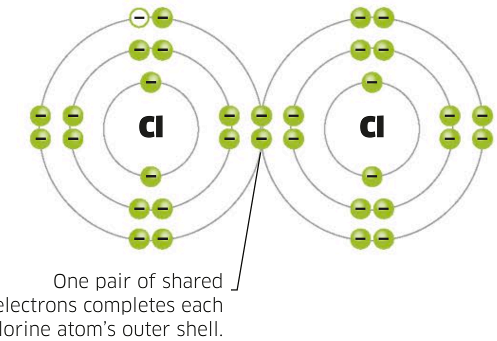


Ionic crystal
Ions of opposite electric charge are attracted to each other, and they form a regular pattern called a crystal. Many solids are ionic crystals, such as salt.

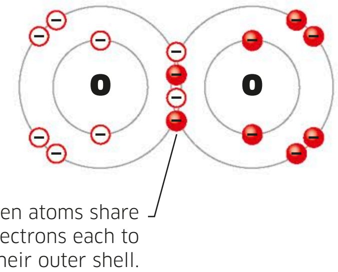
Salt crystal
The ions arrange in a regular pattern, forming a crystal of the compound sodium chloride (NaCl), or table salt.

Covalent bonding

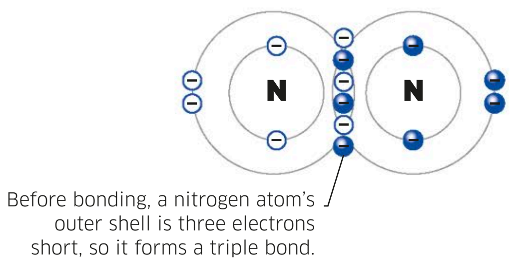
Another way atoms can attain full outer electron shells is by sharing electrons in a covalent bond. A molecule is a group of atoms held together by covalent bonds (see pp.14–15). Some elements exist as molecules formed by pairs of atoms, for example chlorine, oxygen, and nitrogen. Covalent bonds can be single, double, or triple bonds.



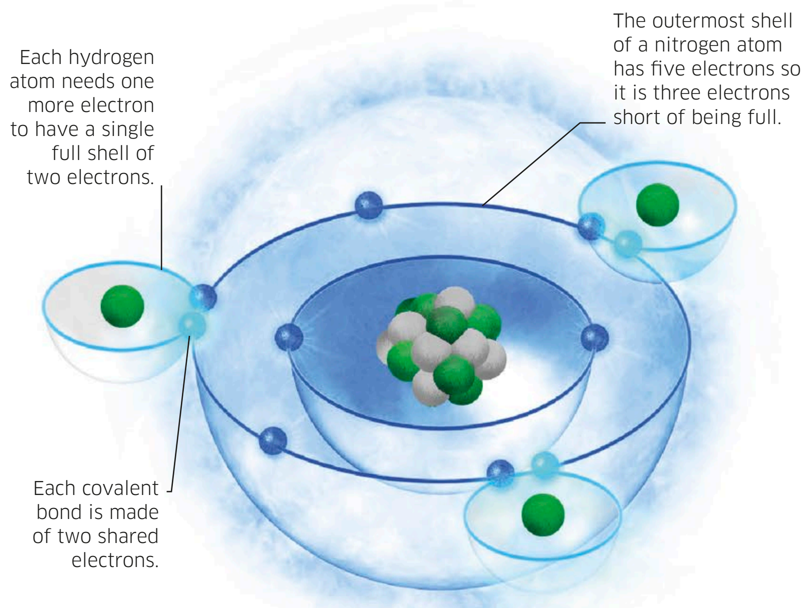
Single bond
Some pairs of atoms share only one electron each, forming a single bond.



Double bond
Sometimes, pairs of atoms share two electrons each, forming a double bond.



Triple bond
In some pairs of atoms, three electrons are shared, forming a triple bond.

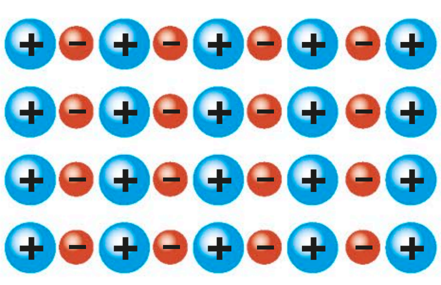


AMMONIA MOLECULE (NH_3)

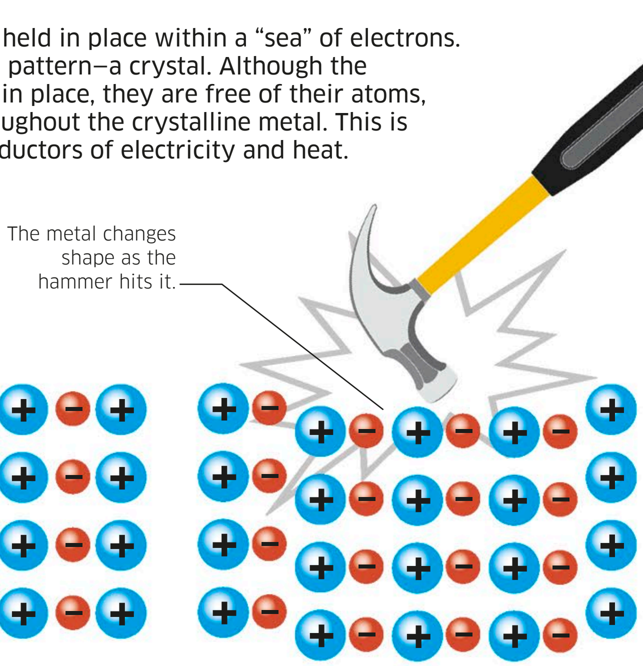
Ammonia molecule
A molecule of the compound ammonia (NH_3) is made of atoms of nitrogen (N) and hydrogen (H). The shell closest to the nucleus of an atom can hold only two electrons. Hydrogen and helium are the only elements with just one shell.

Metallic bonding

In a metal, the atoms are held in place within a "sea" of electrons. The atoms form a regular pattern—a crystal. Although the electrons hold the atoms in place, they are free of their atoms, and can move freely throughout the crystalline metal. This is why metals are good conductors of electricity and heat.

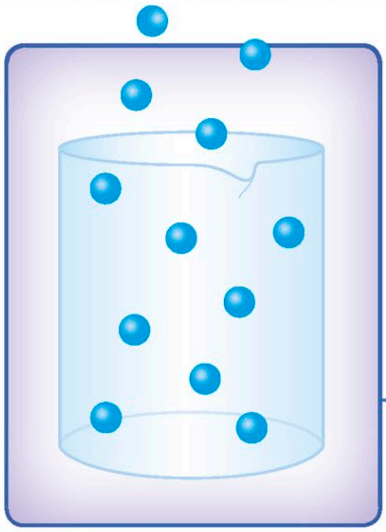


Conducting heat and electricity
An electric current is a flow of electric charge. In a metal, negatively charged electrons can move freely, so electric current can flow through them. The mobile electrons are also good at transferring heat within a metal.



Malleable metals
Metal atoms are held in place by metallic bonding, but are able to move a little within the "sea" of electrons. This is why metals are malleable (change shape when beaten with a hammer) and ductile (can be drawn into a wire).

Getting into shape
With some heat and a hammer, metals can be shaped into anything from delicate jewelry to sturdier objects, such as this horseshoe. Horseshoes used to be made of iron, but these days metal alloys such as steel (see p.63) are more common.



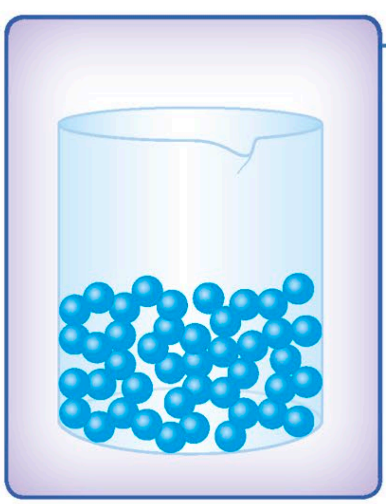
Gas state
The particles of a gas, such as oxygen, or the water vapor in the polar bear's breath, are not tightly held together by bonds. Without these forces keeping them together, they move freely in any direction.

Air
Air is a mixture of gases: mostly nitrogen (78 percent), oxygen (21 percent), and small proportions of argon and carbon dioxide.

Solids, liquids, and gases

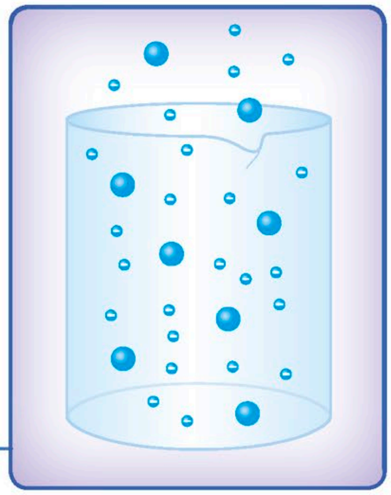
There are four different states of matter: solid, liquid, gas, and plasma. Everything in the universe is in one of those states. States can change depending on temperature and pressure.

All pure substances can exist in all of the three states common on Earth—solid, liquid, and gas. What state a substance is in is determined by how tightly its particles (atoms or molecules) are bound together. When energy (heat) is added, the tightly packed particles in a solid increase their vibration. With enough heat, they start moving around and the solid becomes a liquid. At boiling point, molecules start moving all over the place and the liquid becomes gas. Plasma is a type of gas so hot that its atoms split apart.



Liquid state
The particles of a liquid, such as water, are less tightly packed than in a solid and not neatly arranged, and they have weaker bonds. That is why liquids flow and spread, taking the shape of any container.

Salt water
Salty seawater has a lower freezing point than freshwater, which freezes at 32°F (0°C). Because salt disrupts the bonds between water molecules, seawater stays liquid until about 28°F (-2°C).

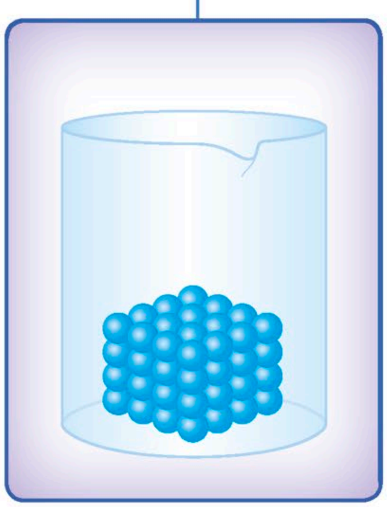


Plasma
Plasma, which makes up the sun and stars, is the most common matter in the universe. Intense heat makes its atoms separate into positively charged nuclei and negatively charged electrons that whiz about at very high speed.

Aurora borealis
Collisions between plasma from space and gases in the atmosphere energize atmospheric atoms, which release light when they return to normal energy levels.

States of matter

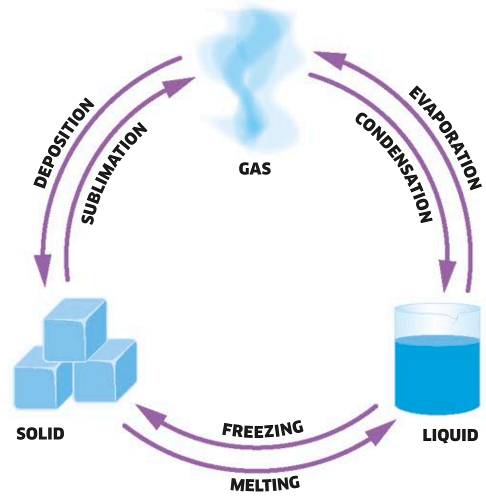
Water exists in three states. Here we see it as solid ice, liquid seawater, and gaseous water vapor exhaled by the polar bear. Water vapor is invisible until it cools and condenses to form steam, a mist of liquid droplets—the same happens when a pan of water boils. In the Arctic Circle, the spectacular northern lights (aurora borealis) reveal the presence of plasma, the fourth state of matter.



Solid state
In a solid, such as ice, particles are held together by bonds and sit tightly packed. The particles vibrate slightly but they don't move around, so solids keep their shape.

Changing states of matter

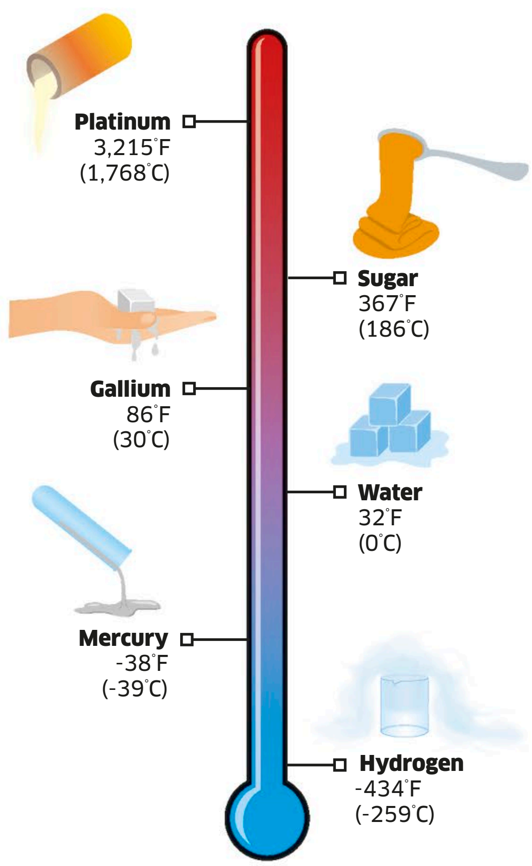
Adding or removing energy (as heat) causes a state change. Solids melt into liquids, and liquids vaporize into gas. Some solids can turn straight to gas; some gases into solids.



Sublimation
Solid carbon dioxide is known as dry ice. With lowered pressure and increased heat it becomes CO_2 gas—this is called sublimation. When a gas goes straight to solid, the term is deposition.

Melting and freezing

All pure substances have a specific melting and freezing point. How high or low depends on how their molecules are arranged.

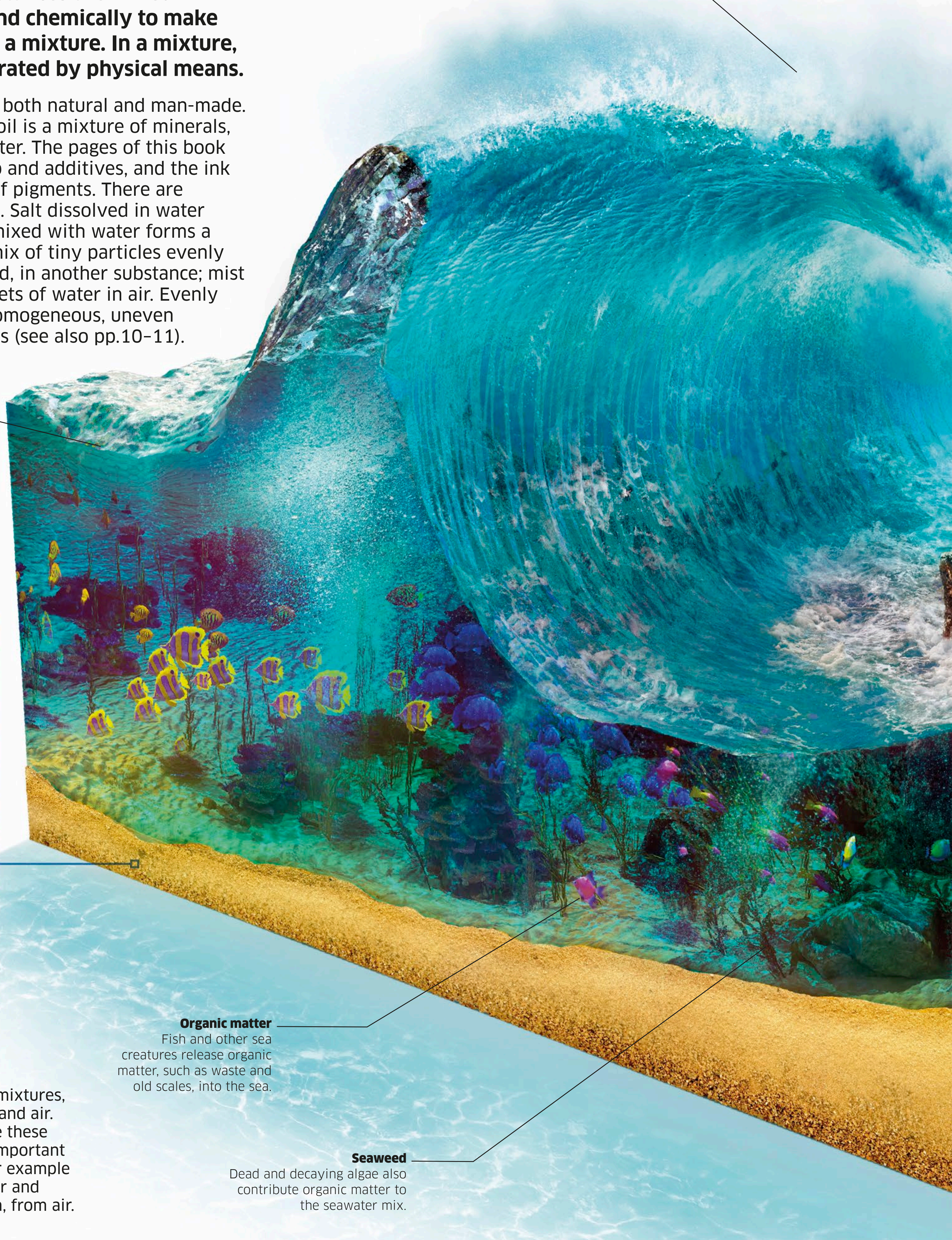


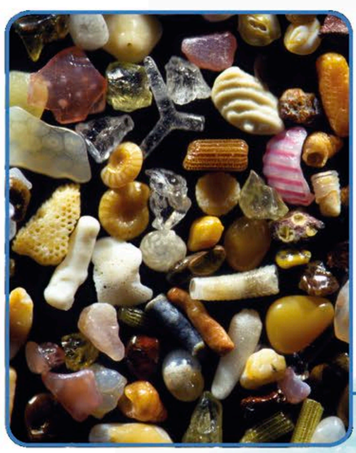
Ice cream is a **colloid mixture** of fats, air, ice crystals, and other substances.

Mixtures

When two or more substances are mixed together, but do not bond chemically to make a compound, they form a mixture. In a mixture, substances can be separated by physical means.

Mixtures are all around us, both natural and man-made. Air is a mixture of gases. Soil is a mixture of minerals, biological material, and water. The pages of this book are a mixture of wood pulp and additives, and the ink on the pages is a mixture of pigments. There are different types of mixtures. Salt dissolved in water is a solution. Grainy sand mixed with water forms a suspension. A colloid is a mix of tiny particles evenly dispersed, but not dissolved, in another substance; mist is a colloid of minute droplets of water in air. Evenly distributed mixtures are homogeneous, uneven mixtures are heterogeneous (see also pp.10–11).





Sand
Sand is a heterogeneous mixture: a close look reveals tiny pieces of eroded rock, crushed shells, glass, and even bits of plastic.

Mixtures in nature

Most substances in nature are mixtures, including seawater, rocks, soil, and air. Understanding how to separate these mixtures provides us with an important supply of natural resources, for example by removing salt from seawater and separating gases, such as argon, from air.

Sea foam
Sea foam forms at the water's edge when wind and waves whip up air and water to frothy bubbles which mix with biological material excreted from algae and other sea life.

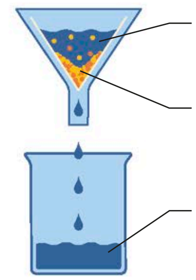
Rock
Lots of different minerals can make up the solid mixture that forms rocks. Most of the minerals that are present in seawater come from eroded rock.

Seawater
The oceans are full of materials dissolved as well as dispersed (scattered) in water: salts, gases, metals, organic compounds, and microscopic organisms. This type of uneven mixture is called a suspension.

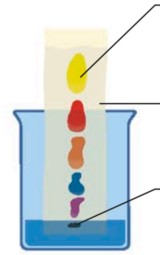
Separating mixtures

There are many ways to separate mixtures, whether it is to extract a substance or analyze a mixture's contents. Different techniques work for different substances depending on their physical properties.

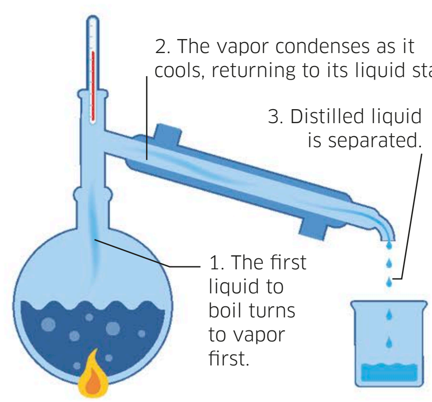
Filtration
Filtration separates insoluble solids from liquids, which pass through the filter.



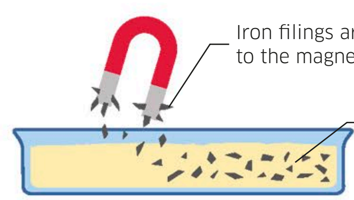
Chromatography
How fast substances in a liquid mixture, such as ink, separate depends on how well they dissolve—the better they dissolve, the further up the soaked paper they travel with the solvent.



Distillation
This method separates liquids according to their boiling point. The mixture is heated, and the substance that boils first evaporates and can be collected as it condenses.



Magnetism
Passing a magnet over a mixture of magnetic and nonmagnetic particles removes the magnetic ones.



Some granite, the **igneous rock** that makes up most of **Earth's land crust**, is more than **4 billion years old**.

Rocks and minerals

The chemistry of Earth is dominated by the huge variety of rocks and minerals that shape the landscape around us.

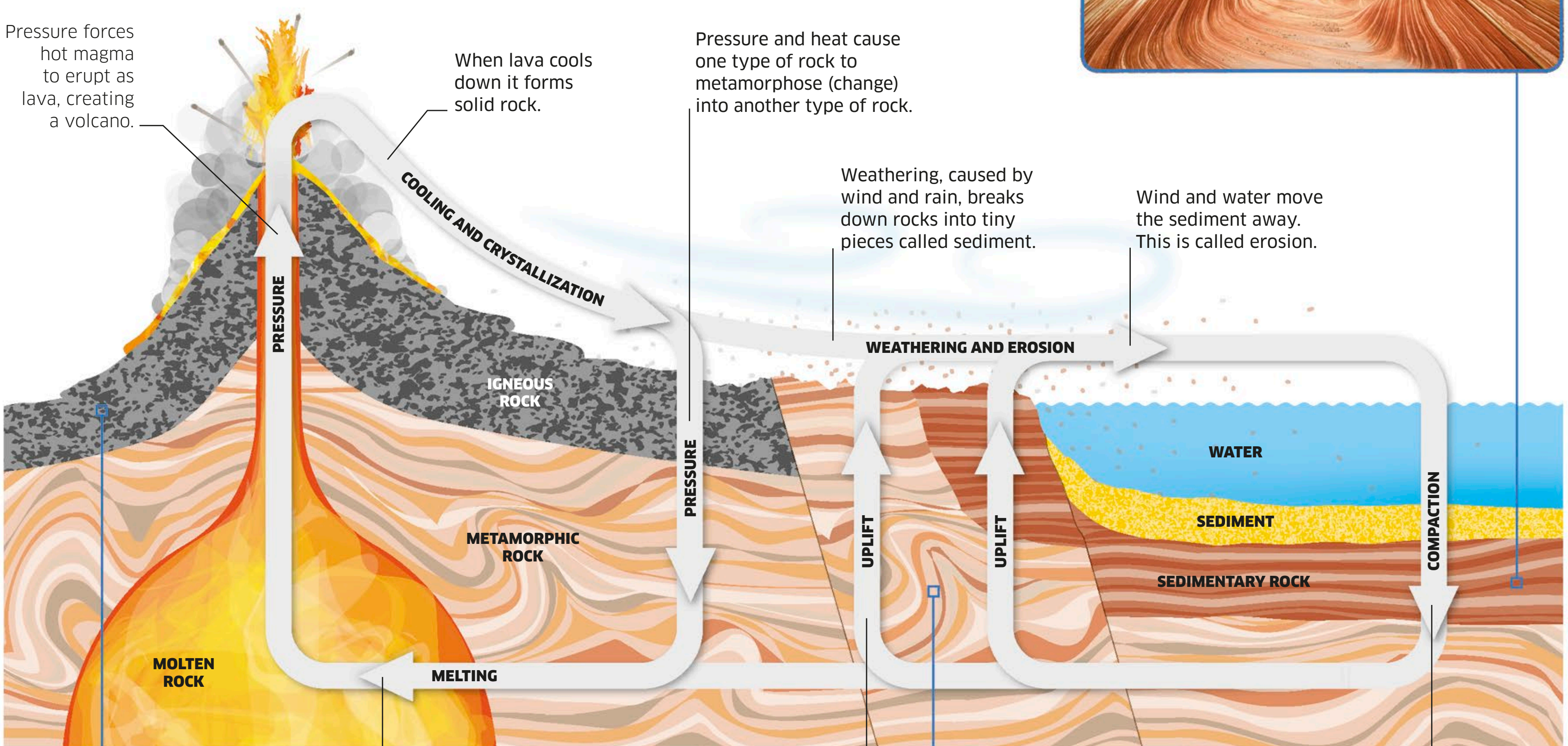
There are thousands of different kinds of rocks and minerals. What they are like depends on the chemical elements they contain, and the way these elements are grouped together. A rock is a mixture of different minerals, arranged as billions of tiny grains. Each mineral is usually a compound of two or more elements chemically bonded together. Many of these form beautiful crystals. Sometimes, a mineral is an element in its raw form—such as copper or gold.

Most of the ocean floor is made of **igneous basalt rock**, much younger than most rocks on land.

Sedimentary rock
Fragments of rock broken away by weathering and erosion join together to form sedimentary rocks, such as sandstone (below) and limestone. The fragments gather in layers at the bottom of lakes and oceans, and get compacted and cemented together under their own weight. Eventually, uplift pushes this rock up to the surface.

The rock cycle

Solid rocks look like they must stay the same forever, but in fact they change over thousands or millions of years. Some melt under the influence of Earth's internal heat and pressure. Others get eroded by wind and rain. The three main forms of rock are linked in a cycle that changes one form into another. The cycle is driven slowly, but inevitably, by a set of dramatic movements deep within the Earth.

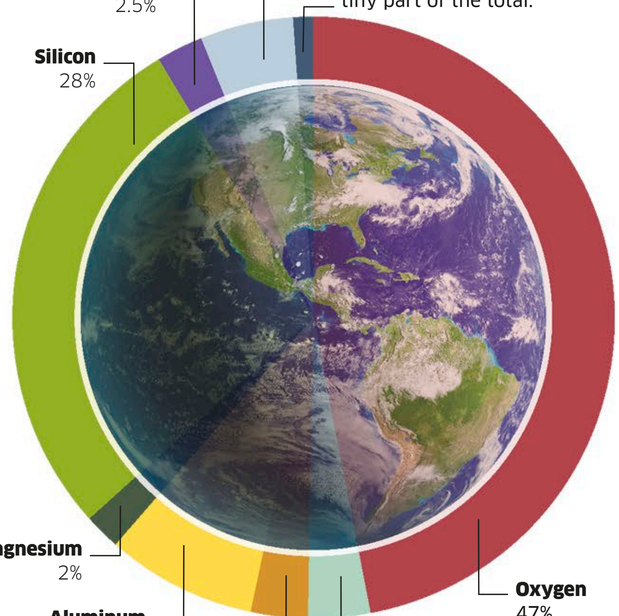


Igneous rock
The interior of the Earth is so hot it melts solid rock, forming a liquid called magma. When magma cools down it solidifies and crystallizes to form igneous rock, such as granite (formed underground) and basalt (seen left) from lava erupted from volcanoes.

Metamorphic rock
Rocks that get buried deep underground are squeezed and heated under pressure. But instead of melting the rock, this rearranges its crystals to form metamorphic rock. For example, buried limestone changes into marble, as in this cave.

Elements of Earth's crust

Planet Earth is mostly made up of the elements iron, oxygen, silicon, and magnesium, with most of the iron concentrated in Earth's core. But Earth's outer layer, the crust, is made from minerals of many different elements, such as silicates (containing silicon and oxygen). This diagram shows which elements are most common in the crust.



Native elements

In Earth's crust, most elements exist combined with others in mineral compounds. But some, called native elements, appear in pure form. About 20 elements can be found in pure form, including metals, such as copper and gold, and non-metals, such as sulfur and carbon.

Sulfur
Powder and crystals of pure sulfur from volcanic gases accumulate around volcanic vents. In the rock cycle, it gets mixed into rocks. It also forms part of many mineral compounds.

Mineral compounds

There are more than 4,000 different kinds of minerals. Scientists classify them according to which elements they contain, and sort them into a few main groups. The group name tells which is the main element in all minerals in that group. All sulfide minerals, for example, contain sulfur. Many minerals exist in ores—rocks from which metals can be extracted—or as pretty gem crystals (see p.24).

Hematite
This oxide contains lots of iron, making it an important iron ore.

Oxides
Different metals combine with oxygen to form these hard minerals. They are in many ores, making these valuable sources of metal. Many make fine gems.

Rose quartz
This is a pink form of quartz, one of the silicates made up of only silicon and oxygen.

Silicates
All silicates, the most common group, contain silicon and oxygen. Some include other elements, too. The rock granite is made of three silicates, including quartz.

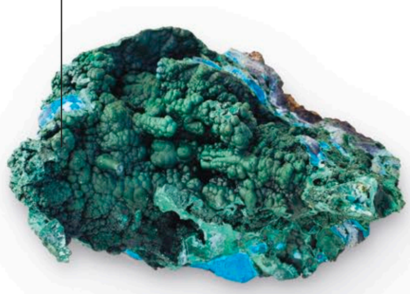
Baryte
The element barium combined with sulphur and oxygen makes baryte, which comes in many different forms.

Sulfates
A sulfur and oxygen compound combines with other elements to form sulfates. Most common are gypsum, which forms cave crystals (see pp.26–27), and baryte.

Chalcopyrite
Both copper and iron can be sourced from ores containing this sulfide.

Sulfides
Metals combined with sulfur, but no oxygen, form sulfides. Sulfides make up many metal ores. Many are colorful, but are usually too soft to use as gemstones.

Malachite
Copper combines with carbon and oxygen to give this useful and decorative mineral its green color.



Carbonates
Compounds of carbon and oxygen combine with other elements to form carbonates. Many are quite soft. Some exist in rocks such as chalk and limestone.

Fluorite
Calcium and fluorine make up this mineral, which comes in many different colors.

Halides
These minerals contain one or more metals combined with a halogen element (fluorine, chlorine, bromine, or iodine; see p.40). Rock salt is an edible halide.

Quartz crystals start to form at temperatures of about **1,700°F (3,090°C)**.

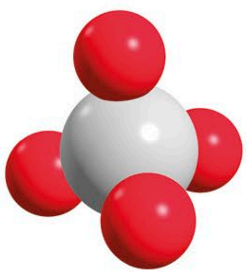
Crystals

A crystal is a solid material, made of atoms set in a repeating 3-D pattern. Crystals form from minerals when molten magma cools to become solid rock. Crystals of some substances, such as salt, sugar, and ice, are formed through evaporation or freezing.

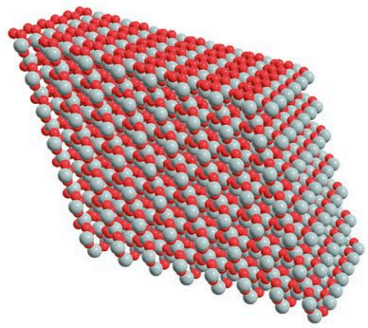
The shapes and colors of mineral crystals depend on the elements from which they are made and the conditions (the temperature and pressure) under which they formed. The speed at which the magma cools decides the size of the crystals. Crystals can change under extreme pressure in the rock cycle (see p.22), when one rock type changes into another.

Crystal structures

Crystals have highly ordered structures. This is because the atoms or molecules in a crystal are arranged in a 3-D pattern that repeats itself exactly over and over again. Most metals have a crystalline structure, too.



Quartz tetrahedron
The molecule that makes up quartz is in the shape of a tetrahedron, made of four oxygen atoms and one silicon atom.



Quartz crystal
A quartz crystal consists of a lattice of tetrahedrons, repeated in all directions.

One mineral, two gem crystals

Crystals of the mineral corundum come in many colors, thanks to different impurities in the crystal structure. Often cut and polished to be used as gems, the best known are sapphire (usually blue) and ruby (red).

BLUE CORUNDUM: SAPPHIRE

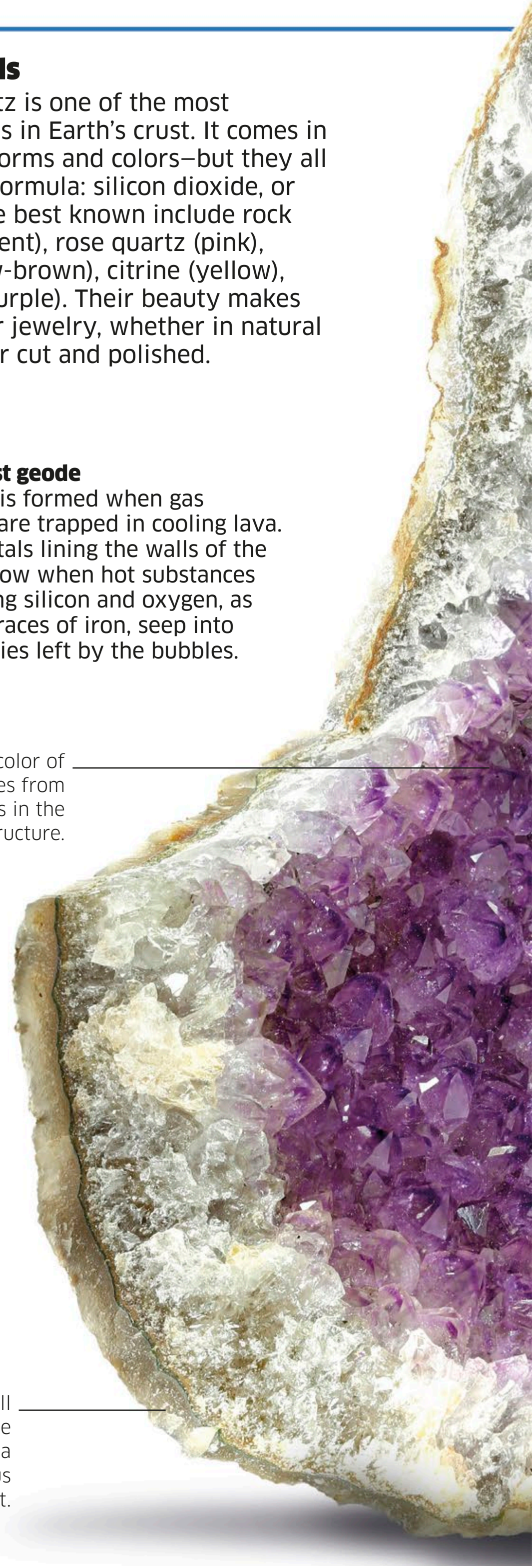
RED CORUNDUM: RUBY

CUT RUBY CRYSTAL SET IN A RING

Quartz crystals

The crystal quartz is one of the most common minerals in Earth's crust. It comes in many different forms and colors—but they all share the same formula: silicon dioxide, or SiO_2. Some of the best known include rock crystal (transparent), rose quartz (pink), tiger-eye (yellow-brown), citrine (yellow), and amethyst (purple). Their beauty makes them popular for jewelry, whether in natural form, tumbled, or cut and polished.

Amethyst geode
A geode is formed when gas bubbles are trapped in cooling lava. The crystals lining the walls of the geode grow when hot substances containing silicon and oxygen, as well as traces of iron, seep into the cavities left by the bubbles.



The purple color of amethyst comes from iron impurities in the crystal structure.

The outer shell of the geode is normally a volcanic, igneous rock such as basalt.

Crystal systems

The shape of a crystal is determined by how its atoms are arranged. This decides the number of flat sides, sharp edges, and corners of a crystal. Crystals are sorted into six main groups, known as systems, according to which 3-D pattern they fit.

Cubic
Gold, silver, diamond, the mineral pyrite (above), and sea salt all form cubic crystals.

Tetragonal
Zircon, a silicate mineral, is a typical tetragonal crystal, looking like a square prism.

Hexagonal and trigonal
Apatite is a hexagonal crystal, with six long sides. Trigonal crystals have three sides.

Monoclinic
Orthoclase (above) and gypsum crystals are monoclinic, one of the most common systems.

Prisms of rock crystal, a colorless type of quartz

The trigonal crystal system of quartz is visible here.

Orthorhombic
The mineral topaz forms beautiful orthorhombic crystals, often with a pyramid-like top.

Axinite, a silicate mineral (see p.23)

Triclinic
The least symmetrical of all, triclinic crystals include axinite (above) and turquoise.

Ice crystals

In an ice crystal, water molecules are aligned hexagonally. These crystals form when water vapor in the air freezes straight to a solid. If liquid water freezes slowly, it will form simple hexagonal crystals, but without the delicate branches and shapes of a snowflake crystal.

The unique pattern of a snowflake is based on a six-sided shape (hexagon).

Snowflake
A snowflake is a six-sided ice crystal. Each snowflake grows into a different variation on this shape, depending on how it drifts down from the sky. No two snowflakes are the same.

Sugar and salt crystals

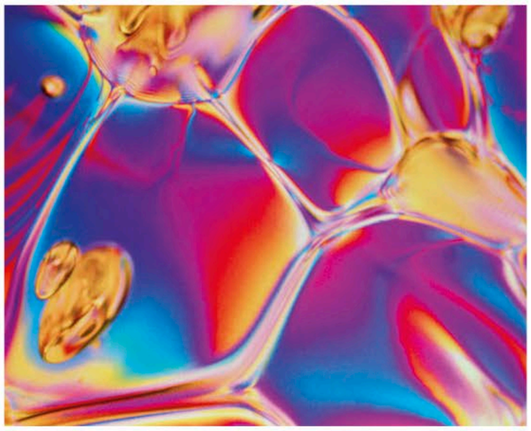
Crystals of sea salt and crystals of sugar are more different than they look. Salt crystals are highly ordered six-sided cubes, while sugar crystals are less well ordered hexagonal prisms.

Sea salt belongs to the cubic crystal system, but when the crystals form quickly they take a pyramid shape.

Sea salt crystals
Crystals of sea salt (sodium chloride) are held together by ionic bonds (see p.16). When salt water evaporates, the dissolved minerals left behind form salt crystals.

Liquid crystals

In nature, cell membranes and the solution produced by silkworms to spin their cocoons are liquid crystals. The molecules in liquid crystals are highly ordered, but they flow like a liquid.



Liquid crystals at work
Man-made liquid crystals, such as the ones seen here, are used in liquid crystal displays (LCDs) in TV screens, digital watches, and mobile phones. They do not produce light, but create clear images by altering the way light passes through them.

Crystal cave

In extremely hot and humid conditions, these scientists are investigating the largest crystals ever found, in the Giant Crystal Cave, Naica, Mexico.

The crystals are made of selenite, a form of the mineral gypsum (calcium sulfate), which is the main ingredient of plaster and blackboard chalk. The crystals form very slowly from calcium, sulfur, and oxygen dissolved in hot water. This water was heated by magma in a geological fault beneath the cave. The largest crystals weigh 55 tons and are 39 ft (12 m) long.

THE ELEMENTS

Shiny gold, tough iron, smelly chlorine, and invisible oxygen—what do they have in common? They are all elements: substances made of only one type of atom that cannot be broken down into a simpler substance. But they can combine with other elements to form new substances, known as compounds. Everything around us is made up of elements, either in pure form or combined. Water, for example, is made of the elements hydrogen and oxygen. There are 118 known elements, of which around 90 exist naturally. The rest have been created in laboratory experiments.

Atomic number
This is the number of protons in the atom's nucleus. The element iron has an atomic number of 26, which means it has 26 protons (and 26 electrons).

Name
In English, some element names look very different to their symbol. We say "iron" rather than "ferrum," its original Latin name.

26 55.845
Fe
IRON

Atomic mass number
An atom's mass is how many protons and neutrons it has. This number shows the relative atomic mass (the average mass of all an element's atoms, see p.13).

Chemical symbol
An element has the same symbol all over the world, while the name can be different in different languages.

The periodic table
In 1869, the Russian scientist Dmitri Mendeleev came up with a system for how to sort and classify all the elements. In his chart, the atomic number increases left to right, starting at the top left with hydrogen, with an atomic number of 1. Arranging elements in rows and columns reveals patterns. For example, elements from the same column, or group, react in similar ways and form a part of similar compounds.

Elemental information
An element's place in the table is decided by its atomic number. Each element has a "tile" showing its atomic number, its chemical symbol, and its atomic weight (weights in brackets are estimates for unstable elements). The symbol is an abbreviation of the element's original name. This name was often invented by the person who discovered the element.

Period	1	2	3	4	5	6
1	1 H HYDROGEN 1.0079					
2	3 Li LITHIUM 6.941	4 Be BERYLLIUM 9.0122				
3	11 Na SODIUM 22.990	12 Mg MAGNESIUM 24.305				
4	19 K POTASSIUM 39.098	20 Ca CALCIUM 40.078	21 Sc SCANDIUM 44.956	22 Ti TITANIUM 47.867	23 V VANADIUM 50.942	24 Cr CHROMIUM 51.996
5	37 Rb RUBIDIUM 85.468	38 Sr STRONTIUM 87.62	39 Y YTTRIUM 88.906	40 Zr ZIRCONIUM 91.224	41 Nb NIOBIUM 92.906	42 Mo MOLYBDENUM 95.94
6	55 Cs CAESIUM 132.91	56 Ba BARIUM 137.33	57-71 La-Lu LANTHANIDES	72 Hf HAFNIUM 178.49	73 Ta TANTALUM 180.95	74 W TUNGSTEN 183.84
7	87 Fr FRANCIUM (223)	88 Ra RADIUM (226)	89-103 Ac-Lr ACTINIDES	104 Rf RUTHERFORDIUM (261)	105 Db DUBNIUM (262)	106 Sg SEABORGIUM (266)

Period	7	8	9	10	11	12
4	25 Mn MANGANESE 54.938	26 Fe IRON 55.845	27 Co COBALT 58.933	28 Ni NICKEL 58.693	29 Cu COPPER 63.546	30 Zn ZINC 65.39
5	43 Tc TECHNETIUM (96)	44 Ru RUTHENIUM 101.07	45 Rh RHODIUM 102.91	46 Pd PALLADIUM 106.42	47 Ag SILVER 107.87	48 Cd CADMIUM 112.41
6	75 Re RHENIUM 186.21	76 Os OSMIUM 190.23	77 Ir IRIDIUM 192.22	78 Pt PLATINUM 195.08	79 Au GOLD 196.97	80 Hg MERCURY 200.59
7	107 Bh BOHRIUM (264)	108 Hs HASSIUM (277)	109 Mt MEITNERIUM (268)	110 Ds DARMSTADTIUM (281)	111 Rg ROENTGENIUM (282)	112 Cn COPERNICUM (285)

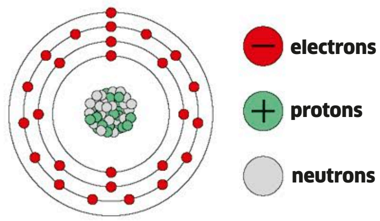
57 La LANTHANUM 138.91	58 Ce CERIUM 140.12	59 Pr PRASEODYMIUM 140.91	60 Nd NEODYMIUM 144.24	61 Pm PROMETHIUM (145)	62 Sm SAMARIUM 150.36	63 Eu EUROPIUM 151.96	64 Gd GADOLINIUM 157.25	65 Tb TERBIUM 158.93
89 Ac ACTINIUM (227)	90 Th THORIUM 232.04	91 Pa PROTACTINIUM 231.04	92 U URANIUM 238.03	93 Np NEPTUNIUM (237)	94 Pu PLUTONIUM (244)	95 Am AMERICIUM (243)	96 Cm CURIUM (247)	97 Bk BERKELIUM (247)

Lanthanides and actinides
Periods 6 and 7 each contain 14 more elements than periods 4 and 5. This makes the table too wide to fit easily in books, so these elements are shown separately. All elements in the actinides group are radioactive.

Periodic table key

- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanide metals
- Actinide metals
- Other metals
- Metalloids
- Other non-metals
- Halogens
- Noble gases

Key to atomic models on pp.30–41.



Models show atoms of the most common isotope.

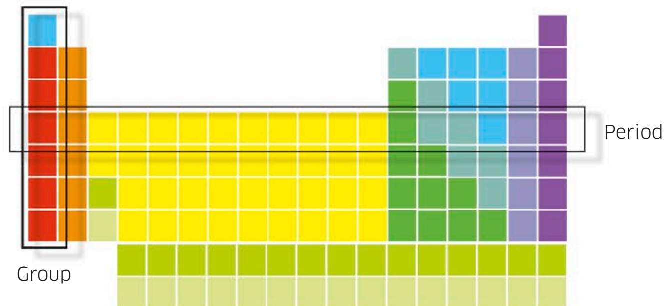
Other non-metals
These include three elements essential for life on Earth–carbon, nitrogen, and oxygen.

13	14	15	16	17	18
					2 4.0026 He HELIUM
5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
13 26.982 Al ALUMINUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULFUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.96 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
113 (284) Nh NIHONIUM	114 (289) Fl FLEROVIUM	115 (288) Mc MOSCOVIUM	116 (293) Lv LIVERMORIUM	117 (294) Ts TENNESSINE	118 (294) Og OGANESSON

66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERBIUM	71 174.97 Lu LUTETIUM
98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

UNDERSTANDING THE PERIODIC TABLE

Within the table are blocks of elements that behave in similar ways. On the left are the most reactive metals. Most everyday metals occur in the middle of the table in a set called the transition metals. Non-metals are mostly on the right of the table and include both solids and gases.

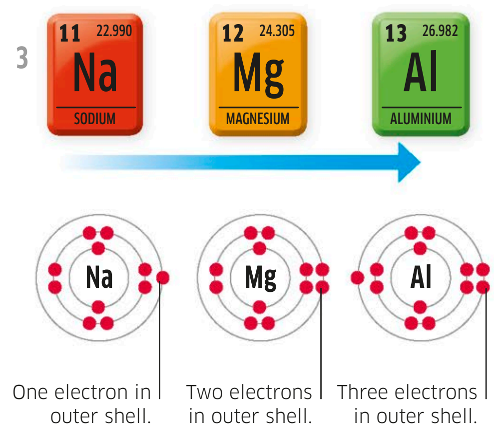


Building blocks

The periodic table is made up of rows called periods and columns called groups. As we move across each period, the elements change from solid metals (on the left) to gases (on the right).

Periods

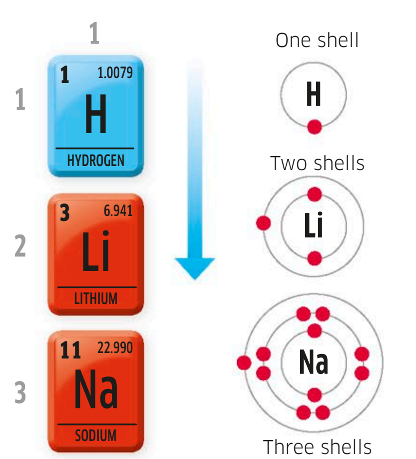
All elements in a period have the same number of electron shells in their atoms. For example, all elements in the third period have three shells (but a different number of electrons).



Shrinking atoms
As you move along each row (period) of the table, the atoms of each element contain more protons and electrons. Each atom has the same number of electron shells, but for each step to the right, there are more positively charged protons pulling the shells inward. This "shrinks" the atom, and makes it more tightly packed.

Groups

The elements in a group react in similar ways because they have the same number of electrons in their outer shell (see p.13). For example, while the elements in group 1 all have different numbers of electrons, and shells, they all have just one electron in their outer shell.



Growing atoms
Atoms get bigger and heavier as we move down each column (group). This is because the atoms of each element below have more protons and more electrons than the element above. As shells fill up with electrons (see p.13), a new shell is added each time we move another step down a group, down to the next period.

Earth's inner core is made up of two transition metals: **iron and nickel.**

Transition metals

What we usually think of as "metals" mostly belong to the group of elements known as transition metals. Most are hard and shiny. They have many other properties in common, including high boiling points and being good at conducting heat and electricity.

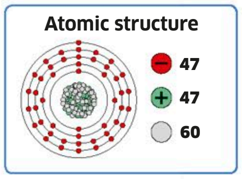
The transition metals make up the biggest element block in the periodic table, spreading out from group 3 through to group 12, and across four periods (see pp.28–29). This wide spread indicates that, although they are similar in many ways, they vary in others, such as how easily they react and what kinds of compounds they form.

Some of these metals have been known for more than 5,000 years. Some were only discovered in the 20th century. This is a selection of some of the 38 transition metals.

SILVER

Argentum

Discovered: c. 3000 BCE



47 107.87 **Ag** SILVER

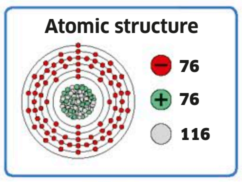
Like gold and copper, silver was one of the elements known and used by the earliest civilizations. It is valuable and easy to mold and used to be made into coins. Today, coins are made of alloys (see pp.62–63). Silver is still one of the most popular metals and is used for jewelry and decorative objects.

Chunk of silver
Silver metal reacts with the sulfur in air, which produces a black coating. That is why silver needs polishing to stay shiny.

OSMIUM

Osmium

Discovered: 1803



76 190.23 **Os** OSMIUM

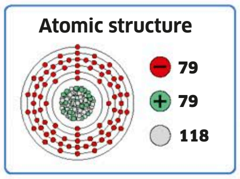
This rare, blue-shimmering metal is incredibly dense—a tennis ball–sized lump of osmium would have a mass of 7.7 lb (3.5 kg). If exposed to air, it reacts with oxygen to form a poisonous oxide compound, so for safe use it needs to be combined with other metals or elements. The powder used to detect fingerprints contains osmium.

Hard but brittle
This sample of refined osmium looks solid enough, but the tiny cracks all over it show that it is fragile in its pure form.

GOLD

Aurum

Discovered: c. 3000 BCE



79 196.97 **Au** GOLD

Since ancient times, gold has been treasured because of its great beauty, and also because it doesn't get damaged by corrosion—it keeps its yellow sheen and does not rust. Easy to shape, it can be seen in jewelry, Egyptian masks, building decorations, and also in electronics. It doesn't easily react or form compounds with other elements.

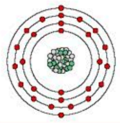
Gold nugget
In nature, pure gold can be found in nuggets such as this or, more commonly, as grains inside rocks.

COBALT

Cobaltum

Discovered: 1739

Atomic structure



− 27
+ 27
○ 32

27 58.933
Co
COBALT

Cobalt is somewhat similar to iron, its neighbor on the periodic table. The metal is often added to alloys, including those used to make permanent magnets. A cobalt compound has long been used to produce "cobalt blue," a deep, vibrant blue for paints and dyes.

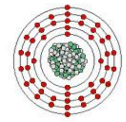
Cobalt color
Extracted from its ore, pure cobalt metal is silvery gray in appearance.

CADMIUM

Cadmium

Discovered: 1817

Atomic structure



− 48
+ 48
○ 66

48 112.41
Cd
CADMIUM

Although it has some uses in industry and laser technology, this metal is now known to be highly toxic and dangerous to humans. If ingested, it can react like calcium, an essential and useful element, but will replace the calcium in our bones. This causes bones to become soft and easy to break.

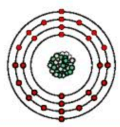
Poisonous pellet
This sample of pure cadmium has been refined in a laboratory.

NICKEL

Niccolum

Discovered: 1751

Atomic structure



− 28
+ 28
○ 30

28 58.693
Ni
NICKEL

This useful metal, which does not rust, is one of the ingredients in stainless steel (see p.63). It is also used to protect ships' propellers from rusting in water. Its best-known role is perhaps in the various alloys used to make coins, including the US 5-cent coin that is called a nickel.

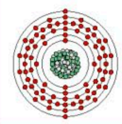
Pure nickel
These samples of pure nickel have been shaped into tiny balls.

MERCURY

Hydrargentum

Discovered: 1500 BCE

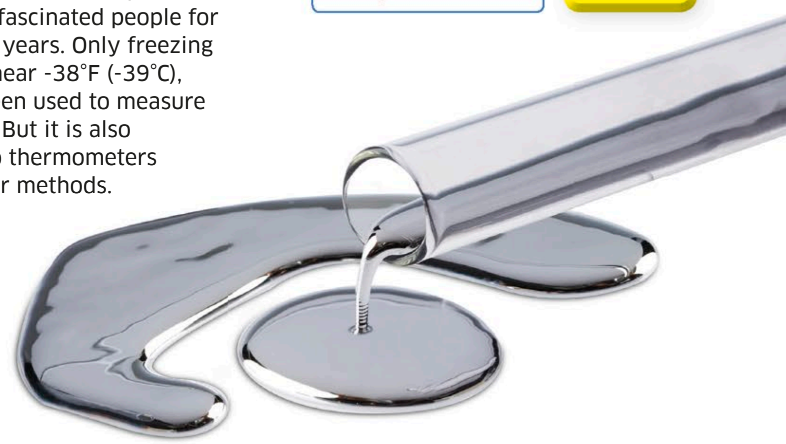
Atomic structure



− 80
+ 80
○ 122

80 200.59
Hg
MERCURY

Famous for being the only metal that is liquid at room temperature, mercury has fascinated people for thousands of years. Only freezing to a solid at near -38°F (-39°C), it has long been used to measure temperature. But it is also poisonous, so thermometers now use other methods.



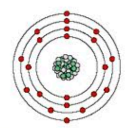
Quick liquid
Mercury is also known as quicksilver, and it is easy to see why.

TITANIUM

Titanium

Discovered: 1791

Atomic structure



− 22
+ 22
○ 26

22 47.867
Ti
TITANIUM

Known for its strength, this metal was named after the Titans, the divine and tremendously forceful giants of Greek mythology. Titanium is hard but also lightweight, and resistant to corrosion. This super combination of properties makes it perfect for use in artificial joints and surgical pins, but also in watches and in alloys for the aerospace industry. It is, however, a very expensive material.

When titanium reacts with oxygen in the air it gets a duller gray coating. This actually works as a protection against corrosion.

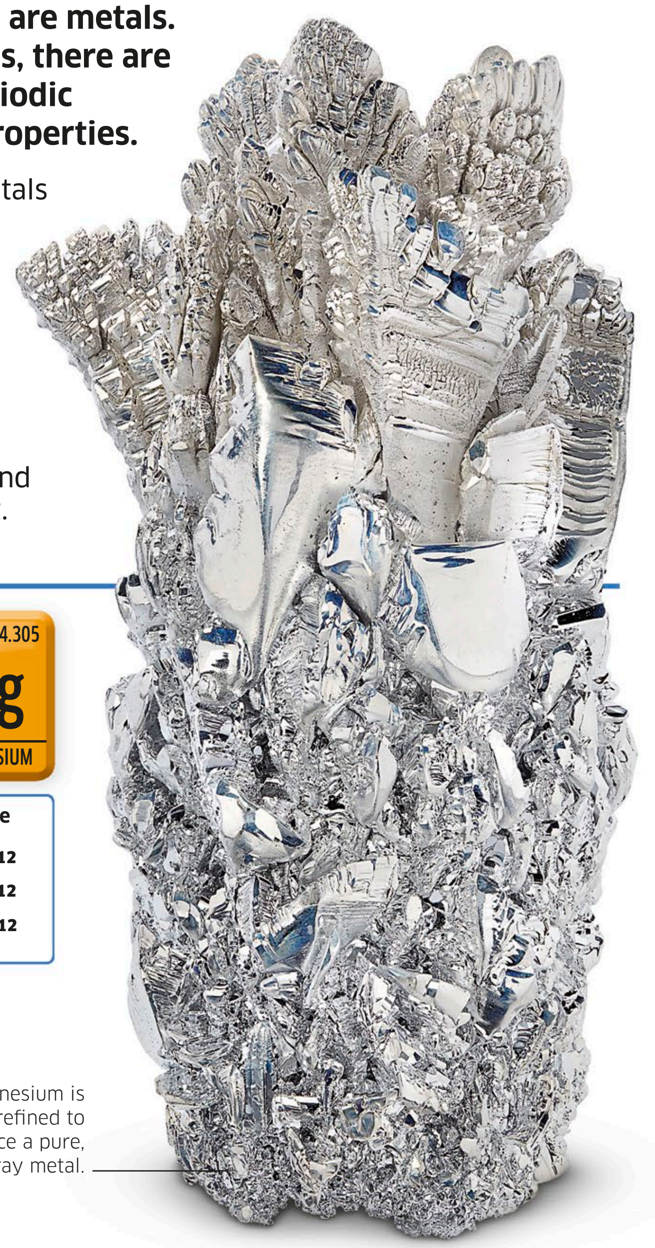
Laboratory sample
Although titanium is a common element in Earth's crust, it usually only exists in mineral compounds, not as a native element. Pure titanium has to be extracted and refined.

Radium, the only radioactive **alkaline earth metal**, was discovered by **Marie and Pierre Curie** in 1898.

More metals

Most of the elements known to us are metals. In addition to the transition metals, there are five other metal groups in the periodic table, featuring a wide range of properties.

The alkali metals and alkaline earth metals are soft, shiny, and very reactive. The elements known as "other metals" are less reactive and have lower melting points. Underneath the transition metals are the lanthanides, which used to be called "rare earth metals," but turned out not to be rare at all, and the radioactive actinides. Whatever the group, these metals are all malleable, and good conductors of electricity and heat.

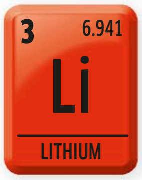


Magnesium is refined to produce a pure, shiny gray metal.

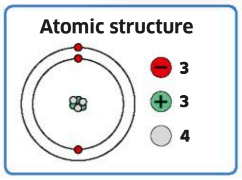
LITHIUM

Lithium

Discovered: 1817



Lithium is the lightest of all metals. It has been used in alloys in the construction of spacecraft. In more familiar uses, we find lithium in batteries, and also in compounds used to make medicines.



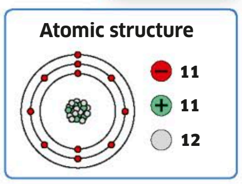
Pure lithium is a soft, silver-colored metal.

SODIUM

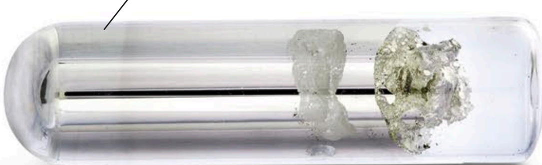
Natrium

Discovered: 1807

So soft it can easily be cut with a knife and very reactive, sodium is more familiar to us when in compounds such as common salt (sodium chloride). It is essential for life, and plays a vital role in our bodies.



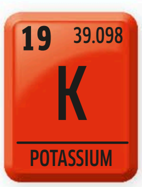
Sodium is so reactive it needs to be stored away from air in sealed vials.



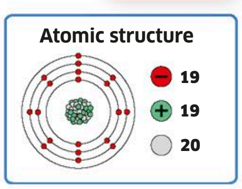
POTASSIUM

Kalium

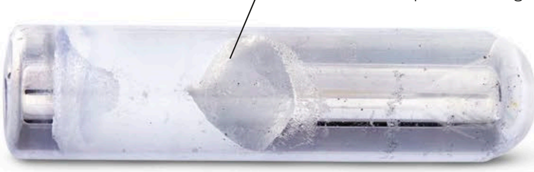
Discovered: 1807



Along with sodium, the alkali metal potassium helps to control the nervous system in our bodies. We get it from foods such as bananas, avocados, and coconut water. It is added to fertilizers and is also part of a compound used in gunpowder.



Highly reactive, potassium is often stored in oil to stop it reacting.

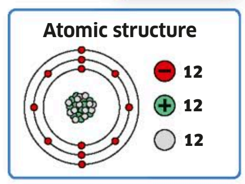


MAGNESIUM

Magnesium

Discovered: 1755

Magnesium is an important metal because it is both strong and light in weight. The oceans are a main source of magnesium, but it's quite expensive to produce, so recycling it is crucial. As a powder, or thin strip, it is flammable and burns with a bright white light. It is often used in fireworks and flares.

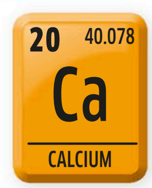


Pure metal samples such as this one are prepared using chemical processes. In nature, calcium is part of many minerals, but it doesn't exist on its own.

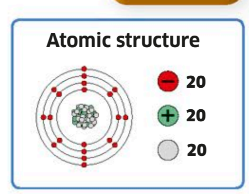
CALCIUM

Calcium

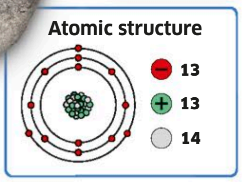
Discovered: 1808



Our bodies are full of calcium, the fifth most common element on Earth. It makes teeth and bones strong, which is why it is important to eat calcium-rich foods, such as broccoli and oranges. It is also a vital part of compounds used to make cement and plaster.



13 26.982
Al
ALUMINUM



ALUMINUM

Aluminium

Discovered: 1825

Light and easy to shape, this metal is the main part of alloys used for anything from kitchen foil to aircraft parts. Much of it is recycled, as extracting it from mineral ores to produce pure metal is expensive and very energy-consuming.

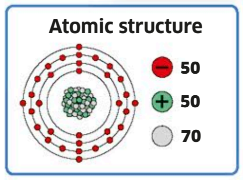
TIN

Stannum

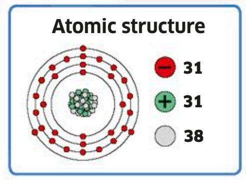
Discovered: c. 3000 BCE

Tin was once smelted with copper to produce the alloy bronze—which led to the Bronze Age. Today it is used in alloys to plate other metal objects, such as pots and "tin cans."

50 118.71
Sn
TIN



31 69.723
Ga
GALLIUM



GALLIUM

Gallium

Discovered: 1875

Famous as an element with a melting point at just above room temperature, gallium metal melts in your hand. In commercial applications, gallium is a vital element in the production of semi-conductors for use in electronics.

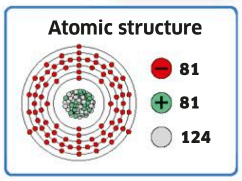
THALLIUM

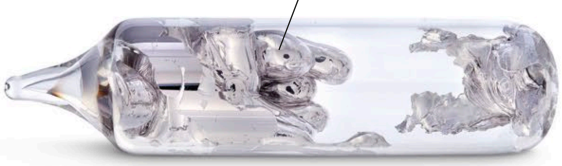
Thallium

Discovered: 1861

81 204.38
Tl
THALLIUM

This soft, silvery metal is toxic in its pure state. It was commonly put to use as rat poison, but sometimes ended up killing humans, too. Combined with other elements it can be useful, for example to improve the performance of lenses.





Toxic thallium in its pure form, safely kept in a vial.

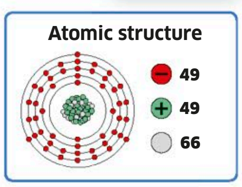
INDIUM

Indium

Discovered: 1863

49 114.82
In
INDIUM

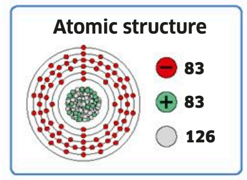
A very soft metal in its pure state, indium is part of the alloy indium tin oxide, or ITO. This material is used in touch screens, LCD TV screens, and as a reflective coating for windows.



BISMUTH

Bismuthum

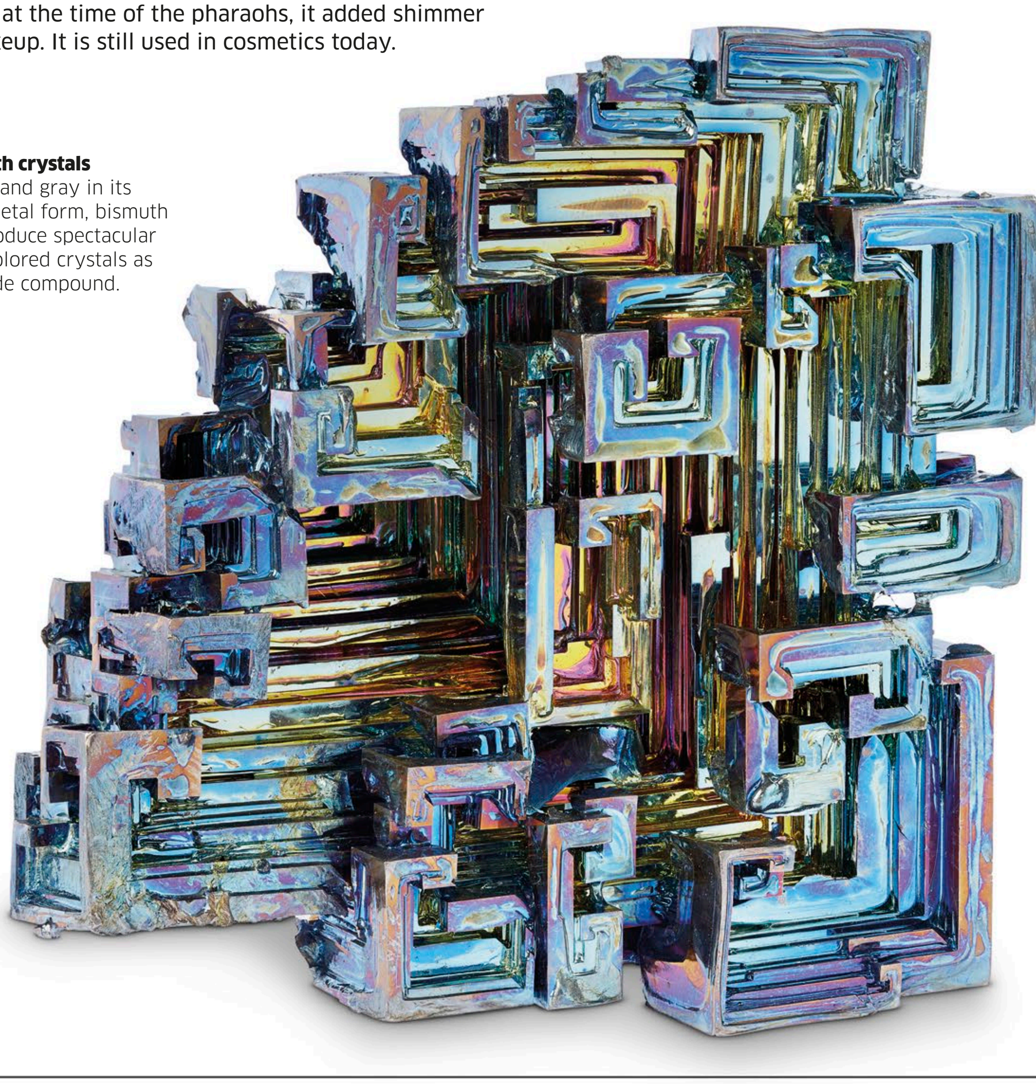
Discovered: 1753



83 208.96
Bi
BISMUTH

Bismuth is a curious element. It is what is known as a heavy metal, similar to lead, but not very toxic. It is a tiny bit radioactive. It was not defined as an individual element until the 18th century, but has been known and used as a material since ancient times. For example in Egypt, at the time of the pharaohs, it added shimmer to makeup. It is still used in cosmetics today.

Bismuth crystals
Brittle and gray in its pure metal form, bismuth can produce spectacular multicolored crystals as an oxide compound.



Human **hair, skin, and nails** need **silicon** to stay healthy.

Metalloids

Also known as semi-metals, the metalloids are an odd collection of elements that show a wide range of chemical and physical properties. Sometimes they act like typical metals, sometimes like non-metals. One example of their behavior as both is their use as semi-conductors in modern electronics.

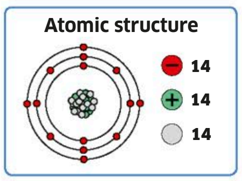
In the periodic table, the metalloids form a jagged diagonal border between the metals on the left, and the non-metals to the right. Some scientists disagree regarding the exact classification of some elements in this part of the periodic table, precisely because of this in-between status. Some of the elements shown here are toxic, some are more useful than others, some are very common, and some very rare. But they are all solid at room temperature.

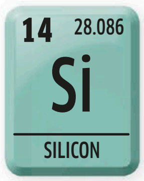
Silicon sample
Pure silicon, such as this sample refined in a laboratory, shatters easily.

SILICON

Silicium

Discovered: 1823





Most of us are familiar with silicon, even if we don't know it. It is the second most abundant element in the Earth's crust, only after oxygen, and appears in many different silicate minerals. Mixed with other elements, silicon, a typical semi-conductor, is at the heart of the electronics industry—used in microchips and solar panels. Silicone baking molds contain silicon, too.

Silicate minerals

Silicon is more or less everywhere, found in the silicate compounds that are better known to us as sand, quartz, talc, and feldspar, and in rocks made up of these minerals. Silicates also include minerals whose crystals make luxurious gems, such as amethyst, opal, lazurite, jade, and emerald. All these contain silica (silicon and oxygen), and sometimes other elements, too (see p.23).

Genesis rock
Collected on the moon by Apollo 15 in 1971, this rock contains feldspar, a type of silicate mineral.

Moon mineral
It is not just on Earth that silicates abound. The surface of the moon is made of 45 percent silica.

Orthoclase
This feldspar is what gives pink granite its color.

Feldspar minerals
A widespread group of silicate minerals, feldspars contain aluminum as well as silica, and often other elements, too, including calcium, sodium, and potassium. They form common rocks, such as granite. The pretty crystal called moonstone is also a type of feldspar.

Silicate sands
Desert sand is chiefly composed of silica, a silicon and oxygen compound with the chemical name silicon dioxide. Sand started out as rock that was gradually broken up and eroded into finer and finer grains. In the Sahara (left), this process started some 7 million years ago.

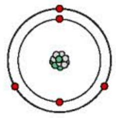
BORON

Boron

Discovered: 1808

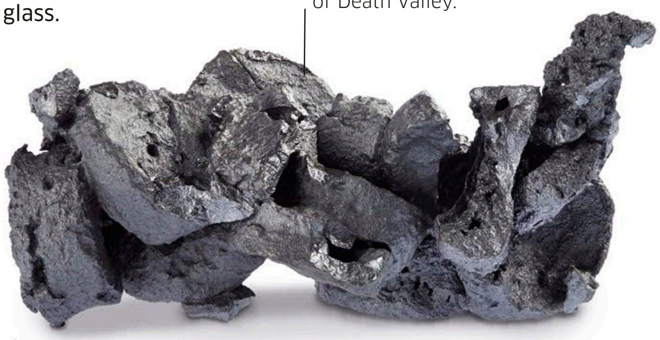
A hard element, boron gets even harder when combined with carbon as boron carbide. This is one of the toughest materials known, used in tank armor and bulletproof vests. Boron compounds are used to make heat-resistant glass.

Atomic structure



5 (electrons) · 5 (protons) · 6 (neutrons)

5 | 10.811 | **B** | BORON



Dark and twisted
Pure boron is extracted from minerals in the deserts of Death Valley.

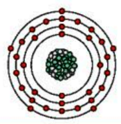
ARSENIC

Arsenicum

Discovered: 1250

Arsenic is an element with a deadly reputation. Throughout history, it has been used to poison people and animals, in fiction as well as in real life. Oddly, in the past it has been used as a medicine, too. It is sometimes used in alloys to strengthen lead, a soft, poisonous metal.

Atomic structure



33 (electrons) · 33 (protons) · 42 (neutrons)

33 | 74.922 | **As** | ARSENIC

Dark matter
Pure arsenic can be refined from mineral compounds.

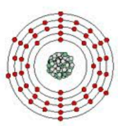
TELLURIUM

Tellurium

Discovered: 1783

A rare element, in nature tellurium exists in compounds with other elements. It has a few specialist uses. It is used in alloys to make metal combinations easier to work with. It is mixed with lead to increase its hardness, and help to prevent it being damaged by acids. In rubber manufacture, it is added to make rubber objects more durable.

Atomic structure



52 (electrons) · 52 (protons) · 78 (neutrons)

52 | 127.60 | **Te** | TELLURIUM

Refined tellurium
Silvery crystals of tellurium are often refined from by-products of copper mining.

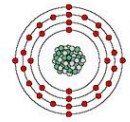
GERMANIUM

Germanium

Discovered: 1886

In the history of the periodic table, germanium is an important element. In 1869, in his first table, Mendeleev predicted that there would be an element to fill a gap below silicon. It was discovered 17 years later, and did indeed fit there. Today germanium is used together with silicon in computer chips.

Atomic structure



32 (electrons) · 32 (protons) · 42 (neutrons)

32 | 72.64 | **Ge** | GERMANIUM

Pure germanium
Refined germanium is shiny but brittle.

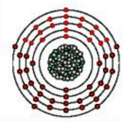
ANTIMONY

Stibium

Discovered: 1600 BCE

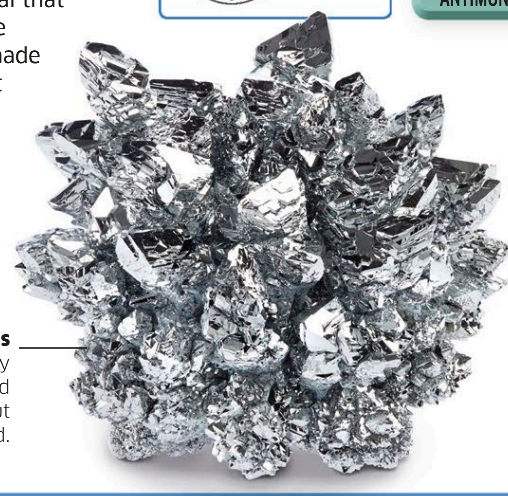
Antimony comes from stibnite, a naturally occurring mineral that also contains sulfur. Stibnite used to be ground up and made into eye makeup by ancient civilizations, as seen on Egyptian scrolls and death masks. Known as kohl, its Arabic name, it is still used in cosmetics in some parts of the world.

Atomic structure



51 (electrons) · 51 (protons) · 70 (neutrons)

51 | 121.76 | **Sb** | ANTIMONY



Brittle crystals
This laboratory sample of refined antimony is hard but easily shattered.

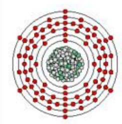
POLONIUM

Polonium

Discovered: 1898

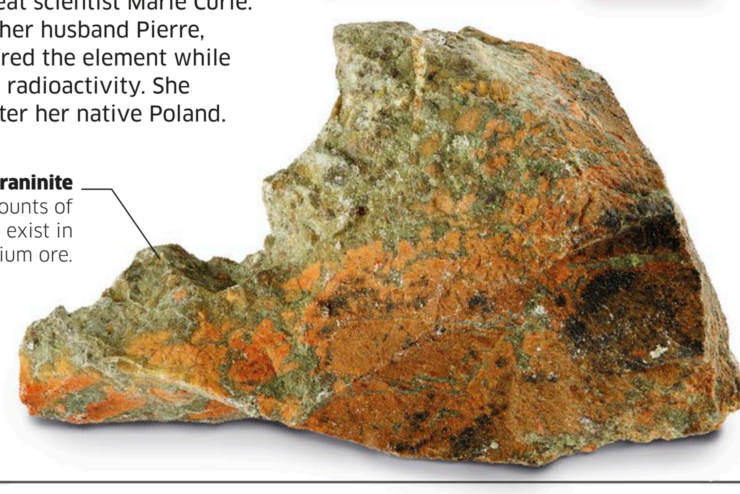
This highly radioactive and toxic element will forever be associated with the great scientist Marie Curie. Along with her husband Pierre, she discovered the element while researching radioactivity. She named it after her native Poland.

Atomic structure



84 (electrons) · 84 (protons) · 125 (neutrons)

84 | (209) | **Po** | POLONIUM



Uraninite
Tiny amounts of polonium exist in this uranium ore.

The human body contains lots of phosphorus, 85 percent of which is in our teeth and bones.

Solid non-metals

Unlike metals, most non-metals do not conduct heat or electricity, and are known as insulators. They have other properties that are the opposite of those of metals, too, such as lower melting and boiling points.

On the right side of the periodic table are the elements that are described as non-metals. These include the halogens and the noble gases (see pp.40–41). There is also a set known as "other non-metals," which contains the elements carbon, sulfur, phosphorus, and selenium, all solids at room temperature. All of these exist in different forms, or allotropes. The "other non-metals" set of elements also includes a few gases (see pp.38–39).

Raw graphite
The surface of pure graphite looks metallic but is soft and slippery.

Raw diamond
Formed deep underground, raw diamonds are found in igneous (volcanic) rocks.

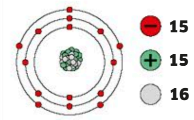
A clear diamond crystal like this can be cut into a precious gem.

PHOSPHORUS

Phosphorus

Discovered: 1669

Atomic structure



15 30.974
P
PHOSPHORUS

As a German alchemist boiled urine to produce the mythical philosopher's stone, he discovered a glowing, and very reactive, material instead. He named it phosphorus. It has a number of forms. The two most common are known as red phosphorus and white phosphorus.

Red phosphorus
More stable than white phosphorus, this form is used in safety matches and fireworks.

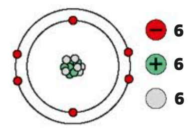
White phosphorus
White phosphorus needs to be stored in water because it bursts into flames when in contact with air. It can cause terrible burns.

CARBON

Carbonium

Discovered: Prehistoric times

Atomic structure

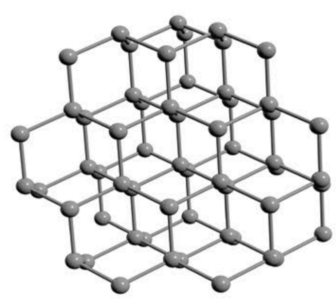


6 12.011
C
CARBON

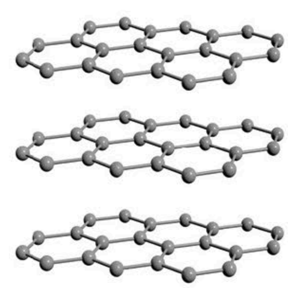
Carbon is at the center of all life. This element forms the backbone of almost all the most important biological molecules. DNA, amino acids, proteins, fats, and sugars all contain multiple joined carbon atoms, bonded with other atoms, to form the molecules that make living organisms work. Carbon is in our bodies, in our food, in plants, and in most fuels we use for heating and transportation. It appears as crystal-clear diamond as well as soft graphite.

Carbon allotropes

Allotropes are different forms of the same element. Carbon has three main allotropes: diamond, graphite, and buckminsterfullerene. It is the way the carbon atoms are arranged and bonded that determines which allotropes exist, and what their chemical and physical properties are.



Diamond
Diamond, an extremely hard allotrope of carbon, has its atoms arranged in a three-dimensional, rigid structure, with very strong bonds holding all of the atoms together.



Graphite
The "lead" in pencils is actually clay mixed with graphite, an allotrope in which the atoms bond in layers of hexagons. These can slide over each other, making it soft and greasy.

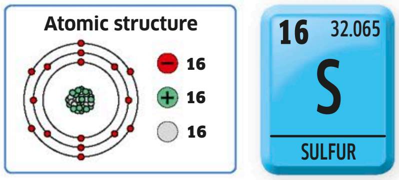
The **largest rough diamond** ever found, mined in South Africa, was just over **4 in (10 cm)** long.

The **Brazil nut** is the richest source of the form of **selenium** that the **human body needs**.

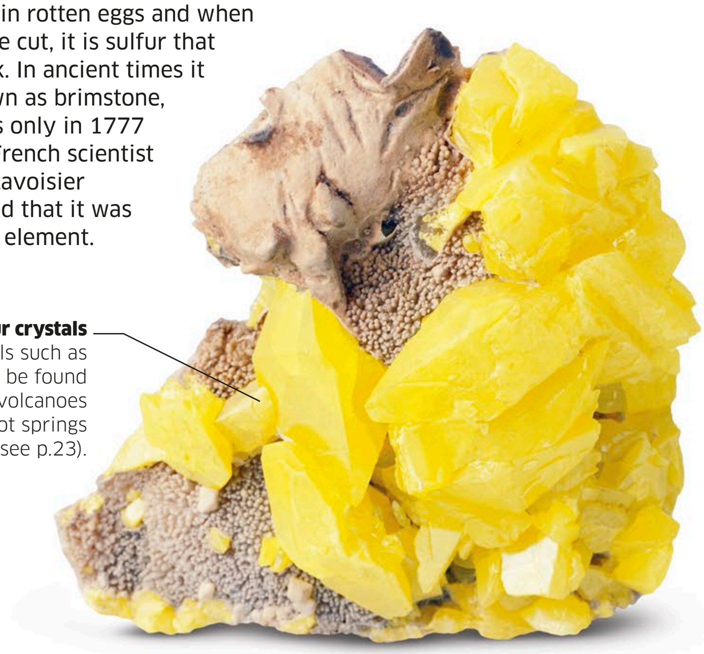
SULFUR

Sulfur

Discovered: 1777



This element has a distinctive yellow color. Many compounds containing sulfur have a strong smell—for example, in rotten eggs and when onions are cut, it is sulfur that is at work. In ancient times it was known as brimstone, but it was only in 1777 that the French scientist Antoine Lavoisier discovered that it was in fact an element.

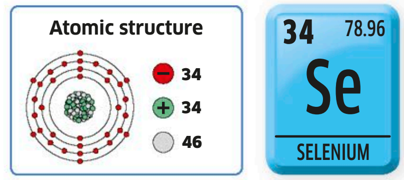


Sulfur crystals Crystals such as these can be found near volcanoes and hot springs (see p.23).

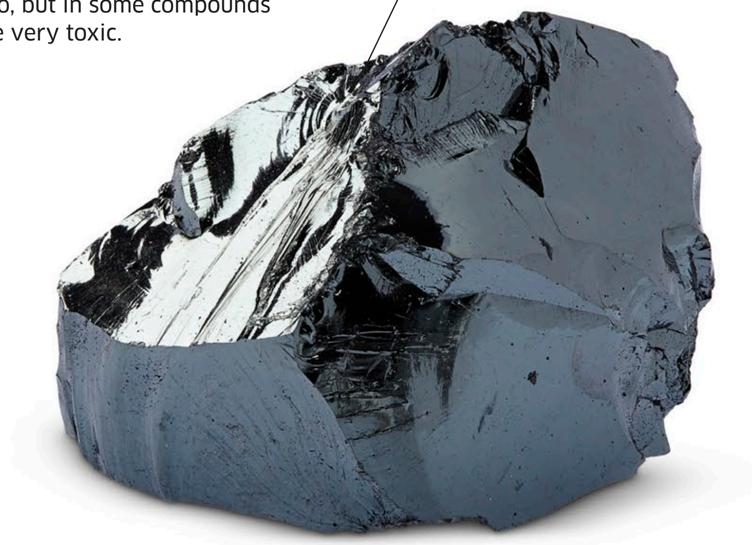
SELENIUM

Selenium

Discovered: 1817

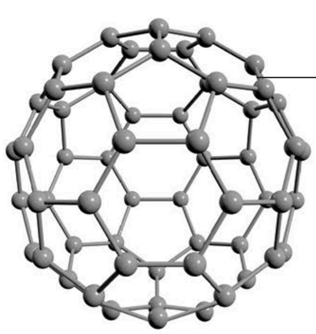


Named after the Greek word *selene*, meaning "moon," selenium exists in three forms: red, gray, and black selenium. This is an element we need in just the right amount for our bodies to stay healthy, and it is a useful ingredient in anti-dandruff shampoo, but in some compounds it can be very toxic.



Gray selenium The most stable form of pure selenium is hard and shiny.

Carbon fiber
In modern materials technology, carbon fibers that are one-tenth of a hair in thickness, but very tough, can be used to reinforce materials such as metals, or plastic (as seen above, enlarged many times).



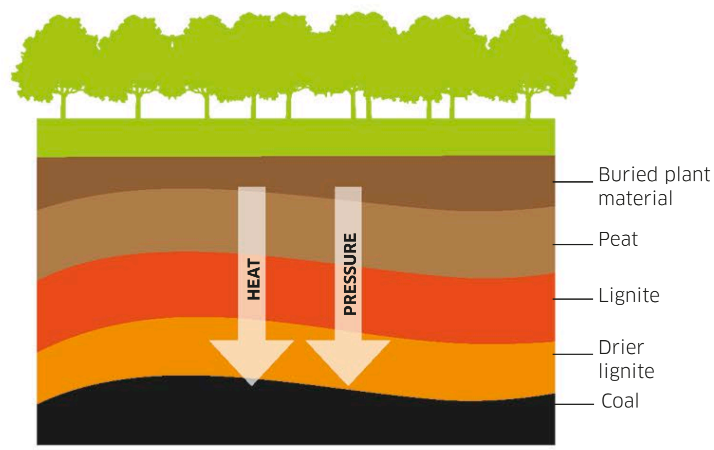
The carbon atoms are arranged in a rigid, stable structure that looks like a football.

Buckminsterfullerene
Nicknamed a buckyball, buckminsterfullerene is any spherical molecule of carbon atoms, bonded in hexagons and pentagons. There are typically 60 atoms in a "ball." They exist in soot, but also in distant stars, and were only discovered in 1985.

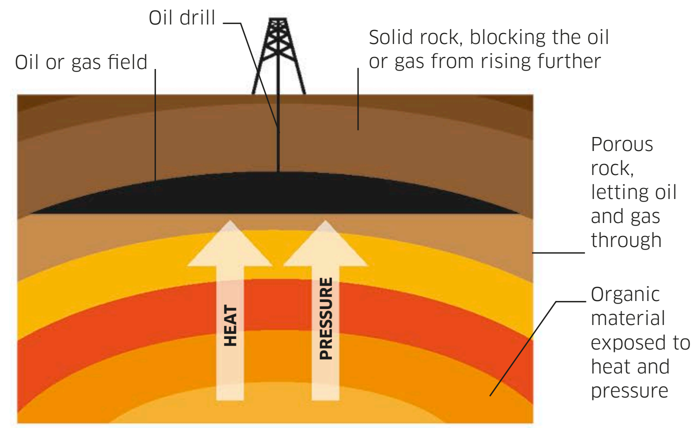
Carbon fossil fuels

The substances we call hydrocarbon or fossil fuels include coal, natural gas, and oil. These fuels were formed over millions of years from decaying dead organisms. They are made up mainly of carbon and hydrogen, and when they burn they produce carbon dioxide gas (see p.50–51).

Coal
A long, slow process turned trees that grew on Earth some 300 million years ago into coal that we can mine today. As dead trees fell, they started to sink deep down in boggy soil. They slowly turned into peat, a form of dense soil, which can be burned when dried. Increasing heat and pressure compacted the peat further, turning it into lignite, a soft, brown rock. Even deeper down, the intense heat turned the lignite into solid coal.



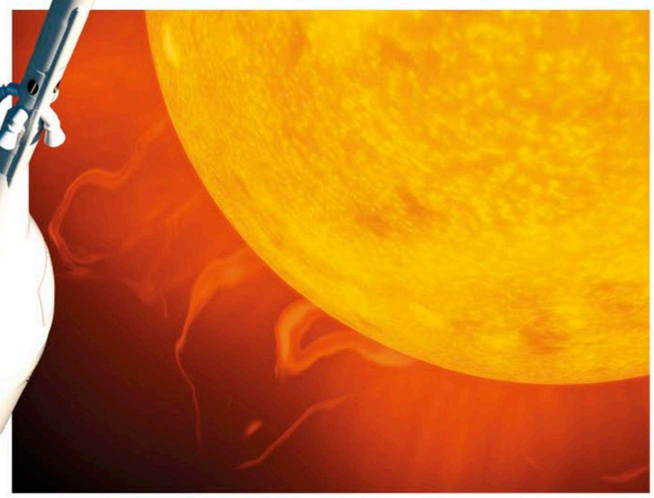
Oil and natural gas
The crude oil that is used to make diesel and gasoline is known as petroleum, meaning "oil from the rock." Millions of years ago, a layer of dead microorganisms covered the seabeds. It was slowly buried under mud and sand, gradually breaking down into hydrocarbons. Heat and pressure changed mud into rock and organic matter into liquid, or gas. This bubbled upward until it reached a "lid" of solid rock, and an oil (or gas) field was formed.



Hydrogen, oxygen, and nitrogen

Among the non-metal elements, these three gases are vital to us in different ways. A mixture of nitrogen and oxygen makes up most of the air we breathe, while hydrogen is the most abundant element in the universe.

Each of these gases has atoms that go in pairs: they exist as molecules of two atoms. That is why hydrogen is written as H_2, oxygen as O_2, and nitrogen as N_2. All three elements are found in compounds, such as DNA and proteins, that are vital for all forms of life on Earth.

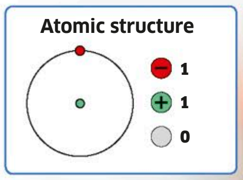


Hydrogen in the universe
Although rare in Earth's atmosphere, hydrogen makes up more than 88 percent of all matter in the universe. Our sun is not much more than a ball of very hot hydrogen. The hydrogen fuses together to produce helium (see p.41), the second element in the periodic table. In the process, a vast amount of energy is produced.

HYDROGEN

Hydrogenium

Discovered: 1766



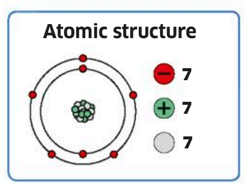
Hydrogen is the simplest of all the elements. Its lightest, and most common, isotope has atoms made of a single proton and a single electron, but no neutrons. Hydrogen gets its name from the Greek *hydro* and *genes* meaning "water forming;" when it reacts with oxygen it makes water, or H_2O.

Hydrogen as fuel
A very reactive element that will burn easily, hydrogen can be used as a fuel. When mixed with oxygen, it forms an explosive mixture. The rocket of a spacecraft uses liquid hydrogen, mixed with liquid oxygen, as fuel. In fuel cells, used in electric cars, the chemical reaction between hydrogen and oxygen is converted to electricity. This combustion reaction produces only water, not water and carbon dioxide as in gasoline-fueled engines, making it an environmentally friendly fuel.

NITROGEN

Nitrogenium

Discovered: 1772



In a nitrogen molecule (N_2), the two atoms are held together with a strong triple bond. The molecule is hard to break apart, which means nitrogen does not react readily with other substances. It is a very common element, making up 78 percent of the air on Earth. It is extremely useful, too. We need it in our bodies and, as part of the nitrogen cycle (see p.186), it helps plants to grow. Where plants and crops need extra help, it is added to fertilizers.

Explosive stuff
Molecules of nitrogen are not reactive, but many compounds containing nitrogen react very easily. These are found in many explosives, such as TNT, dynamite, and gunpowder, and in fireworks, too. On its own, compressed nitrogen gas is used to safely but powerfully blast out paintballs in paintball guns.

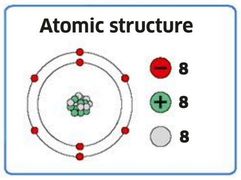
Liquid nitrogen
Nitrogen only condenses to liquid if it is cooled to -321°F (-196°C). This means that it is extremely cold in liquid form, instantly freezing anything it comes into contact with. This is useful for storing sensitive blood samples, cells, and tissue for medical use.

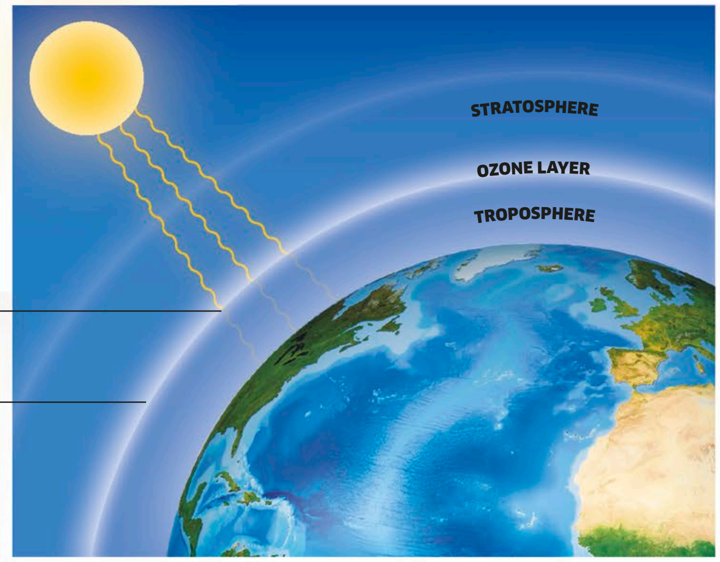
OXYGEN

Oxygenium

Discovered: 1774

The element that we depend on to stay alive, oxygen was only recognized as an element in the late 18th century. Many chemists from different countries had for years been trying to work out precisely what made wood burn, and what air was made of, and several came to similar conclusions at roughly the same time. Oxygen is useful to us in many different forms and roles, some of which are described here.





Most of the harmful UV radiation from the sun is absorbed by the ozone layer.

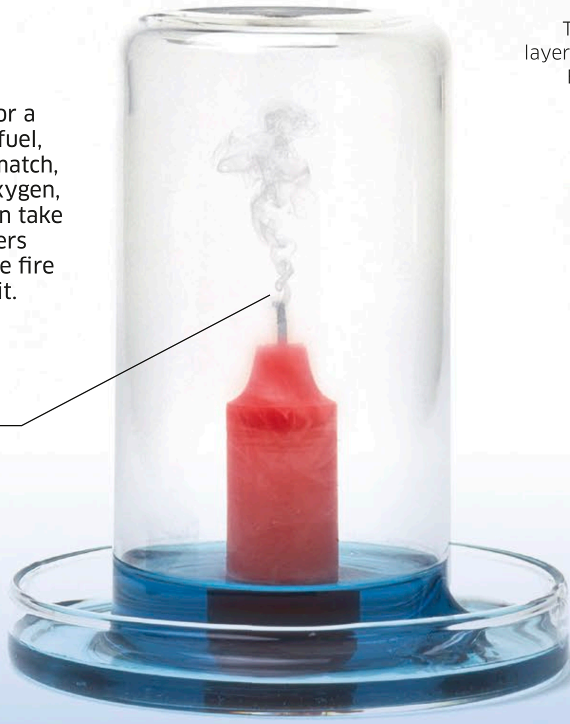
The ozone layer encircles Earth at a height of around 65,000 ft (20 km).

Air

Approximately 21 percent, or one fifth, of the air in Earth's atmosphere is oxygen gas. In the lower atmosphere, the oxygen we breathe is the most common form of oxygen—molecules made up of two oxygen atoms (O_2). Higher above us, however, is the ozone layer that protects us from harmful ultraviolet rays from the sun. Ozone (O_3) is another form, or allotrope, of oxygen, with three oxygen atoms in its molecules.

Fire

Three things are required for a fire to burn: there must be fuel, a source of heat such as a match, and oxygen gas. Without oxygen, no combustion (burning) can take place. Some fire extinguishers spray a layer of foam on the fire to prevent oxygen feeding it.



If a burning candle is placed in a jar, once the oxygen in the jar has been used up the flame soon flickers and goes out.

Life

All animals need oxygen to break down food and produce energy in a vital process called respiration.

Life on Earth

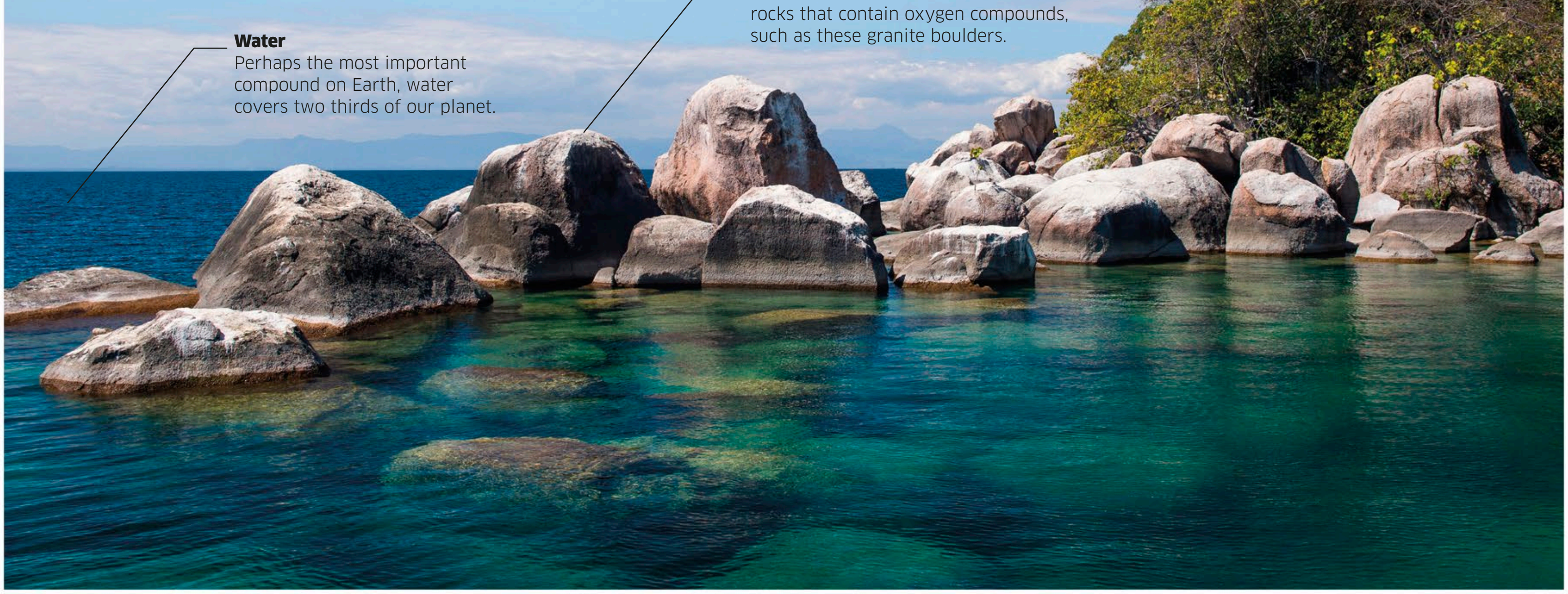
Our planet is the only one that has oxygen in its atmosphere. This is necessary for us to breathe. Oxygen is produced by photosynthesis, the process by which plants produce the food they need to live and grow. Water—which enabled life in the first place, millions of years ago, and is crucial to the survival of life in all forms—also contains oxygen. Even the ground is full of oxygen, in the form of different mineral compounds (see pp.22–23).

Land

Most of Earth's crust is made of rocks that contain oxygen compounds, such as these granite boulders.

Water

Perhaps the most important compound on Earth, water covers two thirds of our planet.



Seaweed and seafood are good sources of iodine, which **we need in our diet.**

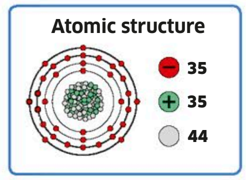
Halogens and noble gases

On the right-hand side of the periodic table are the non-metals known as halogens (group 17) and noble gases (group 18).

The word "halogen" means "salt-forming," and refers to the fact that these elements easily form salt compounds with metals. These include sodium chloride—common table salt—and those metal salts that give fireworks their colors, such as barium chloride which makes green stars. The noble gases don't form bonds with other "common" elements and are always gases at room temperature.

A liquid halogen
A drop of pure, dark orange-brown bromine fills the rest of the glass sphere with paler vapor.

Atomic structure



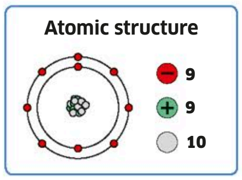
35 79.904 **Br** BROMINE

BROMINE
Bromum
Discovered: 1826

One of only two elements that are liquids at room temperature (the other is mercury), bromine is toxic and corrosive. It forms less harmful salt compounds, such as those found in the Dead Sea in the Middle East.

FLUORINE
Fluor
Discovered: 1886

Atomic structure



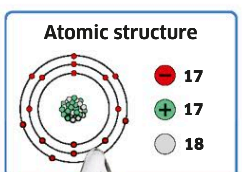
9 18.998 **F** FLUORINE

A pale yellow gas, fluorine is an incredibly reactive element. On its own, it is very toxic, and ready to combine with even some of the least reactive elements. It will burn through materials such as glass and steel. When added to drinking water and toothpaste in small doses, it helps prevent tooth decay.

Calming mixture
In this glass vial, fluorine has been mixed with the noble gas helium to keep it from reacting violently.

CHLORINE
Chlorum
Discovered: 1774

Atomic structure



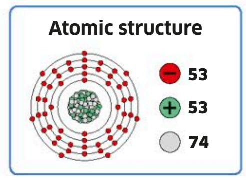
17 35.453 **Cl** CHLORINE

Like its periodic neighbor fluorine, chlorine is a very reactive gas. It is so poisonous that it has been used in chemical warfare, in World War I for example. It affects the lungs, producing a horrible, choking effect. Its deadly properties have been put to better use in the fight against typhoid and cholera: when added to water supplies, it kills the bacteria that cause these diseases. It is also used to keep swimming pools clean, and in household bleach.

Chlorine is a pale green gas.

IODINE
Iodium
Discovered: 1811

Atomic structure



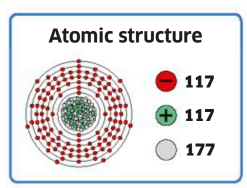
53 126.90 **I** IODINE

The only halogen that is solid at room temperature, iodine will sublime, which means it turns straight from a solid into a gas. It can be used as a disinfectant in medicine, and it is an essential element for human health, in small amounts.

Iodine sublimation
The dark purple, almost black solid turns into a paler gas.

TENNESSINE
Tennessine
Discovered: 2010

Atomic structure



117 294 **Ts** TENNESSINE

A latecomer among the halogens, this artificial element only got its name in 2016, six years after being created. It doesn't exist naturally, but is produced, a few atoms at a time, by crashing smaller atoms into one another until they stick together. The element is so new that so far, almost nothing is known about its chemistry. It is named after the US state of Tennessee, home to the laboratory where much of the research into making it took place.

Fluorine is part of a compound **used to create** the layer in **nonstick pans** that stops food getting stuck.

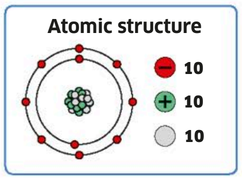
Helium is named after **Helios, the Greek god of the sun**, as it was **discovered in the cloud of gas** surrounding the sun.

NEON

Neon

Discovered: 1898

Neon might be the most well-known of the noble gases because of its use in bright advertising signs and lighting. Like the other members of the noble gases group, it is inert (doesn't react with other elements), and quite rare. Neon is present in air in small quantities; in fact, air is the only source of this element. To extract the neon, air is cooled until it becomes liquid. Then it is heated up again and, through distillation, the different elements present in air can be harvested as they vaporize. Neon can be used as a refrigerant and, when combined with helium, it can be used in lasers.



10 20.180
Ne
NEON

Neon red?
When electricity is passed through neon gas, it glows a stunning red. In fact, only red neon signs are actually made of neon. Other "neon" colors come from other noble gases—argon, for example, gives blue colors.

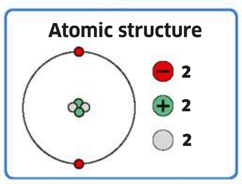
HELIUM

Helium

Discovered: 1895

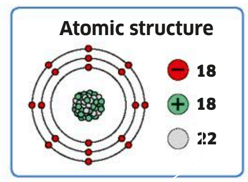
2 4.0026
He
HELIUM

Helium is a very light gas; only hydrogen is lighter. That is why it is put in all kinds of balloons. Airships, weather balloons, and party balloons can all be filled with the gas to make them rise and remain in the air. Helium is very unreactive. Because of this, it forms few compounds. Like neon, it can also be used as a cooling agent.



Dying star
The Crescent Nebula is made of gases thrown off by a dying star. Most of what remains of the star is helium, produced by millions of years of nuclear fusion.

Welding flame
Argon gas is used in welding to prevent water vapor and oxygen gas reacting with the metal.



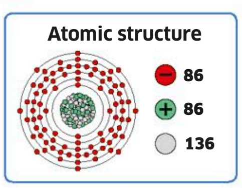
18 39.948
Ar
ARGON

ARGON

Argon

Discovered: 1894

After nitrogen and oxygen, argon is the third most abundant gas in Earth's atmosphere. It is unreactive in nature, and doesn't conduct heat very well. Its name, from the Greek word *argos*, even means "idle." It can be put to good use, however—for example in welding and to protect fragile museum artifacts from decaying in oxygen-rich air.



86 (222)
Rn
RADON

RADON

Radon

Discovered: 1900

Radon is a colorless gas which is released from minerals in the ground that contain the element uranium. Dangerously radioactive, radon can be a serious health risk. Breathing it in can cause lung cancer. It is present everywhere, but usually at very low levels. In areas where higher levels of radon are likely, home radon testing kits are sometimes provided.

Volcanic mud
Radon is present in volcanic springs and the mud surrounding them. Scientists often monitor the levels to make sure the groundwater in the area is safe to drink.

CHEMICAL REACTIONS

A chemical reaction is what happens when one substance meets and reacts with another and a new substance is formed. The substances that react together are called reactants, and those formed are called products. In a chemical reaction, atoms are only rearranged, never created or destroyed.

A change in color of a substance often indicates that a reaction has happened.

DIFFERENT REACTIONS

There are many types of reaction. They vary depending on the reactants involved and the conditions in which they take place. Some reactions happen in an instant, and some take years. Exothermic reactions give off heat while endothermic reactions cool things down. The products in a reversible reaction can turn back into the reactants, but in an irreversible reaction they cannot. Redox reactions involve two simultaneous reactions: reduction and oxidation.

SYNTHESIS REACTION: ATOMS OF TWO OR MORE REACTANTS JOIN TOGETHER

DECOMPOSITION REACTION: ATOMS OF ONE REACTANT BREAK APART INTO TWO PRODUCTS

DISPLACEMENT REACTION: ATOMS OF ONE TYPE SWAP PLACES WITH THOSE OF ANOTHER, FORMING NEW COMPOUNDS

Three kinds of reaction

Reactions can be classified in three main groups according to the fate of the reactants. As shown above, in some reactions the reactants join together, in others they break apart, and in some their atoms swap places.

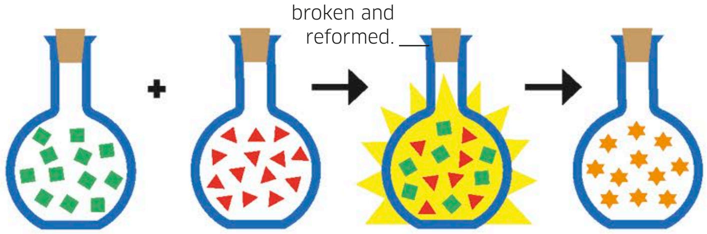
REACTION BASICS

Chemical reactions are going on around us all the time. They help us digest food, they cause metal to rust, wood to burn, and food to rot. Chemical reactions can be fun to watch in a laboratory—they can send sparks flying, create puffs of smoke, or trigger dramatic color changes. Some happen quietly, however, without us even noticing. The important fact behind all these reactions is that all the atoms involved remain unchanged. The atoms that were there at the beginning of the reactions are the same as the atoms at the end of the reaction. The only thing that has changed is how those atoms have been rearranged.

Reactants and products

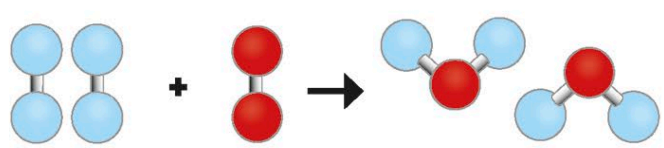
The result of a chemical reaction is a chemical change, and the generation of a product or products that are different from the reactants. Often, the product looks nothing like the reactants. A solid might be formed by two liquids, a yellow liquid might turn blue, or a gas might be formed when a solid is mixed with a liquid. It doesn't always seem as if the atoms in the reactants are the same as those in the products, but they are.

Bonds are broken and reformed.



Chemical equations

The "law of conservation of mass" states that mass is neither created nor destroyed. This applies to the mass of the atoms involved in a reaction, and can be shown in a chemical equation. Reactants are written on the left, and products on the right. The number of atoms on the left of the arrow always equal those on the right. Everything is abbreviated: "2 H_2" means two molecules of hydrogen, with two atoms in each molecule.



Dirty exhaust in

A car's catalytic converter contains a catalyst made of platinum and rhodium.

Carbon monoxide and unburned fuel are converted to harmless carbon dioxide and water as they pass through the converter.

Cleaner exhaust out

Catalysts

Catalysts are substances that make chemical reactions go faster. Some reactions can't start without a catalyst. Catalysts help reactants interact, but they are not part of the reaction and remain unchanged. Different catalysts do different jobs. Cars use catalysts that help reduce harmful engine fumes by speeding up their conversion to cleaner exhausts.

Quick or slow?
Bread dough made with yeast rises slowly through fermentation. In this process, chemical compounds in the yeast react with sugar to produce bubbles of carbon dioxide gas, which make the dough rise. With baking soda, the reaction is between an acid and an alkali, which generates carbon dioxide in an instant.

Hot or cold?
It takes energy to break the bonds between atoms, while energy is released when new bonds form. Often, more energy is released than it takes to break the bonds. That energy is released as heat, such as when a candle burns. This is an exothermic reaction. If the energy released is less than the energy required to break the bonds, the reaction takes energy from its surroundings and both become colder. That reaction is endothermic.

Redox reactions
Redox reactions involve reduction (the removal of oxygen, or addition of electrons) and oxidation (the addition of oxygen or removal of electrons). When an apple turns brown in the air, a chemical inside the apple is oxidized, and oxygen from the air is reduced.

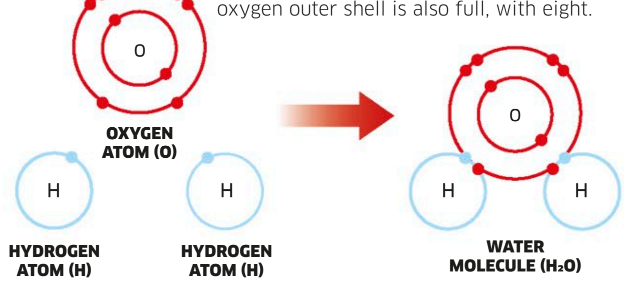
Reversible or irreversible?
Rusting is a redox reaction that, like an apple going brown, is irreversible. In a reversible reaction, certain products can turn back into their original reactants.

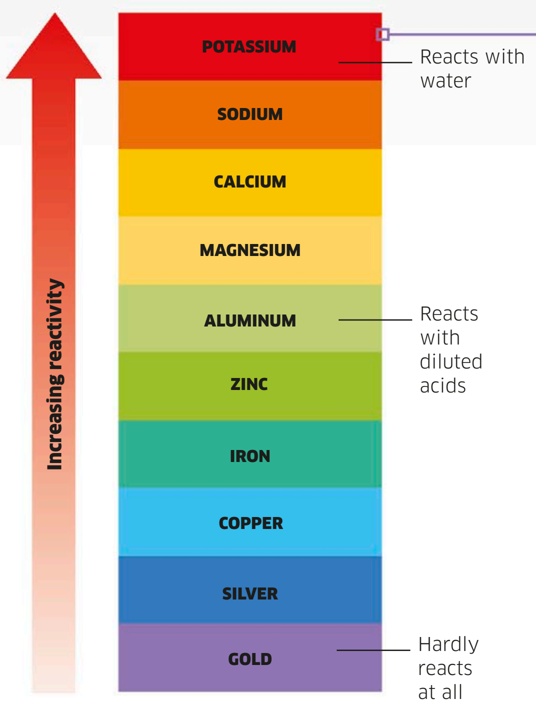
WHY DO REACTIONS HAPPEN?

Different chemical reactions happen for different reasons, including temperature, pressure, and the type and concentration of reactants. Chemical reactions involve the breaking and making of bonds between atoms. These bonds involve the electrons in the outer shell of each atom. It is how the electrons are arranged in atoms of different elements that decides which atoms can lose electrons and which ones gain them.

Why do atoms react?
Atoms that can easily lose electrons are likely to react with atoms that need to fill their outer shell. There are different types of bonds depending on how the atoms do this: covalent, ionic, and metallic (see pp.16–17). A water molecule (below) has covalent bonds.

By sharing electrons, hydrogen atoms get two electrons in their outer shell, and the oxygen outer shell is also full, with eight.





Metal reactivity series
A reactivity series sorts elements according to how readily they react with other elements. The most reactive is at the top; the least reactive at the bottom. It helps predict how elements will behave in some chemical reactions.

Potassium
Potassium is the most reactive metal in the series. Adding a lump of potassium to water causes the potassium to react instantly: it whizzes around on the surface of the water and bursts into spectacular flames.

Ice cream gets its different flavors from both **natural and synthetic compounds.**

Compounds

When two or more elements join together by forming chemical bonds, they make up a new, different substance. This substance is known as a compound.

Compounds are not just mixtures of elements. A mixture can be separated into the individual substances it contains, but it is not easy to turn a compound back into the elements that formed it. For example, water is a compound of hydrogen and oxygen. Only through a chemical reaction can it be changed back into these separate elements. A compound is made of atoms of two or more elements in a particular ratio. In water, for example, the ratio is two hydrogen atoms and one oxygen atom for every water molecule.

Fascinating formula

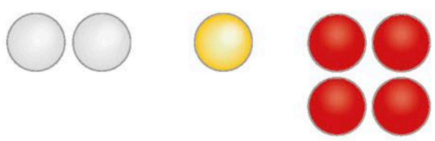
The chemical formula of a compound tells you which elements are present, and in what ratio. The compound sulfuric acid (H_2SO_4) is made of molecules that each contain two hydrogen atoms, one sulfur atom, and four oxygen atoms.

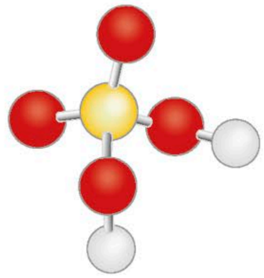
$$H_2SO_4 = \text{Sulfuric acid}$$

2 HYDROGEN ATOMS

1 SULFUR ATOM

4 OXYGEN ATOMS





Great ways to bond

There are two types of bond that can hold the atoms in a compound together: covalent and ionic (see pp.16–17). Covalent bonds form between non-metal atoms. Ionic bonds form between metal and non-metal atoms.

Covalent compounds
Covalent compounds, such as sugar, form molecules in which the atoms form covalent bonds. They melt and boil at lower temperatures than ionic compounds. When they dissolve in water, they do not conduct electricity.

Salt lowers the freezing point of water, so it is used for melting ice and snow on roads.

Ionic compounds
Ionic compounds consist of ions. An ion is an electrically charged particle, formed when an atom has lost or gained electrons. Ions bond together, forming crystals with high melting points. Salt is an ionic compound.

Calcium carbonate is found in egg shells, but also in harder seashells.

Best of both
Most compounds combine ionic and covalent bonding. In calcium carbonate, for example, calcium ions form ionic bonds with carbonate ions. Each carbonate ion contains carbon and oxygen atoms held together by covalent bonds.

Nothing like their elements

When atoms of different elements join to make new compounds, it is hard to tell what these elements are from looking at the compound. For example, no carbon is visible in carbon dioxide (CO_2), and no sodium in table salt, or sodium chloride (NaCl).

Na
Sodium

+

Cl
Chlorine

=

Salt, which contains the elements sodium and chlorine, looks nothing like either.

NaCl
Sodium chloride

Look what they have become
In chemical reactions, atoms from different elements regroup into new, different atom combinations. The resulting substances often look, and feel, completely different, too. For instance, sodium is a shiny metal, and chlorine is a pale green gas, but together they make sodium chloride (salt), a white crystal.

Pyrite, a form of iron sulfide

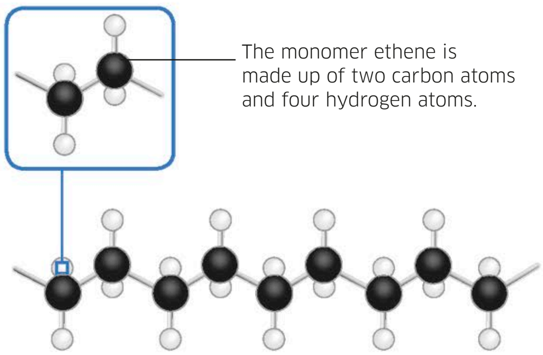
Iron sulfide
Iron sulfide, a compound of iron and sulfur, exists in several forms. Iron filings and yellow sulfur powder can be fused together to form a black solid called iron (II) sulfide (FeS). The mineral pyrite (FeS_2, above), known as "fool's gold," is another form of iron sulfide. Unlike iron, neither of these compounds is magnetic.

Polymers

Some molecules join together in a chain to form long polymers (meaning “many parts”). The smaller molecules that make up the polymer are called monomers. There are many important polymers in living things. Cellulose, which makes up wood, is the most abundant natural polymer on Earth. The DNA in our bodies, and starch in foods such as pasta, rice, and potatoes are also polymers. Polymers can be man-made, too. Synthetic polymers include a vast array of different plastics.

What makes a polymer

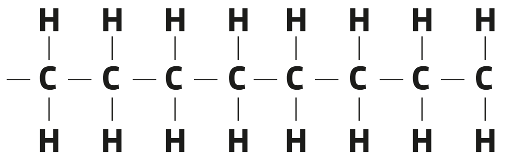
A polymer is like a long string of beads, with each bead, or monomer, in the string made up of exactly the same combination of atoms. Shorter ones, with just two monomers, are called dimers, while those with three are known as trimers.



The monomer ethene is made up of two carbon atoms and four hydrogen atoms.

Polyethylene polymer

A string of ethene monomers is known as polyethylene (or polyethene/polythene). There are several thousand ethene monomers in a polyethylene polymer.



Plastic polymers and recycling

The first man-made polymers were attempts to reproduce the natural polymers silk, cellulose, and latex (see pp.58–59). Today, plastics play a massive role in the way we live, but they also pose a serious risk to the environment. In 1988, an identification code was developed to make plastic recycling easier. The code’s symbols let the recyclers know what plastic an object is made of, which matters when it is time to process and recycle it.

Type of plastic	Symbol	Properties	Use
Polyethylene terephthalate	1 PET or PETE	Clear, lightweight but strong and heat-resistant. Good barrier to gas, moisture, alcohol, and solvents.	• Water bottles • Food jars • Ovenproof film
High-density polyethylene	2 HDPE	Tough; can be stretched without breaking, and easy to process. Resistant to moisture and solvents.	• Milk containers • Trash cans with wheels • Juice bottles
Polyvinyl chloride	3 PVC	Strong; resistant to chemicals and oil. Rigid PVC is used in construction; flexible PVC in inflatables.	• Pipes • Toys and inflatables • Flooring
Low-density polyethylene	4 LDPE	Flexible and tough, can withstand high temperatures. Good resistance to chemicals. Easy to process.	• Plastic bags • Snap-on lids • Six-pack rings
Polypropylene	5 PP	Tough, flexible, and long lasting. High melting point. Resistant to fats and solvents.	• Hinges on flip-top lids • Plastic medicine bottles • Concrete additives
Polystyrene	6 PS	Can be solid or foamed. Good for insulation and easy to shape, but slow to biodegrade.	• Disposable foam cups • Plastic cutlery • Packaging
Miscellaneous	7 Miscellaneous	Other plastics such as acrylic, nylon, polylactic acid, and plastic multi-layer combinations.	• Baby bottles • Safety glasses • “Ink” in 3-D printers

Rain is naturally acidic (pH5), but burning fossil fuels that release polluting **nitrogen oxides and sulfur dioxide** makes it more acidic.

Acids and bases

Chemical opposites, acids and bases react when they are mixed together, neutralizing one another. Bases that are soluble in water are called alkalis. All alkalis are bases, but not all bases are alkalis.

Bases and acids can be weak or strong. Many ingredients in food contain weak acids (vinegar, for instance) or alkalis (eggs), while strong acids and alkalis are used in cleaning products and industrial processes. Strong acids and alkalis break apart entirely when dissolved in water, whereas weak acids and alkalis do not.

Corrosive power

Strong acids and alkalis can cause serious burns to skin. Very strong acids and alkalis can burn through metal, and some can even dissolve glass. While dangerous, their corrosive power can be useful, for instance, for etching glass or cleaning metals.

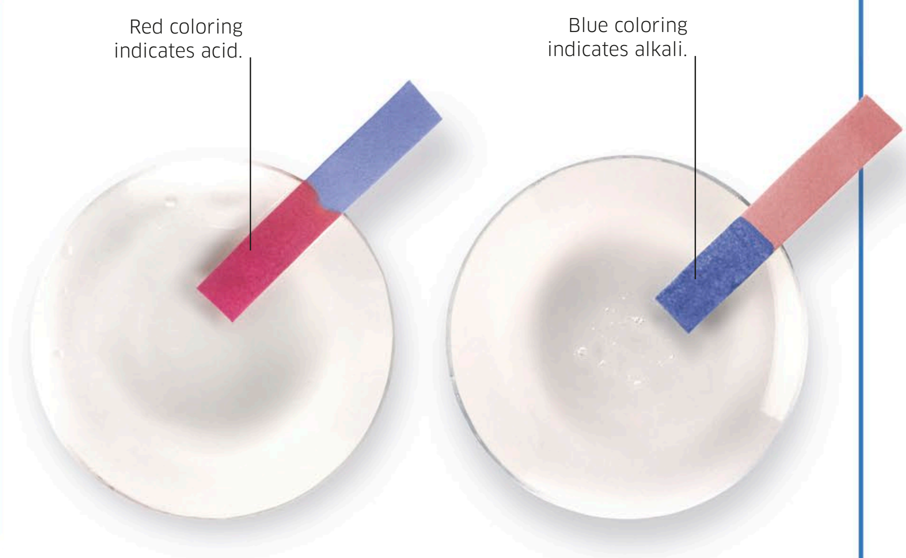
Is it an acid or a base?

The acidity of a substance is measured by its number of hydrogen ions—its "power of hydrogen" or pH. Water, with a pH of 7, is a neutral substance. A substance with a pH lower than 7 is acidic; one with a pH above 7 is alkaline. Each interval on the scale represents a tenfold increase in either alkalinity or acidity. For instance, milk, with a pH of 6, is ten times more acidic than water, which has a pH of 7. Meanwhile, seawater, with a pH of 8, is ten times more alkaline than pure water.

Hydrogen ions (H^+)
determine whether a solution is an acid or an alkali. Acids are H^+ donors while alkalis are H^+ acceptors.

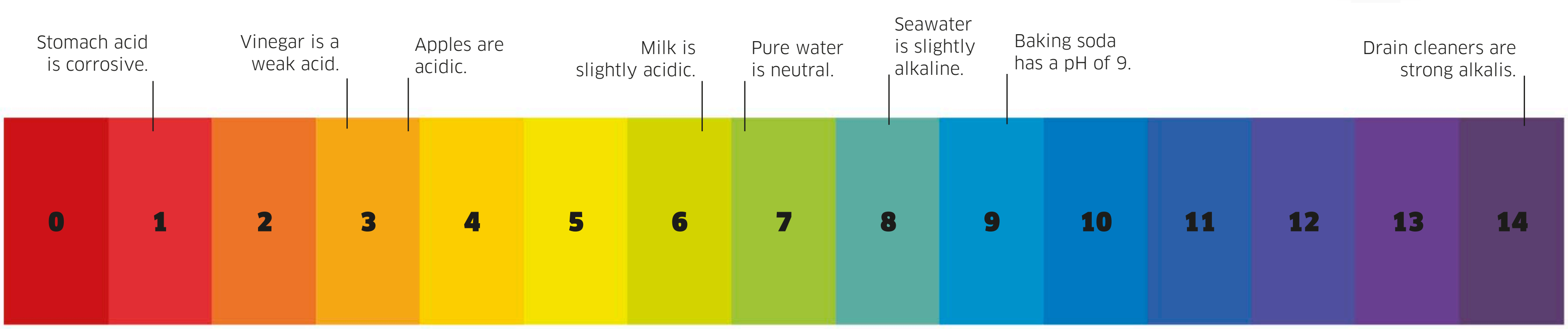
The litmus test

A version of the litmus test has been used for hundreds of years to tell whether a solution is acidic or alkaline. Red litmus paper turns blue when dipped into an alkali. Blue litmus paper turns red when dipped into an acid.



The pH scale

Running from 0 to 14, the pH scale is related to the concentration of hydrogen ions (H^+). A pH of 7 is neutral. A pH of 1 indicates a high concentration of hydrogen ions (acidic). A pH of 14 shows a low concentration (alkaline).

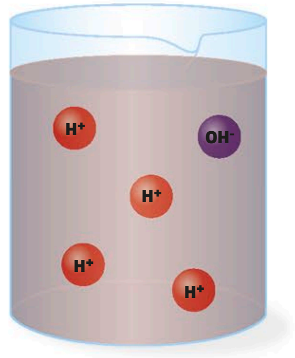


The universal indicator test

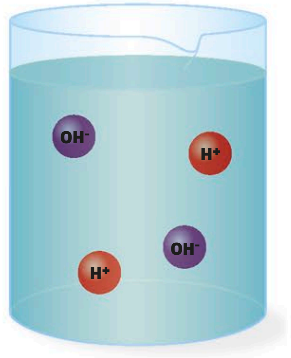
Indicator paper contains several different chemicals that react, turning a range of colors in response to different pH values. Dipping indicator paper into an unknown solution reveals its pH.

It's all about the ions

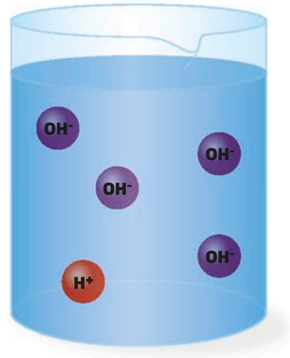
The difference between an acid and an alkali comes down to their proportion of positively charged particles called hydrogen ions (H^+). When an acidic compound is dissolved in water, it breaks up, releasing H^+ ions: it has an increased proportion of positively charged ions. When an alkaline compound dissolves in water it releases negatively charged particles called hydroxide ions (OH^-). Acids are called H^+ donors; alkalis are called H^+ acceptors.



Acid
There are more positively charged H^+ ions than negatively charged OH^- ions in an acid.



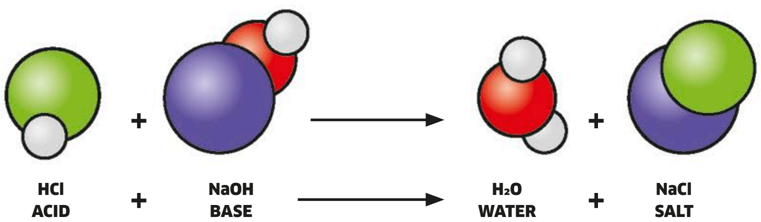
Neutral
A neutral solution contains equal numbers of positive H^+ and negative OH^- ions.



Base
There are more negatively charged OH^- ions than positively charged H^+ ions in an alkali.

Mixing acids and bases

The reaction between an acid and an alkali produces water and a salt. It is called a neutralization reaction. The H^+ ions in the acid react with the OH^- ions in the alkali, resulting in a substance that is neither acid nor alkali. Different acids and alkalis produce different salts when they react.

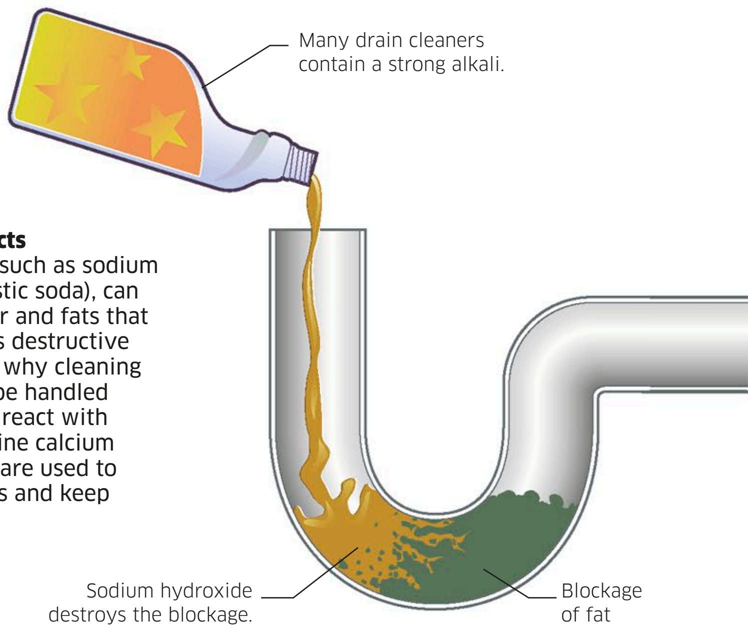


Neutralization formula
When hydrochloric acid (HCl) reacts with the alkali sodium hydroxide (NaOH), they produce a neutral solution that consists of water (H_2O) and a well-known salt—sodium chloride (NaCl), or table salt.

Acids and bases in agriculture
Farmers monitor soil pH levels carefully. Soils are naturally acidic or alkaline, and different crops prefer a higher or lower pH. Farmers can reduce the soil pH by adding certain fertilizers, or raise the soil pH with alkalis, such as lime (calcium hydroxide).

Kitchen chemistry

The kitchen is a great place to see acids and alkalis in action. Weak acids—found in lemon juice and vinegar—can preserve or improve the flavor of food. When baking, we use weak alkalis present in baking soda to help cakes to rise. Strong acids and alkalis are key ingredients in a range of cleaning products. They are so powerful that protective gloves must be worn when using them.



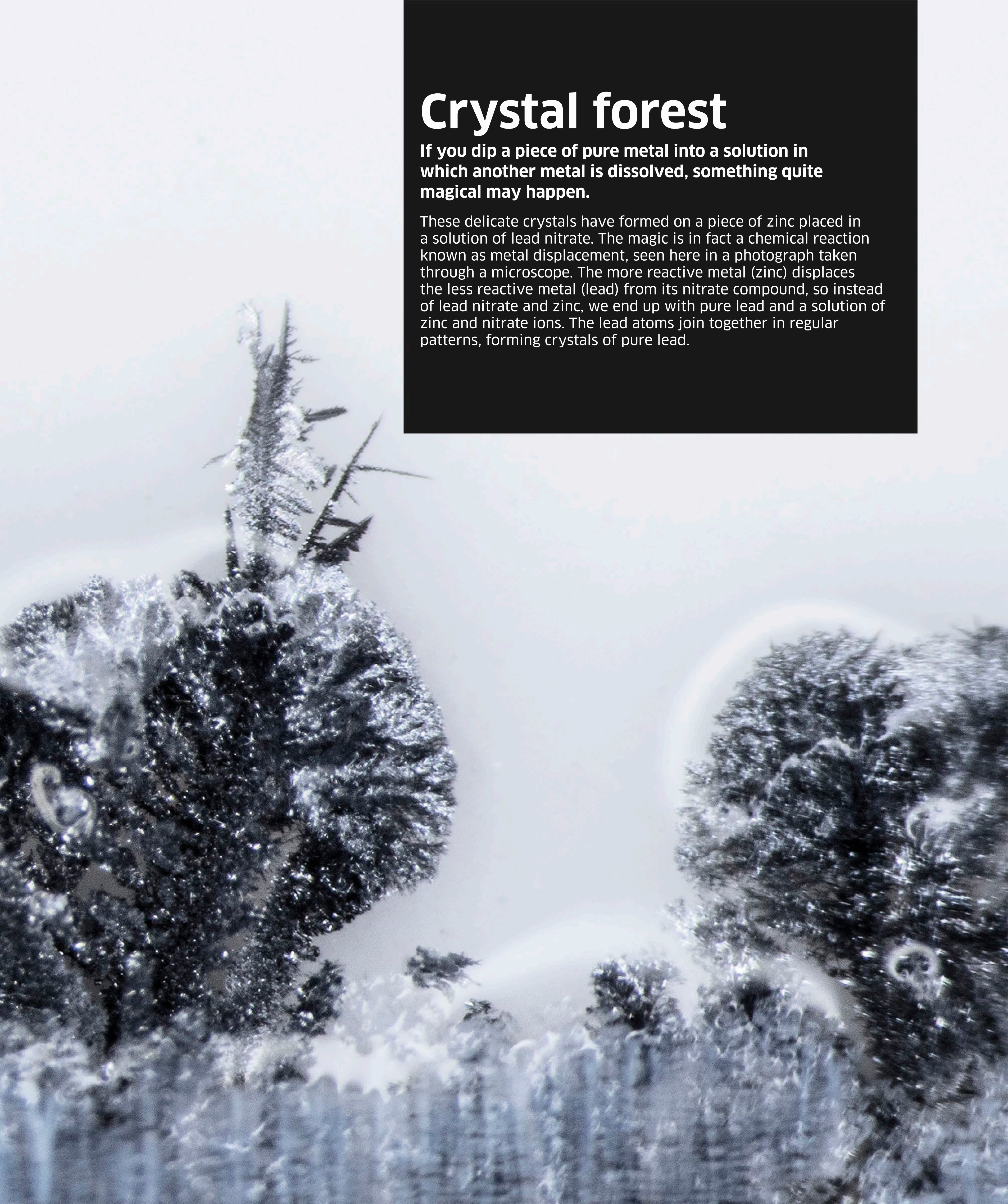
Cleaning products
A strong alkali, such as sodium hydroxide (caustic soda), can break down hair and fats that clog drains. This destructive power explains why cleaning products must be handled carefully. Acids react with limescale (alkaline calcium carbonate) and are used to descale showers and keep taps shiny.

Baking powder
Added to flour to help cakes rise, baking powder contains an acid and an alkali, which react together when a liquid and heat are added. The reaction produces bubbles of carbon dioxide that push the cake mixture upward.

Crystal forest

If you dip a piece of pure metal into a solution in which another metal is dissolved, something quite magical may happen.

These delicate crystals have formed on a piece of zinc placed in a solution of lead nitrate. The magic is in fact a chemical reaction known as metal displacement, seen here in a photograph taken through a microscope. The more reactive metal (zinc) displaces the less reactive metal (lead) from its nitrate compound, so instead of lead nitrate and zinc, we end up with pure lead and a solution of zinc and nitrate ions. The lead atoms join together in regular patterns, forming crystals of pure lead.



Space rockets use combustion to take off, fueled by **liquid hydrogen**.

Combustion

Combustion is the reaction between a fuel—such as wood, natural gas, or oil—and oxygen. The combustion reaction releases energy in the form of heat and light. Fuel needs a trigger (a match or a spark) before combustion can start.

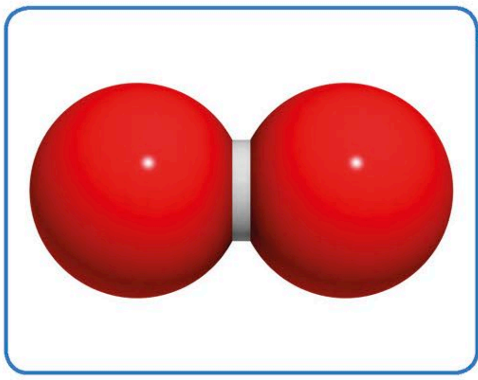
Combustion is at work in bonfires, fireworks, and when we light a candle. But more than just a spectacle, it is essential to the way we live. Most of the world's power stations generate electricity using the combustion of fossil fuels such as coal, oil, and gas. Most cars, semi trucks, boats, and planes are driven by engines powered by combustion. Scientists are working hard to create alternatives to what is now understood to be a potentially wasteful and harmful source of energy. But for now we all rely on it to keep warm and to get where we need.

Campfire chemistry

Dry wood contains cellulose (made of the elements carbon, hydrogen, and oxygen). It burns well in oxygen, which makes up about one fifth of air.

Carbon dioxide
Carbon dioxide (CO_2) is produced when wood burns. Known as a greenhouse gas, it contributes to global warming if there is too much of it in the atmosphere.

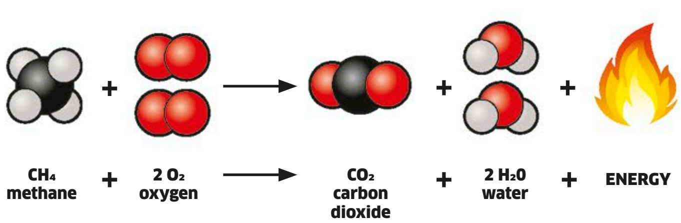
Water vapor
The combustion of cellulose, which makes up about half the dry mass of wood, produces water (H_2O) as well as carbon dioxide (CO_2). In the heat of a fire, the water evaporates as steam.



Oxygen
For combustion to work, there needs to be a good supply of the element oxygen. Oxygen in the air exists as molecules made up of two oxygen atoms, with the chemical formula O_2.

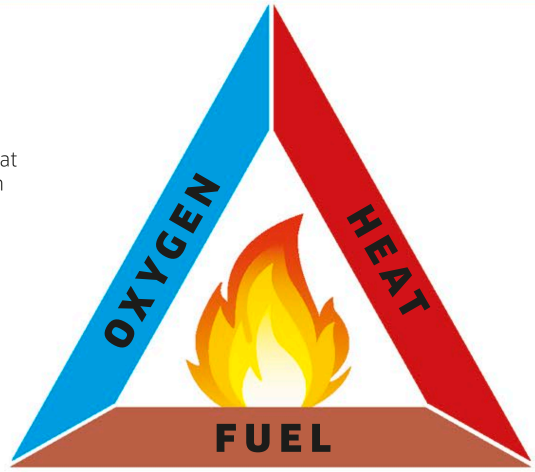
A balanced reaction

During combustion, substances known as reactants are transformed into new substances called products. The reaction rearranges the atoms of the reactants. They swap places, but the number of each is the same. Energy (heat and light) is released when the bonds that hold the initial molecules together are broken and new ones are formed.



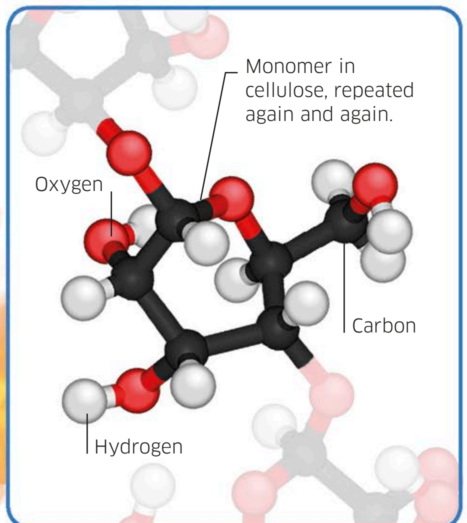
Methane combustion
Above is the reaction formula for the combustion of methane (natural gas). The number of carbon (C), hydrogen (H), and oxygen (O) atoms is the same on each side of the arrow, but the substances they make up have changed.

Heat and light
Combustion releases energy in the form of heat and light. Although it can feel very hot at the top of the flame, the hottest part of a flame is the blue area near its base.



Combustion triangle
These three ingredients—fuel, oxygen, and heat—are all essential for combustion. Removing any one of them will extinguish a fire.

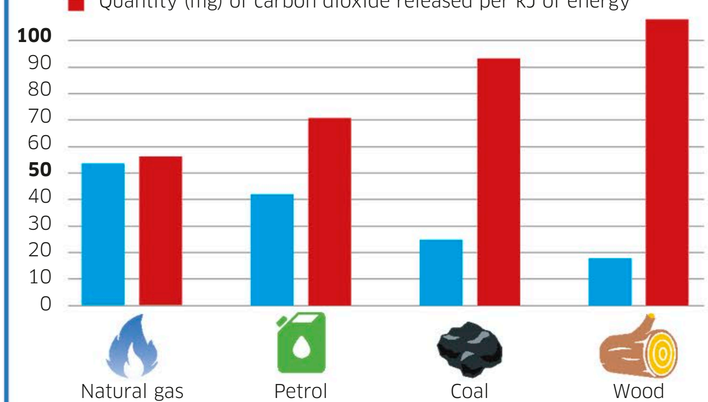
Fuel: firewood
Wood contains a material called cellulose. It consists of long molecules known as polymers (see p.45). Each polymer is made of a chain of smaller identical parts, called monomers. Each monomer in cellulose has six carbon atoms, ten hydrogen atoms, and five oxygen atoms, so its formula is $C_6H_{10}O_5$.



Fuel efficiency and the environment

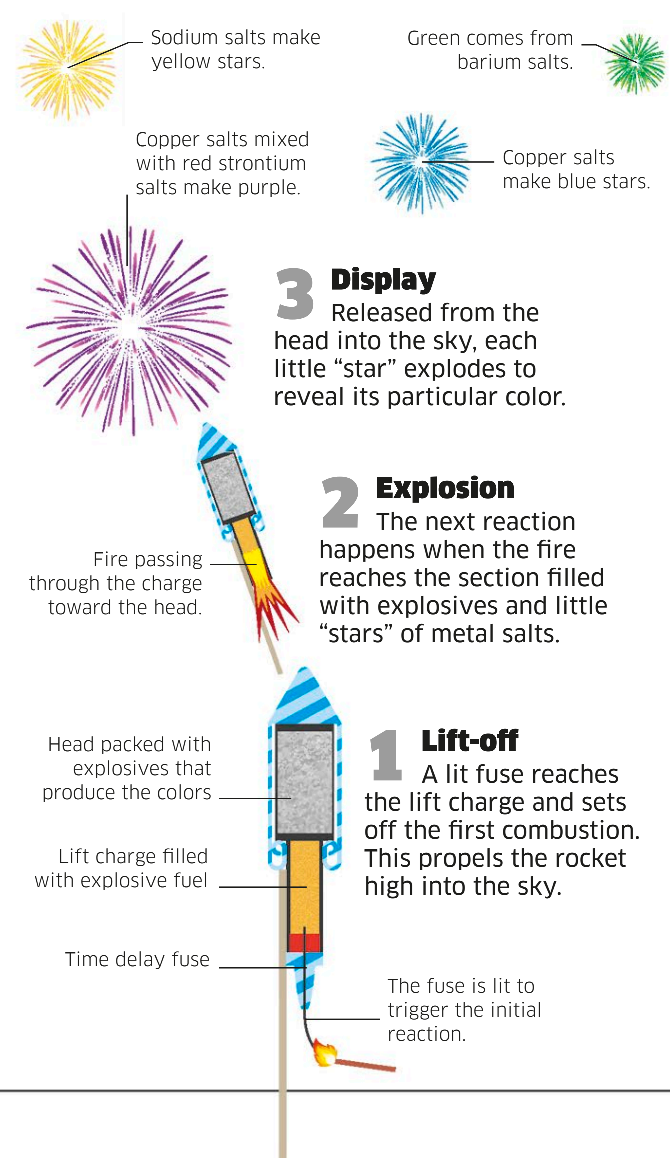
Different fuels release different amounts of energy. They also produce different amounts of carbon dioxide when they burn. Wood is least efficient and produces the most carbon dioxide, which makes it the least environmentally friendly fuel.

Energy values of different fuels



Fireworks

Fireworks shoot up in the air and explode into colorful displays thanks to combustion. The fuel used is charcoal, mixed with oxidizers (compounds providing oxygen) and other agents. The colors come from different metal salts.



3 Display
Released from the head into the sky, each little "star" explodes to reveal its particular color.

2 Explosion
The next reaction happens when the fire reaches the section filled with explosives and little "stars" of metal salts.

1 Lift-off
A lit fuse reaches the lift charge and sets off the first combustion. This propels the rocket high into the sky.

Electrochemistry

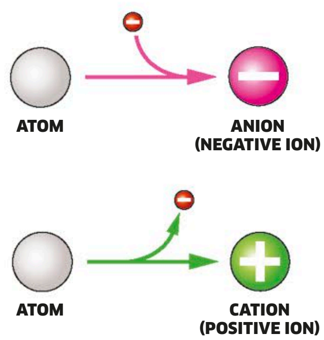
Electricity and chemical reactions are closely linked, and together fall under the heading electrochemistry. Electrochemistry is the study of chemical processes that cause electrons to move.

An electric current is a steady flow of electrons, the tiny negative particles that whizz around in the shells of atoms. Electrons can flow in response either to a chemical reaction taking place inside a battery, or to a current delivered by the main electrical grid.

Electricity is key to electrolysis. This process is used in industries to extract pure elements from ionic compounds (see p.44) that have been dissolved in a liquid known as an electrolyte. Electrolysis can also be used to purify metals, and a similar process can be used to plate (cover) objects with a metal. The result depends on the choice of material of the electrodes and, in particular, the exact contents of the electrolyte.

Ions and redox reactions

Chemical reactions where electrons are transferred between atoms are called oxidation-reduction (redox) reactions. Atoms that have lost or gained electrons become ions, and are electrically charged. Atoms that gain electrons become negative ions (anions). Atoms that lose electrons become positive ions (cations). These play an important role in electrolysis.

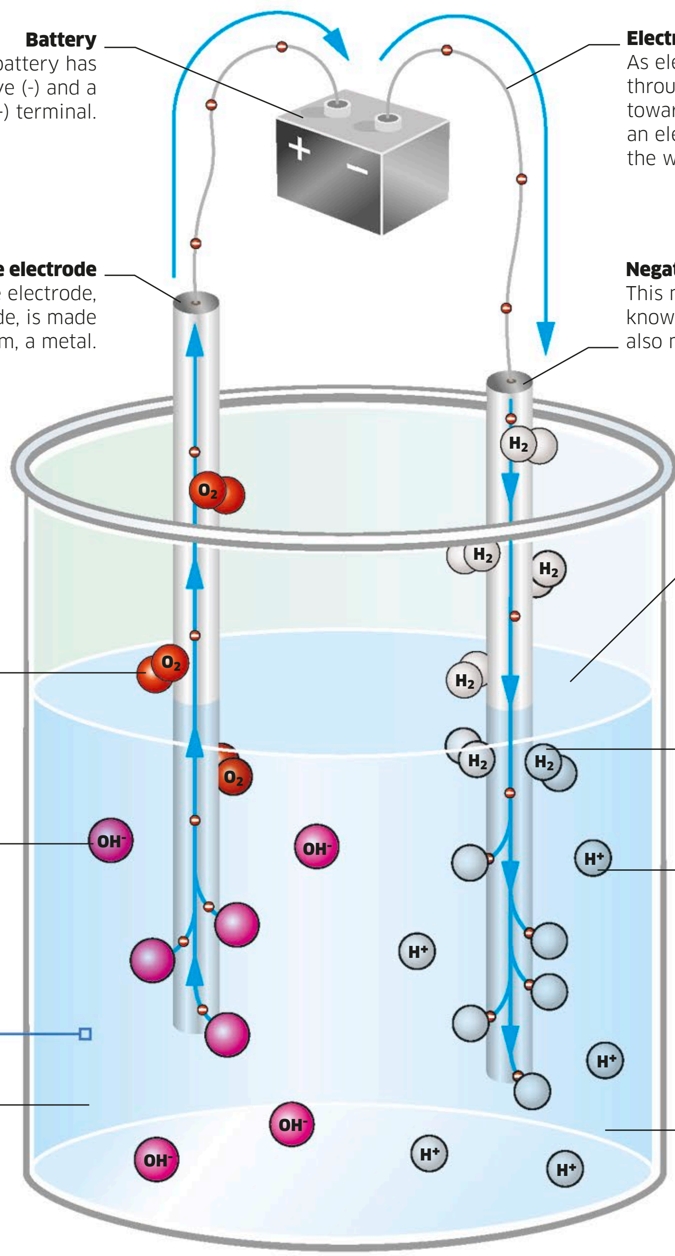


Reduction
Reduction is "gain of electrons."

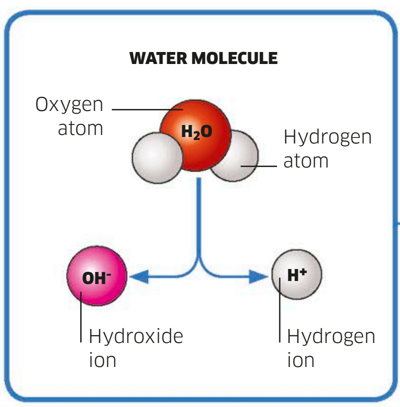
Oxidation
Oxidation is "loss of electrons."

Electrolysis

Ionic compounds contain positive and negative ions. They can be separated using electricity, by a process called electrolysis. If electricity passes through an electrolyte (an ionic compound that has been dissolved in water), the negative ions in the electrolyte will flow toward the positive electrode and the positive ions will flow toward the negative electrode. The products created in the process will depend on what is in the electrolyte. This diagram shows how water (H_2O) can be split back into its original pure elements, oxygen and hydrogen. The two gases can be trapped and collected as they bubble up along the electrodes.

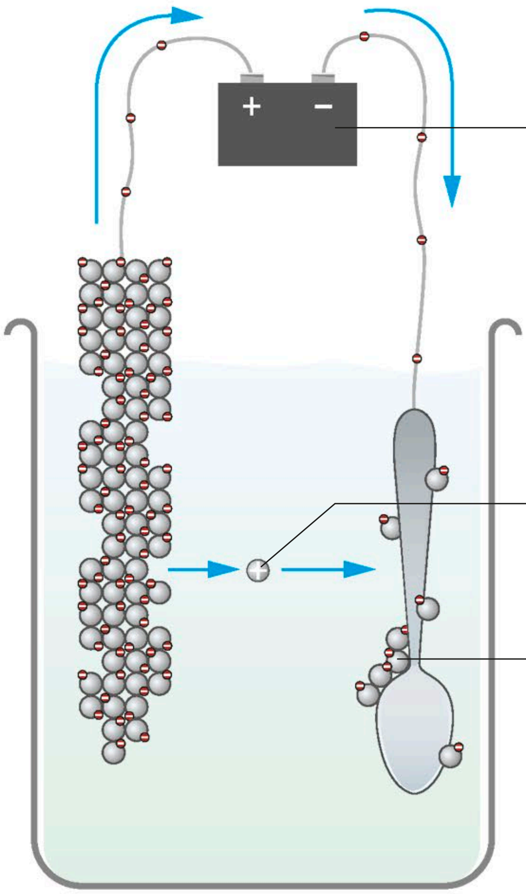


Water as electrolyte
The electric current makes each neutral water molecule (H_2O) split up into electrically charged ions: a positive hydrogen ion (H^+) and a negative hydroxide ion (OH^-).



Electroplating

Similar to electrolysis, electroplating is a process that coats a cheaper metal with a more expensive metal, such as silver. To turn a cheap metal spoon into a silver-plated spoon, the cheap metal spoon is used as a cathode (negative electrode) and a silver bar is used as the anode (positive electrode). These two electrodes are bathed in an electrolyte that contains a solution of the expensive metal, in this case silver nitrate solution.



1 Battery This power supply has a cheap metal spoon connected to its negative terminal. A silver bar is connected to the positive terminal.

2 Oxidation When an electric current is switched on, silver loses electrons at the anode and is oxidized. Positive silver ions enter the silver nitrate solution.

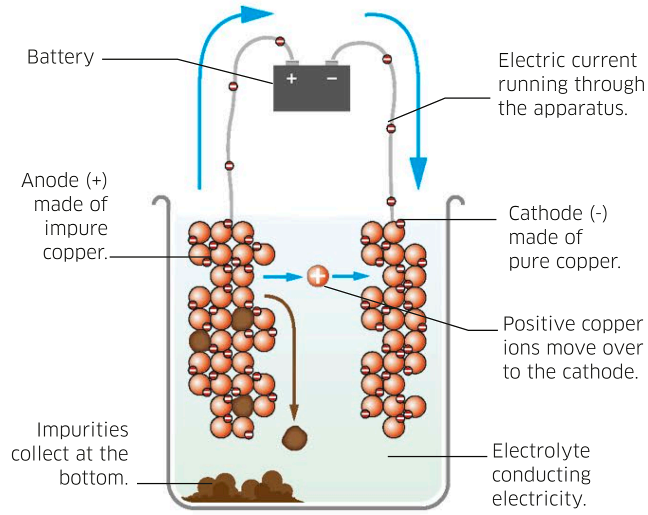
3 Reduction The positive silver ions are attracted to the negative cathode. When they arrive, they gain electrons and are reduced. Metallic silver coats the spoon cathode.

Oxidation in air
Silver oxidizes when exposed to air, so silver plated items eventually lose their shine as a gray tarnish forms on the surface. Polishing removes the tarnish but the plating might be damaged.

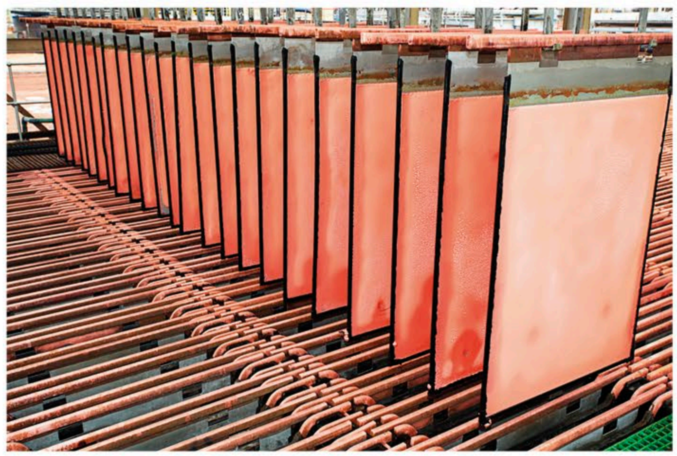
Galvanizing
Steel or iron can be prevented from rusting (a form of oxidation) by coating them in the metal zinc, a process called galvanizing. These nails have been galvanized.

Purifying metals

The copper that is extracted from copper ore is not pure enough to become electrical wiring. It has to be purified by electrolysis. Impure copper acts as the anode, and pure copper as the cathode. These electrodes lie in a solution of copper sulfate.

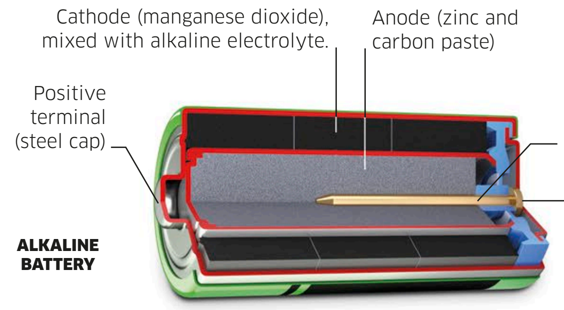


Electrorefining
Pure copper is used to make electrical wiring and components. Here you can see copper purification, called electrorefining, being carried out on a massive scale in a factory, in the process described above.



Electrochemistry in batteries

Batteries turn chemical energy into electrical energy (see p.92). This is the opposite of electrolysis, which turns electrical energy into chemical energy. In a battery, it is the anode that is negative and the cathode that is positive. The reaction at the anode is still oxidation and at the cathode it is still reduction.



Hot metal

Ignite a mixture of chemicals called thermite and you'll need to stand back! These chemicals react together very quickly, producing enormous amounts of heat.

A thermite reaction is a spectacular display, but also serves a practical purpose: it is used to extract molten iron from iron oxide for welding. It takes a lot of heat to start the reaction, which then releases enough heat to melt the iron. The process most commonly uses a mixture of iron oxide and aluminum. A slim ribbon of magnesium is inserted into the mixture as a fuse. When ignited, it starts the reaction, breaking the bonds between the iron and oxygen atoms. Aluminum then bonds with the released oxygen, producing more heat. This in turn breaks more bonds and melts the leftover iron.

MATERIALS

The word "materials" describes the kind of matter we use for making and building things. Every object is made of a material—a hard material or a soft material, a rough or a smooth, a multicolored or a plain gray one. Nature has come up with millions of different materials, and people have developed millions more. You might think that is more than enough materials, but researchers are continually discovering amazing new natural materials, and inventing incredible new synthetic materials.

NATURAL OR SYNTHETIC?

People have used natural materials—such as wool, leather, and rubber—for thousands of years. Today we also make materials using chemicals. These synthetic materials have unique properties and make us less reliant on precious natural materials, but they can be difficult to dispose of in an environmentally friendly way.

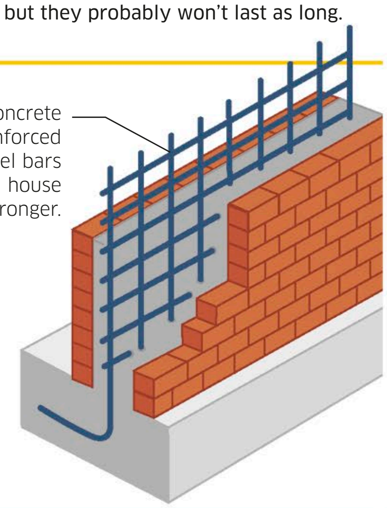
Natural leather
Leather is made from animal skin. People have worn leather since the Stone Age, and still do. Leather can be molded into shape, retains heat, is fairly waterproof, and resists tears.

Synthetic trainer
The synthetic materials in this sports shoe offer several advantages over leather. They are easier and cheaper to produce, and have more flexibility, but they probably won't last as long.

CHOOSING MATERIALS

Different materials suit different purposes—there is no single "best material." It all depends on what you want a material to do. Among their many properties, materials vary according to how hard they are, what they feel like, how strong or elastic they are, and whether or not they are waterproof.

Composite materials
Sometimes the properties of one material are not enough, so two or more materials are combined into a composite. There are different composites. Concrete is made from strong stones, sand to fill the gaps, and cement to bind it all together. It stays together thanks to a chemical reaction that sets it. It can be made even stronger by adding steel bars in wet concrete. Fiberglass is a type of plastic reinforced with glass fibers. It is lightweight and easy to mold, and is used to make anything from bathtubs to boats and surfboards.



Concrete reinforced with steel bars makes a house wall stronger.

Properties of materials
This chart lists some of the properties we need to think about when choosing a material for a certain product, and some common materials. Some of these properties are relative: marble, for example, is hard, but for a rock it is quite soft, which is why sculptors have chosen it to carve into statues since ancient times.

Material	Hardness	Texture	Strength	Elasticity	Water resistance
 **Wood**	From soft (balsa) to hard (mahogany)	Rough unless polished	Strength varies	Can be elastic or rigid	Some woods are more waterproof
 **Glass**	Very hard (does not flex under pressure)	Smooth	Not very strong; shatters on impact	Not elastic	Waterproof
 **Diamond**	One of the hardest materials known	Smooth when cut	Strong	Not elastic	Waterproof
 **Marble**	Hard (but soft for a rock)	Smooth	Strong	Not elastic	Waterproof
 **Wool**	Soft natural fibers	Rough or smooth	Strong fibers	Elastic in wool yarn and clothing	Not waterproof
 **Kevlar®**	Hard synthetic fibers	Smooth	Strong	Elastic	Waterproof
 **Nylon**	Hard synthetic	Smooth	Strong	Elastic in tights; less so in rope	Waterproof
 **Steel**	Hard metal alloy	Smooth	Strong	Elastic, particularly in springs	Waterproof
 **Copper**	Soft metal	Smooth	A weak metal	Not elastic	Waterproof

LASTING MATERIALS

Materials last for different lengths of time. Some materials decay in a matter of weeks, while some last for tens of thousands of years. The materials that survive for millennia provide a fascinating window into the way our ancestors used to live.

Viking long ship
Several Viking longships dating back more than a thousand years have been discovered intact in burial mounds. These ships were built of wood such as oak. Wood normally decays after a few hundred years, but the organisms that break it down need oxygen. There was no oxygen supply around the ships that lay buried, so the wood survived. Hulls of sunken wooden sailing ships survive underwater for the same reason.

The Oseberg ship, dating from 800 CE, was found in a burial mound in Norway.

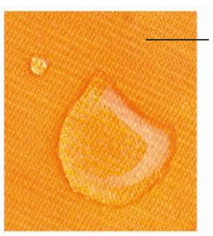
Roman amphitheater
Rome's Colosseum is made of several materials—a rock called travertine; another rock made of volcanic ash, called tuff; and concrete. It was built in 80 CE as an amphitheater. Since then it has been through wars and used as housing, factories, shops, and a fortress, but the basic materials have remained in place.

NEW MATERIALS

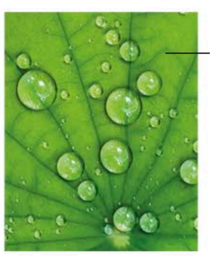
Material scientists—chemists, physicists, and engineers—research and deliver a steady stream of exciting new materials. Some materials resist damage, some heal themselves. There are plastics that conduct electricity, and wall coverings that reduce pollution. Environmental concerns are leading to materials designed to use fewer natural resources and to decompose without harmful waste.

Aerogel
Aerogels are incredibly lightweight. Normal gels have a liquid and a solid component. In aerogels, the liquid is replaced by air—more than 99.8 percent of an aerogel is air. It protects from both heat and cold. Possible uses include insulation for buildings, space suits, and sponges for mopping up chemical spills.

Nanotechnology
Nanotechnology deals with materials that are between 1 and 100 nanometers wide or long. A nanometer is a millionth of a millimeter (making a housefly about 5 million nanometers long). This means new materials can be designed by moving and manipulating atoms.



This fabric is coated with water-repellent nanoparticles made of aluminium oxide.



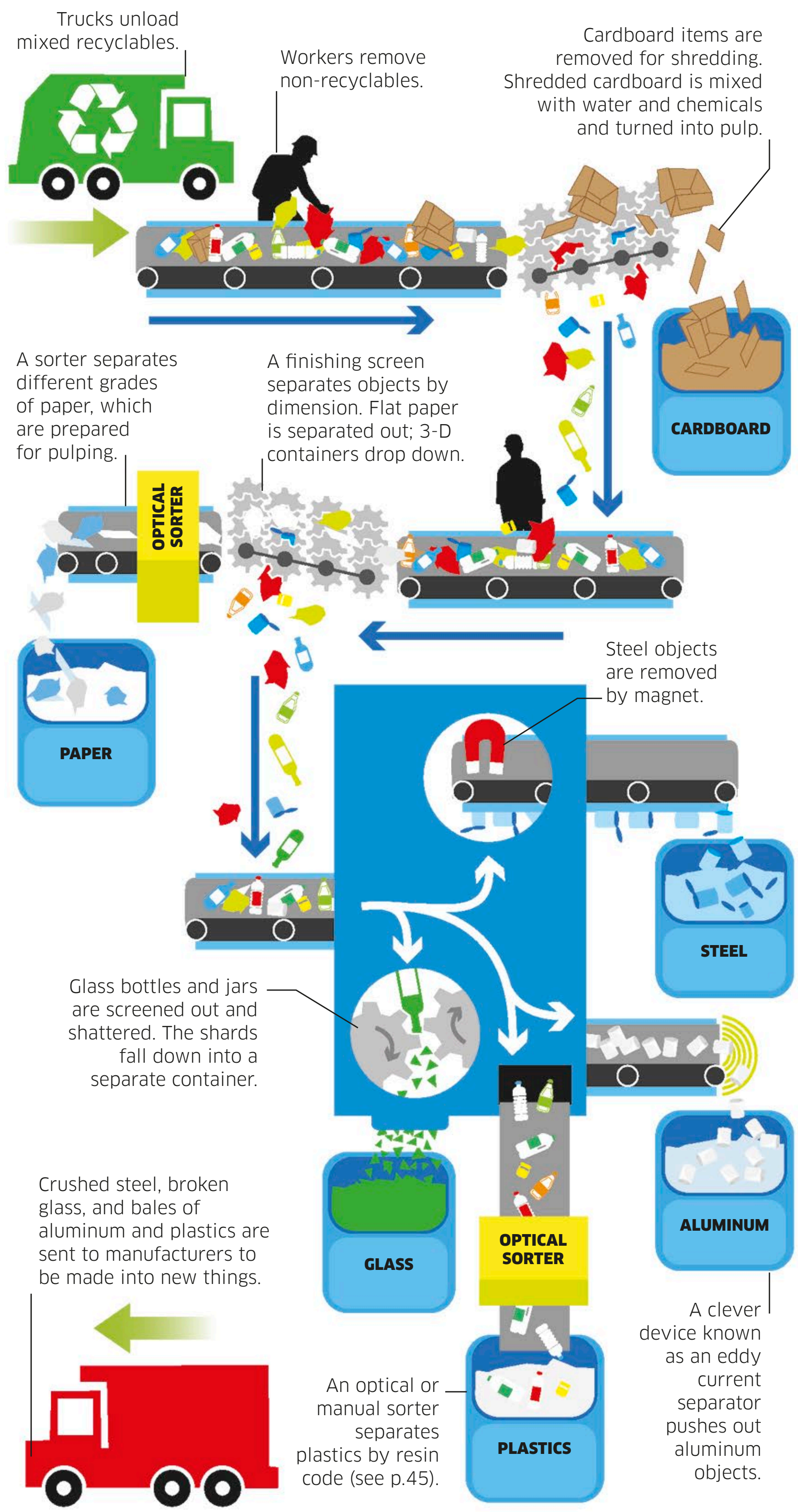
The surface of a lotus leaf is naturally "nanostructured" to repel water.

REUSING AND RECYCLING

Reusing and recycling materials reduces the need to produce ever more of the materials we use a lot. This helps conserve raw materials, and cuts harmful carbon emissions. Materials production today considers the full life-cycle of a product—from reducing the raw materials and energy needed to produce it in the first place, to preventing materials from ending up in landfills and oceans.

The recycling sorting process

Different materials must be recycled in separate ways, and some things that get put in recycling bins cannot be recycled at all. The vast amount of materials we throw away gets processed in huge recycling centers.



600 The **number of trees** needed to build a medieval **warship**.

Natural materials

Early humans learned to use the materials they found around them to make tools, clothes, and homes. Many natural materials are still used in the same way, while others are combined to make new ones.

Some natural materials come from plants (for example wood, cotton, and rubber), others from animals (silk and wool), or from Earth's crust (clay and metals). Their natural properties—bendy or rigid, strong or weak, absorbent or waterproof—have been put to good use by humans for millions of years. People have also learned to adjust these properties to suit their needs. Soft plant fibers and animal wool are spun into longer, stronger fibers. Animal skins are treated to make leather to wear. Skins were also used to make parchment to write on; now we use paper made from wood. Metals are mixed to make stronger materials called alloys (see pp.62–63).

Materials from animals

Animals, from insects to mammals, are a rich source of materials. The skin of pigs, goats, and cows can be treated and turned into leather. Caterpillars called silkworms spin themselves cocoons that can be unraveled into fine silk threads. Sheep grow thick, waterproof hair that can be cut off, or shorn, and spun into wool thread used for knitting or woven into fabrics.

Silk
Silkworms and their moth parents have been farmed for more than 5,000 years. A cocoon can produce up to 2,950 ft (900 m) of silk thread that can be made into beautiful fabrics.

The silk used for these bright scarves has been dyed. Natural silk is pale in color, and its tone depends on what the silkworms are eating.

Different breeds of sheep produce different types of wool.

Wool
Sheep have been bred for their wool for more than 6,000 years. An average sheep produces wool for about eight sweaters a year—or 60 pairs of socks. Today, wool is often mixed with acrylic fibers.

Wool yarn
Wool is washed, then spun into long fibers, and dyed.

Materials from plants

Plant materials have played a key role in humanity's success as a species. Wood has provided shelters, tools, and transportation, while cotton and flax (a plant used to make linen) have clothed people for thousands of years. Plant materials can be flexible or rigid, heavy or light, depending on the particular combination of three substances in their cell walls: lignin, cellulose, and hemicellulose.

Latex and rubber
Today, a lot of rubber is synthetic, but natural rubber comes from latex, a fluid that can be tapped from certain types of trees. It contains a polymer that makes it elastic.

Cotton
Fluffy cotton, consisting mainly of cellulose, protects the cotton plant's seeds. It is picked and spun into yarn or thread. The texture of cotton fabrics vary depending on how they are woven.

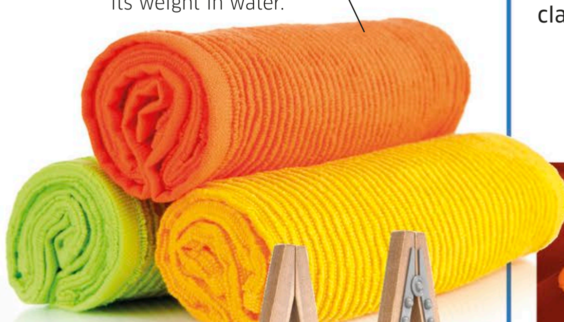
Wood
Different types of wood have different properties, including color, texture, weight, and hardness, making them suitable for different things. Wood pulp is used to make paper. A lot of wood is harvested from wood plantations.

Keeping it natural
Natural materials, such as rubber, cotton, and different types of wood, are used in a wide range of everyday items, such as the ones seen here.

Vulcanized tires
Adding sulfur to natural rubber, a process called vulcanization, increases its durability.

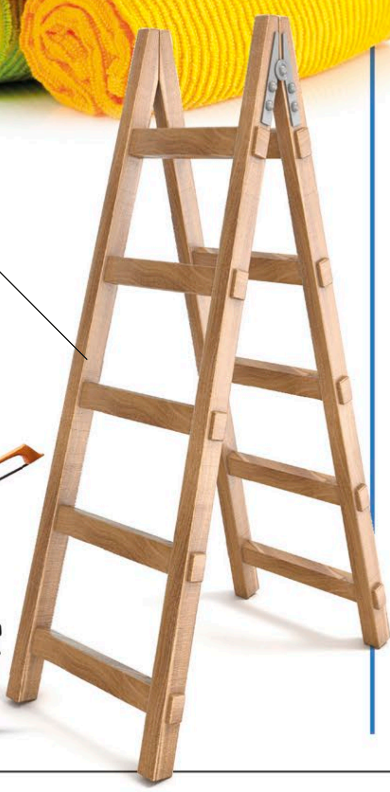
Elastic, not plastic
Rubber gloves are often made of flexible latex.

Thin but strong
Cellulose polymer chains line up together to give cotton thread its strength.

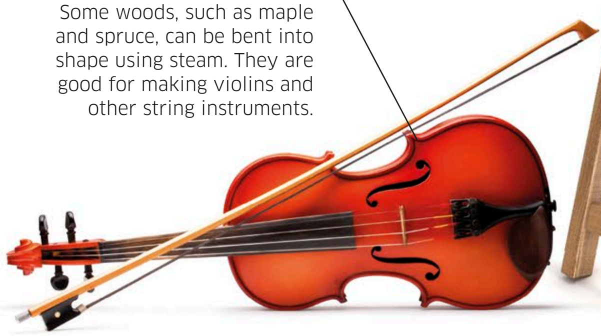


Absorbent cotton
Cotton is great for towels and cotton swabs as it is soft and can absorb up to 27 times its weight in water.

Cotton swabs



Steady support
Lignin is the substance that holds cellulose and hemicellulose fibers together and makes wood stiff and strong—useful properties for ladders.

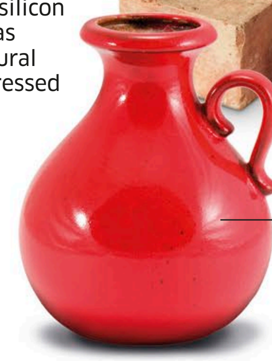


Curved wood
Some woods, such as maple and spruce, can be bent into shape using steam. They are good for making violins and other string instruments.

Materials from Earth's crust

Earth materials range from sand, clay, and rocks to minerals and metals. Materials from the earth have always been important for building. If you look at buildings, you can usually see what materials lie underground in the area—flint or slate, sandstone, limestone, marble, or clay. These materials are also essential for practical and decorative cookware, earthenware, and utensils.

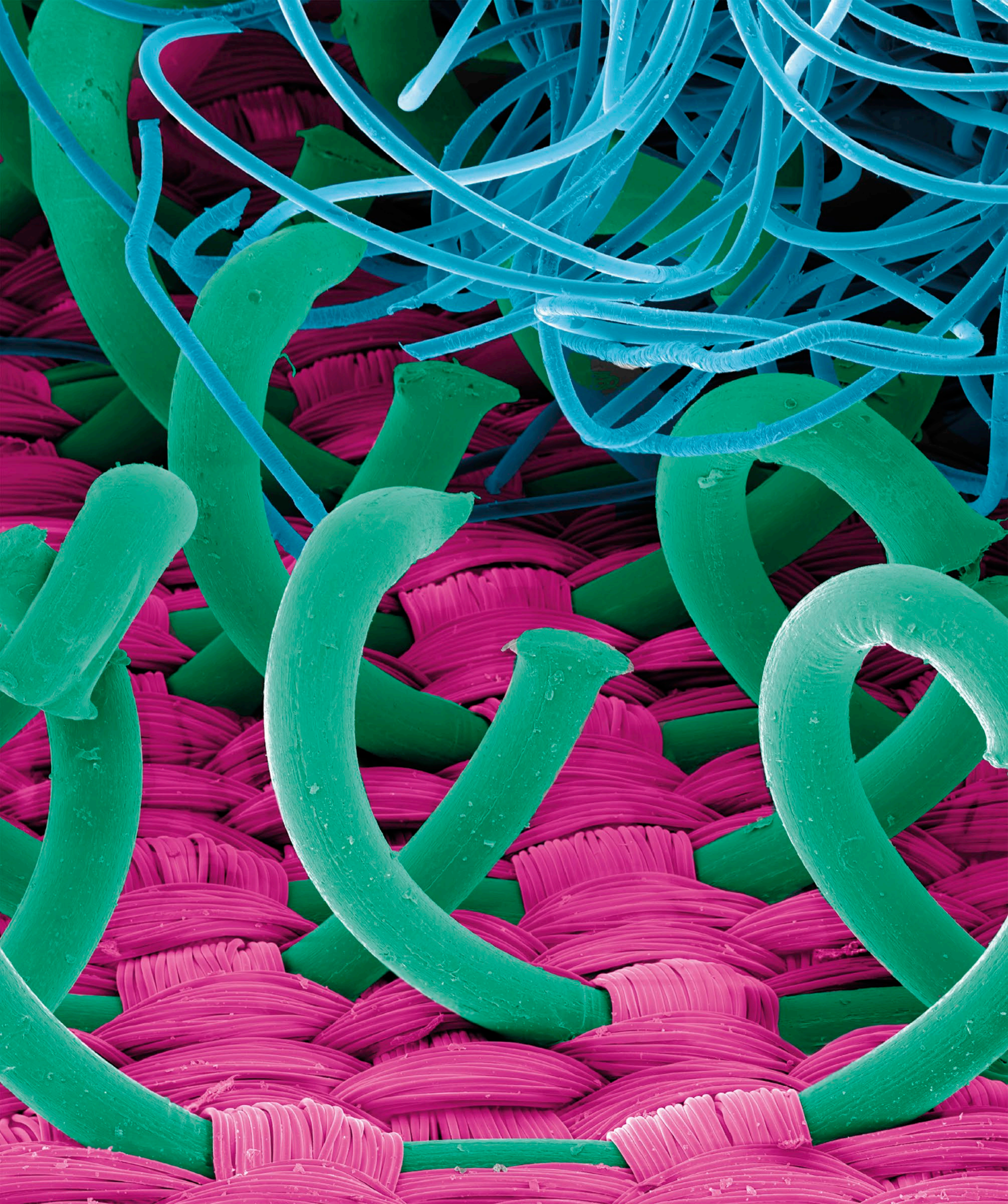
Clay and clay products
Clay, a mixture of the minerals silicon dioxide and aluminum oxide, has many uses. To make bricks, natural clay is mixed with water and pressed into shape before being dried. It is then baked at very hot temperatures to make it waterproof. Pottery is made in a similar way, but with clay of finer particles.

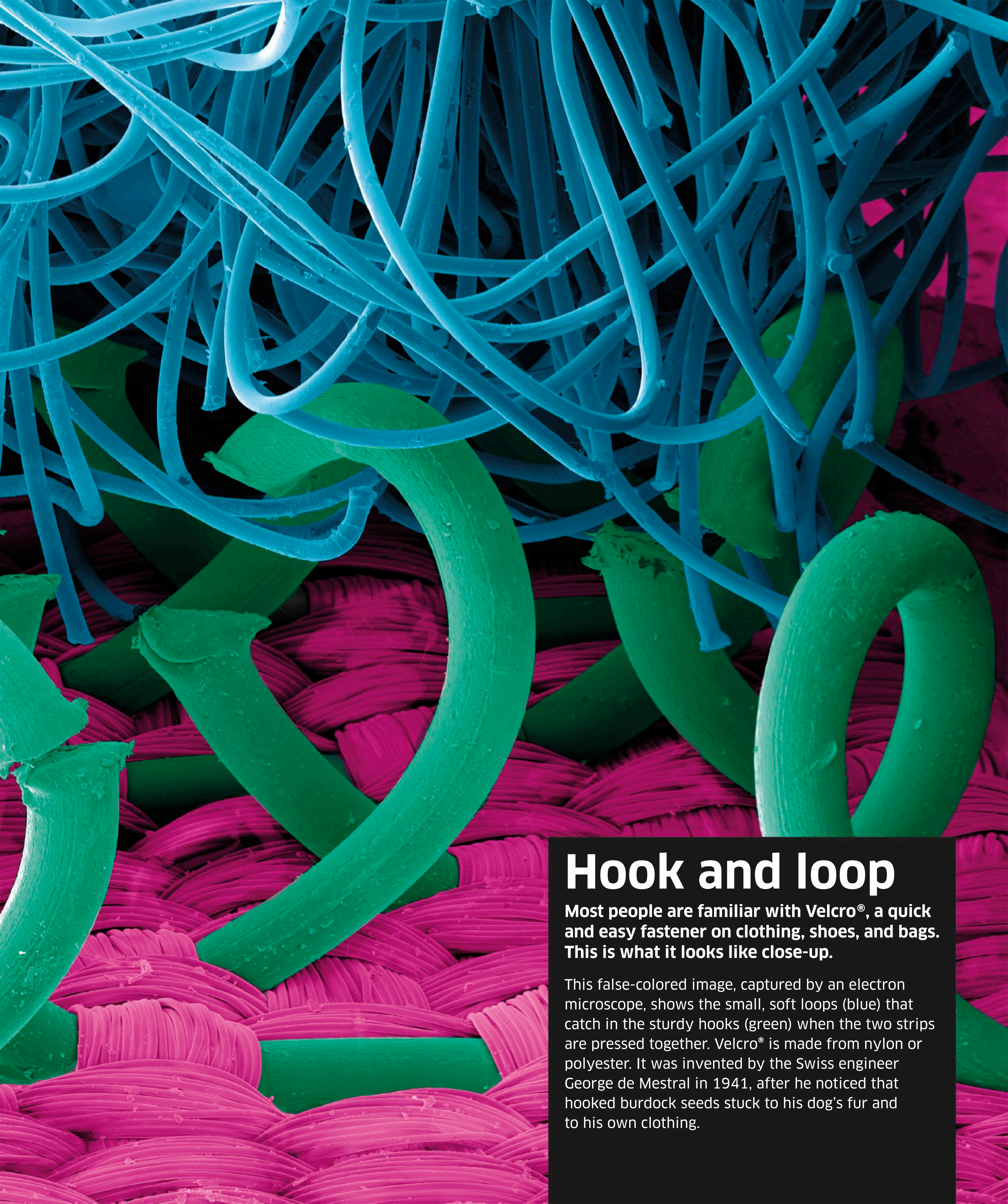


Earthenware pottery is fired at temperatures of around 1,830°F (1,000°C).

Sand and glass
Glass is made from sand. It is usually the sand common in deserts, which consists of the mineral silica. Beach sand often has traces of other substances, making less clear glass. Carefully chosen additives color the glass. The ingredients are melted together at 2,732°F (1,500°C) before being shaped into window panes, drinking glasses, or bottles.

Eyeglass lenses used to be made of pure glass. Today they are often plastic.





Hook and loop

Most people are familiar with Velcro®, a quick and easy fastener on clothing, shoes, and bags. This is what it looks like close-up.

This false-colored image, captured by an electron microscope, shows the small, soft loops (blue) that catch in the sturdy hooks (green) when the two strips are pressed together. Velcro® is made from nylon or polyester. It was invented by the Swiss engineer George de Mestral in 1941, after he noticed that hooked burdock seeds stuck to his dog's fur and to his own clothing.

1874 The year that the **Eads Bridge**, the **world's first bridge** all **made of steel**, opened for traffic across **the Missouri River**.

Alloys

An alloy is a mixture of at least two different elements, at least one of which is a metal. Alloys are used to make many things, including car and airplane parts, musical instruments, jewelry, and medical implants.

In many alloys, all the elements are metal. However, some alloys contain non-metals, such as carbon. The ingredients of an alloy are carefully chosen for the properties they bring to the alloy, whether to make it stronger, more flexible, or rust-resistant. All alloys have metallic properties, are good electrical conductors, and have advantages over pure metals.

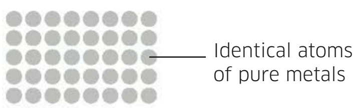
Early alloys

The first man-made alloy was bronze. It was developed around 5,000 years ago by smelting (heating) copper and tin together. This was the start of the Bronze Age, a period in which this new, strong alloy revolutionized the making of tools and weapons. Some thousand years later, people learned to make brass from copper and zinc.

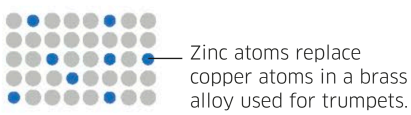
Bronze weapons
Bronze can be hammered thin, stretched, and molded. These objects, made in Mesopotamia around 2000 BCE, were designed to fit on a mace (a clublike weapon).

Atomic arrangements

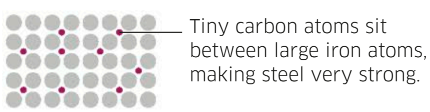
It is how the atoms are arranged in a material that decides how it behaves in different conditions. Atoms of pure metals are regularly arranged, but in alloys this arrangement is disrupted. The atoms of the main component of an alloy may be of a similar size, or much bigger, than those of the added one. They can be arranged in several ways.



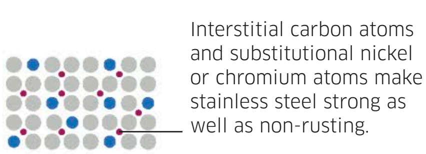
Pure metals
The atoms in a pure metal such as gold (left) are neatly arranged. Under pressure, they will slide over one another, causing cracking.



Substitutional alloys
Atoms of the added component take up almost the same space as atoms of the main one. This distorts the structure and makes it stronger.



Interstitial alloys
These alloys, such as steel used for bridges, are strong: smaller atoms fill the gaps between larger ones, preventing cracking or movement.



Combination alloys
Some alloys have a combination of atom arrangements to improve their properties. An example is stainless steel, used in cutlery.

Alloys in coins

Coins used to be made of gold and silver, but these metals are too expensive and not hard-wearing enough for modern use. Several different alloys are used for coins today. They are selected for their cost, hardness, color, density, resistance to corrosion, and for being recyclable.

EU €2-coin
Outer ring: copper (75%), nickel (25%). Center: copper (75%), zinc (20%), nickel (5%).

British £1-coin
Outer ring: copper (76%), zinc (20%), nickel (4%). Inner ring: copper (75%), nickel (25%).

Egyptian £1-coin
Outer ring: steel (94%), copper (2%), nickel plating (4%). Inner ring: steel (94%), nickel (2%), copper plating (4%).

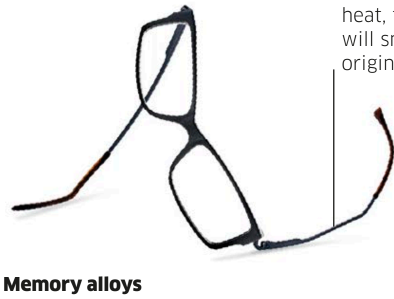
Australian $1-coin
Copper (92%), nickel (2%), aluminum (6%).

Sterling silver, used in most silver **jewelry**, is in fact an **alloy**, containing **7.5 percent copper**.

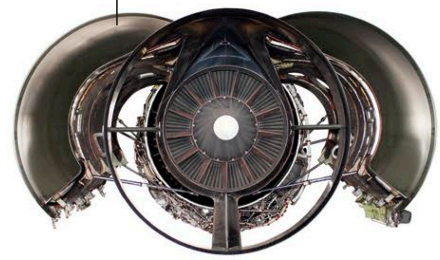
Mercury makes up about half of **amalgam, an alloy** sometimes used as **dental filling**; the rest is **silver, copper, and tin**.

Clever alloys

All alloys are developed to be an improvement on the individual metals from which they were made. Some alloys are an extreme improvement. Superalloys, for example, have incredible mechanical strength, resistance to corrosion, and can withstand extreme heat and pressure. These properties makes them very useful in aerospace engineering, as well as in the chemical industries. Memory alloys, or smart alloys, often containing nickel and titanium, "remember" their original shape.



Memory alloys
An object made from a memory alloy can return to its original shape if it has been bent. Simply applying heat restores the alloy to the shape it was in.



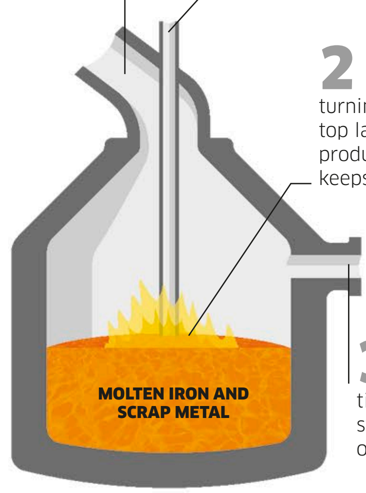
Superalloys
These high-performance alloys hold their shape in temperatures close to their high boiling points of around 1,832°F (1,000°C).

Aluminum alloys

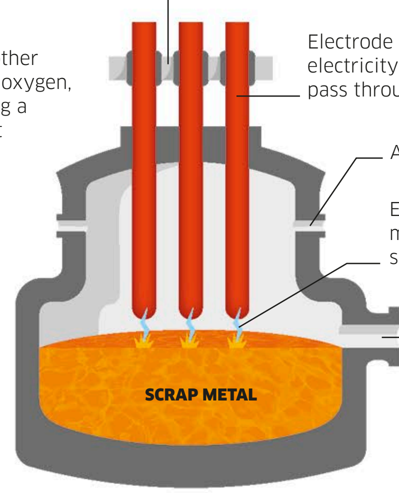
The metal aluminum is lightweight, resistant to corrosion, and has a high electrical conductivity. It is useful on a small scale (as foil, for example) but, because it is soft, it needs to be alloyed with other elements to be strong enough to build things. Aluminum alloys are often used in car bodies and bicycle frames.

Steel

Iron, a pure metal, has been used since the Iron Age, some 3,000 years ago. But although it is very strong, iron is also brittle. There were some early iron alloys, but the strongest one, steel, came into common use during the Industrial Revolution in the 19th century. There are two ways of making steel: it can be produced from molten "pig iron" (from iron ore) and scrap metal in a process called basic oxygen steelmaking (BOS), or from cold scrap metal in the electric arc furnace (EAF) process. Impurities, such as too much carbon, are removed, and elements such as manganese and nickel are added to produce different grades of steel. The molten steel is then shaped into bars or sheets ready to make into various products.



Basic oxygen steelmaking (BOS)
Oxygen is blown through molten "pig iron" and scrap metal to reduce its carbon content and other impurities. Then alloying elements are added, turning the molten metal into steel.



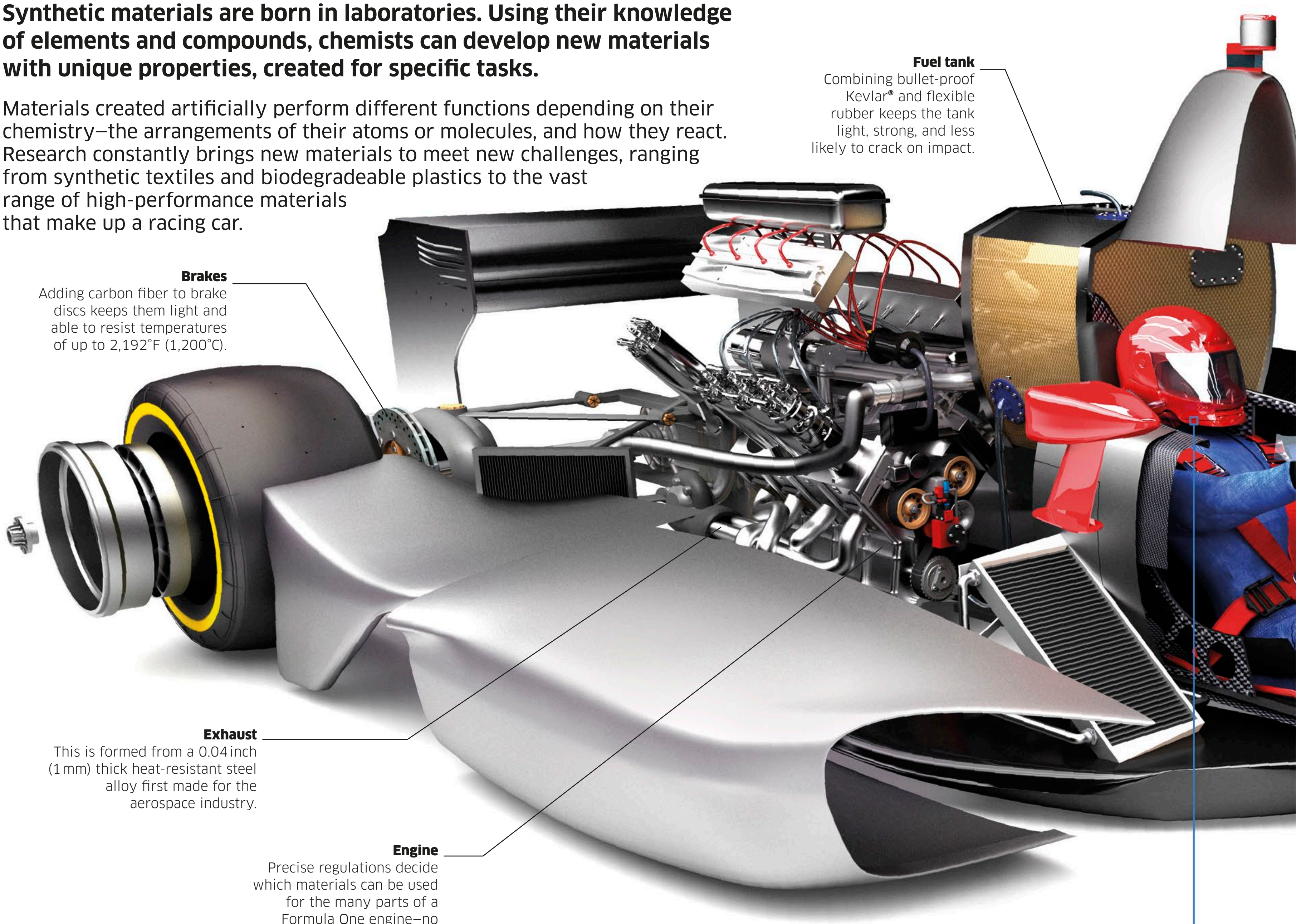
Electric arc furnace (EAF)
Cold scrap metal is loaded into the furnace. An electric current forms an "arc" (a continuous spark), which melts the metal. The final grade of steel is determined by adding alloying elements.

10 billion tons of **plastics** have been **made** since the 1950s.

Materials technology

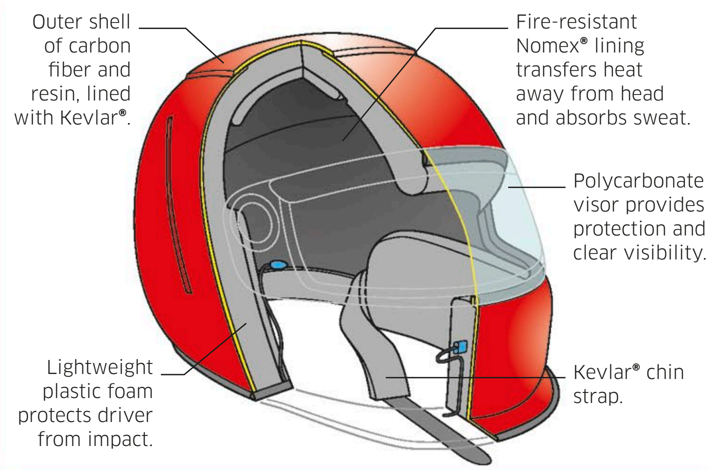
Synthetic materials are born in laboratories. Using their knowledge of elements and compounds, chemists can develop new materials with unique properties, created for specific tasks.

Materials created artificially perform different functions depending on their chemistry—the arrangements of their atoms or molecules, and how they react. Research constantly brings new materials to meet new challenges, ranging from synthetic textiles and biodegradeable plastics to the vast range of high-performance materials that make up a racing car.



Racing car

Formula One cars rely on materials that can withstand extreme heat and pressure. The structure must be rigid in some parts and flexible in others; some parts are heavy while some have to be light. The drivers are also exposed to heat and pressure—and speeds over 200 mph (320 km/h)—and rely on synthetic materials to keep safe. Their clothing is made with layers of Nomex®, a fire-resistant polyamide (a type of plastic) used for fire and space suits. Kevlar®, similar to Nomex® but so strong it is bullet proof, is used to reinforce various car parts as well as the driver's helmet.



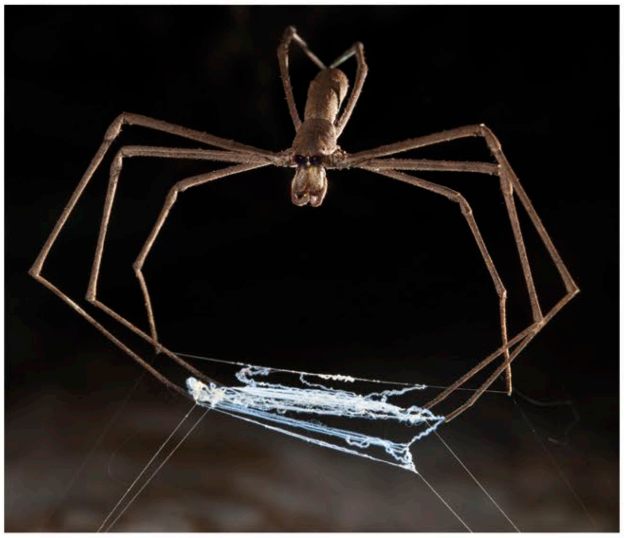
Helmet anatomy

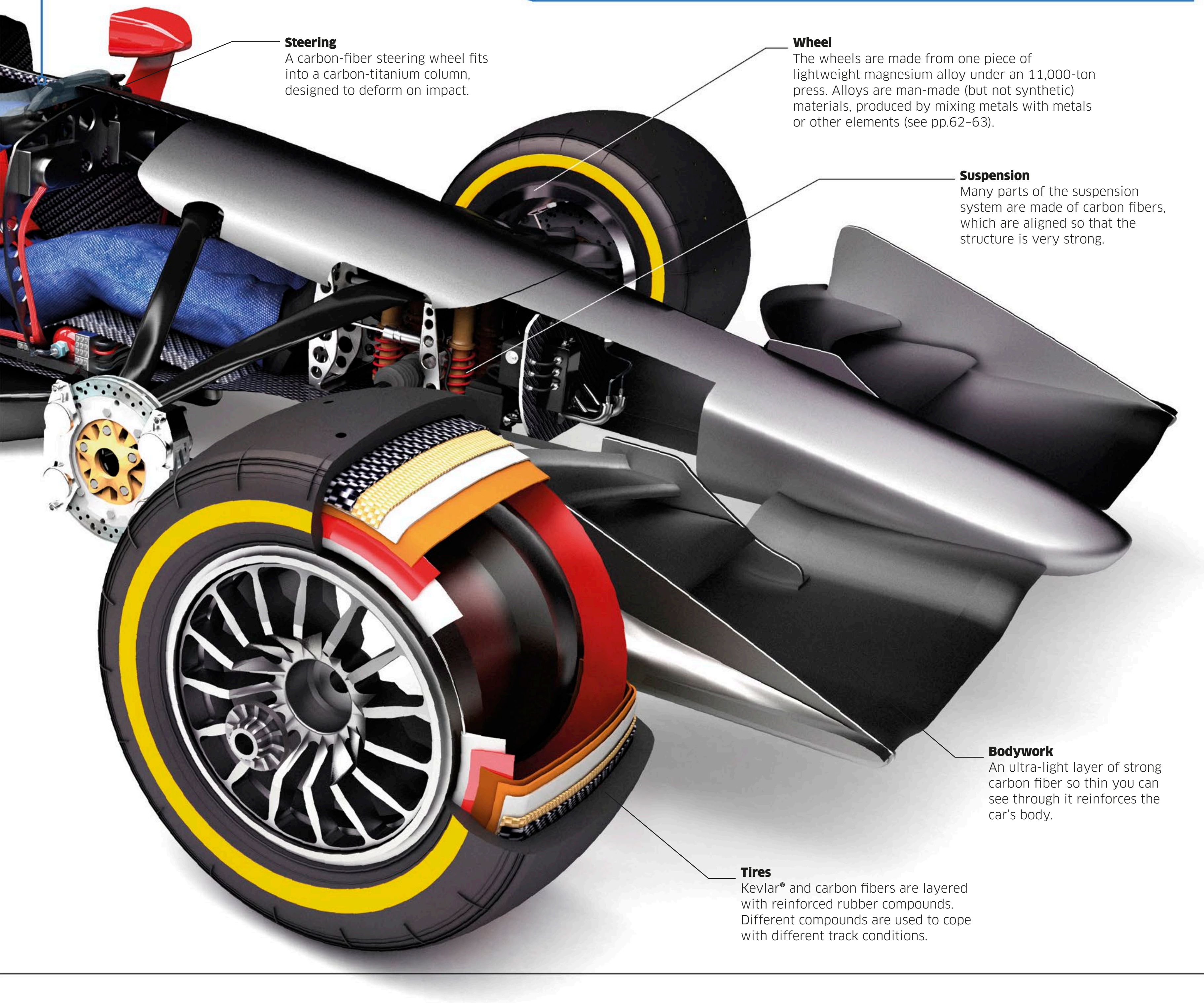
Drivers are subjected to extreme G-forces when braking and cornering. This puts great strain on their necks. To help keep their heads up, their helmets must be as light as possible. Highly specialized materials are used for the helmets, which need to be light and comfortable, yet strong and able to absorb impacts and resist penetration in case of an accident.

Survival cell
The monocoque, or survival cell, surrounds the cockpit where the driver sits. It is made of a strong, stiff carbon-fiber composite that can absorb the full energy of an impact without being damaged. Carbon fiber is much lighter than steel or aluminium, helping the car go faster and use less fuel.

Mimicking nature

Many synthetic materials were invented to replace natural materials that were too hard, or too expensive, to extract or harvest. For example, nylon was invented to replace silk in fabrics, and polyester fleece can be used instead of wool. Ever advancing technology makes it possible to imitate some amazing materials, such as spider silk, which is tougher than Kevlar®, stronger than steel, yet super flexible.





Steering
A carbon-fiber steering wheel fits into a carbon-titanium column, designed to deform on impact.

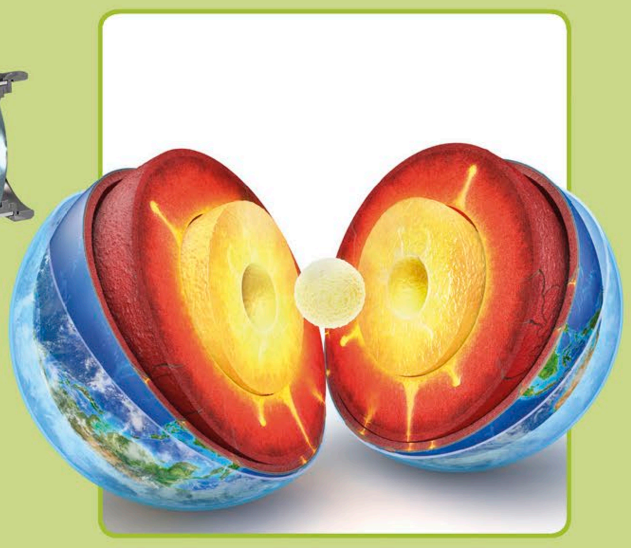
Wheel
The wheels are made from one piece of lightweight magnesium alloy under an 11,000-ton press. Alloys are man-made (but not synthetic) materials, produced by mixing metals with metals or other elements (see pp.62–63).

Suspension
Many parts of the suspension system are made of carbon fibers, which are aligned so that the structure is very strong.

Bodywork
An ultra-light layer of strong carbon fiber so thin you can see through it reinforces the car's body.

Tires
Kevlar® and carbon fibers are layered with reinforced rubber compounds. Different compounds are used to cope with different track conditions.

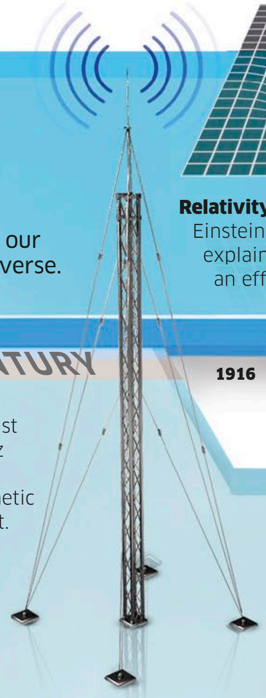


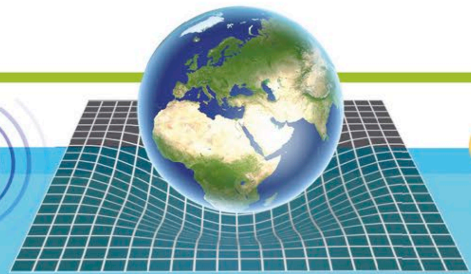


ENERGY AND FORCES

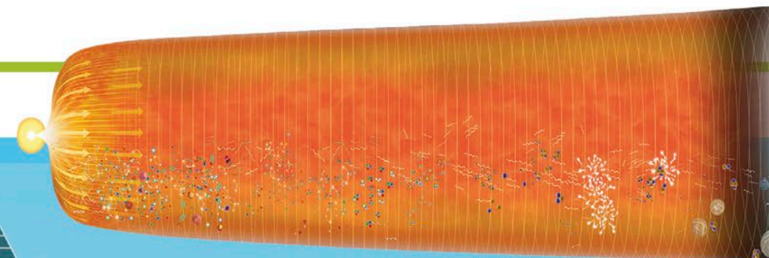
Energy and forces are essential concepts in science; nothing can happen without them. Forces change the motion of an object, and energy is behind everything that changes—from a flower opening to an exploding bomb. The amount of energy in the universe is fixed; it cannot be created or destroyed.

The modern age
Scientific discovery and technology go hand in hand as astronomers and physicists use computer science and particle accelerators to expand our knowledge of the universe.





Relativity
Einstein's General Theory of Relativity explains that what we perceive as gravity is an effect of the curvature of space and time.



MODEL OF THE EXPANDING UNIVERSE

Big Bang theory
Belgian priest and physicist Georges Lemaître comes up with the theory of an ever-expanding universe that began with the Big Bang—the source of all energy and forces.

20TH CENTURY

1916

1927

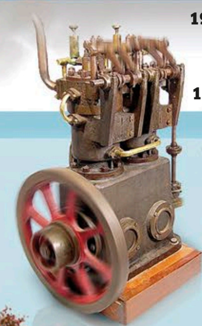
Radio waves
German physicist Heinrich Hertz proves that electromagnetic waves exist.

RADIO MAST

1886

1876

Combustion engine
German engineer Nikolaus Otto develops the internal combustion engine. It uses understanding gained over two hundred years of how the temperature, volume, and pressure of gases relate.



OTTO'S ENGINE

1848

THERMOMETER

Absolute zero
Scottish scientist Lord Kelvin calculates the lowest possible temperature—at which particles almost cease to vibrate—as −460°F (−273°C), calling it absolute zero.

Discovering energy and forces

People have been asking questions about how the world around them works, and using science to find answers for them, for thousands of years.

From the forces that keep a ship afloat and the magnetism that helps sailors to navigate the oceans with a compass, to the atoms and subatomic particles that make up our world and the vast expanses of space, people through history have learned about the universe by observation and experiment. In ancient and medieval times, as the tools available to study the world were limited, so was knowledge of science. The modern scientific method is based on experiments, which are used to test hypotheses (unproven ideas). Observed results modify hypotheses, improving our understanding of science.

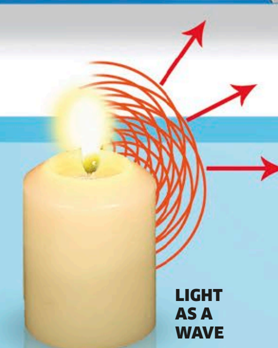
ISAAC NEWTON

18TH CENTURY

Gravity
English scientist Isaac Newton (left) explains how gravity works after an apple falls on his head.

1687

1678



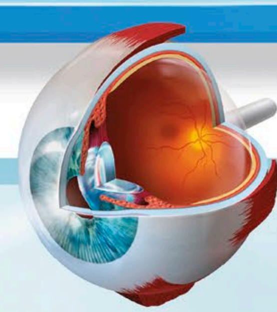
LIGHT AS A WAVE

Wave theory of light
Dutch scientist Christiaan Huygens announces his theory that light travels in waves. This is contested by Newton's idea that light is made of particles.

Ancient and medieval ideas
The ancient Greeks and Romans used debate to help them understand the universe, while Arab and Chinese scholars studied mathematics and natural phenomena such as rainbows and eclipses.

Buoyancy
The Greek thinker Archimedes realizes the force pushing upward on an object in water is equal to the weight of water displaced.

Magnetic compass
The Chinese create primitive compasses with lodestone, a naturally occurring magnet.



Light vision
Arab scholar Alhazen suggests that light is emitted from objects into the eye, not the reverse.

BEFORE 1500

240 BCE

200 BCE

1011 CE

Timeline of discoveries

Since ancient times, debate and experiment have led to discoveries that further human understanding of how the world works—but there are still many questions left to answer.

16TH CENTURY

1300

Bending light
German monk Theodoric of Freiburg uses bottles of water and water droplets in rainbows to understand refraction.

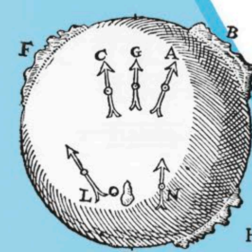
A new age of science
The scientific revolution, from the mid-16th to the late 18th centuries, transformed understanding of astronomy and physics. This period saw the development of the scientific method of experiment and observation.

1543

NICOLAUS COPERNICUS

Solar system
Polish astronomer Nicolaus Copernicus states that the Earth and planets orbit around the sun.

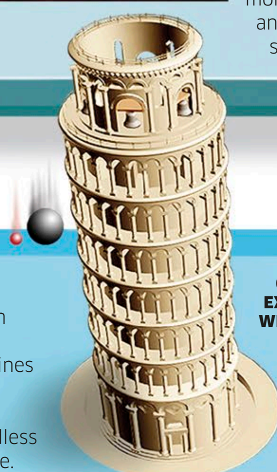
1600



GILBERT'S MAGNET

Earth's magnetism
English scientist William Gilbert theorizes that the Earth must have a huge magnet inside.

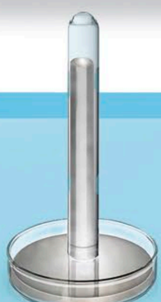
1604



GALILEO'S EXPERIMENT WITH FALLING BODIES

Falling bodies
In a letter to theologian Paolo Sarpi, Italian scientist Galileo outlines his theory that all objects fall at the same rate, regardless of mass or shape.

1643



BAROMETER

Atmospheric pressure
Italian physicist Evangelista Torricelli creates a simple barometer that demonstrates atmospheric pressure.

1500-1700

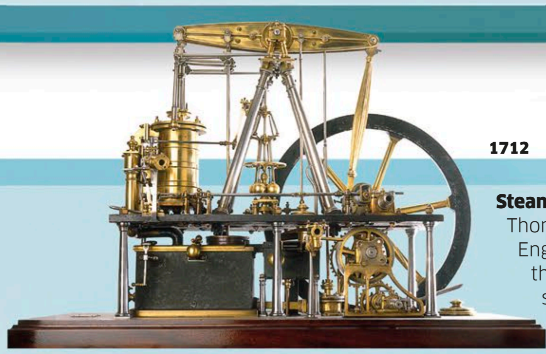
1712

LEYDEN JAR

Static electricity
German scientist Ewald Georg von Kleist invents the Leyden jar, a device that can store a static electric charge and release it later.

1712

Steam engine
Thomas Newcomen, an English engineer, builds the world's first practical steam engine. It is followed by James Watt's more efficient engine and Richard Trevithick's steam locomotive.



NEWCOMEN ENGINE

The Industrial Revolution
Scientific principles understood by the 18th century were applied to large-scale practical machines during the Industrial Revolution. The power of electricity was unlocked, which led the way for a surge in new technology.

1700-1890

1799

VOLTAIC PILE

Current electricity
Italian inventor Alessandro Volta creates an electric current by stacking disks of zinc, copper, and cardboard soaked in salt water in alternate layers—the first battery.

1831

FARADAY'S COIL

Electromagnetic induction
After electricity and magnetism are linked, English scientist Michael Faraday uses electromagnetic induction to generate electricity.

1847

PERPETUAL MOTION MACHINE

Energy conservation
German physicist Hermann von Helmhotz states that energy cannot be created or destroyed, it can only change its form.

1700-1890

1936

BOMBE CODE-BREAKING MACHINE

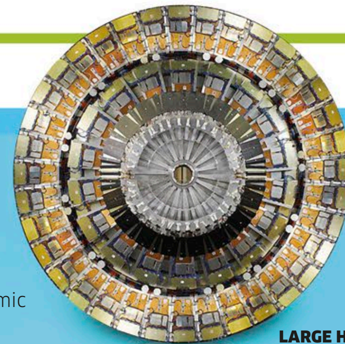
Computer science
British code-breaker Alan Turing develops the first programmable computer, laying the foundations of modern computer science.

1942

NUCLEAR EXPLOSION

Nuclear energy
Italian-American physicist Enrico Fermi leads a US team that builds the world's first nuclear fission reactor. In 1945, the first atomic bomb is dropped on Hiroshima.

2012



LARGE HADRON COLLIDER

Higgs boson
The Higgs boson particle is identified, confirming the Standard Model of particle physics developed in the 1970s.

1890-PRESENT

ENERGY

Energy is all around us—the secret power behind everything in our world, from a bouncing ball to an exploding star. Energy is what makes things happen. It is what gives objects the ability to move, to glow with heat and light, or to make sounds. The ultimate source of all energy on Earth is the sun. Without energy, there would be no life.

TYPES OF ENERGY

Energy exists in many different forms. They are all closely related and each one can change into other types.

Potential energy
This is stored energy. Climb something, and you store potential energy to jump, roll, or dive back down.

Mechanical energy
Also known as elastic energy, this is the potential stored in stretched objects, such as a taut bow.

Nuclear energy
Atoms are bound together by energy, which they release when they split apart in nuclear reactions.

Chemical energy
Food, fuel, and batteries store energy within the chemical compounds they are made of, which is released by reactions.

Sound energy
When objects vibrate, they make particles in the air vibrate, sending energy waves traveling to our ears, which we hear as sounds.

Heat energy
Hot things have more energy than cold ones, because the particles inside them jiggle around more quickly.

Electrical energy
Electricity is energy carried by charged particles called electrons moving through wires.

Light energy
Light travels at high speed and in straight lines. Like radio waves and X-rays, it is a type of electromagnetic energy.

Kinetic energy
Moving things have kinetic energy. The heavier and faster they are, the more kinetic energy they have.

Measuring energy

Scientists measure energy in joules (J). One joule is the energy transferred to an object by a force of 1 newton (N) over a distance of 1 meter (m), also known as 1 newton meter (Nm).

- **Energy of the sun**
The sun produces four hundred octillion joules of energy each second!

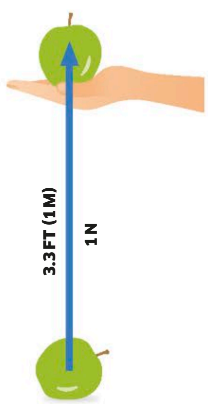
- **Energy in candles**
A candle emits 80 J—or 80 W—of energy (mainly heat) each second.

- **Energy of a light bulb**
An LED uses 15 watts (W), or 15 J, of electrical energy each second.

- **Energy in water**
To raise water temperature 1.8°F (1°C) takes 1 calorie (1/1,000 kilocalories).

- **Energy in food**
The energy released by food is measured in kilo-calories: 1 kcal is 4,184 J.

- **Tiny amounts of energy**
Ergs measure tiny units of energy. There are 10 million ergs in 1 J.



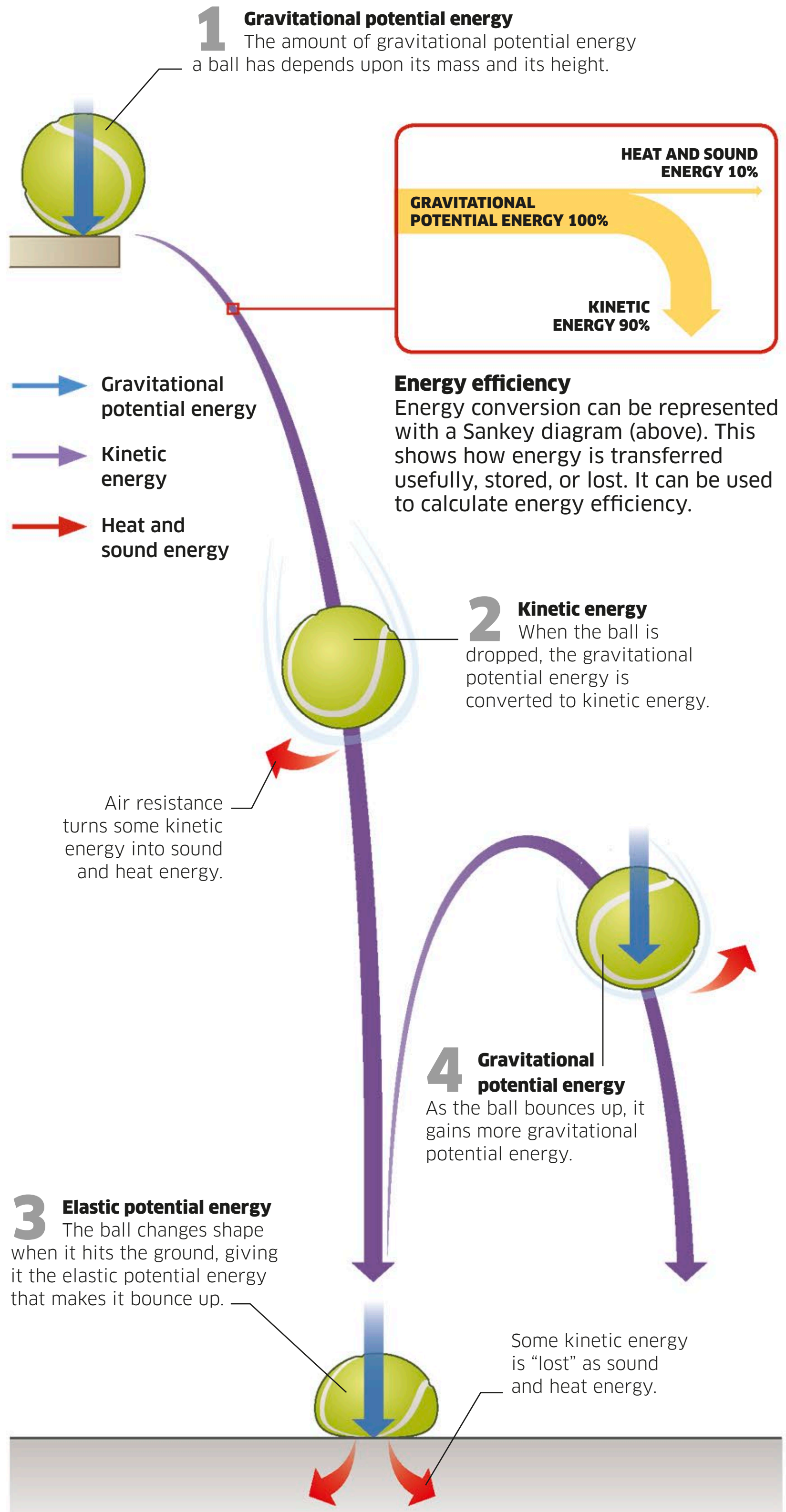
Lifting an apple
One joule is roughly equivalent to lifting an apple 3.3 ft (1 m).

CONSERVATION OF ENERGY

There's a fixed amount of energy in the universe that cannot be created or destroyed, but it can be transferred from one object to another and converted into different forms.

Energy conversion

The total amount of energy at the start of a process is always the same at the end, even though it has been converted into different forms. When you switch on a lamp, for example, most of the electrical energy is converted into light energy—but some will be lost as heat energy. However, the total amount of energy that exists always stays the same.



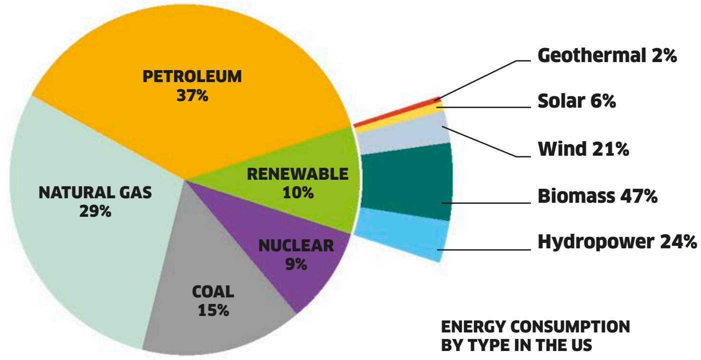
Energy efficiency
Energy conversion can be represented with a Sankey diagram (above). This shows how energy is transferred usefully, stored, or lost. It can be used to calculate energy efficiency.

ENERGY SOURCES

People in the industrialized world use a lot of energy in homes, business, and industry, for travel and transportation. The energy used comes from primary sources such as fossil fuels, nuclear energy, and hydropower. Crude oil, natural gas, and coal are called fossil fuels because they were formed over millions of years by heat from Earth's core and pressure from rock on the remains (fossils) of plants and animals (see p.37).

Energy consumption

Most energy consumed in the US is from nonrenewable sources, with more than 80 percent derived from fossil fuels. Despite advances, just 10 percent comes from renewable sources, of which nearly half is from biomass.



ENERGY CONSUMPTION BY TYPE IN THE US

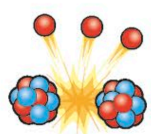
Nonrenewable sources

Fossil fuels are limited resources on our planet, which create greenhouse gases (see pp.128–129) and toxic pollutants. Nuclear energy produces fewer greenhouse gases, but leaves harmful waste.

Crude oil
Liquid hydrocarbons found deep underground.

Natural gas
Hydrocarbon gas formed millions of years ago.

Coal
Solid hydrocarbons made by heat and pressure.

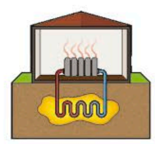


Nuclear energy
Energy released by splitting uranium atoms.

Renewable sources

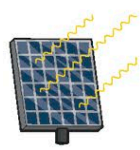
Energy produced by resources that cannot run out, such as sunlight, wind, and water, is more sustainable. Their use does not produce greenhouse gases and other harmful waste products. Biomass releases carbon dioxide, however, and must be offset by planting new trees.

Biomass
Fuel from wood, plant matter, and waste.



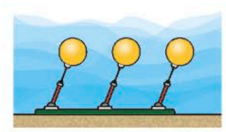
Geothermal energy
Heat deep inside the Earth, in water and rock.

Wind power
Moving air caused by uneven heating of Earth.



Solar energy
The sun's radiation, converted into heat.

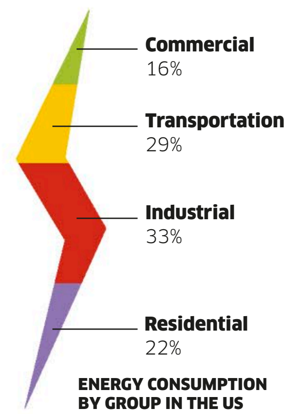
Hydropower
The energy of falling or flowing water.



Tidal and wave power
The motion of tides and wind-driven waves.

Energy use

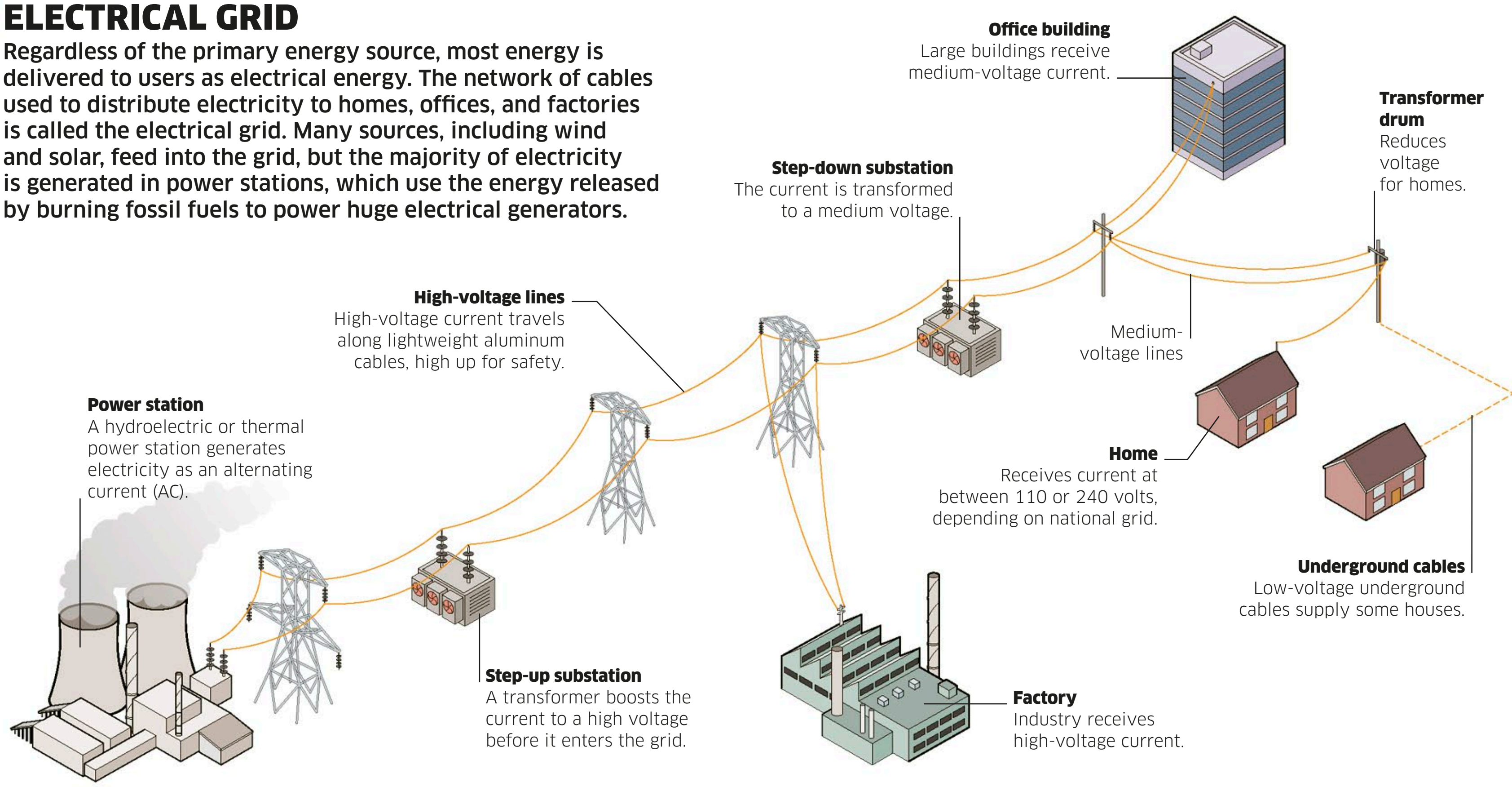
In the developed world, industry and transportation are the most energy-hungry sectors, while efficiency has reduced energy consumption in the home.



ENERGY CONSUMPTION BY GROUP IN THE US

ELECTRICAL GRID

Regardless of the primary energy source, most energy is delivered to users as electrical energy. The network of cables used to distribute electricity to homes, offices, and factories is called the electrical grid. Many sources, including wind and solar, feed into the grid, but the majority of electricity is generated in power stations, which use the energy released by burning fossil fuels to power huge electrical generators.

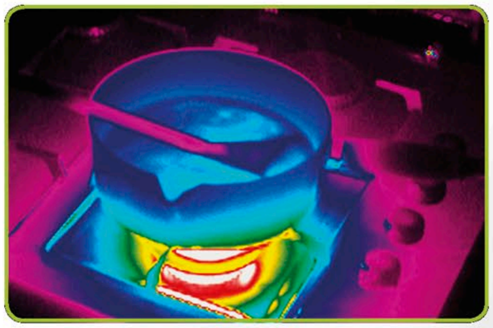


Metals are good heat conductors because their electrons are free to move and pass energy on.

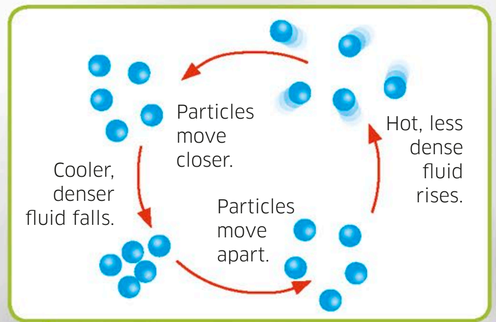
Copper, gold, silver, and aluminum are all good conductors of heat.

Heat transfer

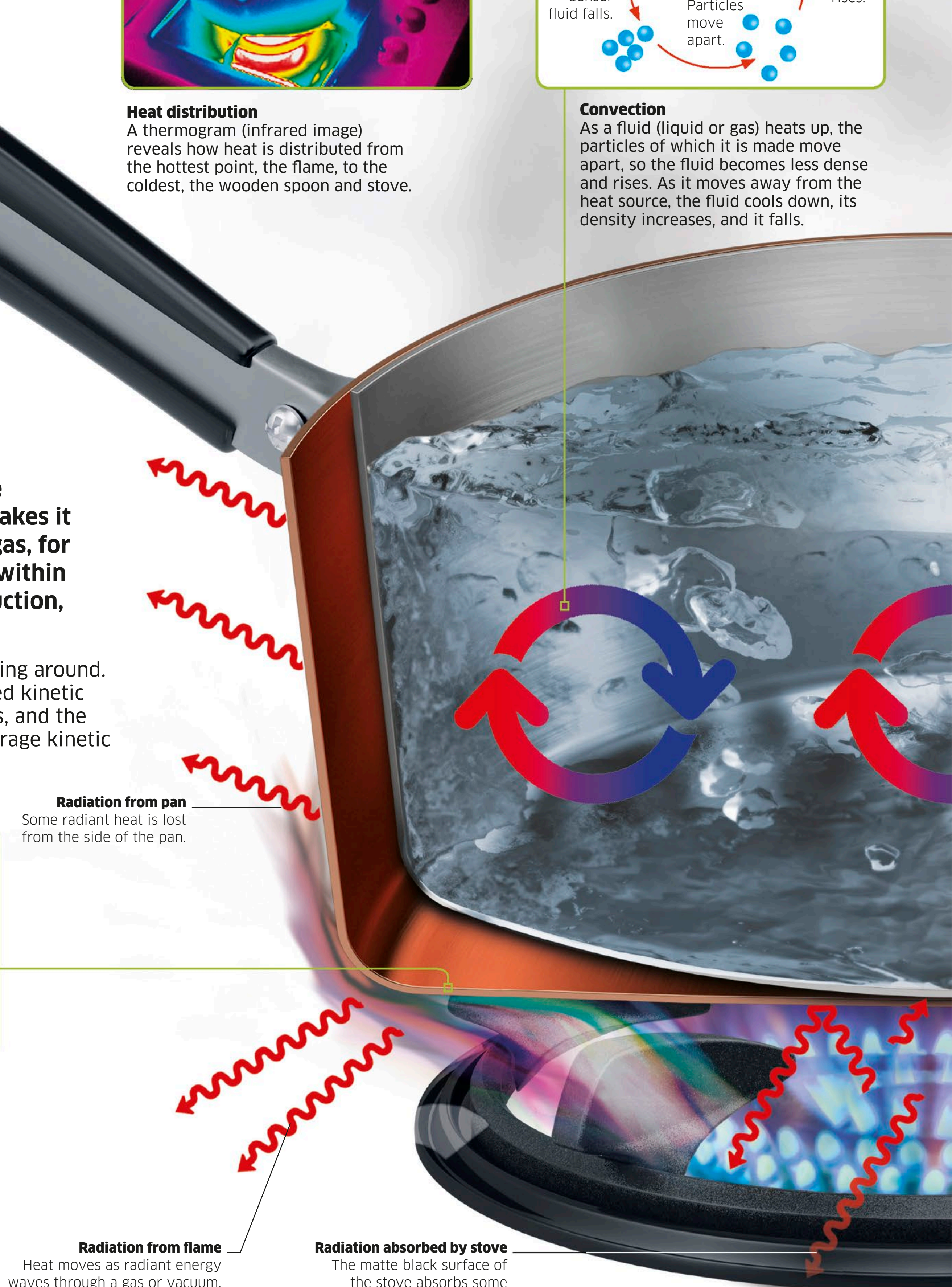
Heat in this pan of boiling water can be seen to move in three ways—radiation, conduction, and convection—between the heat source, the metal pan, and the water.



Heat distribution
A thermogram (infrared image) reveals how heat is distributed from the hottest point, the flame, to the coldest, the wooden spoon and stove.



Convection
As a fluid (liquid or gas) heats up, the particles of which it is made move apart, so the fluid becomes less dense and rises. As it moves away from the heat source, the fluid cools down, its density increases, and it falls.



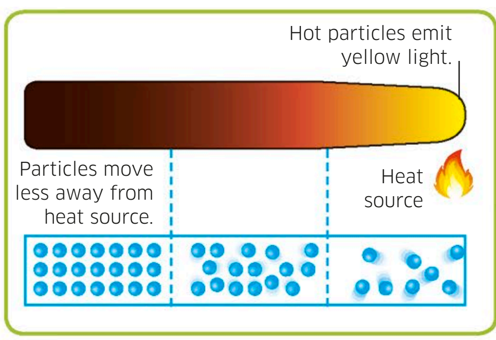
Thermal insulation
Materials such as plastic and wood are thermal insulators, which do not conduct heat.

Heat

Heat is energy that increases the temperature of a substance or makes it change state—from a liquid to a gas, for example. Heat can move into or within a substance in three ways: conduction, convection, or radiation.

Atoms and molecules are always moving around. The energy of their movement is called kinetic energy. Some move faster than others, and the temperature of a substance is the average kinetic energy of its atoms and molecules.

Radiation from pan
Some radiant heat is lost from the side of the pan.



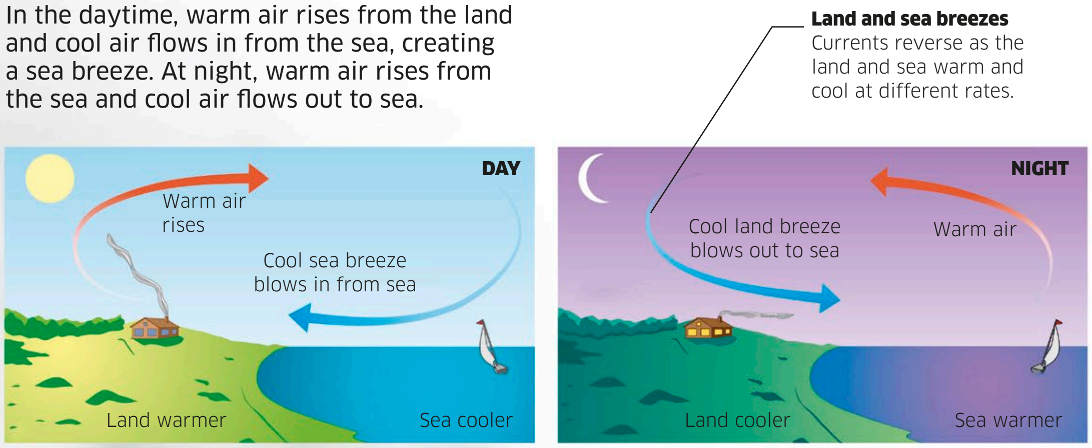
Conduction
When the particles (atoms or molecules) of a solid are heated, they move faster, bumping into other particles and making them move faster, too. The movement of the particles conducts heat away from the heat source. As the temperature increases in a metal, the particles lose heat as thermal radiation, making the metal glow red, yellow, and then white hot.

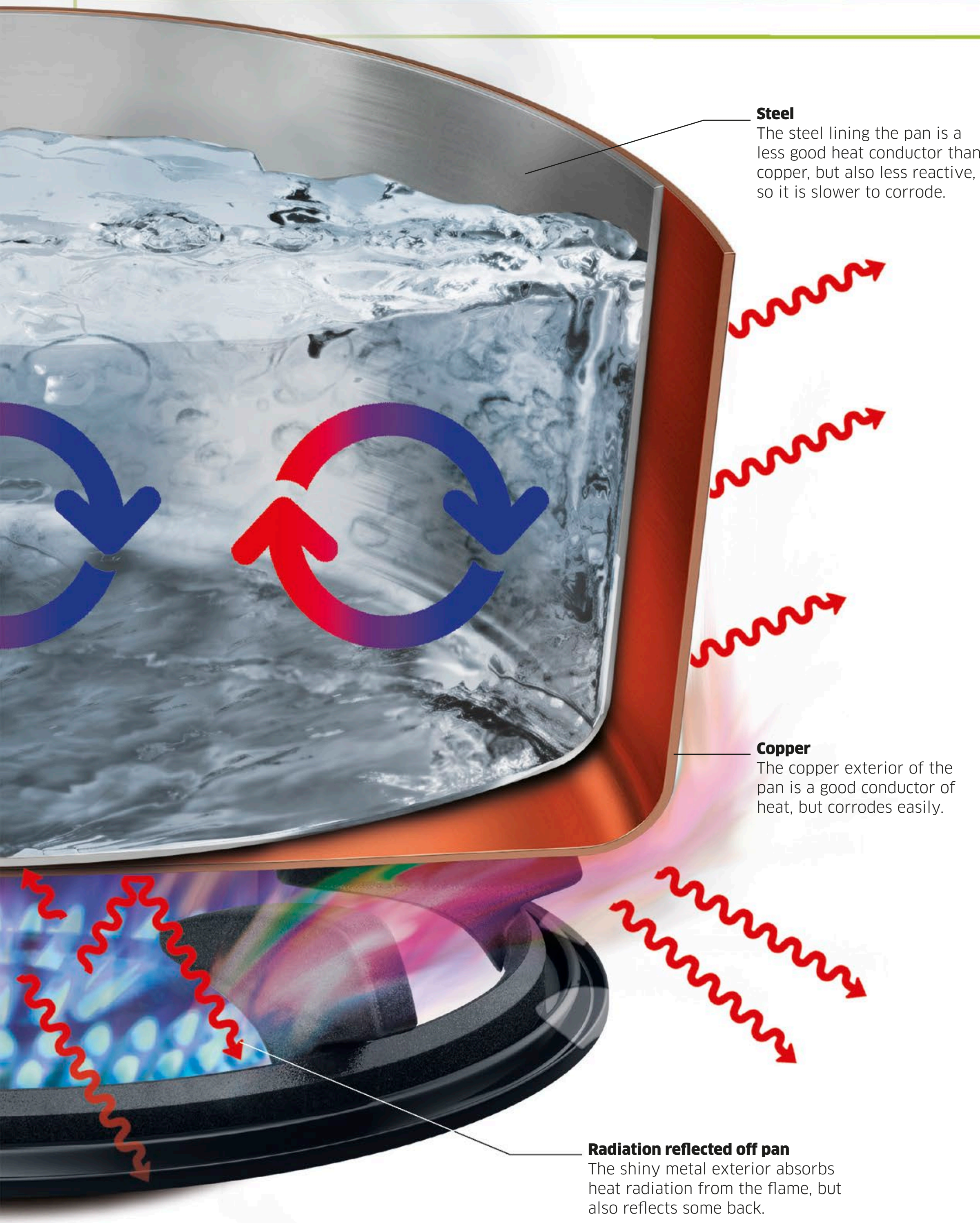
Radiation from flame
Heat moves as radiant energy waves through a gas or vacuum. This is how the sun heats Earth.

Radiation absorbed by stove
The matte black surface of the stove absorbs some heat radiation.

Convection currents in air

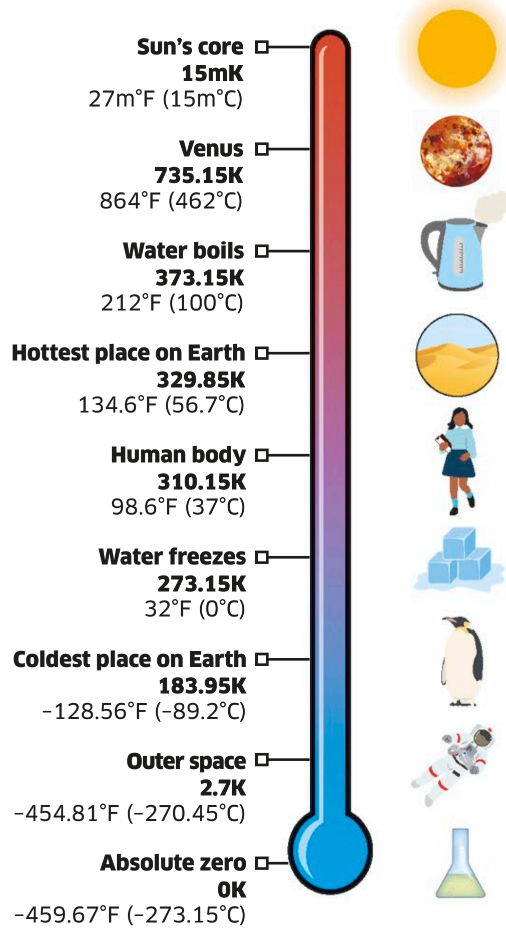
In the daytime, warm air rises from the land and cool air flows in from the sea, creating a sea breeze. At night, warm air rises from the sea and cool air flows out to sea.





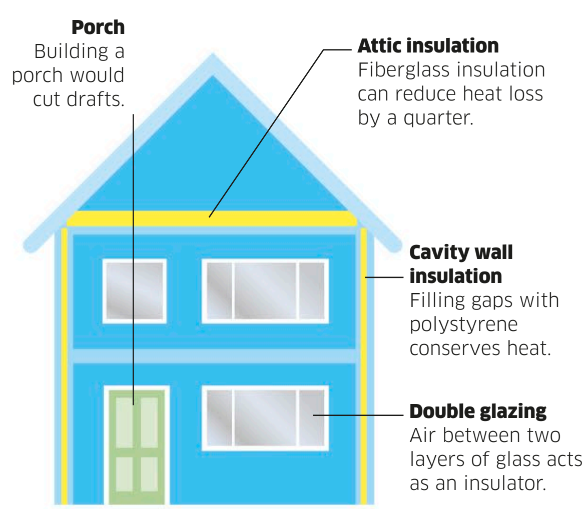
Measuring temperature

Temperature measures how hot or cold an object is by taking the average value of its heat energy. It is measured in degrees Celsius (°C), Fahrenheit (°F), or Kelvin (K). A degree is the same size on the °C scale and K scale. All atoms stop moving at absolute zero (0K).



Heat loss and insulation

Heat is easily lost from our homes through floors, walls, roofs, windows, and doors. To increase energy efficiency by reducing heat loss, materials that are poor conductors—such as plastics, wood, cork, fiberglass, and air—can be used to provide insulation.



449 The number of **operational nuclear reactors in the world**, with many more being built.

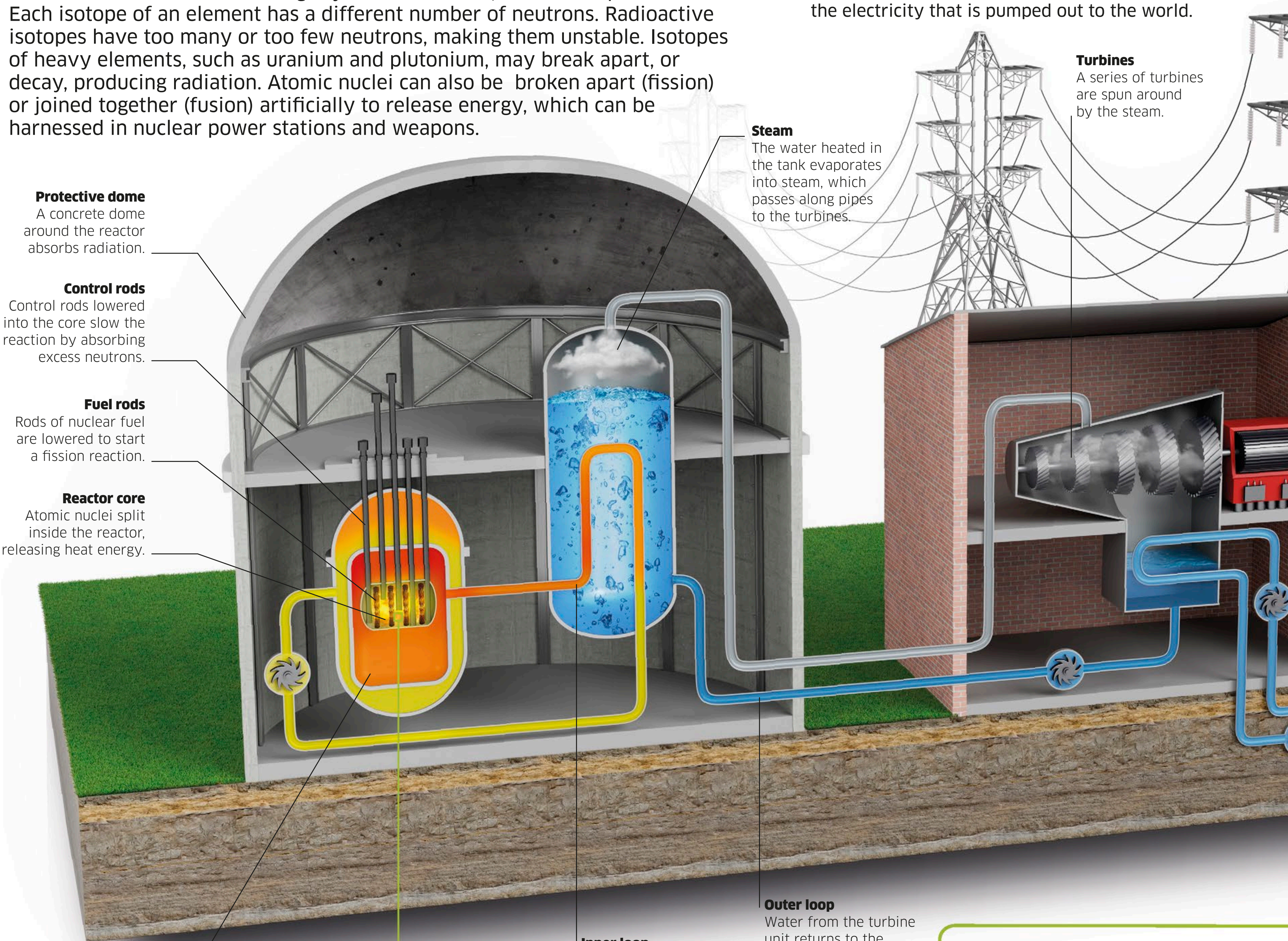
Nuclear energy

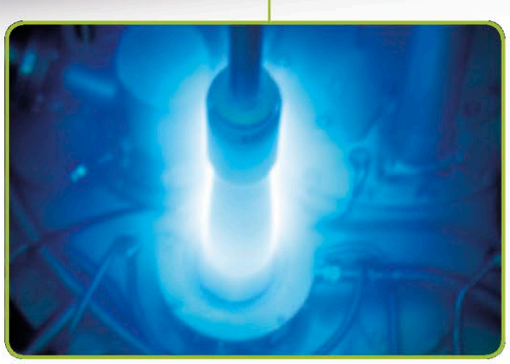
Nuclear reactions are a highly efficient way of releasing energy. Smashing atomic particles together sets off a chain reaction—producing enough heat to generate large amounts of electricity.

Most elements have several slightly different forms, called isotopes. Each isotope of an element has a different number of neutrons. Radioactive isotopes have too many or too few neutrons, making them unstable. Isotopes of heavy elements, such as uranium and plutonium, may break apart, or decay, producing radiation. Atomic nuclei can also be broken apart (fission) or joined together (fusion) artificially to release energy, which can be harnessed in nuclear power stations and weapons.

Nuclear reactor

Nuclear fission power stations are found all over the world. They all use the same basic principles to generate electricity. Firstly, atoms are smashed apart in the reactor to release heat energy. This energy passes into a nearby chamber to heat up water and produce large quantities of steam. The steam powers spinning turbines attached to a generator, which converts this kinetic energy into the electricity that is pumped out to the world.





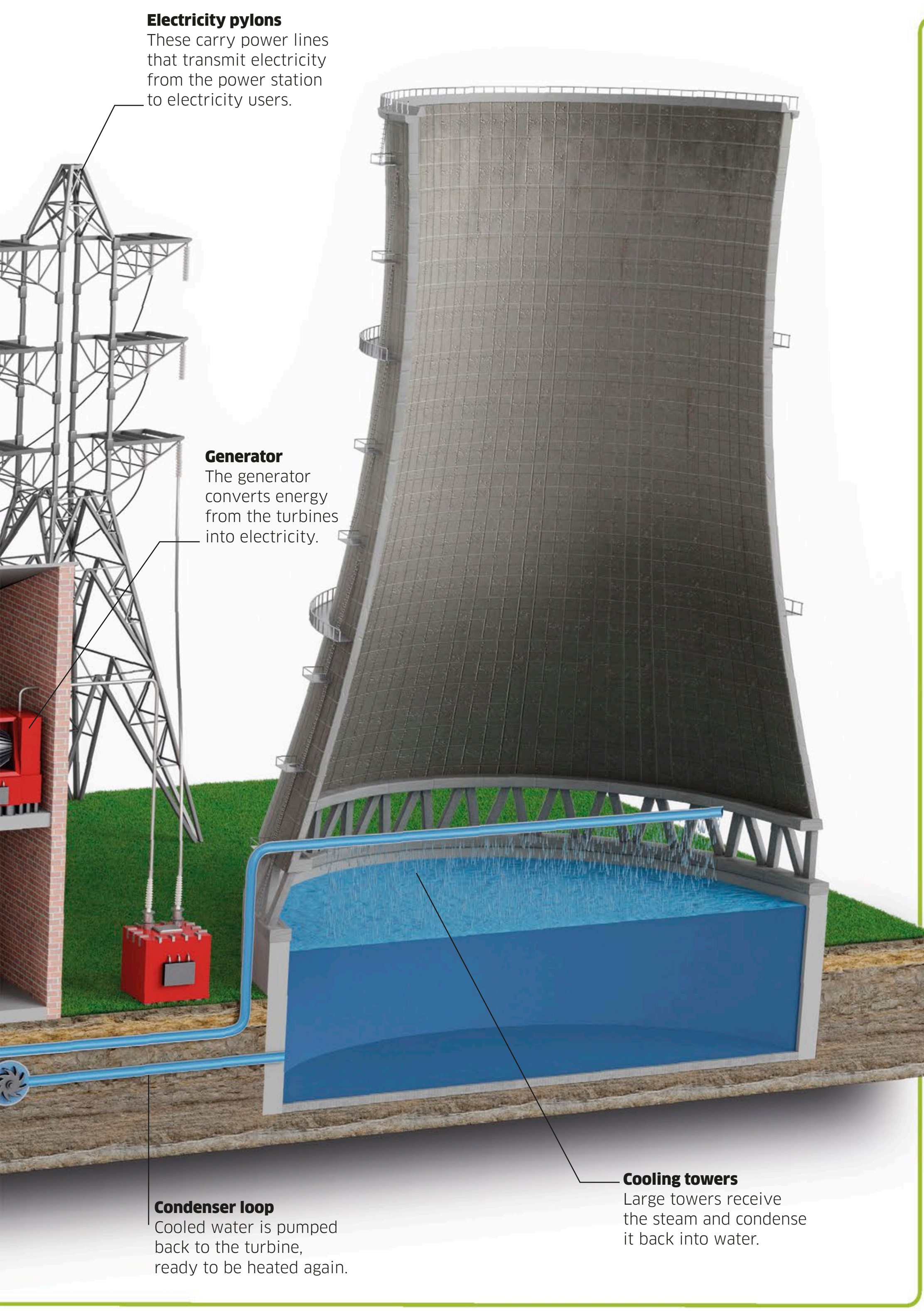
Cherenkov radiation
The atomic particles in the reactor travel incredibly fast. In doing so, they generate a type of radiation called Cherenkov radiation, which makes the water surrounding the reactor glow an eerie blue color.

Types of radiation

When unstable nuclei break apart, or decay, they may release three types of radiation: alpha, beta, and gamma. Alpha and beta radiation are streams of particles released by atomic nuclei. Gamma rays, released during alpha and beta decay or even by lightning, are a form of electromagnetic radiation—similar to light, but more powerful and dangerous.

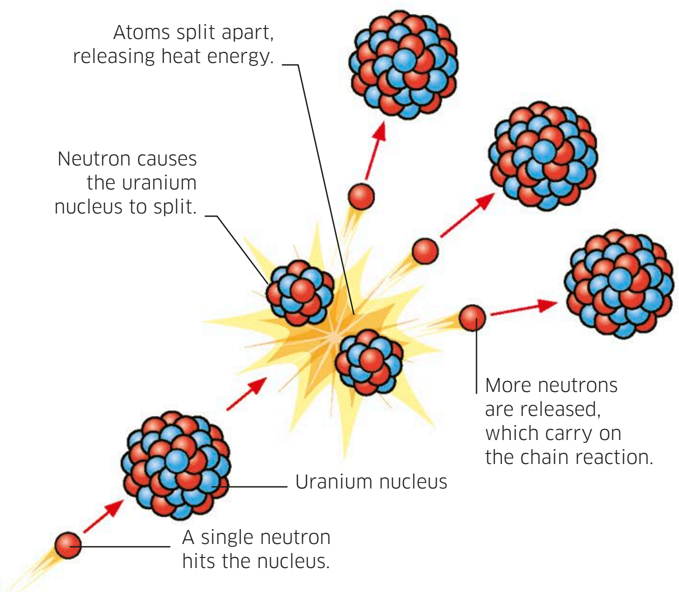
British physicists **John Cockcroft and Ernest Walton** carried out the **first artificial nuclear fission** in 1932.

11 **percent of the world's electricity** is provided by nuclear power plants.



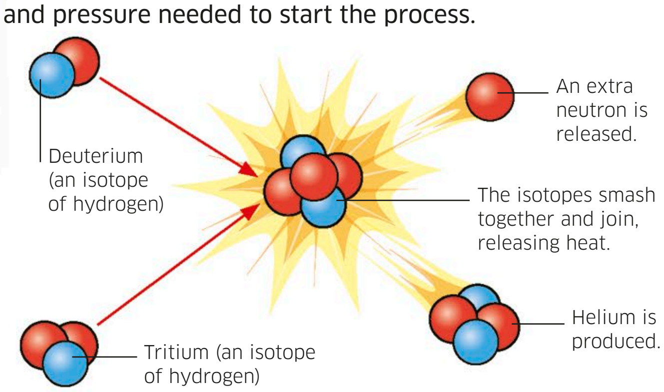
Nuclear fission

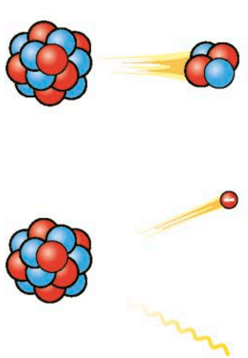
The nuclei of atoms can split apart or join together, forming new elements and releasing energy. A large atomic nucleus splitting in two is called nuclear fission. A neutron hits the nucleus of a uranium atom, causing it to split, or fission, in two. More neutrons are released as a result, and these hit more nuclei, creating a chain reaction. The extra energy that is released ends up as heat that can be used to generate electricity.



Nuclear fusion

The process in which two smaller atomic nuclei join together is called fusion. Two isotopes of hydrogen are smashed into each other to make helium, releasing heat energy and a spare neutron. Fusion takes place in stars, but has not yet been mastered as a viable form of producing energy on Earth, due to the immense heat and pressure needed to start the process.





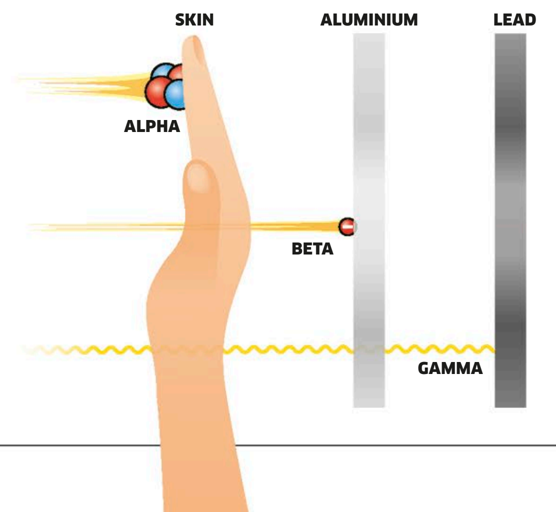
Alpha radiation
Some large nuclei release a positively charged particle made of two protons and two neutrons, called an alpha particle.

Beta radiation
In some nuclei, a neutron changes to a proton, creating an electron called a beta particle, which shoots out of the nucleus.

Gamma radiation
Gamma rays are electromagnetic waves released during alpha and beta decay.

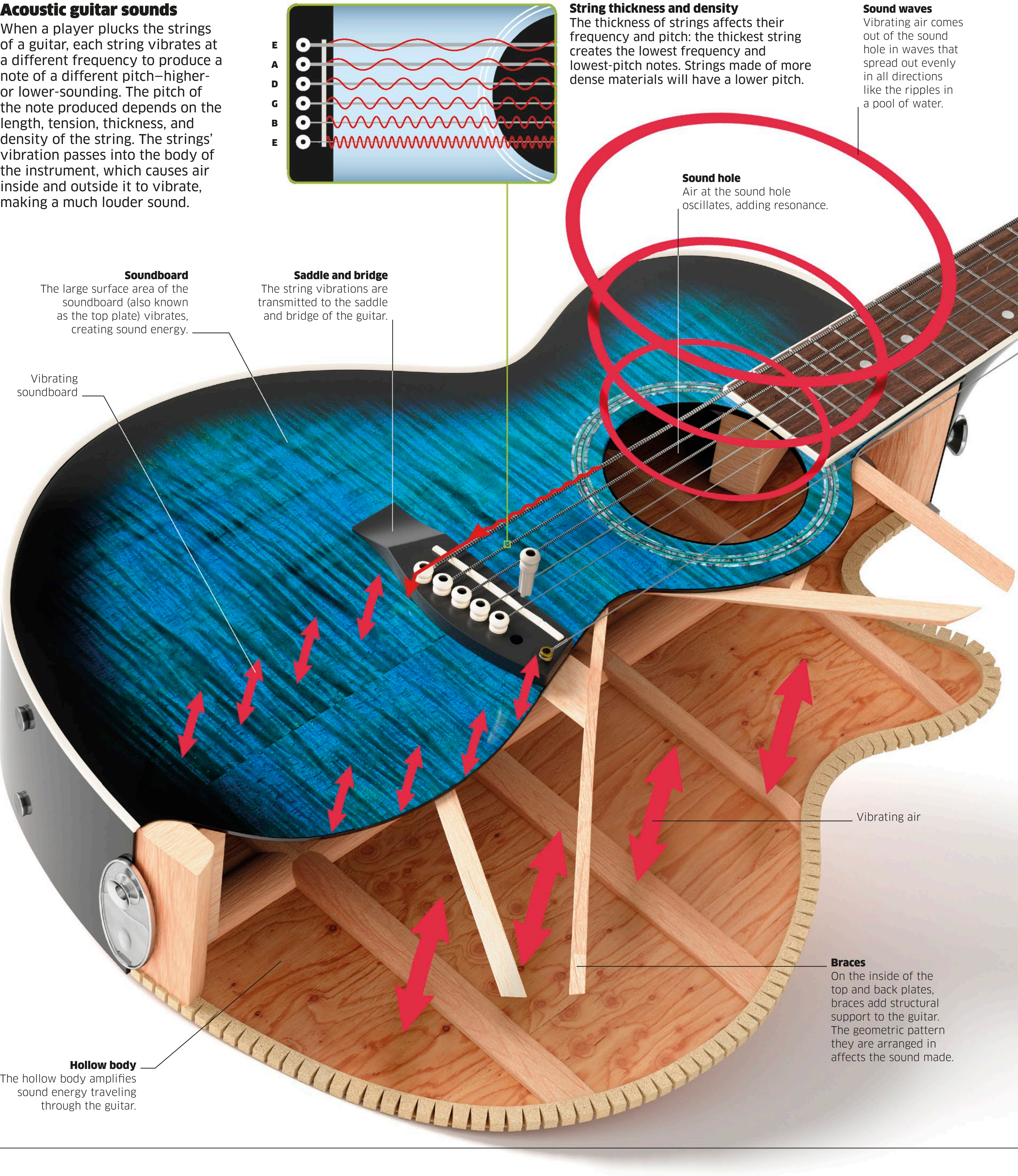
Containing radiation

Radiation can be extremely harmful to human health and containing it can be tricky. Alpha, beta, and gamma radiation can pass through different amounts of matter because they have different speeds and energy. Alpha particles can be stopped by just a sheet of paper, or skin. Beta rays can pass through skin but not metal. Gamma rays can only be stopped by a sheet of lead or thick concrete.



Acoustic guitar sounds

When a player plucks the strings of a guitar, each string vibrates at a different frequency to produce a note of a different pitch—higher- or lower-sounding. The pitch of the note produced depends on the length, tension, thickness, and density of the string. The strings' vibration passes into the body of the instrument, which causes air inside and outside it to vibrate, making a much louder sound.



String thickness and density
The thickness of strings affects their frequency and pitch: the thickest string creates the lowest frequency and lowest-pitch notes. Strings made of more dense materials will have a lower pitch.

Sound waves
Vibrating air comes out of the sound hole in waves that spread out evenly in all directions like the ripples in a pool of water.

Sound hole
Air at the sound hole oscillates, adding resonance.

Soundboard
The large surface area of the soundboard (also known as the top plate) vibrates, creating sound energy.

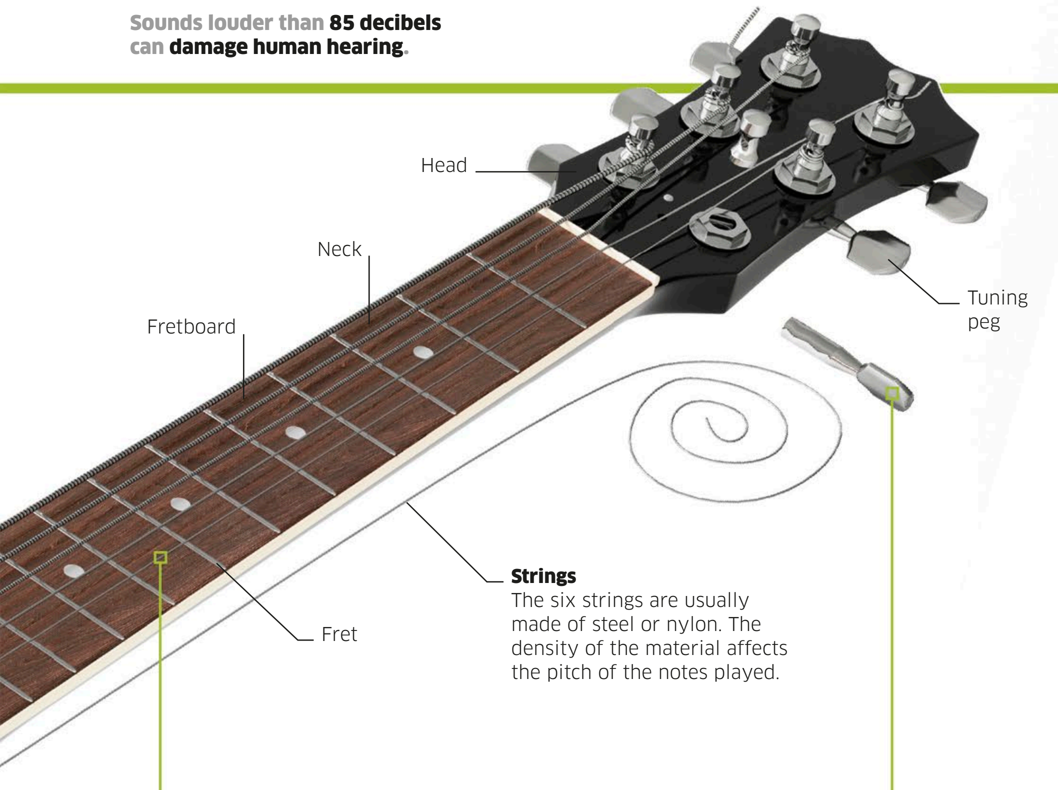
Saddle and bridge
The string vibrations are transmitted to the saddle and bridge of the guitar.

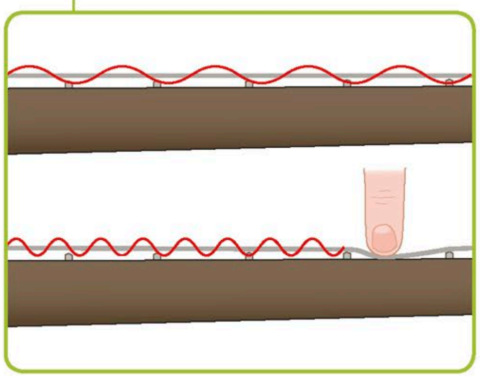
Vibrating soundboard

Vibrating air

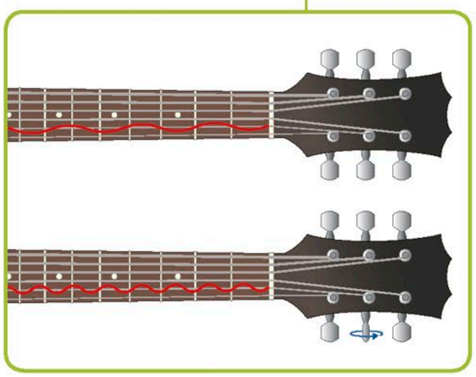
Braces
On the inside of the top and back plates, braces add structural support to the guitar. The geometric pattern they are arranged in affects the sound made.

Hollow body
The hollow body amplifies sound energy traveling through the guitar.





String length
Frets (raised bars) are spaced along the fretboard on the front of the neck. The player presses a string down on the fretboard to shorten its length, increasing the frequency and raising the pitch of the sound.



String tension
Turning the tuning pegs enables the player to tighten or loosen the strings, adjusting the pitch so that the guitar is in tune. As the strings are tightened, the frequency increases, raising the pitch.

Sound

Sound carries music, words, and other noises at high speed. It travels in waves, created by the vibration of particles within a solid, liquid, or gas.

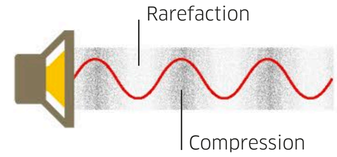
If you pluck a guitar string, it vibrates. This disturbs the air around it, creating a wave of high and low pressure that spreads out. When the wave hits our ears, the vibrations are passed on to tiny hairs in the inner ear, which send information to the brain, where it is interpreted. What distinguishes sounds such as human voices from one another is complex wave shapes that create distinctive quality and tone.

20 Hz to 20 kHz—the normal range of human hearing. This range decreases as people get older. Children can usually hear higher frequencies than adults.

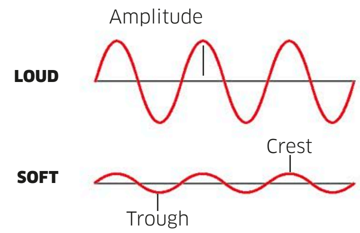
How sound travels

Sounds waves squeeze and stretch the air as they travel. They are called longitudinal waves because the particles of the medium they are traveling through vibrate in the direction of the wave.

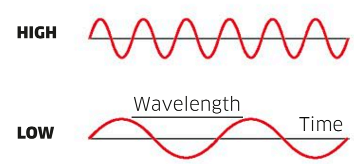
Vibrating particles
As vibrations travel through air, particles jostle each other to create high-pressure areas of compression and low-pressure areas of rarefaction.



Amplitude and loudness
The energy of a sound wave is described by its amplitude (height from center to crest or trough), corresponding to loudness.

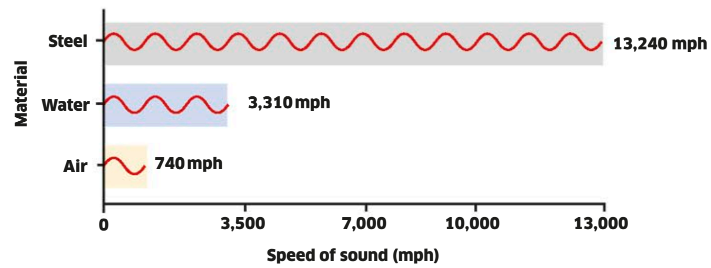


Frequency and pitch
A sound wave's pitch is defined by its frequency—the number of waves that pass a point in a given time. It is measured in hertz (Hz).



Speed of sound in different materials

Sound moves fastest in solids, because the particles are closer together, and slowest in gases, such as air, because the particles are further apart. The speed of sound is measured in miles per hour.



The decibel range

Loudness describes the intensity of sound energy, and is measured in decibels (dB) on a logarithmic scale, so 20 dB is 10 times more intense than 10 dB, or twice as loud. Human hearing ranges from 0 to 150 dB.

LEAF FALLING NEARBY (10 dB)
Barely audible

WHISPERING IN EAR (30 dB)
Quiet

SPEAKING NEAR YOU (60 dB)
Moderate

VIOLIN AT ARM'S LENGTH (90 dB)
Loud

FRONT OF ROCK GIG (120 dB)
Very loud

FIREWORK AT CLOSE RANGE (150 dB)
Painfully loud

Artificial light

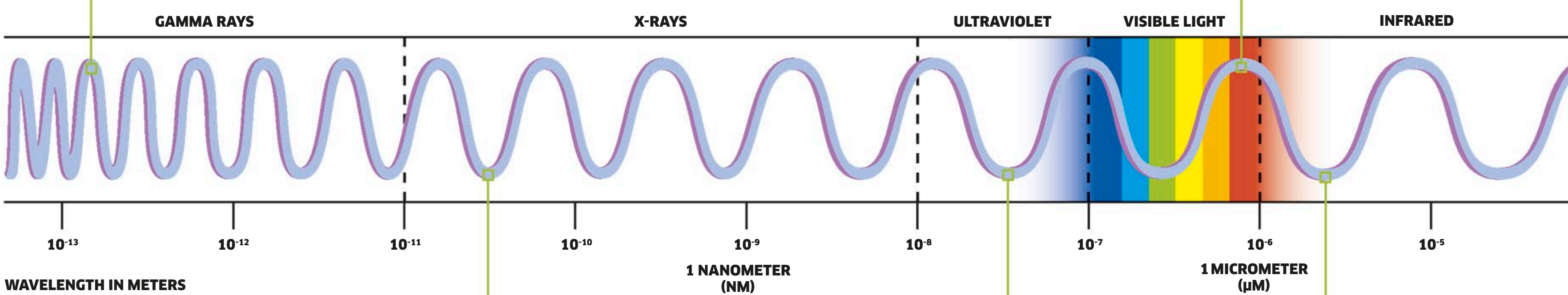
Sprawling cities across the East Coast at night are clearly visible in this photograph taken by astronauts aboard the International Space Station (ISS).

Long Island and New York can be seen on the right, Philadelphia, Pittsburgh, and other major cities in the center. Streetlights and lights in homes and gardens contribute to the glow. For people on the ground, some of the light is reflected back by a haze of dust and water vapor, creating light pollution that makes it hard to see the stars in the night sky.

Gamma rays can cause cancer, but can also **kill cancer cells.**

Gamma rays
The highest-energy waves, with wavelengths the size of an atomic nucleus, gamma rays are emitted by nuclear fission in weapons and reactors and by radioactive substances. Gamma radiation is very harmful to human health.

Visible light
This is the range of wavelengths that is visible to the human eye. Each drop in a raindrop is like a tiny prism that splits white light into the colors of the spectrum.



X-rays
With the ability to travel through soft materials but not hard, dense ones, X-rays are used to look inside the body and for security bag checks.

Ultraviolet (UV)
Found in sunlight, UV radiation can cause sunburn and eye damage. The shortest, most harmful wavelengths are blocked by the ozone layer.

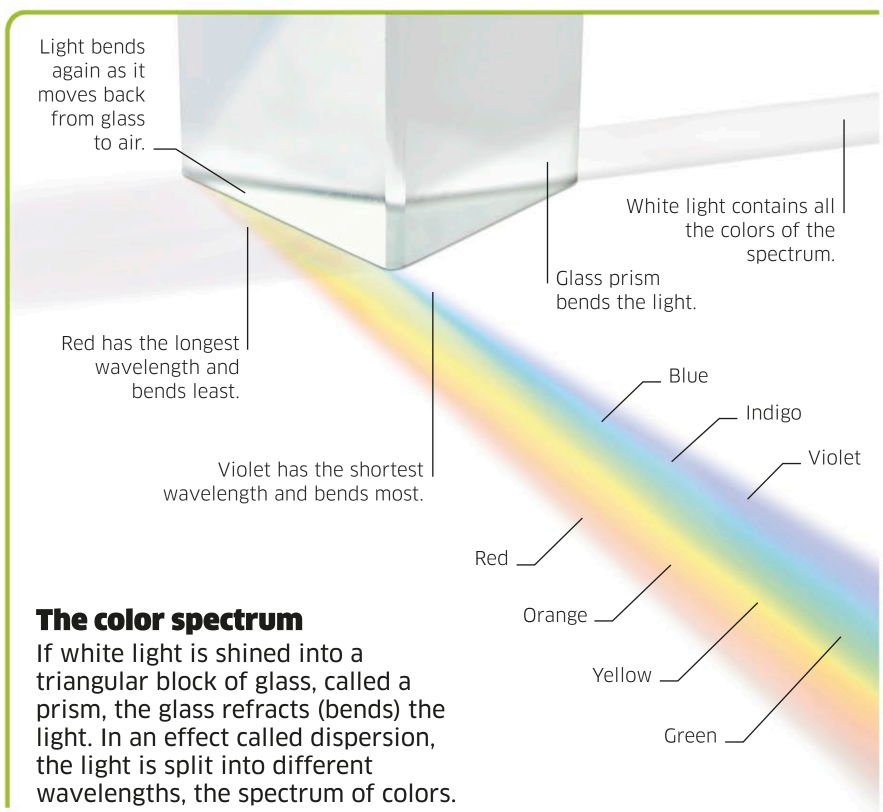
Infrared
Known as heat radiation, infrared is invisible, but special cameras are able to detect it and "see" the temperature of objects such as these penguins.

Electromagnetic radiation

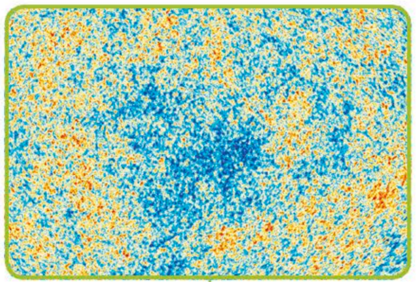
Light is one of several types of wave energy called electromagnetic radiation, which also includes radio waves, X-rays, and gamma radiation.

Electromagnetic radiation reaches us from the sun, stars, and distant galaxies. The Earth's atmosphere blocks most types of radiation, but allows radio waves and light, which includes some wavelengths of infrared and ultraviolet, to pass through.

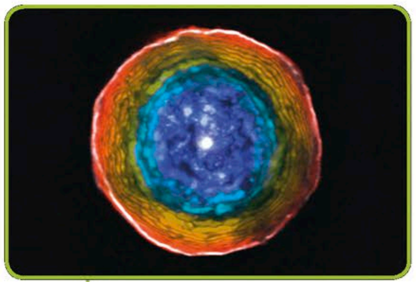
The electromagnetic spectrum beyond visible light was discovered between 1800, when British astronomer William Herschel first observed infrared, and 1900, when French physicist Paul Villard discovered gamma radiation.



The color spectrum
If white light is shined into a triangular block of glass, called a prism, the glass refracts (bends) the light. In an effect called dispersion, the light is split into different wavelengths, the spectrum of colors.

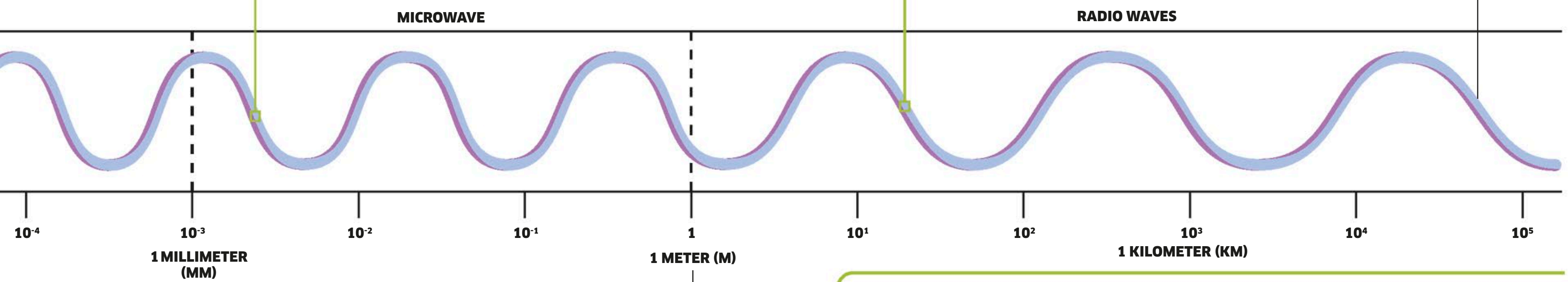


Microwaves
On Earth, microwaves are used for radar, cell phone, and satellite communications. Scientists have captured images (left) of microwaves left over from the Big Bang at the birth of the universe.



Radio waves
The longest waves on the spectrum, radio waves carry TV as well as radio signals. Radio telescopes are able to capture radio waves emitted by sources in space and convert them into images, such as this star (left).

Waves at this end of the spectrum have the least energy and lowest frequencies.



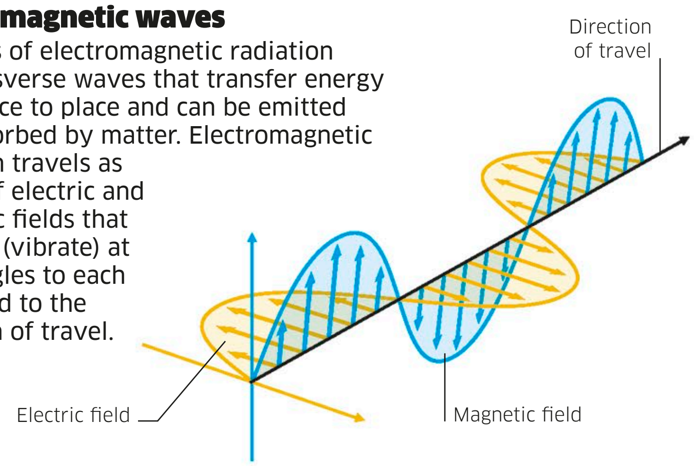
The electromagnetic spectrum

There are electromagnetic waves over a wide range of wavelengths, from gamma waves, which have the shortest wavelength and highest energy, to radio waves, which have the longest wavelength and lowest energy. All electromagnetic waves are invisible, except for those that make up light. As you move along the spectrum, different wavelengths are used for a variety of tasks, from sterilizing food and medical equipment to communications.

The dividing line between some types of electromagnetic radiation is distinct, whereas other types overlap. Microwaves, for example, are the shortest wavelength radio waves, ranging from 1 mm to 1 m.

Electromagnetic waves

All types of electromagnetic radiation are transverse waves that transfer energy from place to place and can be emitted and absorbed by matter. Electromagnetic radiation travels as waves of electric and magnetic fields that oscillate (vibrate) at right angles to each other and to the direction of travel.

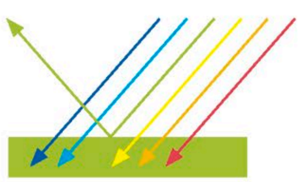


Seeing color

We see color based on information sent to the brain from light-sensitive cells in the eye called cones. There are three types of cone, which respond to red, green, or blue light. We see all colors as a mix of these three colors. Objects reflect or absorb the different colors in white light. We see the reflected colors.

White object
White objects reflect all the colors that make up the visible light spectrum, which is why they appear white.

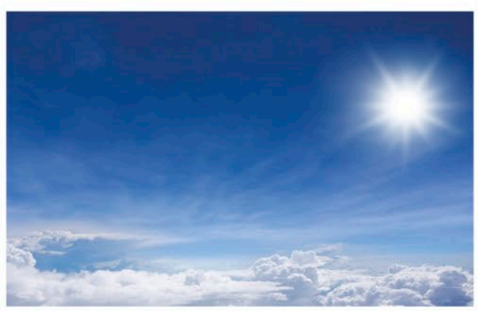
Black object
Black objects absorb all the colors of the visible light spectrum and reflect none. They also absorb more heat.



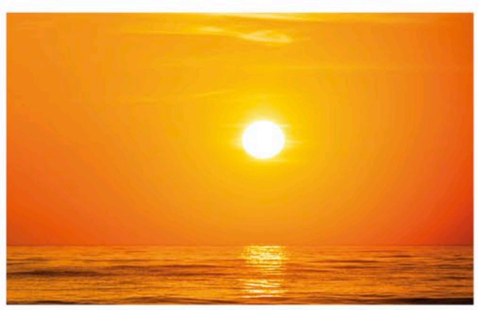
Green object
We see green objects because they reflect only the green wavelengths of visible light.

Light scattering

When sunlight hits Earth's atmosphere, air molecules, water droplets, and dust particles scatter the light, but they don't scatter the colors equally. This is why the sky is blue, clouds are white, and sunsets red.



Blue sky
The blue of the sky is caused by air molecules in the atmosphere, which scatter short-wavelength light at the blue end of the spectrum. Larger water and dust particles scatter the full spectrum as white light. The bluer the sky, the purer the air.

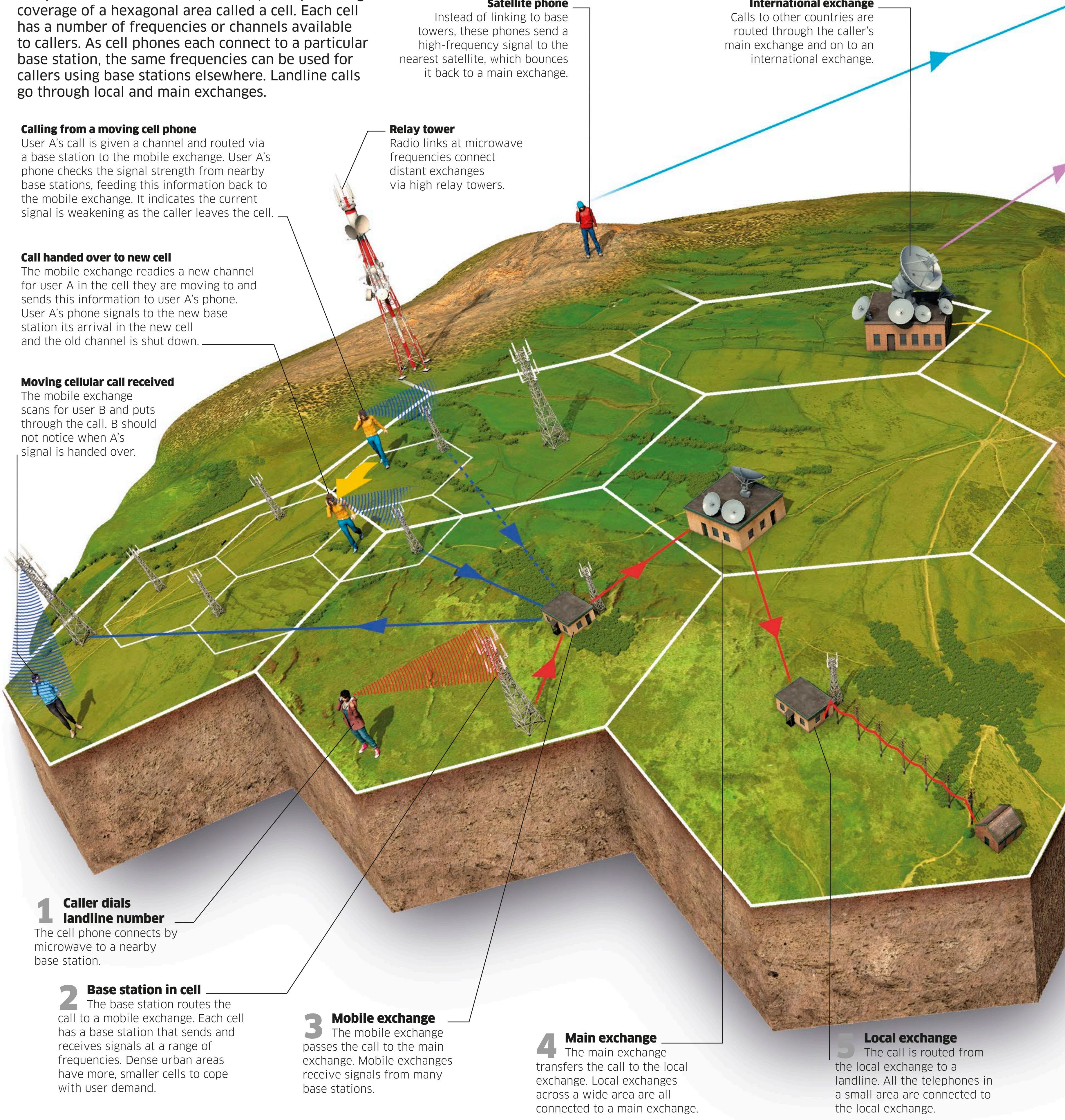


Red sunset
When the sun is low in the sky, light takes a longer path through the atmosphere, more light is scattered, and shorter wavelengths are absorbed. At sunrise and sunset, clouds may appear red, reflecting the color of light shining on them.

1 million threads of **fiber-optic cable** can fit in a **½ in- (12.7 mm-) diameter tube.**

Telephone network

Cell phones connect to base stations, each providing coverage of a hexagonal area called a cell. Each cell has a number of frequencies or channels available to callers. As cell phones each connect to a particular base station, the same frequencies can be used for callers using base stations elsewhere. Landline calls go through local and main exchanges.



Satellite phone
Instead of linking to base towers, these phones send a high-frequency signal to the nearest satellite, which bounces it back to a main exchange.

International exchange
Calls to other countries are routed through the caller's main exchange and on to an international exchange.

Calling from a moving cell phone
User A's call is given a channel and routed via a base station to the mobile exchange. User A's phone checks the signal strength from nearby base stations, feeding this information back to the mobile exchange. It indicates the current signal is weakening as the caller leaves the cell.

Relay tower
Radio links at microwave frequencies connect distant exchanges via high relay towers.

Call handed over to new cell
The mobile exchange readies a new channel for user A in the cell they are moving to and sends this information to user A's phone. User A's phone signals to the new base station its arrival in the new cell and the old channel is shut down.

Moving cellular call received
The mobile exchange scans for user B and puts through the call. B should not notice when A's signal is handed over.

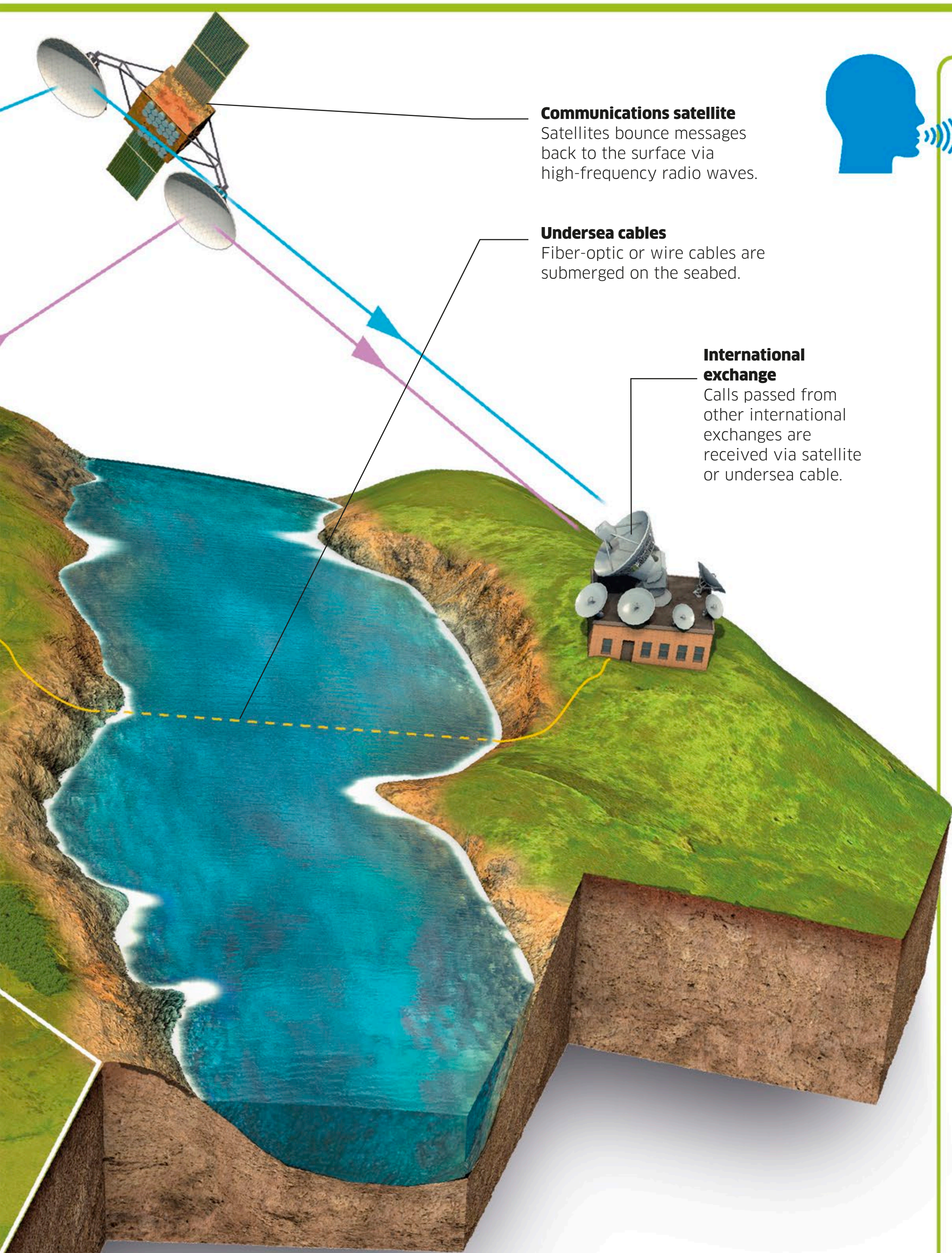
1 Caller dials landline number
The cell phone connects by microwave to a nearby base station.

2 Base station in cell
The base station routes the call to a mobile exchange. Each cell has a base station that sends and receives signals at a range of frequencies. Dense urban areas have more, smaller cells to cope with user demand.

3 Mobile exchange
The mobile exchange passes the call to the main exchange. Mobile exchanges receive signals from many base stations.

4 Main exchange
The main exchange transfers the call to the local exchange. Local exchanges across a wide area are all connected to a main exchange.

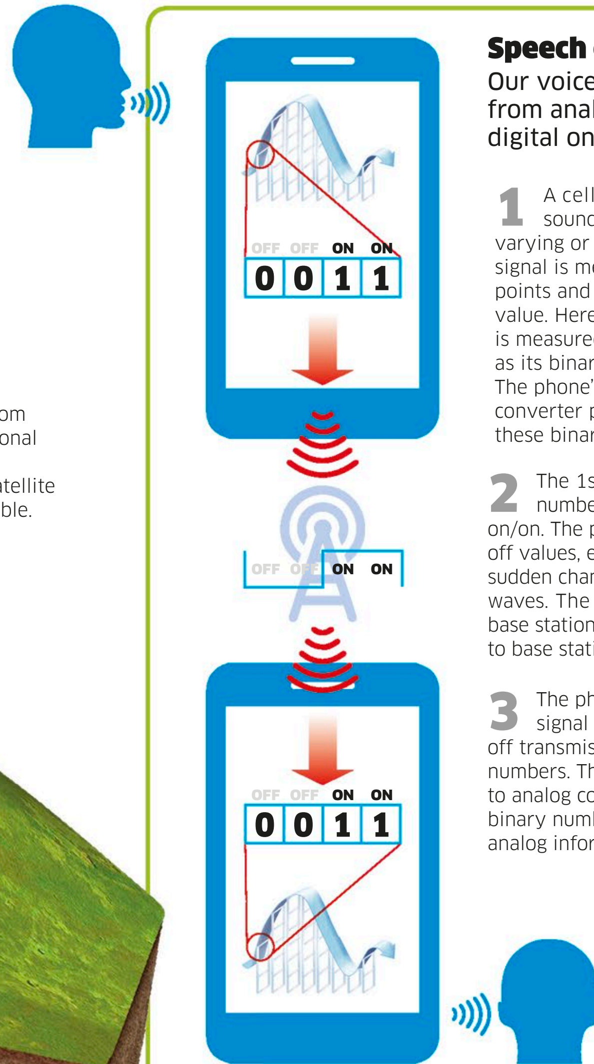
5 Local exchange
The call is routed from the local exchange to a landline. All the telephones in a small area are connected to the local exchange.



Telecommunications

Modern telecommunications use electricity, light, and radio as signal carriers. The global telephone network enables us to communicate worldwide, using radio links, fiber-optic cables, and metal cables.

Signals representing sounds, images, and other data are sent as either analog signals, which are unbroken waves, or as digital signals that send binary code as abrupt changes in the waves. Radio waves transmit radio and TV signals through the air around Earth, while microwave wavelengths are used in cell phones, Wi-Fi, and Bluetooth. Cables carry signals both above and below ground—as electric currents along metal wires, or as pulses of light that reflect off the glass interiors of fiber-optic cables.



Speech conversion

Our voices are converted from analog signals to digital ones to make calls.

1 A cell phone captures sound as a continuously varying or analog signal. The signal is measured at various points and each point is given a value. Here a point on the signal is measured as 3, which is shown as its binary equivalent of 0011. The phone's analog to digital converter produces strings of these binary numbers (see p.95).

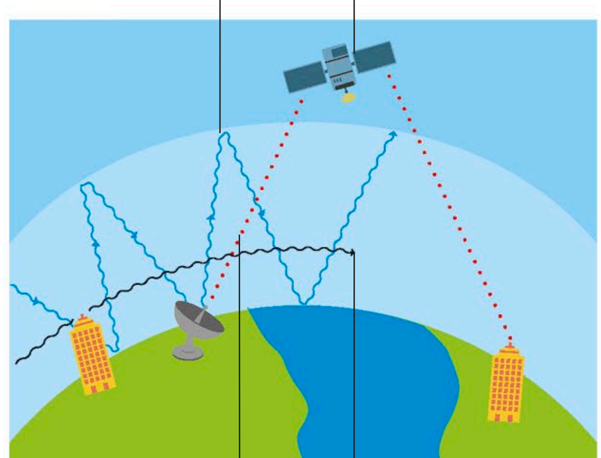
2 The 1s and 0s of the binary number 0011 become off/off/on/on. The phone transmits the on/off values, encoding them as sudden changes to the signal's waves. The signal passes from base station to mobile exchange to base station.

3 The phone receives the digital signal and interprets the on/off transmission as strings of binary numbers. The phone's digital to analog converter turns the binary numbers back into analog information.

4 The phone's speaker sends an analog signal we hear as a sound wave.

The ionosphere and radio waves

The ionosphere is a region of the atmosphere that contains ions and free electrons. This causes it to reflect some lower-frequency, longer-wavelength radio waves over large distances.



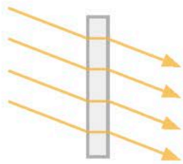
Light

Light is a type of electromagnetic radiation. It is carried by a stream of particles, called photons, that can also behave like a wave.

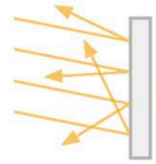
The most important source of light on Earth is the sun. Sunlight is produced by energy generated in the sun's core. Like the sun, some objects such as candles emit (send out) light—they are luminous. In contrast, most objects reflect and/or absorb light. Light travels as transverse waves, like ripples in water; the direction of wave vibration is at right angles to the direction that the light travels.

Light and matter

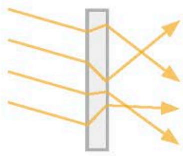
A material appears shiny, dull, or clear depending on whether it transmits, reflects, or absorbs light rays. Most materials absorb some light.



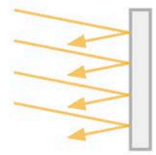
Transparent
Light passes through transparent (clear) materials. The light is transmitted, bending as it changes speed.



Opaque (matte)
Dull, opaque materials have a rough surface that absorbs some light, and reflects and scatters the rest.



Translucent
Materials that are translucent (milky) let light through, but scatter it in different directions.



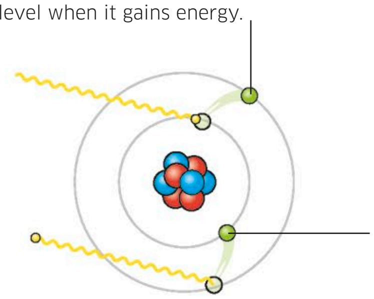
Opaque (shiny)
Shiny, opaque materials have a smooth surface that reflects light in a single beam.

Sources of light

Light is a form of energy. It is produced by two distinct processes: incandescence and luminescence. Incandescence is the emission of light by hot objects. Luminescence is the emission of light without heat.

Photons
If an atom gains energy, electrons orbiting the nucleus jump to higher orbits, or "energy levels." When the electrons return to their original orbits, they release photons of light, or other electromagnetic radiation.

Excited atom
Electron jumps to higher level when it gains energy.

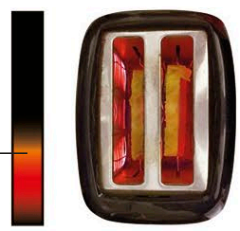


Atom calms down
Electron gives out photon as it returns to its original orbit.

Incandescence
Incandescent light sources produce light because they are hot. The hotter an object, the more of the visible color spectrum it produces. Incandescent light produces all the colors in its range in a continuous spectrum.

Color spectrum
A spectroscope image shows the spectrum of colors a light source emits.

Toaster grill
A grill or the element of a toaster, at about 1,110°F (600°C), will glow with only red light. It also emits light in the infrared range.

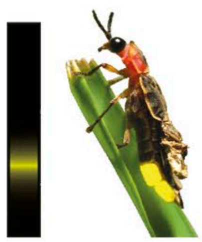


Candle flame
A candle flame, at about 1,550°F (850°C), produces some green and yellow light, as well as red, so it glows with a bright yellow light.

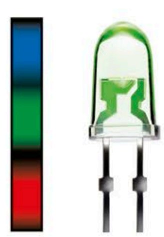
Incandescent light bulb
The filament of an old-style light bulb, at about 4,500°F (2,500°C), produces nearly all the spectrum. Missing some blue light, it has a yellow tinge.

Luminescence
A luminescent light source produces light by electrons losing energy in atoms. Energy is lost in exact amounts, which determine the color of the light produced, depending on the chemistry of the luminescent material.

Bioluminescence
Bioluminescent animals such as fireflies produce a single wavelength of yellowish-green light by oxidizing a molecule called luciferin.



Light-emitting diode (LED)
An LED may produce two or more colors. Energy-saving LEDs produce red, green, and blue light, chosen to give an impression of white light.



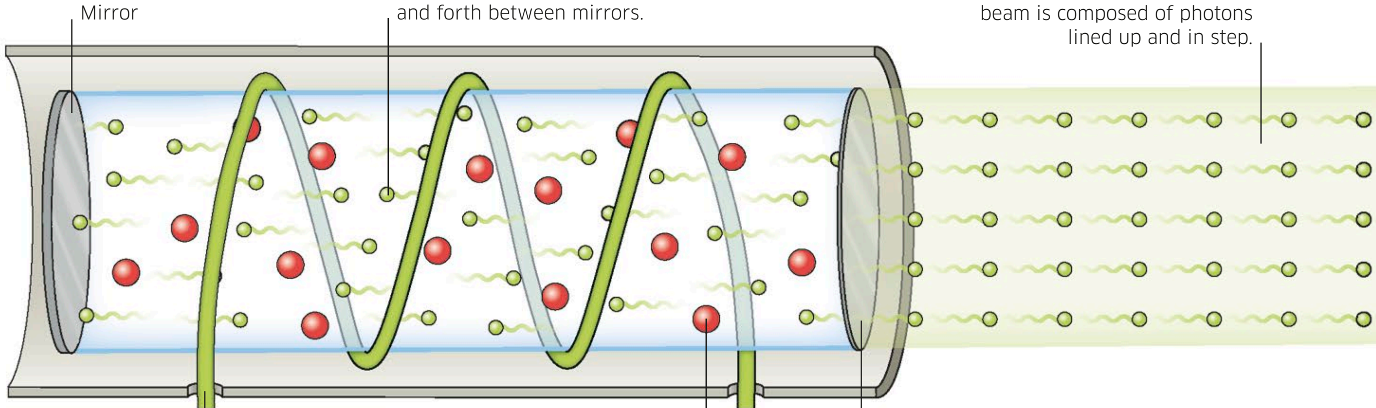
Compact fluorescent lamp
Luminescent paints on the inside of glass produce red, green, and blue light, giving an impression of white light (not a continuous spectrum).

Lasers
A laser produces an intense beam of light of a single wavelength. The light is concentrated in a "lasing medium" such as crystal. In a crystal laser, light from a coiled tube "excites" atoms in a tube made of crystals, such as ruby. The photons of light that these excited atoms produce reflect between the tube's mirrored ends and escape as a powerful beam. We say the light is coherent, because the waves are in step.

Mirror

Photons are reflected back and forth between mirrors.

Powerful, concentrated laser beam is composed of photons lined up and in step.



A flash tube is a powerful lamp whose light excites electrons in the crystal.

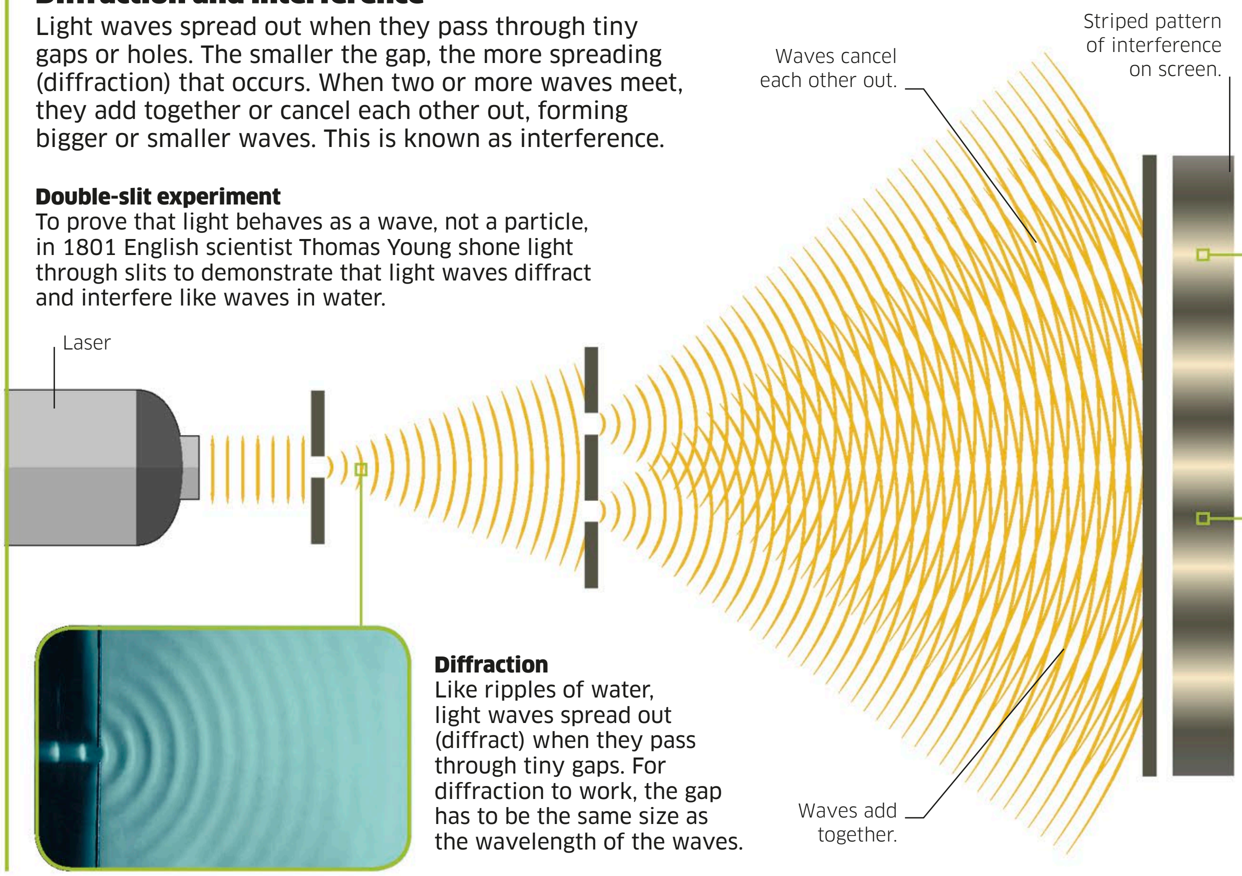
Excited atoms give off photons, which excite other atoms, too.

Light emerges from partial (semi-silvered) mirror.

Diffraction and interference

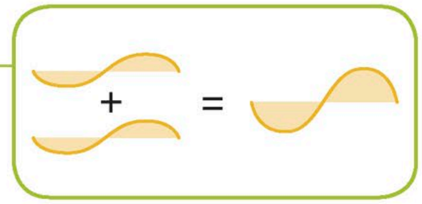
Light waves spread out when they pass through tiny gaps or holes. The smaller the gap, the more spreading (diffraction) that occurs. When two or more waves meet, they add together or cancel each other out, forming bigger or smaller waves. This is known as interference.

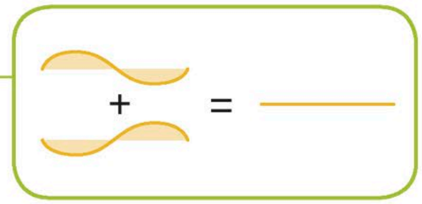
Double-slit experiment
To prove that light behaves as a wave, not a particle, in 1801 English scientist Thomas Young shone light through slits to demonstrate that light waves diffract and interfere like waves in water.



Diffraction
Like ripples of water, light waves spread out (diffract) when they pass through tiny gaps. For diffraction to work, the gap has to be the same size as the wavelength of the waves.

Constructive interference
When two waves of the same length and height (amplitude) overlap in phase, they add together to make a new wave that has twice the height, making a light twice as bright.



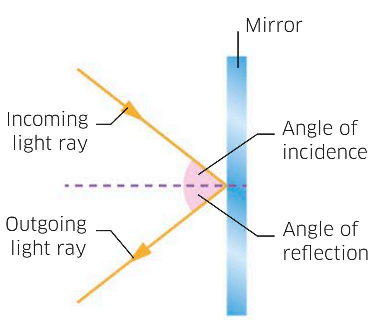


Destructive interference
When two identical waves add together, but are out of phase, they cancel each other out. The wave they make has zero amplitude, making darkness.

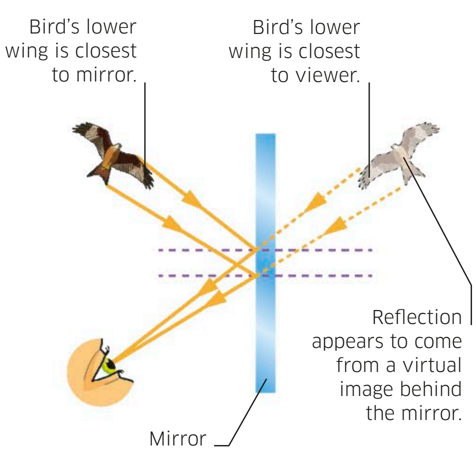
Reflection

Light rays bounce off a smooth surface, such as a mirror, in a single beam. This is called specular reflection. If the surface is rough, the rays bounce off randomly in different directions. This is called diffuse reflection.

The law of reflection
A light ray beamed at a mirror bounces off again at exactly the same angle, or, in more scientific terms, the angle of incidence is equal to the angle of reflection.



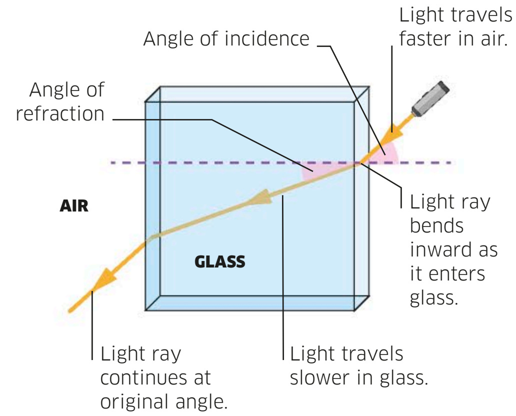
Reverse images
Mirrors don't reverse things left to right—writing looks reversed because you've turned it around. What mirrors do is to reverse things back to front along an axis at right angles to the mirror.



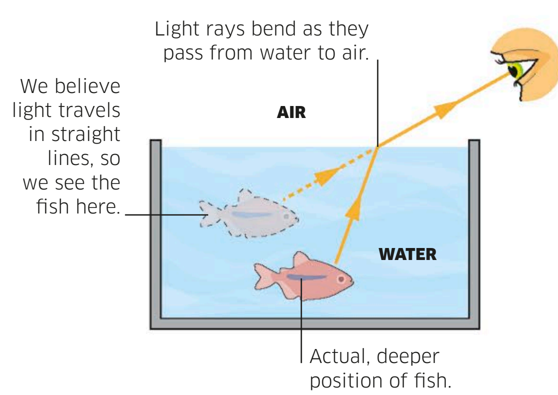
Refraction

Light rays travel more slowly in more dense substances such as water and glass than in air. The change in speed causes light to bend (refract) as it passes from air to glass or water and back. How much a material refracts light is known as its refractive index.

Bending light
Light rays slow down and bend as they pass from air to glass, and speed up and bend outward as they pass from glass to air. The refractive index of air is 1. For glass, it is around 1.60, depending on the quality of the glass, whereas for diamond—which is harder and denser—it is 2.40.



Real and apparent depth
Refraction makes an object in water appear nearer the surface. Because our brains assume that light rays travel in a straight line, rather than bending, we see the object in the water higher up than it really is. For a person under water, the reverse applies: an object on land appears higher up than it is.



James Gregory designed a reflecting telescope in 1663, a few years before Isaac Newton created the Newtonian telescope in 1668.

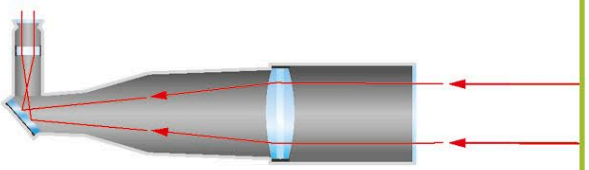
Telescopes

Powerful telescopes make faint objects, such as distant stars and galaxies, easier to see. They work by first gathering as much light as they can, using either a lens or a mirror, and then focusing that light into a clear image.

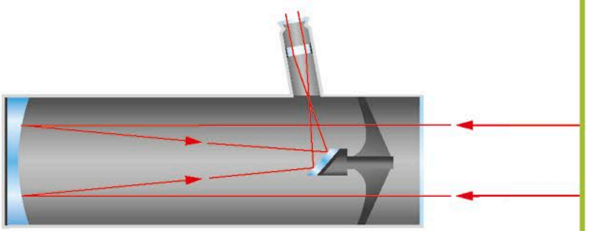
There are two main types of telescope: refracting, which focus light using lenses, and reflecting, which focus light using mirrors. Optical telescopes see visible light, but telescopes can also look for different kinds of electromagnetic radiation: radio telescopes receive radio waves and X-ray telescopes image X-ray sources. Telescopes use large lenses compared to microscopes, which are used to look at things incredibly close up, while binoculars work like two mini telescopes side by side.

Types of telescope

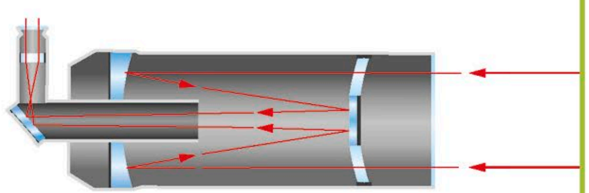
Refracting telescopes use lenses to gather and focus light. Reflecting telescopes do the same with mirrors—huge space telescopes use very large mirrors. Compound telescopes combine the best of lenses and mirrors.



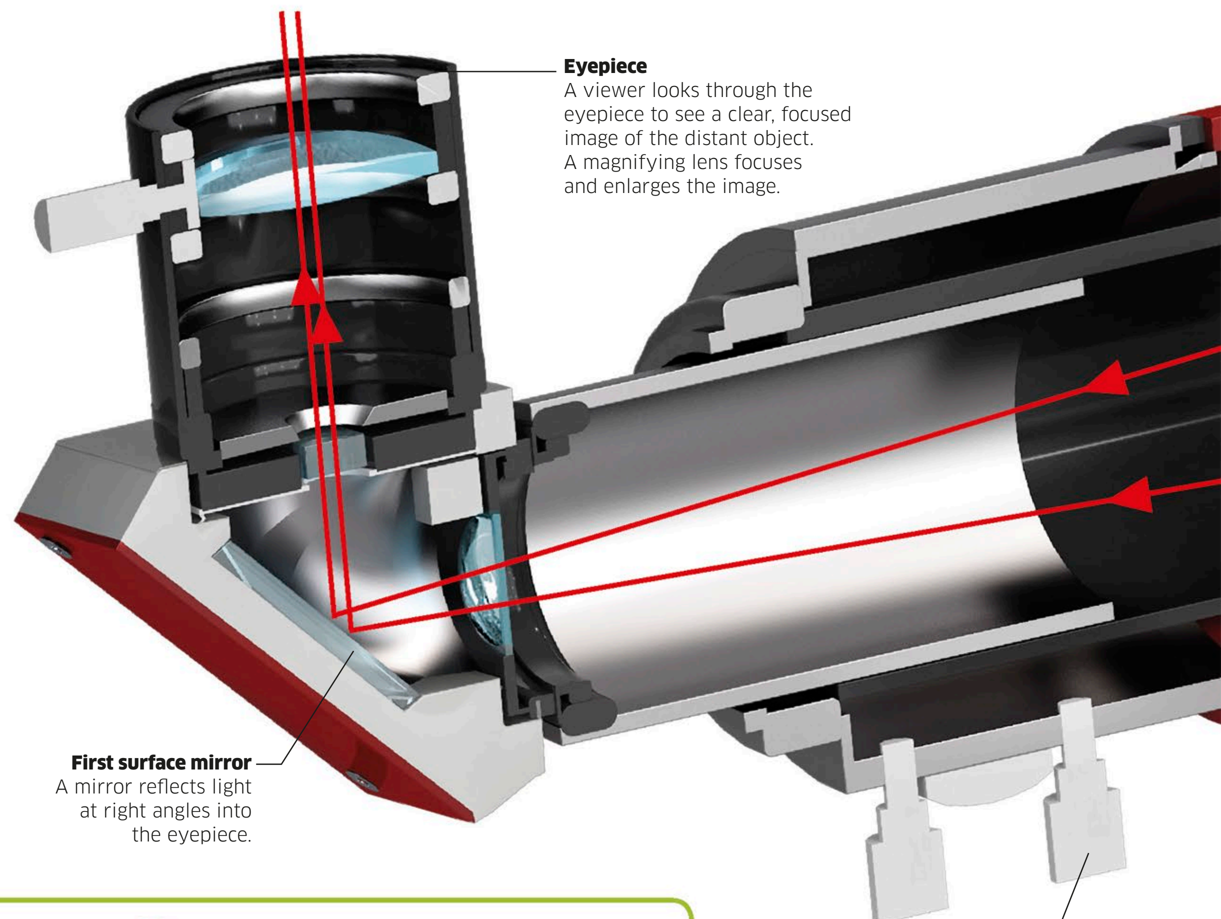
Refracting telescope
A large convex lens focuses light rays to a mirror that reflects the light into the eyepiece, where a lens magnifies the image. Lenses refract the light, causing color distortion.



Reflecting telescope
A concave mirror reflects and focuses light to a secondary mirror, which reflects it into an eyepiece, where a lens magnifies the image. There is no color distortion.

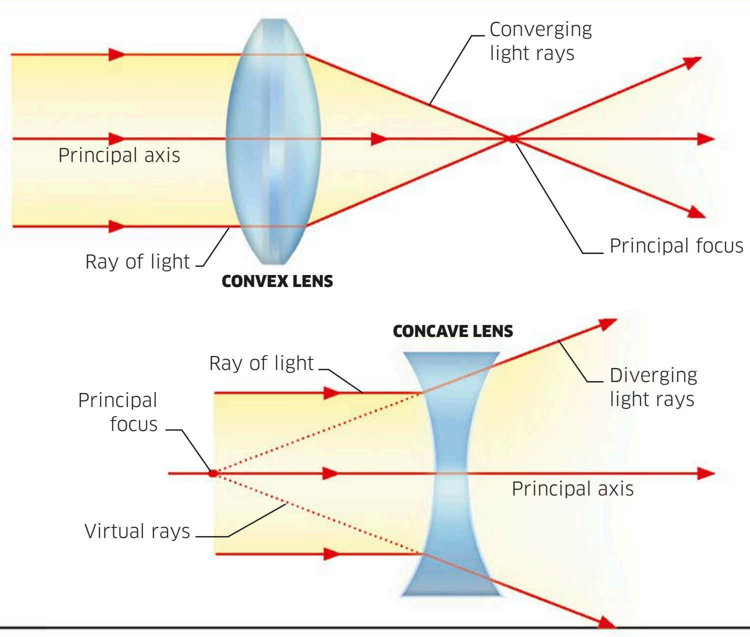


Compound telescope
The most common type of telescope, this combines lenses and mirrors to maximize magnification and eliminate distortion.



Convex and concave lenses

Convex, or converging, lenses take light and focus it into a point behind the lens, called the principal focus. This is the type of lens used in the glasses of a short-sighted person. By contrast, concave, or diverging, lenses spread light out. When parallel rays pass through a concave lens, they diverge as if they came from a focal point—the principal focus—in front of the lens.

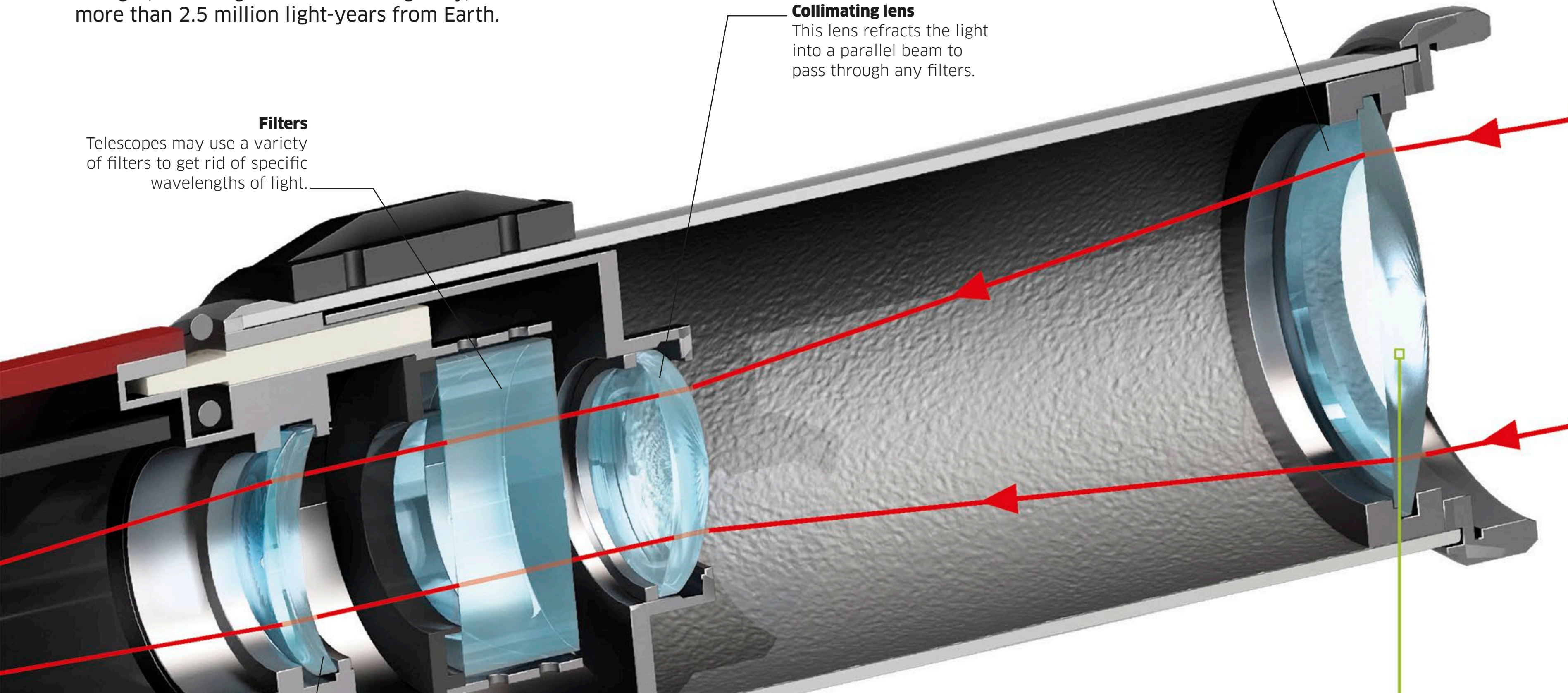
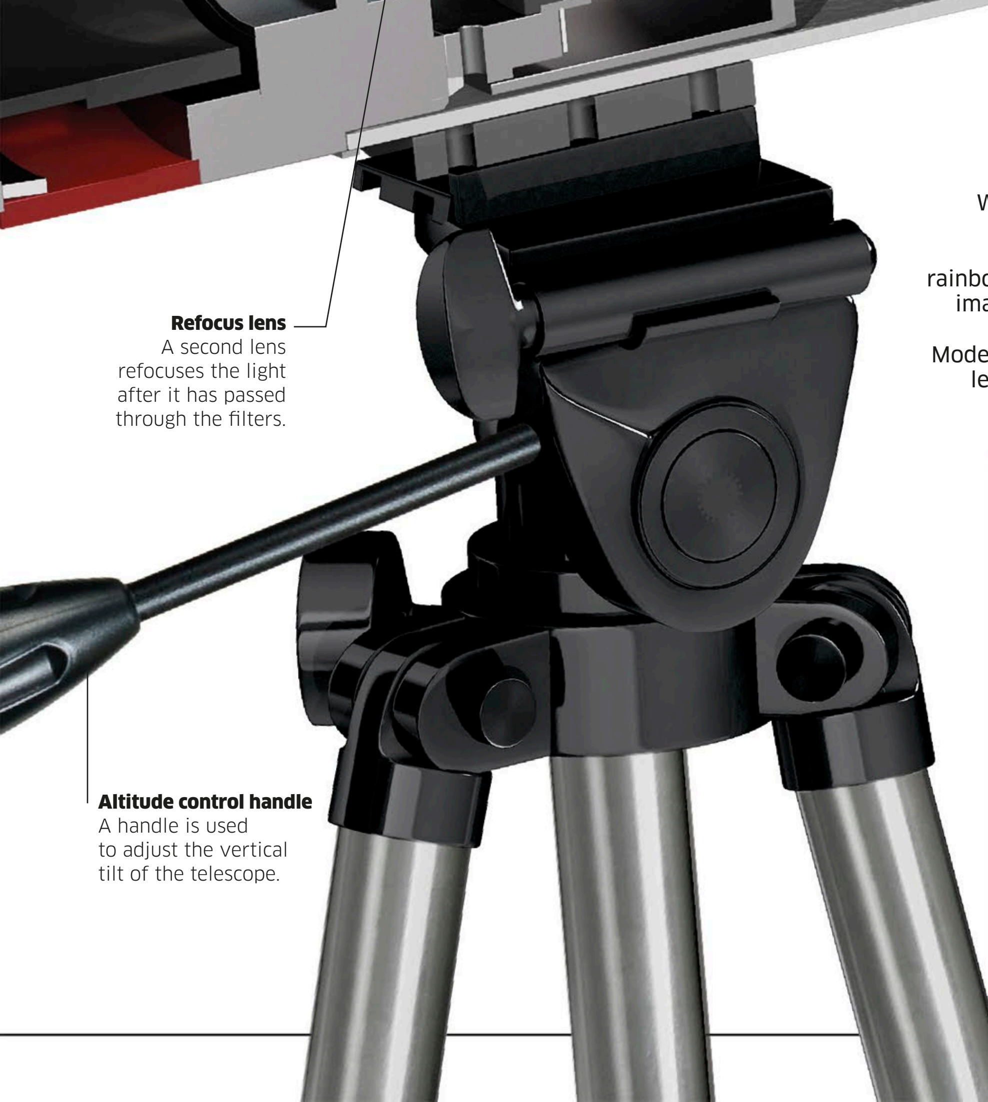


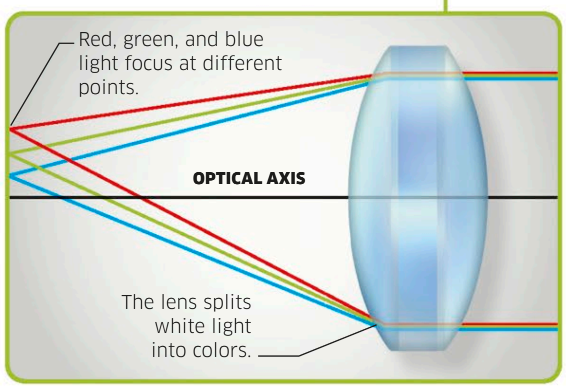
A GERMAN-DUTCH LENS MAKER **CALLED HANS LIPPERSHEY DEVELOPED THE EARLIEST** REFRACTING TELESCOPE **IN THE YEAR 1608.** GALILEO IMPROVED THE DESIGN.

Isaac Newton
created the first reflecting telescopes to get around the problem of color distortion.

Refracting telescope

This type of telescope uses a convex lens to gather and focus as much light as possible from the distant object. It can be used to look at anything bright enough for light to reach us at night, including the Andromeda galaxy, more than 2.5 million light-years from Earth.

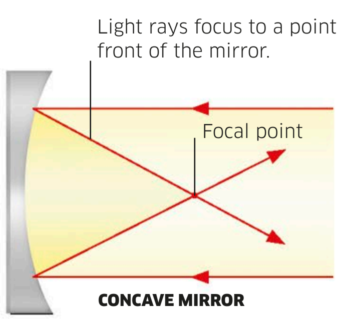



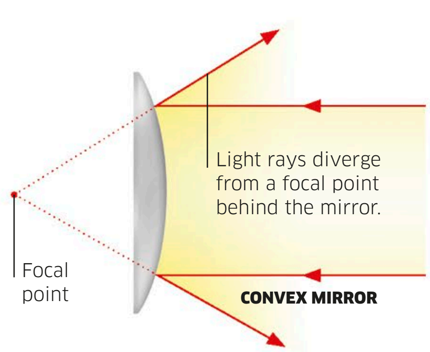


Rainbow effect
When white light passes through a glass lens, it is refracted, creating a rainbow of colors around the image—an effect known as "chromatic aberration." Modern telescopes use extra lenses to counteract this.

Concave and convex mirrors

An image reflected in a concave mirror appears small and, depending how far the viewer is from the mirror, may be upside down. The image in a convex mirror is formed by a virtual image behind the mirror, and appears large.





The direction of Earth's magnetic field has reversed suddenly about 10 times in the past three million years.

Magnetism

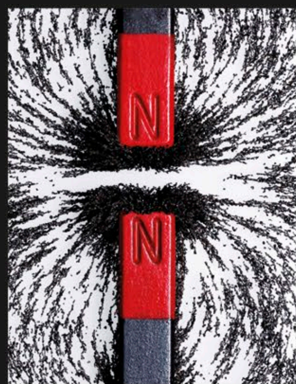
Magnetism is an invisible force exerted by magnets and electric currents. Magnets attract iron and a few other metals, and attract or repel other magnets. Every magnet has two ends, called its north and south poles, where the forces it exerts are strongest.

A magnetic material can be magnetized or will be attracted to a magnet. Iron, cobalt, nickel—and their alloys—and rare earth metals are all magnetic, which means they can be magnetized by stroking with another magnet or by an electric current. Once magnetized, these materials stay magnetic unless demagnetized by a shock, heat, or an electromagnetic field (see p.93). Most other materials, including aluminum, copper, and plastic, are not magnetic.

Unlike poles attract, like poles repel

The invisible field of force around a magnet is called a magnetic field. Iron filings show how the magnetic field loops around the magnet from pole to pole.

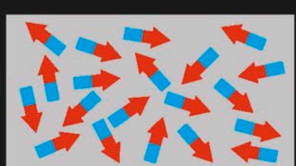
Attraction
Unlike or opposite poles (a north pole and a south pole) attract each other. Iron filings reveal the lines of force running between unlike poles.



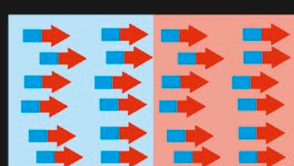
Repulsion
Like poles (two north or two south poles) repel each other. Iron filings show the lines of force being repelled between like poles.

Magnetic induction

An object made of a magnetic material, such as a steel paper clip, is made of regions called domains, each with its own magnetic field. A nearby magnet will align the domain's fields, turning the object into a magnet. The two magnets now attract each other—that is why paper clips stick to magnets. Stroking a paper clip with a magnet can align the domains permanently.



Domains scattered
In an unmagnetized object, the domains point in all directions.

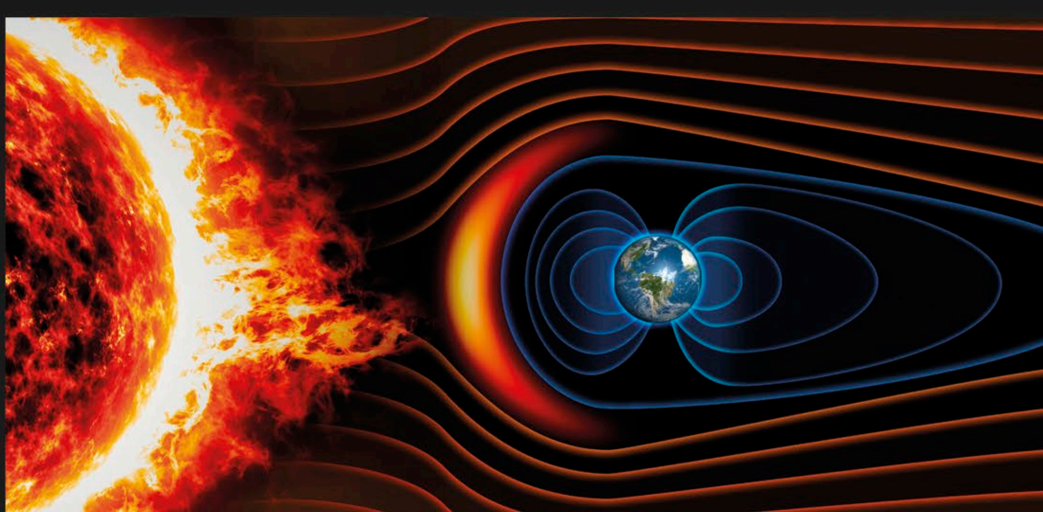


Domains aligned
When a magnet is nearby, the domain's fields align in the object.

Magnetic compass
Made of magnetized metal and mounted so that it can spin freely, the needle of a magnetic compass lines up in a north-south direction in Earth's magnetic field. Because the Earth's magnetic North Pole attracts the north, or north-seeking, pole of other magnets, it is in reality the south pole of our planet's magnetic field.

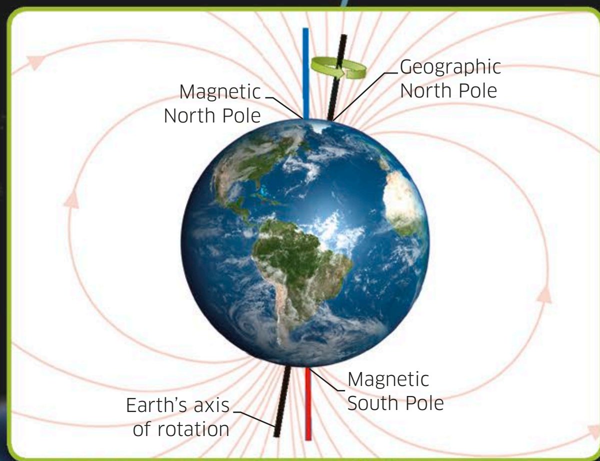
A teardrop-shaped magnetic field

Earth's magnetic field protects us from the harmful effects of solar radiation. In turn, a stream of electrically charged particles from the sun, known as the solar wind, distorts the magnetic field into a teardrop shape and causes the auroras—displays of light around the poles (see pp.90–91).



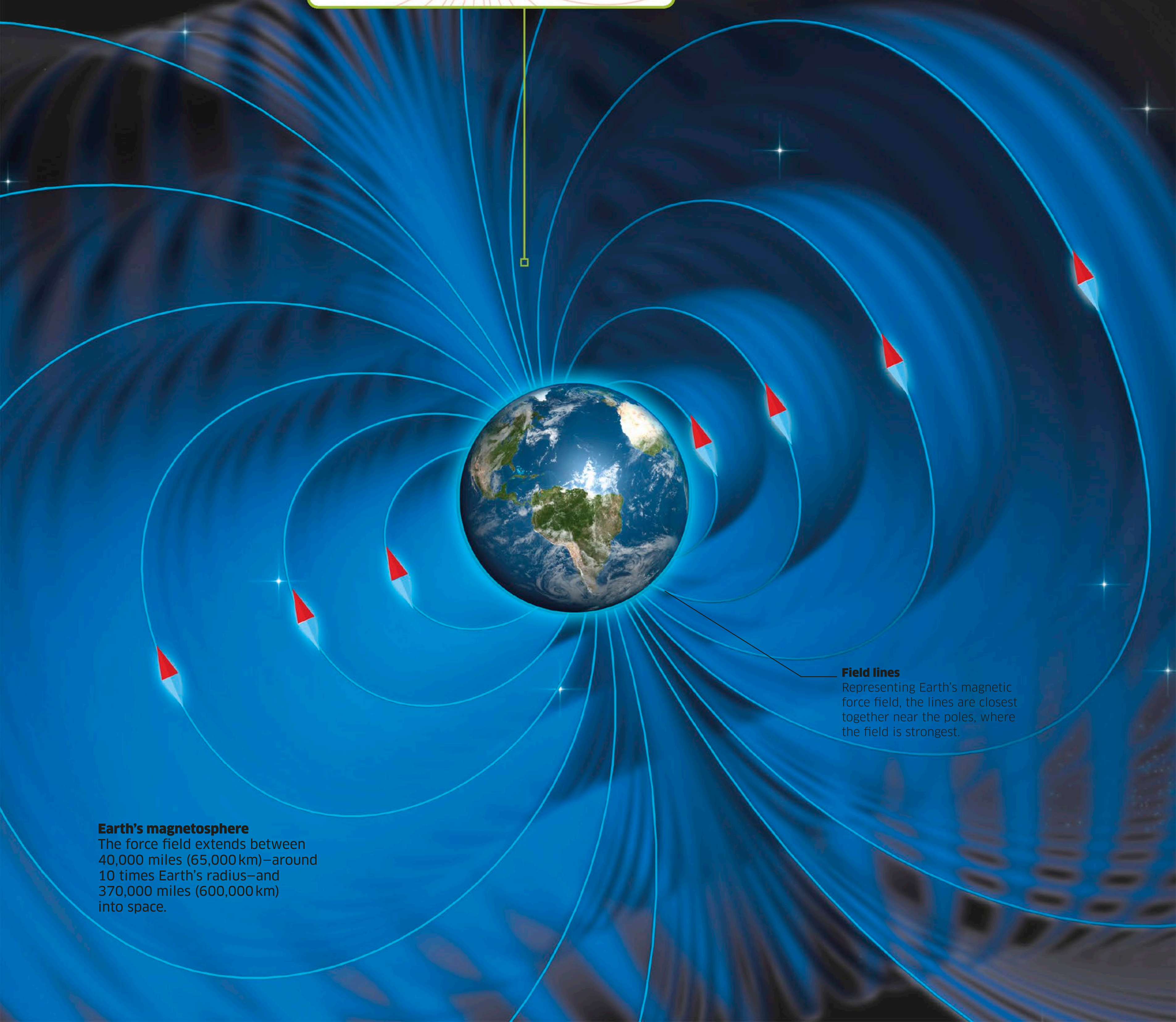
Distortion of the magnetosphere
The stream of charged particles from the sun compresses Earth's magnetic field on the side nearest the sun and draws the field away from Earth into a long "magnetotail" on the far side.

Magnetic and geographic north
There is a difference of a few degrees between the direction that a compass points, known as true north, and the geographic North Pole, which is on the axis of rotation that Earth spins around as it orbits the sun. In reality, the magnetic poles are constantly moving, and reverse completely every few thousand years.



Earth's magnetism

The Earth can be thought of as one big, powerful magnet with a magnetic force field, called the magnetosphere, that stretches thousands of miles into space. The magnetic field is produced by powerful electric currents in the liquid iron and nickel swirling around in Earth's outer core.



Field lines
Representing Earth's magnetic force field, the lines are closest together near the poles, where the field is strongest.

Earth's magnetosphere
The force field extends between 40,000 miles (65,000 km)—around 10 times Earth's radius—and 370,000 miles (600,000 km) into space.

Aurora borealis

The spectacular natural light show known as the aurora borealis, or northern lights, is a dazzling spectacle of ribbons and sheets of green, yellow, and pink light.

The cause of the aurora is a stream of charged particles ejected from the surface of the sun, known as the solar wind. These particles are guided toward the poles by Earth's magnetic field. When they hit oxygen and nitrogen molecules in the atmosphere, electrons in the molecules emit colored light. The northern lights—and aurora australis, or southern lights, around the South Pole—occur whenever the solar wind blows, typically about two hundred nights a year.

The word "electricity" comes from ***elektron***, **the Greek name for amber**, which gains an electric charge when rubbed with a cloth.

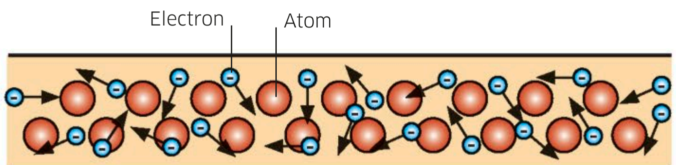
Electricity

A useful form of energy that can be converted to heat, light, and sound, electricity powers the modern world.

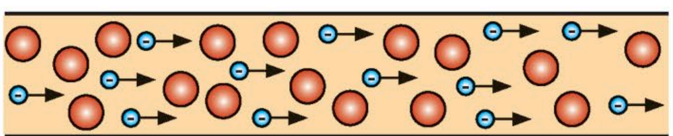
Atoms contain tiny particles called electrons that carry negative electrical charge. These orbit the positively charged atomic nucleus, but can become detached. Static electricity is the build-up of charge in an object. Current electricity is when charge flows.

Current electricity

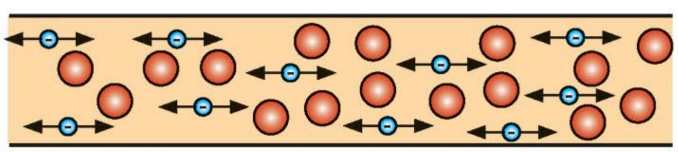
When an electric charge flows through a metal, it is called an electric current. The current is caused by the drift of negatively charged electrons through a conductor in an electrical circuit. Individual electrons actually travel very slowly, but pass electrical energy along a wire very fast.



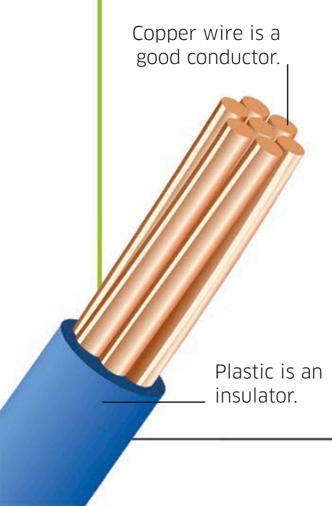
No current
If a conductor wire is not connected to a power supply, the free electrons within it move randomly in all directions.



Direct current (DC)
If the wire is given energy by a battery, electrons drift toward the positive pole of the power supply. If the charge flows in one direction, it is known as direct current (DC).



Alternating current (AC)
Electrical grid electricity runs on an alternating current (AC) supply. The charge changes direction periodically, sending the electrons first one way and then the other.



Conductors and insulators

Charged particles can flow through some substances but not others. In metals, electrons move between atoms. In solutions of salts, ions (positively charged atoms) can also flow. These substances are known as conductors. Current cannot pass through insulators, such as plastic, which have no free electrons. Semi-conductors such as silicon have atomic structures that can be altered to control the flow of electricity. They are widely used in electronics.

Static electricity

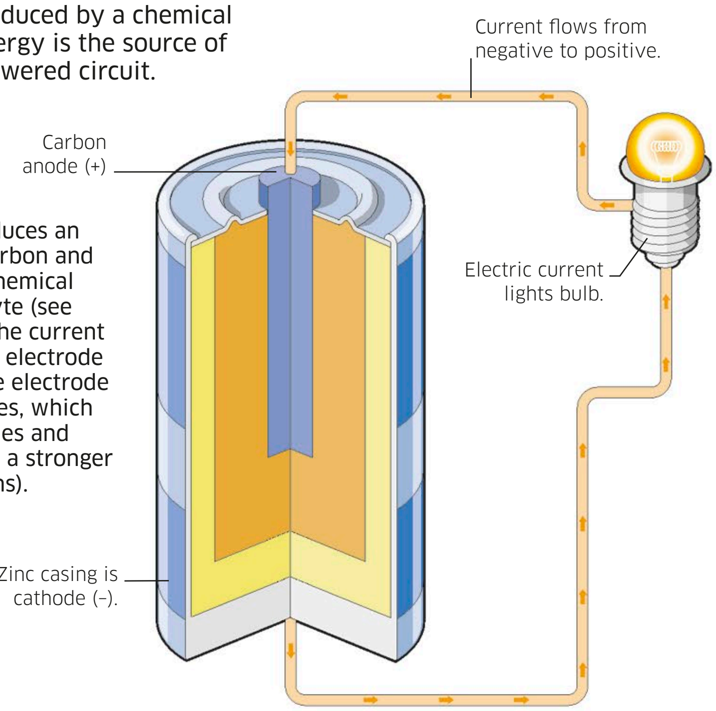
Electricity that does not flow is called static electricity. A static charge can be produced by rubbing two materials together, transferring electrons from one to the other. Objects that gain electrons become negatively charged, while objects that lose electrons become positively charged.

Attraction and repulsion
Rubbing balloons against your hair will charge the balloons with electrons, leaving your hair positively charged. The negative charge of the balloons will attract the positive charge of your hair.

Static discharge
When ice particles within a cloud collide, they gain positive and negative charge. Lightning is an electrical discharge between positive and negative parts of a thunderstorm cloud and the ground.

Making electricity

In order to make electrons move, a source of energy is needed. This energy can be in the form of light, heat, or pressure, or it can be the energy produced by a chemical reaction. Chemical energy is the source of power in a battery-powered circuit.



Battery
A standard battery produces an electric current using carbon and zinc conductors and a chemical paste called an electrolyte (see pp.52–53). In a circuit, the current flows from the negative electrode (cathode) to the positive electrode (anode). Lithium batteries, which have manganese cathodes and lithium anodes, produce a stronger voltage (flow of electrons).

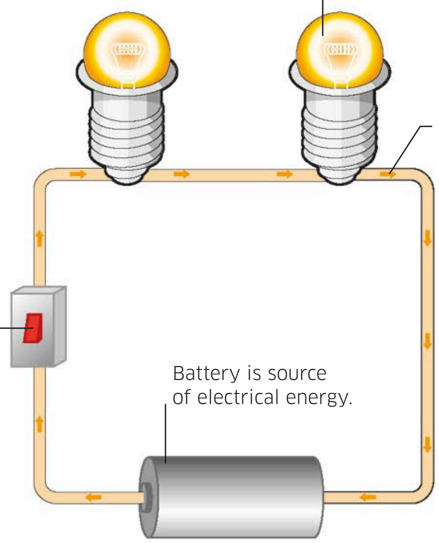
Solar cell
Light falling onto a "photovoltaic" cell, such as a solar cell, can produce an electric current. Light knocks electrons out of their orbits around atoms. The electrons move through the cell as an electric current.

Electric circuits

An electric circuit is the path around which a current of electricity flows. A simple circuit includes a source of electrical energy (such as a battery) and conducting wires linking components (such as switches, bulbs, and resistors) that control the flow of the current. Resistance is the degree to which materials resist the flow of current.

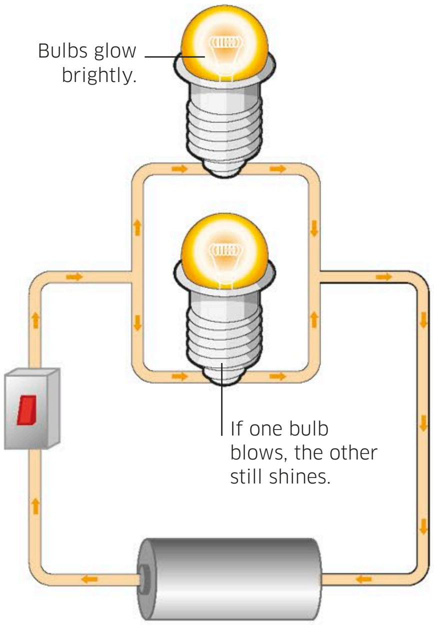
Series circuit

In a series circuit, all the components are connected one after another, so that they share the voltage of the source. If the circuit is broken, electricity ceases to flow.



Parallel circuit

A parallel circuit has two or more branches, so that each branch gets the full voltage from the source. If the circuit is broken on one of the branches, it continues to flow through the others.

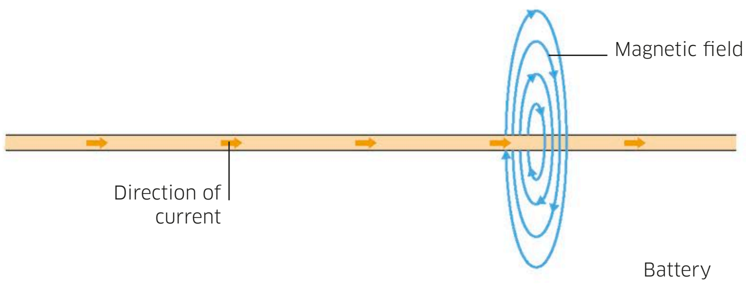


Electromagnetism

Moving a wire in a magnetic field causes a current to flow through the wire, while an electric current flowing through a wire generates a magnetic field around the wire. This creates an electromagnet—a useful device because its magnetism can be switched on and off.

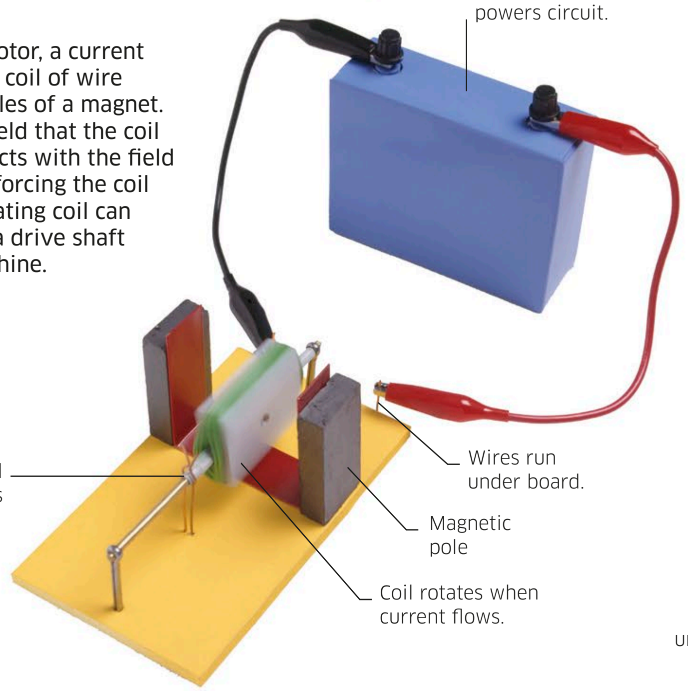
Electromagnetic field

When an electric current flows through a wire, it generates rings of magnetic field lines all around it. You can see this by placing a compass near a wire carrying a current. The stronger the current, the stronger the magnetism.



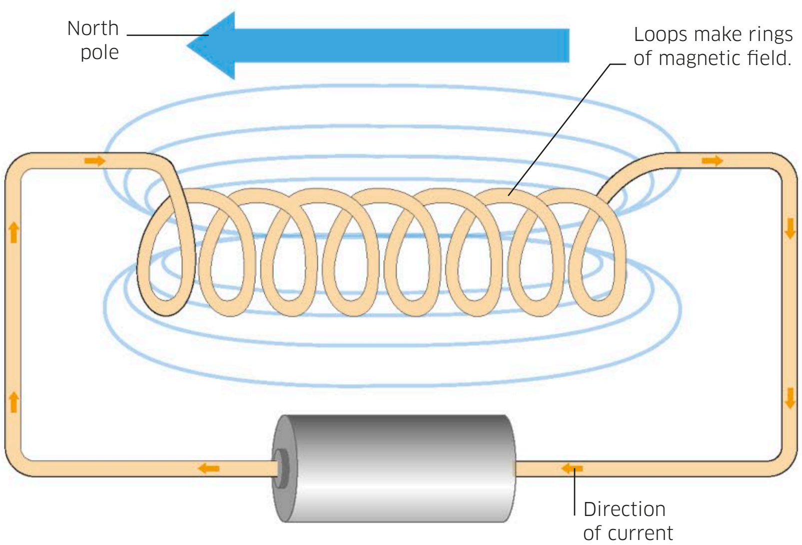
Electric motors

In an electric motor, a current flows through a coil of wire between the poles of a magnet. The magnetic field that the coil produces interacts with the field of the magnet, forcing the coil to turn. The rotating coil can be attached to a drive shaft to power a machine.



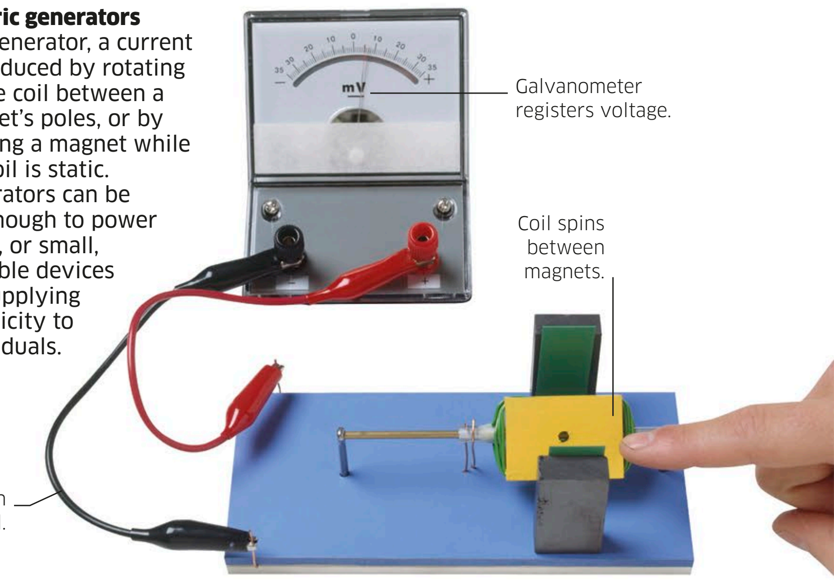
Solenoid

A coil of wire carrying a current produces a stronger magnetic field than a straight wire. This coil creates a common type of electromagnet called a solenoid. Winding a solenoid around an iron core creates an even more powerful magnetic field.



Electric generators

In a generator, a current is produced by rotating a wire coil between a magnet's poles, or by rotating a magnet while the coil is static. Generators can be big enough to power a city, or small, portable devices for supplying electricity to individuals.

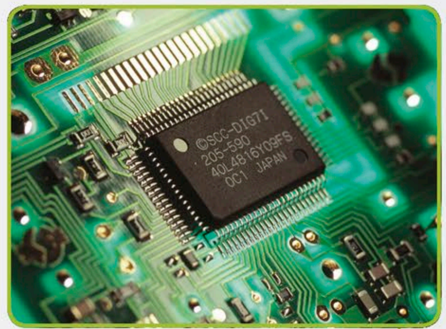


In 1965, Intel co-founder George Moore correctly predicted that the number of transistors on a chip would double every two years.

Electronics

Electric current is caused by a drift of electrons through a circuit. An electronic device uses electricity in a more precise way than simple electric appliances, to capture digital photos or play your favorite songs.

While it takes a large electric current to boil water, electronics use carefully controlled electric currents thousands or millions of times smaller, and sometimes just single electrons, to operate a range of complex devices. Computers, smartphones, amplifiers, and TV remote controls all use electronics to process information, communicate, boost sound, or switch things on and off.



Printed circuit board (PCB)
The "brain" of a smartphone is on its printed circuit board—a premanufactured electronic circuit unique to a particular device. The PCB is made from interconnected microchips, each of which is constructed from a tiny wafer of silicon and has an integrated circuit inside it containing millions of microscopic components.


Smartphone

Cell phones are now so advanced that they are really hand-sized computers. As well as linking to other digital devices, they contain powerful processor chips and plenty of memory to store applications.

Electronic components

Electronic circuits are made of building blocks called components. A transistor radio may have a few dozen, while a processor and memory chip in a computer could have billions. Four components are particularly important and appear in nearly every circuit.

Diode
Diodes make electric current flow in just one direction, often converting alternating to direct current.

Resistor
Resistors reduce electric current so it is less powerful. Some are fixed and others are variable.

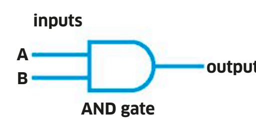
Transistor
Transistors switch current on and off or convert small currents into bigger ones.

Capacitor
Capacitors store electricity. They are used to detect key presses on touch screens.

Smartphones today are **more powerful** than the **NASA computers that sent Apollo 11 to the moon.**

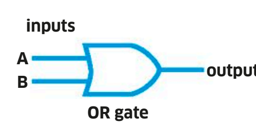
Circuits and logic gates

Computers process digital information with circuits called logic gates, which are used to make simple decisions. A logic gate accepts an electrical signal from its inputs and outputs either a 0 (off/low-voltage signal) or a 1 (on/high-voltage signal). The main types of gate are AND, OR, and NOT.



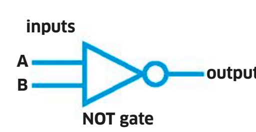
AND gate		
Input A	Input B	Output
1	0	0
0	1	0
0	0	0
1	1	1

AND gate
This compares the two numbers and switches on only if both the numbers are 1. There will only be an output if both inputs are on.



OR gate		
Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	1

OR gate
This switches on if either of the two numbers is 1. If both numbers are 0, it switches off. There will be an output if one or both inputs are on.

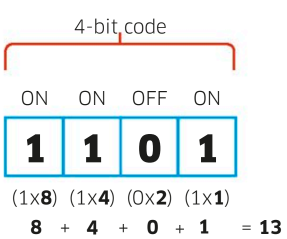


NOT gate	
Input	Output
0	1
1	0

NOT gate
This reverses (inverts) whatever goes into it. A 0 becomes a 1, and vice versa. The output is only on if the input is off. If the input is on, the output is off.

Digital electronics

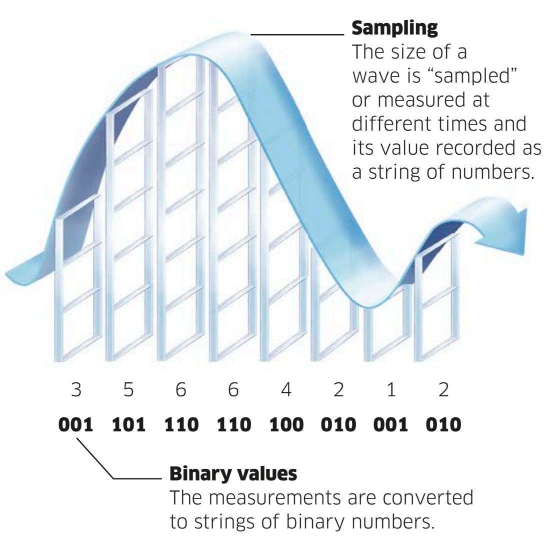
Most technology we use today is digital. Our devices convert information into numbers or digits and process these numbers in place of the original information. Digital cameras turn images into patterns of numbers, while cell phones send and receive calls with signals representing strings of numbers. These are sent in a code called binary, using only the numerals 1 and 0 (rather than decimal, 0–9).



Binary numbers
In binary, the position of 1s and 0s corresponds to a decimal value. Each binary position doubles in decimal value from right to left (1, 2, 4, 8) and these values are either turned on (x1) or off (x0). In the 4-bit code shown, the values of 8, 4, and 1 are all "on," and when added together equal 13.

Analog to digital

A sound wave made by a musical instrument is known as analog information. The wave rises and falls as the sound rises and falls. A wave can be measured at different points to produce a digital version with a pattern more like a series of steps than a wave form.



FORCES

Invisible forces are constantly at play in our day-to-day life, from the wind rustling the leaves of trees to the tension in the cables of a suspension bridge. A force is any push or pull. Forces can change an object's speed or direction of motion, or can change its shape. English scientist Isaac Newton figured out how forces affect motion over three hundred years ago (see pp.98–99). His principles are still applied in many fields of science, engineering, and in daily life today.

WHAT IS A FORCE?

A force can be a push or a pull. Although you can't see a force, you can often see what it does. A force can change the speed, direction, or shape of an object. Motion is caused by forces, but forces don't always make things move—balanced forces are essential for building stability.

Contact forces

When one object comes into contact with another and exerts a force, this is called a contact force. Either a push or a pull, this force changes the direction, speed, or shape of the object.

Changing direction
If a player bounces a ball against a wall during practice, the wall exerts a force on the ball that changes its direction.

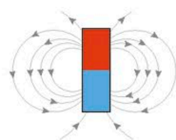
Changing speed
When a player kicks, back-heels, or volleys a soccer ball, the force that is applied changes the ball's speed.

Changing shape
Kicking or stepping on the soccer ball applies a force that momentarily squashes it, changing the ball's shape.

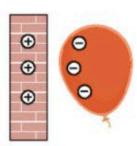
Non-contact forces

All forces are invisible, but some are exerted without physical contact between objects. The closer two objects are to each other, the stronger is the force.

Gravity
Gravity is a force of attraction between objects with mass. Every object in the universe pulls on every other object.



Magnetism
A magnet creates a magnetic field around it. If a magnetic material is brought into the field, a force is exerted on it.



Static electricity
A charged object creates an electric field. If another charged object is moved into the field, a force acts on it.

Weight, gravity, and mass

Weight is not the same as mass, which is a measure of how much matter is in an object. Weight is the force acting on that matter and is the result of gravity. The mass of an object is the same everywhere, but its weight can change.

Measuring forces
Forces can be measured using a force meter, which contains a spring connected to a metal hook. The spring stretches when a force is applied to the hook. The bigger the force, the longer the spring stretches and the bigger the reading. The unit of force is the newton (N).

Calculating weight
Mass is measured in kilograms (kg). Weight can be calculated as mass x gravity (N/kg). The pull of gravity at Earth's surface is roughly 10 N/kg, so an object with a mass of 1 kg weighs 10 N.

BALANCED AND UNBALANCED FORCES

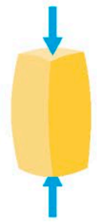
Not all forces acting on an object make it move faster or in a different direction: forces on a bridge must be balanced for the structure to remain stable. In a tug of war, there's no winner while the forces are balanced; it takes a greater force from one team to win.

Balanced forces
If two forces acting on an object are equal in size but opposite in direction, they are balanced. An object that is not moving will stay still, and an object in motion will keep moving at the same speed in the same direction.

Unbalanced forces
If two forces acting on an object are not equal, they are unbalanced. An object that is not moving will start moving, and an object in motion will change speed or direction.

DEFORMING FORCES

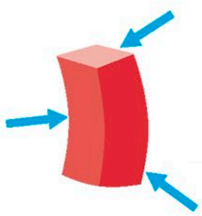
When a force acts on an object that cannot move, or when a number of different forces act in different directions, the whole object changes shape. The type of distortion an object undergoes depends on the number, directions, and strengths of the forces acting upon it, and on its structure and composition—if it is elastic (returns to its original shape) or plastic (deforms easily but does not return to its original shape). Brittle materials fracture, creep, or show fatigue if forces are applied to them.



Compression
When two or more forces act in opposite directions and meet in an object, it compresses and bulges.

Tension
When two or more forces act in opposite directions and pull away from an elastic object, it stretches.

Torsion
Turning forces, or torques, that act in opposite directions twist the object.



Bending
When several forces act on an object in different places, the object bends (if malleable) or snaps.

Resultant forces
A force is balanced when another force of the same strength is acting in the opposite direction. Overall, this has the same effect as no force at all.

RESULTANT FORCE: 0 N

When opposing teams pull with equal force, the resultant force is 0 N.

RESULTANT FORCE: 100 N

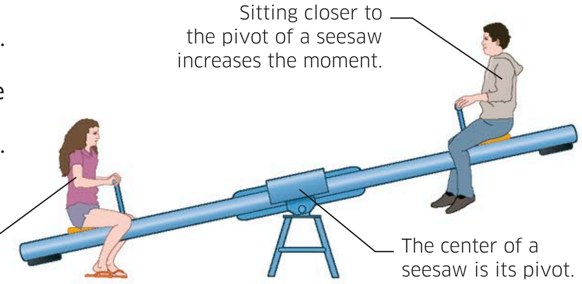
One team pulls with more force than the other. The resultant force is 100 N.

TURNING FORCES

Instead of just moving or accelerating an object in a line, or sending an object off in a straight line in a different direction, forces can also be used to turn an object around a point known as an axis or a pivot. This kind of force works on wheels, seesaws, and fairground rides such as carousels. The principles behind these turning forces are also used in simple machines (see pp.106–107).

Moment

When a force acts to turn an object around a pivot, the effect of the force is called its moment. The turning effect of a force depends on the size of the force and how far away from the pivot the force is acting. Calculated as force (N) x distance (m), moment is measured in newton meters (Nm).



Centripetal forces

A constant force has to be applied to keep an object turning in a circle, obeying Newton's first law of motion (see pp.98–99). Known as centripetal force, it pulls the turning object toward the center of rotation—imagine a yo-yo revolving in a circle on its string—continually changing its direction, while the motion changes its speed. Without this force, the object would move in a straight line away from the center.

In frictionless space, **spacecraft travel at a constant velocity**—obeying Newton's first law of motion.

Laws of motion

When a force acts on an object that is free to move, the object will move in accordance with Newton's three laws of motion.

English physicist and mathematician Isaac Newton published his laws of motion in 1687. They explain how objects move—or don't move—and how they react with other objects and forces. These three scientific laws form the basis of what is known as classical mechanics. Modern physics shows that Newton's laws are not perfectly accurate, but they are still useful in everyday situations.

First law of motion

Any object will remain at rest, or move in a straight line at a steady speed, unless an external force acts upon it. So, a soccer ball is stationary until it is kicked and then moves until other forces stop it. This is known as inertia. If all external forces are balanced, the object will maintain a constant velocity. For an object that is not moving, this is zero.

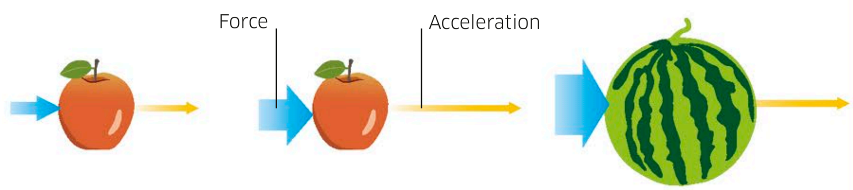
At rest
Gravity acts on the ball, but the ground stops it from moving so it remains at rest.

Force causes motion
The impact of a cleat kicking the ball applies a force that accelerates the ball.

Force stops motion
The ball slows down due to friction and stops when it meets a cleat.

Second law of motion

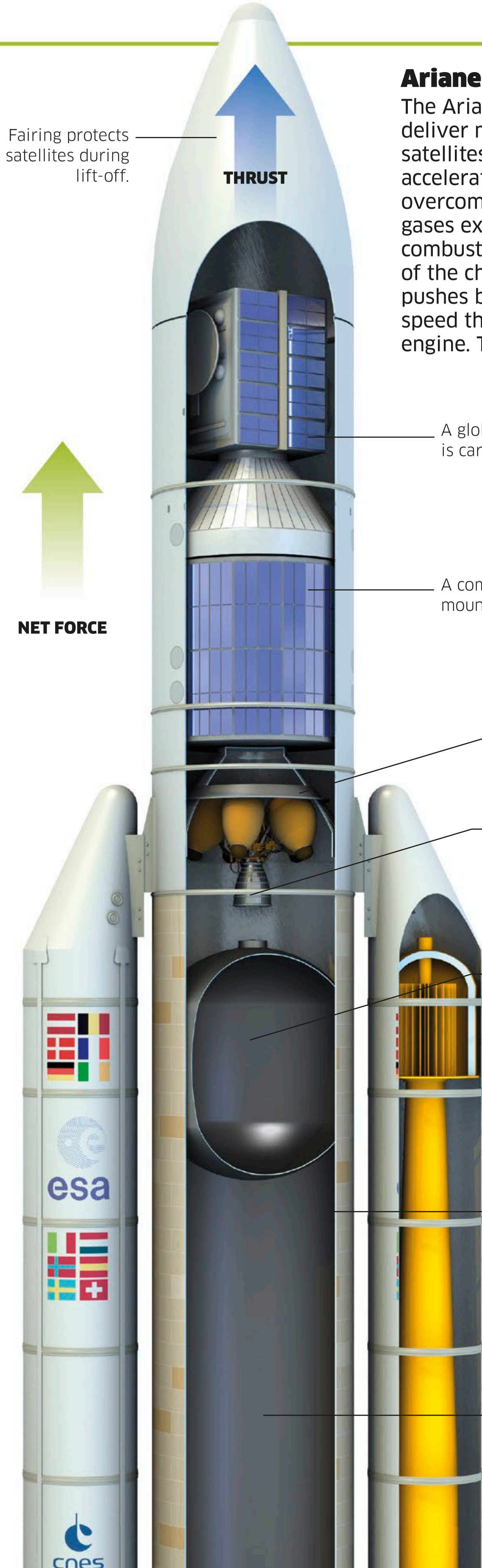
When a force acts on an object, the object will generally move in the direction of the force. This causes a change in velocity, known as acceleration. The larger the force, the greater an object's acceleration will be. The more massive an object is, the greater the force needed to accelerate it. This is written as force = mass x acceleration.



Small mass, small force
A force causes an object to accelerate, changing its velocity per second, at a certain rate.

Small mass, double force
If the mass stays the same but the force doubles, the object will accelerate at twice the rate.

Double mass, double force
If the mass doubles and the force doubles again, the rate of acceleration stays the same.

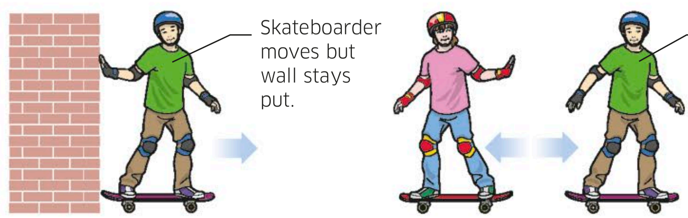


Ariane 5

The Ariane 5 rocket is a launch vehicle used to deliver massive payloads, such as communication satellites, into orbit. Causing a rocket to accelerate upward requires enormous forces to overcome the gravity pulling it downward. Hot gases expand, exerting forces on the walls of the combustion chamber to lift the rocket. The walls of the chamber produce a reaction force that pushes back on the gases, which escape at high speed through the nozzles at the bottom of the engine. These forces create acceleration.

Third law of motion

Forces come in pairs, and any object will react to a force applied to it. The force of reaction is equal and acts in an opposite direction to the force that produces it. If one object is immobile, then the other will move. If both objects can move, then the object with less mass will accelerate more than the other. Every action has an equal and opposite reaction.



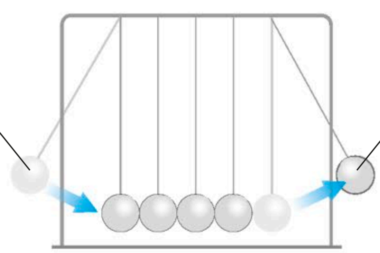
Action
If a skateboarder pushes a wall, the wall pushes back with a reaction force that causes the skater to roll away from it.

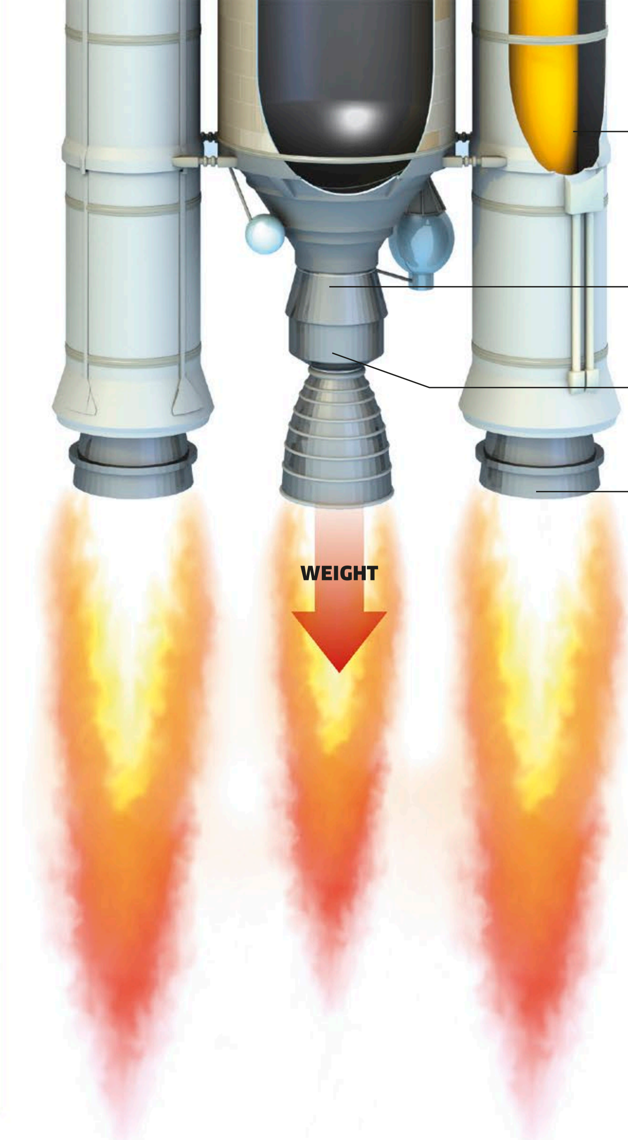
Reaction
If one skateboarder pushes another, action and reaction cause both skaters to roll away from each other.

Momentum

A moving object keeps moving because it has momentum. It will keep moving until a force stops it. However, when it collides with another object, momentum will be transferred to the second object.

Newton's cradle
Energy is conserved when the balls collide.

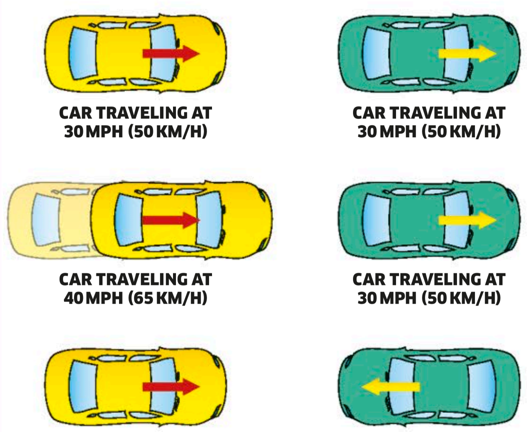




Newton's three laws at work
A rocket taking off shows Newton's laws in action. Before liftoff, the rocket's enormous weight—the result of gravity pulling it down toward Earth—is balanced by the upward force of the launch pad so it remains stationary (first law). Fuel combustion in the engines creates thrust, propelling the rocket forward (second law). The thrust that pushes the rocket forward is a reaction to the hot exhaust gases pushing backward (third law).

Relative velocity

The velocity of an object is its speed in a particular direction. Two objects traveling at the same speed but in opposite directions, or at different speeds in the same direction, have different velocities.



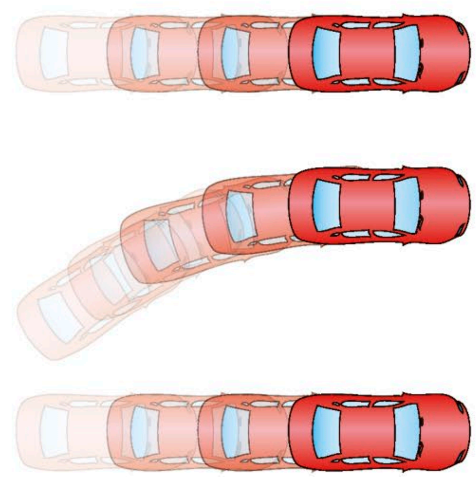
Same direction, same speed
The relative velocity of the two cars is 0 mph (0 km/h).

Same direction, different speeds
The relative velocity of the two cars is 10 mph (15 km/h).

Opposite direction, same speed
The relative velocity of cars on a collision course is 60 mph (100 km/h).

Velocity, speed, and acceleration

Speed is a measure of the rate at which a distance is covered. Velocity is not the same as speed; it measures direction as well as speed of movement. Acceleration measures the rate of change of velocity. Speeding up, turning, and slowing down are all acceleration.



Increasing speed
When a force is applied to an object, its speed increases—it accelerates.

Changing direction
When an object changes direction, its velocity changes. This is also a type of acceleration.

Decreasing speed
When a force slows a moving object down, its speed decreases—it decelerates, or accelerates negatively.

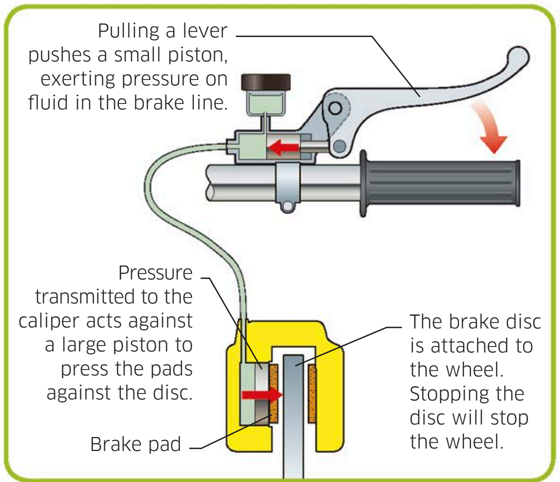
Friction

Friction is a force that occurs when a solid object rubs against or slides past another, or when it moves through a liquid or a gas. It always acts against the direction of movement.

The rougher surfaces are and the harder they press together, the stronger the friction—but friction occurs even between very smooth surfaces. Friction can be useful—it helps us to stand, walk, and run—but it can also be a hindrance, slowing movement and making machines inefficient. A by-product of friction is heat.

Friction in a motorcycle

The force of friction both helps and hinders a motorcycle rider. Friction between the tires and ground is essential for movement and grip, and is the force behind braking. Drag, the friction that occurs between air and the bike, slows the rider down, and friction between moving parts makes the bike less efficient.

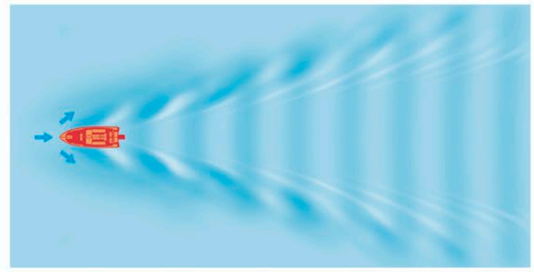


How disc brakes work
Most modern motorcycles have disc brakes on their wheels. When the brake lever is pulled, hydraulic pressure (see p.106) multiplies the force to press the brake pads against the disc. Friction between the pads and disc slows or stops the bike, generating heat as "lost" energy.

How tread maintains friction
Friction helps the tires to grip the ground as the bike moves, preventing it from skidding. The tread is designed to channel water through grooves, so that the tires still grip on wet and muddy roads.

Fluid resistance (drag)

When an object moves through a fluid, it pushes the fluid aside. That requires energy, so the object slows down—or has to be pushed harder; this is known as form drag. Fluid also creates friction as it flows past the object's surface; this is called skin friction.



Water resistance
When a boat moves through water, it pushes water out of the way. The water resists, rising up as bow and stern waves and creating transverse waves in the boat's wake.

Air resistance

When an object moves through air, the drag is called air resistance. The bigger and less streamlined the object and the faster the object is moving, the greater the drag. When spacecraft re-enter the atmosphere, moving very fast, the drag heats their surfaces to as much as 2,750°F (1,500°C).

Helpful and unhelpful friction

It is tempting to think of friction as an unhelpful force that slows movement, but friction can be helpful, too. Without friction between surfaces, there would be no grip and it would be impossible to walk, run, or cycle. However, the boot is on the other foot for skiers, snowboarders, and skaters, who minimize friction to slide.

Reducing friction
The steel blades of ice skates reduce friction, enabling skaters to glide across ice.

Increasing friction
The treads of rubber-soled mountain boots increase friction and grip for climbers.

51 lb (23 kg)—the **weight on Mars**, due to lower gravity, **of a person weighing 137 lb (62 kg) on Earth**.

Law of Falling Bodies

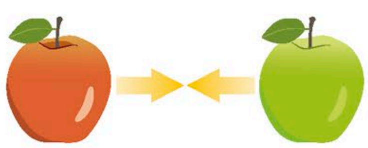
Gravity pulls more strongly on heavier objects—but heavier objects need more force to make them speed up than lighter ones. Galileo was the first person to realize, in 1590, that any two objects dropped together should speed up at the same rate and hit the ground together. We are used to lighter objects falling more slowly—because air resistance slows them more.

In the near-frictionless environment of the moon, a heavy hammer and a light feather fall at the same rate.

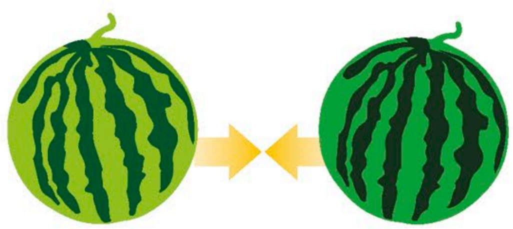
Falling in a vacuum
In 1971, astronaut Dave Scott proved Galileo right when he dropped a feather and a hammer on the moon.

Law of Universal Gravitation

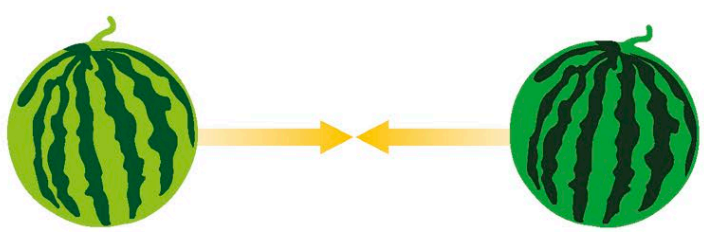
In 1687, English scientist Isaac Newton came up with his Law of Universal Gravitation. It states that any two objects attract each other with a force that depends on the masses of the objects and the distance between them.



Equal and opposite
The gravitational force between two objects pulls equally on both of them—whatever their relative mass—but in opposite directions.



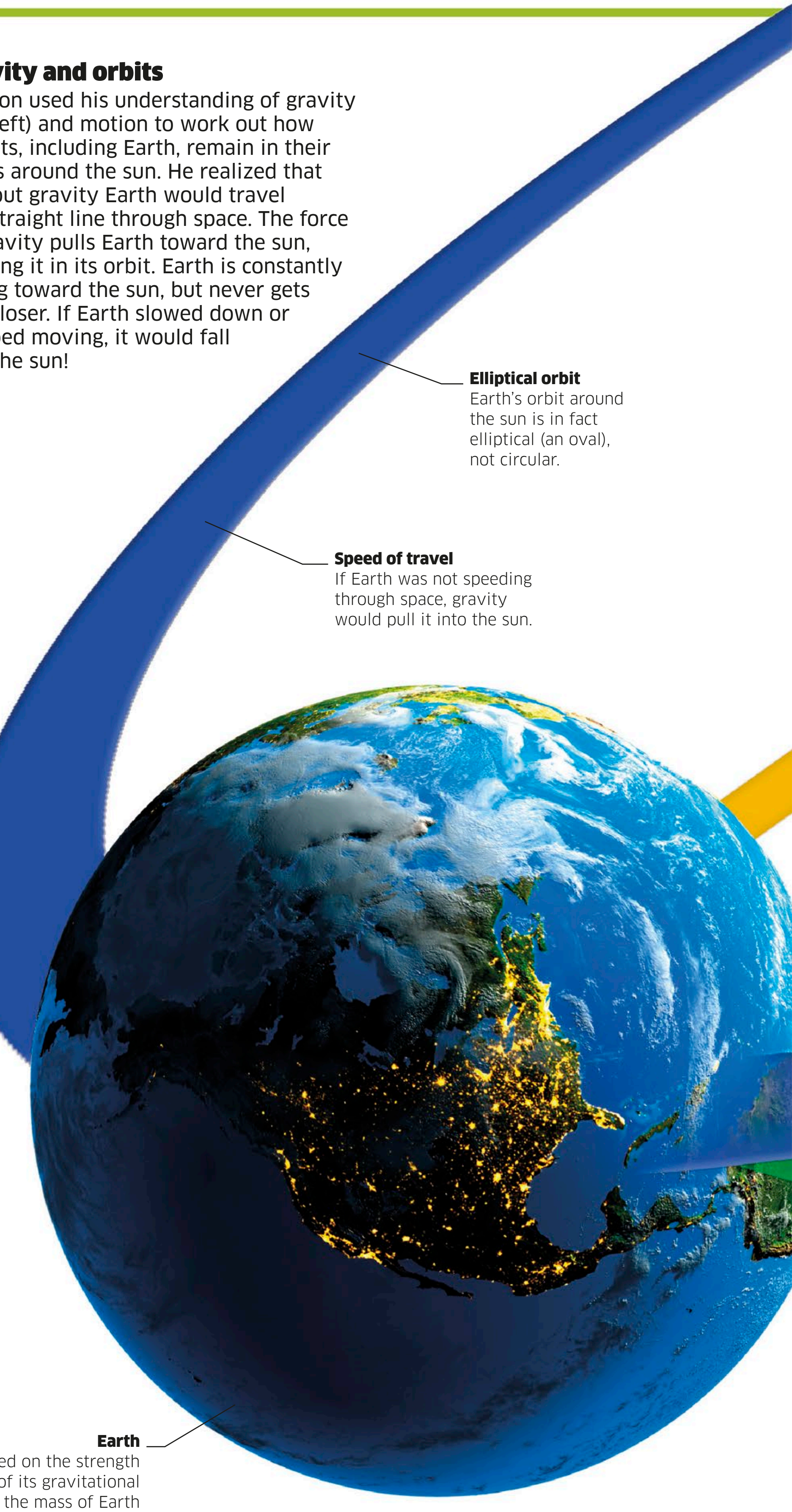
Double the mass
If one object's mass is doubled, the gravitational force doubles. If the mass of both objects is doubled (as here), the force is four times as strong.



Double the distance
If the distance between two objects is doubled, the gravitational force is quartered.

Gravity and orbits

Newton used his understanding of gravity (see left) and motion to work out how planets, including Earth, remain in their orbits around the sun. He realized that without gravity Earth would travel in a straight line through space. The force of gravity pulls Earth toward the sun, keeping it in its orbit. Earth is constantly falling toward the sun, but never gets any closer. If Earth slowed down or stopped moving, it would fall into the sun!



Elliptical orbit
Earth's orbit around the sun is in fact elliptical (an oval), not circular.

Speed of travel
If Earth was not speeding through space, gravity would pull it into the sun.

Earth
Based on the strength of its gravitational force, the mass of Earth is estimated to be 6.5 sextillion tons!

The force of gravity 62 miles (100 km) above Earth is **3 percent less** than at sea level on Earth.

32.2 ft/s²—the rate at which a falling object accelerates toward Earth.

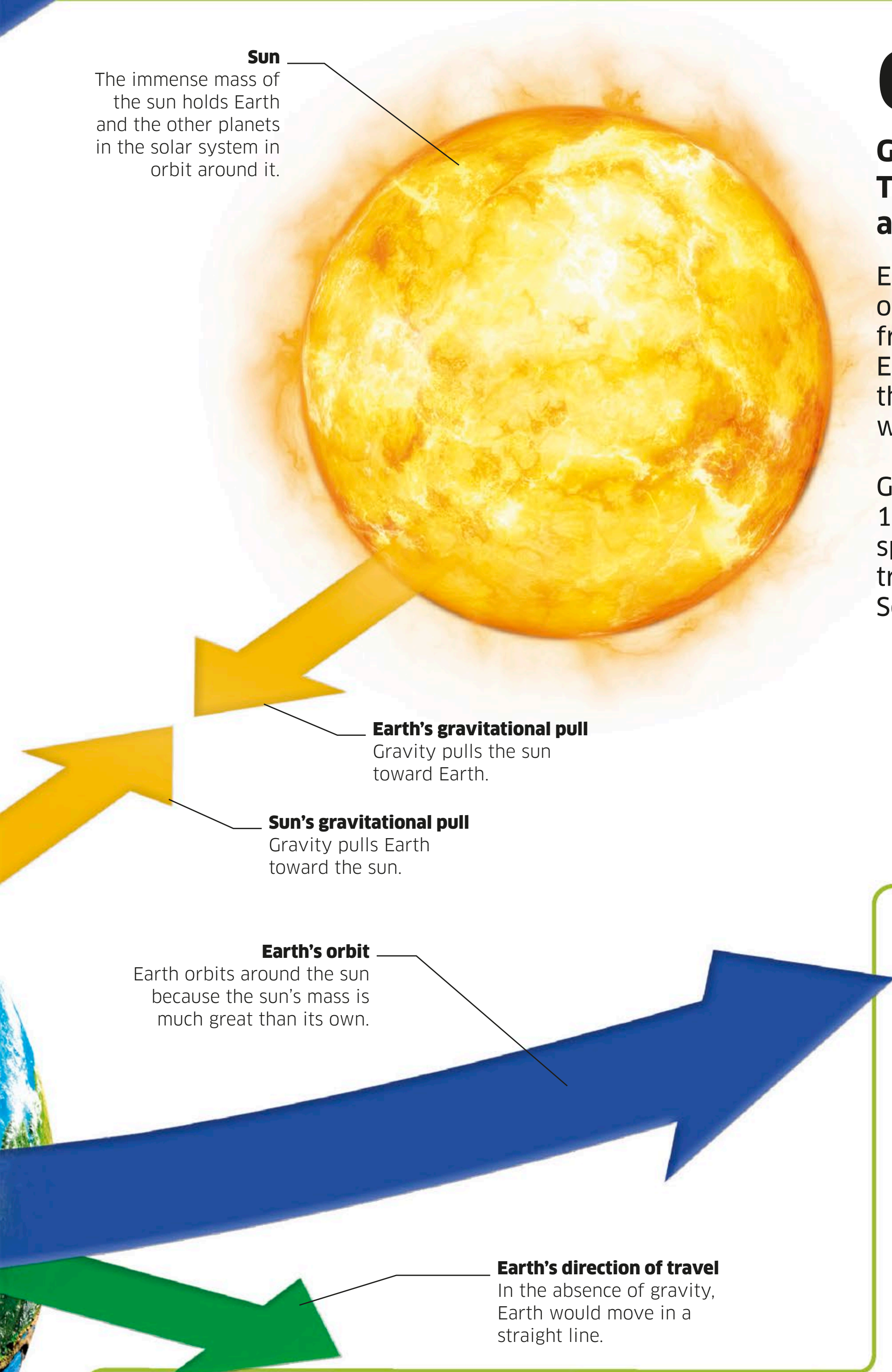
Gravity is the weakest of the four fundamental forces: strong nuclear, electromagnetic, weak nuclear, and gravitational.

Gravity

Gravity is a force of attraction between two objects. The more mass the objects have and the closer they are to each other, the greater the force of attraction.

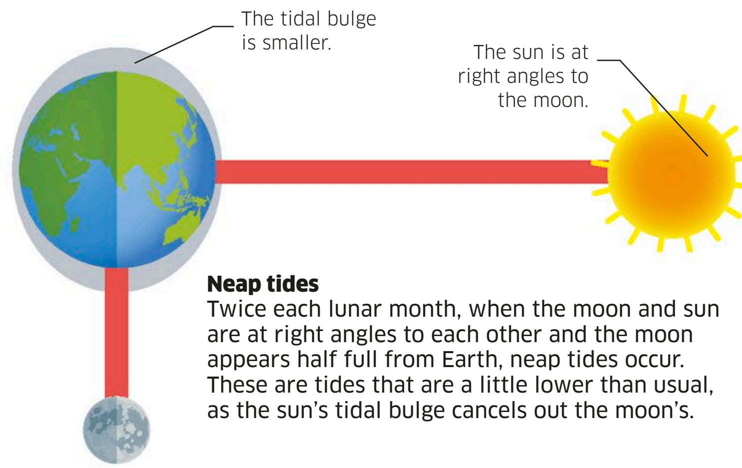
Earth's gravity is the gravitational force felt most strongly on the planet: it is what keeps us on the ground and keeps us from floating off into space. In fact, we pull on Earth as much as Earth pulls on us. Gravity also keeps the planets in orbit around the sun, and the moon around Earth. Without it, each planet would travel in a straight line off into space.

The best way scientists can explain gravity is with the General Theory of Relativity, formulated by Albert Einstein in 1915. According to this theory, gravity is actually caused by space being distorted around objects with mass. As objects travel through the distorted space, they change direction. So, according to Einstein, gravity is not a force at all!

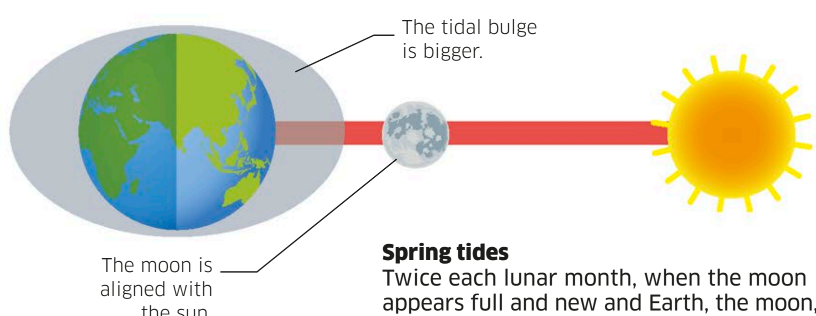


Tides

The gravitational pull of the moon and the sun cause the oceans to bulge outward. The moon's pull on the oceans is strongest because it is closest to Earth, and it is the main cause of the tides. However, at certain times of each lunar month, the sun's gravity also plays a role, increasing or decreasing the height of the tides.



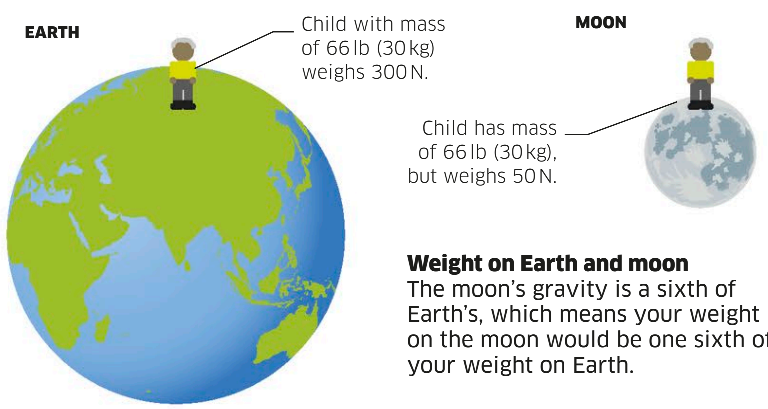
Neap tides
Twice each lunar month, when the moon and sun are at right angles to each other and the moon appears half full from Earth, neap tides occur. These are tides that are a little lower than usual, as the sun's tidal bulge cancels out the moon's.



Spring tides
Twice each lunar month, when the moon appears full and new and Earth, the moon, and the sun are aligned, spring tides occur. These are unusually high tides.

Mass and weight

Mass is the amount of matter an object contains, which stays the same wherever it is. It is measured in kilograms (kg). Weight is a force caused by gravity. The more mass an object has and the stronger the gravity, the greater its weight. Weight is measured in newtons (N).



Weight on Earth and moon
The moon's gravity is a sixth of Earth's, which means your weight on the moon would be one sixth of your weight on Earth.

Whales can withstand dramatic pressure changes because their bodies are more flexible than human bodies.

Pressure

Pressure is the push on a surface created by one or more forces. How much pressure is exerted depends upon the strength of the forces and the area of the surface. Walk over snow in showshoes and you won't sink in—but walk on grass in stiletto heels and you will.

Solids, liquids, and gases can apply pressure onto a surface because of their weight pressing down on it. The pressure applied by liquids and gases can be increased by squashing them. Pressure is measured in pounds per square inch (psi) or in newtons per square meter (N/m^2)—also called Pascals (Pa).

Atmospheric and water pressure

Near sea level, the weight of the air around us presses with a force of about 15 psi (100,000 Pa). Pressure decreases with altitude, because there is less air above pressing down. In the ocean, pressure increases quickly with depth, since water is denser than air.

Felix Baumgartner makes a record-breaking skydive from 127,852 ft (38,964 m).

Pilots of fighter jets cruising at 50,000 ft (15,000 m) wear pressure suits.

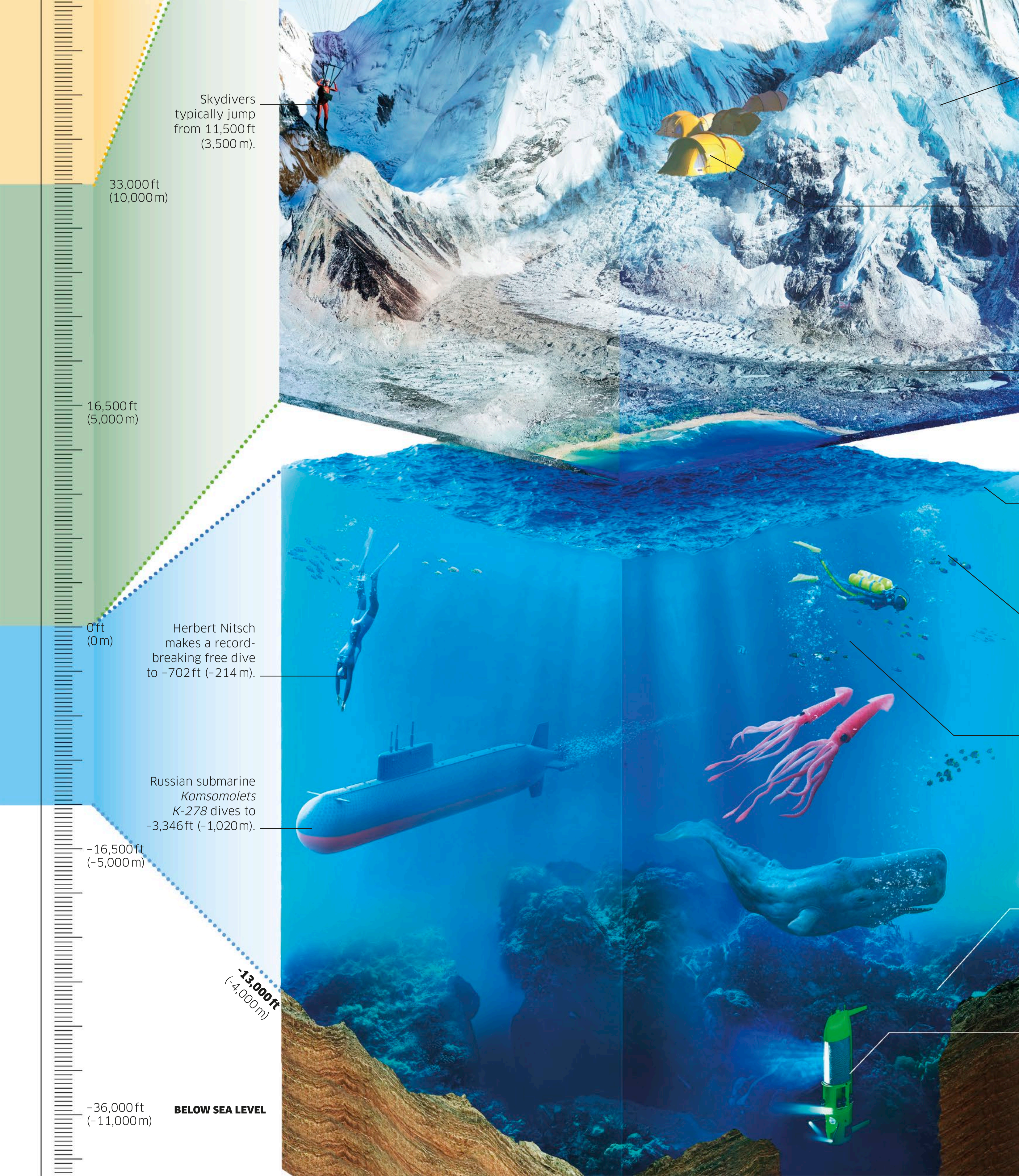
250 miles (400 km)
As a Soyuz spacecraft travels to the International Space Station (ISS), which orbits at 250 miles (400 km), gas molecules are so few and far between that air pressure is almost nonexistent. The space station's atmosphere is maintained at the same pressure as sea level.

115,000 ft (35,000 m)
As weather balloons ascend into the stratosphere, they expand from 6 ft 6 in (2 m) to 26 ft (8 m) across as air pressure decreases to just 0.1 psi (1,000 Pa). The gas molecules within the balloon spread out as pressure from outside diminishes.

60,000 ft (18,000 m)
Above this altitude—the Armstrong limit—humans cannot survive in an unpressurized environment. Air pressure is 1 psi (7,000 Pa) and exposed body fluids such as saliva and moisture in the lungs will boil away—but not blood in the circulatory system.

36,000 ft (111,000 m)
This is the cruising altitude of passenger jets. As a plane lifts off, your ears may pop due to the change in pressure: air trapped in the inner ear stays at the same pressure, but air pressure outside changes, exerting a force on your eardrum. Pressure falls to 3 psi (23,000 Pa) on the plane's exterior.

28,871 ft (8,848 m)
At Everest's summit, atmospheric pressure is one third of that at sea level: 4.5 psi (33,000 Pa). It is hard to make tea as water boils at 162°F (72°C)—not hot enough for a good brew. Liquids boil when the particles of which they are made move fast enough to have the same pressure as air—so when pressure falls, the boiling point is lower.



18,000 ft (5,500 m)
One half of the atmosphere is contained between Earth's surface and 18,000 ft (5,500 m), where air pressure is 7.3 psi (50,000 Pa). The other half is between this altitude and 100,000 ft (30,000 m).

17,400 ft (5,300 m)
At Everest base camp, atmospheric pressure is about half that at sea level. Altitude sickness is common as air pressure falls to 7.4 psi (51,000 Pa) and there is a low concentration of gas molecules. Climbers pause here to acclimatize and few go higher without extra oxygen.

5,000 ft (1,500 m)
Air pressure decreases to 12 psi (84,000 Pa) at this altitude and breathing is difficult. Lower air density means there are fewer molecules in the same volume of air so people have to breathe faster and deeper to take in the same amount of oxygen.

0 ft (0 m)
At sea level, the pressure pushing down on the surface, known as "one atmosphere," is 15 psi (101,000 Pa). It is the result of the weight of all the air above that surface.

–32 ft (–9.75 m)
Atmospheric pressure is double that at sea level: 30 psi (200,000 Pa). This means that a 32-ft (9.75-m) column of water weighs as much as the entire column of air above it from outer space to 0 ft (0 m).

–130 ft (–40 m)
The normal depth limit for a qualified scuba diver. Pressure here is 73 psi (500,000 Pa)—nearly five times sea level. The spongy tissue of the lungs begins to contract, making it hard to breathe. Diving tanks contain compressed, oxygen-enriched air to overcome this.

–13,000 ft (–4,000 m)
The average depth of the oceans is six times that of the maximum crush depth of most modern submarines, which can survive pressure of 5,800 psi (40 million Pa)—four hundred times what it is at sea level.

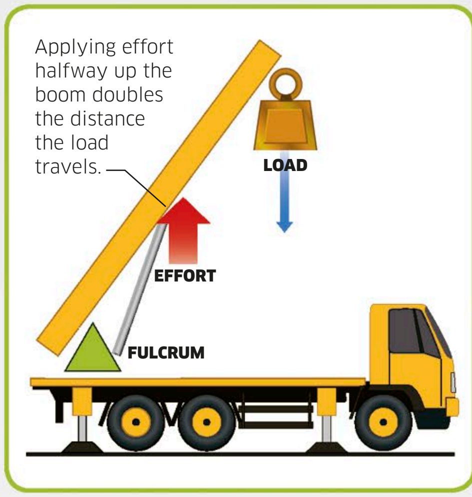
–36,070 ft (–10,994 m)
The *Deepsea Challenger* submersible dove close to the deepest known point in Earth's ocean, Challenger Deep in the Marianas Trench, where pressure is 16,040 psi (110 million Pa)—more than a thousand times atmospheric pressure at sea level.

A complex system of levers connects the keys of a piano to the hammers that hit the strings to sound the notes.

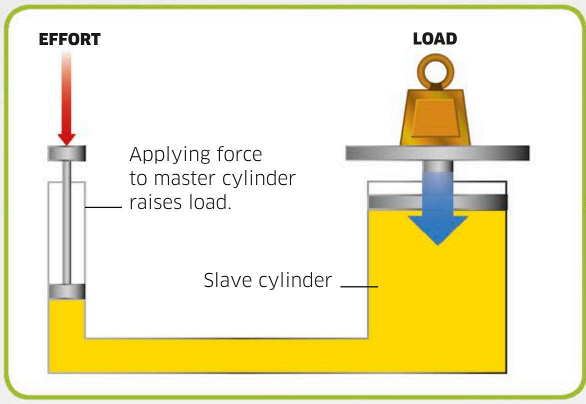
Simple machines

A machine is anything that changes the size or direction of a force, making work easier. Simple machines include ramps, wedges, screws, levers, wheels, and pulleys.

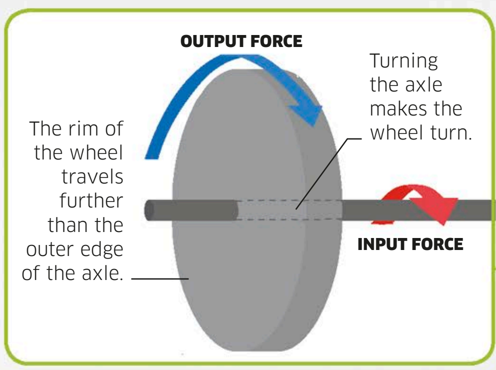
Complex machines such as cranes and diggers combine a number of simple machines, but whatever the scale, the physical principles remain the same. Many of the most effective machines are the simplest—a sloping path (ramp); a knife (wedge); a jar lid (screw); scissors, nutcrackers, and tweezers (levers); a faucet (wheel and axle); or hoist (pulley), for example. Hydraulics and pneumatics use the pressure in fluids (liquids and gases) to transmit force.



Lever
The crane's boom is a long, third-class lever. When a hydraulic ram applies a force greater than the load between the load and the fulcrum, the crane lifts the load.

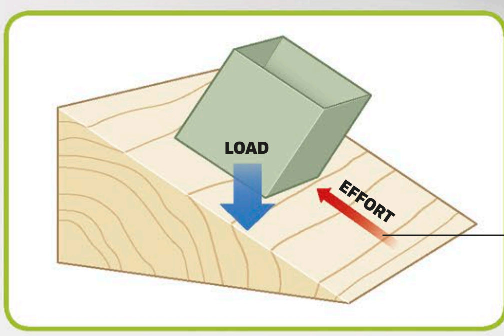


Hydraulics
A hydraulic system makes use of pressure in a liquid by applying force (effort) to a "master" cylinder, which increases fluid pressure in a "slave" cylinder. The hydraulic ram lifts the crane's boom by using pressure from fluid in the cylinder to push a piston.

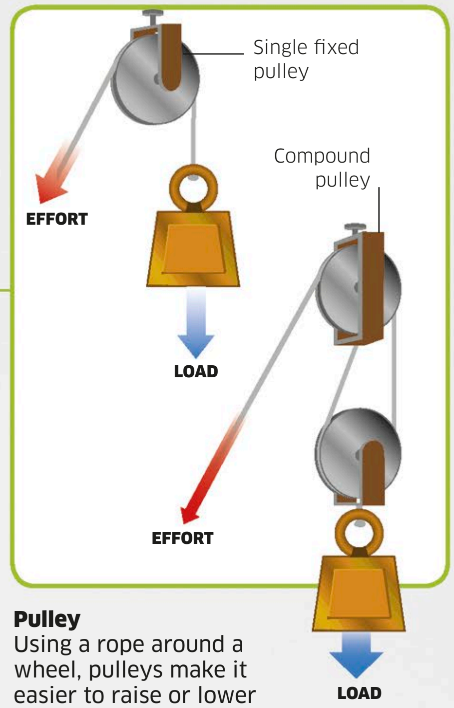


Wheel and axle
A wheel with an axle can be used in two ways: either by applying a force to the axle to turn the wheel, which multiplies the distance traveled; or by applying a force to the wheel to turn the axle, like a spanner.

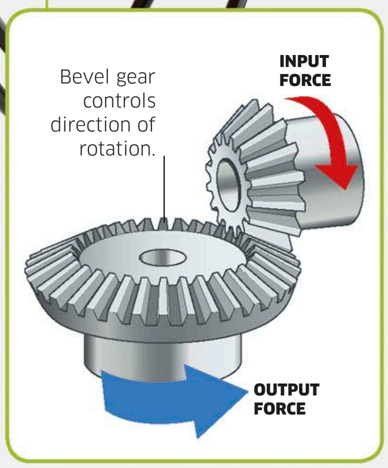
Ramp and wedge
Also known as an inclined plane, a ramp reduces the force needed to move an object from a lower to a higher place. A wedge acts like a moving inclined plane, applying a greater force to raise an object.



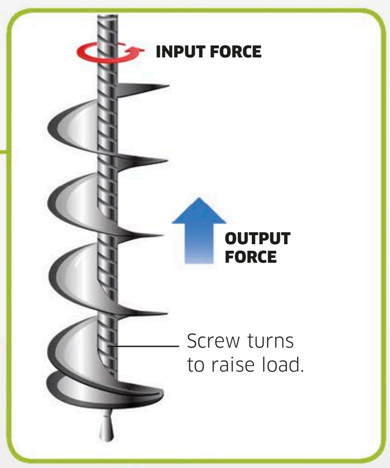
Less effort is needed to push a load up a ramp, but the load has to move further along the slope than it moves vertically.



Pulley
Using a rope around a wheel, pulleys make it easier to raise or lower a load. A single fixed pulley changes the direction of movement. A compound (block and tackle) pulley reduces the effort, too.



Gears
Gears are toothed wheels that transmit force and come in four main types. In all of them, one gear wheel turns faster or slower than the other or moves in a different direction. In "bevel" gears, two wheels interlock to change the direction of rotation.



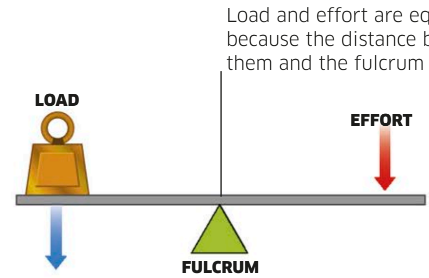
Screw
An auger—the screwlike drill bit of this boring tool—is a ramp that winds around itself, with a wedge at the tip. It is used to lift earth as it excavates. Other screws, such as light bulbs or wood and masonry screws, hold things together.

Compound machines

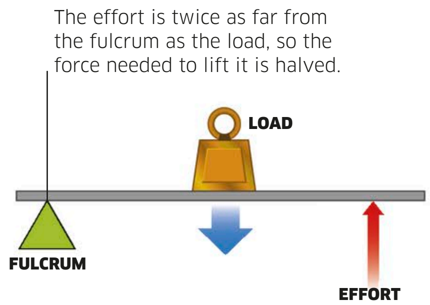
A big mechanical crane and digger combines a number of simple machines with a powerful engine to make light work of heavy lifting and excavation.

Types of lever

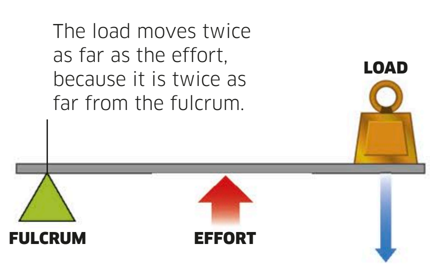
A lever is a bar that tilts on a fulcrum or pivot. If you apply force (effort) to one part of a lever, the lever swings on the fulcrum to raise a load. Levers work in three ways, depending on the relative position of the fulcrum, load, and effort on the bar.



First-class levers
The fulcrum is in between the effort and the load—as in a beam scale or a pair of scissors (two levers hinged at a fulcrum).



Second-class levers
The fulcrum is at one end and effort is applied to the other, with a load between—as in a wheelbarrow or nutcracker.

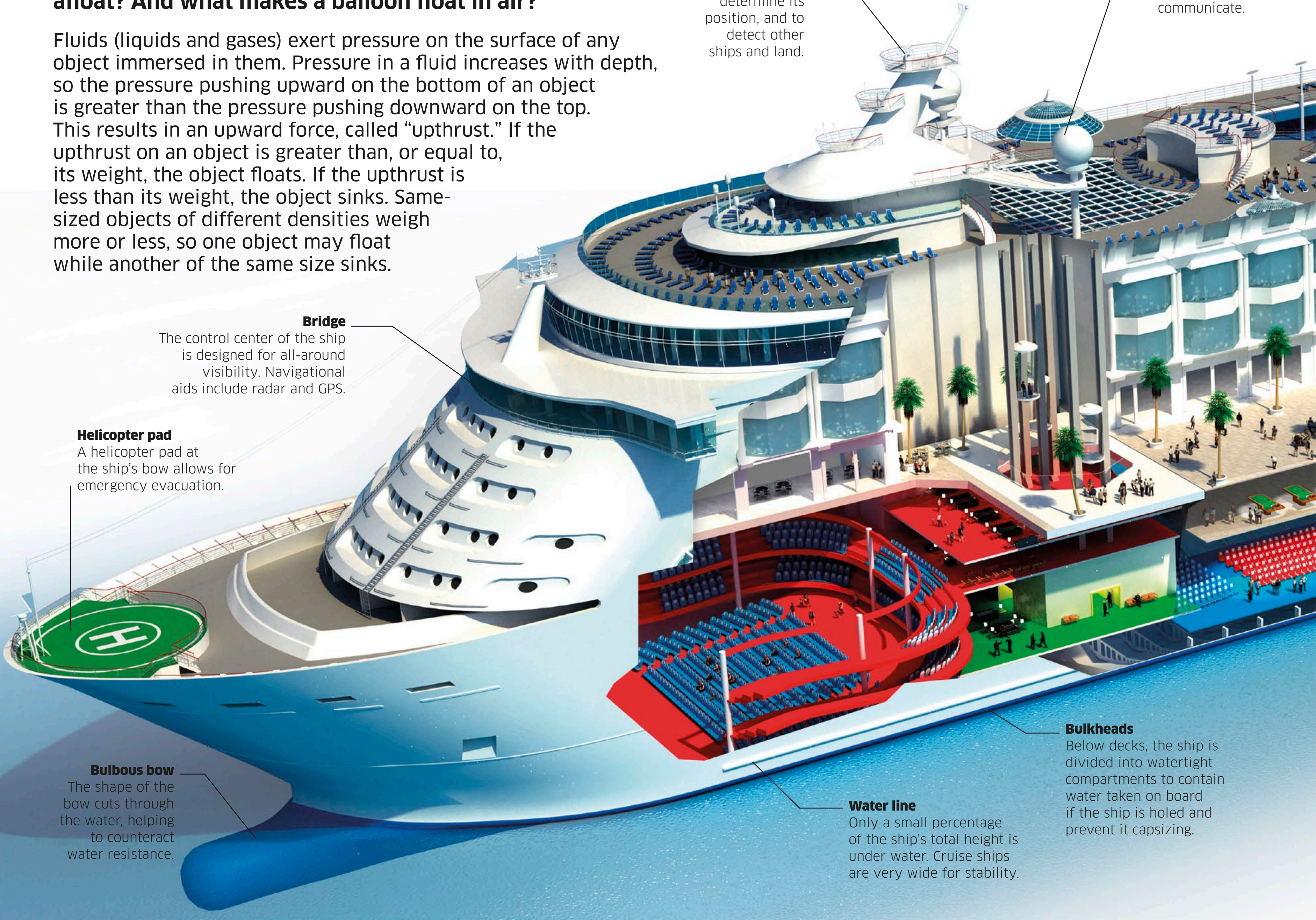


Third-class levers
The fulcrum is at the end, with load at the other end and effort applied in between—as in a hammer or a pair of tweezers.

Floating

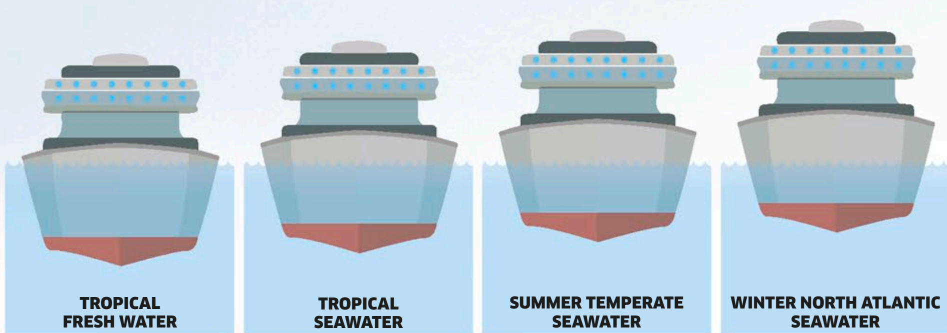
Why does an apple float but a gold apple of the same size sink? How do ships carrying a cargo across the sea stay afloat? And what makes a balloon float in air?

Fluids (liquids and gases) exert pressure on the surface of any object immersed in them. Pressure in a fluid increases with depth, so the pressure pushing upward on the bottom of an object is greater than the pressure pushing downward on the top. This results in an upward force, called "upthrust." If the upthrust on an object is greater than, or equal to, its weight, the object floats. If the upthrust is less than its weight, the object sinks. Same-sized objects of different densities weigh more or less, so one object may float while another of the same size sinks.



Water density

When ocean trade routes opened up around the globe, sailors were surprised to find their carefully loaded ships sank when they got near the equator. This was because the density of warm tropical waters was less than that of cool northern waters, and so provided less upthrust. When the ships entered freshwater ports, the water density was lower still, and ships were even more likely to sink.

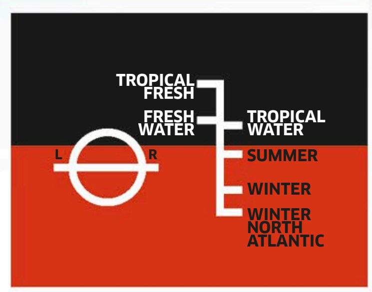


Warm water that is not salt has a low density, so a ship floats low in it.

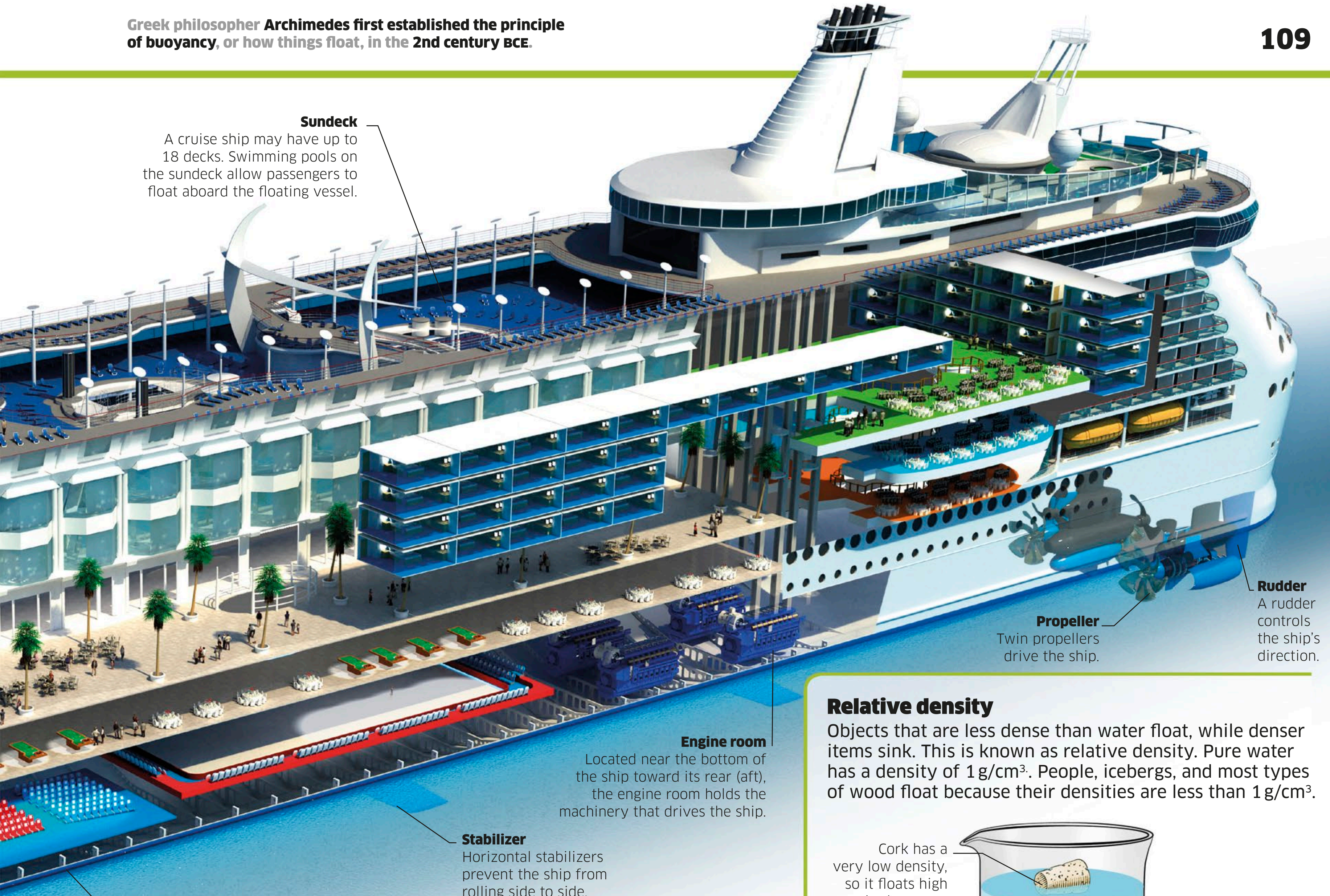
Salt water has a higher density than fresh water, so a ship floats higher.

As salt water cools, its density decreases and a ship becomes more buoyant.

In the freezing cold waters of the North Atlantic, ships float high in the water.



The Plimsoll line
On a ship's hull, this mark shows the depth to which the ship may be immersed when loaded. This varies with a ship's size, type of cargo, time of year, and the water densities in port and at sea.

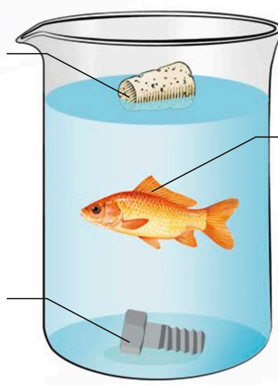


Floating city

Vast cruise ships can carry nearly 10,000 people, along with fuel, food, water, and cargo (known as dead weight), and the ship's machinery (lightweight), displacing 110,230 tons of water. How can these juggernauts of the sea float?

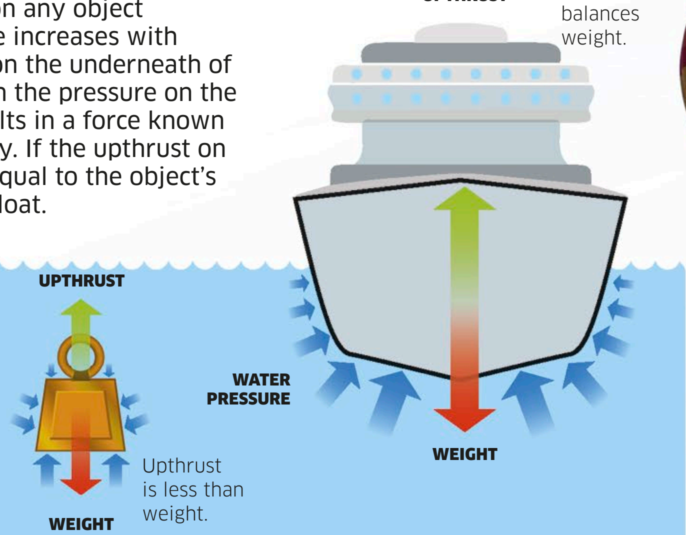
Relative density

Objects that are less dense than water float, while denser items sink. This is known as relative density. Pure water has a density of 1 g/cm^3. People, icebergs, and most types of wood float because their densities are less than 1 g/cm^3.



How boats float

Water exerts pressure on any object immersed in it. Pressure increases with depth, so the pressure on the underneath of an object is greater than the pressure on the top. The difference results in a force known as upthrust, or buoyancy. If the upthrust on a submerged object is equal to the object's weight, the object will float.



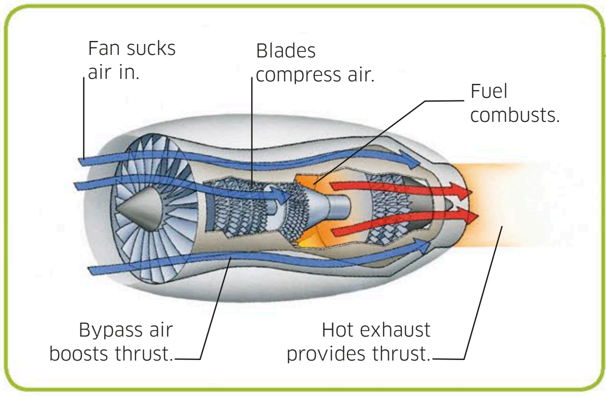
Sink or swim
A solid block of steel sinks because its weight is greater than upthrust, but a steel ship of the same weight floats because its hull is filled with air so its density overall is less than the density of water.

Floating in air

Like water, air exerts pressure on objects with a force called upthrust that equals the weight of air pushed aside by the object. Few objects float in air because it is light, but the air in hot-air balloons is less dense than cool air.

Airbus planes employ a **"fly-by-wire"** system—the pilot controls the plane with a **joystick and pedals**.

Turbofan jet engine
A large fan sucks air into the engine. Some air is compressed before flowing into a combustion chamber. There it mixes with fuel and ignites to create hot exhaust gases that leave the engine at high velocity, pushing the plane forward. Most air bypasses the engine at a lower velocity, but still contributes to thrust.



Flight

Dynamics is the science of movement, and aerodynamics is movement through air. In order to fly, planes use thrust and lift to counteract the forces of drag and gravity.

Just over a hundred years since the first powered flight, today more than 100,000 planes fly every day and it seems normal to us that an airliner weighing as much as 619 tons when laden can take to the skies. To take off, a plane must generate enough lift to overcome gravity, using the power of its engines to create drag-defying thrust.

Airbus A380

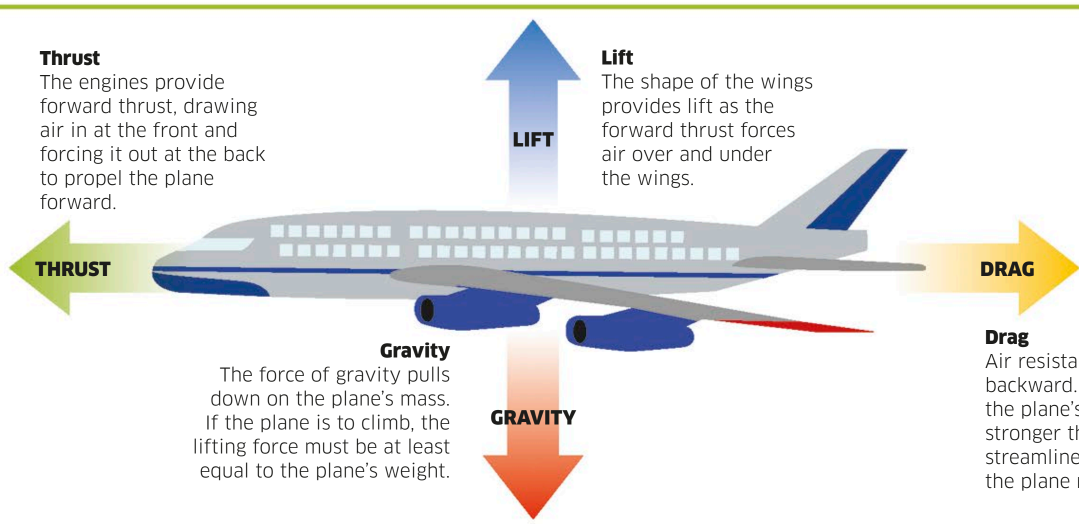
The Airbus 380 is the world's biggest passenger aircraft: 234 ft (73 m) long with a wing span of 262 ft (79.8 m), it can seat 555 people on two decks and carry 165 tons of cargo.

The forces of flight

Four forces act upon an airplane traveling through the air: thrust, lift, gravity, and drag. Thrust from the engines pushes the plane forward, forcing air over the wings, which creates lift to get it off the ground, while gravity pulls the plane downward, and drag – or air resistance – pulls it backward. In level flight at a constant speed, all four of these forces are perfectly balanced.

Thrust
The engines provide forward thrust, drawing air in at the front and forcing it out at the back to propel the plane forward.

Lift
The shape of the wings provides lift as the forward thrust forces air over and under the wings.

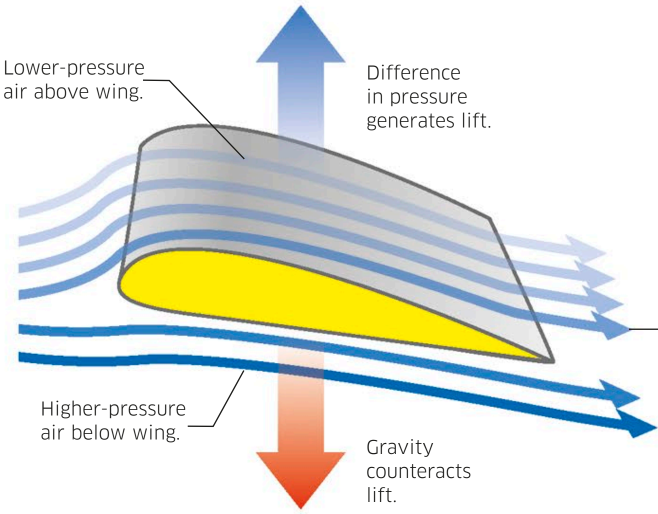


Gravity
The force of gravity pulls down on the plane's mass. If the plane is to climb, the lifting force must be at least equal to the plane's weight.

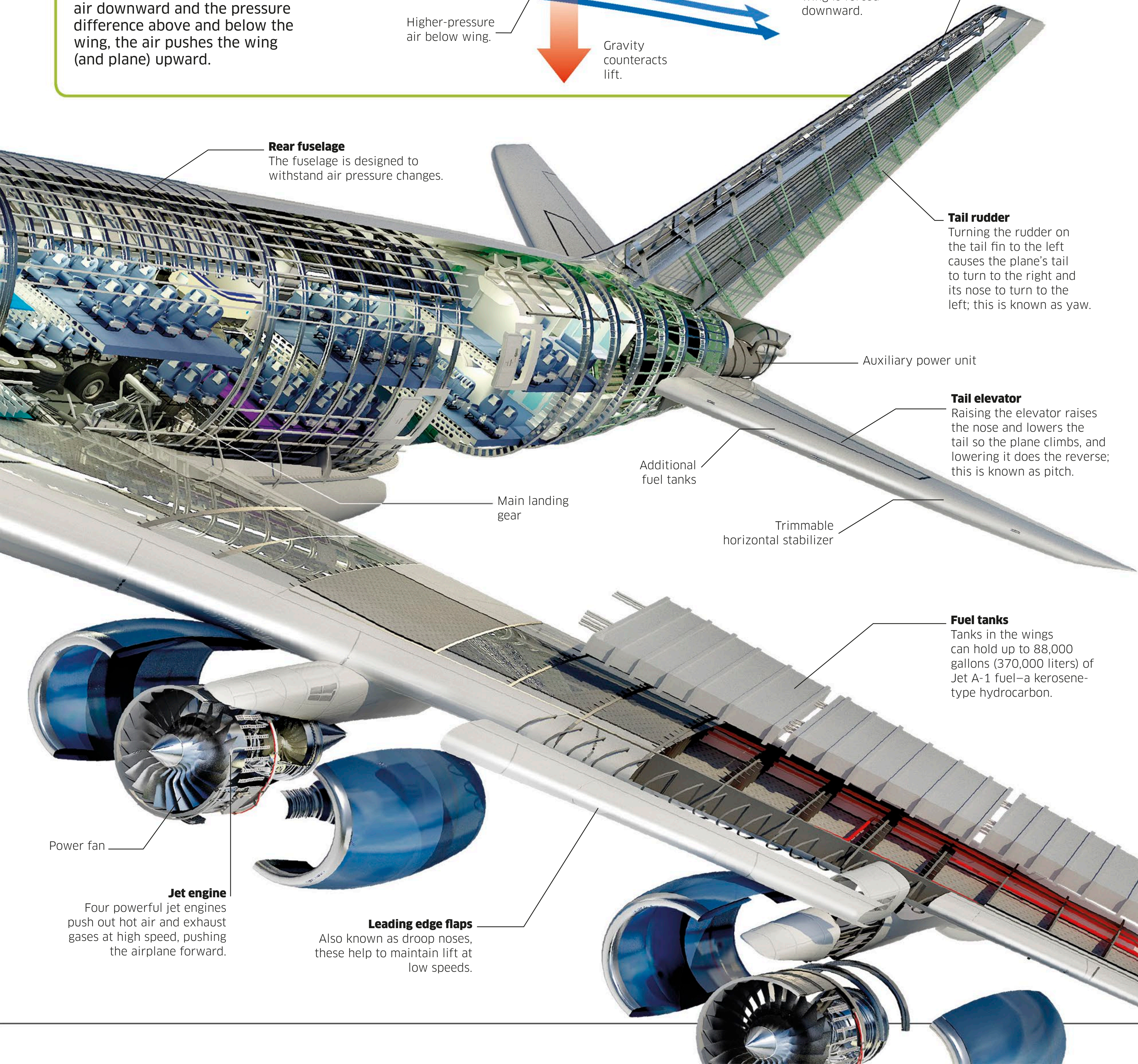
Drag
Air resistance pulls backward. The greater the plane's speed, the stronger the drag. The streamlined shape of the plane reduces drag.

Airfoil

The cross-section of a plane's wing has a shape called an airfoil, which forces air to speed up over the top surface and slow down beneath. The aerofoil is angled so that air passing under the wing is forced downward. Air passing over the wing is forced downward too. The angle also creates an area of very low pressure above the wing. As a result of the wing pushing the air downward and the pressure difference above and below the wing, the air pushes the wing (and plane) upward.



Angle of attack
The streamlined shape of the airfoil is angled downward toward the rear of the plane, allowing air to move smoothly over it. This is known as the angle of attack.

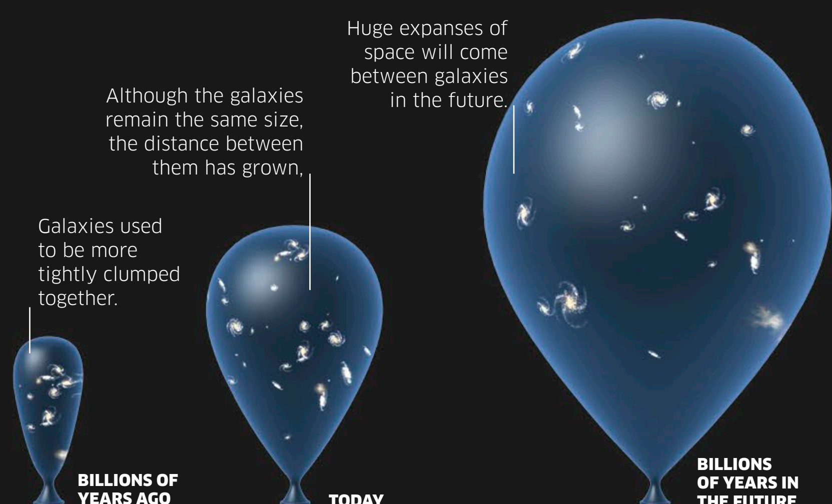


SPACE AND EARTH

All of space, matter, energy, and time make up the universe—a vast, ever-expanding creation that is so big it would take billions of years to cross it, even when traveling at the speed of light. Within the universe are clumps of matter called galaxies, and within those are planets like our own—Earth.

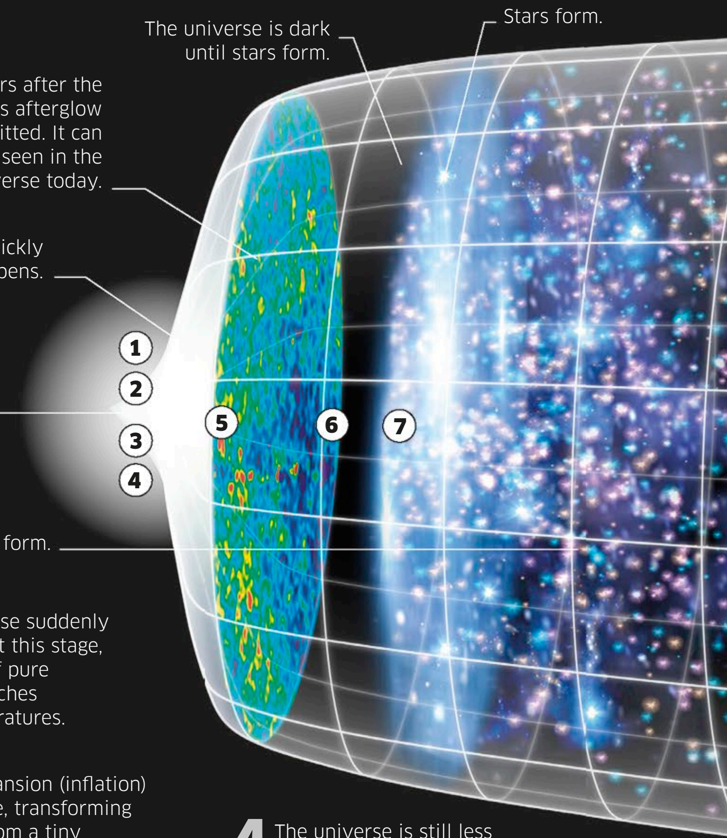
THE EXPANSION OF SPACE

Astronomers on Earth can observe galaxies moving away from us, but in reality they are moving away from every other point in the universe as well. These galaxies are not moving into new space—all of space is expanding and pulling them away from each other. This effect can be imagined by thinking of the universe as a balloon. As the balloon inflates, the rubber stretches and individual points on it all move further away from each other.



THE BIG BANG

The universe came into existence around 13.8 billion years ago in a cataclysmic explosion known as the Big Bang. Starting out as tinier than an atom, it rapidly expanded—forming stars, and clusters of stars called galaxies. A large part of this expansion happened incredibly quickly—it grew by a trillion kilometers in under a second.



1 The universe suddenly appears. At this stage, it is made up of pure energy and reaches extreme temperatures.

2 Rapid expansion (inflation) takes place, transforming the universe from a tiny mass smaller than a fraction of an atom into a gigantic space the size of a city.

3 Matter is created from the universe's energy. This starts out as minuscule particles and antiparticles (the same mass as particles but with an opposite electric charge). Many of these converge and cancel each other out, but some matter remains.

4 The universe is still less than a second old when the first recognizable subatomic particles start to form. These are protons and neutrons—the particles that make up the nucleus of an atom.

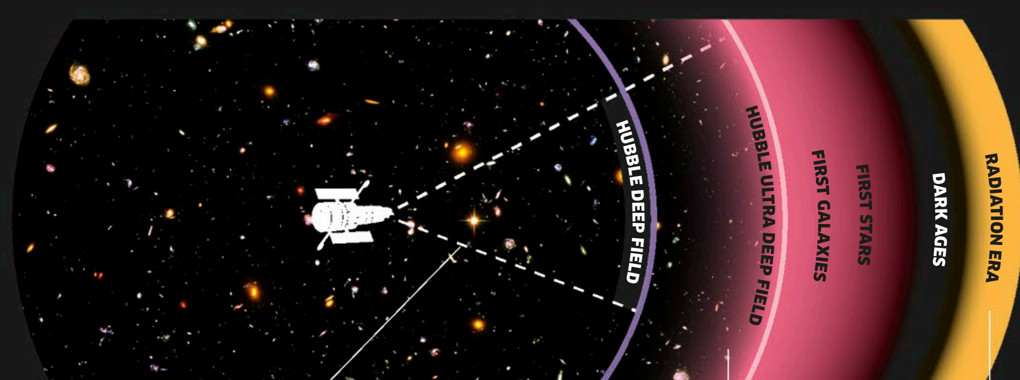
5 Over the next 379,000 years, the universe slowly cools, until eventually atoms are able to form. This development changes the universe from a dense fog into an empty space punctuated by clouds of hydrogen and helium gas. Light can now pass through it.

THE OBSERVABLE UNIVERSE

When we look at distant objects in the night sky, we are actually seeing what they looked like millions, or even billions, of years ago, because that is how long the light from them has taken to reach us. All of the space we can see from Earth is known as the observable universe. Other parts lie beyond that, but are too far away for the light from them to have reached us yet. However, using a space-based observatory such as the Hubble Space Telescope, we can capture images of deep space and use them to decipher the universe's past.

Hubble imaging

The Hubble Space Telescope has been operating since 1990 and has captured thousands of images of the universe. Many of these have been compiled to create amazing views of the furthest (and therefore oldest) parts of the universe and we can see. These are known as Deep Field images.



The first Hubble Deep Field observed one part of the night sky over 10 days. It revealed galaxies formed less than a billion years after the Big Bang.

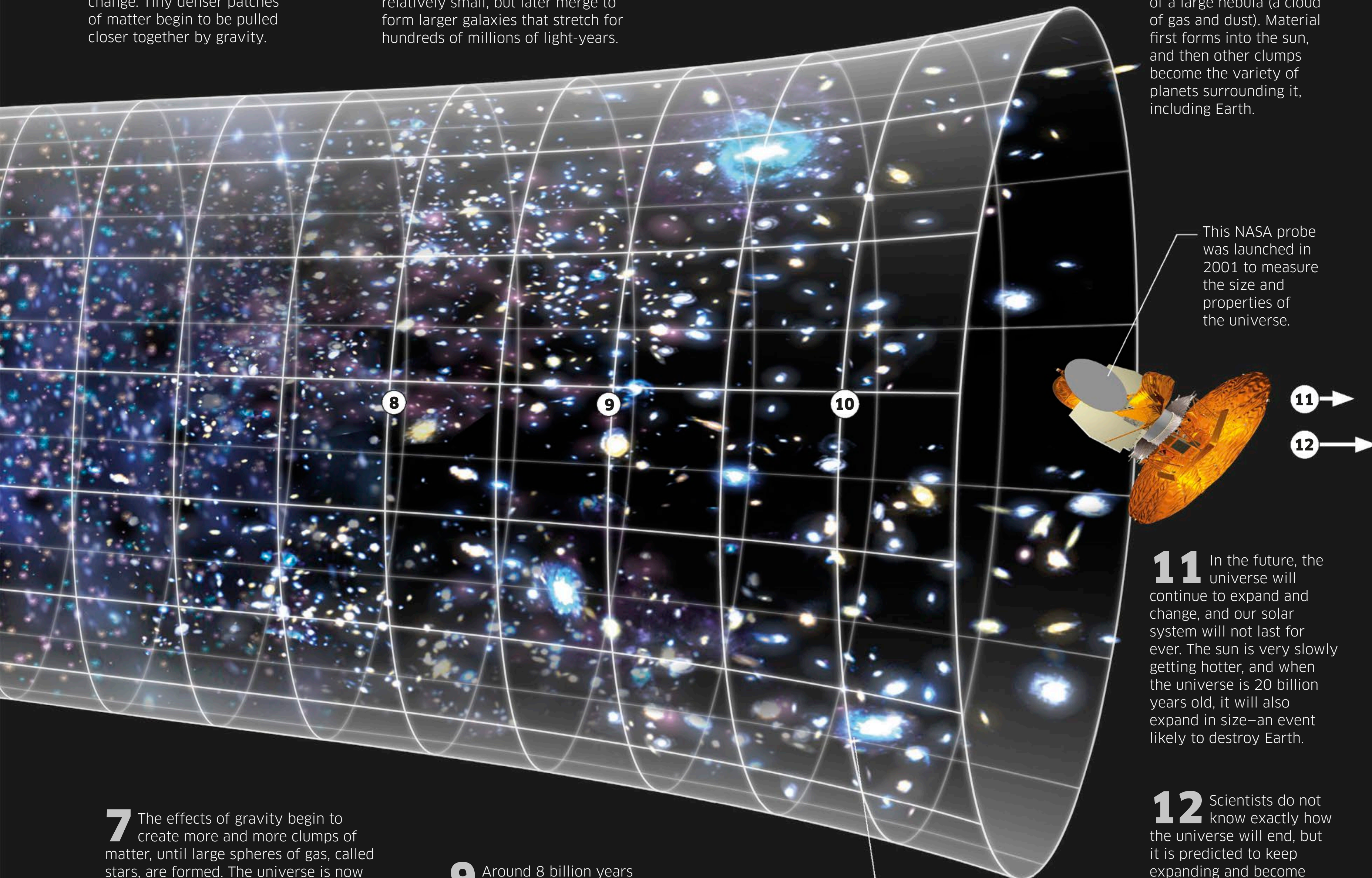
The later Hubble Ultra Deep Field image (above) shows even further into the past, picturing galaxies formed 13 million years ago, when the Universe was between 400 and 700 million years old.

There are regions of space further back in time that Hubble and other powerful space telescopes cannot see.

6 Just over half a million years after the Big Bang, the distribution of matter in the universe begins to change. Tiny denser patches of matter begin to be pulled closer together by gravity.

8 Stars form in groups within the universe's vast clouds of gas. The first groups become the first galaxies. Most of these are relatively small, but later merge to form larger galaxies that stretch for hundreds of millions of light-years.

10 Our solar system comes into being after 9 billion years, formed from the collapse of a large nebula (a cloud of gas and dust). Material first forms into the sun, and then other clumps become the variety of planets surrounding it, including Earth.



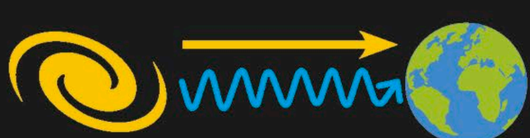
11 In the future, the universe will continue to expand and change, and our solar system will not last for ever. The sun is very slowly getting hotter, and when the universe is 20 billion years old, it will also expand in size—an event likely to destroy Earth.

7 The effects of gravity begin to create more and more clumps of matter, until large spheres of gas, called stars, are formed. The universe is now 300 million years old. These stars produce the energy to sustain themselves by nuclear fusion.

9 Around 8 billion years after the Big Bang, the expansion of the universe begins to accelerate.

12 Scientists do not know exactly how the universe will end, but it is predicted to keep expanding and become incredibly cold and dark—a process known as the "Big Chill."

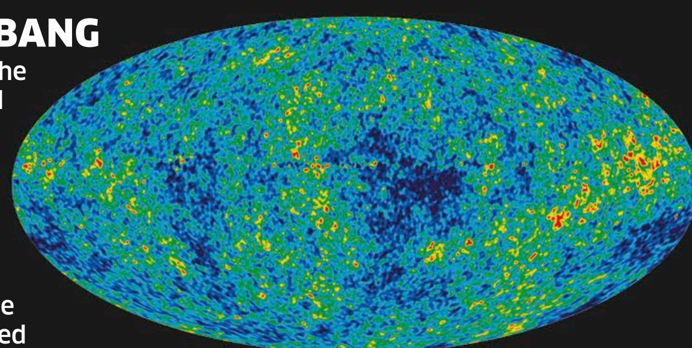
Redshift
When an object (a distant galaxy) is moving away from the observer (us), its wavelengths get longer. The light it produces therefore shifts into the red end of the light spectrum. More distant galaxies have greater redshift—supporting the theory that the universe is expanding.



Blueshift
A few nearby galaxies are actually moving toward us. Their wavelengths will be shorter, shifting the light they produce to the blue end of the spectrum.

DISCOVERING THE BIG BANG

Scientists did not always believe in the theory of an expanding universe and the Big Bang. However, during the 20th century, several discoveries were made which supported this idea. In 1929, American astronomer Edwin Hubble observed that the light coming from distant galaxies appeared redder than it should be. He attributed this to a phenomenon called redshift, suggesting that galaxies must be moving away from us. Another piece of evidence was the discovery of cosmic background radiation—microwaves coming from all directions in space that could only be explained as an after effect of the Big Bang.



Cosmic background radiation
This image, captured by NASA's Wilkinson Microwave Anisotropy Probe, shows a false color depiction of the background radiation that fills the entire universe. This is the remains of the intense burst of energy that was released by the Big Bang.

Most of a **galaxy's mass** is made up of **dark matter**.

It is estimated that there are **2 trillion galaxies** in the parts of **the universe** we can see.

Galaxies

Unimaginably huge collections of gas, dust, stars, and even planets, galaxies come in many shapes and sizes. Some are spirals, such as our own galaxy, others are like squashed balls, and some have no shape at all.

When you look up at the sky at night, every star you see is part of our galaxy, the Milky Way. This is part of what we call the Local Group, which contains about 50 galaxies. Beyond it are countless more galaxies that stretch out as far as telescopes can see. The smallest galaxies in the universe have a few million stars in them, while the largest have trillions. The Milky Way lies somewhere in the middle, with between 100 billion and 1 trillion stars in it. The force of gravity holds the stars in a galaxy together, and they travel slowly around the center. A supermassive black hole hides at the heart of most galaxies.

Astronomers have identified four types of galaxies: spiral, barred spiral, elliptical, and irregular. Spiral galaxies are flat spinning disks with a bulge in the center, while barred spiral galaxies have a longer, thinner line of stars at their center, which looks like a bar. Elliptical galaxies are an ellipsoid, or the shape of a squashed sphere—these are the largest galaxies. Then there are irregular galaxies, which have no regular shape.

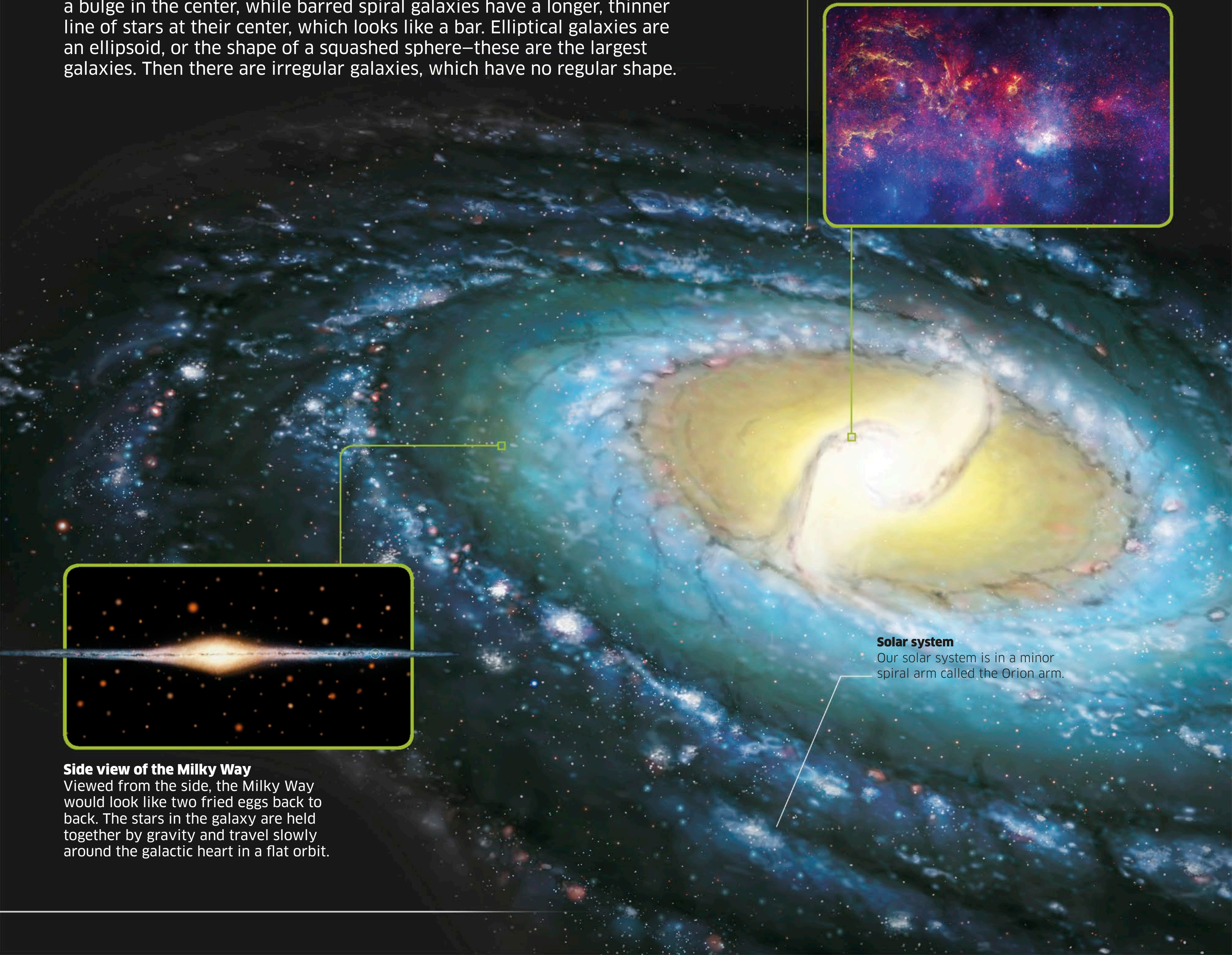
MILKY WAY

Type: *Barred spiral*

Diameter: *100,000 light years*

Our own galaxy, the Milky Way, is thought to be a barred spiral shape, but we cannot see its shape clearly from Earth because we are part of it. From our solar system, it appears as a pale streak in the sky with a central bulge of stars. From above, it would look like a giant whirlpool that takes 200 million years to rotate.

Galactic core
Infrared and X-ray images reveal intense activity near the galactic core. The galaxy's center is located within the bright white region. Hundreds of thousands of stars that cannot be seen in visible light swirl around it, heating dramatic clouds of gas and dust.



Side view of the Milky Way
Viewed from the side, the Milky Way would look like two fried eggs back to back. The stars in the galaxy are held together by gravity and travel slowly around the galactic heart in a flat orbit.

Solar system
Our solar system is in a minor spiral arm called the Orion arm.

ANDROMEDA

Type: *Spiral*

Distance: *2,450,000 light years*

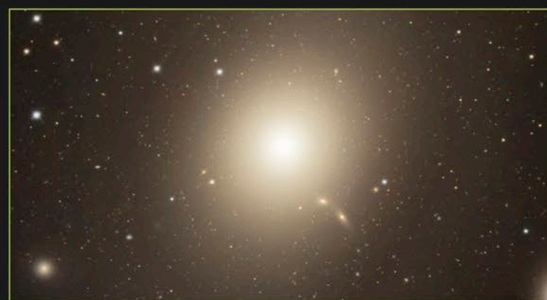
Our closest large galaxy, Andromeda—a central hub surrounded by a flat, rotating disc of stars, gas, and dust—can sometimes be seen from Earth with the naked eye. In 4.5 billion years, Andromeda is expected to collide with the Milky Way, forming one huge elliptical galaxy.

MESSIER 87

Type: *Elliptical*

Distance: *53 million light years*

M87, also known as Virgo A, is one of the largest galaxies in our part of the universe. The galaxy is giving out a powerful jet of material from the supermassive black hole at its center, energetic enough to accelerate particles to nearly the speed of light.



SMALL MAGELLANIC CLOUD

Type: *Dwarf (irregular)*

Distance: *197,000 light years*

The dwarf galaxy SMC stretches 7,000 light years across. Like its neighbor the Large Magellanic Cloud (LMC), its shape has been distorted by the gravity of our own galaxy. Third closest to the Milky Way, it is known as a satellite galaxy because it orbits our own.

CARTWHEEL GALAXY

Type: *Ring (irregular)*

Distance: *500 million light years*

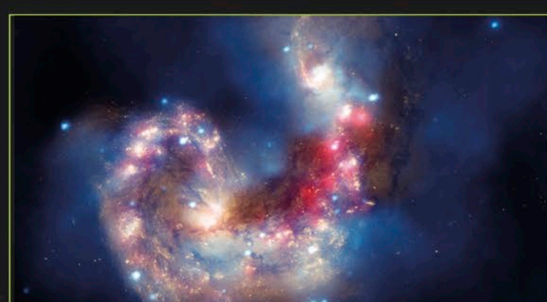
The Cartwheel Galaxy started out as a spiral. However, 200 million years ago it collided with a smaller galaxy, causing a powerful shock throughout the galaxy, which tossed lots of the gas and dust to the outside, creating its unusual shape.

ANTENNAE GALAXIES

Type: *Merging spirals*

Distance: *45 million–65 million light years*

Around 1.2 billion years ago, the Antennae Galaxies were two separate galaxies: one barred spiral and one spiral. They started to merge a few hundred million years ago, when the antennae formed and are expected to become one galaxy in about 400 million years.

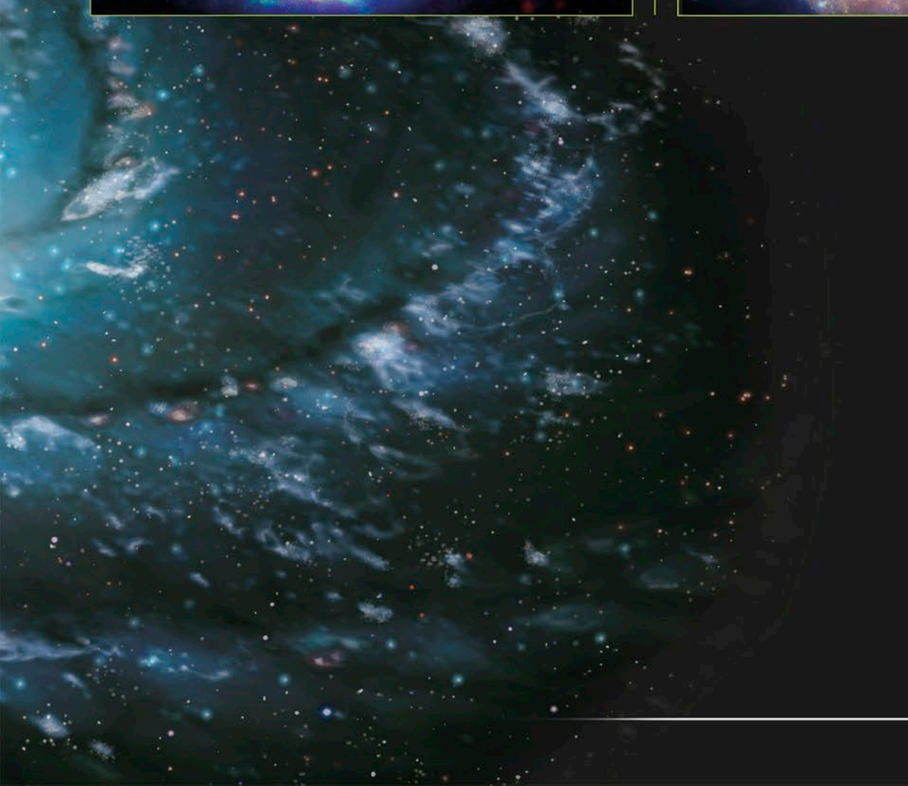


WHIRLPOOL GALAXY

Type: *Colliding spiral and dwarf*

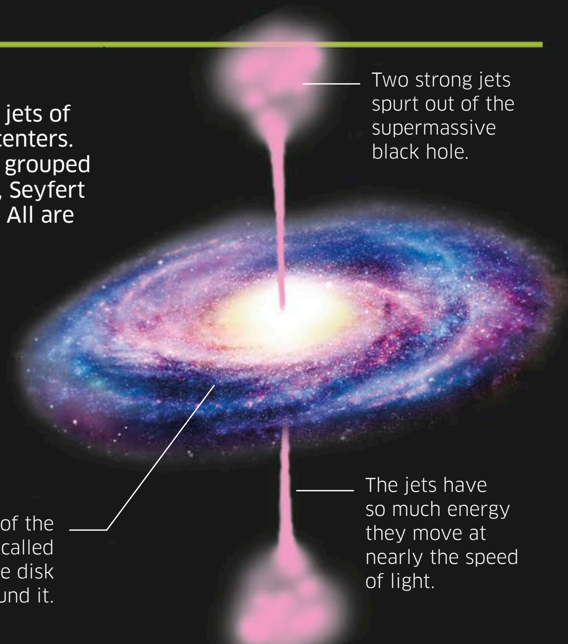
Distance: *23 million light years*

About 300 million years ago, the spiral Whirlpool Galaxy was struck by a dwarf galaxy, which now appears to dangle from one of its spiral arms. The collision stirred up gas clouds, triggering a burst of star formation, which can be seen from Earth with a small telescope.



Active galaxies

Some galaxies send out bright jets of light and particles from their centers. These "active" galaxies can be grouped into four types: radio galaxies, Seyfert galaxies, quasars, and blazars. All are thought to have supermassive black holes at their core, known as the active galactic nuclei, which churn out the jets of material.

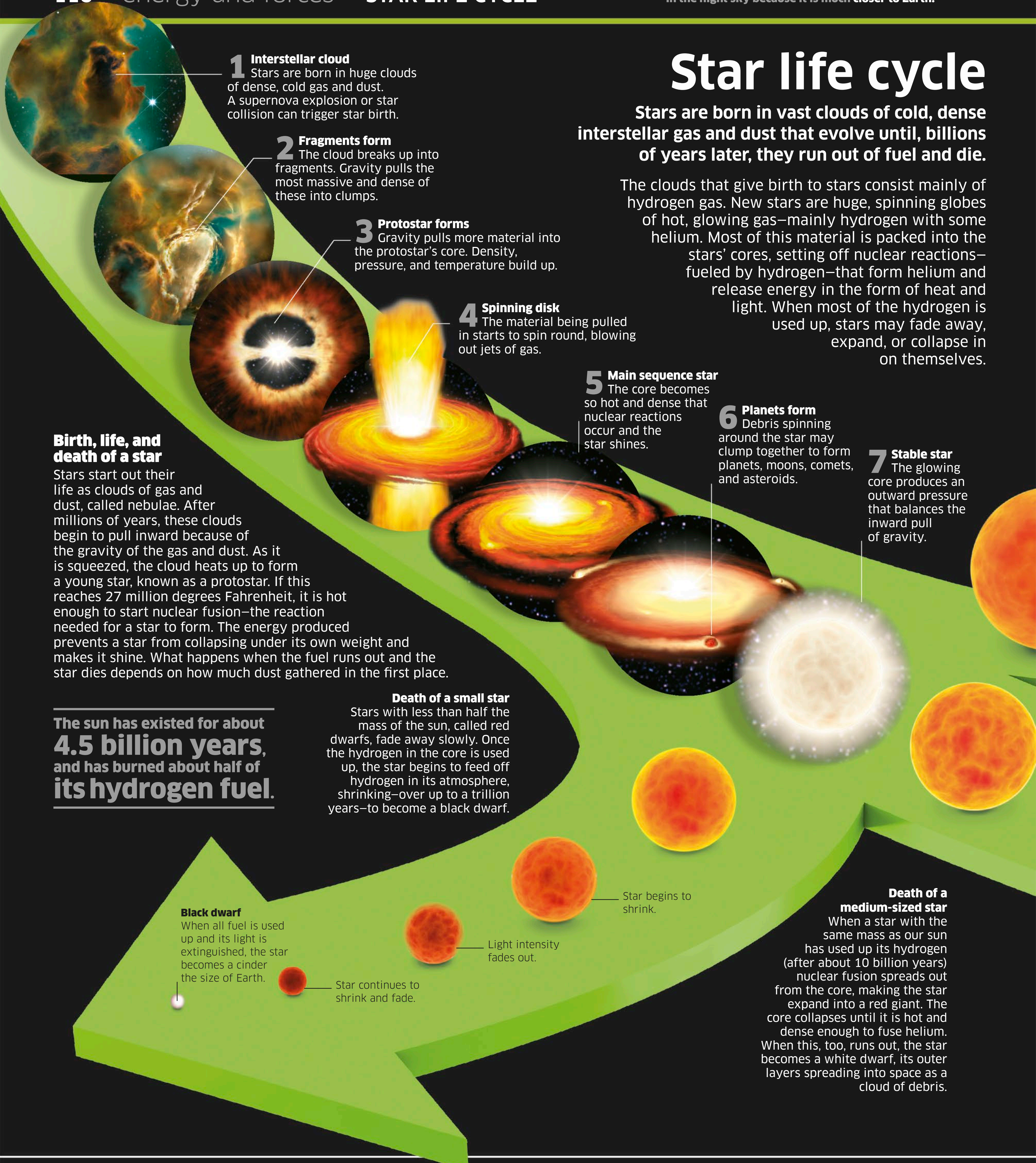


Our sun is a star—it only seems bigger than other stars in the night sky because it is much closer to Earth.

Star life cycle

Stars are born in vast clouds of cold, dense interstellar gas and dust that evolve until, billions of years later, they run out of fuel and die.

The clouds that give birth to stars consist mainly of hydrogen gas. New stars are huge, spinning globes of hot, glowing gas—mainly hydrogen with some helium. Most of this material is packed into the stars' cores, setting off nuclear reactions—fueled by hydrogen—that form helium and release energy in the form of heat and light. When most of the hydrogen is used up, stars may fade away, expand, or collapse in on themselves.



1 Interstellar cloud
Stars are born in huge clouds of dense, cold gas and dust. A supernova explosion or star collision can trigger star birth.

2 Fragments form
The cloud breaks up into fragments. Gravity pulls the most massive and dense of these into clumps.

3 Protostar forms
Gravity pulls more material into the protostar's core. Density, pressure, and temperature build up.

4 Spinning disk
The material being pulled in starts to spin round, blowing out jets of gas.

5 Main sequence star
The core becomes so hot and dense that nuclear reactions occur and the star shines.

6 Planets form
Debris spinning around the star may clump together to form planets, moons, comets, and asteroids.

7 Stable star
The glowing core produces an outward pressure that balances the inward pull of gravity.

Birth, life, and death of a star

Stars start out their life as clouds of gas and dust, called nebulae. After millions of years, these clouds begin to pull inward because of the gravity of the gas and dust. As it is squeezed, the cloud heats up to form a young star, known as a protostar. If this reaches 27 million degrees Fahrenheit, it is hot enough to start nuclear fusion—the reaction needed for a star to form. The energy produced prevents a star from collapsing under its own weight and makes it shine. What happens when the fuel runs out and the star dies depends on how much dust gathered in the first place.

The sun has existed for about **4.5 billion years**, and has burned about half of **its hydrogen fuel**.

Death of a small star
Stars with less than half the mass of the sun, called red dwarfs, fade away slowly. Once the hydrogen in the core is used up, the star begins to feed off hydrogen in its atmosphere, shrinking—over up to a trillion years—to become a black dwarf.

Star begins to shrink.

Light intensity fades out.

Star continues to shrink and fade.

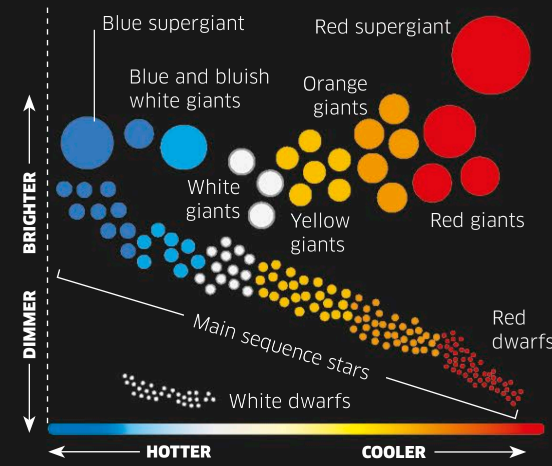
Black dwarf
When all fuel is used up and its light is extinguished, the star becomes a cinder the size of Earth.

Death of a medium-sized star
When a star with the same mass as our sun has used up its hydrogen (after about 10 billion years) nuclear fusion spreads out from the core, making the star expand into a red giant. The core collapses until it is hot and dense enough to fuse helium. When this, too, runs out, the star becomes a white dwarf, its outer layers spreading into space as a cloud of debris.

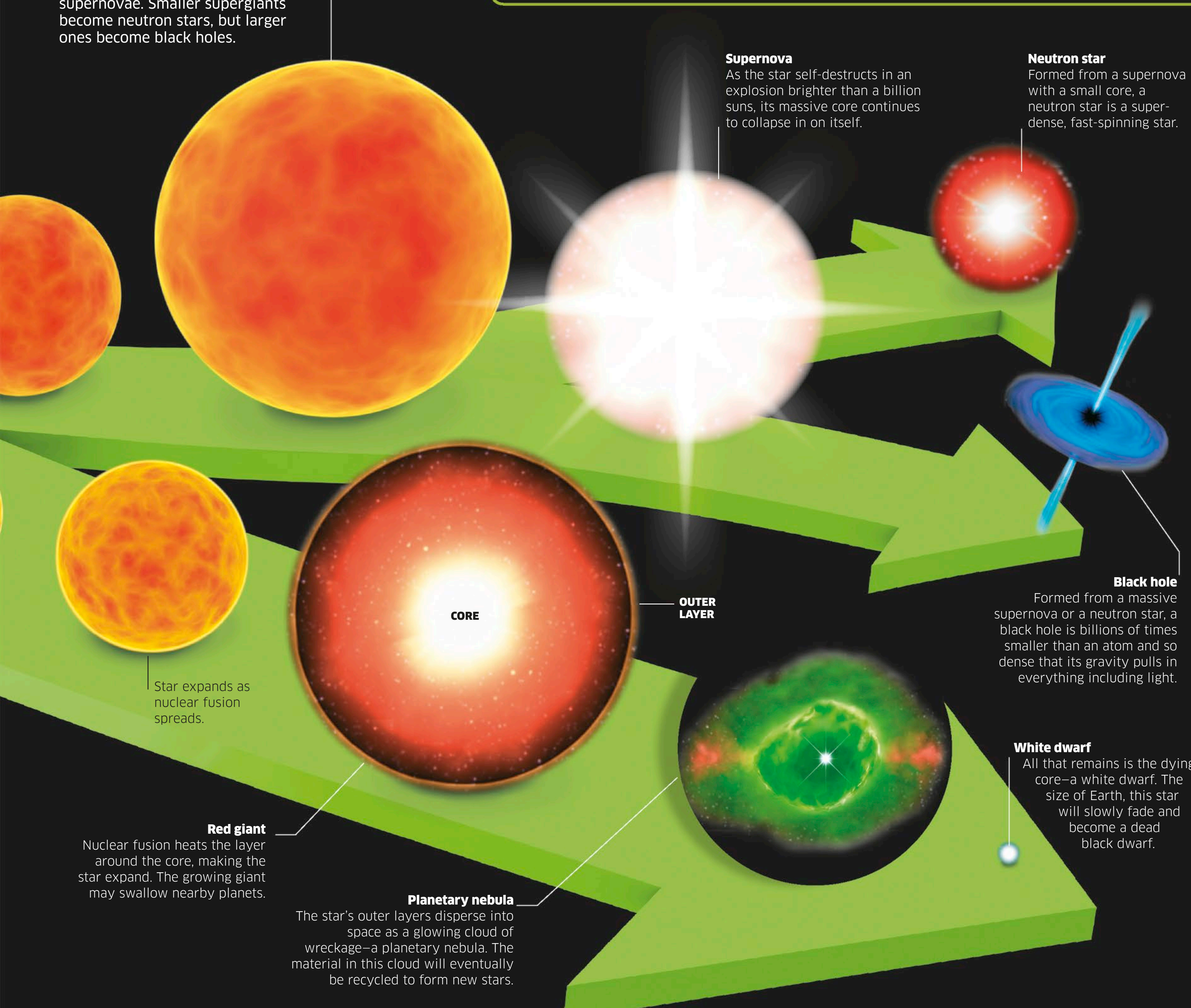
If you sorted all the stars into piles, the biggest pile, by far, would be **red dwarfs—stars** with less than half of the sun's mass.

Star types

The Hertzsprung-Russell diagram is a graph that astronomers use to classify stars. It plots the brightness of stars against their temperature to reveal distinct groups of stars, such as red giants (dying stars) and main sequence stars (ordinary stars). Astronomers also classify stars by color, which relates to temperature. Red is the coolest color, seen in stars cooler than 6,000°F (3,500°C). Stars such as our sun are yellowish white and average around 10,000°F (6,000°C). The hottest stars are blue, with surface temperatures above 21,000°F (12,000°C).



Death of a massive star
Stars more than eight times the mass of our sun will be hot enough to become supergiants. The heat and pressure in the core become so intense that nuclear fusion can fuse helium and larger atoms to create elements such as carbon or oxygen. As this happens, the stars swell into supergiants, which end their lives in dramatic explosions called supernovae. Smaller supergiants become neutron stars, but larger ones become black holes.



Red supergiant
Nuclear fusion carries on inside the core of the supergiant, forming heavy elements until the core turns into iron and the star collapses.

Supernova
As the star self-destructs in an explosion brighter than a billion suns, its massive core continues to collapse in on itself.

Neutron star
Formed from a supernova with a small core, a neutron star is a super-dense, fast-spinning star.

Black hole
Formed from a massive supernova or a neutron star, a black hole is billions of times smaller than an atom and so dense that its gravity pulls in everything including light.

Star expands as nuclear fusion spreads.

Red giant
Nuclear fusion heats the layer around the core, making the star expand. The growing giant may swallow nearby planets.

Planetary nebula
The star's outer layers disperse into space as a glowing cloud of wreckage—a planetary nebula. The material in this cloud will eventually be recycled to form new stars.

White dwarf
All that remains is the dying core—a white dwarf. The size of Earth, this star will slowly fade and become a dead black dwarf.

Carina Nebula

This remarkable image of part of the Carina Nebula was captured by the Hubble Space Telescope. Inside this enormous pillar of dust and gas, stars are being born.

The nebula comprises mostly hydrogen and helium, but also contains the debris from old stars that exploded long ago. Gravity pulls all of this matter into clumps that heat up and begin to shine, their light and other radiation sculpting the cloud with jets and swirls. The Carina Nebula lies 7,500 light-years away, in our own galaxy, the Milky Way.

The Solar System

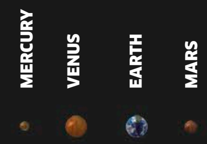
The solar system is a huge disk of material, with the sun at its center, that stretches out over 19 billion miles (30 billion km) to where interstellar space begins.

Most of the solar system is empty space, but scattered throughout are countless solid objects bound to the sun by gravity and orbiting around it. These include the eight planets, hundreds of moons and dwarf planets, millions of asteroids, and possibly billions of comets. The sun itself makes up 99.8 percent of the mass of the solar system.

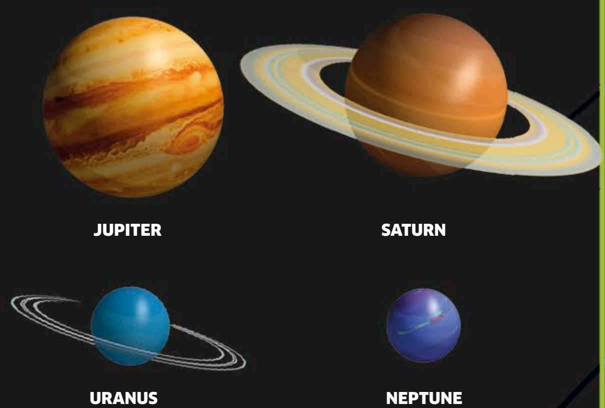
Size comparison

With a diameter of nearly 870,000 miles (1.4 million km), the sun is 10 times wider than Jupiter, the biggest of the planets, and over 1,000 times more massive.

Inner planets
The inner four planets are smaller than the outer four. They are called terrestrial planets.

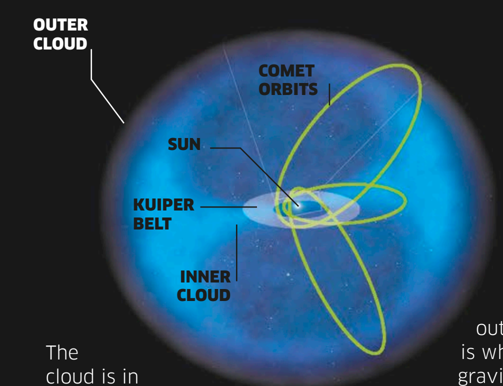


Outer planets
The outermost four planets are larger and made up of gas, so they are called the gas giants.



Oort Cloud

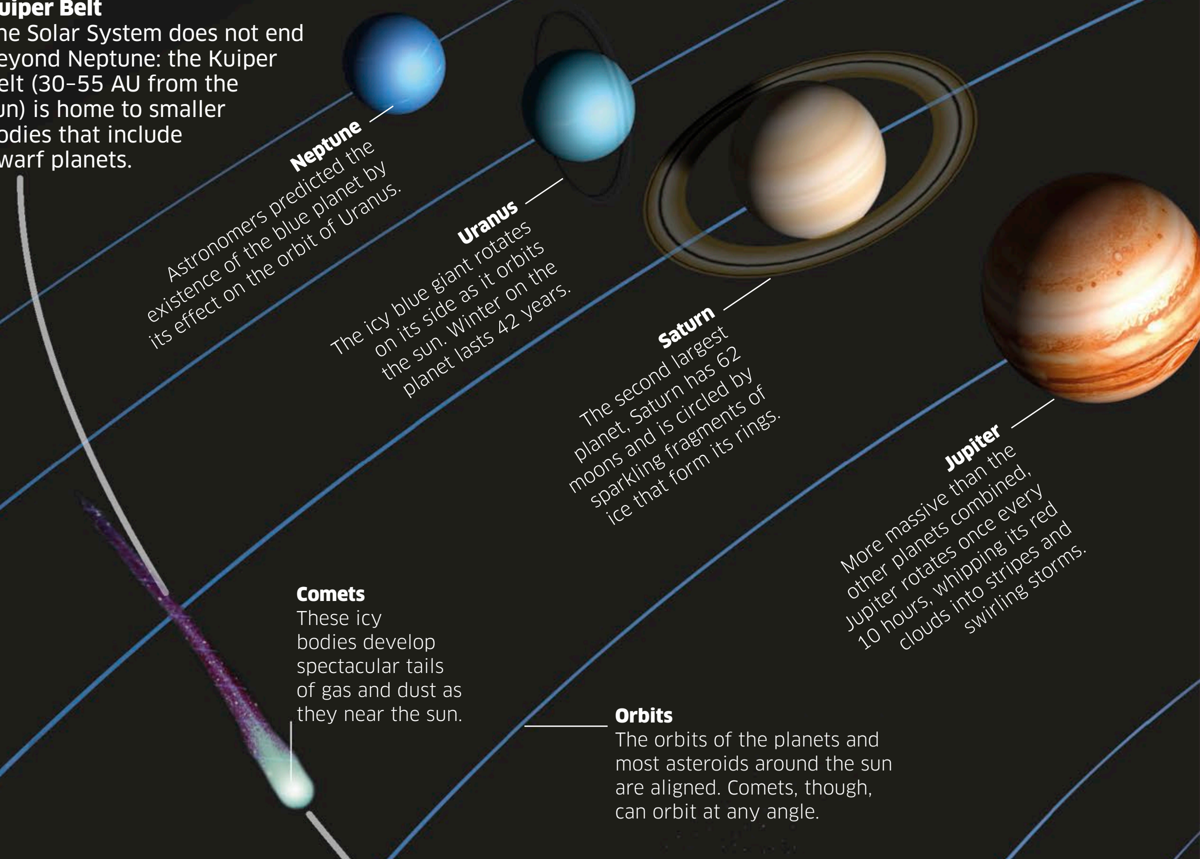
The Oort Cloud is a ring of tiny, icy bodies that is thought to extend between 50,000 and 100,000 times farther from the sun than the distance from the sun to Earth—but it's so far away that no one really knows.



The cloud is in what we call interstellar space.

The cloud's outer edge is where the gravitational influence of the sun ends.

Kuiper Belt
The Solar System does not end beyond Neptune: the Kuiper Belt (30–55 AU from the sun) is home to smaller bodies that include dwarf planets.



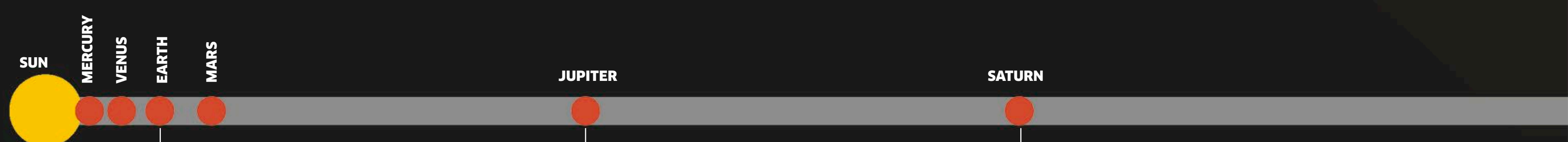
Comets
These icy bodies develop spectacular tails of gas and dust as they near the sun.

Orbits
The orbits of the planets and most asteroids around the sun are aligned. Comets, though, can orbit at any angle.

Orbiting planets

There are eight planets in the solar system. They form two distinct groups. The inner planets—Mercury, Venus, Earth, and Mars—are solid balls of rock and metal. The outer planets—Jupiter, Saturn, Uranus, and Neptune— are gas giants: enormous, swirling globes made mostly of hydrogen and helium.

Distance from the sun
It is hard to imagine how far Earth is from the sun, and how much bigger the sun is than Earth. If Earth were a peppercorn, the sun would be the size of a bowling ball—100 times bigger.

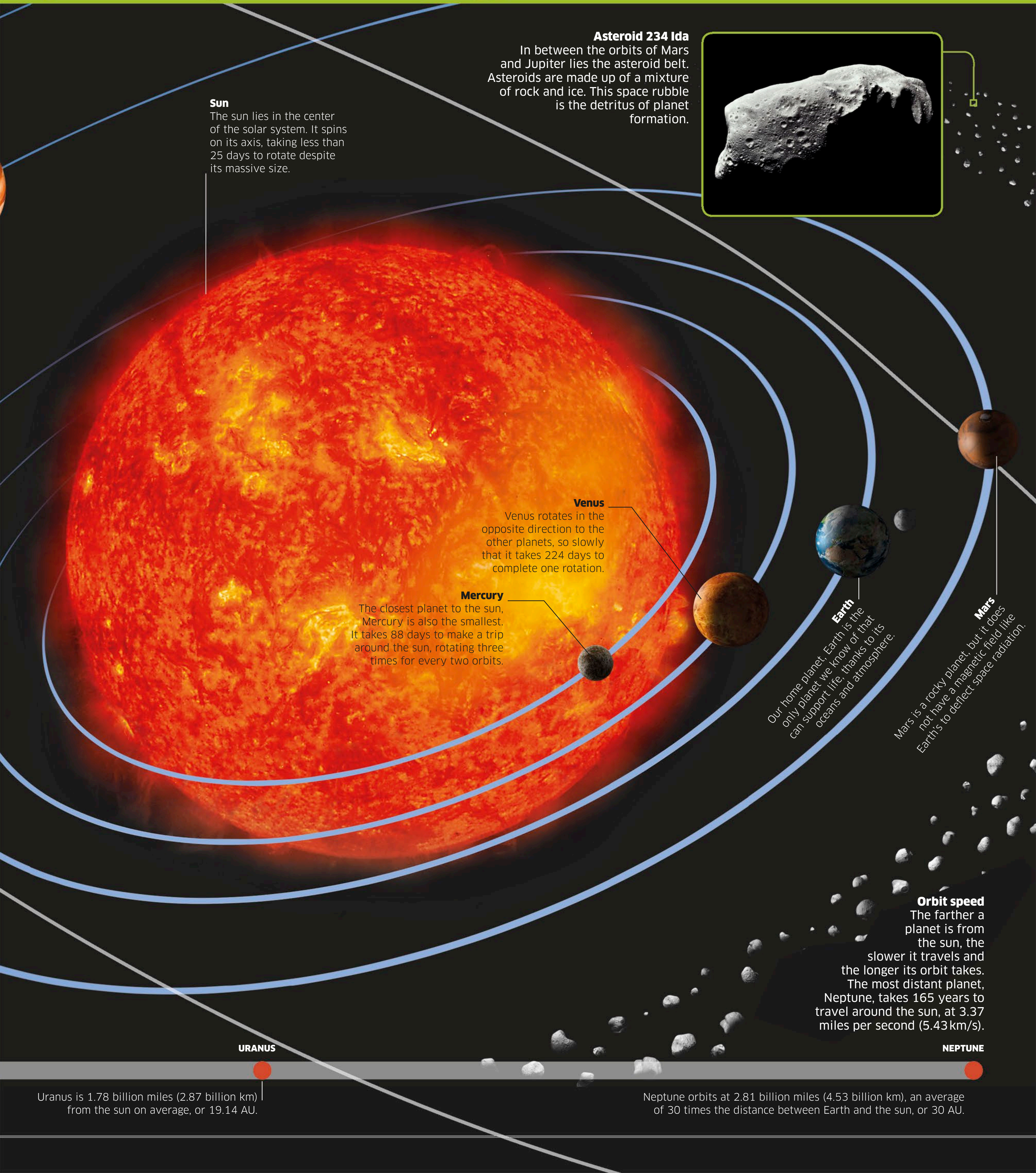


Earth is 92.9 million miles (149.6 million km) from the sun—or one astronomical unit (AU).

Jupiter is 484 million miles (780 million km) from the sun, which is equal to 5.2 AU.

Saturn orbits on average 890 million miles (1.43 billion km) from the sun, or 9.58 AU.

There are five known dwarf planets:
Ceres, Pluto, Makemake, Eris, and Haumea.



Earth's **rotation** is getting **slower** by **17 milliseconds every 100 years.**

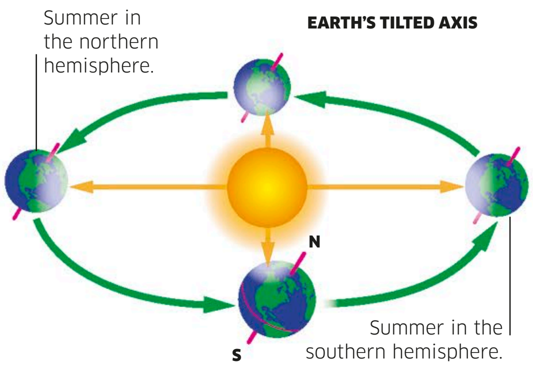
Earth and Moon

Our home, Earth, is about 4.5 billion years old. With a diameter of just over 7,500 miles (12,000 km), it orbits the sun every 365.3 days and spins on its axis once every 23.9 hours.

Of all the planets in the universe, ours is the only place life is known to exist. Earth is one of the solar system's four rocky planets, and the third from the sun. Its atmosphere, surface water, and magnetic field—which protects us from solar radiation—make Earth the perfect place to live.

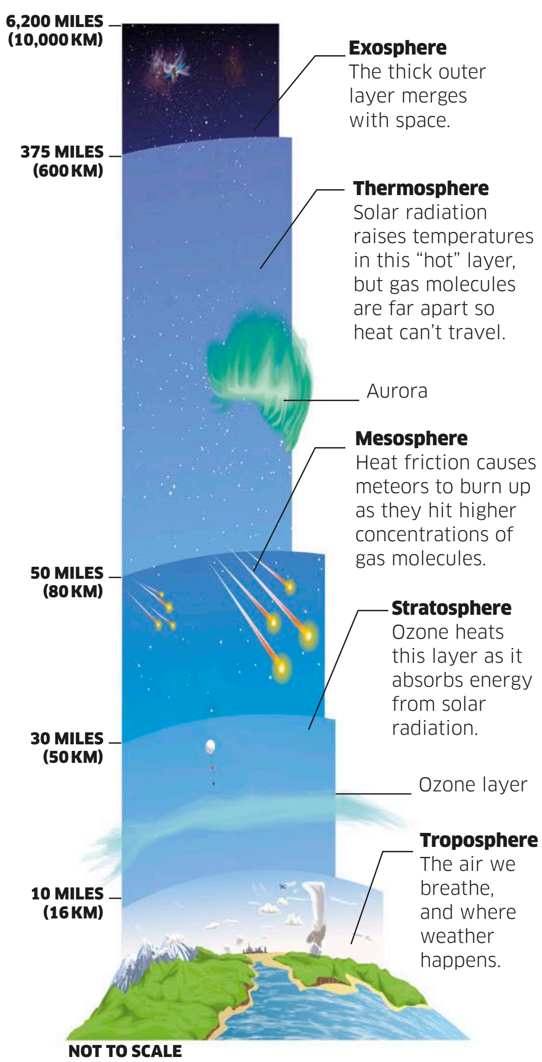
The seasons

As Earth orbits around the sun, it also rotates around its axis—an imaginary north–south line. This axis is tilted by 23.4° compared to Earth's orbit, so that one part of the planet is always closer to or farther away from the sun, resulting in the seasons.



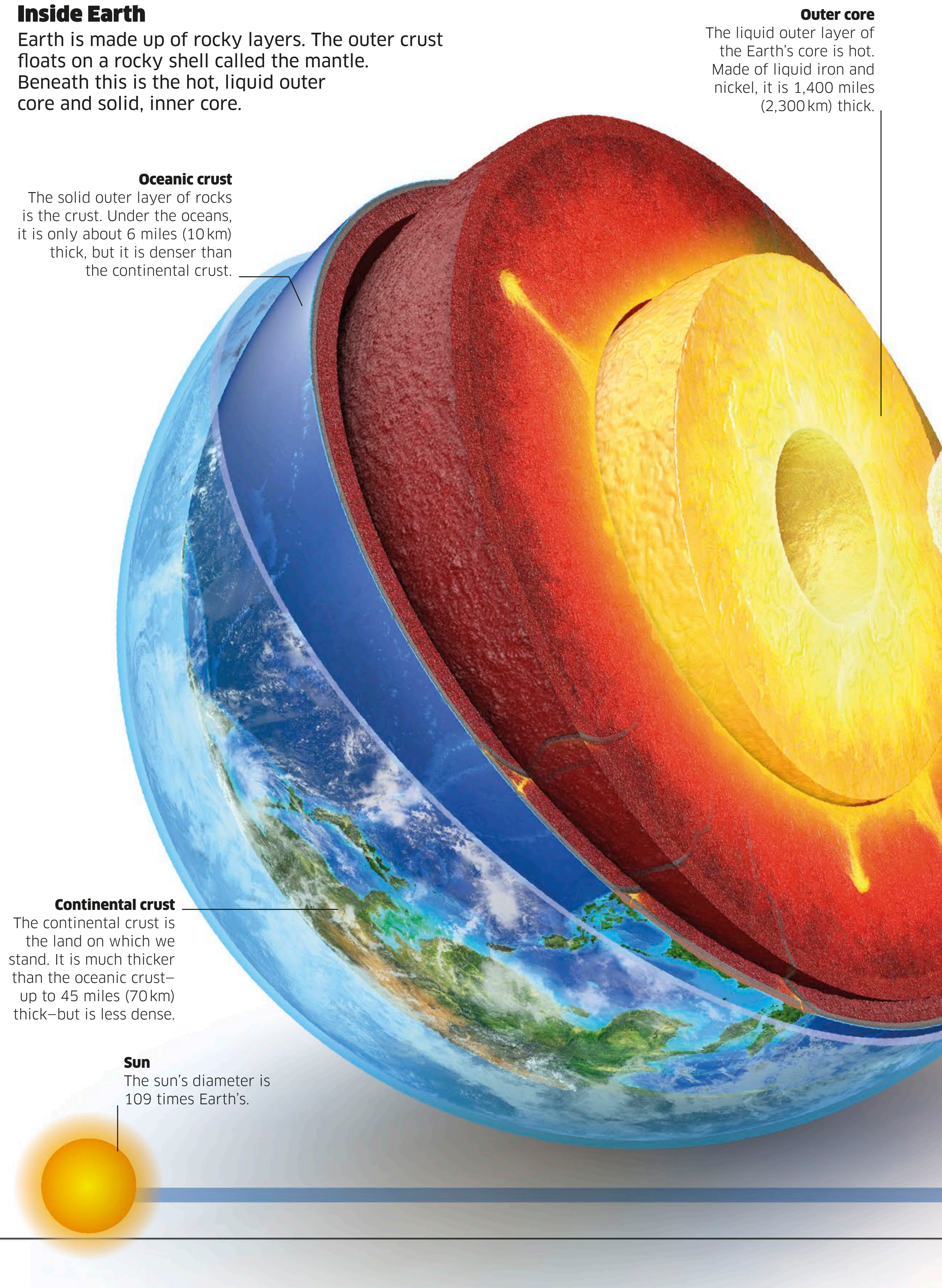
Atmosphere

Earth's atmosphere is made up of a mix of gases—78 percent nitrogen, 21 percent oxygen, and a small amount of others, such as carbon dioxide and argon. These gases trap heat on the planet and let us breathe. The atmosphere has five distinct layers.



Inside Earth

Earth is made up of rocky layers. The outer crust floats on a rocky shell called the mantle. Beneath this is the hot, liquid outer core and solid, inner core.

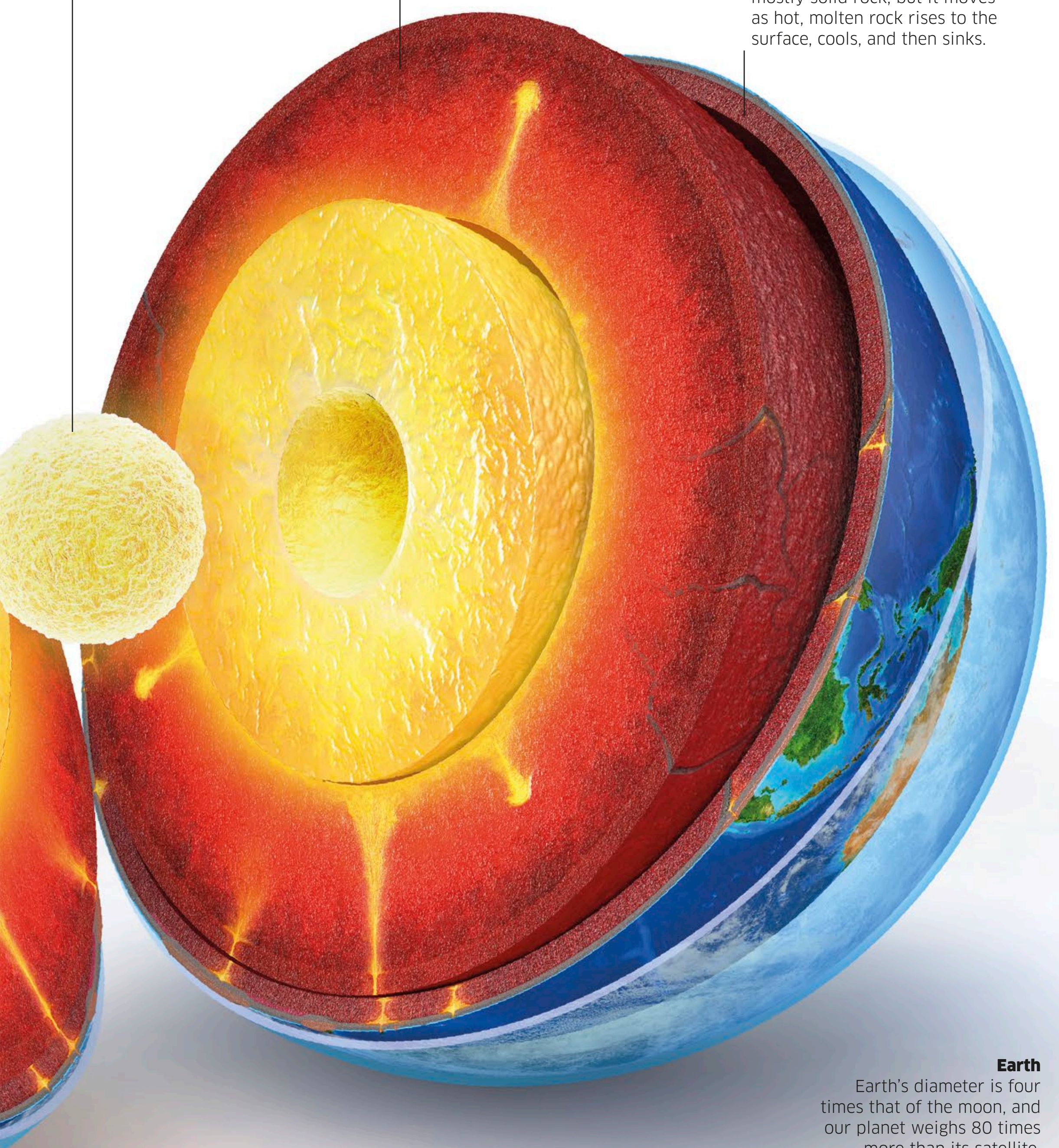


The moon
Orbiting Earth every 27 days, the moon is a familiar sight in the night sky. The same side of the moon always faces Earth. The dark side of the moon can only be seen from spacecraft.

Inner core
The iron inner core is just over two-thirds of the size of the moon and as hot as the surface of the sun. It is solid because of the immense pressure on it.

Lower mantle
The lower layer of the mantle contains more than half the planet's volume and extends 1,800 miles (2,900 km) below the surface. It is hot and dense.

Upper mantle
The layer extending 255 miles (410 km) below the crust is mostly solid rock, but it moves as hot, molten rock rises to the surface, cools, and then sinks.

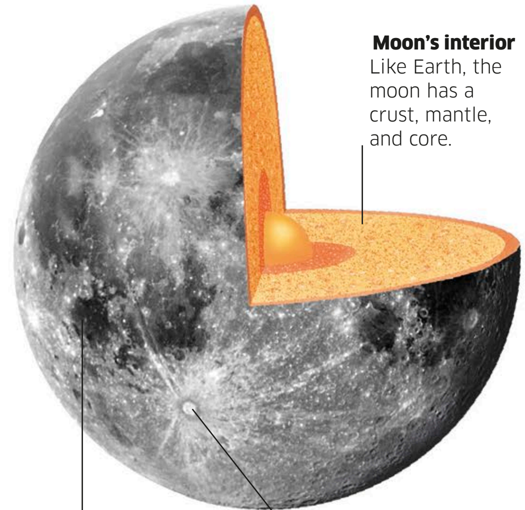


Earth
Earth's diameter is four times that of the moon, and our planet weighs 80 times more than its satellite.

Earth to sun
The sun is 93 million miles (150 million km) from Earth. It takes light 8 minutes to travel this distance, known as one astronomical unit (AU).

Moon
The moon is 239,000 miles (384,000 km) from Earth.

Moon
Our only natural satellite, the moon is almost as old as Earth. It is thought it was made when a flying object the size of Mars crashed into our planet, knocking lots of rock into Earth's orbit. This rock eventually clumped together to form our moon. It is the moon's gravitational pull that is responsible for tides.

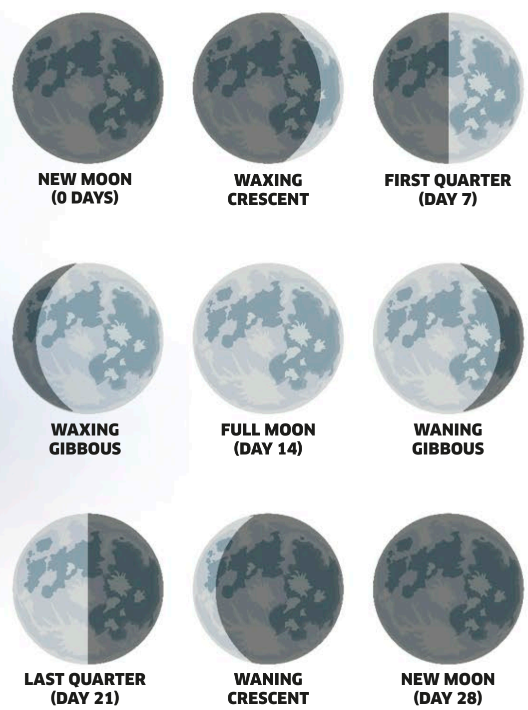


Moon's interior
Like Earth, the moon has a crust, mantle, and core.

Lunar maria
Dark, flat areas known as maria, or seas, are in fact huge plains of solidified lava.

Lunar craters
Craters, formed by asteroid impacts 3.5 billion years ago, pockmark the moon.

Lunar cycle
The moon doesn't produce its own light. The sun illuminates exactly half of the moon, and the amount of the illuminated side we see depends upon where the moon is in its orbit around Earth. This gives rise to the phenomenon known as the phases of the moon.



34 miles (55 km)—**the average width of the 1,850-mile (3,000-km) long East African Rift System** of active faults.

Tectonic Earth

Earth's surface is a layer of solid rock split into huge slabs called tectonic plates, which slowly shift, altering landscapes and causing earthquakes and volcanoes.

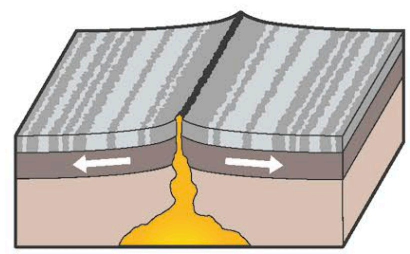
The tectonic plates are made up of Earth's brittle crust fused to the top layer of the underlying mantle, forming a shell-like elastic structure called the lithosphere. Plate movement is driven by convection currents in the lower, viscous layers of the mantle—known as the asthenosphere—when hot, molten rock rises to the surface and cooler, more solid rock sinks. Most tectonic activity happens near the edges of plates, as they move apart from, toward, or past each other.

Continental drift

Over millions of years, continents carried by different plates have collided to make mountains, combined to form supercontinents, or split up in a process called rifting. South America's east coast and Africa's west coast fit like pieces of a jigsaw puzzle. Similar rock and life forms suggest that the two continents were once a supercontinent.

270 MILLION YEARS AGO | 180 MILLION YEARS AGO | 66 MILLION YEARS AGO

Plates move at between ¼ in (7 mm) per year, one-fifth **the rate human fingernails grow,** and 6 in (150 mm) per year—the rate human hair grows.



Divergent boundary
As two plates move apart, magma welling up from the mantle fills the gap and creates new plate. Linked with volcanic activity, divergent boundaries form mid-ocean spreading ridges under the sea.

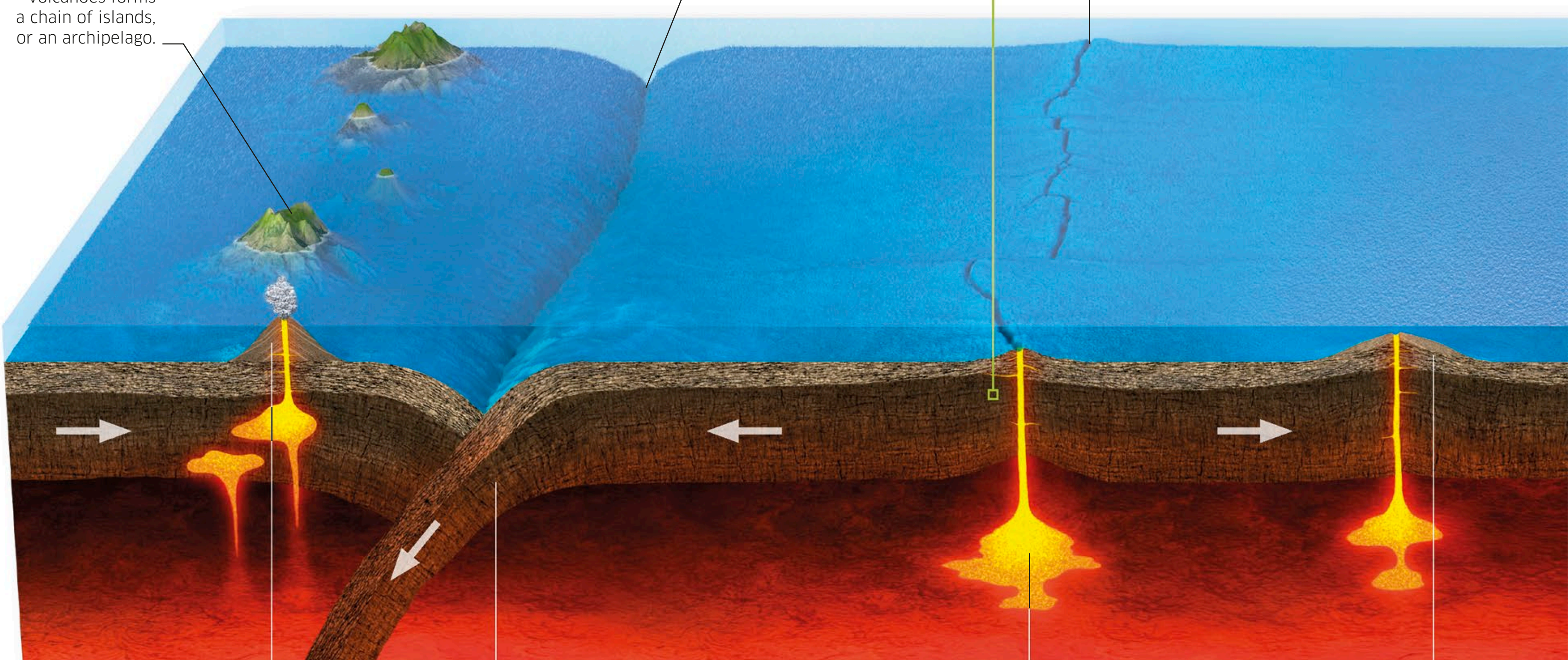
Plate tectonics

Where plates meet, landscape-changing events, such as island formation, rifting (separation), mountain-building, volcanic activity, and earthquakes take place. Plate boundaries fall into three main classes: divergent, convergent, and transform.

Island arc
A series of underwater volcanoes forms a chain of islands, or an archipelago.

Ocean trench
Two ocean plates subduct to form a deep-sea trench.

Mid-ocean ridge
Magma wells up as plates move apart, forming a ridge on the ocean floor.



Strato volcano
Layers of hardened lava and ash build up, making these volcanoes steeper than shield volcanoes.

Ocean–ocean subduction
At a convergent boundary under the sea, one oceanic plate slides under the other, creating a mid-ocean trench.

Hot spot
Heat concentrated in some areas of the mantle can erupt as molten magma.

Shield volcano
A shield volcano is built almost entirely of very fluid lava flows, making it quite shallow in shape.

4 billion years old—the age of the **oldest parts of Earth's crust.**

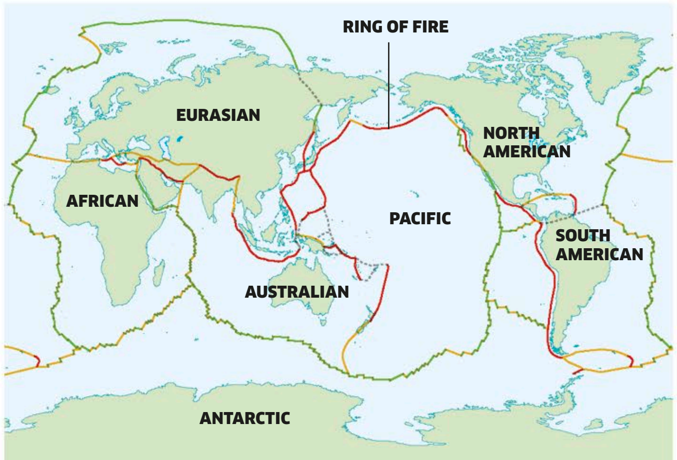
9.5 The magnitude of the **largest recorded earthquake** in the world, **in Chile on May 22, 1960.**

452 The number of **volcanoes** around the **Pacific Ring of Fire.**

Tectonic plates

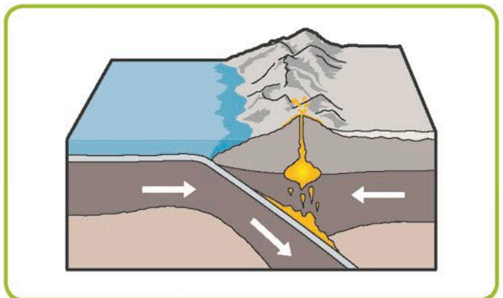
There are seven large plates and numerous medium-sized and smaller plates, which roughly coincide with the continents and oceans. The Ring of Fire is a zone of earthquakes and volcanoes around the Pacific plate from California in the northeast to Japan and New Zealand in the southwest.

- CONVERGENT
- DIVERGENT
- TRANSFORM
- UNCERTAIN

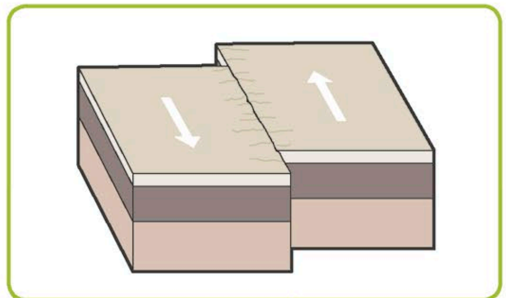


Colliding continents

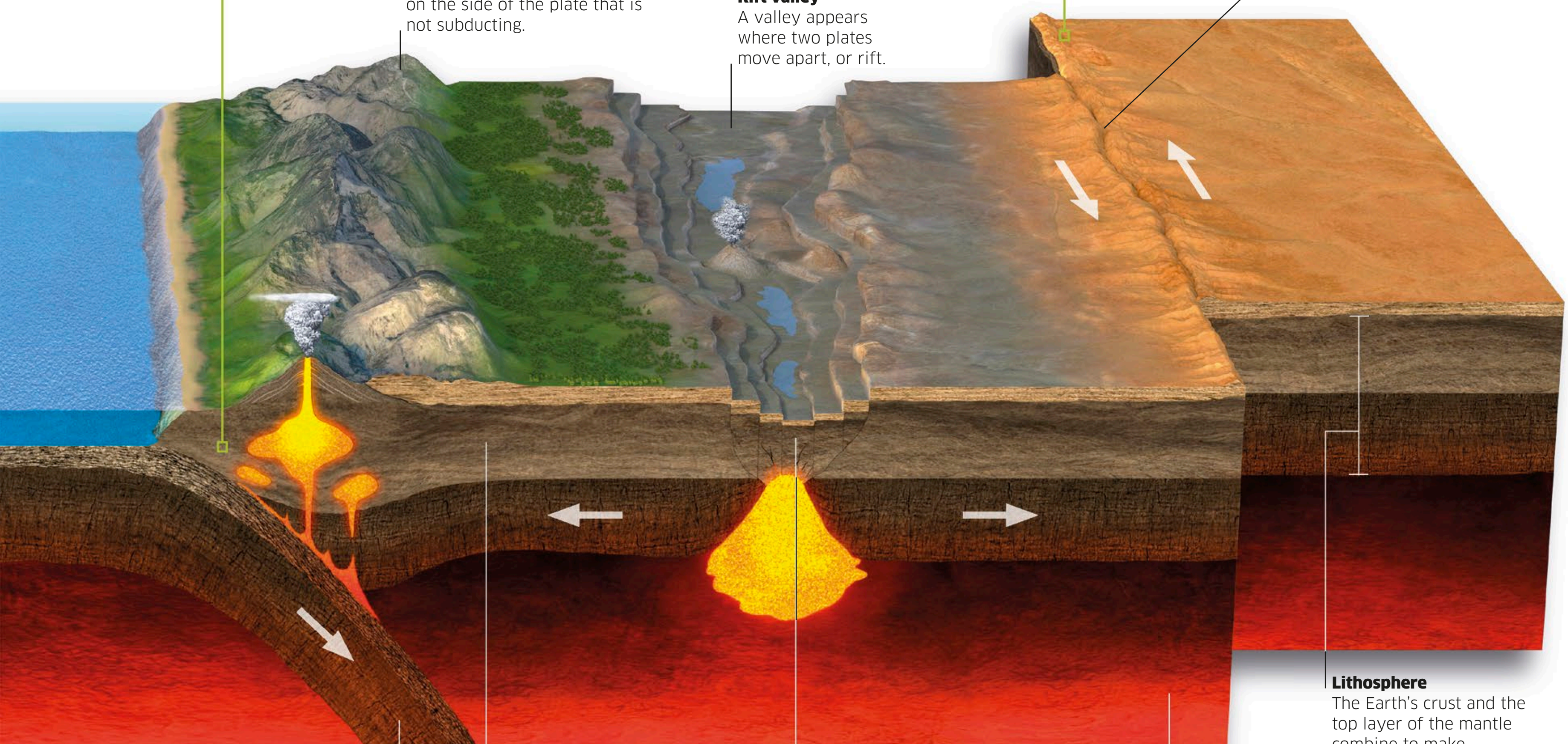
When continents collide, layers of rock are pushed up into mountain ranges. Continental convergence between the Indian subcontinent and Eurasian landmass formed the Himalayas.



Convergent boundary
As two plates move toward each other, one plate moves down, or subducts, under the other and is destroyed. A deep-sea trench or chain of volcanoes may form, and earthquakes often occur.



Transform boundary
When plate edges scrape past each other, earthquakes are frequent. The San Andreas fault in California is a famous example.



Supercell storms can **last 12 hours** and **travel 500 miles (800 km)**.

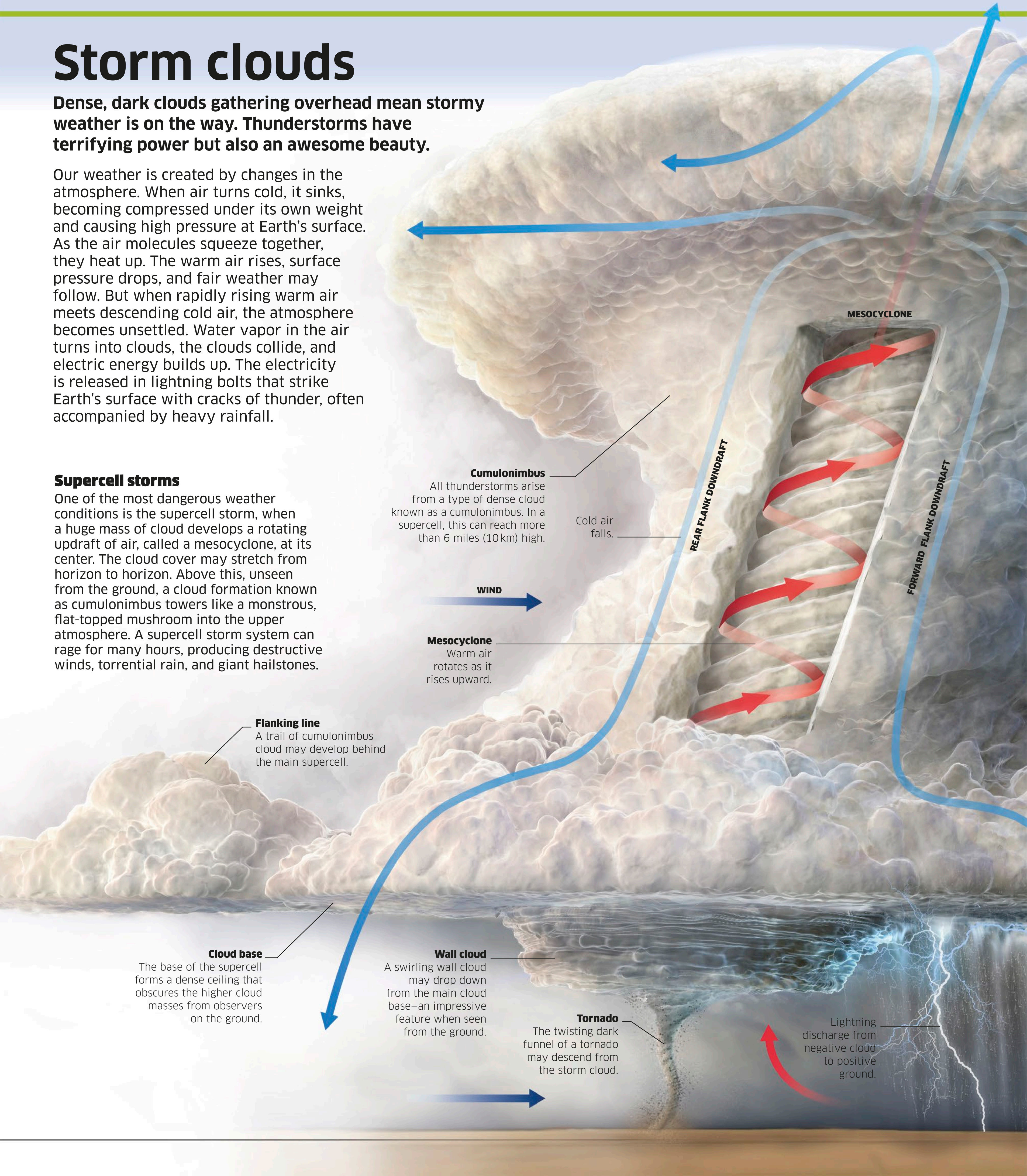
Storm clouds

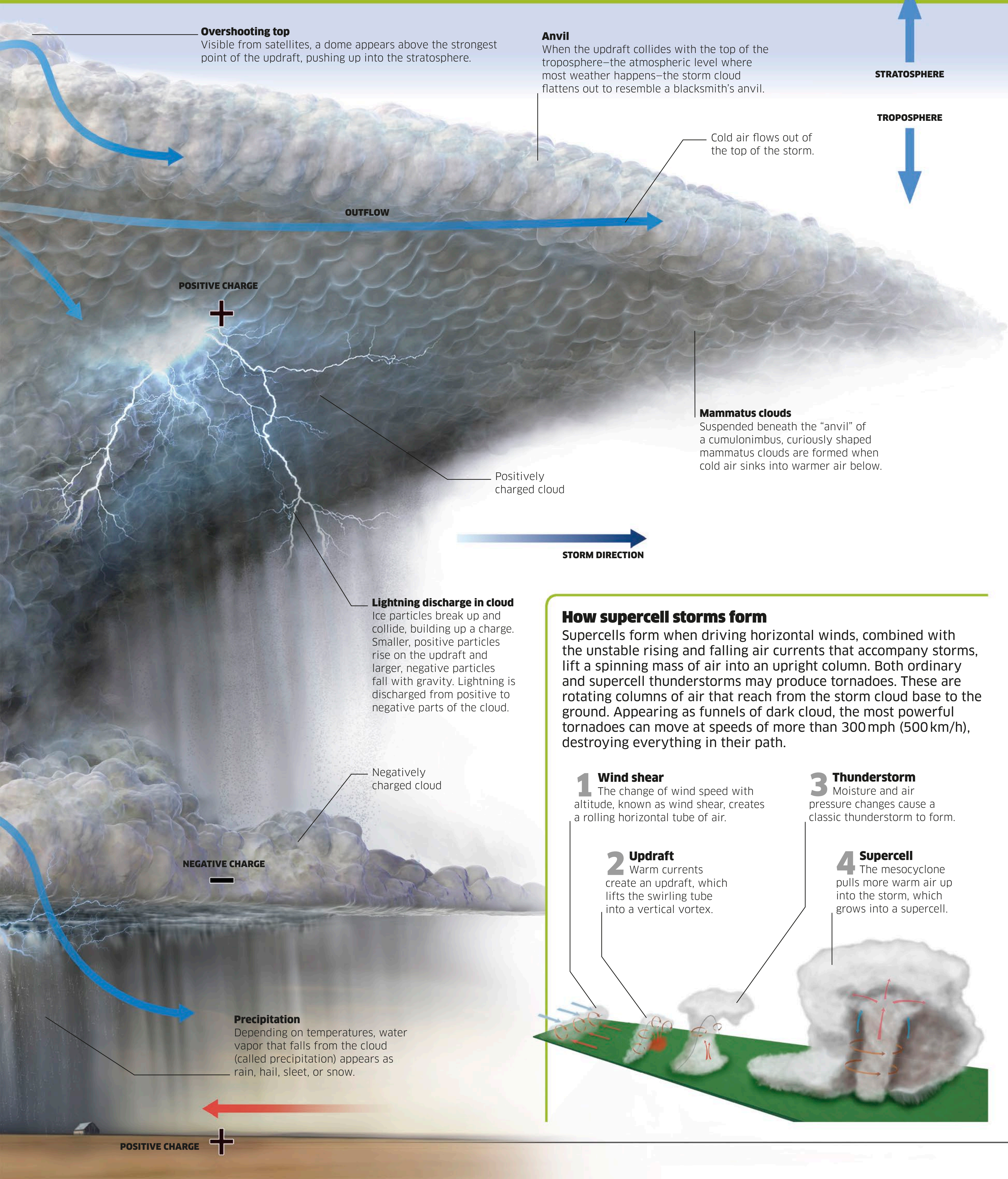
Dense, dark clouds gathering overhead mean stormy weather is on the way. Thunderstorms have terrifying power but also an awesome beauty.

Our weather is created by changes in the atmosphere. When air turns cold, it sinks, becoming compressed under its own weight and causing high pressure at Earth's surface. As the air molecules squeeze together, they heat up. The warm air rises, surface pressure drops, and fair weather may follow. But when rapidly rising warm air meets descending cold air, the atmosphere becomes unsettled. Water vapor in the air turns into clouds, the clouds collide, and electric energy builds up. The electricity is released in lightning bolts that strike Earth's surface with cracks of thunder, often accompanied by heavy rainfall.

Supercell storms

One of the most dangerous weather conditions is the supercell storm, when a huge mass of cloud develops a rotating updraft of air, called a mesocyclone, at its center. The cloud cover may stretch from horizon to horizon. Above this, unseen from the ground, a cloud formation known as cumulonimbus towers like a monstrous, flat-topped mushroom into the upper atmosphere. A supercell storm system can rage for many hours, producing destructive winds, torrential rain, and giant hailstones.





How supercell storms form

Supercells form when driving horizontal winds, combined with the unstable rising and falling air currents that accompany storms, lift a spinning mass of air into an upright column. Both ordinary and supercell thunderstorms may produce tornadoes. These are rotating columns of air that reach from the storm cloud base to the ground. Appearing as funnels of dark cloud, the most powerful tornadoes can move at speeds of more than 300 mph (500 km/h), destroying everything in their path.

1 Wind shear The change of wind speed with altitude, known as wind shear, creates a rolling horizontal tube of air.

2 Updraft Warm currents create an updraft, which lifts the swirling tube into a vertical vortex.

3 Thunderstorm Moisture and air pressure changes cause a classic thunderstorm to form.

4 Supercell The mesocyclone pulls more warm air up into the storm, which grows into a supercell.

6 in (15 cm)—the amount **sea levels** have **risen** over the **last century**.

Climate change

For the last half century, Earth's climate has been getting steadily warmer. The world's climate has always varied naturally, but the evidence suggests that this warming is caused by human activity—and it could have a huge impact on our lives.

Humans make the world warmer mainly by burning fossil fuels such as coal and oil, which fill the air with carbon dioxide that traps the sun's heat. This is often referred to as global warming, but scientists prefer to talk about climate change because the unpredictable effects include fueling extreme weather. In future, we can expect more powerful storms and flooding as well as hotter summers and droughts.

Greenhouse effect

The cause of global warning is the greenhouse effect. In the atmosphere, certain gases—known as greenhouse gases—absorb heat radiation that would otherwise escape into space. This causes our planet to be warmer than it would be if it had no atmosphere. The main greenhouses gases are carbon dioxide, methane, nitrous oxide, and water vapor.

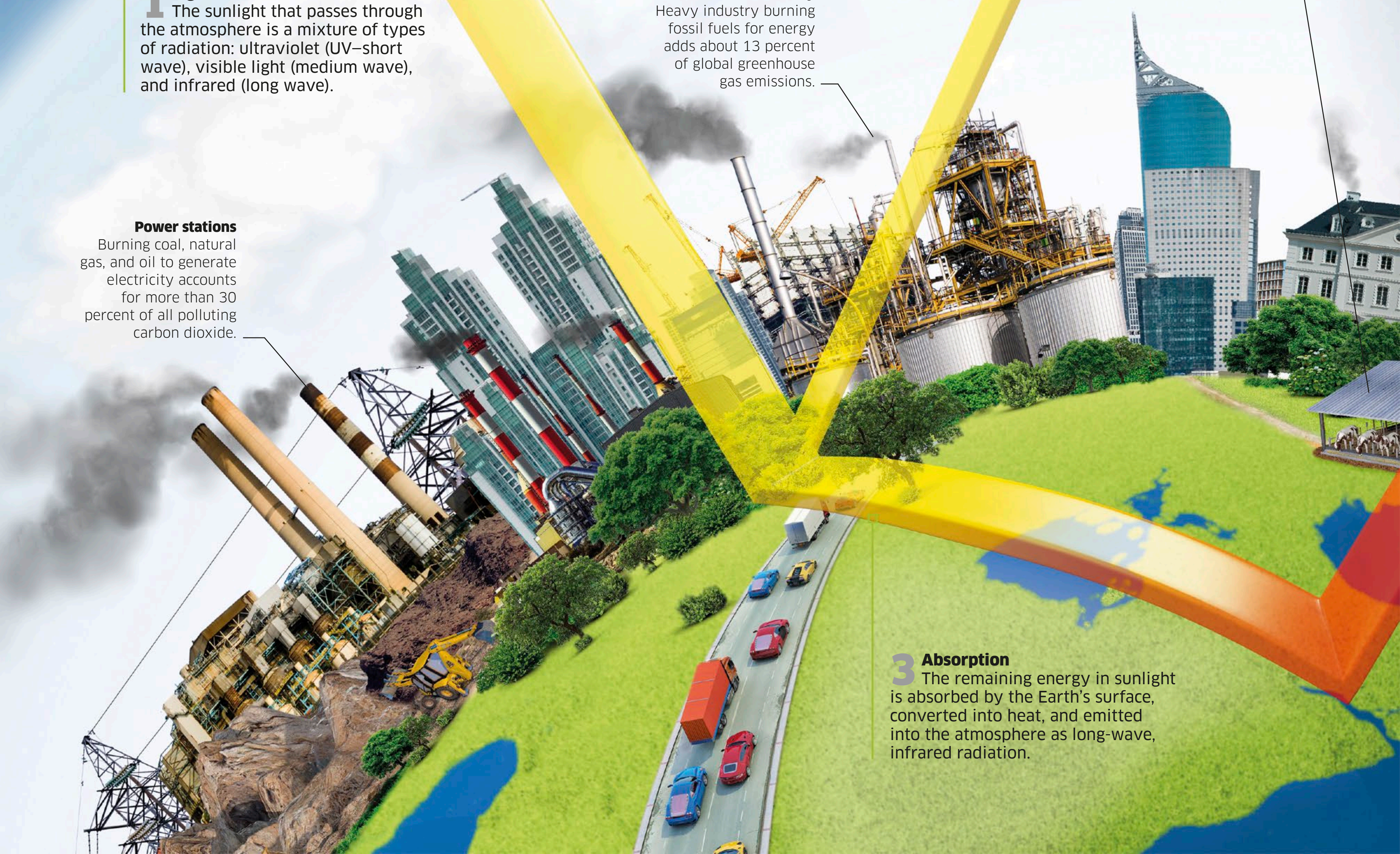
2 Reflection
Almost a third of the energy in sunlight is reflected back into space as UV and visible light.

Transportation
Gasoline- and diesel-guzzling trucks and cars, as well as fuel-burning airplanes, produce around 15 percent of greenhouse gases.

Farming and deforestation
Intensively farmed cows, sheep, and goats release huge amounts of methane, a greenhouse gas. Forests absorb carbon dioxide, so deforestation leaves more carbon dioxide in the atmosphere.

1 Light from the sun
The sunlight that passes through the atmosphere is a mixture of types of radiation: ultraviolet (UV—short wave), visible light (medium wave), and infrared (long wave).

Industry
Heavy industry burning fossil fuels for energy adds about 13 percent of global greenhouse gas emissions.



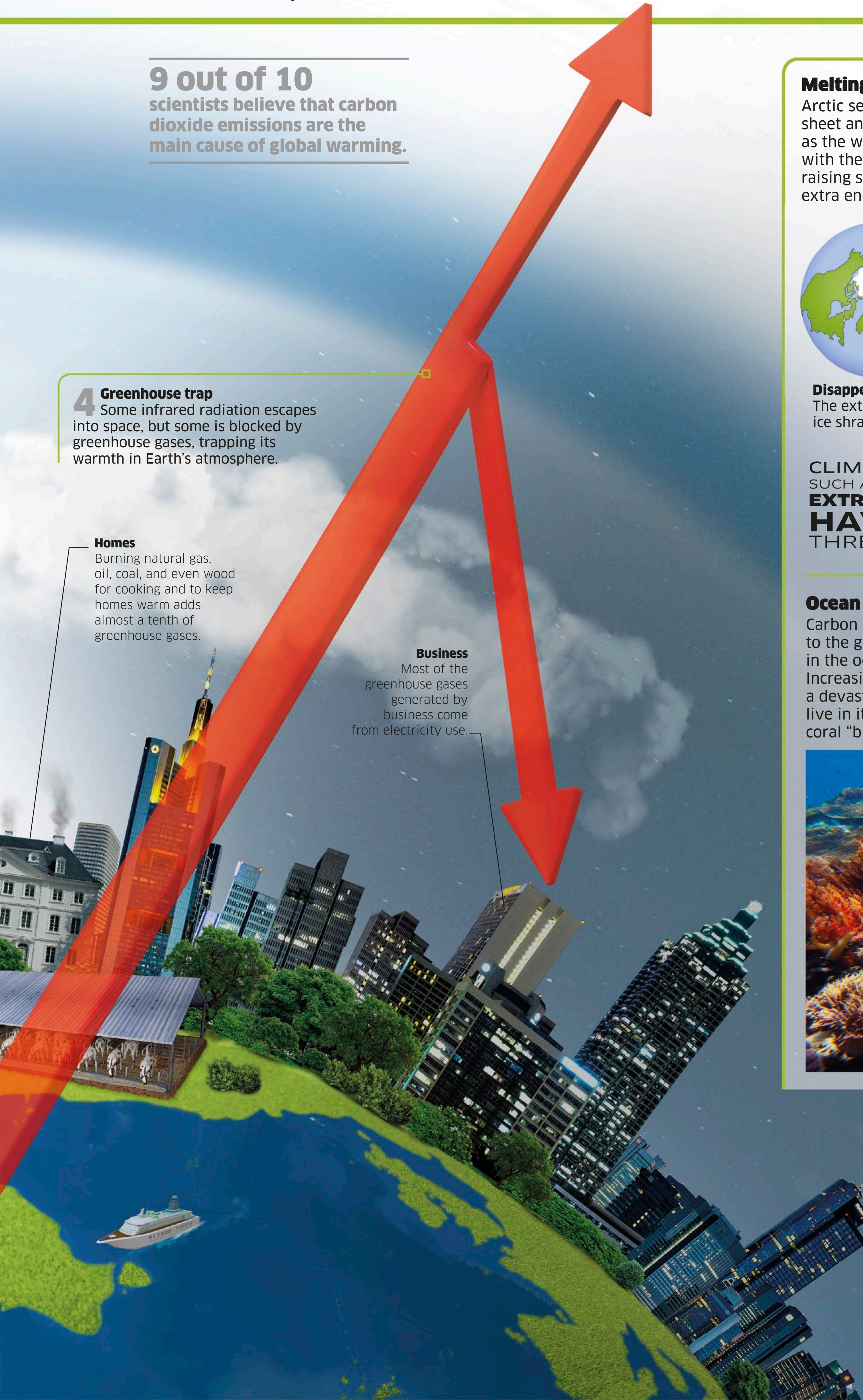
Power stations
Burning coal, natural gas, and oil to generate electricity accounts for more than 30 percent of all polluting carbon dioxide.

3 Absorption
The remaining energy in sunlight is absorbed by the Earth's surface, converted into heat, and emitted into the atmosphere as long-wave, infrared radiation.

26 ft (8 m)—the amount **sea levels** would **rise** if the **polar ice sheets melted**.

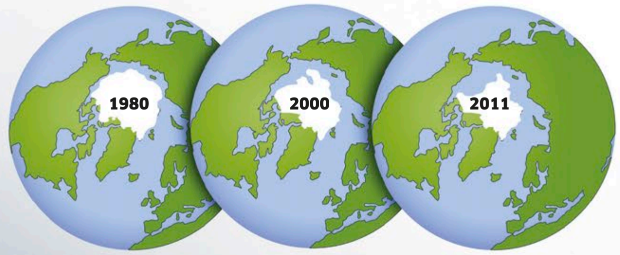
50 percent—the **increase** in the amount of **carbon dioxide** in the air **since 1980**.

9 out of 10
scientists believe that carbon dioxide emissions are the main cause of global warming.



Melting ice caps

Arctic sea ice is melting and the Antarctic ice sheet and mountain glaciers are shrinking fast as the world warms. Melting land ice combined with the expansion of seawater as it warms are raising sea levels. Sea warmth is also adding extra energy into the air, driving storms.

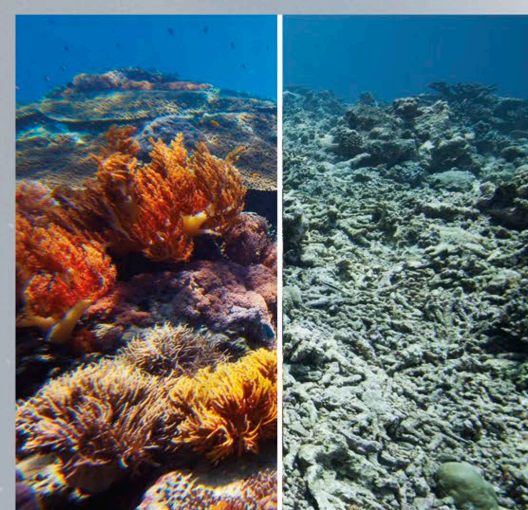


Disappearing ice
The extent of Arctic and Antarctic sea ice shrank to record lows in 2017.

CLIMATE-RELATED DISASTERS SUCH AS FLOODS, STORMS, AND OTHER **EXTREME WEATHER EVENTS HAVE INCREASED** THREE TIMES SINCE 1980.

Ocean acidification

Carbon dioxide emissions not only contribute to the greenhouse effect. The gas dissolves in the oceans, making them more acidic. Increasing the acidity of seawater can have a devastating effect on fragile creatures that live in it. It has already caused widespread coral "bleaching," and reefs are dwindling.



LIFE

There is nothing more complex in the entire universe than living things. Life comes in an extraordinarily diverse range of forms—from microscopic bacteria to giant plants and animals. Each organism has specialized ways of keeping its body working, and of interacting with its environment.

1736 The year **Carl Linnaeus**, the “father of classification,” **first used the word “biology.”**

Discovering life

Ever since people first began to observe the natural world around them, they have been making discoveries about life and living things.

Biology—the scientific study of life—emerged in the ancient world when philosophers studied the diversity of life’s creatures, and medical experts of the day dissected bodies to see how they worked. Hundreds of years later, the invention of the microscope opened up the world of cells and microbes, and allowed scientists to understand the workings of life at the most basic level. At the same time, new insights helped biologists answer some of the biggest questions of all: the cause of disease, and how life reproduces.

Timeline of discoveries

More than 2,000 years of study and experiment has brought biology into the modern age. While ancient thinkers began by observing the plants and animals around them, scientists today can alter the very structure of life itself.

BEFORE 1600

Antiquity to 16th century
Ancient civilizations in Europe and Asia were the birthplace of science. Here the biologists of the day described the anatomy (structure) of animals and plants and used their knowledge to invent ways to treat illness.

Describing fossils
Many ancient peoples discover fossils. In 500 BCE, Xenophanes, a Greek philosopher, proposes that they are the remains of animals from ancient seas that once covered the land.

LEECHES

Healing theories
Early medical doctors believe that illness is caused by an imbalance of bodily fluids, called humors, that can be treated with blood-sucking leeches.

Early anatomy
Human anatomy is scrutinized in detail by cutting open dead bodies. Dissections are even public spectacles—the first public one is carried out in 1315.

19TH CENTURY

19th century
The next hundred years saw some of the most important discoveries in biology. Some helped medicine become safer and more effective. Others explained the inheritance of characteristics and the evolution of life.

1800s

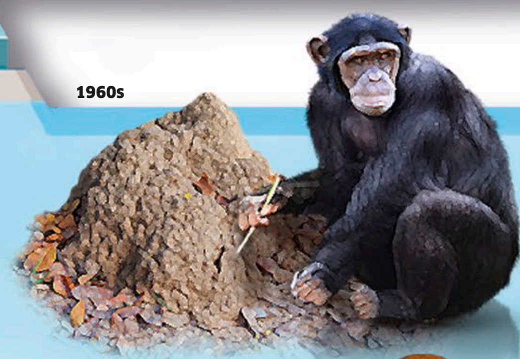
Anesthetics and antiseptics
The biggest steps in surgery happen in the 1800s: anesthetics are used to numb pain, while British surgeon Joseph Lister uses antiseptics to reduce infection.

1856–1865

Inheritance
An Austrian-born monk called Gregor Mendel, carries out breeding experiments with pea plants that help to explain the inheritance of characteristics.

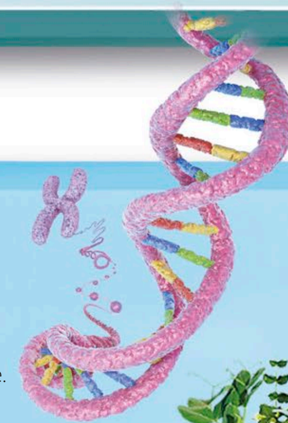
1900–1970

1960s



Animal behavior
More biologists begin studying the behavior of wild animals. In the 1960s, British biologist Jane Goodall discovers that chimpanzees use tools.

1953



The structure of DNA
American and British scientists James Watson and Francis Crick identify that DNA (the genetic code of life packed into cells) has a double helix shape.

MODERN TIMES

Modern times
In the most recent biological developments, things that were thought to be impossible just a hundred years ago became routine. Faulty body parts could be replaced with artificial replicas and even genes could be changed to switch characteristics.

1977

New worlds
American scientists discover deep-sea animals supported by the chemical energy of volcanic vents—the only life not dependent on the sun and photosynthesis.

1978–1996

New life
The first human “test tube” baby—made with cells fertilized outside the human body—is born in 1978. Then, in 1996, Dolly the sheep becomes the first mammal to be artificially cloned from body cells.

DOLLY THE SHEEP

The Greek philosopher Aristotle produced the first classification of animals and separated vertebrates from invertebrates.

In 2001, scientists published the results of the Human Genome Project: a catalog of all human genes.

1970–PRESENT

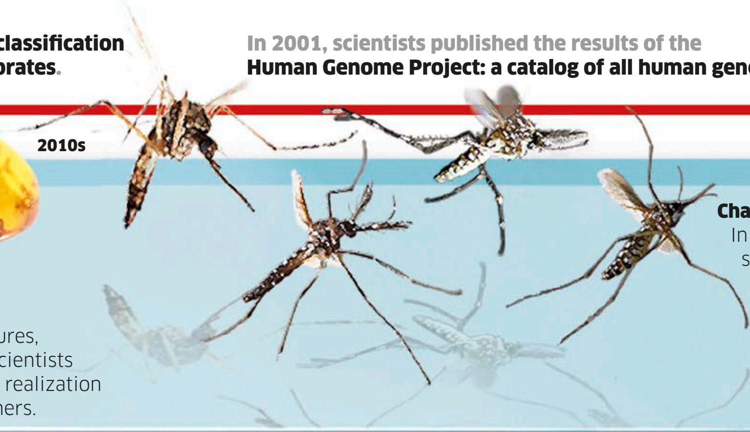
2015

Artificial parts
False limbs had been used since antiquity, but the 20th century brings more sophisticated artificial body parts. The first bionic eye is implanted in 2015.

2010s

Fossil evidence
More discoveries of ancient creatures, often preserved in amber, lead scientists to new conclusions, such as the realization that many dinosaurs had feathers.

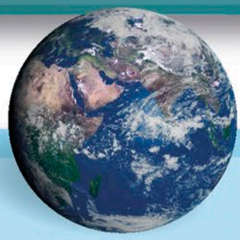
2017



Changing genes
In the late 20th century scientists become able to edit the genes of living things. In 2017, some mosquitoes are genetically altered to try and stop the spread of the disease malaria.

20TH CENTURY

1930s



The rise of ecology
The study of ecology (how organisms interact with their surroundings) emerges in the 1930s, as British botanist Arthur Tansley introduces the idea of ecosystems.

1928

Antibiotics discovered
British biologist Alexander Fleming discovers that a substance—penicillin, the first known antibiotic—stops the growth of microbes. Antibiotics are now used to treat many bacterial infections.

1900s

Chromosomes and genes
American scientist Thomas Hunt Morgan carries out experiments on fruit flies, which prove that the units of inheritance are carried as genes on chromosomes.

Early 20th century
Better microscopes and advances in studying the chemical makeup of cells helped to show how all life carries a set of building instructions—in the form of chromosomes and DNA—while ecology and behavior became new topics of focus.

1800–1900

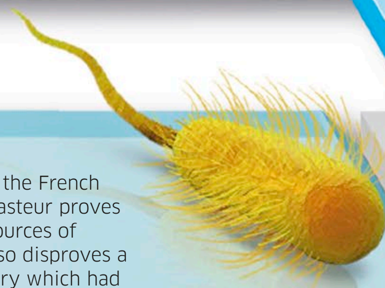
1859

Evolution
British biologist Charles Darwin publishes a book—*On the Origin of Species*—explaining how life on Earth has evolved by natural selection.

CHARLES DARWIN

1860s

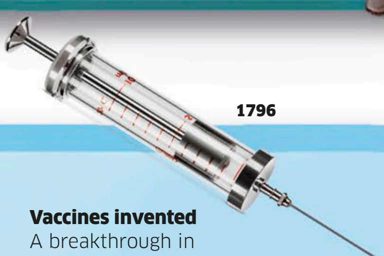
Microbes
An experiment by the French biologist Louis Pasteur proves microbes are sources of infection. It also disproves a popular theory which had argued that living organisms could be spontaneously generated from nonliving matter.



MICROBE

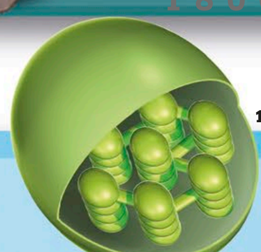
1600–1800

1796



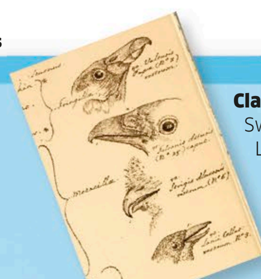
Vaccines invented
A breakthrough in medicine, the first vaccine is used by British doctor Edward Jenner to protect against a deadly disease—smallpox.

1770s



Photosynthesis discovered
In the 1770s, the experiments of a Dutch biologist, Jan Ingenhousz, show that plants need light, water, and carbon dioxide to make sugar.

1735



Classifying life
Swedish botanist Carl Linnaeus devises a way of classifying and naming plants and animals that is still used today.

1665

VAN LEEUWENHOEK'S MICROSCOPE

Microscopic life
British scientist Robert Hooke views cells down a microscope and inspires a Dutchman, Antony van Leeuwenhoek, to invent his own unique version of a microscope.

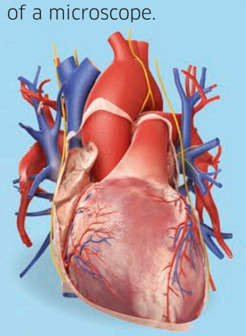
17TH CENTURY

Cataloging life
The ancient Greeks are the first to try classifying life, but it is not until the 16th century that species are first cataloged in large volumes.

17th–18th centuries
New scientific experiments added to the wealth of knowledge laid down by the first philosophers. This research helped to answer important questions about life's vital processes, such as blood circulation in animals and photosynthesis in plants.

1628

Blood circulation
A British doctor called William Harvey combines observation with experiment to show how the heart pumps blood around the body.

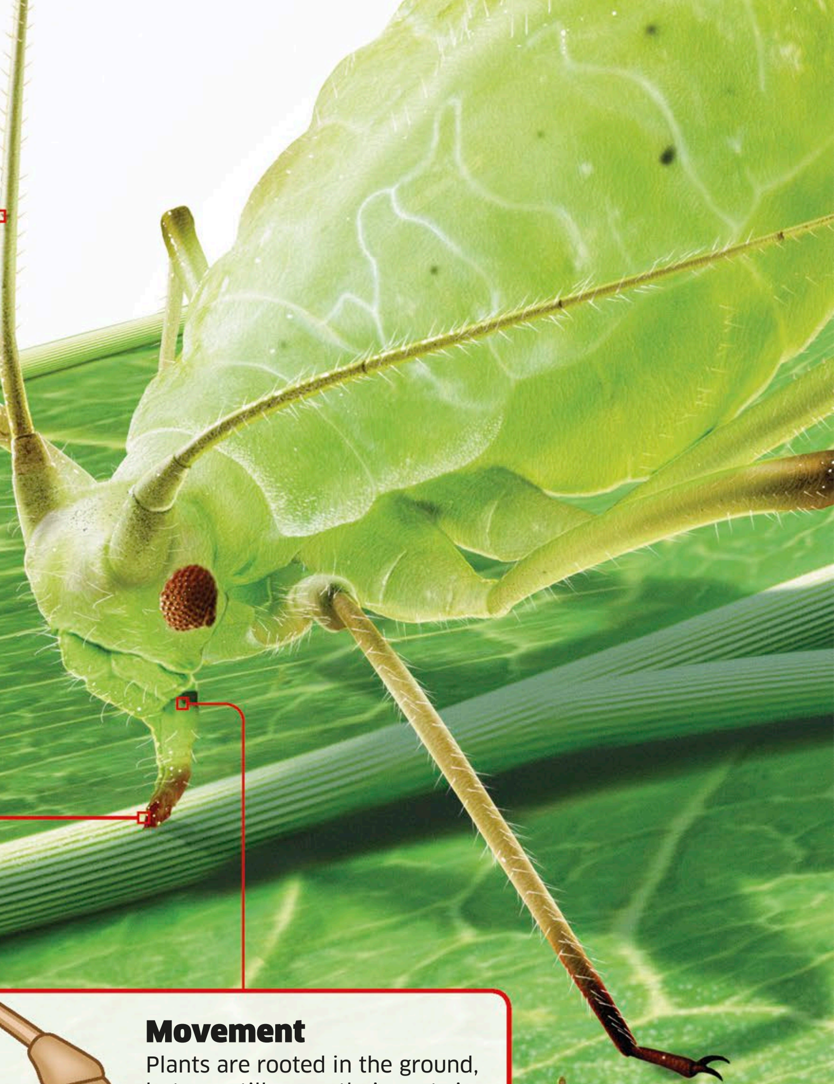


WHAT IS LIFE?

Life can be defined as a combination of seven main actions—known as the characteristics of life—that set living things apart from nonliving things. However big or small, every organism must process food, release energy, and excrete its waste. All will also, to some degree, gather information from their surroundings, move, grow, and reproduce.

Life on a leaf

The characteristics of life can all be seen in action on a thumbnail-sized patch of leaf. Tiny insects, called aphids, suck on the leaf's sap and give birth to the next generation, while leaf cells beneath the aphids' feet generate the sap's sugar.



Sensitivity

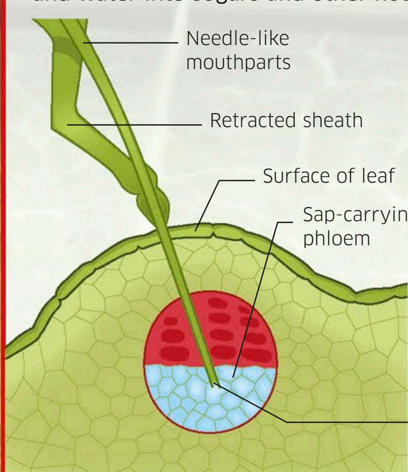
Sense organs detect changes in an organism's surroundings, such as differences in light or temperature. Each kind of change—called a stimulus—is picked up by them. With this information, the body can coordinate a suitable response.

Segments near the end of the aphid's antenna contain sense organs.

Antenna
Aphid antennae carry different kinds of sensors, including some that detect odors indicating a leaf is edible.

Nutrition

Food is either consumed or made. Animals, fungi, and many single-celled organisms take food into their body from their surroundings. Plants and algae make food inside their cells, by using light energy from the sun to convert carbon dioxide and water into sugars and other nutrients.



Proboscis
Like most other animals, aphids pass food through a digestive system, from which nutrients move into the body's cells. Aphids can only drink liquid sap. They use a sharp proboscis that works like a needle to puncture a leaf vein to get sap.

Movement

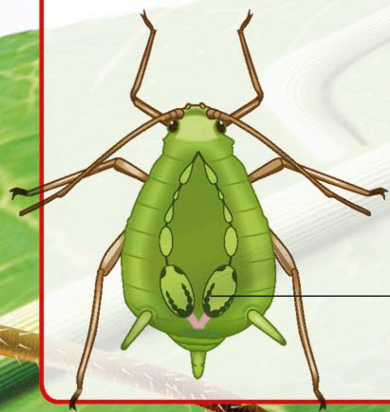
Plants are rooted in the ground, but can still move their parts in response to their surroundings—for instance, to move toward a light source. Animals can move their body parts much faster by using muscles, which can even carry their entire body from place to place.

Head muscles
Muscles are found all over an aphid's body. As the aphid eats, muscles in its head contract (shorten) to pull and widen its feeding tube. This allows it to consume the sap more effectively.

Birth
A female aphid gives birth to live young.

Reproduction

By producing offspring, organisms ensure that their populations survive, as new babies replace the individuals that die. Breeding for most kinds of organisms involves two parents reproducing sexually by producing sex cells. But some organisms can breed asexually from just one parent.

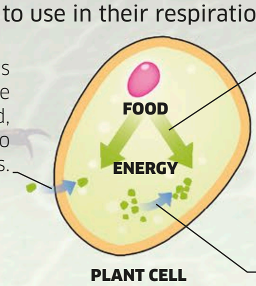


Babies in babies
Some female aphids carry out a form of asexual reproduction where babies develop from unfertilized eggs inside the mother's body. A further generation of babies can develop inside the unborn aphids.

The daughters that are old enough to be born already contain the aphid's granddaughters.

Respiration

Organisms need energy to power their vital functions, such as growth and movement. A chemical process happens inside their cells to release energy, called respiration. It breaks down certain kinds of foods, such as sugar. Most organisms take in oxygen from the environment to use in their respiration.



Some energy is used to move materials around, including into and out of cells.

Energy is released from food.

Some energy is used to build materials inside the cell to help the body grow.

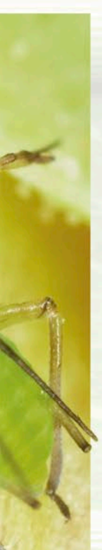
Excretion

Hundreds of chemical reactions happen inside living cells, and many of these reactions produce waste substances that would cause harm if they built up. Excretion is the way an organism gets rid of this waste. Animals have excretory organs, such as kidneys, to remove waste, but plants use their leaves for excretion.

Excretion by leaf
Plant leaves have pores, called stomata, for releasing waste gases, such as oxygen and carbon dioxide.

Growth

All organisms get bigger as they get older and grow. Single cells grow very slightly and stay microscopic, but many organisms, such as animals and plants, have bodies made up of many interacting cells. As they grow, these cells divide to produce more cells, making the body bigger.

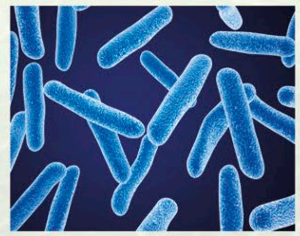


Molting
The body of an aphid is covered in a tough outer skin called an exoskeleton. In order to grow, an aphid must periodically shed this skin so its body can get bigger. Its new skin is initially soft and flexible, but soon toughens.

SEVEN KINGDOMS OF LIFE

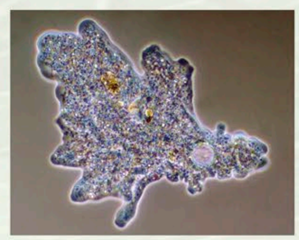
Living things are classified into seven main groups called kingdoms. Each kingdom contains a set of organisms that have evolved to perform the characteristics of life in their own way.

Archaea
Looking similar to bacteria, many of these single-celled organisms survive in very extreme environments, such as hot, acidic pools.



Bacteria
The most abundant organisms on Earth, bacteria are usually single-celled. They either consume food, like animals do, or make it, like plants do.

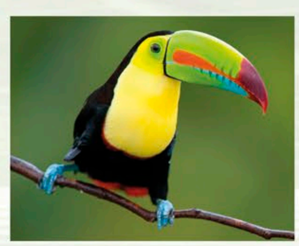
Algae
Simple relatives of plants, algae make food by photosynthesis. Some are single-celled, but others, such as seaweeds and this *Pandorina*, are multicelled.



Protozoa
These single-celled organisms are bigger than bacteria. Many of them behave like miniature animals, by eating other microscopic organisms.

Plants
Most plants are anchored to the ground by roots and have leafy shoots to make food by photosynthesis.

Fungi
This kingdom includes toadstools, mushrooms, and yeasts. They absorb food from their surroundings, often by breaking down dead matter.

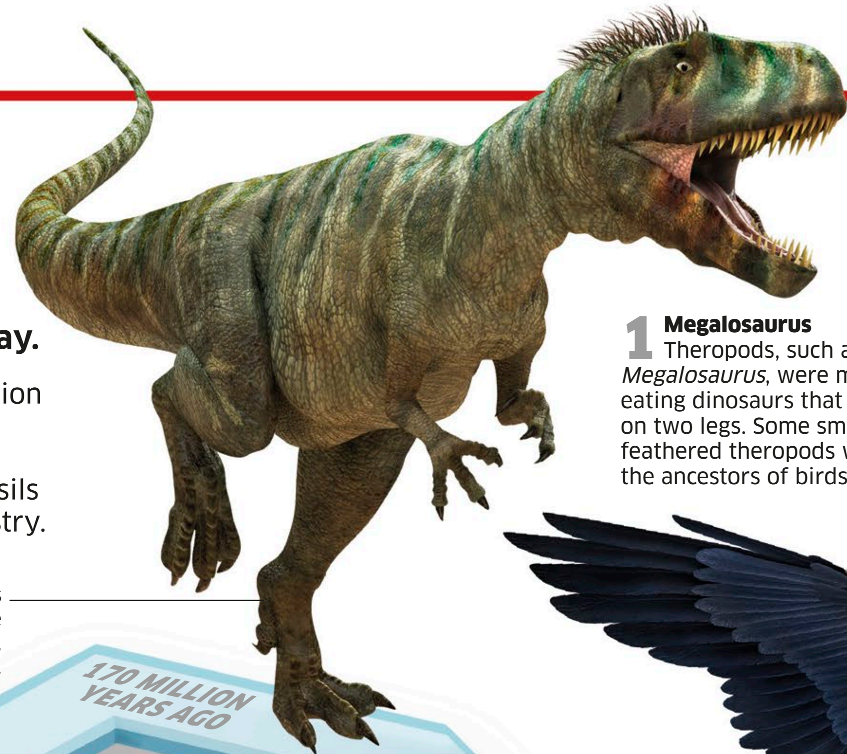


Animals
From microscopic worms to giant whales, all animals have bodies made up of large numbers of cells and feed by eating or absorbing food.

The fossil record

Fossils from prehistoric times show just how much life has changed across the ages, and how ancient creatures are related to the organisms on Earth today.

Life has been evolving on our planet for more than four billion years—ever since it was just a world of simple microbes. Across this vast expanse of time, more complex animals and plants developed. Traces of their remains—found as fossils in prehistoric rocks—have helped us to work out their ancestry.



1 Megalosaurus
Theropods, such as *Megalosaurus*, were meat-eating dinosaurs that walked on two legs. Some smaller, feathered theropods were the ancestors of birds.

Like most birds, theropods had feet with three forward-pointing toes, and hollow bones.


EARLIER DINOSAUR ANCESTORS

170 MILLION YEARS AGO

150 MILLION YEARS AGO

The origins of birds

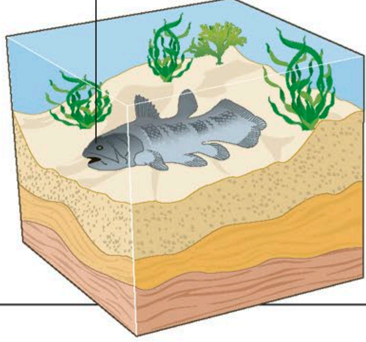
Fossilized skeletons show us that the first prehistoric birds were remarkably similar to a group of upright-walking dinosaurs. From these fossils, it is possible to see how their forelimbs evolved into wings for flight, and how they developed the other characteristics of modern birds.

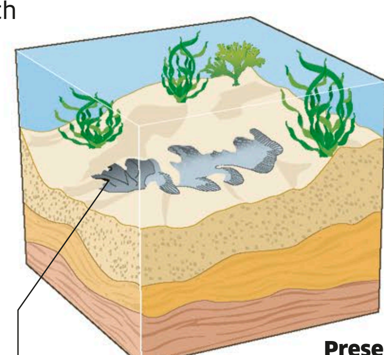
Archaeopteryx fossil
This fossil of *Archaeopteryx* has been preserved in soft limestone. Around the animal's wing bones, the imprints left by the feathers are clearly visible.

How fossils form

Fossils are the remains or impressions of organisms that died more than 10,000 years ago. Some fossils have recorded what is left of entire bodies, but usually only fragments, such as parts of a bony skeleton, have survived.

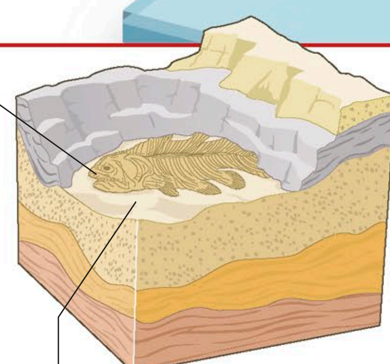
1 Death
Bodies that settled under water or in floodplains could be quickly buried beneath sand and silt.





2 Burial
Layers of sediment cover the body and build up into rock on top of it.

Skeletons and other hard parts are more likely to leave an impression than soft tissues.



3 Reveal
Millions of years later, movements of Earth's crust cause rocks to move upward, exposing the fossil on dry land.

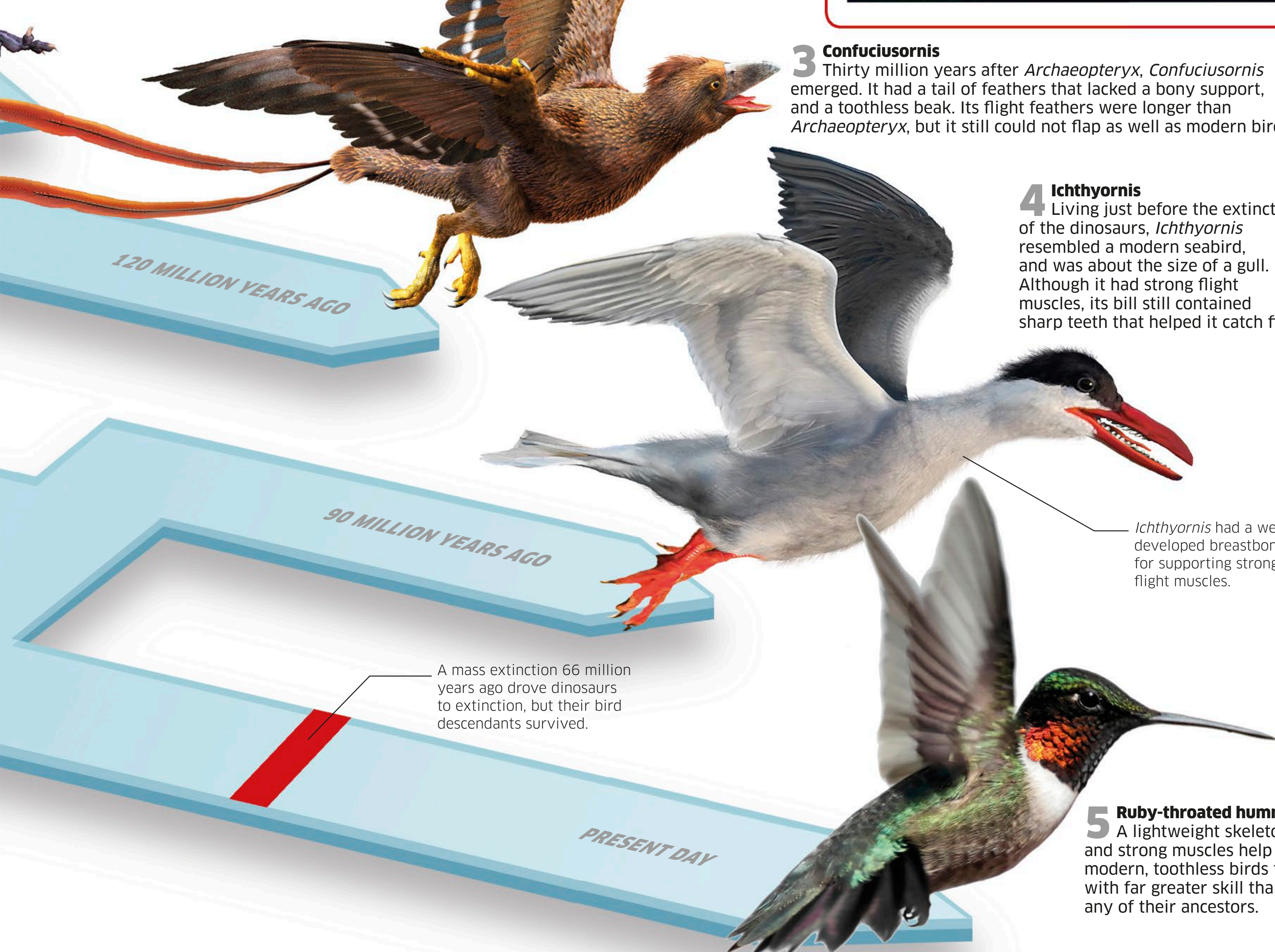
Preserved in time
When organisms in the prehistoric world died, their bodies were more likely to be preserved if they were quickly buried. Rotting under layers of sediment, the body slowly turned into mineral, until the resulting fossil was exposed by erosion.

Over millions of years, groups of organisms split up as they evolve and become adapted to new environments or situations.

Confuciusornis fossil
Lots of preserved *Confuciusornis* specimens have long tail streamers. These are now thought to be exclusive to males and to have been used in displays to attract a mate during breeding season.

Mass extinction

Life in the prehistoric past was occasionally rocked by catastrophic events that wiped out entire groups of organisms. Five mass extinction events have occurred in the last 500 million years. Many may have been caused by climate change and volcanic eruptions, but there is also strong evidence that the event that eliminated the dinosaurs was caused by an asteroid striking the Earth.



Claws on the bird's thumb and third finger may have helped it climb through trees.

2 Archaeopteryx
Thought to be the first true bird, *Archaeopteryx* had feathered wings, but retained dinosaur characteristics, such as clawed forelimbs, a toothed beak, and a bony tail. Its small wing muscles suggest it may not have been able to fly well.

3 Confuciusornis
Thirty million years after *Archaeopteryx*, *Confuciusornis* emerged. It had a tail of feathers that lacked a bony support, and a toothless beak. Its flight feathers were longer than *Archaeopteryx*, but it still could not flap as well as modern birds.

4 Ichthyornis
Living just before the extinction of the dinosaurs, *Ichthyornis* resembled a modern seabird, and was about the size of a gull. Although it had strong flight muscles, its bill still contained sharp teeth that helped it catch fish.

Ichthyornis had a well-developed breastbone for supporting strong flight muscles.

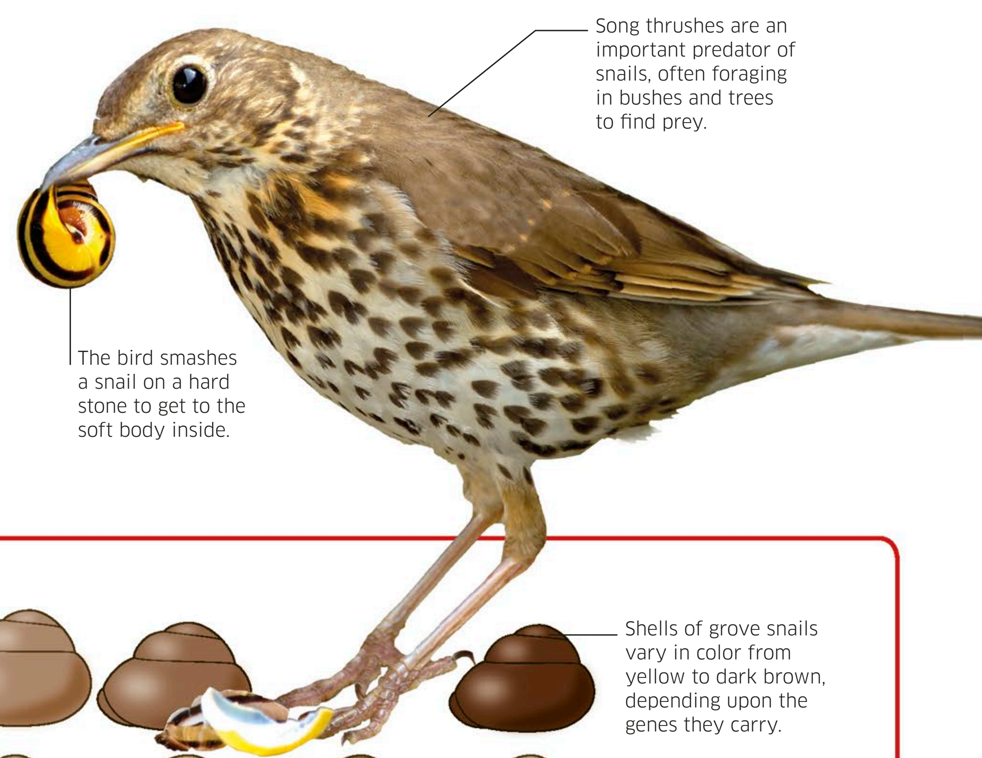
A mass extinction 66 million years ago drove dinosaurs to extinction, but their bird descendants survived.

5 Ruby-throated hummingbird
A lightweight skeleton and strong muscles help most modern, toothless birds fly with far greater skill than any of their ancestors.

Evolution

All living things are related and united by a process called evolution. Over millions of years, evolution has produced all the species that have ever lived.

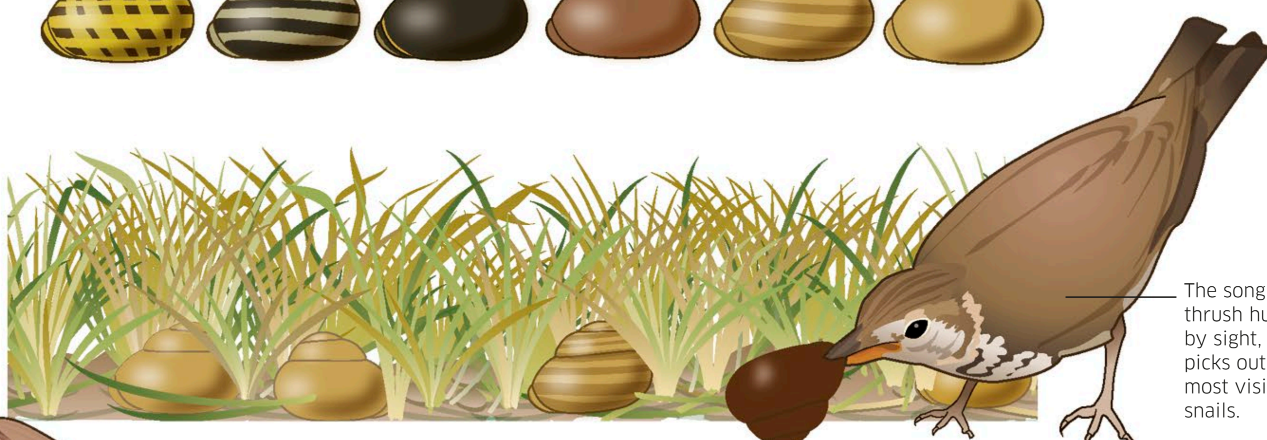
Change is a fact of life. Every organism goes through a transformation as it develops and gets older. But over much longer periods of time—millions or billions of years—entire populations of plants, animals, and microbes also change by evolving. All the kinds of organisms alive today have descended from different ones that lived in the past, as tiny variations throughout history have combined to produce entirely new species.



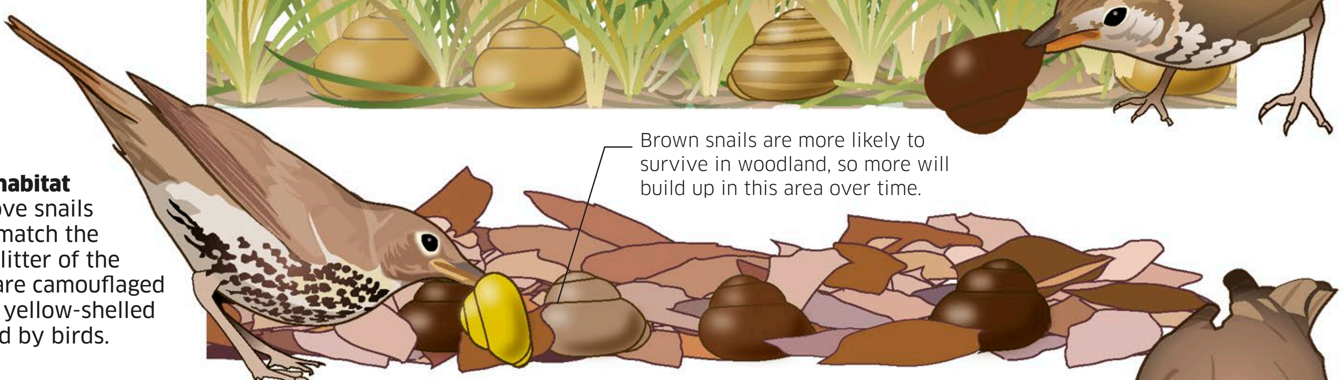
Natural selection

The characteristics of living things are determined by genes (see pp.180–181), which sometimes change as they are passed down through generations—producing mutations. All the variety in the natural world—such as the colors of snail shells—comes from chance mutations, but not all of the resulting organisms do well in their environments. Only some survive to pass their attributes on to future generations—winning the struggle of natural selection.

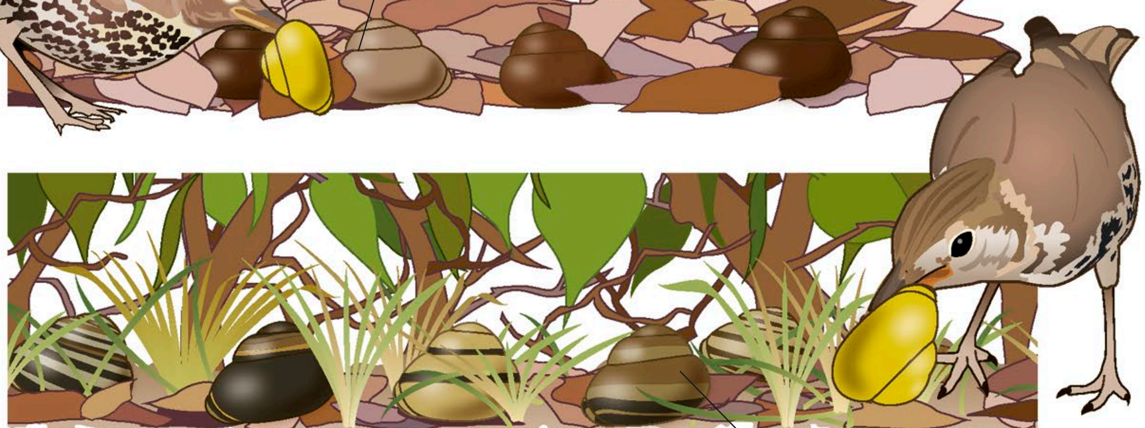
Dry grassy habitat
Against a background of dry grass, snails with darker shells are most easily spotted, causing the paler ones to survive in greater numbers.



Dark woodland habitat
In woodland, grove snails with shells that match the dark brown leaf litter of the woodland floor are camouflaged and survive, but yellow-shelled snails are spotted by birds.

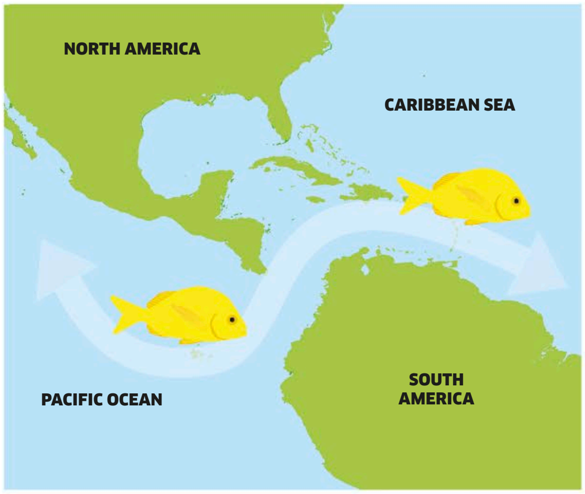


Hedge habitat
In some sun-dappled habitats with a mixture of grass, twigs, and leaves, stripy-shelled grove snails are better disguised, and plain brown or yellow ones become prey.

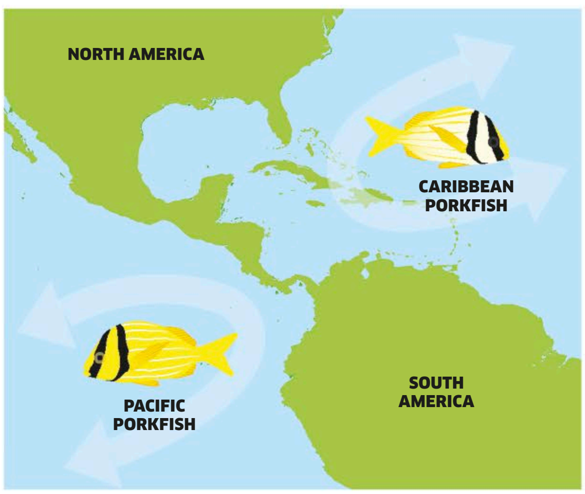


How new species emerge

Over a long period of evolution, varieties of animals can end up becoming so different that they turn into entirely new species—a process called speciation. This usually happens when groups evolve differences that stop them from breeding outside their group, especially when their surroundings change so dramatically that they become physically separated from others.



1 Ancestral species Five million years ago, before North and South America were joined, a broad sea channel swept between the Pacific Ocean in the west and the Caribbean in the east. Marine animals, such as the reef-dwelling porkfish, could easily mix with one another in the open waters. Porkfish from western and eastern populations had similar characteristics and all of them could breed together, so they all belonged to the same species.

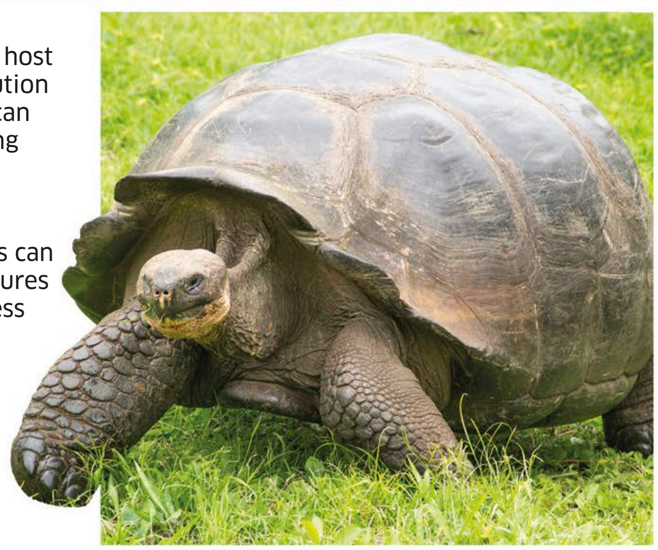


2 Modern species The shifting of Earth's crust caused North and South America to collide nearly 3 million years ago. This cut off the sea channel, isolating populations of porkfish on either side of Central America. Since then, the two populations have evolved so differently that they can no longer breed with each other. Although they still share a common ancestor, today the whiter Caribbean porkfish and the yellower Pacific porkfish are different species.

Evolution on islands

Isolated islands often play host to the most dramatic evolution of all. Animals and plants can only reach them by crossing vast expanses of water, and—once there—evolve quickly in the new and separate environment. This can lead to some unusual creatures developing—such as flightless birds and giant tortoises.

Out of all the reptiles and land mammals of the Galápagos Islands, 97 percent are found nowhere else in the world.

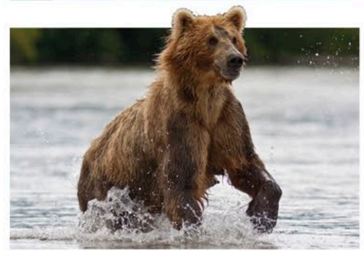


Tortoise travels
The famous giant tortoises unique to the Galápagos Islands are descended from smaller tortoises that floated there from nearby South America.

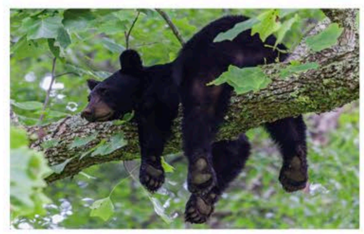
Adaptation

Living things that survive the grueling process of natural selection are left with characteristics that make them best suited to their surroundings. This can be seen in groups of closely related species that live in very different habitats—such as these seven species of bears.

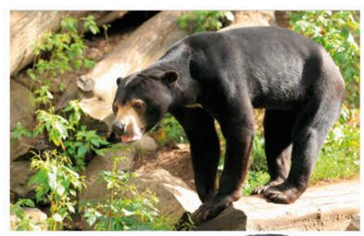
Polar bear
The biggest, most carnivorous species of bear is adapted to the icy Arctic habitat. It lives on fat-rich seal meat and is protected from the bitter cold by a thick fur coat.



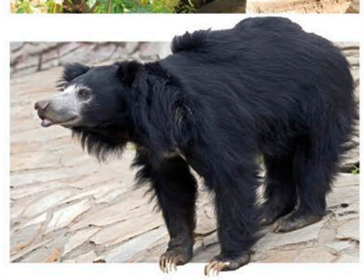
Brown bear
The closest relative of the polar bear lives further south in cool forests and grassland. As well as preying on animals, it supplements its diet with berries and shoots.



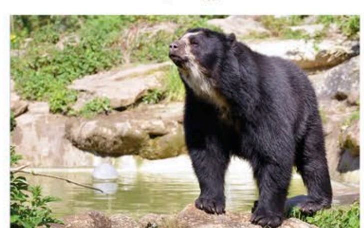
Black bear
The North American black bear is the most omnivorous species of bear, eating equal amounts of animal and plant matter. This smaller, nimbler bear can climb trees to get food.



Sun bear
The smallest bear lives in tropical Asia and has a thin coat of fur to prevent it from overheating. It has a very sweet tooth and extracts honey from bee hives with its long tongue.



Sloth bear
This shaggy-coated bear from India is adapted to eat insects. It has poorly developed teeth and, instead, relies on long claws and a long lower lip to obtain and eat its prey.



Spectacled bear
The only bear in South America has a short muzzle and teeth adapted for grinding tough plants. It feeds mainly on leaves, tree bark, and fruit, only occasionally eating meat.

Giant panda
The strangest bear of all comes from the cool mountain forests of China. It is almost entirely vegetarian, with paws designed for grasping tough bamboo shoots.

200 million **lives have been saved by penicillin—the drug produced by the *Penicillium* fungus.**

Miniature life

Some organisms are so tiny that thousands of them can live out their lives in a single drop of water.

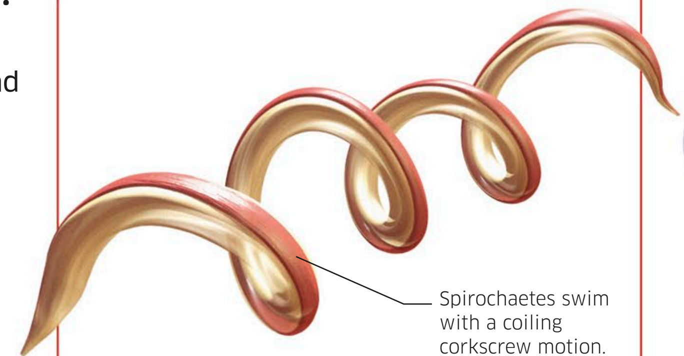
The minuscule home of the microbe, or microorganism, is a place where sand grains are like giant boulders and the slightest breeze feels like a hurricane. These living things can only be seen through a microscope, but manage to find everything they need to thrive in soil, oceans, or even deep inside the bodies of bigger animals.

SPIROCHAETE

Kingdom: Bacteria


1/100 mm

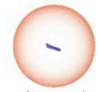
Any place good for life can be home to bacteria—the most abundant kinds of microorganisms on the planet. They are vital for recycling nutrients, although some—such as the corkscrew-shaped spirochaetes—are parasites that cause disease in humans and other animals.



Spirochaetes swim with a coiling corkscrew motion.

THERMOPLASMA

Kingdom: Archaea


1/1,000 mm

These microbes look like bacteria, but are a distinct life form. Many, like the *Thermoplasma volcanium*, live in the most hostile habitats imaginable, such as hot pools of concentrated acid.

Like bacteria, archaea have no cell nucleus and are protected by a tough cell wall.

GIARDIA

Kingdom: Protozoa


1/100 mm

Animal-like microbes that are single-celled are called protozoans. Some, such as amoebas, use extensions of cytoplasm (cell material) to creep along. Others, such as giardia, swim, and absorb their food by living in the intestines of animals.

PENICILLIUM

Kingdom: Fungi


1/10 mm

The microscopic filaments of fungi smother dead material, such as leaf litter, so their digestive juices can break it down. When their food runs out, they scatter dustlike spores, which grow into new fungi.

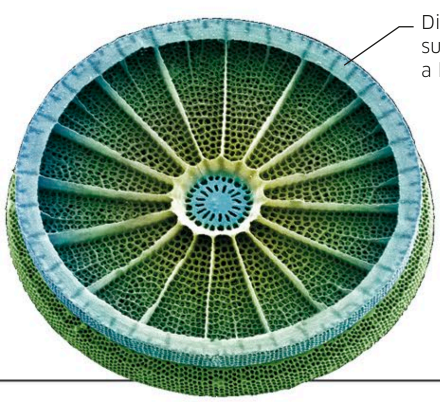
Single-celled spherical spores grow from the *Penicillium* fungus before detaching.

DIATOM

Kingdom: Algae


1/100 mm

The biggest algae grow as giant seaweeds, but many, such as diatoms, are microscopic single cells. All make food by photosynthesis, forming the bottom of many underwater food chains that support countless lives.



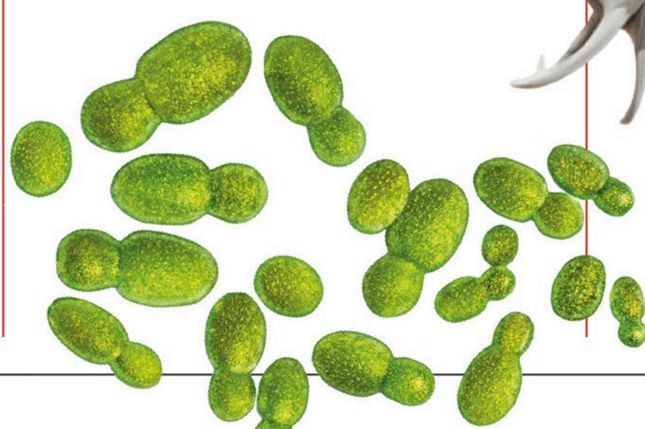
Diatoms are surrounded by a large cell wall.

WATERMEAL

Kingdom: Plants


1 mm

The smallest plant, called watermeal, floats on ponds, blanketing the surface in its millions. A hundred could sit comfortably on a fingertip, each one carrying a tiny flower that allows it to reproduce.

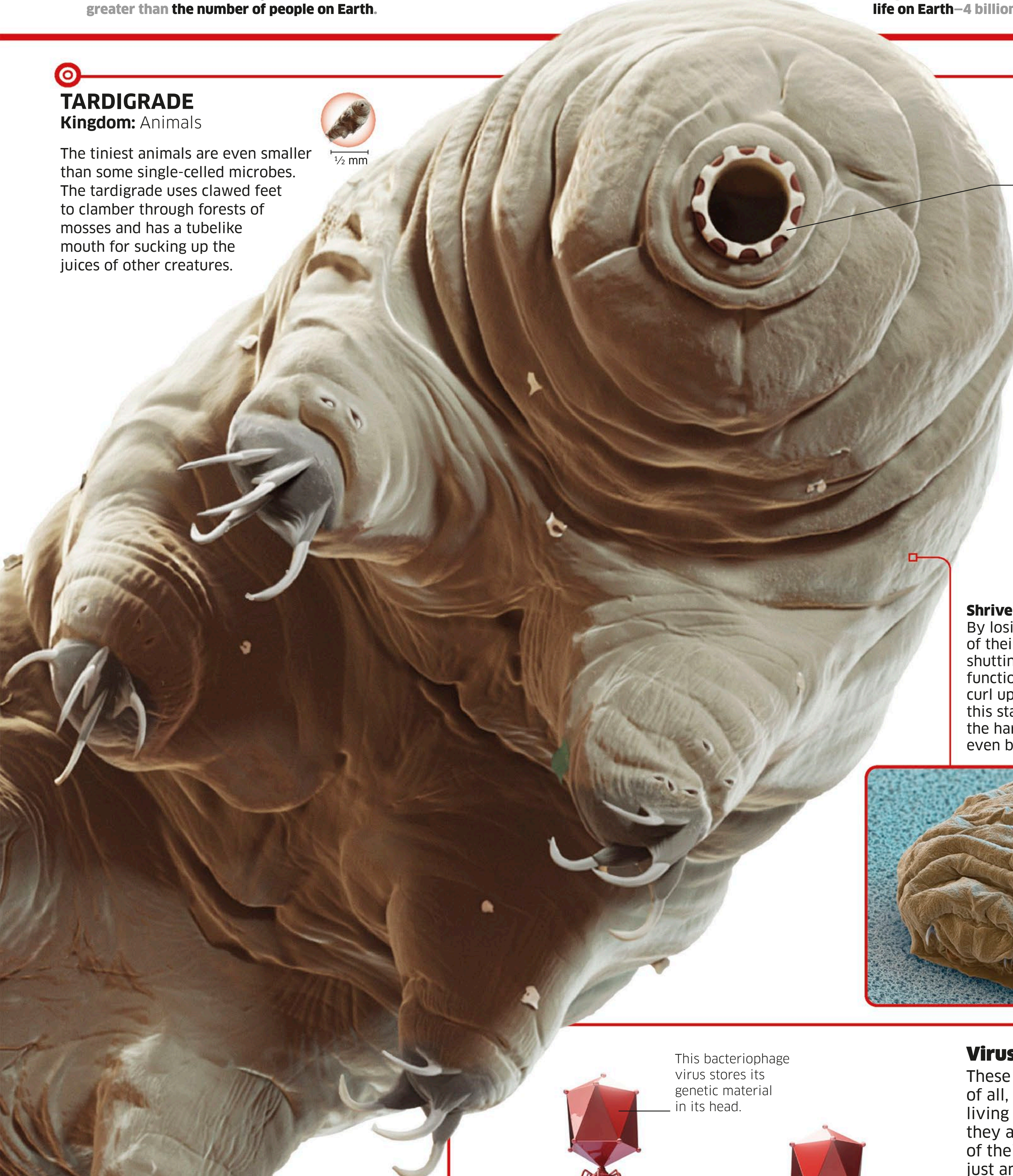


TARDIGRADE

Kingdom: Animals

½ mm

The tiniest animals are even smaller than some single-celled microbes. The tardigrade uses clawed feet to clamber through forests of mosses and has a tubelike mouth for sucking up the juices of other creatures.



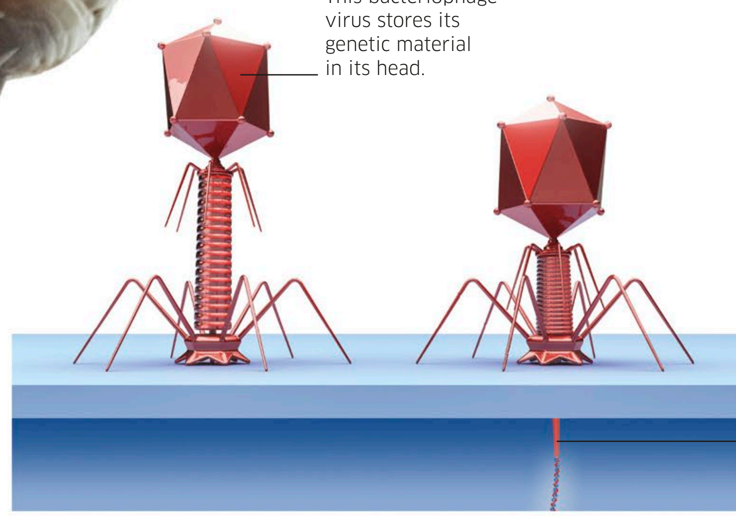
Deadly jaws
The tardigrade has needle-sharp mouthparts around the opening of its feeding tube—to pierce the cells of its prey.

Shrivelled survivor
By losing 99 percent of their water and shutting down their bodily functions, tardigrades can curl up into dry husks. In this state, they can endure the harshest conditions—even being sent into space.

Stumpy legs
The way a tardigrade lumbers along on thick legs has earned it the popular name of “water bear.”

Viruses

These are the tiniest microbes of all, but they are not true living organisms because they are not made up of cells of their own. Each virus is just an encased bundle of genetic material that invades the living cells of other organisms. It then uses the host cells to reproduce itself.



This bacteriophage virus stores its genetic material in its head.

The virus’s sharp spikes pierce the wall of a bacterium and inject the DNA inside.

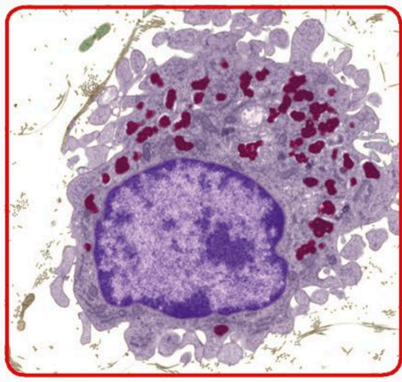
60 **trillion cells** make up the **human body**.

Along with cytoplasm and a nucleus, **the yolk of an unfertilized bird egg is a giant single cell**.

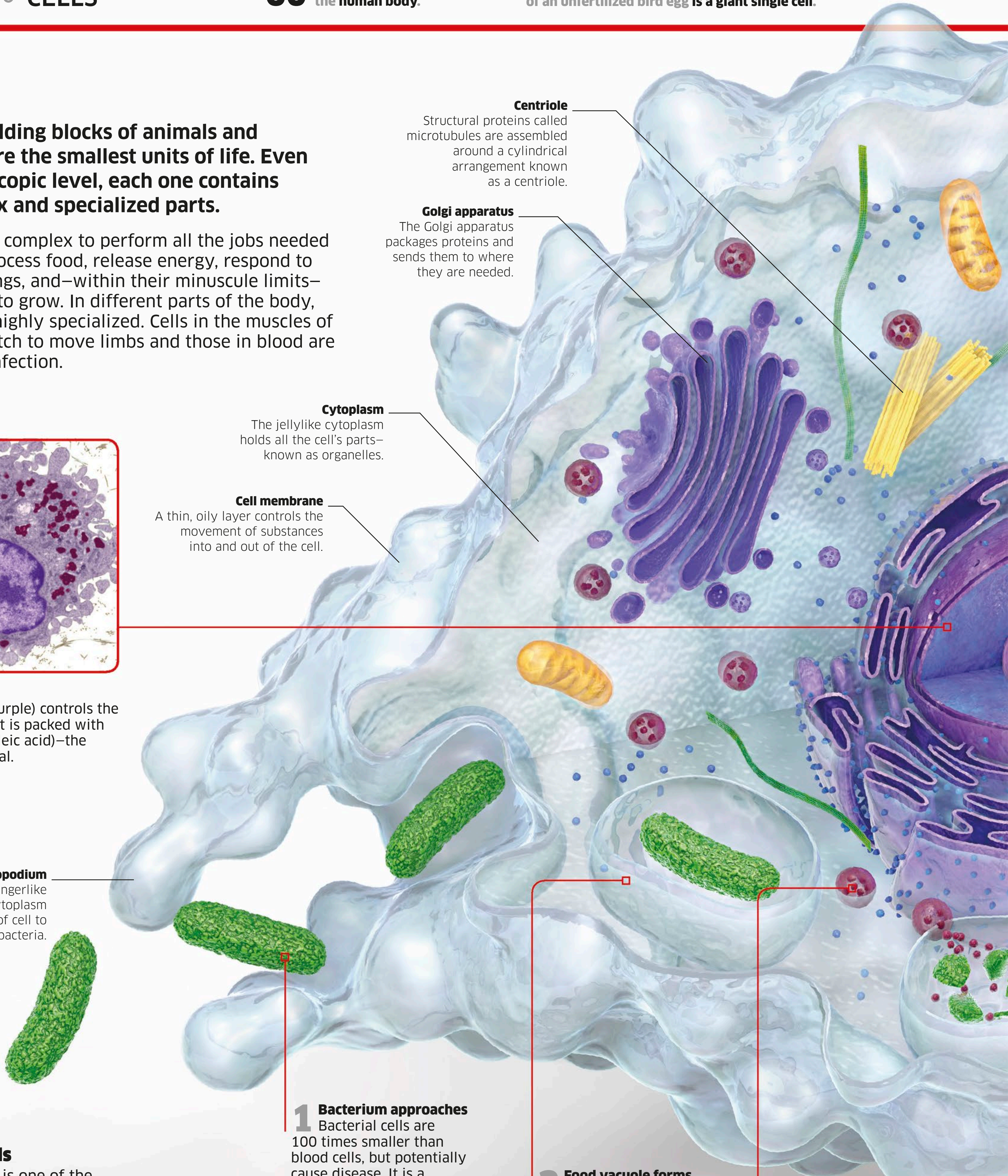
Cells

The living building blocks of animals and plants, cells are the smallest units of life. Even at this microscopic level, each one contains many complex and specialized parts.

Cells need to be complex to perform all the jobs needed for life. They process food, release energy, respond to their surroundings, and—within their minuscule limits—build materials to grow. In different parts of the body, many cells are highly specialized. Cells in the muscles of animals can twitch to move limbs and those in blood are ready to fight infection.

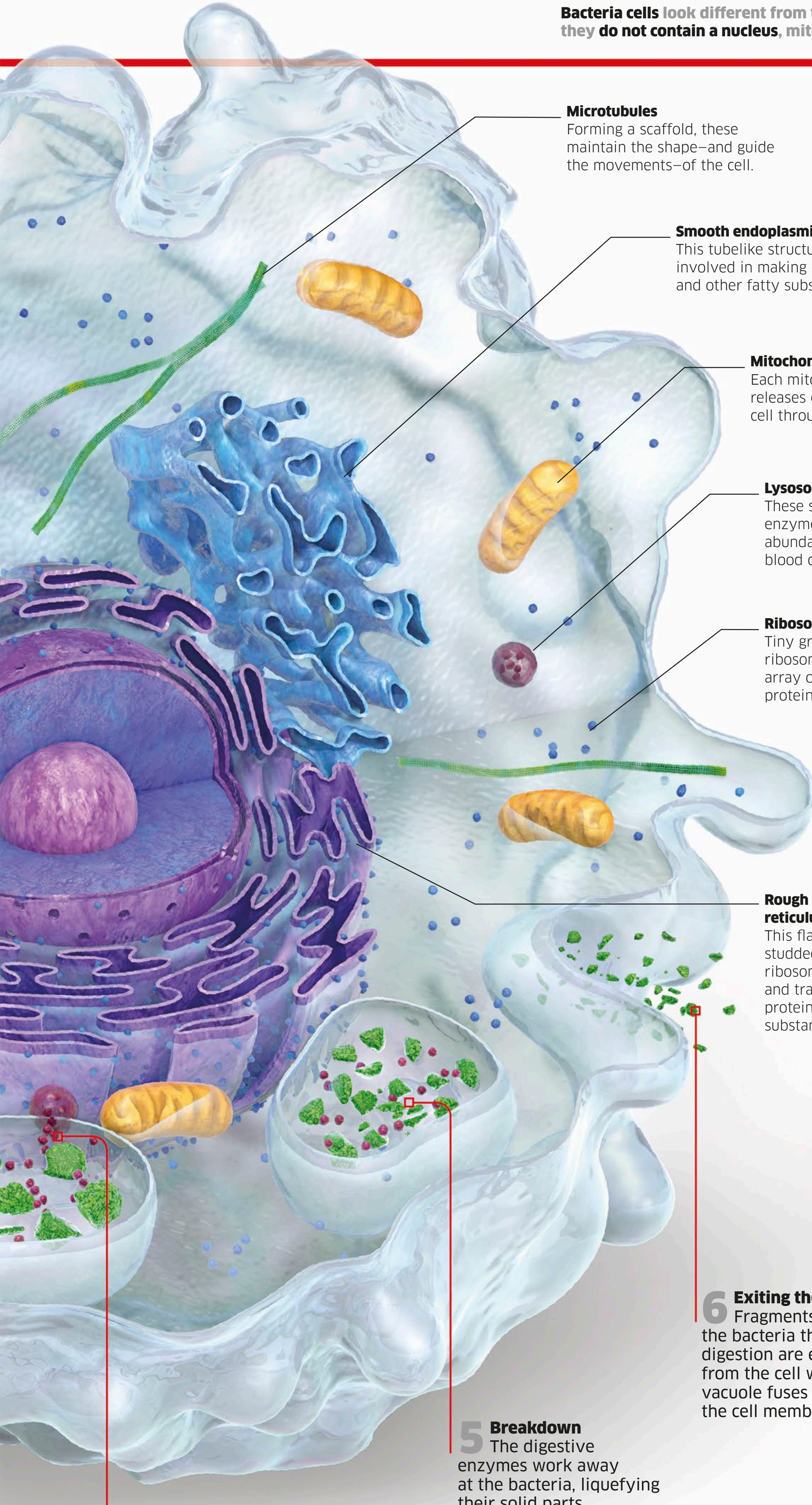


Nucleus
The nucleus (dark purple) controls the activity of the cell. It is packed with DNA (deoxyribonucleic acid)—the cell's genetic material.



Cells eating cells

A white blood cell is one of the busiest cells in a human body, part of a miniature army that destroys potentially harmful bacteria. Many white blood cells do this by changing shape to swallow invading cells: they extend fingers of cytoplasm that sweep bacteria into sacs for digestion.



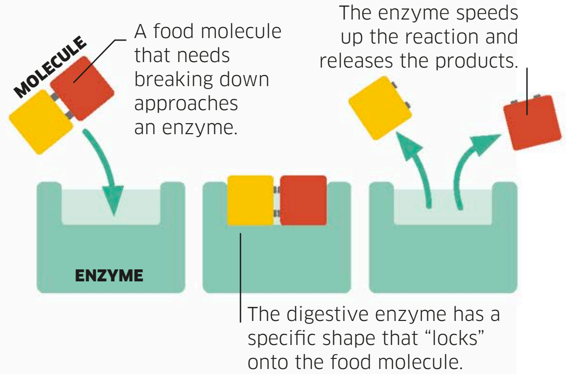
4 Enzymes at work The digestive fluid contains substances called enzymes. These are proteins made by the cell that help drive the process of digestion.

5 Breakdown The digestive enzymes work away at the bacteria, liquefying their solid parts.

6 Exiting the cell Fragments of the bacteria that resist digestion are expelled from the cell when the vacuole fuses with the cell membrane.

Enzymes

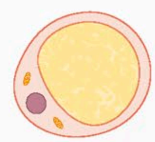
Cells make complex molecules called proteins, many of which work as enzymes. Enzymes are catalysts—substances that increase the rate of chemical reactions and can be used again and again. Each type of reaction needs a specific kind of enzyme.



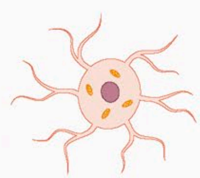
Cell variety

Unlike animal cells, plant cells are ringed by a tough cell wall and many have food-making chloroplasts. Both animals and plants have many specialised cells for different tasks.

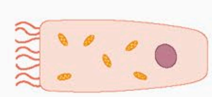
ANIMAL CELLS



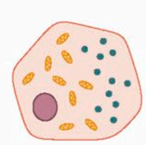
Fat cell
Its large droplet of stored fat provides energy when needed.



Bone-making cell
Long strands of cytoplasm help this cell connect to others.

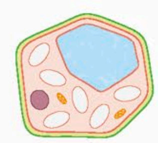


Ciliated cell
Hairlike cilia waft particles away from airways.

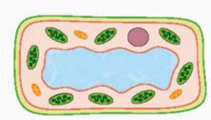


Secretory cell
These cells release useful substances, such as hormones.

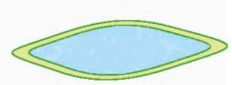
PLANT CELLS



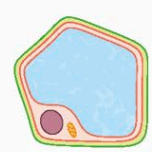
Starch-storing cell
Some root cells store many granules of energy-rich starch.



Leaf cell
Inside this cell, green chloroplasts make food for the plant.



Supporting cell
Thick-walled cells in the stem help support plants.



Fruit cell
Its large sap-filled vacuole helps to make a fruit juicy.

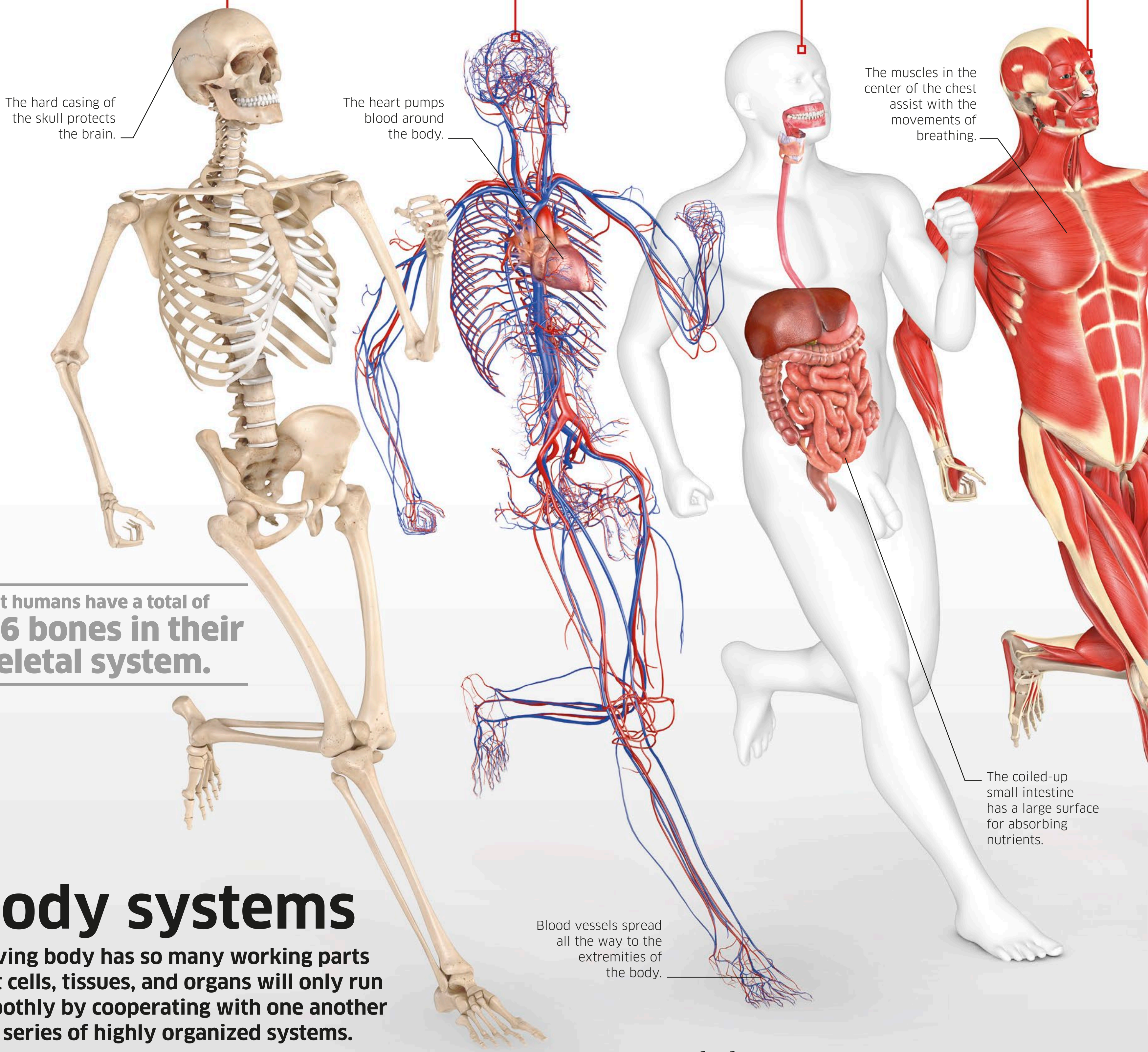
3.3 lb (1.5 kg)—the **weight of the liver**, which is the **largest internal organ** in the human body.

Skeletal system
Some of the hardest parts of the body make up the skeleton. Bone contains living cells but is also packed with hard minerals. This helps it support the stresses and strains of the moving body, and to protect soft organs, too.

Circulatory system
No living cell is very far from a blood vessel. The circulatory system serves as a lifeline to every cell. It circulates food, oxygen, and chemical triggers—such as hormones—as well as transporting waste to the excretory organs.

Digestive system
By processing incoming food, the digestive system is the source of fuel and nourishment for the entire body. It breaks down food to release nutrients, which then seep into the bloodstream to be circulated to all living cells.

Muscular system
The moving parts of the body rely on muscles that contract when triggered to do so by a nerve impulse or chemical trigger. Contraction shortens the muscle, which pulls on a part of the body to cause motion.



Adult humans have a total of 206 bones in their skeletal system.

Body systems

A living body has so many working parts that cells, tissues, and organs will only run smoothly by cooperating with one another in a series of highly organized systems.

Each system is designed to carry out a particular function essential to life—whether breathing, eating, or reproducing. Just as organs are interconnected in organ systems, the systems interact, and some organs, such as the pancreas, even belong to more than one system.

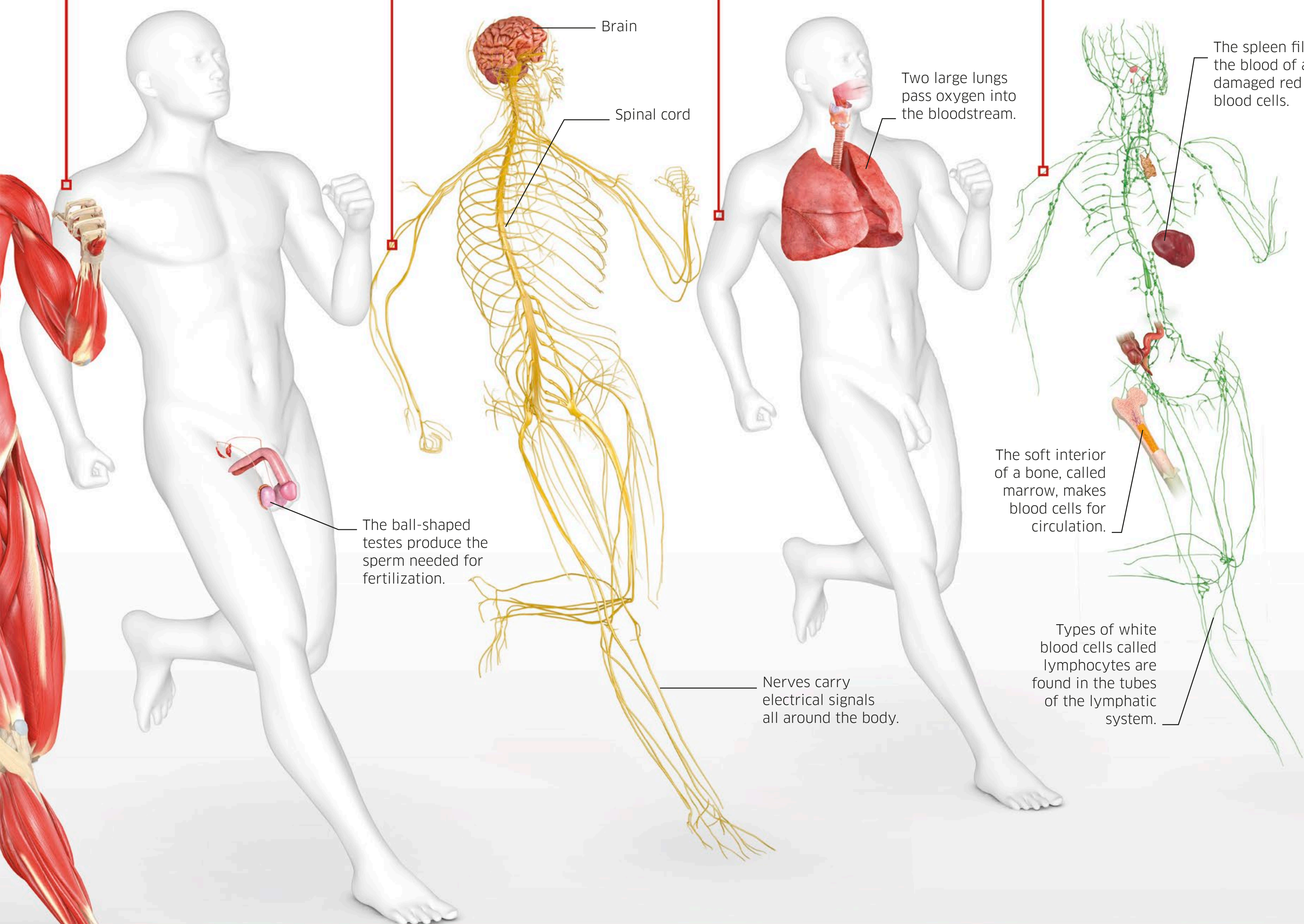
Human body systems
There are 12 systems of the human body, of which 8 of the most vital are shown here. The others are the urinary system (see pp.162–163), the integumentary system (skin, hair, and nails), the lymphatic system (which drains excess fluid), and the endocrine system (which produces hormones).

Reproductive system
Differing significantly between the sexes, the reproductive system produces the next generation of life. Female organs produce eggs, and the female body also hosts the developing child before it is born. Male organs produce sperm to fertilize the eggs.

Nervous system
A network of nerves carries high-speed electrical impulses all around the body. These are coordinated by the brain and the spinal cord. When they reach their destination, they trigger responses that control the body's behavior.

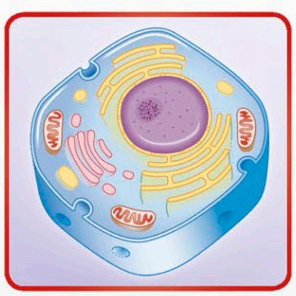
Respiratory system
The lungs in the respiratory system breathe in air and extract oxygen from it. This oxygen is used in cells to release energy to power the body, while waste carbon dioxide from this reaction is expelled back out through the nose and mouth.

Immune system
The immune system is made up of white blood cells. These travel around the body in the circulatory and lymphatic systems, as well as being found in certain tissues. They help to fight off infectious microbes that have invaded the body.



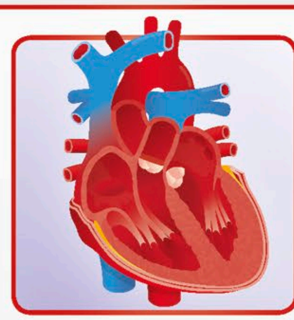
Building a body

Each of the trillions of cells that make up a human body are busy with life's vital processes, such as processing food. But cells are also organized for extra tasks in arrangements called tissues, such as muscles and blood. Multiple tissues, in turn, make up organs, each of which has a specific vital function. A collection of organs working together to carry out one process is called a system.

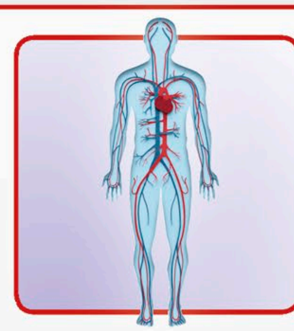


Cell
The basic building blocks of life, cells can be specialized for a variety of different tasks.

Tissue
Groups of complementary cells work together in tissues that perform particular functions.



Organ
Combinations of tissues are assembled together to make up organs, such as the human heart.



System
Complementary organs are connected into organ systems, which carry out key body processes.

Photosynthesizers
Leaves contain a green pigment called chlorophyll. This traps the energy of sunlight, which is used to build sugars. The process, called photosynthesis, is the origin of virtually all the food chains on Earth.

Flies are drawn to the giant Rafflesia flower because it has the odor of their favorite food: rotting meat.

An indigo flycatcher snatches flies attracted to the foul stench of the Rafflesia flower.

A Kinabalu pit viper hunts small mammals and birds.

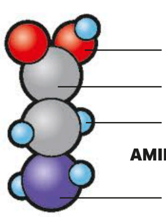
Nutrition

All life needs food—whether it's the sugary sap made in the green leaves of plants, or the solid meals eaten by hungry animals.

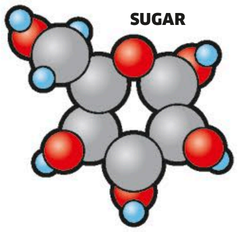
Food gives organisms the fuel to power all the living processes that demand energy, such as growth. Animals, fungi, and many microbes consume it from their surroundings—by eating or absorbing the materials of other organisms, living or dead. In contrast, plants and other microbes start with very simple chemical ingredients, such as carbon dioxide and water, and use these to make food inside their cells.

What is food?

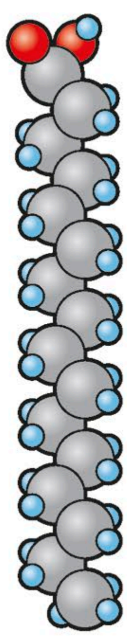
The nutrients in food come from a complex mixture of molecules—each one containing carbon, hydrogen, and oxygen as its main elements. Three main groups—carbohydrates, fats, and proteins—make up the bulk of food molecules, although all organisms require different amounts of each type.



Proteins
Groups of atoms called amino acids link into chains of proteins, which help with growth and repair.



Carbohydrates
Rings of atoms called sugars provide energy and link to form chains of starch.



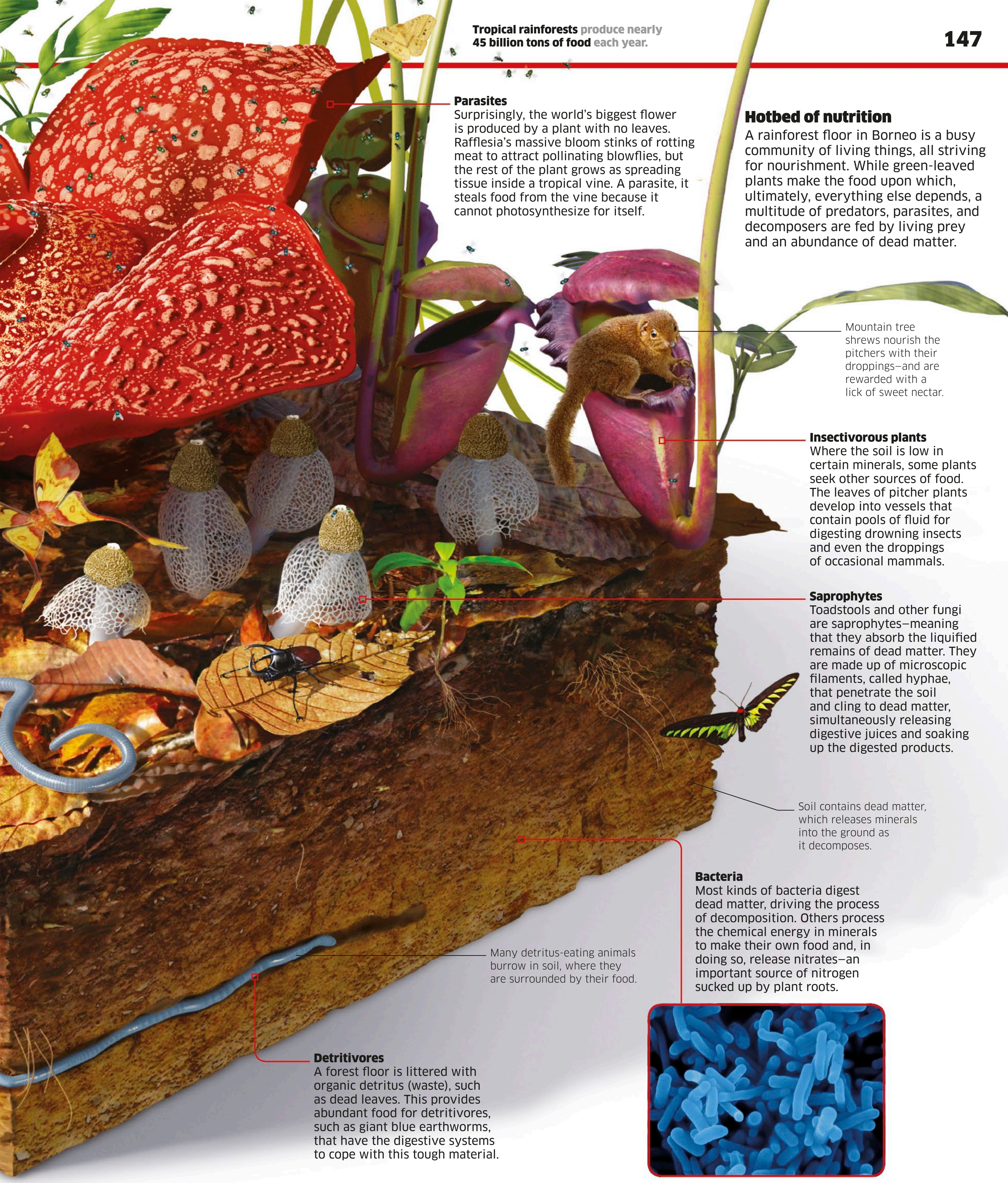
Fats and oils
Used for storing energy or building cells, these are made of long molecules called fatty acids.

Mycorrhizae
A network of fungus filaments—called mycorrhizae—grows among plant roots. Together, roots and filaments have a feeding partnership: the plants pass sugars to the fungi in exchange for minerals gathered by the fungi.

Predators
Animals that prey on others are called predators. Leeches are famous for sucking blood, but the giant red leech has a taste for meat—grabbing giant earthworms as they emerge from burrows after rainfall.

Hotbed of nutrition

A rainforest floor in Borneo is a busy community of living things, all striving for nourishment. While green-leaved plants make the food upon which, ultimately, everything else depends, a multitude of predators, parasites, and decomposers are fed by living prey and an abundance of dead matter.



Parasites
Surprisingly, the world's biggest flower is produced by a plant with no leaves. Rafflesia's massive bloom stinks of rotting meat to attract pollinating blowflies, but the rest of the plant grows as spreading tissue inside a tropical vine. A parasite, it steals food from the vine because it cannot photosynthesize for itself.

Mountain tree shrews nourish the pitchers with their droppings—and are rewarded with a lick of sweet nectar.

Insectivorous plants
Where the soil is low in certain minerals, some plants seek other sources of food. The leaves of pitcher plants develop into vessels that contain pools of fluid for digesting drowning insects and even the droppings of occasional mammals.

Saprophytes
Toadstools and other fungi are saprophytes—meaning that they absorb the liquified remains of dead matter. They are made up of microscopic filaments, called hyphae, that penetrate the soil and cling to dead matter, simultaneously releasing digestive juices and soaking up the digested products.

Soil contains dead matter, which releases minerals into the ground as it decomposes.

Bacteria
Most kinds of bacteria digest dead matter, driving the process of decomposition. Others process the chemical energy in minerals to make their own food and, in doing so, release nitrates—an important source of nitrogen sucked up by plant roots.

Many detritus-eating animals burrow in soil, where they are surrounded by their food.

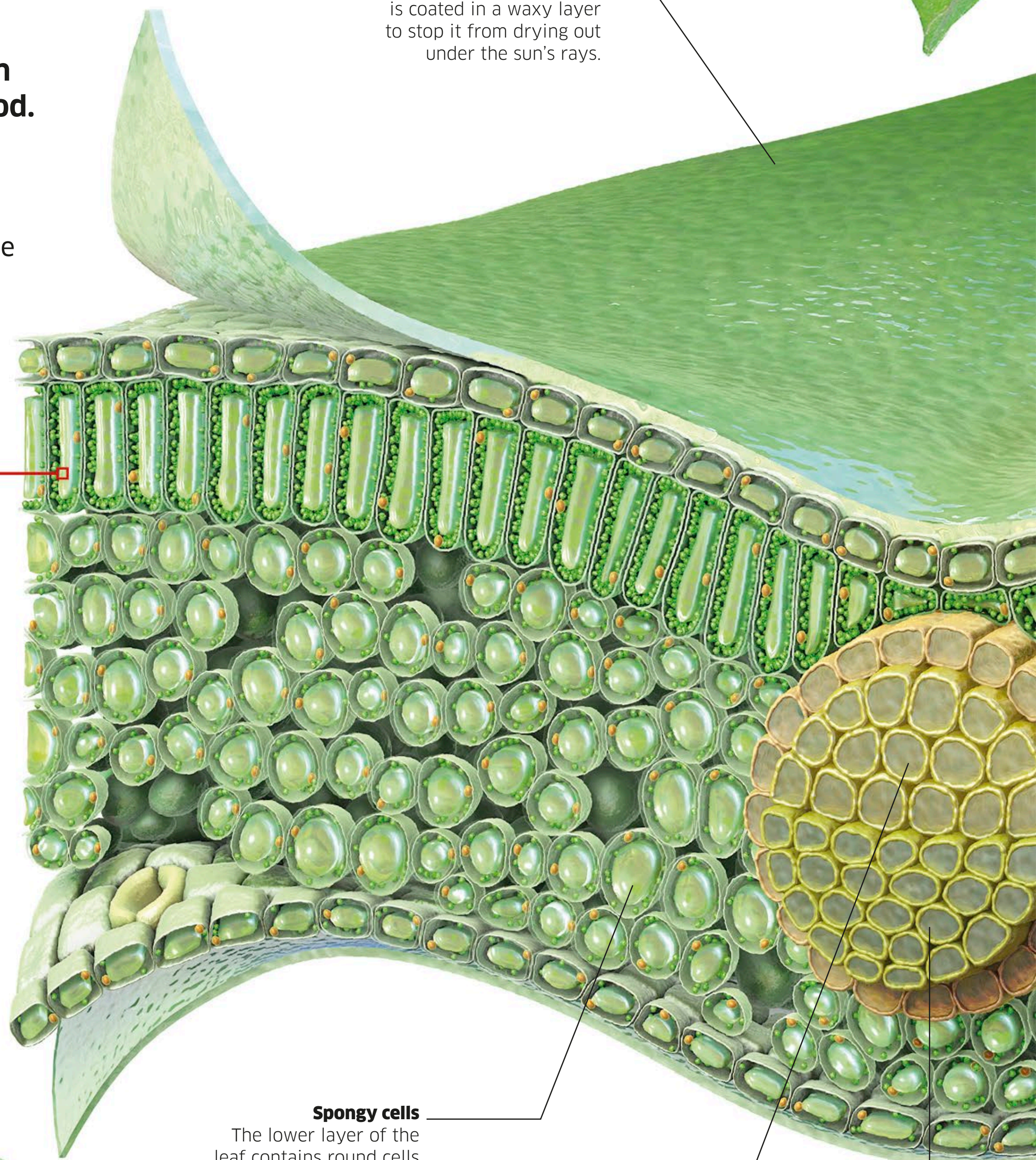
Detritivores
A forest floor is littered with organic detritus (waste), such as dead leaves. This provides abundant food for detritivores, such as giant blue earthworms, that have the digestive systems to cope with this tough material.

Some kinds of ocean algae use brown or red pigment for their photosynthesis, to **make better use of the light wavelengths** that penetrate the water.

Photosynthesis

Virtually all food chains on Earth begin with photosynthesis—the chemical process in green leaves and algae that is critical for making food.

All around the planet when the sun shines, trillions of microscopic chemical factories called chloroplasts generate enough food to support all the world's vegetation. These vital granules are packed inside the cells of plant leaves and ocean algae. They contain a pigment, called chlorophyll, that makes our planet green and absorbs the sun's energy to change carbon dioxide and water into life-giving sugar.

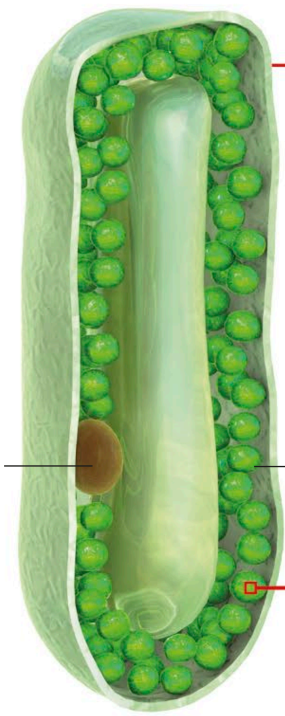


Waxy layer
The surface of the leaf is coated in a waxy layer to stop it from drying out under the sun's rays.

Spongy cells
The lower layer of the leaf contains round cells surrounded by air-filled spaces. These spaces help carbon dioxide in the air reach photosynthesizing cells.

Xylem
Tubes called xylem carry water into the leaf.

Phloem
Phloem tubes transport the food made during photosynthesis to other parts of the plant.



Palisade cell
Oblong-shaped palisade cells form a layer near the surface of the leaf. They contain the most chloroplasts, so they perform the most photosynthesis.

Chlorophyll
Chlorophyll is attached to membranes around the disks. Having lots of disks means there is more room for chlorophyll.

Chloroplast
A chloroplast is a bean-shaped granule. Together, all the chloroplasts contain so much of the pigment chlorophyll that the entire leaf appears green.

Fluid around the disks contains chemicals called enzymes that drive the production of sugar.

Inside a leaf

Cells that are near the sunlit surface of a leaf contain the most chloroplasts. Each chloroplast is sealed by transparent oily membranes and encloses stacks of interconnected discs that are at the heart of the photosynthesis process. The discs are covered in green chlorophyll, which traps light energy from the sun. This energy then drives chemical reactions that form sugar in the fluid surrounding the disks.

Epidermis
A single layer of cells, called the epidermis, forms a skin that protects the photosynthesizing layers underneath.

Bundle sheath
A layer of cells strengthens the bundle of xylem and phloem.

Stoma
The lower epidermis is punctured by pores called stomata that let carbon dioxide into the leaf and oxygen back out.

Guard cells
Two guard cells make up each stoma and control when it opens and closes.

Photosynthesis in winter

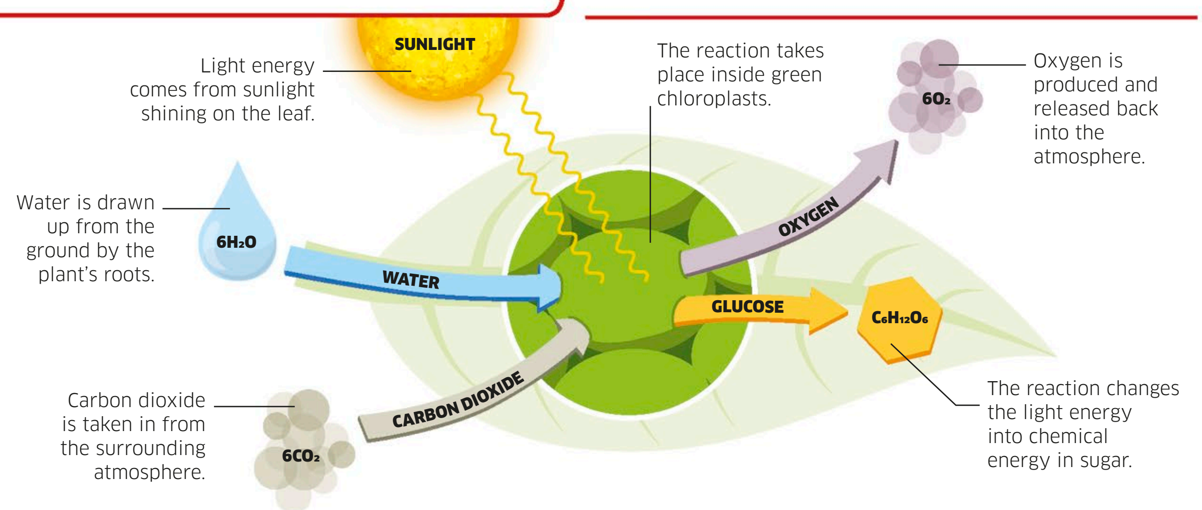
During the winter season, some kinds of plants retain their leaves—even though their photosynthesis slows down. Other species drop their leaves and become dormant, having stored up enough food to last them until spring.

Evergreen tree
Pine trees have tough needlelike leaves that can keep working even in freezing temperatures.

Deciduous tree
Many broad-leaved trees drop all their leaves at once in winter and grow a new set in spring.

Chemical reactions

Inside a chloroplast, a complex chain of chemical reactions takes place, which uses up water and carbon dioxide and generates sugar and oxygen. The light energy trapped by chlorophyll is first used to extract hydrogen from water, and expel the excess oxygen into the atmosphere. The hydrogen is then combined with carbon dioxide to make a kind of sugar called glucose. This provides the energy the plant needs for all the functions of life.



Tapeworms are **parasites** that live inside the bodies of other animals, and **absorb food without using a digestive system** of their own.

Feeding strategies

All animals need food to keep them alive—in the form of other organisms, such as plants and animals. Many will go to extreme lengths to obtain their nutrients.

Whether they are plant-eating herbivores, meat-eating carnivores, or omnivores that eat many different foods, all animals are adapted to their diets. Every kind of animal has evolved a way for its body to get the nourishment it needs. Some animals only ever drink liquids, such as blood, or filter tiny particles from water, while others use muscles and jaws to tear solid food to pieces.

COLORADO BEETLE

Strategy: Leaf eater

Leaves can be a bountiful source of food, but leaf eaters must first get past a plant's defenses. Many are specialized to deal with particular plants, such as the Colorado beetle, which eats potato plant leaves that are poisonous to other animals.

VAMPIRE BAT

Strategy: Parasite

Some animals obtain food directly from living hosts—without killing them. Blood suckers, such as the vampire bat, get a meal rich in protein. The bat attacks at night, and is so stealthy that the sleeping victim scarcely feels its bites.

HAGFISH

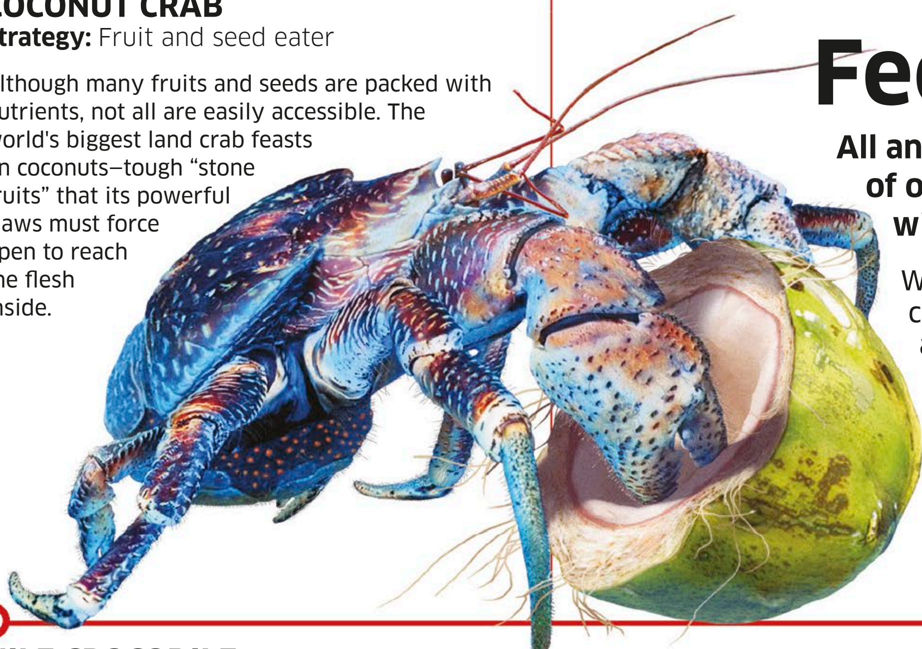
Strategy: Scavenger

Deep-sea hagfishes are scavengers: they feed on dead matter. By tying themselves into knots, they are able to brace themselves against the carcasses of dead whales so that their spiny jawless mouths can rasp away at the flesh.

COCONUT CRAB

Strategy: Fruit and seed eater

Although many fruits and seeds are packed with nutrients, not all are easily accessible. The world's biggest land crab feasts on coconuts—tough "stone fruits" that its powerful claws must force open to reach the flesh inside.



NILE CROCODILE

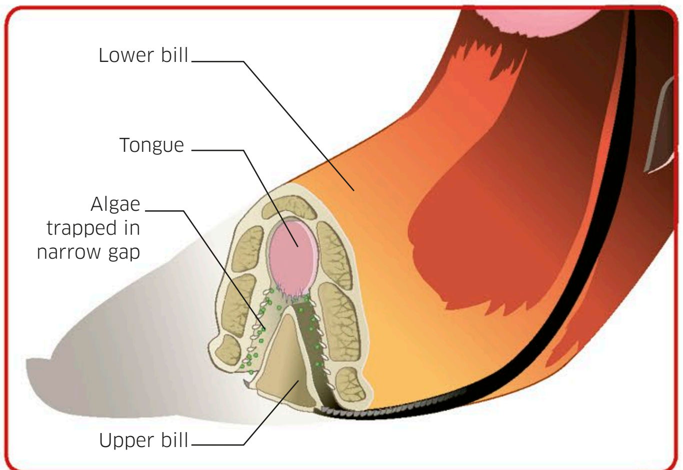
Strategy: Predator

Carnivores that must kill to obtain food not only need the skill to catch their prey, but also the strength to overpower it. Some predators rely on speed to chase prey down, but the Nile crocodile waits in ambush instead. It lurks submerged at a river's edge until a target comes to drink, then grabs the prey with its powerful jaws and pulls the struggling animal underwater to drown it.

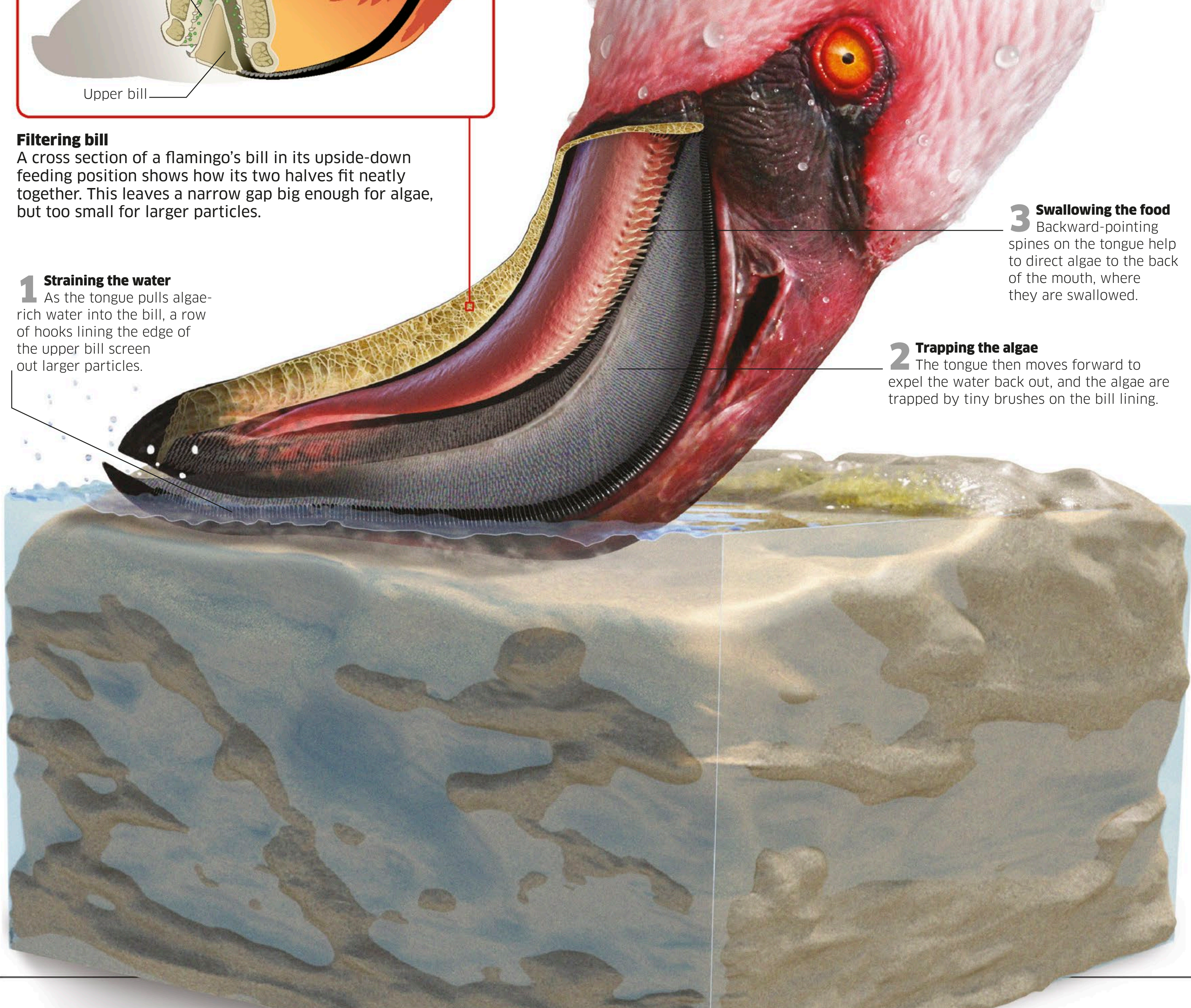
LESSER FLAMINGO

Strategy: Filter feeder

The lesser flamingo is nourished almost entirely by the microscopic algae in African salt lakes. Each cupful of water from the lakes is a rich soup containing billions of algae, which the bird filters out with its unusual bill. By lowering its head upside down into the lake and pumping its tongue backward and forward like a piston, water gets drawn into and out of the long bill. A coating of minute brushes on the inner lining of the bill trap the algae, which are then rapidly swallowed by the hungry bird.



Filtering bill
A cross section of a flamingo's bill in its upside-down feeding position shows how its two halves fit neatly together. This leaves a narrow gap big enough for algae, but too small for larger particles.



1 Straining the water As the tongue pulls algae-rich water into the bill, a row of hooks lining the edge of the upper bill screen out larger particles.

2 Trapping the algae The tongue then moves forward to expel the water back out, and the algae are trapped by tiny brushes on the bill lining.

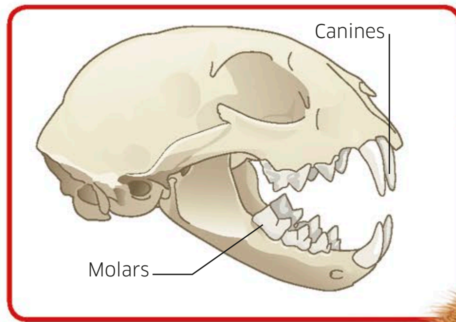
3 Swallowing the food Backward-pointing spines on the tongue help to direct algae to the back of the mouth, where they are swallowed.

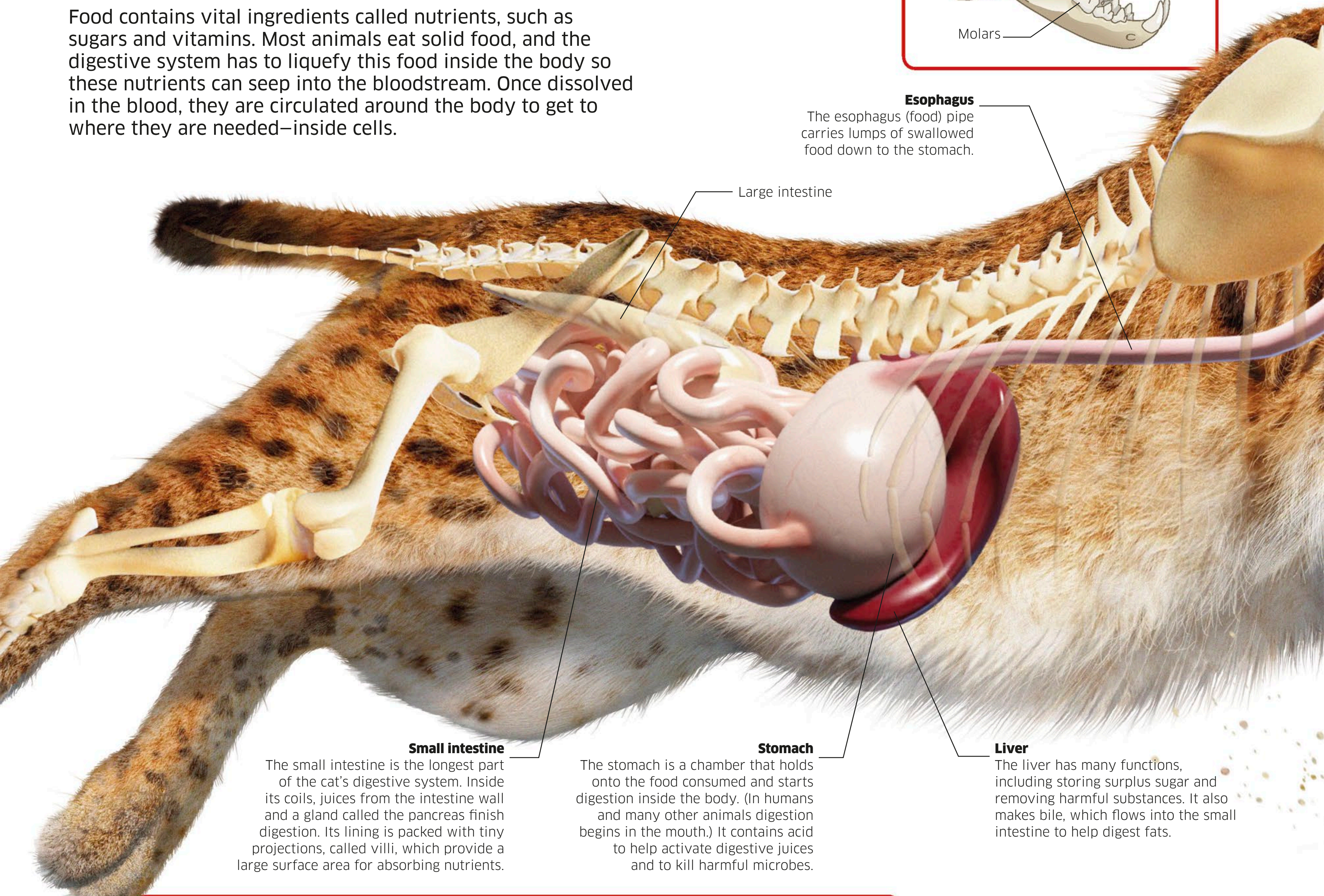
Processing food

Eating is only part of the story of how the body gets nourishment. An animal's digestive system must then break down the food so that nutrients can reach cells.

Food contains vital ingredients called nutrients, such as sugars and vitamins. Most animals eat solid food, and the digestive system has to liquefy this food inside the body so these nutrients can seep into the bloodstream. Once dissolved in the blood, they are circulated around the body to get to where they are needed—inside cells.

Carnivore teeth
Stabbing canines and sharp-edged, bone-crunching molars help the bobcat kill prey and bite through its skin and bones.





Esophagus
The esophagus (food) pipe carries lumps of swallowed food down to the stomach.

Small intestine
The small intestine is the longest part of the cat's digestive system. Inside its coils, juices from the intestine wall and a gland called the pancreas finish digestion. Its lining is packed with tiny projections, called villi, which provide a large surface area for absorbing nutrients.

Stomach
The stomach is a chamber that holds onto the food consumed and starts digestion inside the body. (In humans and many other animals digestion begins in the mouth.) It contains acid to help activate digestive juices and to kill harmful microbes.

Liver
The liver has many functions, including storing surplus sugar and removing harmful substances. It also makes bile, which flows into the small intestine to help digest fats.

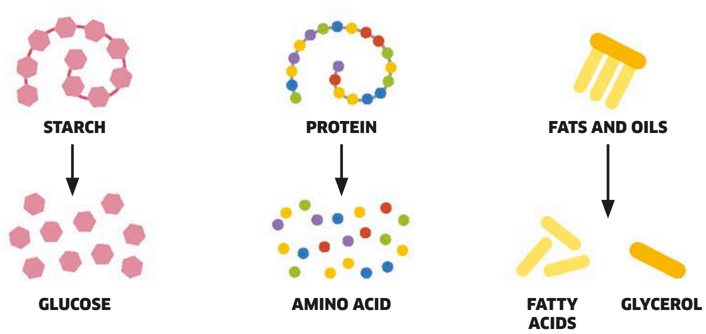
Releasing the nutrients

Biting and chewing by the mouth reduces food into manageable lumps for swallowing, but further processing is needed to extract the nutrients. Muscles in the wall of the digestive system churn food into a lumpy paste and mix it with digestive juices containing chemicals called enzymes. The enzymes help to drive chemical reactions that break big molecules into smaller ones, which are then absorbed into the blood.

Carbohydrates
Starch is digested into sugars, such as glucose.

Proteins
Proteins are digested into amino acids.

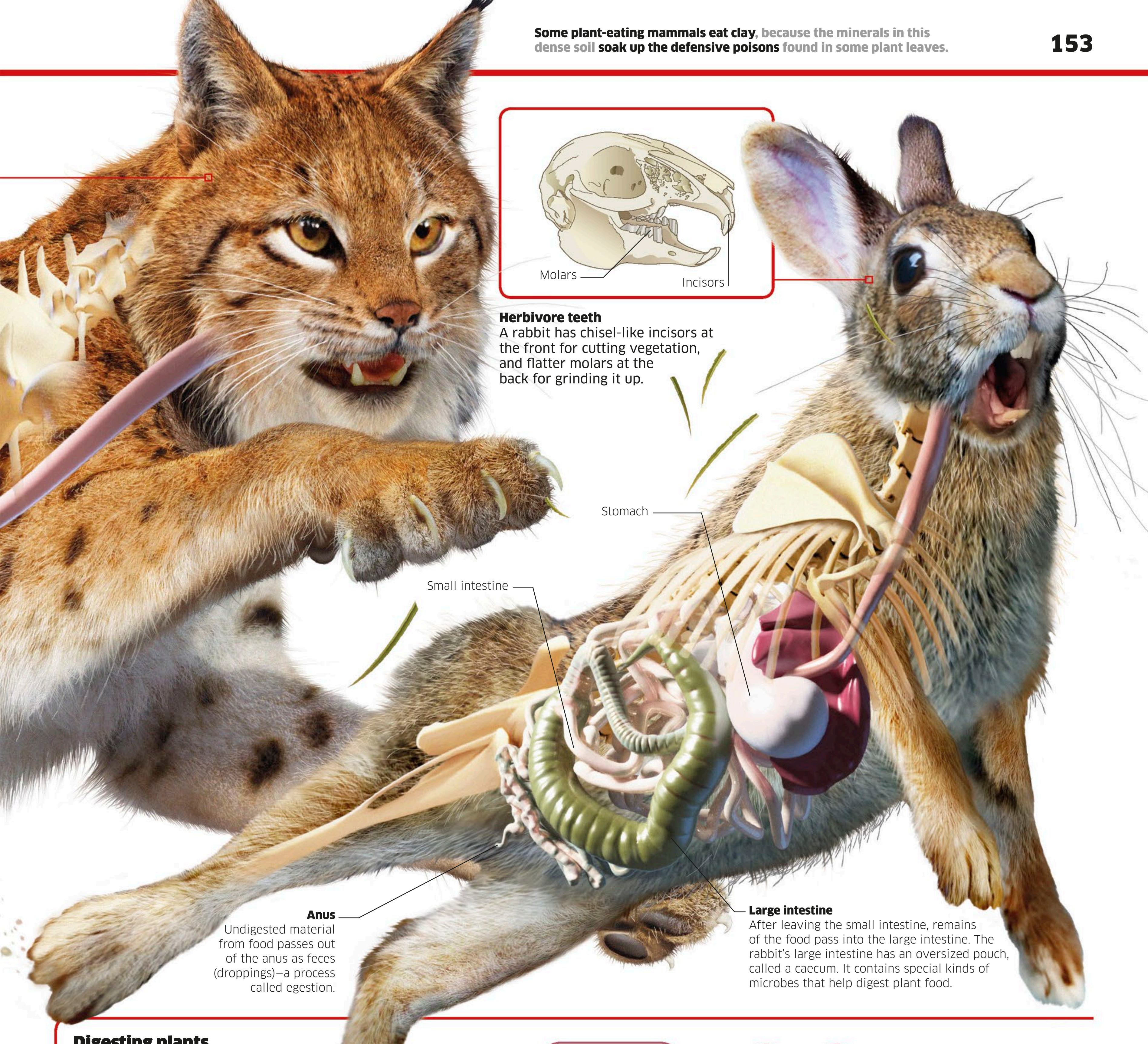
Fats
Fats and oils are broken down to release fatty acids and glycerol.



Digestive systems

A carnivorous bobcat and a herbivorous rabbit both have digestive systems filled with muscles and digestive juices to help break up their food. But they have important differences—each is adapted to the challenges of eating either chewy meat or tough vegetation.

There are more than **100 trillion bacteria** in the digestive tract.



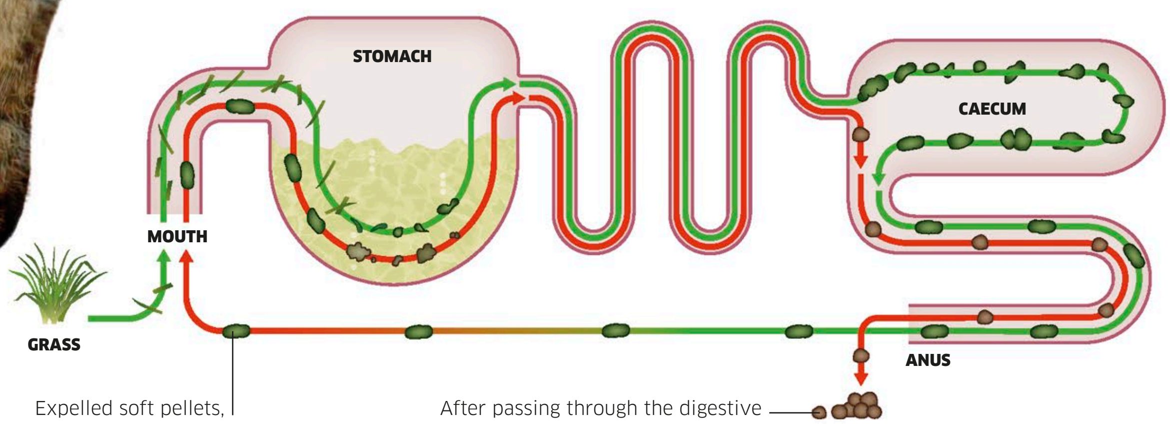
Herbivore teeth
A rabbit has chisel-like incisors at the front for cutting vegetation, and flatter molars at the back for grinding it up.

Anus
Undigested material from food passes out of the anus as feces (droppings)—a process called egestion.

Large intestine
After leaving the small intestine, remains of the food pass into the large intestine. The rabbit's large intestine has an oversized pouch, called a caecum. It contains special kinds of microbes that help digest plant food.

Digesting plants

Leaves, stems, and roots contain a lot of tough fibers. Some herbivores, such as cows, have enormous stomachs, where vegetation can be held longer for processing. Rabbits, however, pass food through their digestive system twice. The first passage produces soft droppings that are still green. These are expelled and then swallowed, so that a second passage through the gut can extract the last possible nutrients from them.



Expelled soft pellets, called caecotrophs, are eaten.

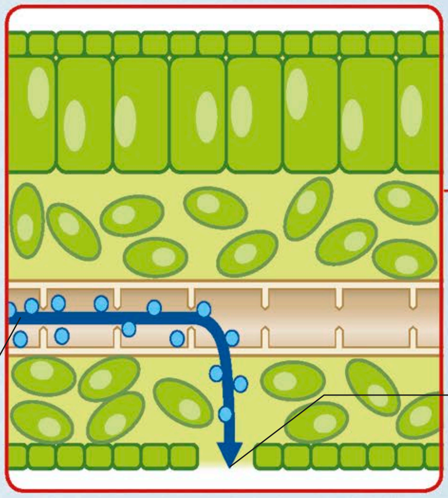
After passing through the digestive system twice, the droppings are expelled as hard pellets.

Plant transpiration

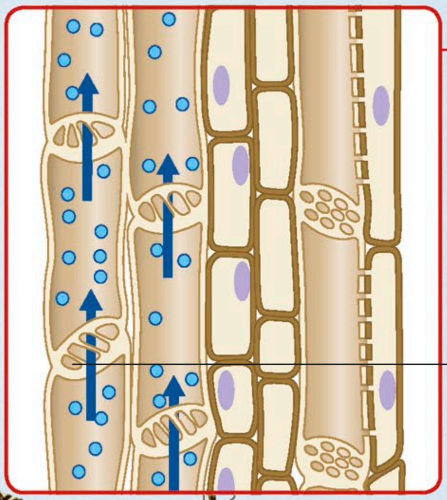
To lift water to their topmost branches, trees need incredible water carrying systems. The tallest ones can pull water with the force of a high-pressure hose.

Plants owe this remarkable ability to impressive engineering. Their trunks and stems are packed with bundles of microscopic pipes. Water and minerals are moved from the soil to the leaves, while food made in the leaves is sent around the entire plant.

3 Pull from above Water evaporates from the moist tissues inside living leaves. The vapor it generates spills out into the surrounding atmosphere through pores called stomata. This water loss, known as transpiration, is replaced with water arriving from the ground in pipelike xylem vessels.



2 Rising water The microscopic xylem vessels carry unbroken columns of water through the stem all the way up to the leaves. Water molecules stick together, so as transpiration pulls water into the leaves, all the columns of water rise up through the stem—like water climbing through drinking straws. This is called the transpiration stream.

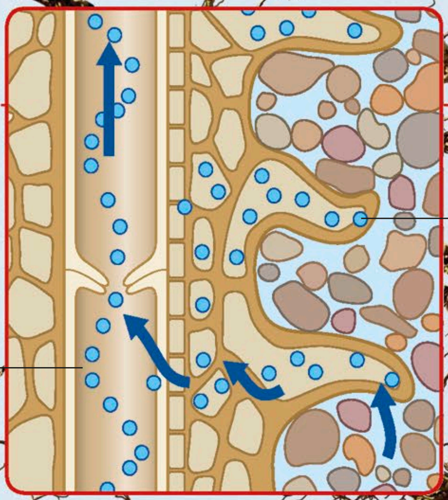


Transpiration

A tree's water carrying system is incredibly efficient and, unlike similar systems in animals, does not require any energy from the organism. The sun's heat causes water to evaporate from the leaves, a process called transpiration, which triggers the tree to pull more water up from the ground.

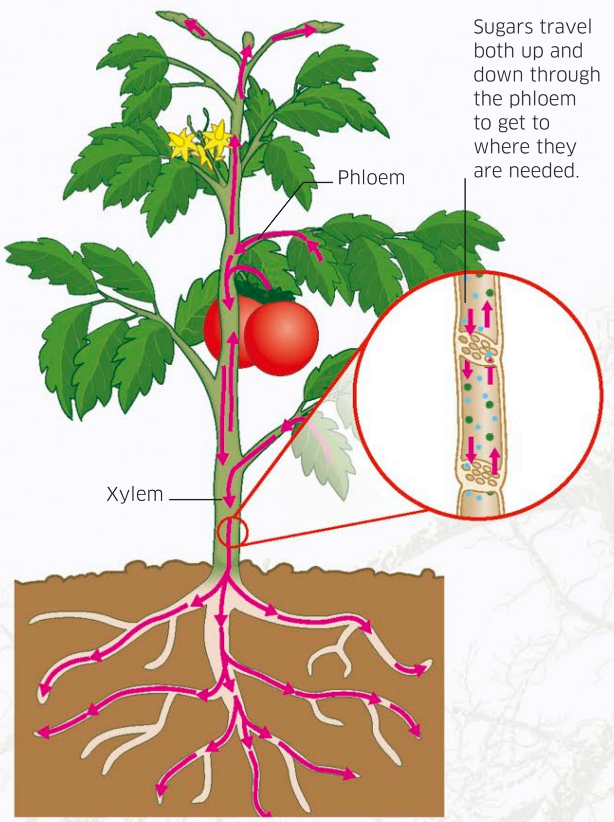
Bark
Tough outer layers of bark serve to protect the tree's trunk from injury.

1 Absorption from below Water seeps into the roots from the soil by a process called osmosis. It then passes into tubes called xylem vessels to join the transpiration stream upward. Microscopic extensions to the root, called root hairs, help maximize the absorption area so the tree can pick up large amounts of water and minerals.



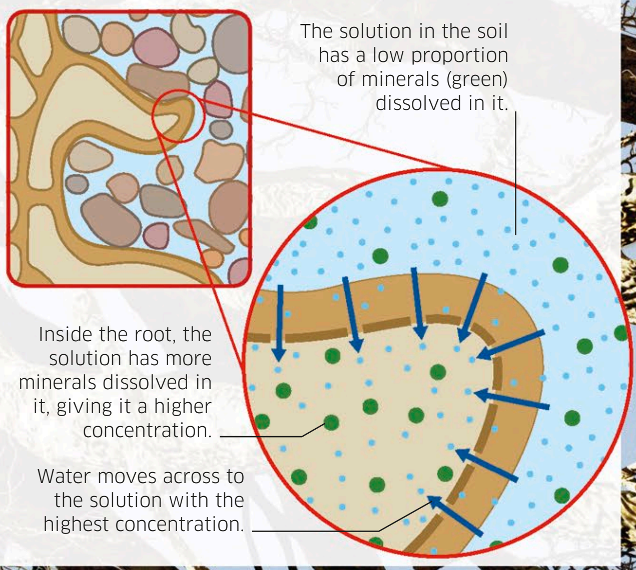
Food distribution

Sugars and other food are made in the leaves through photosynthesis (see pp.148–149). They are then carried through pipes called phloem—traveling to roots, flowers, and others parts that cannot make food for themselves.



Osmosis

When cell membranes stretch between two solutions with different concentrations, water automatically passes across to the higher concentration by a process called osmosis. This happens in plant roots—where root cell membranes are situated between the weak mineral solutions found in soil and the higher concentrations inside the root cells.



Some invertebrates have blue **blood**—colored by copper pigments.

70 **times a minute** is how fast the **human heart** beats on average.

Circulation

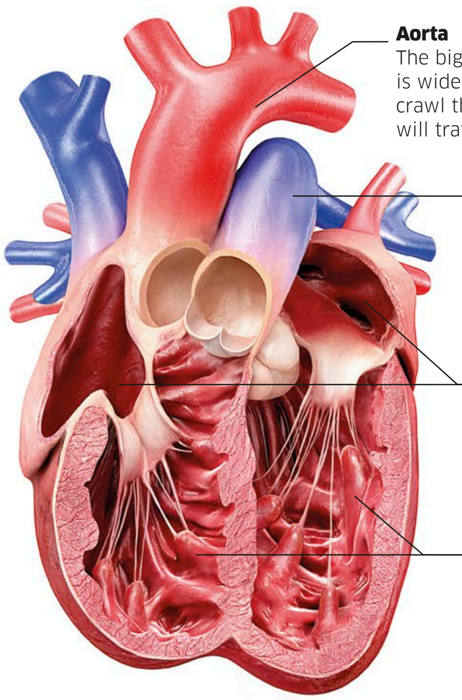
Blood is an animal's essential life support system, transporting food and oxygen around its body and removing waste from cells.

Animals have trillions of cells that need support, and a vast network of tiny tubes called blood vessels stretches throughout their bodies in order to reach them all. A pumping heart keeps blood continually flowing through the blood vessels, and this bloodstream gathers food from the digestive system and oxygen from lungs or gills. When the blood reaches cells, these essentials pass inside, while waste moves back out of the cells and is then carried away by the blood to excretory organs, such as the kidneys.

11 **tons of blood are contained within the body of a blue whale. Its heart pumps the equivalent of two baths with every beat.**

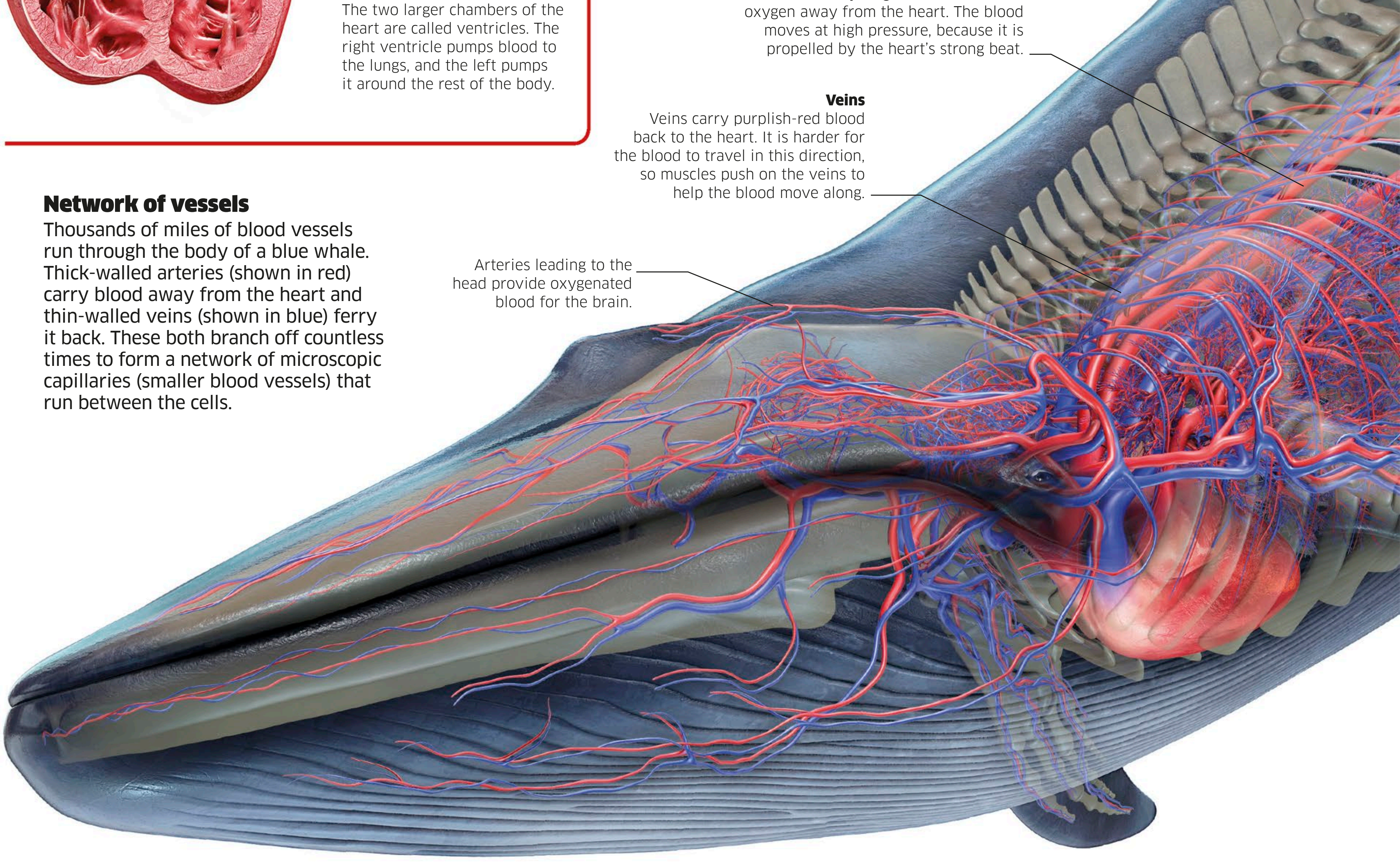
The heart

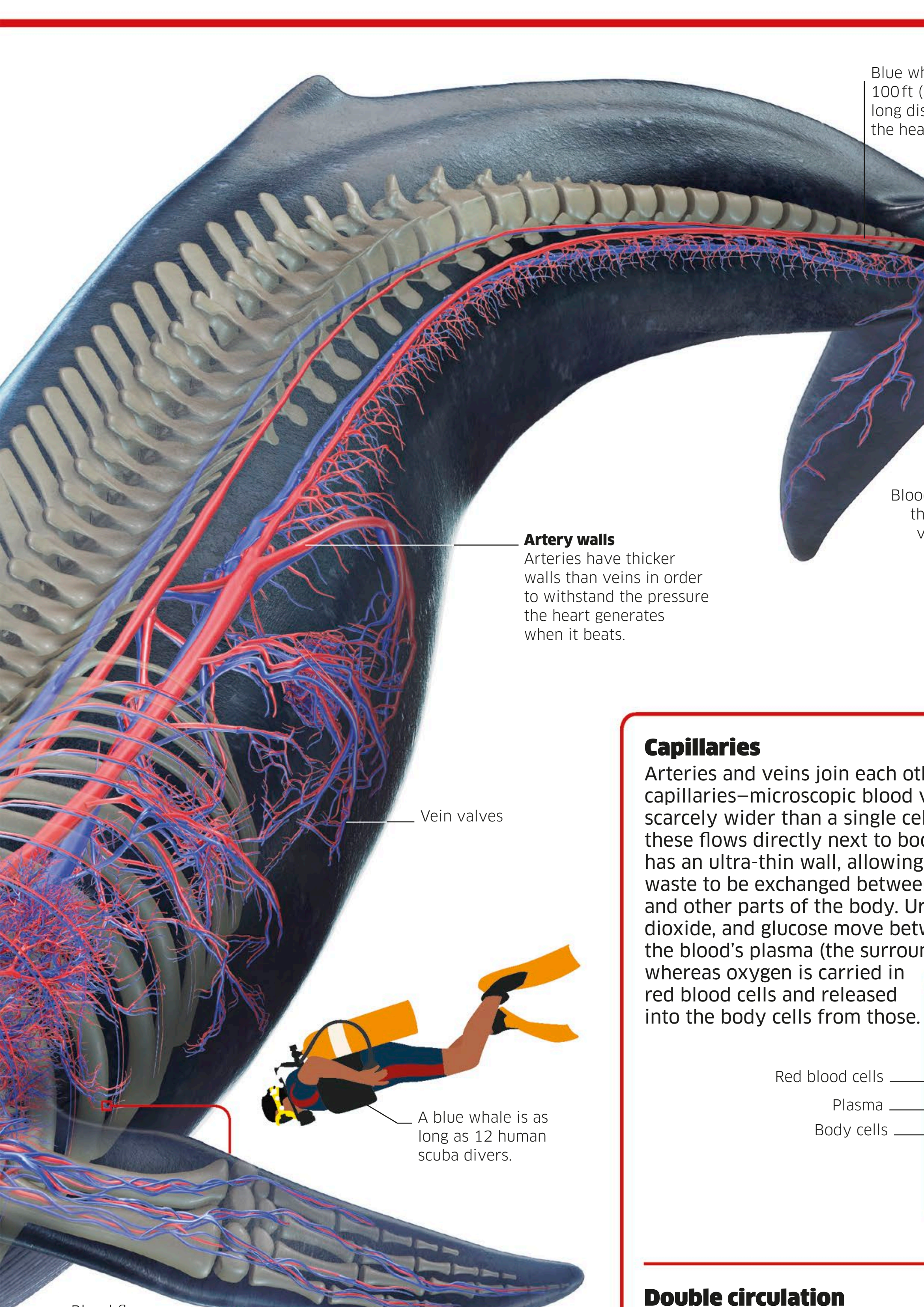
The blue whale has the biggest heart of any animal: weighing in at 400 lb (180 kg) and standing as tall as a 12-year-old child. Containing four chambers, it is made of solid muscle, and contracts with a regular rhythm to pump blood out through the body's arteries. When its muscles relax, the pressure inside the chambers dips very low to pull in blood from the veins.



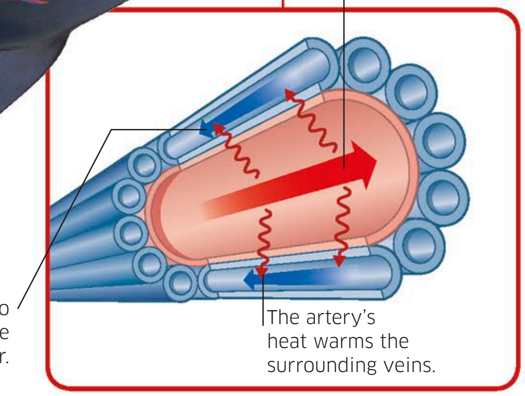
Network of vessels

Thousands of miles of blood vessels run through the body of a blue whale. Thick-walled arteries (shown in red) carry blood away from the heart and thin-walled veins (shown in blue) ferry it back. These both branch off countless times to form a network of microscopic capillaries (smaller blood vessels) that run between the cells.

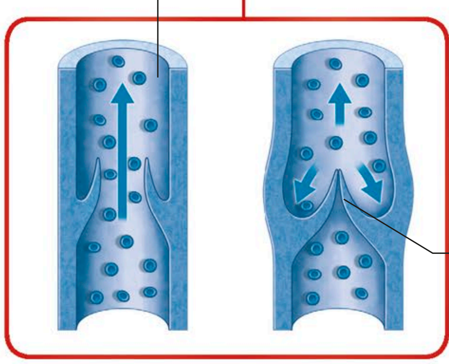




Artery walls
Arteries have thicker walls than veins in order to withstand the pressure the heart generates when it beats.



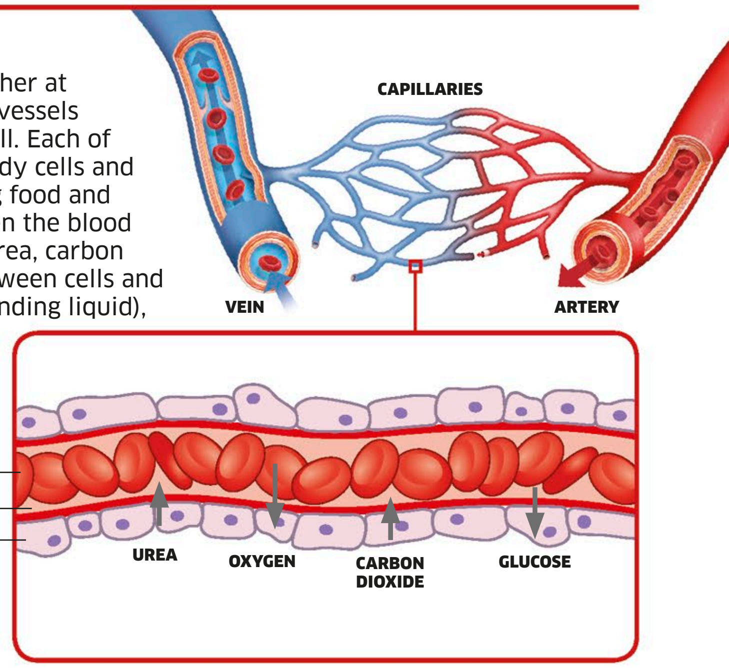
Tail fluke
The arrangement of blood vessels in the extreme end of a whale's tail—its fluke—helps to trap heat inside the body, as warm arteries transfer their heat to cooler surrounding veins.



Vein valves
One-way valves in the veins close off behind the blood as it passes through, to stop it flowing back the other way.

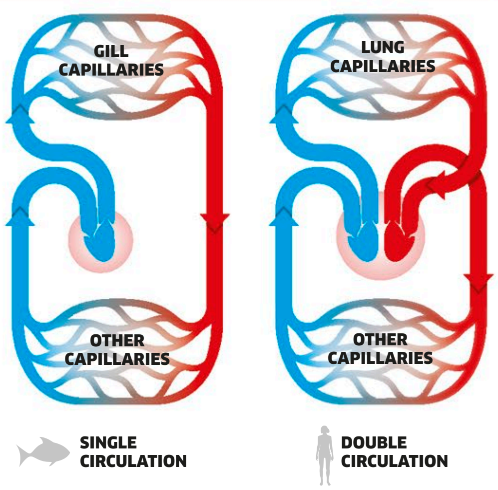
Capillaries

Arteries and veins join each other at capillaries—microscopic blood vessels scarcely wider than a single cell. Each of these flows directly next to body cells and has an ultra-thin wall, allowing food and waste to be exchanged between the blood and other parts of the body. Urea, carbon dioxide, and glucose move between cells and the blood's plasma (the surrounding liquid), whereas oxygen is carried in red blood cells and released into the body cells from those.



Double circulation

Mammals have a more efficient circulation than fishes. Blood pumped by a fish's heart moves through the gills to pick up oxygen, travels around the rest of the body, and only then returns back to the heart. However, in mammals, blood returns to the heart directly after the lungs. It then has more pressure when it flows to the cells, making exchanges easier. This is why mammals have four chambers in their hearts—both an upper and lower chamber for each circuit.



Spiders breathe using structures called book lungs—flat air-filled plates stacked on top of each other that resemble the pages of a book.

Breathing

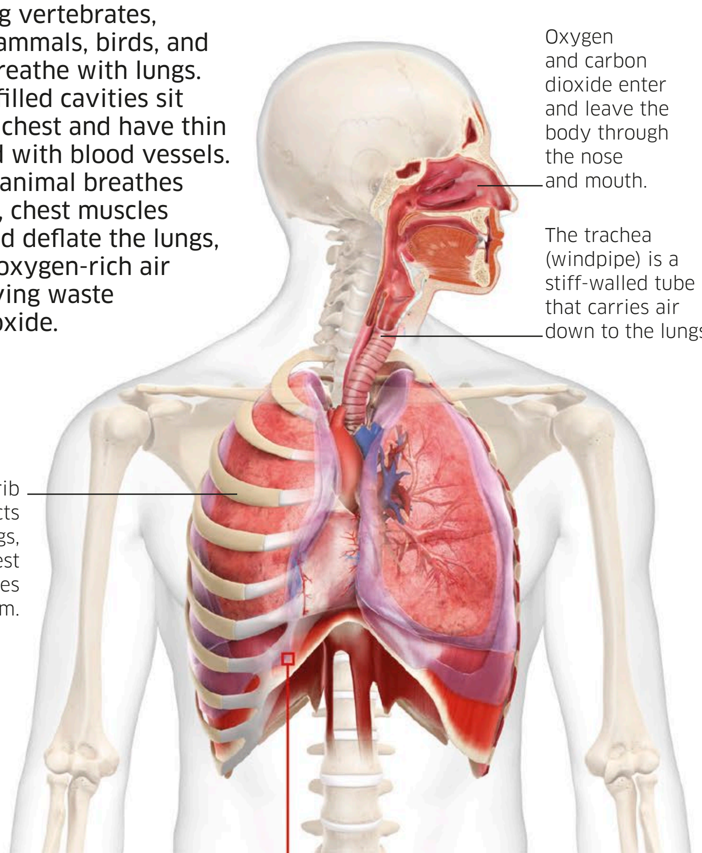
An animal breathes to supply its cells with oxygen—a vital resource that helps to burn up food and release much-needed energy around the body.

All organisms—including animals, plants, and microbes—get energy from respiration, a chemical reaction that happens inside cells. Most do this by reacting food with oxygen, producing carbon dioxide as a waste product. To drive the oxygen into the body, different animals have highly adapted respiratory systems, such as lungs or gills. These can exchange large quantities of gas, carrying oxygen to respiring cells in the bloodstream, and excreting waste carbon dioxide.

Oxygen traveling in the blood is attached to a pigment called hemoglobin—
the substance that gives blood its red color.

Breathing with lungs

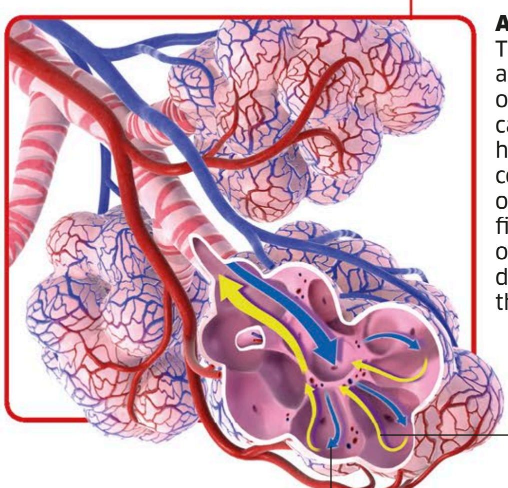
Land-living vertebrates, such as mammals, birds, and reptiles, breathe with lungs. These air-filled cavities sit inside the chest and have thin walls lined with blood vessels. When the animal breathes in and out, chest muscles expand and deflate the lungs, pulling in oxygen-rich air and removing waste carbon dioxide.



Oxygen and carbon dioxide enter and leave the body through the nose and mouth.

The trachea (windpipe) is a stiff-walled tube that carries air down to the lungs.

A sturdy rib cage protects the lungs, while chest muscles power them.



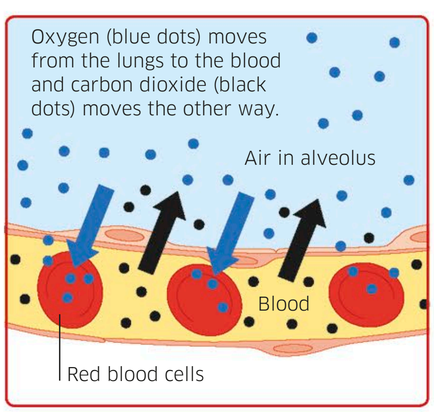
Alveoli
The lungs of mammals are made up of millions of microscopic sacs called alveoli. Each sac has an ultra-thin wall covered in a network of blood capillaries. This fine surface allows lots of oxygen and carbon dioxide to move between the air and the blood.

Waste carbon dioxide is transferred back from the blood to the lungs.

Oxygen moves through the very thin walls of the alveoli into the blood capillaries.

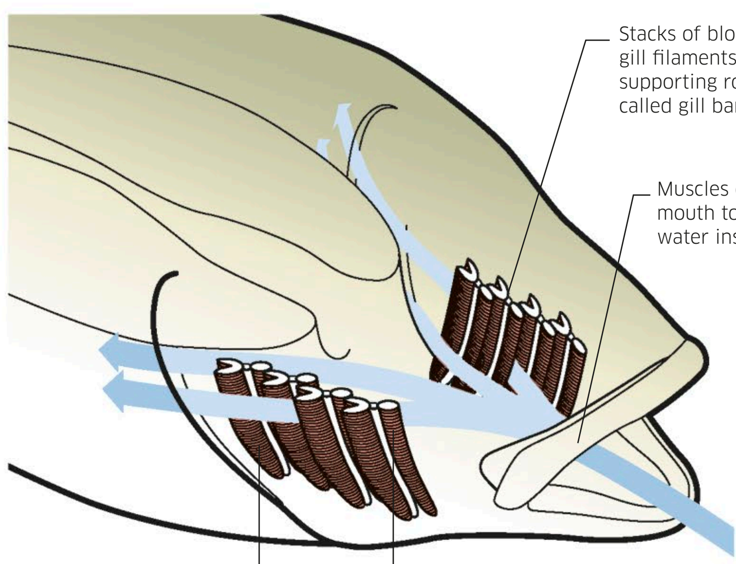
Diffusion

Oxygen and carbon dioxide are able to cross the microscopic membrane between the lungs and the blood by diffusion: a process by which molecules naturally move from an area where they are highly concentrated to one in which their numbers are fewer. This happens all around the body, as gases move between blood and respiring cells.



Breathing with gills

Gills are feathery extensions of the body that splay out in water so that aquatic animals can breathe. The delicate, blood-filled gills of fish are protected inside chambers on either side of their mouth cavity. A fish breathes by opening its mouth to draw oxygen-rich water over its gills. Some fishes rely on the stream created as they swim forward, but most use throat muscles to gulp water. Oxygen moves from the gills into the blood, while stale water emerges from the gill openings on either side of the head.



Stacks of blood-filled gill filaments sit on supporting rods called gill bars.

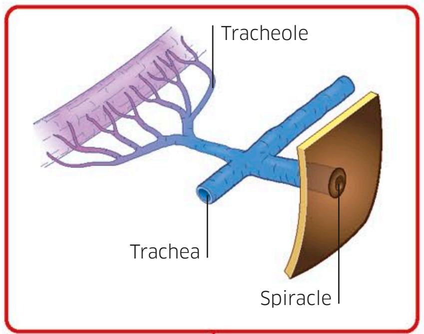
Muscles open the mouth to draw water inside.

Gill filaments on the bars absorb oxygen and release waste carbon dioxide.

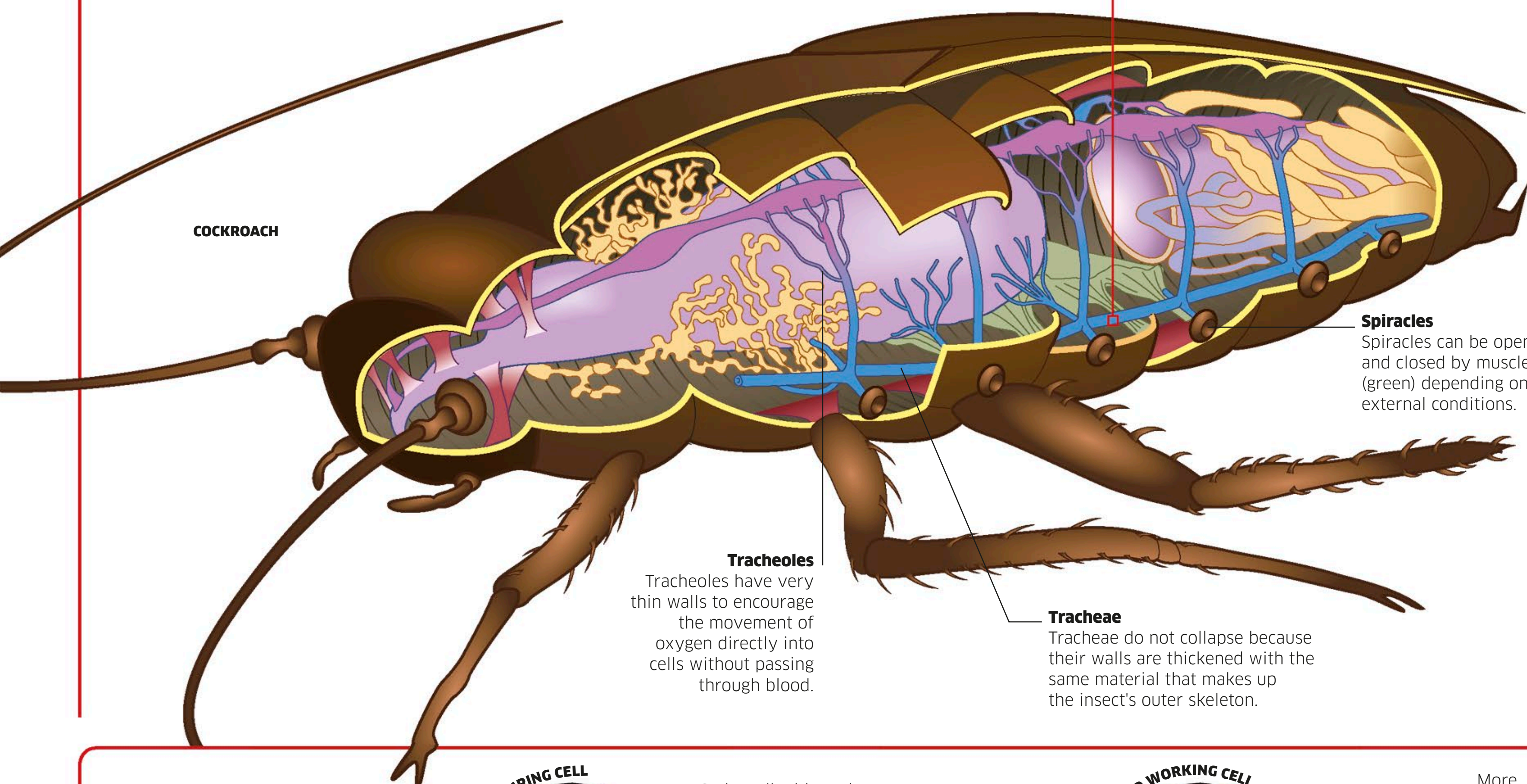
Throat muscles push water out between the gill bars.

Breathing with tracheae

Insects and related invertebrates have a breathing system that gets oxygen directly to their muscles. Instead of oxygen being carried in the blood, an intricate network of pipes reaches into the body from breathing holes called spiracles. Each pipe—known as a trachea—splits into tinier branches called tracheoles. The tracheoles are precisely arranged so that their tips penetrate the body's cells. This delivers oxygen-rich air from the surroundings deep into the insect, where respiration takes place.

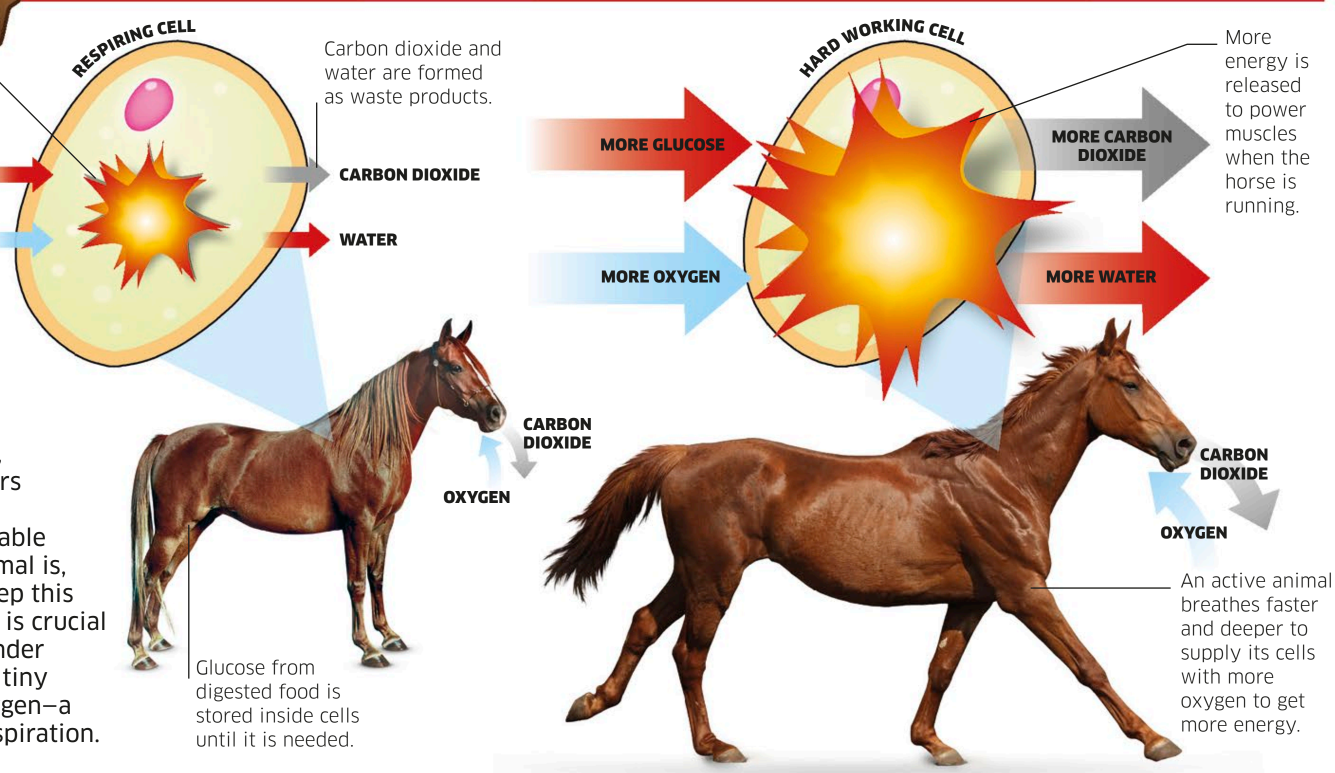


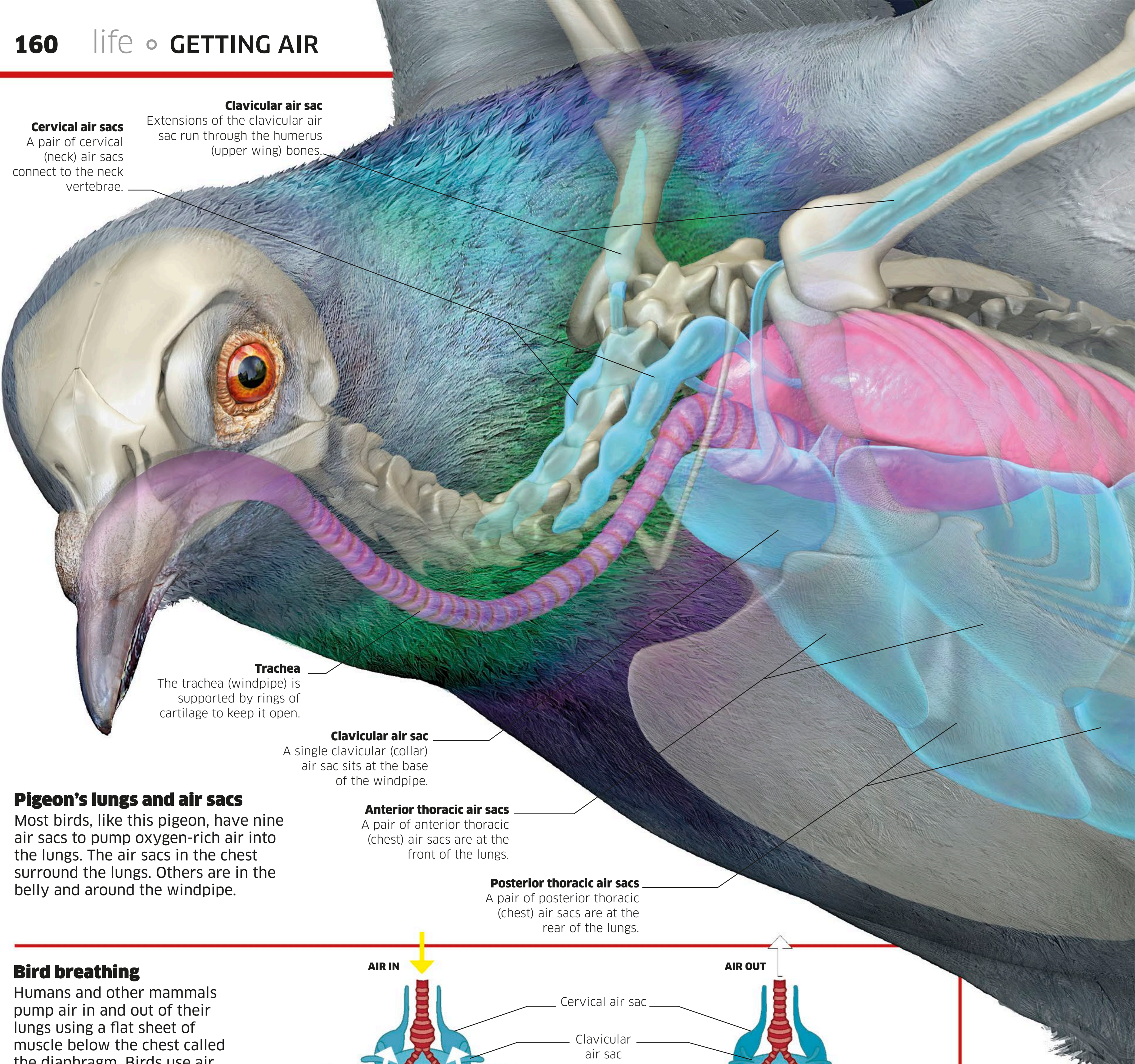
Tracheoles
Microscopic air-filled tracheoles in the body of an insect perform a similar role to blood-filled capillaries in other animals: they pass oxygen into the cells, while carbon dioxide moves out. This direct and efficient system means cells get oxygen delivered straight to them.



Cellular respiration

The oxygen an animal brings into its body is used in a chemical process called respiration. This mainly takes place in capsules within cells, called mitochondria. Here, energy-rich foods, such as sugars (glucose), are broken down into smaller molecules to release usable energy. The more active an animal is, the more oxygen it needs to keep this reaction running. While oxygen is crucial for most respiration, animals under physical pressure can release a tiny bit of extra energy without oxygen—a process known as anaerobic respiration.



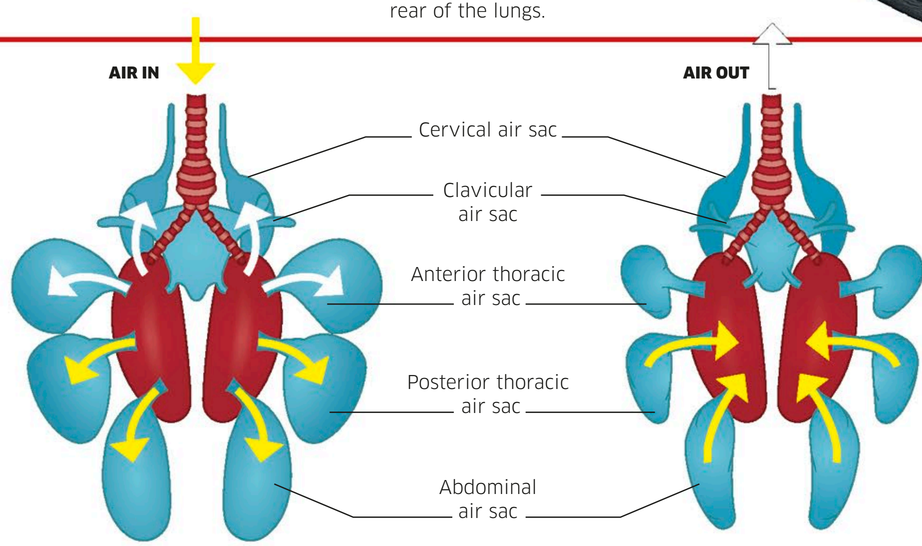


Pigeon's lungs and air sacs

Most birds, like this pigeon, have nine air sacs to pump oxygen-rich air into the lungs. The air sacs in the chest surround the lungs. Others are in the belly and around the windpipe.

Bird breathing

Humans and other mammals pump air in and out of their lungs using a flat sheet of muscle below the chest called the diaphragm. Birds use air sacs instead to move fresh air through their bodies when breathing in and breathing out. Air circulates one way from the rear air sacs, through the lungs to the front air sacs. The air sacs—which account for 20 percent of the body volume—also help to stop the bird overheating, and make swimming birds buoyant.



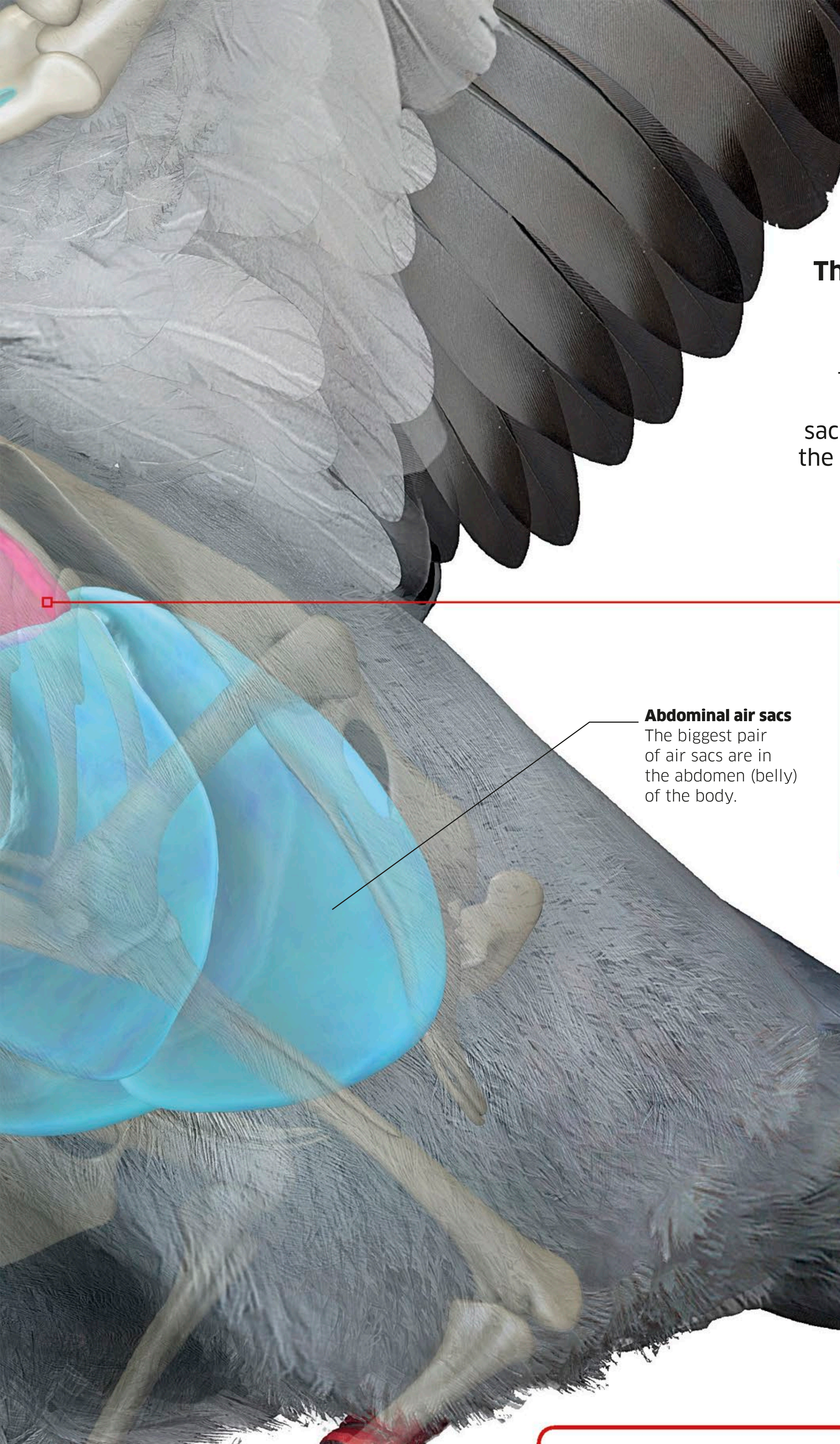
Inhalation
When a bird breathes in, the air entering the body first fills air sacs at the rear (yellow). At the same time, the air that was already in the lungs moves out to inflate the front air sacs (white).

Exhalation
When breathing out, all the air sacs work like bellows to pump air as they deflate. The rear air sacs fill the lungs with air, while the front air sacs push air back out through the mouth.

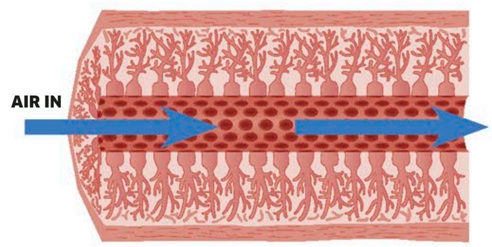
Getting air

Birds need plenty of energy to fuel active lives. Their beautifully efficient system for getting oxygen to cells is unique—no other animal has one quite like it.

The key to a bird's breathing system lies in big, air-filled sacs that pack the body. They help supply air to the lungs, which—unlike human lungs—are small and rigid. Breathing makes the sacs inflate and deflate like balloons, sweeping fresh air through the lungs. Oxygen continually seeps into the blood and circulates to the cells, so they can release energy in respiration.



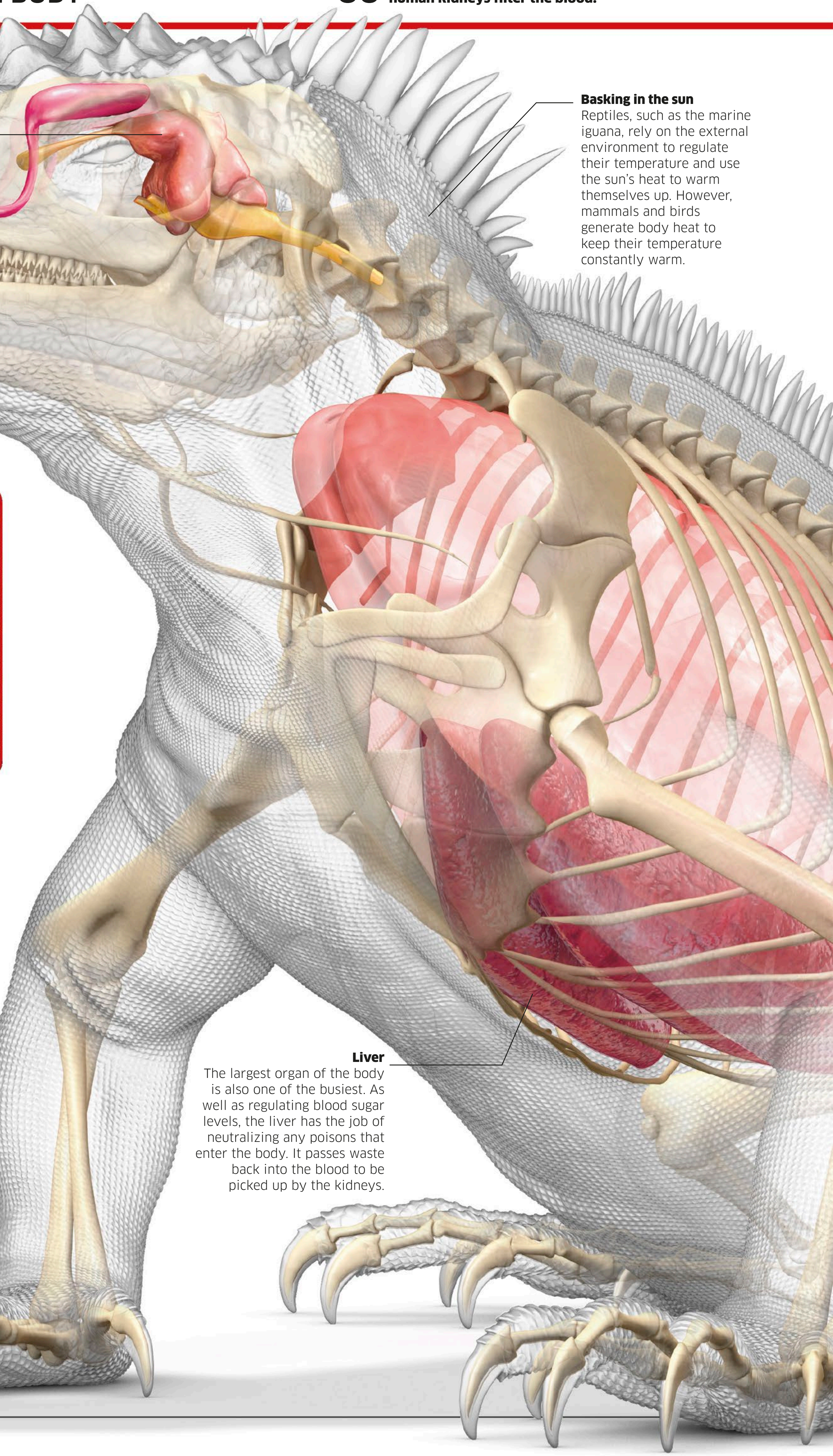
Abdominal air sacs
The biggest pair of air sacs are in the abdomen (belly) of the body.



Gaseous exchange
Each lung is filled with tiny air-filled vessels intermingled with microscopic blood vessels, helping to bring oxygen as close to the blood as possible.

Breathing at high altitudes
Traveling at high altitudes poses a special problem for some high-flying birds, as the air gets so thin that there is little oxygen. The migration route of bar-headed geese takes them over the Himalayas—the highest any known bird has flown. To cope with this, they have bigger lungs than other waterfowl and can breathe more deeply, while the pigment in their blood (hemoglobin) traps oxygen in the thin air especially well.

60 **times a day**—how often human kidneys filter the blood.



Brain
The brain contains sensors that continually monitor the levels of substances, such as sugar and water, in the blood. When action is needed to regulate the levels, the brain sends signals—either nerve impulses or hormones—to parts of the body that are able to fix this, such as the kidneys.

Basking in the sun
Reptiles, such as the marine iguana, rely on the external environment to regulate their temperature and use the sun's heat to warm themselves up. However, mammals and birds generate body heat to keep their temperature constantly warm.

Dealing with salt
A diet of seaweed and an ocean life is high in salt. But too much salt damages cells, drawing water from them and making them dehydrated. Marine iguanas are able to stop the levels of salt from getting too high by removing the excess. Glands in the nose concentrate the salt into mucus and then an explosive sneeze scatters the salty spray.

Marine Iguana

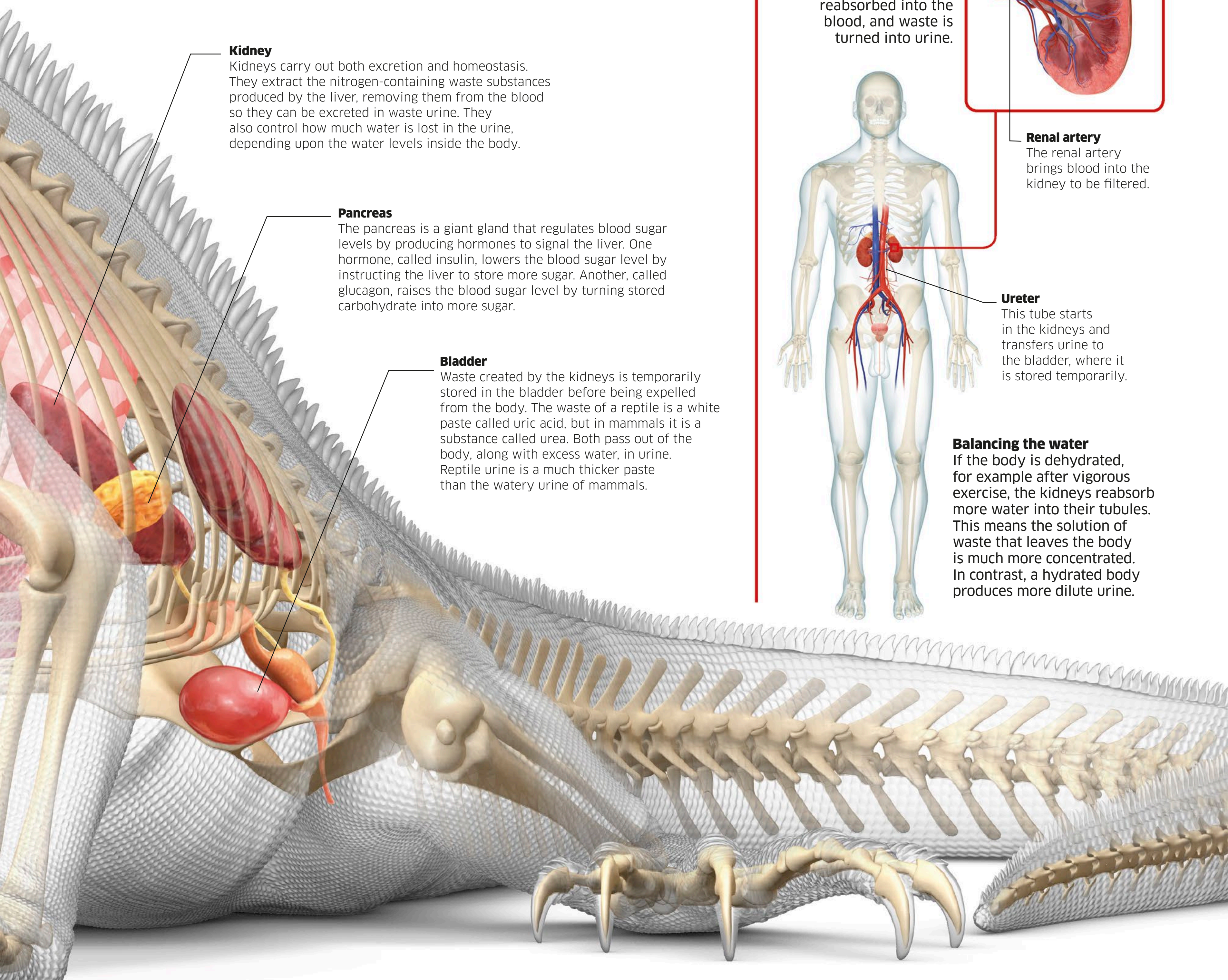
Found only in the Galápagos Islands, marine iguanas live an unusual life—diving for food in cold oceans, and then basking on rocks to warm up in the sun's rays. Homeostasis is carried out in each iguana's body by a complex variety of organs and glands. Glands are organs that produce chemical substances called hormones—tiny messengers that travel through the bloodstream to signal the relevant organ to take action.

Liver
The largest organ of the body is also one of the busiest. As well as regulating blood sugar levels, the liver has the job of neutralizing any poisons that enter the body. It passes waste back into the blood to be picked up by the kidneys.

Balancing the body

While external conditions may change from rain to shine, the internal environment of an animal's body is carefully controlled to ensure the vital processes of life can take place.

This balancing act is called homeostasis. Complex vertebrate (backboned) animals have especially good systems of homeostasis that regulate factors such as body temperature, blood sugar levels, and water levels. Alongside this, other areas of the body carry out a process called excretion to remove waste, which can be harmful if left to accumulate. This continual regulation gives the body the right set of conditions to carry out all the functions of life, such as processing food and releasing energy.



Kidney
Kidneys carry out both excretion and homeostasis. They extract the nitrogen-containing waste substances produced by the liver, removing them from the blood so they can be excreted in waste urine. They also control how much water is lost in the urine, depending upon the water levels inside the body.

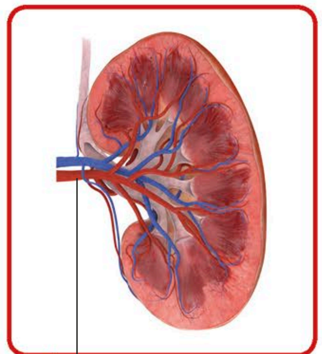
Pancreas
The pancreas is a giant gland that regulates blood sugar levels by producing hormones to signal the liver. One hormone, called insulin, lowers the blood sugar level by instructing the liver to store more sugar. Another, called glucagon, raises the blood sugar level by turning stored carbohydrate into more sugar.

Bladder
Waste created by the kidneys is temporarily stored in the bladder before being expelled from the body. The waste of a reptile is a white paste called uric acid, but in mammals it is a substance called urea. Both pass out of the body, along with excess water, in urine. Reptile urine is a much thicker paste than the watery urine of mammals.

Urinary system

Although mammal and reptile kidneys differ in their shape, both contain a complex system of blood vessels and tubes to filter the blood of waste products. These, along with the bladder, make up the urinary system. As well as removing excess water, most kidneys can also excrete in urine any unwanted salt, unlike those of the marine iguana.

Filtering the blood
Kidneys filter liquid, containing waste, directly from the blood. This liquid drains through tiny tubes, called tubules. Any useful substances are reabsorbed into the blood, and waste is turned into urine.



Renal artery
The renal artery brings blood into the kidney to be filtered.

Ureter
This tube starts in the kidneys and transfers urine to the bladder, where it is stored temporarily.

Balancing the water
If the body is dehydrated, for example after vigorous exercise, the kidneys reabsorb more water into their tubules. This means the solution of waste that leaves the body is much more concentrated. In contrast, a hydrated body produces more dilute urine.

Their **spindly nerve fibers** make nerve cells the longest of all cells—up to **3 ft (1 m)** in length.

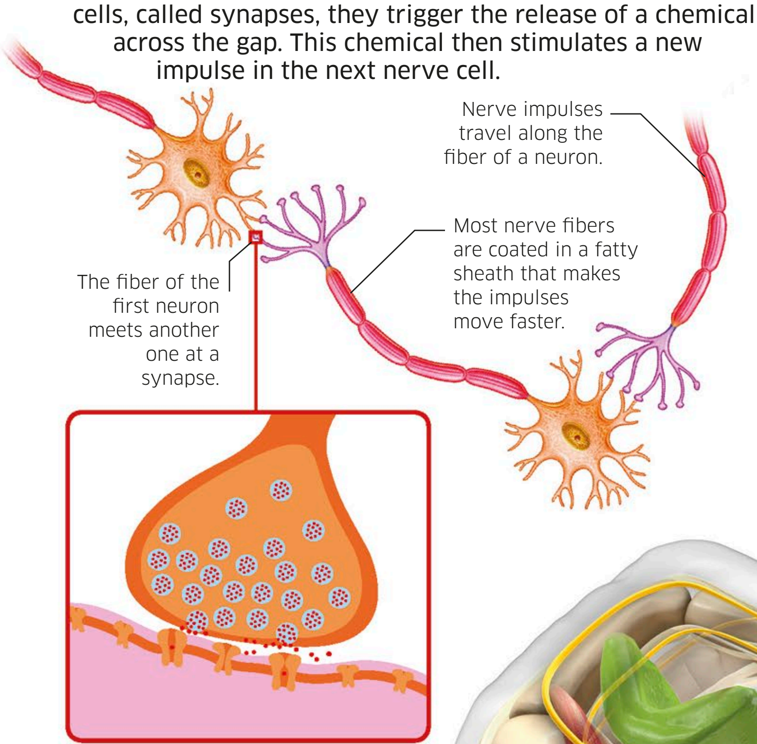
Nervous system

The speediest body system has cables that carry messages faster than a racing car, and a central control that is smarter than the best computer.

The cables of the nervous system are its nerves, and its control center is the brain. Every moment that the body senses its surroundings, the entire system sends countless electrical impulses through billions of fibers. The nerves trigger muscles to respond, and the brain coordinates all this complex activity.

Nerve cells and synapses

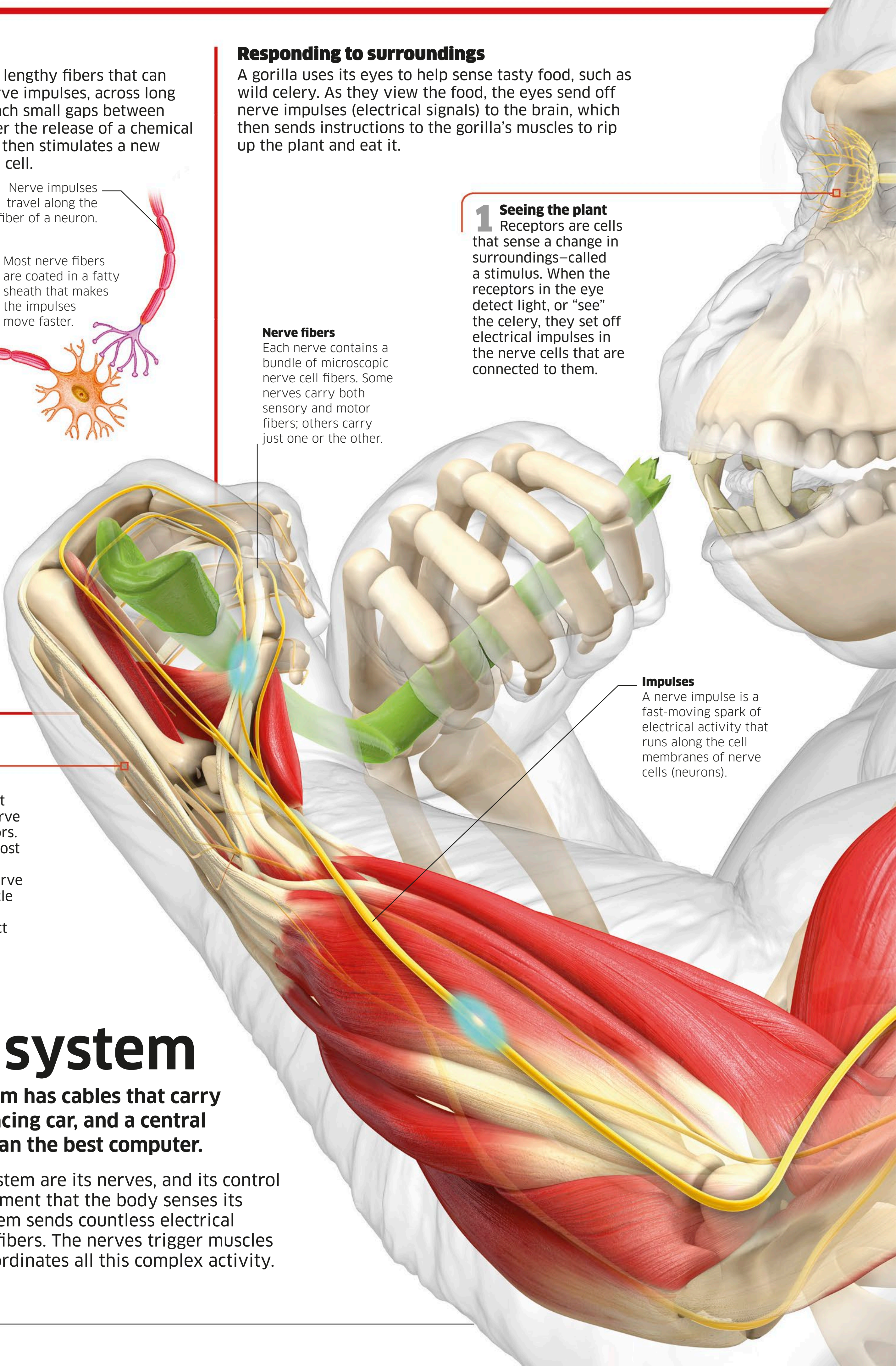
Cells of the nervous system have lengthy fibers that can carry electrical signals, called nerve impulses, across long distances. When these signals reach small gaps between cells, called synapses, they trigger the release of a chemical across the gap. This chemical then stimulates a new impulse in the next nerve cell.



Synapses
Tiny chemicals called neurotransmitters cross the gap between nerve cells. They are picked up by receptors on the other side.

Responding to surroundings

A gorilla uses its eyes to help sense tasty food, such as wild celery. As they view the food, the eyes send off nerve impulses (electrical signals) to the brain, which then sends instructions to the gorilla's muscles to rip up the plant and eat it.

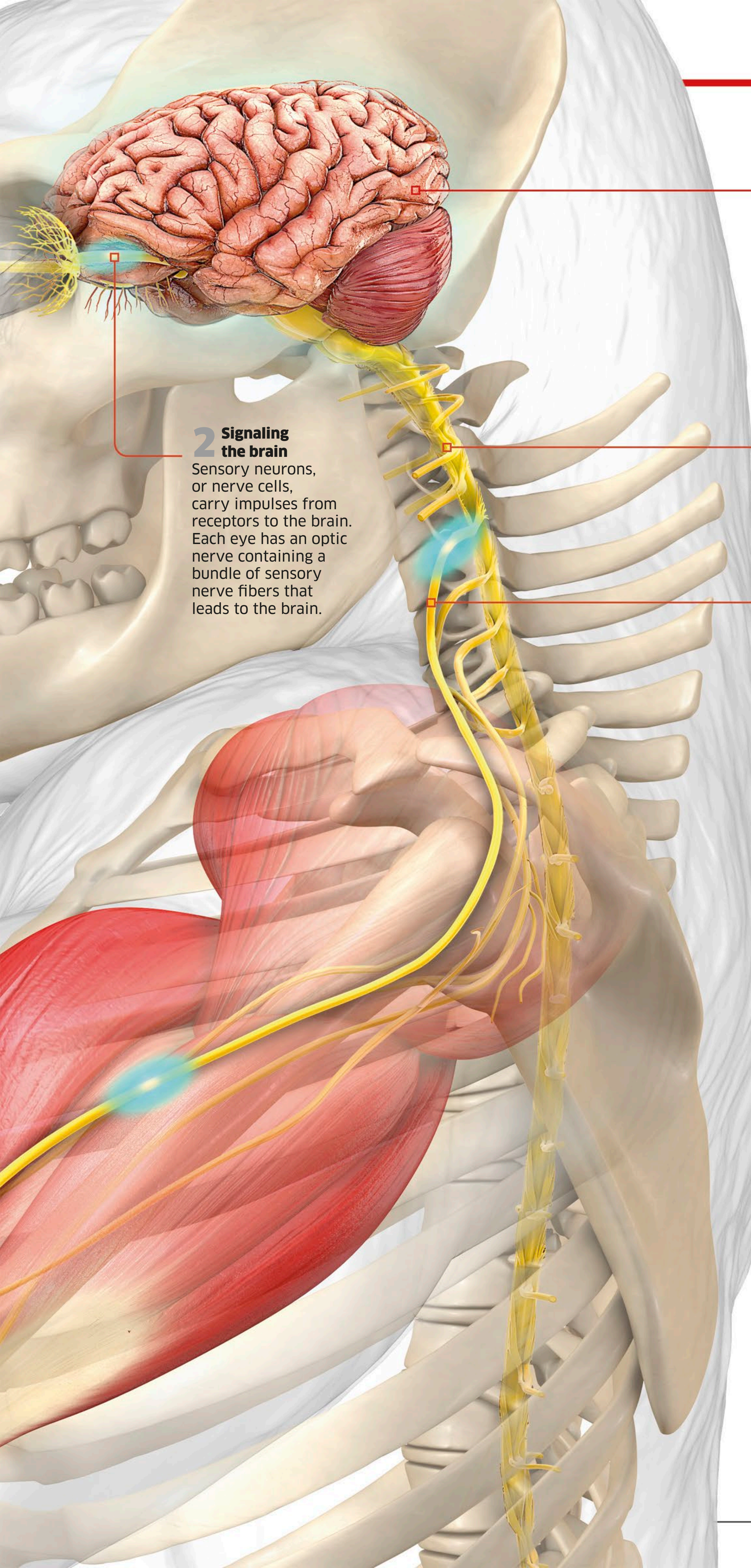


1 Seeing the plant
Receptors are cells that sense a change in surroundings—called a stimulus. When the receptors in the eye detect light, or "see" the celery, they set off electrical impulses in the nerve cells that are connected to them.

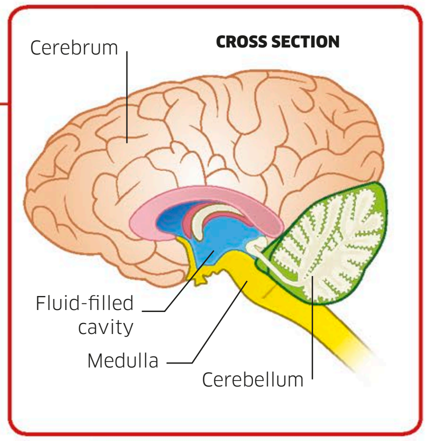
Nerve fibers
Each nerve contains a bundle of microscopic nerve cell fibers. Some nerves carry both sensory and motor fibers; others carry just one or the other.

Impulses
A nerve impulse is a fast-moving spark of electrical activity that runs along the cell membranes of nerve cells (neurons).

6 Hands respond
Parts of the body that move in response to a nerve impulse are called effectors. Muscles are among the most important effectors of an animal's body. When a nerve impulse arrives at a muscle along a motor neuron, it makes the muscle contract (shorten)—in this case to grip and tear the celery.



2 Signaling the brain
Sensory neurons, or nerve cells, carry impulses from receptors to the brain. Each eye has an optic nerve containing a bundle of sensory nerve fibers that leads to the brain.



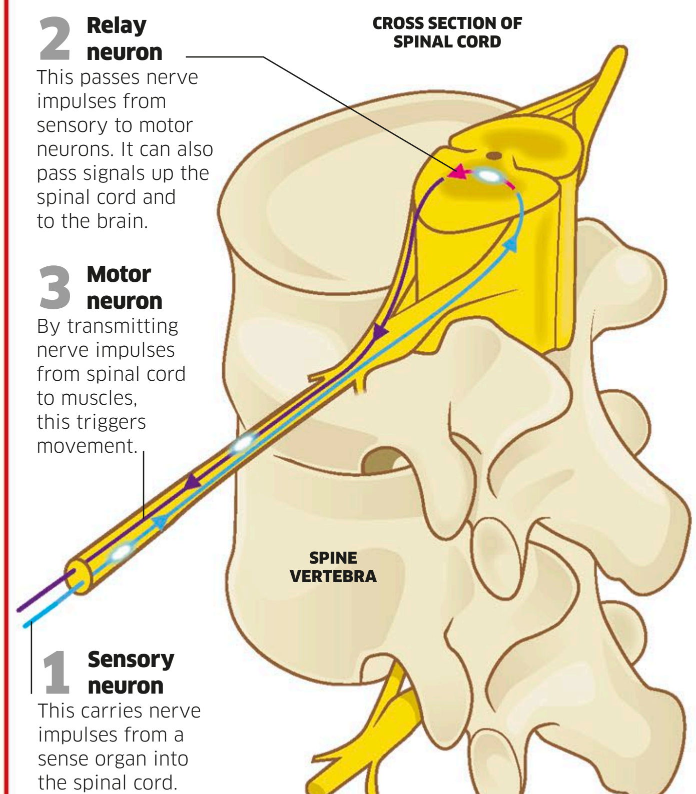
3 Coordinating a response
The brain coordinates where impulses go in order to control the body's behavior. The cerebrum manages complex actions that demand intelligence, like peeling and breaking up food. More routine actions, such as walking, are controlled by the cerebellum, while the medulla effects internal functions, like breathing.

4 Traveling onward
Together with the brain, the spinal cord makes up the central nervous system. It works with the brain to pass signals around the body. Impulses traveling from the brain branch off from the spinal cord to motor neurons.

5 Signaling the muscles
Cells that carry impulses from the central nervous system to muscles are called motor neurons. Bundles of motor neuron fibers are grouped into nerves that run all the way from the spinal cord to the limb muscles.

Reflex actions

Some automatic responses, called reflex actions, do not involve the brain, such as when you recoil after touching something hot. In these instances, impulses travel from the sense organs to the spinal cord, where relay neurons pass the signal to the muscles. Bypassing the brain allows the impulses to reach the effectors and generate a response much more quickly.



2 Relay neuron
This passes nerve impulses from sensory to motor neurons. It can also pass signals up the spinal cord and to the brain.

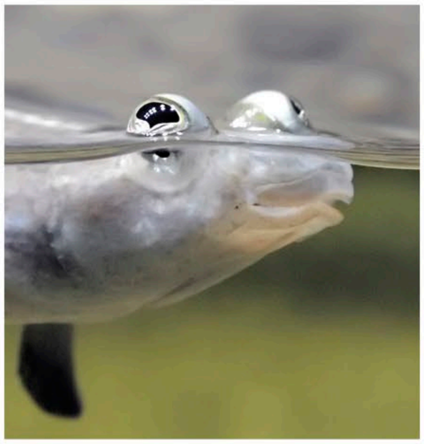
3 Motor neuron
By transmitting nerve impulses from spinal cord to muscles, this triggers movement.

1 Sensory neuron
This carries nerve impulses from a sense organ into the spinal cord.

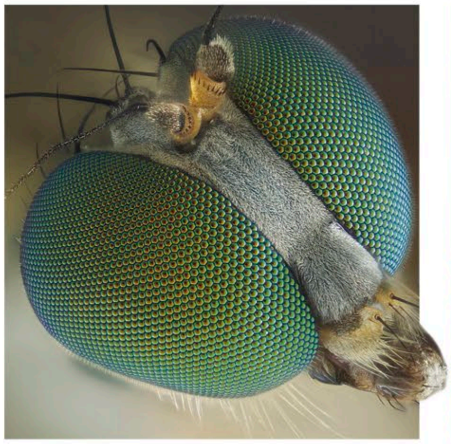
Catfish have **10 times more taste buds** on their body **than on a human tongue.**

Vision

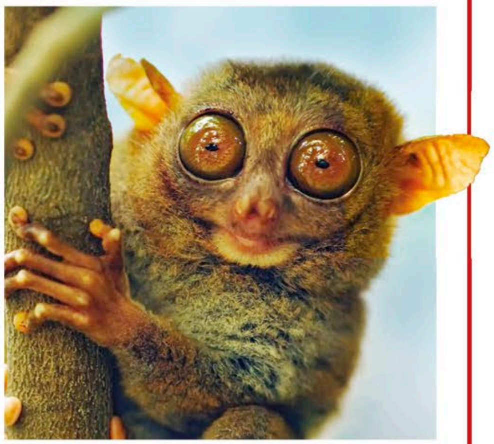
Eyes packed with light-sensitive cells enable animals to see. Vertebrates, such as humans, have two camera-like eyes that focus light onto the back of the eye. But some invertebrates rely on many more eyes—the giant clam has hundreds of tiny eyes scattered over its body. Each animal's eyes are specialized in different ways. Some are so sensitive that they can pick up the faintest light in the dark of night or in the deep sea.



Four-eyed fish
When it swims at the surface, this fish's split-level eyes help it to focus on objects above and below the water.



Long-legged fly
Flies and many other insects have compound eyes—made up of thousands of tiny lenses.



Tarsier
This primate's eyes are the biggest of any mammal when compared to the size of its head. They help it see well at night.

Senses

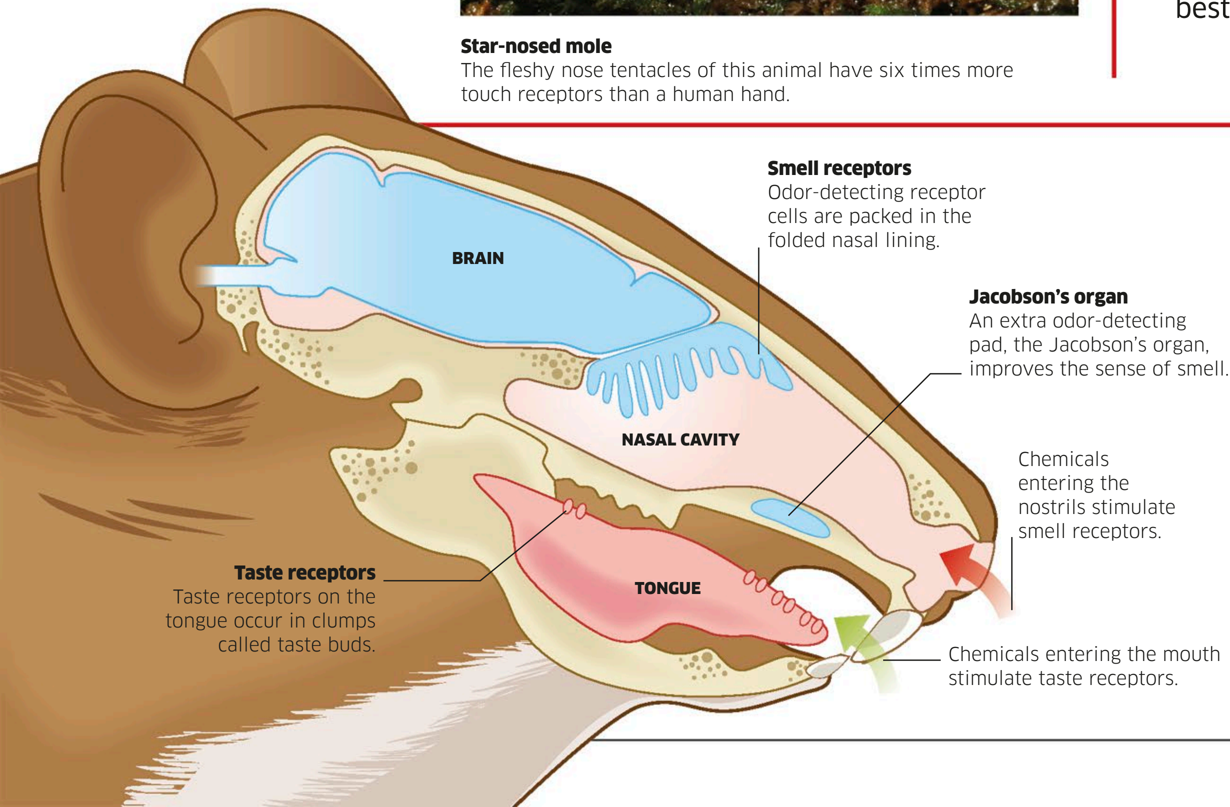
Animals sense their surroundings using organs that are triggered by light, sound, chemicals, or a whole range of other cues.

Sense organs are part of an animal's nervous system. They contain special cells called receptors that are stimulated by changes in the environment and pass on signals to the brain and the rest of the body. Through these organs animals can gain a wealth of information about their surroundings, equipping them to react to threats or opportunities. Each kind of animal has sense organs that are best suited to the way it lives.

Touch

Animals have receptors in their skin that sense when other things come into contact with their body. Some receptors only pick up firm pressures, while others are sensitive to the lightest of touches. Receptor cells are especially concentrated in parts of the body that rely a lot on feeling textures or movement. Human fingertips are crammed with touch receptors, as are the whiskers of many cats, and the unusual nose of the star-nosed mole.

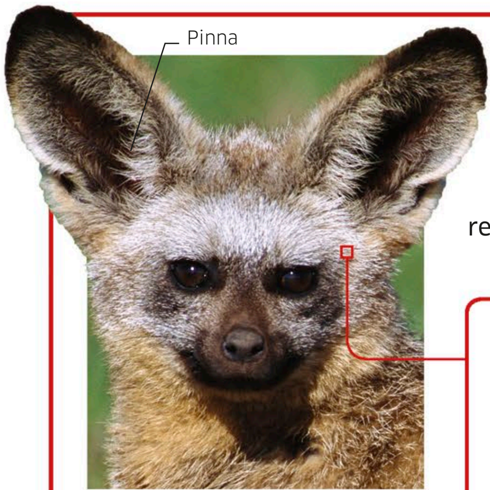
Star-nosed mole
The fleshy nose tentacles of this animal have six times more touch receptors than a human hand.



Taste and smell

Smelling and tasting are two very similar senses, as they both detect chemicals. The tongue has receptors that taste the chemicals dissolved in food and drinks, and receptors inside the nose cavities pick up the chemicals in odors. Some animals that are especially reliant on chemical senses, or that do not have receptors elsewhere, have a concentrated patch of receptors in the roof of their mouth, called a Jacobson's organ.

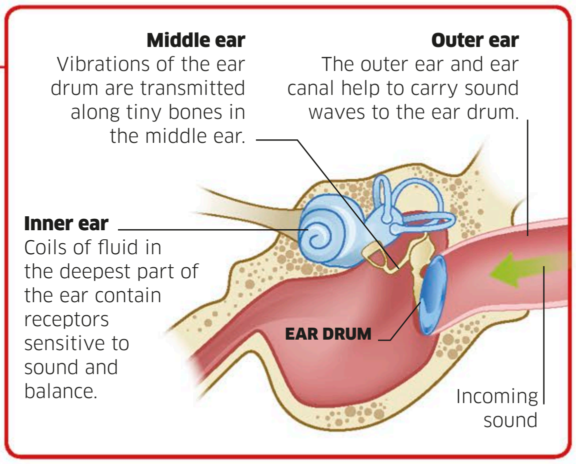
Mouse senses
Like most mammals, a mouse has a keen nose. It uses smell to communicate with others of its kind: signaling a territorial claim or a willingness to mate. A mouse's tongue detects tastes in food, and both tongue and nose send signals to the brain.



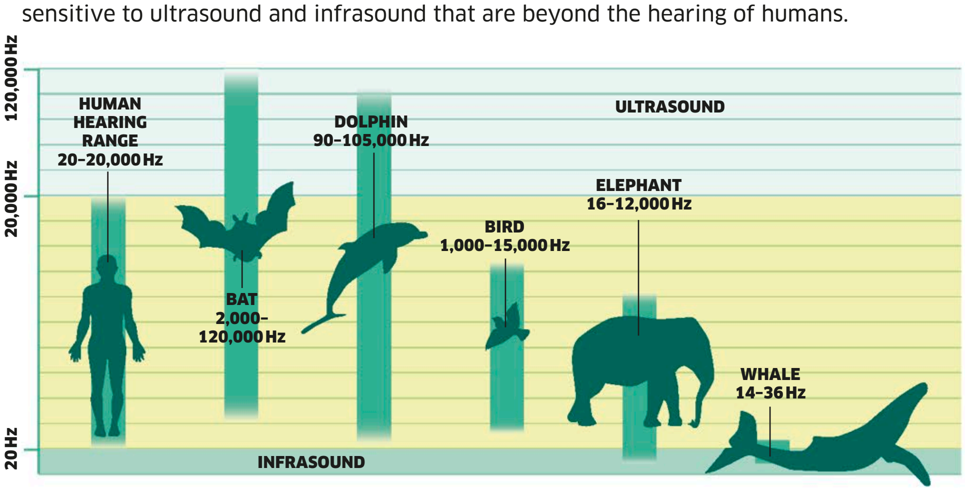
Hearing

Animals hear because their ears contain receptors that are sensitive to sound waves. As the waves enter the ear, they vibrate a membrane called an ear drum. The vibrations pass along a chain of tiny bones until they reach the receptors within the inner ear.

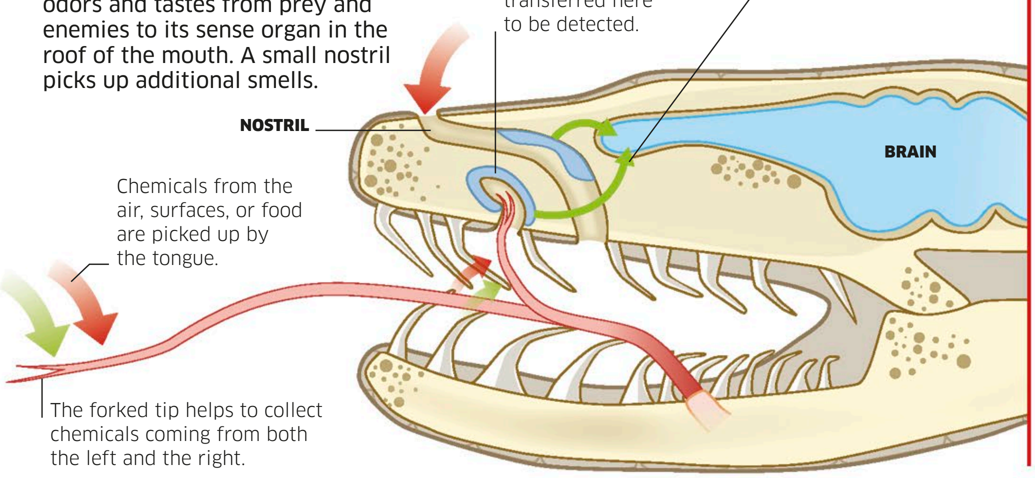
Bat-eared fox
In mammals, each ear opening is surrounded by a fleshy funnel for collecting sound, called a pinna. The desert-living bat-eared fox has such large pinnae that it also uses them to radiate warmth to stop it from overheating.



Hearing ranges
The pitch, or frequency, of a sound is measured in hertz (Hz): the number of vibrations per second. Different kinds of animals detect different ranges of pitch, and many are sensitive to ultrasound and infrasound that are beyond the hearing of humans.

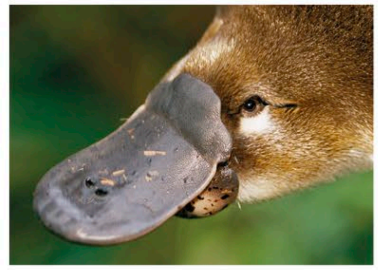


Snake senses
A snake's tongue has no receptors and instead is used for transferring odors and tastes from prey and enemies to its sense organ in the roof of the mouth. A small nostril picks up additional smells.



Other ways of sensing the world

The lives of many kinds of animals rely on quite extraordinary sensory systems. Some have peculiar types of receptors that are not found in other animals. These give them the power to sense their surroundings in ways that seem quite unfamiliar to us—such as by picking up electrical or magnetic fields.

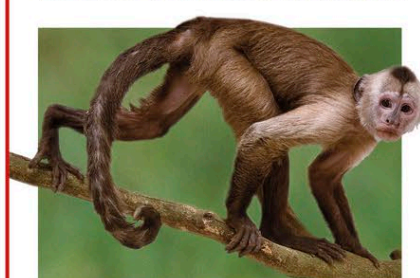


Electroreception
The rubbery bill of the platypus—an aquatic egg-laying mammal—contains receptors that detect electrical signals coming from the muscles of moving prey. They help the platypus find worms and crayfish in murky river waters.

Echolocation
Bats and dolphins use echolocation to navigate and find food. By calling out and listening for the echoes bouncing back from nearby objects, they can work out the positions of obstacles and prey.

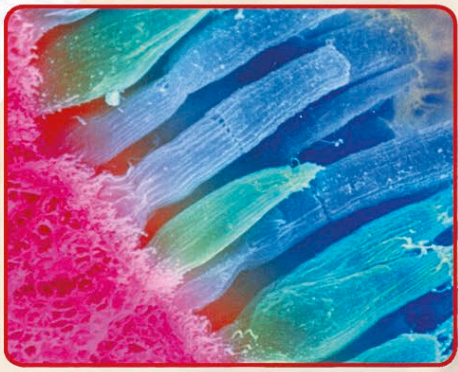
Fire detection
Most animals flee from fire, but the fire beetle thrives near flames. Its receptors pick up the infrared radiation coming from a blaze, drawing it to burned-out trees where it can breed undisturbed by predators.

Magnetoreception
Birds can sense the earth's magnetic field. By combining this with information about the time of day and position of the sun or stars, they can navigate their way on long-distance migrations.

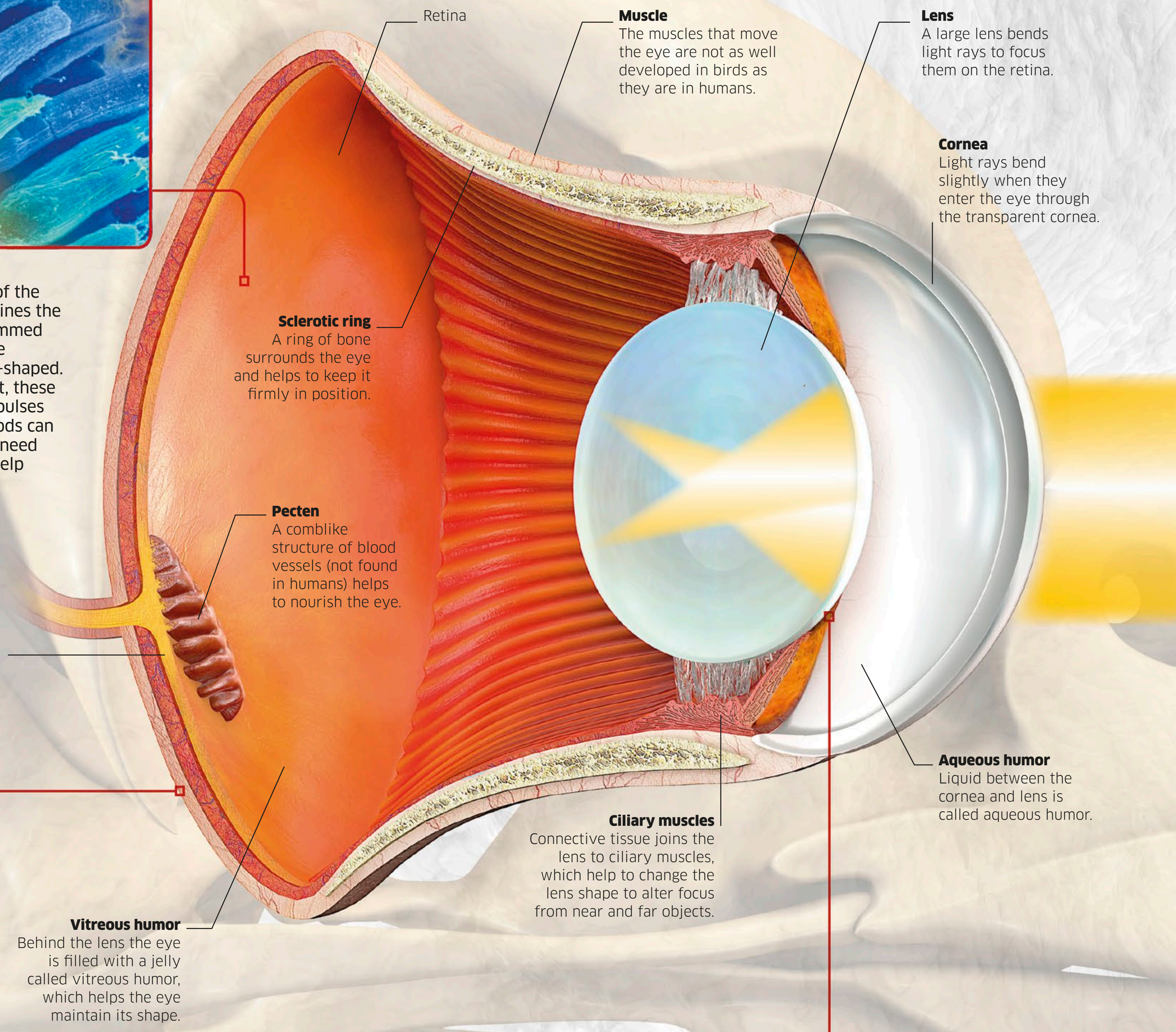


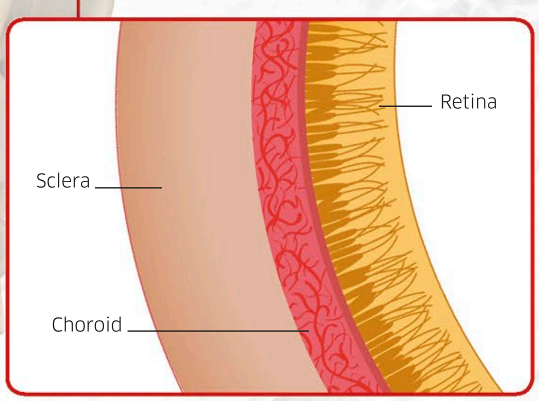
Balance
All vertebrate animals have balance receptors in their ears to sense the position of their head and tell up from down. These help humans walk upright and stop climbing animals, such as capuchin monkeys, from falling out of trees.

Time
Tiny animals, such as insects, experience time more slowly because their senses can process more information every second. Compared with humans, houseflies see everything in slow motion—helping them to dodge predators.

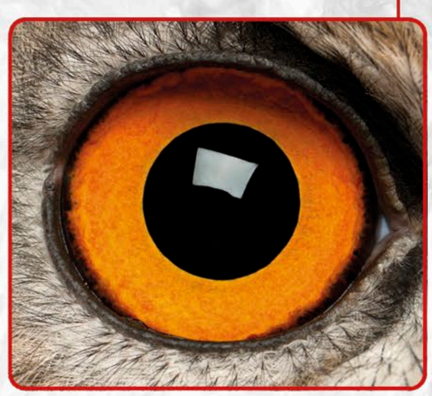


Seeing the detail
The light-sensitive part of the eye is the retina, which lines the back of the eye. It is crammed with receptor cells—some rod-shaped, others cone-shaped. When stimulated by light, these send electrical nerve impulses to the brain. While the rods can work in dim light, cones need brighter light, but they help the animal see things in more detail and in color.





Layers of the eye
As well as the light-sensitive retina, the eye has two other layers: the sclera, and the choroid. The sclera is the tough outer layer—in humans extending around the front to form the "white" of the eye. The choroid is packed with blood vessels and provides the eye's oxygen supply. It also contains a dark pigment, which in day-active animals stops light from being reflected too much inside the eye.



Iris and pupil
The iris is located at the front of the eye, just behind the transparent cornea and a layer of clear liquid. It forms a bright colored ring with a dark hole at its center—the pupil—which is where light enters. Iris muscles control the amount of light coming into the eye by expanding the pupil in dim light and making it shrink in bright light.

Vision

The ability to see allows all animals to build up a detailed picture of their surroundings—vital for finding food and avoiding danger.

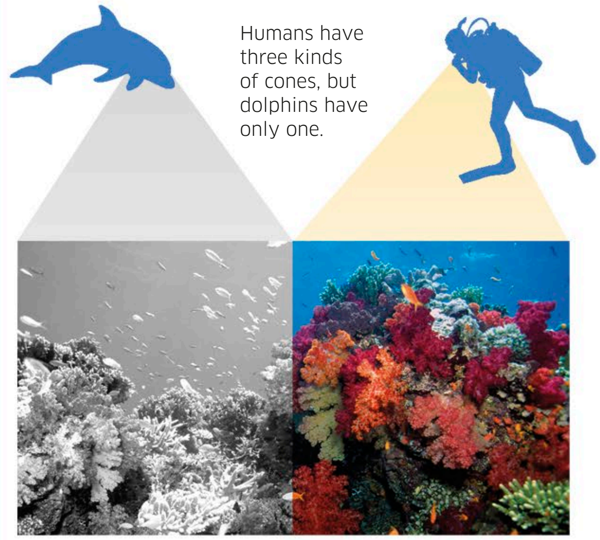
When an animal sees the world, its eyes pick up light and use lenses to focus this onto light-sensitive receptor cells. These cells then send signals to the brain, which composes a visual image of everything in the field of view. For animals with the best vision, the image can be finely detailed—even when the light is poor.

Night eyes

The eyes of birds are so big in proportion to their head that they are largely fixed inside their sockets. This means a bird must rotate its flexible neck to look around. Owl eyes, like those of many nocturnal birds, are especially large and are designed for good night vision. Their unusual shape creates room for a larger space at the back of the eye, packed with extra light-sensitive cells.

Seeing color

Receptor cells called cones are what allow animals to see color. These detect different light wavelengths—from short blue wavelengths to long red ones. Animals with more types of cones can see more colors, but those with just one are only able to see the world in black and white.

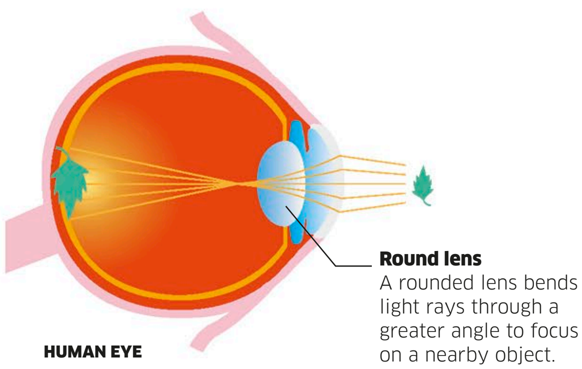


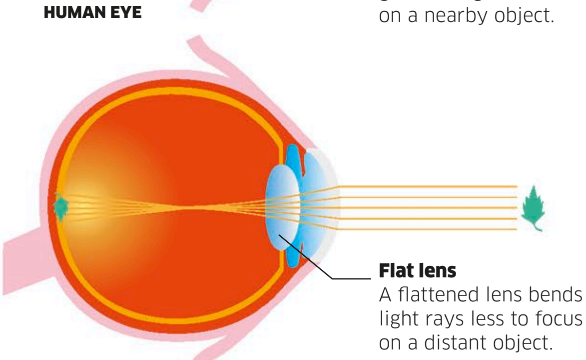
Three cones help humans see three primary colors: red, green, and blue, plus all their combinations.

Many day-flying birds have one more type of cone than humans, meaning they can see ultraviolet.

Near and far

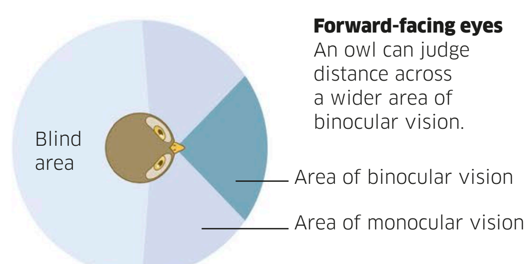
The eye's lens focuses light onto the retina, and can change shape to better focus on either closer objects or those farther away. A ring of muscle controls this shape. It contracts to make the lens rounder for near focus, and relaxes to pull the lens flatter for distant focus.

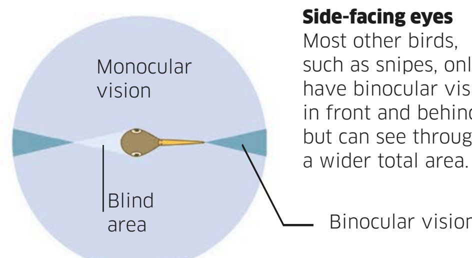


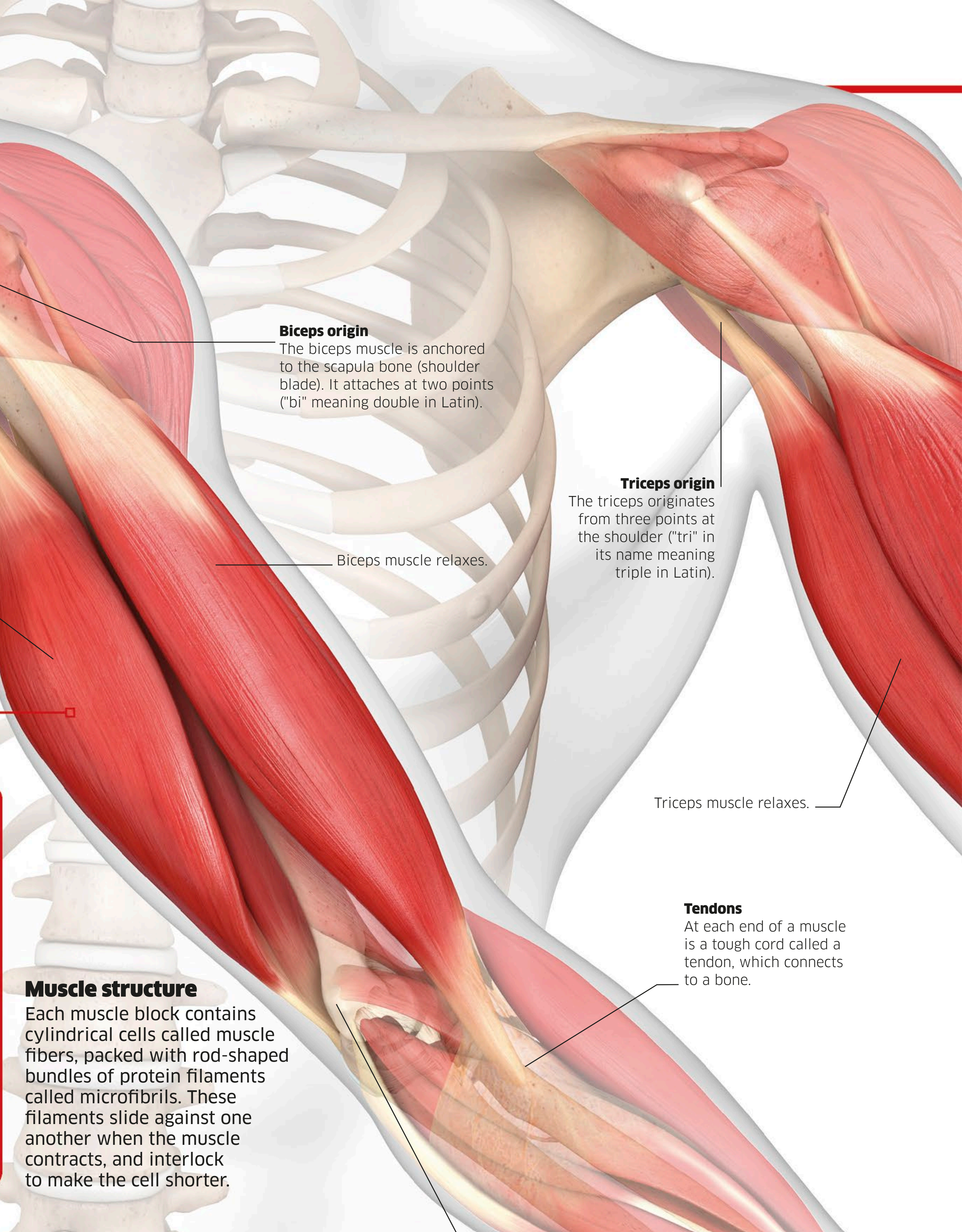


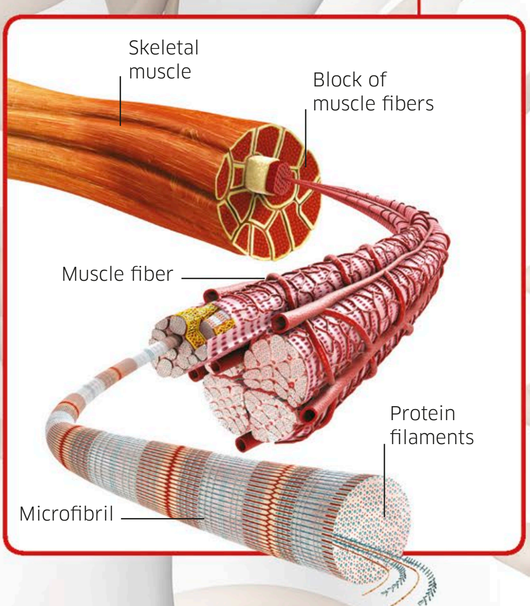
Binocular vision

When two forward-facing eyes have overlapping fields of view, this is called binocular vision. This gives an animal a three-dimensional view of the world, helping it to judge distance—a skill especially important for predators that hunt prey. Other animals with eyes on the sides of their head have a narrower range of binocular vision, but better all-around vision.









Muscle structure

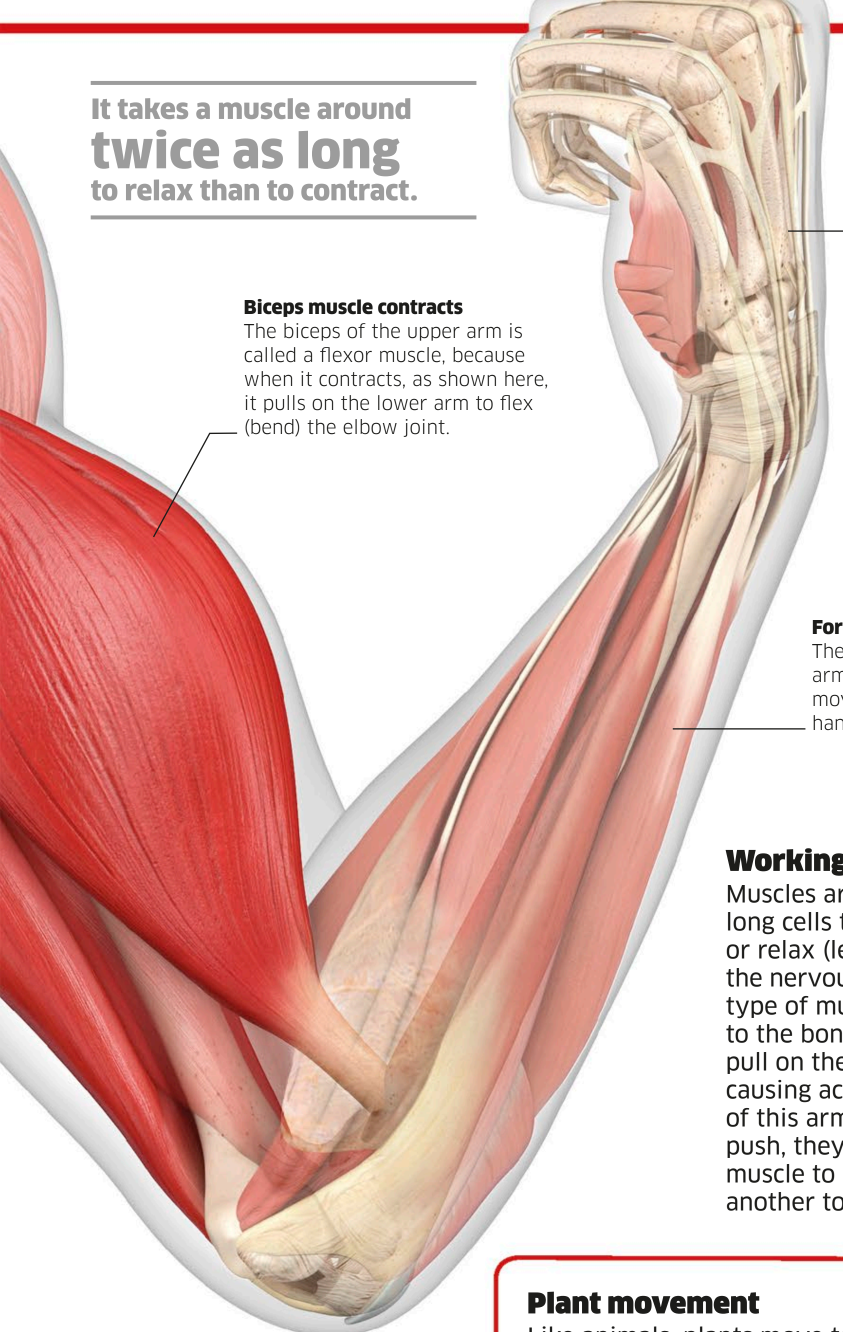
Each muscle block contains cylindrical cells called muscle fibers, packed with rod-shaped bundles of protein filaments called microfibrils. These filaments slide against one another when the muscle contracts, and interlock to make the cell shorter.

Movement

The ability to move can be the most obvious sign of life, found in all organisms from steadily climbing plants to sprinting animals that are some of the fastest things alive.

Animals have nerves and muscles that can work to make parts of their body move very quickly. Plants move, too: even though they are rooted to the ground, they make tiny motions that are hardly perceptible but build up over time. Even microscopic single-celled organisms can move. Movement can be a way of improving survival, enabling organisms to get nourishment, find mates, and avoid danger.

It takes a muscle around twice as long to relax than to contract.



Biceps muscle contracts
The biceps of the upper arm is called a flexor muscle, because when it contracts, as shown here, it pulls on the lower arm to flex (bend) the elbow joint.

Finger movement
There are no muscles in the fingers—only tendons. These connect to the muscles in the rest of the hand.

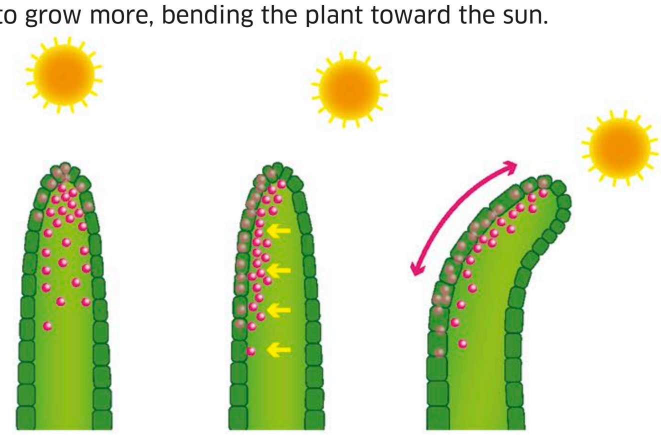
Forearm muscles
The muscles in the lower arm control the complex movements of the wrist, hand, and fingers.

Working in pairs

Muscles are made up of bundles of long cells that either contract (shorten) or relax (lengthen) when triggered by the nervous system. The most common type of muscles are those connected to the bones of the skeleton. They pull on the bones when they contract, causing actions like the movement of this arm. Because muscles cannot push, they have to work in pairs—one muscle to pull the arm upward and another to pull it back down.

Plant movement

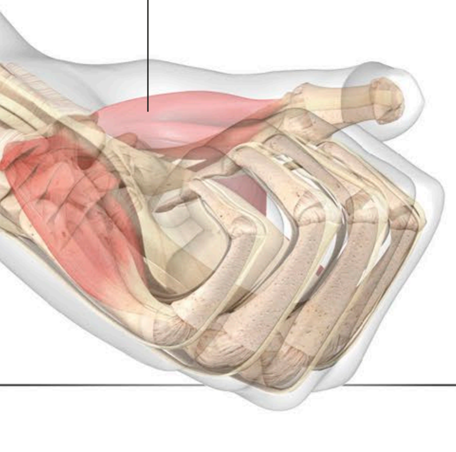
Like animals, plants move to make the most of their environment. The shoot tips of plants are especially sensitive to light and can slowly bend toward a light source. A chemical called auxin (which regulates growth) encourages the shadier side of the shoot to grow more, bending the plant toward the sun.



Auxin (pink) produced in the shoot tip spreads down through the shoot, making it grow upward.

When light shines from one direction, auxin moves to the shadier side.

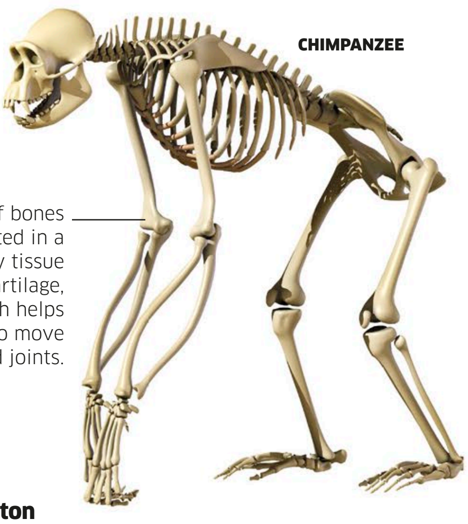
On the shadier side, the auxin stimulates the plant cells to grow bigger, so that the shoot bends toward the light.



Rotating the arm
As well as pulling the lower arm toward it, the biceps can also rotate the forearm so the palm of the hand faces upward.

Support structures

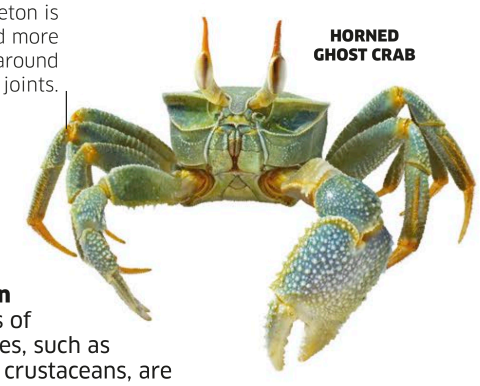
Animals have a skeleton to support their bodies and protect their soft organs. This is especially important for large land-living animals that are not supported by water. Skeletons also provide a firm support for contracting muscles, helping animals to have the strength to move around.



CHIMPANZEE

The ends of bones are coated in a slippery tissue called cartilage, which helps them to move around joints.

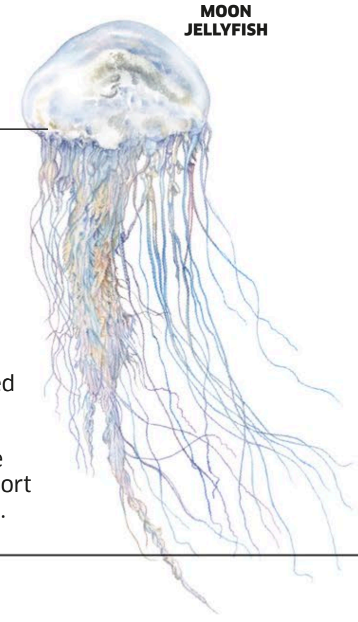
Endoskeleton
Vertebrate animals—including fish, amphibians, reptiles, birds, and mammals—have a hard internal skeleton within their bodies. The muscles surround the skeleton and pull on its bones.



HORNED GHOST CRAB

The skeleton is thinner and more flexible around the joints.

Exoskeleton
Many types of invertebrates, such as insects and crustaceans, are supported by an external skeleton that covers their body like a suit of armor with muscles inside. Exoskeletons cannot grow with the rest of the body, so must be periodically shed and replaced.



MOON JELLYFISH

Muscles in a jellyfish contract around a layer of thin jelly that keeps its body firm.

Hydroskeleton
Some kinds of soft-bodied animals, such as sea anemones and earthworms, are supported by internal pouches that stay firm because they are filled with fluid. These water-filled pouches support the muscles as they move.

Some **air-breathing fishes**, such as mudskippers and climbing perch, **use their fins to waddle over land**.

Getting around

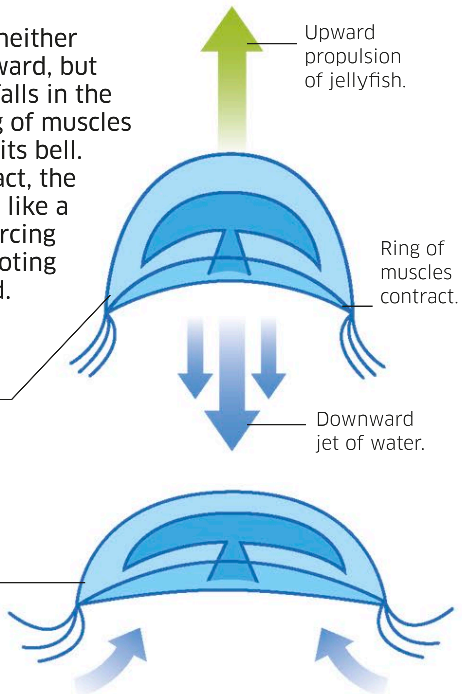
Whether over land, underwater, or in the air, animals can move themselves around in extraordinary ways when all their muscles work together.

Although all living things move parts of their body to an extent, only animals can truly "locomote". This is when the entire body moves to a different location. Some animals do it without any muscle power at all—riding on ocean currents or getting blown by the wind. But most animals locomote under their own steam. They do so for many different reasons: to find food or a mate, or to escape from predators. Some animals migrate over enormous distances from season to season, or even from day to day.

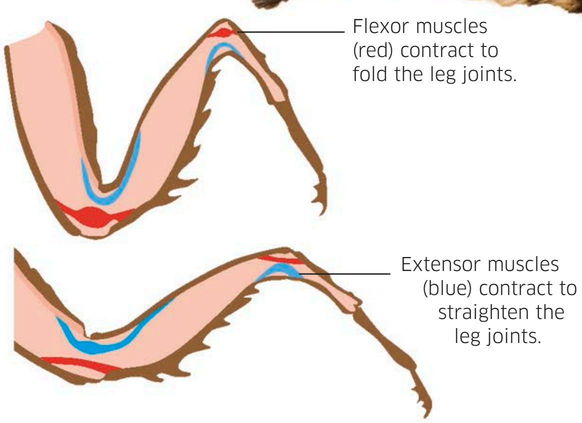
Tiny, deep ocean pygmy sharks grow no bigger than 8 in (20 cm), but each night swim 1 mile (1.5 km) up to the surface and back in order to feed.

Pulsating

A jellyfish moves neither forward nor backward, but instead rises and falls in the water. It has a ring of muscles around the rim of its bell. When these contract, the bell closes slightly like a drawstring bag, forcing water out and shooting the animal upward.



Tiger beetle
Predatory tiger beetles are fast sprinters. Like all insects, they have six legs, and when running they lift three simultaneously, leaving three in contact with the ground. However, their big eyes cannot keep up with their speed, meaning their vision is blurred every time they run.

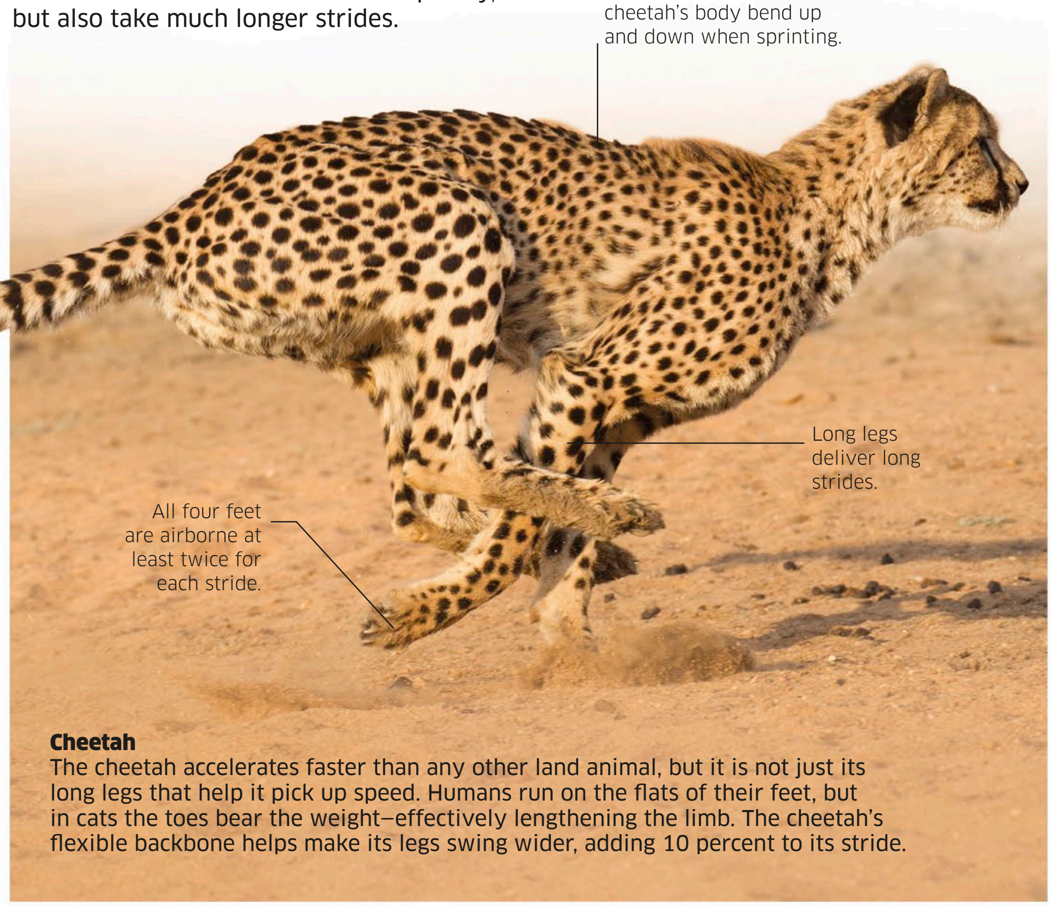


Multi-jointed leg
Arthropods, including insects, spiders, and crabs, have multi-jointed legs that carry an armorlike outer skeleton, with their muscles attached on the inside. Their muscles work in pairs around each joint—one to flex (bend) and the other to extend.

Running

An animal that moves over land needs its muscles to pull against a strong supporting framework. It also needs good balance to stay upright, meaning that its muscles and skeleton must work together with the nervous system. Some animals move slowly, even when in a hurry, but others are born to run. The fastest runners not only have powerful muscles to move their limbs more quickly, but also take much longer strides.

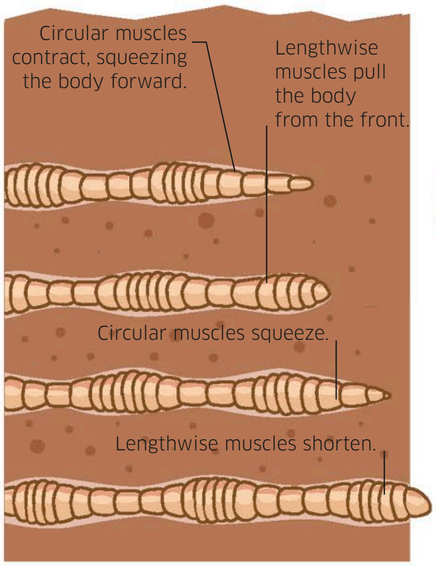
A cheetah can accelerate to 62 mph (100 km/h) in just three seconds.



Cheetah
The cheetah accelerates faster than any other land animal, but it is not just its long legs that help it pick up speed. Humans run on the flats of their feet, but in cats the toes bear the weight—effectively lengthening the limb. The cheetah's flexible backbone helps make its legs swing wider, adding 10 percent to its stride.

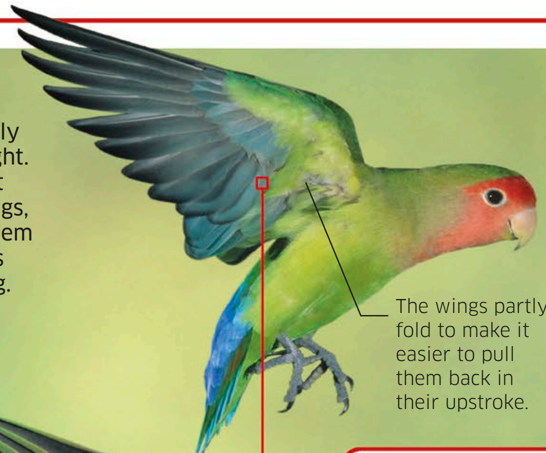
Burrowing

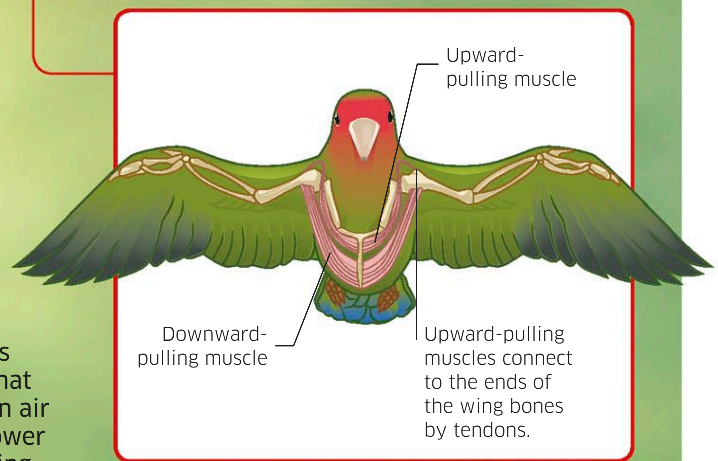
Life underground comes with special challenges. Burrowers need the strength to dig through soil to create a passage, and the ability to crawl through small openings. Moles use their feet like shovels to claw back the soil, but earthworms bulldoze their way through with their bodies.



Earthworm
An earthworm has two sets of muscles. One set encircles the body and squeezes to push it forward, like toothpaste from a tube. The other pulls the body forward.

Peach-faced lovebird
These birds are supremely adapted for powered flight. They have massive flight muscles to flap their wings, hollow bones to make them lightweight, and feathers to help with streamlining.





Flying

The wings of flying animals are airfoils. This means they are slightly curved on top, so that air flowing over the wing travels faster than air passing beneath. Faster-moving air has a lower pressure, so air pressure underneath the wing is higher. It is this that causes the lift force and keeps the animal in the sky. Some airborne animals, such as flying squirrels, can only glide, but three groups flap their wings in powered flight: insects, bats, and birds.

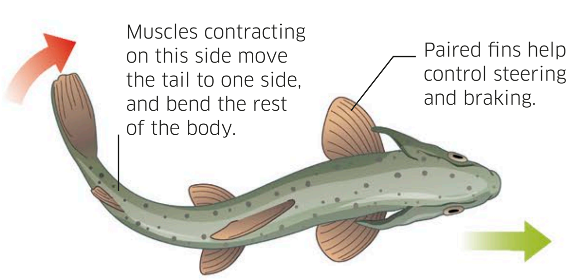
The flying system
The largest chest muscles lower the wings by pulling down on the bones in the forearm. Other chest muscles connect on top of the forearm bones and pull the wings back up.

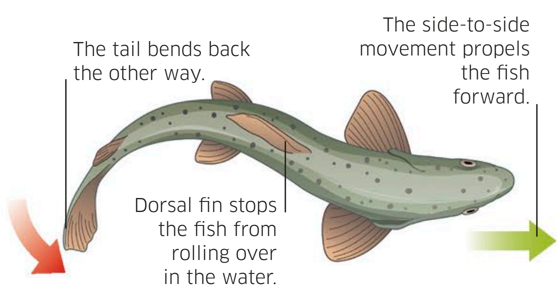
Swimming

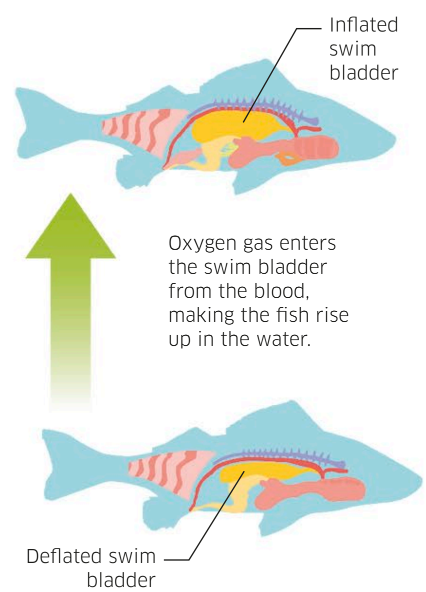
Water is thicker than air, so it exerts a bigger force called drag against any animal that moves through it. Swimming animals reduce drag by being streamlined. Even though marine animals, such as fish and dolphins are only distantly related, they both have similar body shapes, to better propel themselves through the water.

Swimming fish
Fish have blocks of muscle in the sides of their body. These contract to bend the body in an "S" shape, sweeping the tail from side to side and propelling the fish forward.

Sailfish
The enormous fin of a sailfish helps to steady its body—letting it get close to prey undetected. However, when the sail is lowered, it gives chase faster than any other fish in the ocean.





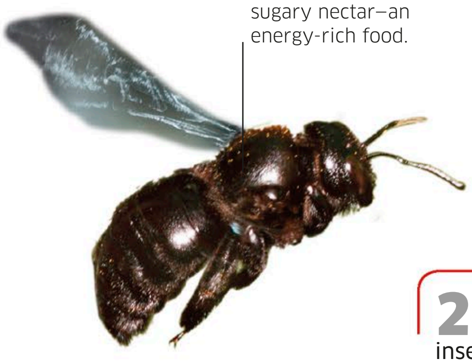


Controlling buoyancy
Fish are heavier than water, but most bony fish have a gas-filled chamber—the swim bladder—for staying buoyant when swimming. By controlling the volume of gas inside the swim bladder, fish can rise or sink through different water levels.

Plant reproduction

Despite being rooted in the ground, plants work hard to ensure the survival of their species. With the help of wind, water, and animals, they fertilize one another and disperse their seeds far and wide.

Flowers are the reproductive organs of most kinds of plants and contain both male and female cells. The male cells—encased in dusty pollen grains—fertilize eggs in the flower's female parts. Each tiny young plant produced is then enclosed inside a seed: a survival capsule that protects its contents until they are ready to germinate.

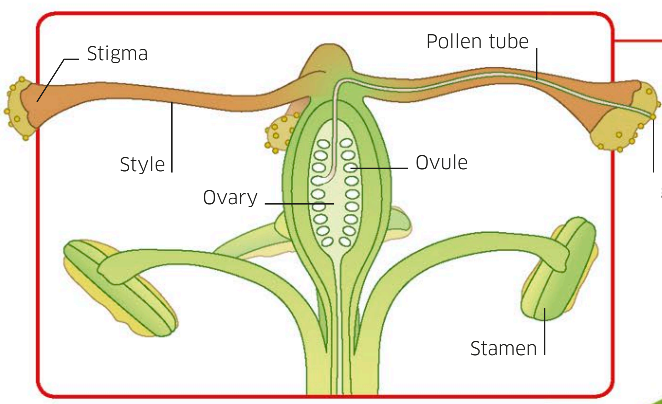


Carpenter bees visit the flowers to collect sugary nectar—an energy-rich food.

Stamen
Yellow stamens, which produce dustlike pollen grains, are the male parts of the plant.

1 Flowering
The flower's vibrant purple stripes guide a carpenter bee to the nectar glands at its center. Other plants with less attractive flowers may instead scatter their pollen on the wind.

2 Pollination
Yellow stamens brush the insect's hairy body with pollen, which the bees carry with them to the purple clublike stigmas of another plant in the species.



3 Fertilization
After landing on the stigma, the pollen grains sprout microscopic tubes to carry their male cells down the style to reach the female eggs. Each fertilized egg then grows into an embryo, nestled inside a white capsule called an ovule.

After fertilization, the petals of a flower shrivel and fall off.

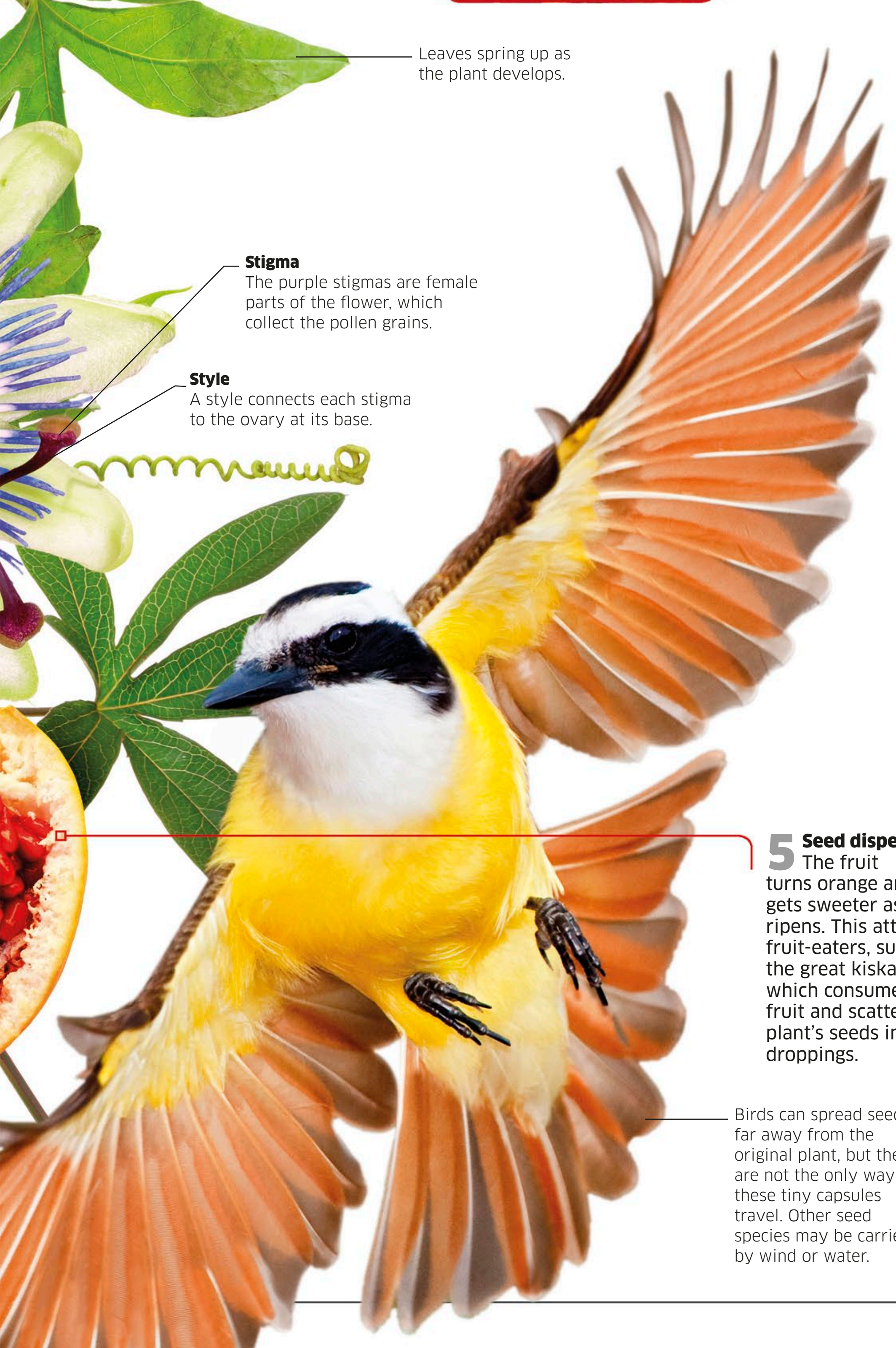
4 Fruiting
When fertilized, the base of the flower begins to develop into a fleshy fruit. The ovules embedded inside harden to form seeds.

Reproduction partnerships

Like many kinds of plants, the passion vine from South America relies on animals to help it reproduce. Large, hairy carpenter bees in search of sweet nectar carry pollen from flower to flower, while birds with a taste for fruit—here the great kiskadee—spread the seeds.

A new shoot emerges from the split seed capsule.

6 Germination If seeds land on moist ground, the embryos inside them start to grow and the seeds germinate. Roots grow down to absorb water and minerals, while shoots sprout upward to make leaves.



5 Seed dispersal The fruit turns orange and gets sweeter as it ripens. This attracts fruit-eaters, such as the great kiskadee, which consume the fruit and scatter the plant's seeds in their droppings.

Birds can spread seeds far away from the original plant, but they are not the only way these tiny capsules travel. Other seed species may be carried by wind or water.

Asexual reproduction

Many plants can reproduce asexually–meaning without producing male and female sex cells. Some develop side shoots, or runners, that split away into new plants. A few grow baby plants on their leaves.

Tiny new plants growing on the leaf of a hen-and-chicken fern fall off to produce entirely new ferns.

Reproducing by spores

Mosses and ferns do not produce flowers and seeds, but scatter spores instead. Spores are different from seeds, as they contain just a single cell rather than a fertilized embryo. These cells grow into plants with reproductive organs, which must fertilize each other to develop into mature plants that can produce a new generation of spores.

1 Scattering spores Fully-grown moss shoots release countless single-celled spores from spore capsules. These are carried by the wind, landing where each can grow into a new plant.

2 Sex organs develop Landing on moist ground, the spores grow into tiny, leafy shoots with microscopic sex organs. Male organs produce sperm, and female organs produce eggs.

3 Fertilization Falling raindrops allow swimming sperm cells to reach the eggs held inside the female sex organs, where they fertilize them.

4 Spore capsule grows Each fertilized egg grows into a new spore-producing shoot with a spore capsule, ready to make more spores and repeat the life cycle.

The deadly **female praying mantis eats the head of her partner** during mating, making **more sperm** enter her body.

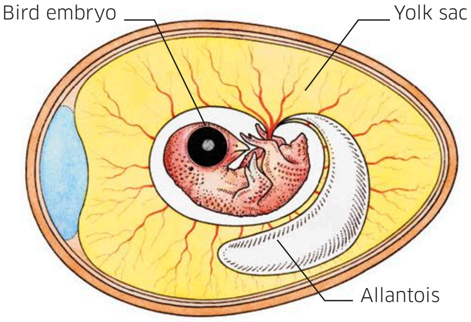
Producing young

The drive to reproduce is one of the most basic instincts in all animals. Many species devote their entire lives to finding a mate and making new young.

The most common way for animals to reproduce is through sexual reproduction—where sperm cells produced by a male fertilize egg cells produced by a female. The fertilized egg then becomes an embryo that will slowly grow and develop into a new animal. Many underwater animals release their sperm and eggs together into open water, but land animals must mate so that sperm are passed into the female's body and can swim inside it to reach her eggs.

Laying eggs on land

In some land animals, such as birds and reptiles, eggs are fertilized inside the mother's body and then laid—usually into a nest. These eggs have a hard, protective shell that encases the embryo inside and stops it from drying out. They also contain a big store of food—the yolk—which nourishes the embryo as it develops. It can take weeks or even months before the baby is big enough to hatch and survive in the world outside.

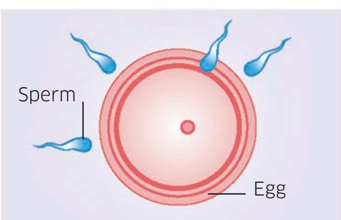


Inside a bird's egg
The shell of a bird's egg lets in air to help the embryo breathe. The yolk sac provides nutrients as it grows into a chick, while another sac, the allantois, helps collect oxygen and waste.

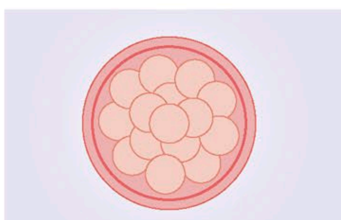
Giving birth to live young

Except for a few egg-laying species (called monotremes), mammals give birth to live young. The mother must support the growing embryos inside her body—a demanding task that may involve her taking in extra nutrients. The babies grow in a part of the mother's body called the uterus, or womb, where a special organ called a placenta passes them food and oxygen.

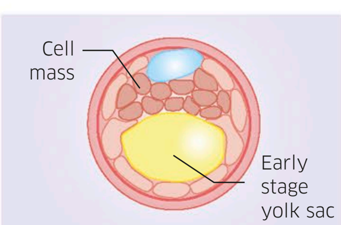
A new generation of mice
Some mammals, such as humans, usually give birth to one baby at a time. Others have large litters—like mice, which can produce up to 14 babies at one time. Each one starts as a fertilized egg, grows into an embryo, and then is born just three weeks later.



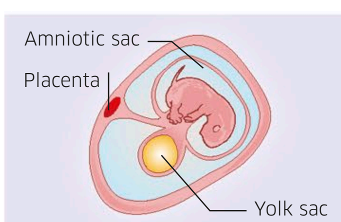
1 Fertilization
When a male mouse mates with a female, thousands of sperm enter her body and swim to her eggs. The first to arrive penetrates an egg—fertilizing it.



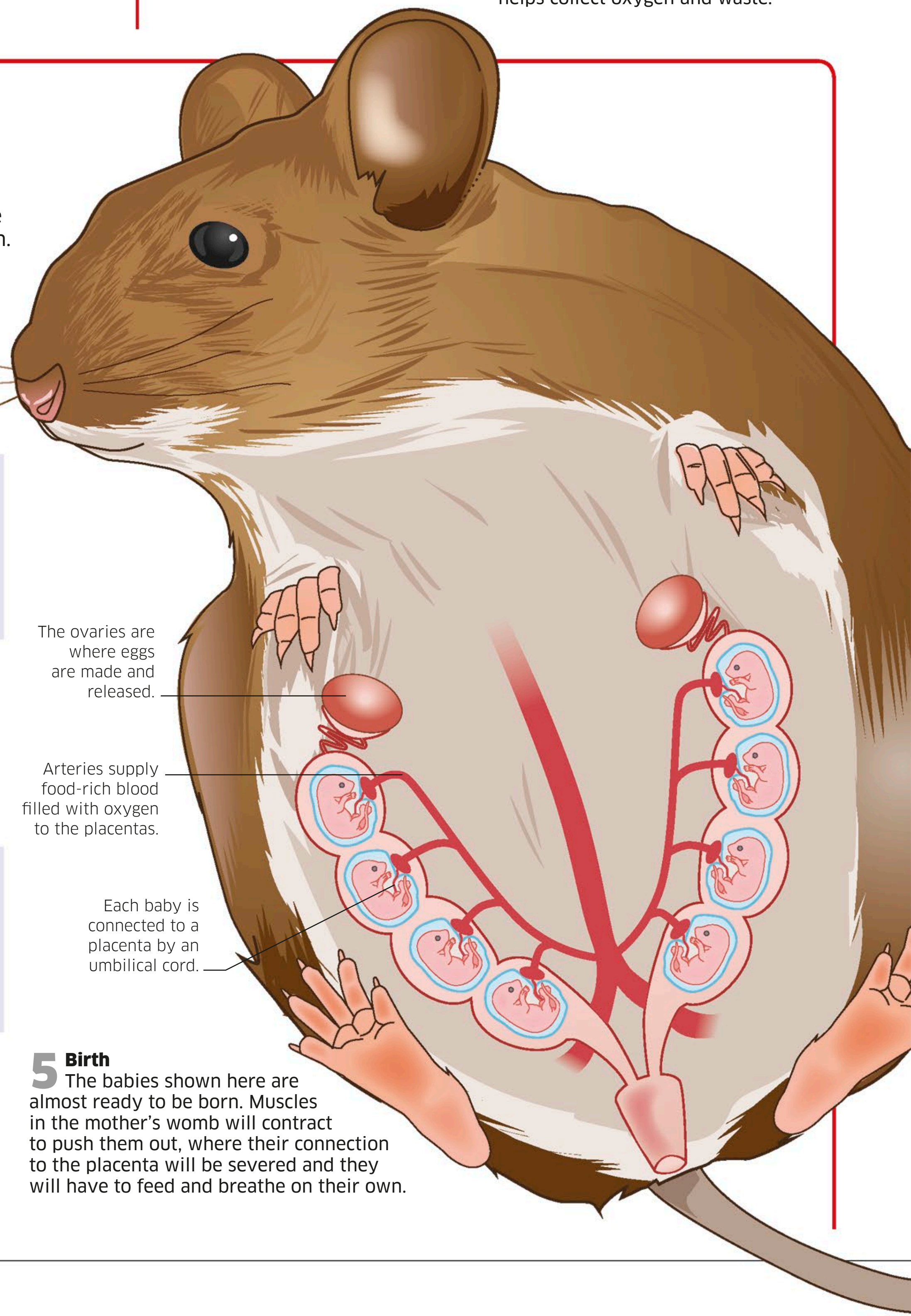
2 Embryo forms
The fertilized egg cell now contains a mixture of genes from the sperm and the egg. It divides multiple times to form a microscopic ball of cells called an embryo.



3 Implantation
The embryo becomes a hollow ball. A cell mass on one side will become the mouse's body. The ball travels into the womb to embed into its wall—an event called implantation.



4 Placenta grows
The baby mouse begins to form and gets nutrients from first a temporary yolk sac and then a placenta. A fluid-filled bag, the amniotic sac, cushions the embryo.



5 Birth
The babies shown here are almost ready to be born. Muscles in the mother's womb will contract to push them out, where their connection to the placenta will be severed and they will have to feed and breathe on their own.

Laying eggs in water

Fish fertilize their eggs externally, so the females lay unfertilized eggs directly into the water. Instead of having hard shells, fish eggs are usually coated in a soft jelly that will cushion and protect the developing embryos. Most fish do not wait around to see the embryos develop, but simply scatter lots of floating eggs and swimming sperm and leave the outcome to chance. However, some species, such as clown fish, carefully tend to their developing babies.

1 Laying and fertilization A female clown fish lays her eggs onto a hard surface. The male then releases his sperm to fertilize them.

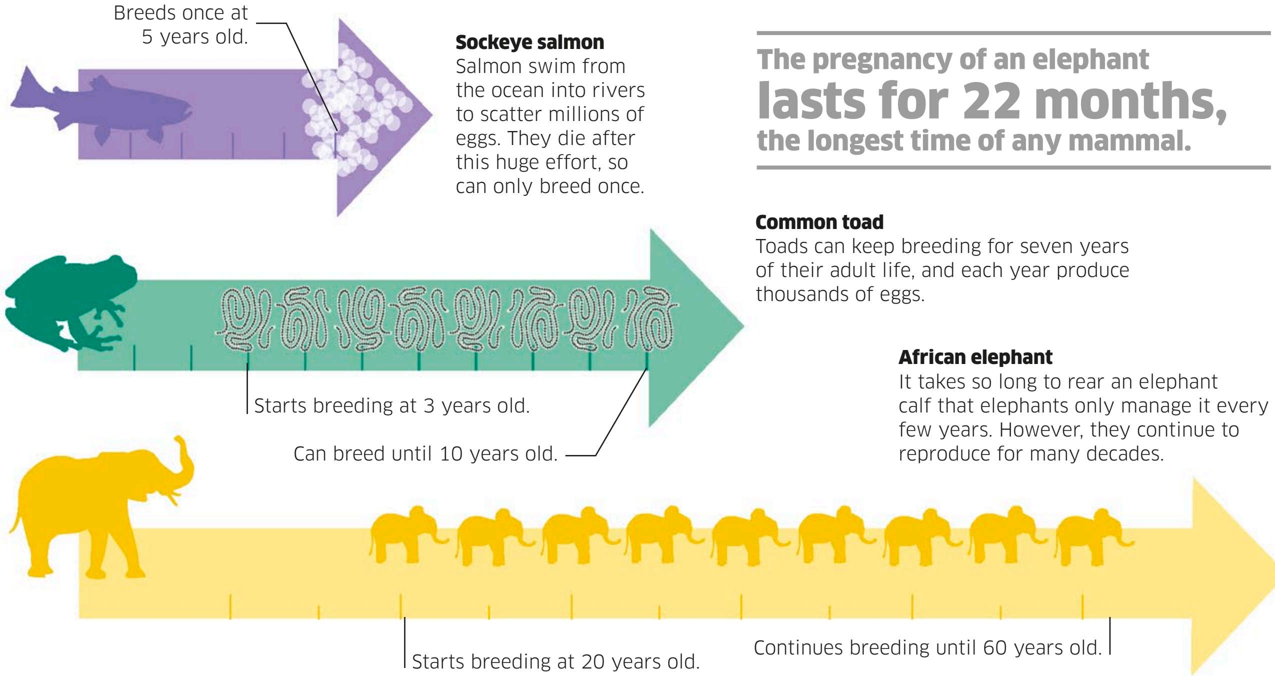
2 Caring for the eggs During the week it takes for them to hatch, the father guards the eggs, using his mouth to clean them.

3 Hatching Tiny babies, called fry, break out of the eggs. They grow quickly, feeding on nutrients in their yolk sac.

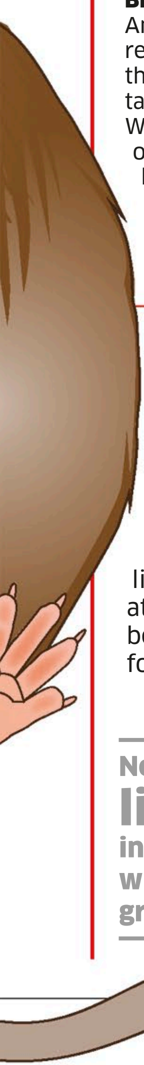
Investing in babies

All animals spend a lot of time and effort in breeding, but they invest this energy in different ways. Some—such as many insects and most fish—produce thousands of eggs at once, and a few even die after breeding. Others produce just one baby at a time, but spend a lot of time caring for each one.

The pregnancy of an elephant lasts for 22 months, the longest time of any mammal.



Breeding lifetimes
Animals must have fully grown reproductive systems before they can breed, and some can take years to develop these. While some animals breed often throughout their long lives, shorter-lived species make up for their limited life spans by producing many babies each time.



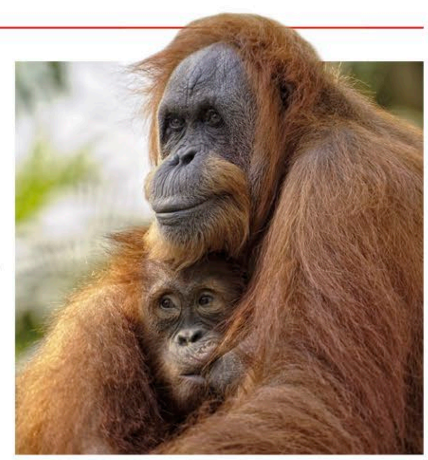
Parental care

The best way to ensure that babies survive is to give them good care when they are at their most vulnerable, but animal parents vary a lot in their degree of devotion. Many invertebrates give limited parental care or none at all. But mammal babies may be nurtured by their parents for many years.

Newborn kangaroos live in a pouch in their mother's bodies, where they continue to grow and develop.

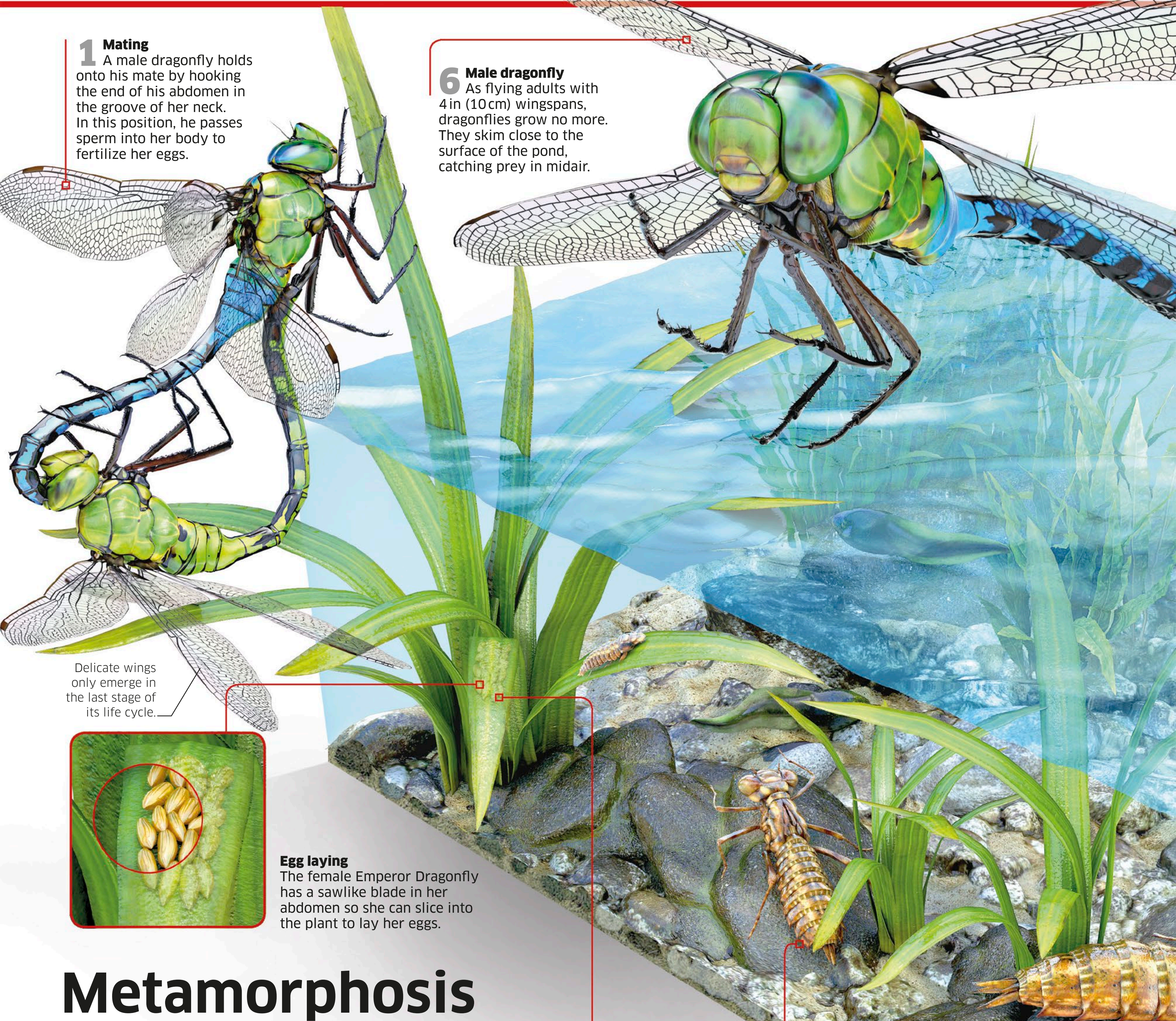
Coral
Adult coral provide no parental care. Young microscopic stages of coral—called larvae—must fend for themselves in the open ocean, where most will get eaten by predators.

Black lace weaver spider
This spider mother makes the ultimate sacrifice for her babies. After laying more eggs for her young to eat, she encourages them to bite her. This stirs their predatory instincts, and they eat her.



Orangutan
Childhood for this tree-living ape lasts well into the teenage years—just like in humans. During this time, the young will stick close to their mother for protection and learn vital survival skills from her.

A male dragonfly **guards over his pond** and the females in his territory.



1 Mating
A male dragonfly holds onto his mate by hooking the end of his abdomen in the groove of her neck. In this position, he passes sperm into her body to fertilize her eggs.

6 Male dragonfly
As flying adults with 4 in (10 cm) wingspans, dragonflies grow no more. They skim close to the surface of the pond, catching prey in midair.

Delicate wings only emerge in the last stage of its life cycle.

Egg laying
The female Emperor Dragonfly has a sawlike blade in her abdomen so she can slice into the plant to lay her eggs.

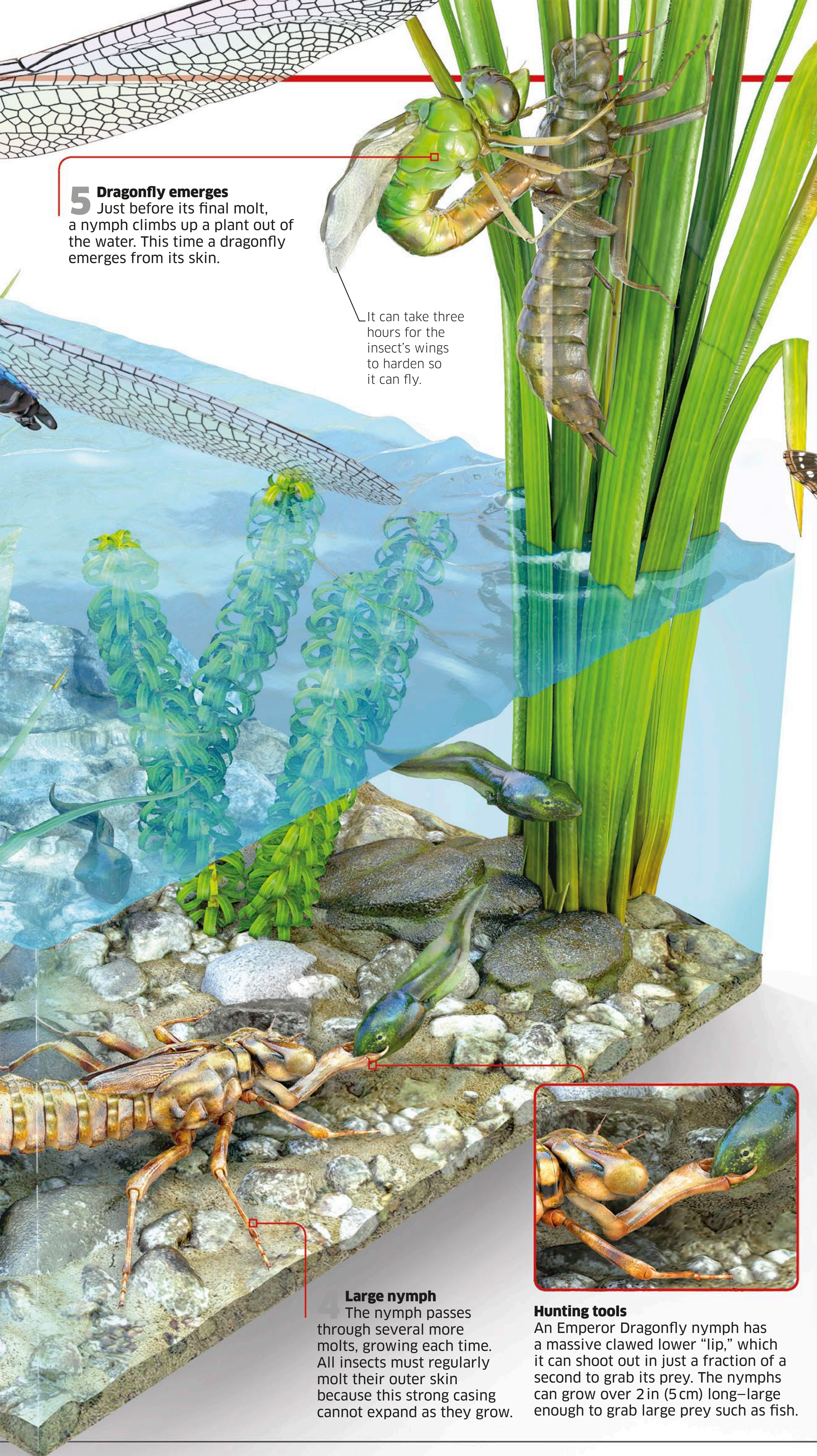
Metamorphosis

Some animals go through such dramatic changes as they grow that their adult forms look very different from their offspring. This kind of development is called metamorphosis.

Such a significant transformation not only causes changes in shape, but in lifestyle, too. Dragonflies and frogs start off as underwater larvae until they are old enough to turn into air-breathing creatures. Similarly, crawling caterpillars must live life in the slow lane before they can become butterflies. In each case, metamorphosis reshapes their bodies to prepare them for the future stages of their life cycle.

2 Eggs
The female Emperor Dragonfly lays hundreds of eggs in water weeds just below the surface of the water. Each egg is narrower at the ends so it slides easily into a plant stem.

3 Nymph
After a few weeks, each egg hatches into a tiny wriggling prolarva, which quickly molts into a nymph that can swim and feed. It walks across the pond floor to hunt.



5 Dragonfly emerges Just before its final molt, a nymph climbs up a plant out of the water. This time a dragonfly emerges from its skin.

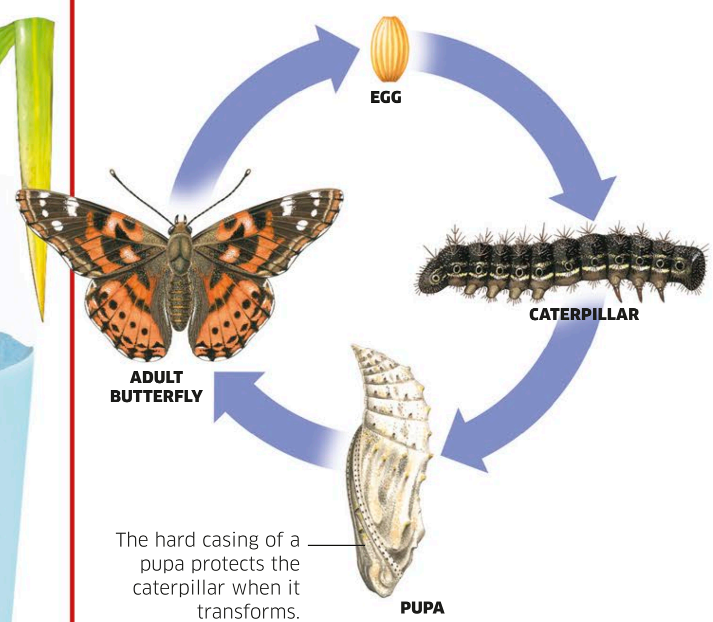
It can take three hours for the insect's wings to harden so it can fly.

4 Large nymph The nymph passes through several more molts, growing each time. All insects must regularly molt their outer skin because this strong casing cannot expand as they grow.

Hunting tools
An Emperor Dragonfly nymph has a massive clawed lower "lip," which it can shoot out in just a fraction of a second to grab its prey. The nymphs can grow over 2 in (5 cm) long—large enough to grab large prey such as fish.

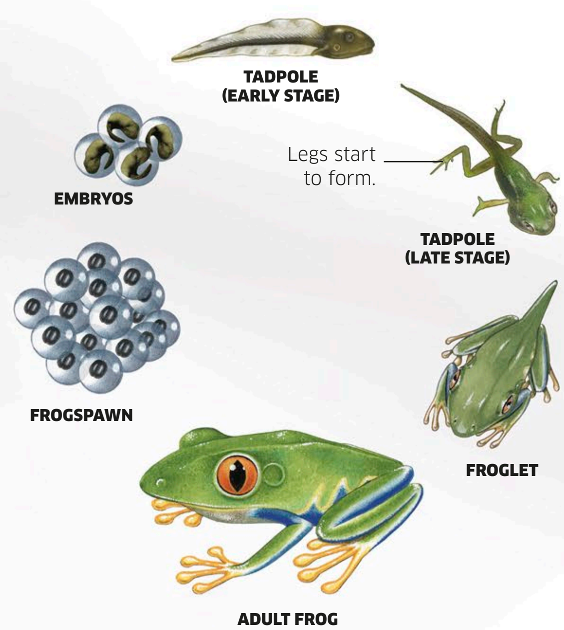
Complete metamorphosis

Along with many other insects, a butterfly undergoes a different kind of metamorphosis to a dragonfly. Its larva is a caterpillar, a leaf-eating creature that has no resemblance to the adult form at all. It changes into a flying butterfly in a single transformation event. This process is different to incomplete metamorphosis, where the multiple larval forms are smaller versions of the adult.



Amphibian life cycle

Amphibians grow more gradually than insects because they do not need to molt. Tiny wiggling tadpoles—with gills for breathing underwater—hatch from frogspawn and then take weeks or months to get bigger and turn into air-breathing frogs. During this time, they steadily grow their legs and their tails get absorbed back into their bodies.



Genetics and DNA

The characteristics of a living thing—who we are and what we look like—are determined by a set of instructions carried inside each of the body's cells.

Instructions for building the body and keeping it working properly are held in a substance called DNA (deoxyribonucleic acid). The arrangement of chemical building blocks in DNA determines whether a living thing grows into an oak tree, a human being, or any other kind of organism. DNA is also copied whenever cells divide, so that all the cells of the body carry a set of these vital genetic instructions. Half of each organism's DNA is also passed on to the next generation in either male or female sex cells.

GENES ON A SECTION OF DNA

Genes vary in length and position. Each DNA molecule can contain thousands of them.

This blue-colored section of DNA makes up one gene. It determines one characteristic, such as eye color.

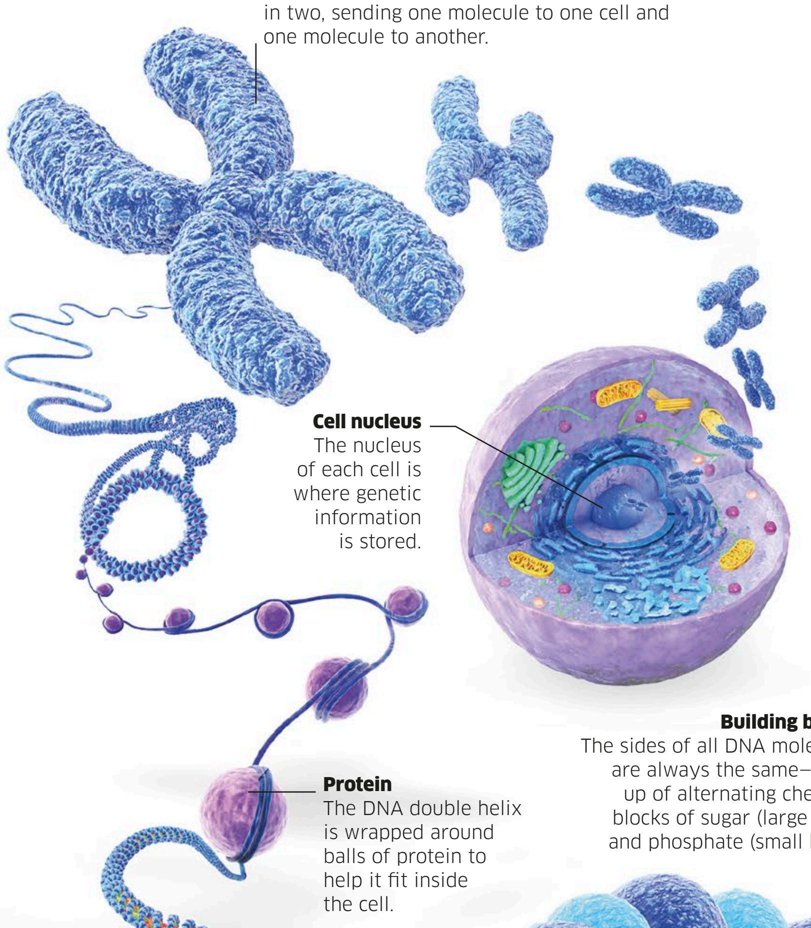
What is a gene?

The information along DNA is arranged in sections called genes. Each gene has a unique sequence of bases. This sequence acts as a code to tell the cell to make a specific protein, which, in turn, affects a characteristic of the body.

Packaging the information

Inside the nucleus of every cell in the human body are 46 molecules of DNA, carrying all the information needed to build and maintain a human being. Each molecule is shaped like a twisted ladder—named a double helix—and packaged up into a bundle called a chromosome. Genetic information is carried by the sequence of different chemical units, known as bases, that make up the "rungs" of the ladder.

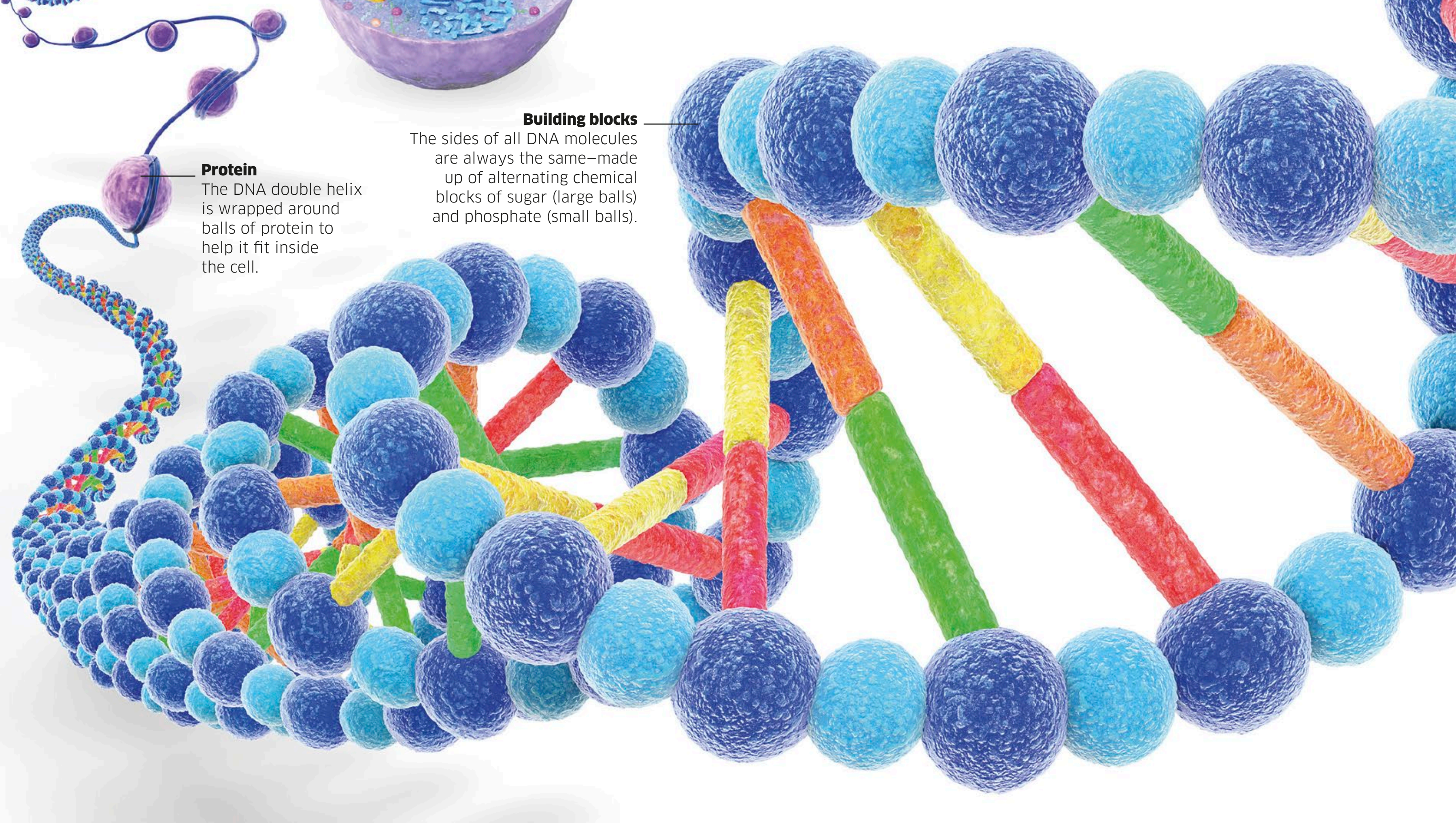
Chromosome
A tightly packed mixture of protein and DNA forms a chromosome. Each chromosome contains one long molecule of DNA. The DNA in this chromosome has replicated to make an X-shape. It is ready to split in two, sending one molecule to one cell and one molecule to another.

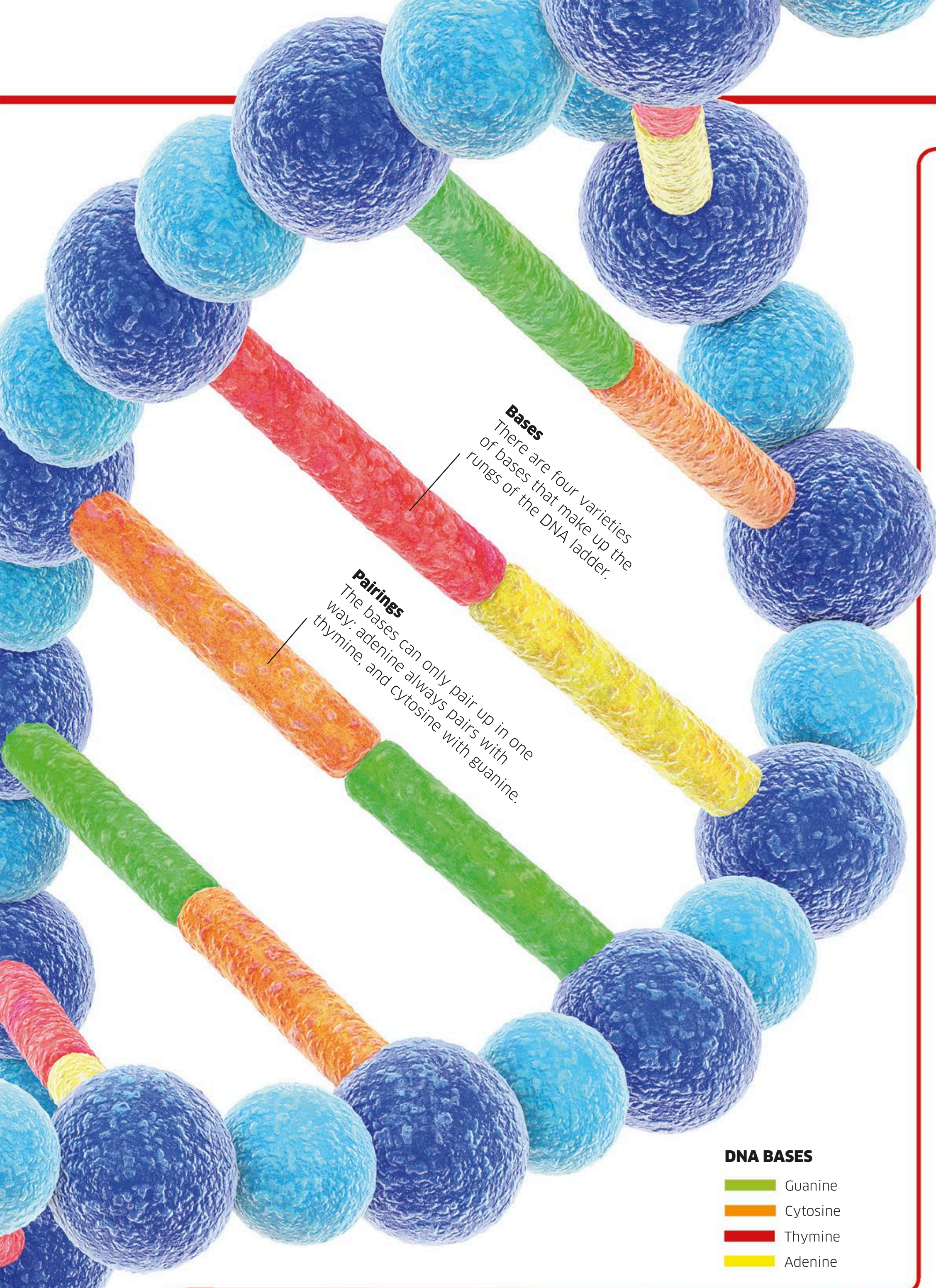


Cell nucleus
The nucleus of each cell is where genetic information is stored.

Protein
The DNA double helix is wrapped around balls of protein to help it fit inside the cell.

Building blocks
The sides of all DNA molecules are always the same—made up of alternating chemical blocks of sugar (large balls) and phosphate (small balls).



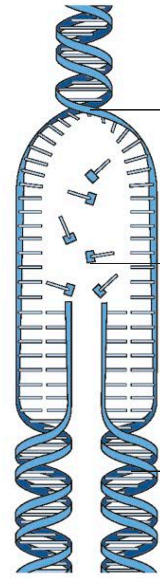


DNA BASES

- Guanine
- Cytosine
- Thymine
- Adenine

DNA replication

Cells replicate themselves by splitting in two. Therefore, all the instructions held in DNA must be copied before a cell divides, so each new cell will have a full set. The DNA does this by splitting into two strands. Each of these then provides a template for building a new double helix.



1 Each molecule of DNA is made of two complementary strands. When it is ready to replicate, the double helix unzips into two separate strands.

2 New DNA building blocks come together to make the other sides of each double helix. As each base can only pair with one other, it is clear which blocks are needed to complete the "ladder."

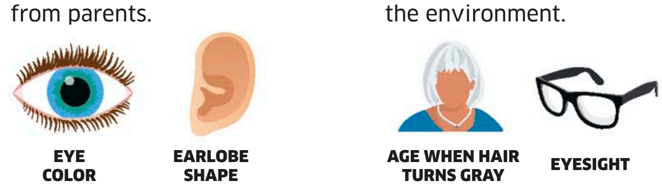
3 Two new double helixes are formed. Each of these is then ready to go into two new cells when the original cell divides.

What gets inherited?

Many human features, such as eye color, hair color, and blood type, are due to particular genes. Different varieties of genes, called alleles, determine variation in these characteristics. Other characteristics, such as height, are affected by many genes working together, but also by other factors, such as diet.

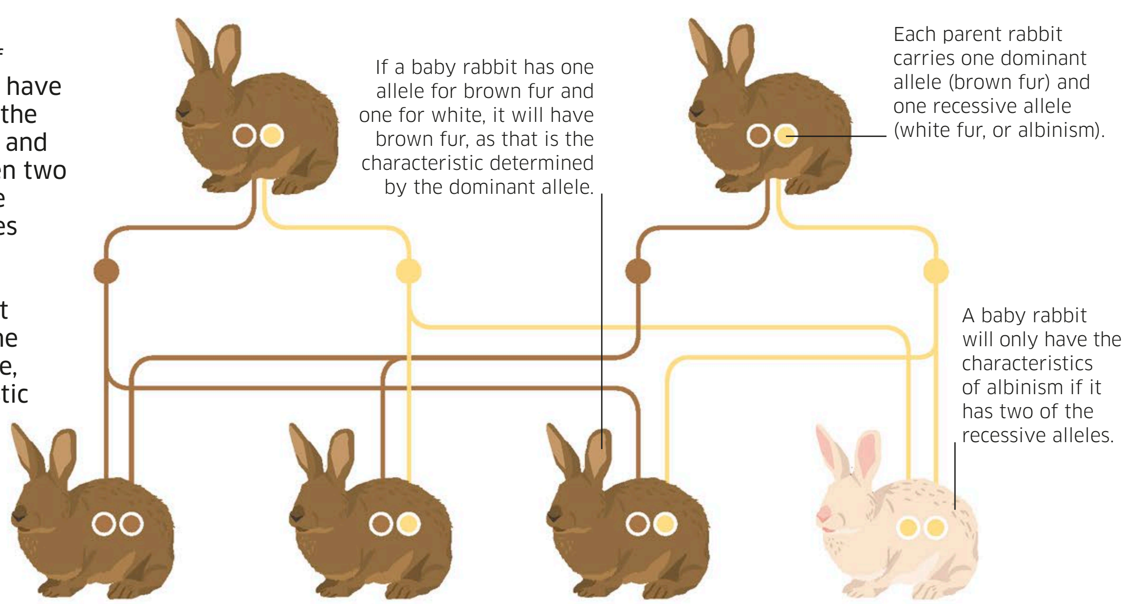
Genes
Some characteristics are only inherited from parents.

Genes and environment
Other characteristics are influenced by genes and the environment.



How inheritance works

Most organisms have two of each kind of gene—one from each parent. Many genes have two or more variations, called alleles, so the genes an animal inherits from its mother and father may be identical or different. When two animals, such as rabbits, reproduce, there are many different combinations of alleles their offspring can receive. Some alleles are dominant (like those for brown fur), and when a baby rabbit has two different alleles it will have the characteristic of the dominant allele. Other alleles are recessive, and babies will only have the characteristic they determine if they have two of them. This explains why some children inherit physical characteristics not seen in their parents.



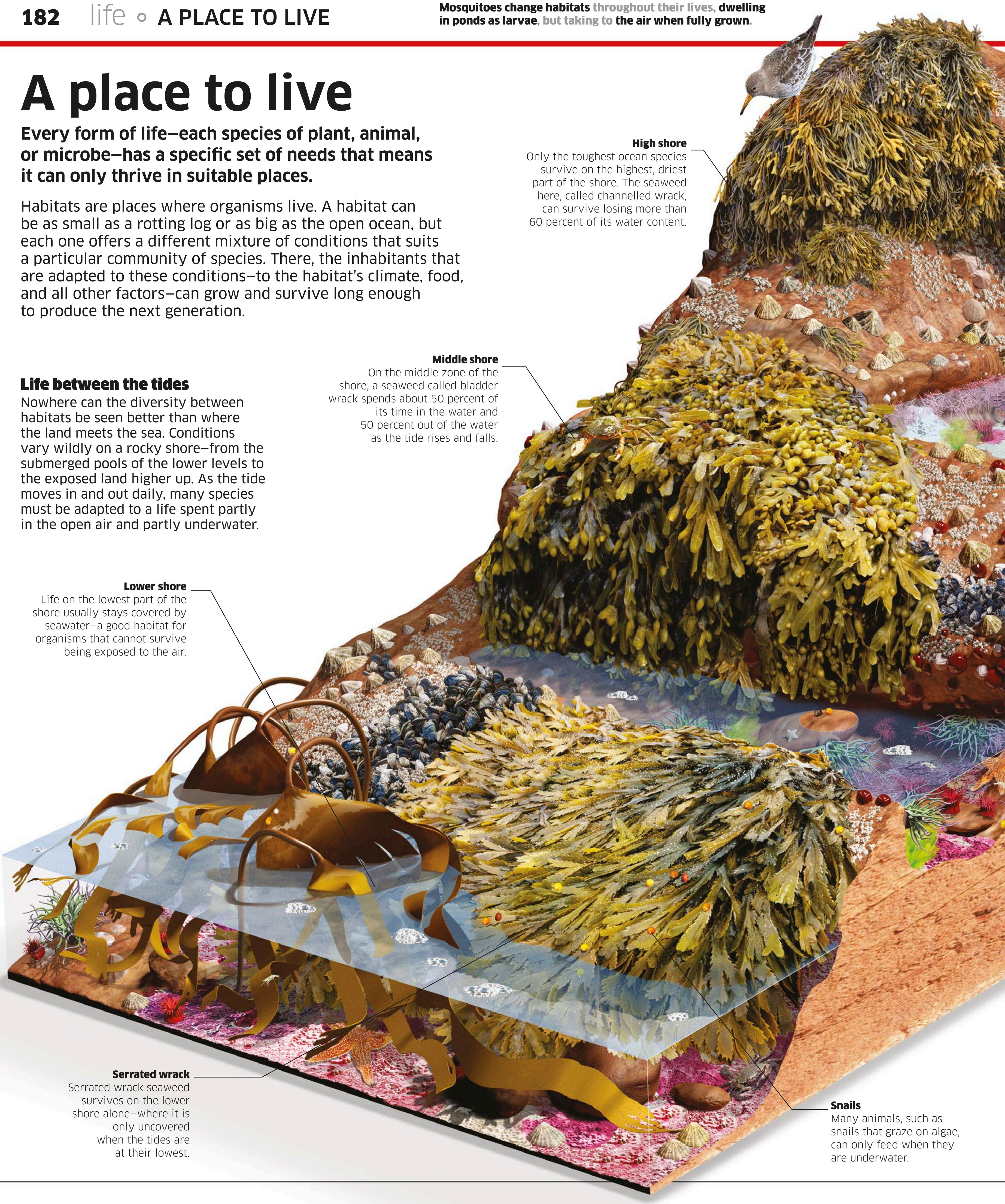
A place to live

Every form of life—each species of plant, animal, or microbe—has a specific set of needs that means it can only thrive in suitable places.

Habitats are places where organisms live. A habitat can be as small as a rotting log or as big as the open ocean, but each one offers a different mixture of conditions that suits a particular community of species. There, the inhabitants that are adapted to these conditions—to the habitat's climate, food, and all other factors—can grow and survive long enough to produce the next generation.

Life between the tides

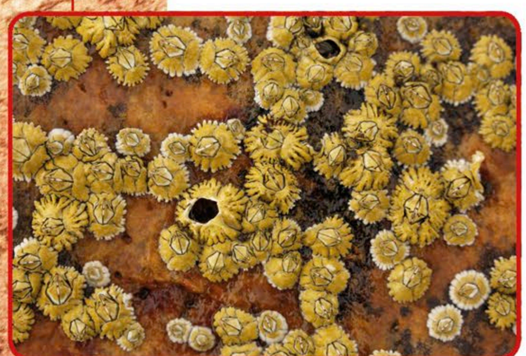
Nowhere can the diversity between habitats be seen better than where the land meets the sea. Conditions vary wildly on a rocky shore—from the submerged pools of the lower levels to the exposed land higher up. As the tide moves in and out daily, many species must be adapted to a life spent partly in the open air and partly underwater.



Barnacles
Barnacles are shrimp-related animals that attach themselves to rocks. They filter-feed on ocean water when the tide is high enough to cover them.

Limpets
These small molluscs stay clamped tightly to the rock when the tide is low.

Populations
All the individuals of the same species living and breeding together make up a population—such as these acorn barnacles attached to the rocks.

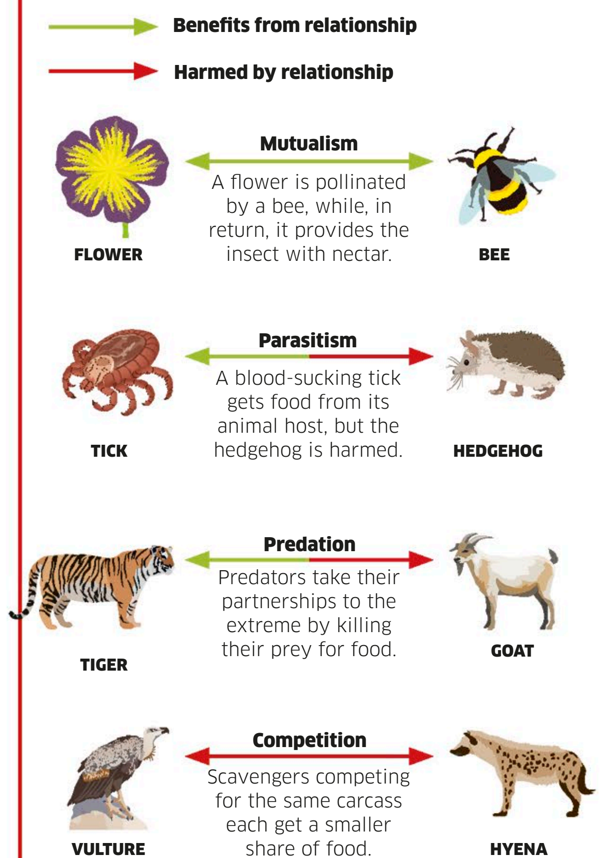


Tidal pool
A tidal pool is a refuge for ocean organisms, helping them stay under water higher up the shore, even when the tide is low.

Communities
All the interacting species in a habitat—such as this colorful collection of anemones, seaweeds, and starfish—make up a community. Communities and the nonliving parts of the environment, such as air, rock, and water, make up an ecosystem.

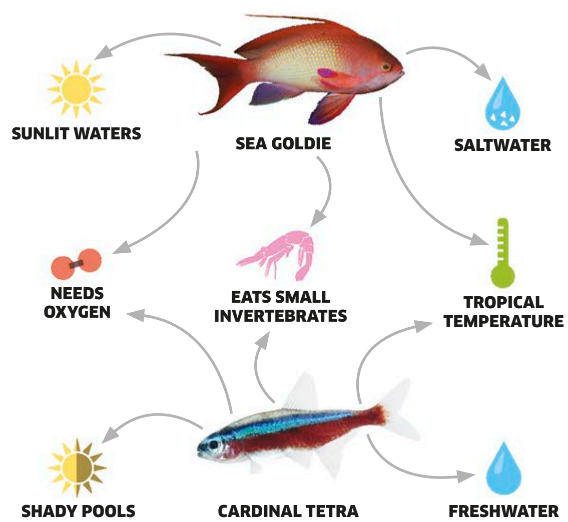
Interactions between species

Within a habitat's community, species interact with one another in many ways. Each kind of interaction is called a symbiosis, and there are several different kinds of partnerships: some helpful, and some harmful.



Niches

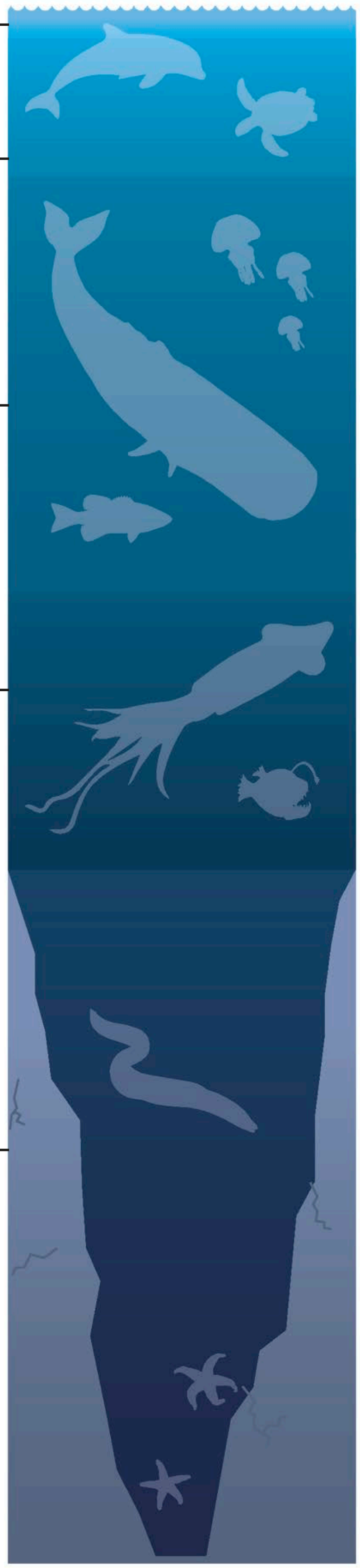
The conditions required by a species (such as water) and the role the species plays in its habitat is called its niche. No two species have exactly the same niche. The sea goldie and the cardinal tetra share some conditions (both need warm temperatures), but not others (one lives in freshwater, the other in saltwater).



Coral reefs cover less than **1 percent of the ocean floor**, but are **home to more than a quarter of all known species**.

Oceanic zones

Covering nearly three-quarters of Earth's surface, and reaching down to 9 miles (11 km) at their deepest point, the oceans make up the biggest biome by volume. All life here lives submerged in salty marine waters, but conditions vary enormously from the coastlines down to the ocean's bottom.



Sunlit zone
(0–650 ft/0–200 m)
Bright sunlight provides energy for ocean food chains that start with algae.

Twilight zone
(650–3,280 ft/200–1,000 m)
Sunlight cannot penetrate far into the ocean. As depth increases, conditions are too dark for algae, but animals thrive.

Midnight zone
(3,280–13,000 ft/1,000–4,000 m)
Animals find different ways of surviving in the dark ocean depths. Many use bioluminescence: they have light-producing organs to help them hunt for food or avoid danger.

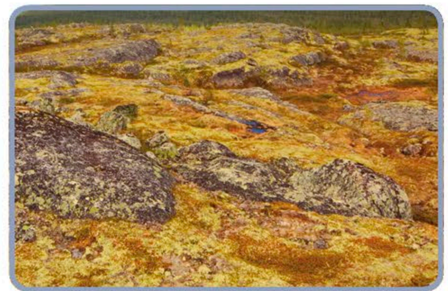
Abyssal zone
(13,000–19,650 ft/4,000–6,000 m)
Near the ocean floor, water pressure is strong enough to crush a car and temperatures are near freezing. Most food chains here are supported by particles of dead matter raining down from above.

Hadal zone
(19,650–36,000 ft/6,000–11,000 m)
The ocean floor plunges down into trenches that form the deepest parts of the ocean. But even here there is life—with a few kinds of fishes diving down to 26,000 ft (8,000 m) and invertebrates voyaging deeper still.

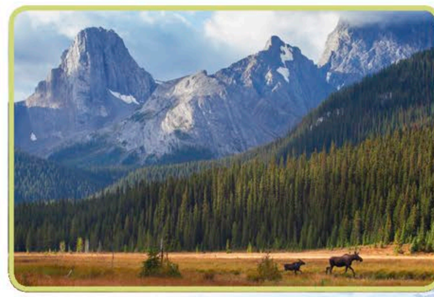
Biomes

Places exposed to similar sets of conditions—such as temperature or rainfall—have similar-looking habitats, even when they are as far apart as North America and Asia. These habitat groups are called biomes. Over continents and islands, they include tundra, deserts, grasslands, forests—and freshwater lakes and rivers.

Tundra
Where land is close to the poles, conditions are so cold that the ground is permafrost—meaning it is frozen throughout the year. Here, trees are sparse or cannot grow at all, and the thin vegetation is made up of grasses, lichens, and small shrubs.



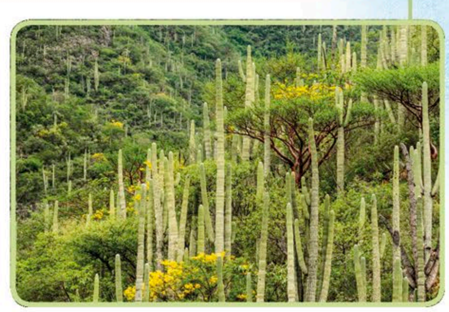
Taiga
The largest land biome is a broad belt of coniferous forest that encircles the world below the Arctic tundra. Conifers, pines, and related trees have needlelike leaves that help them survive low temperatures. They are evergreen—so they retain their tough foliage even in the coldest winters.



Temperate forest
The Earth's temperate zones are between the cold polar regions and the tropics around the equator. Many of the forests that grow in these seasonal regions are deciduous: they produce their leaves during the warm summers, but lose them in the cold winters.

Temperate grassland
Where the climate is too dry to support forests but too wet for desert, the land is covered with grassland—a habitat that supports a wide range of grazing animals. Temperate grasslands experience seasonal changes in temperature, but stay green throughout the year.

Tropical dry and coniferous forest
Some tropical regions have pronounced dry seasons that can last for months. Here, many kinds of trees drop their leaves in times of drought. Others have adaptations that help them to stay evergreen. In places, the forests are dominated by conifers with drought-resistant leaves.



Habitats and biomes

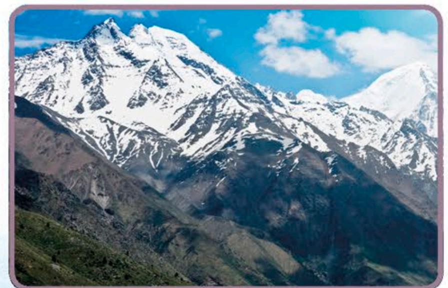
Around Earth, plants, animals, and other organisms live in habitats that are as different as the driest, most windswept deserts and the deepest, darkest oceans.

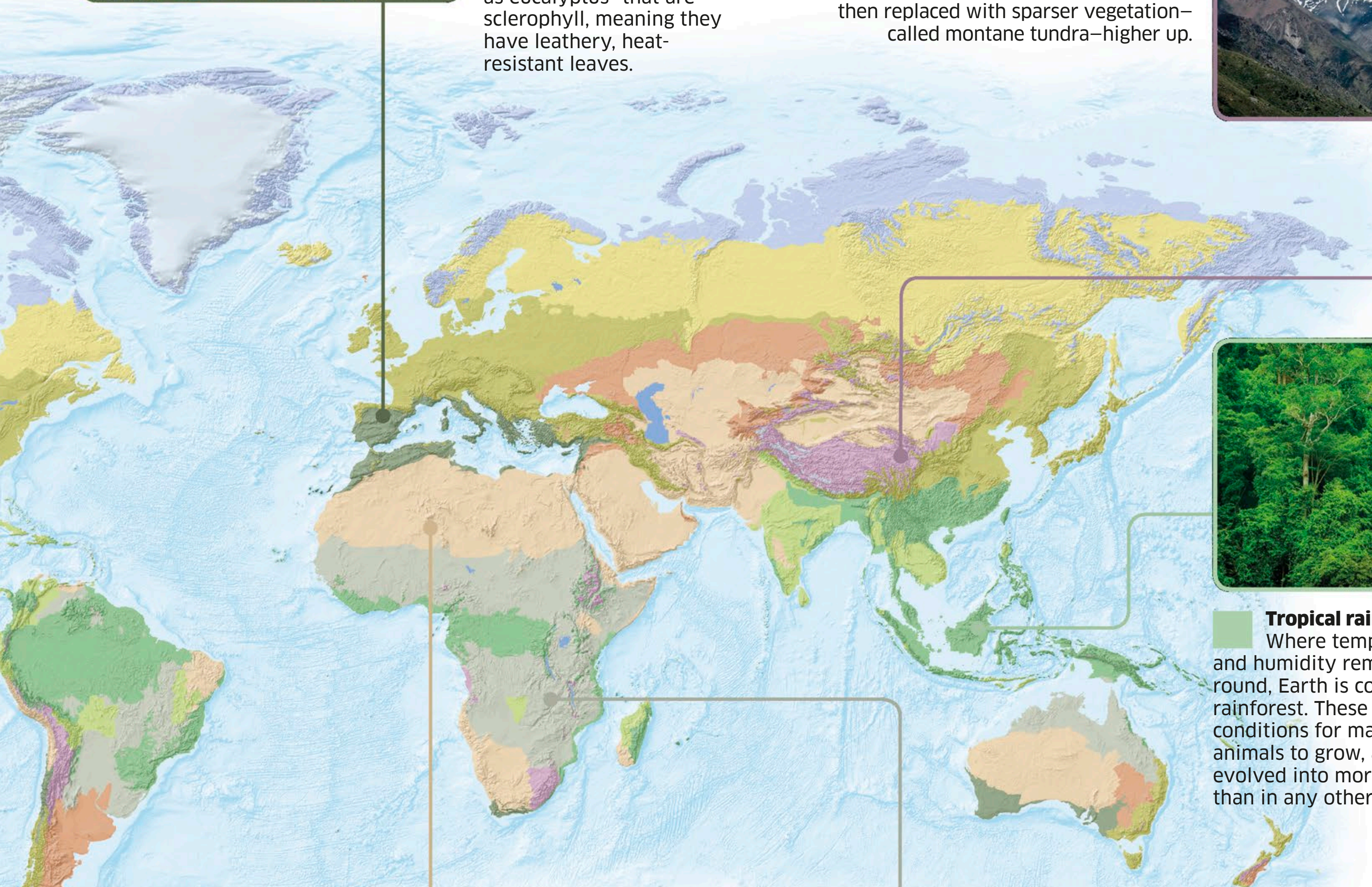
Conditions vary from one part of the world to another, and they have a big effect on the kinds of living things that can survive together in any place. The freezing cold poles experience a winter of unbroken darkness for half the year, while the equator basks in tropical temperatures year-round. And the world of the oceans reaches from the sunlit surfaces down into the dark abyss.

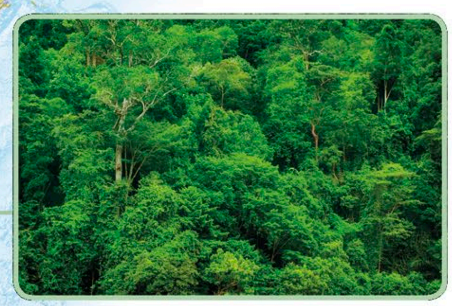
Freshwater
Rainfall collecting in rivers and lakes creates freshwater habitats. Aquatic plants grow in their shallows and animals swim in the open water or crawl along their muddy or stony bottoms. Where rivers meet the sea, water is affected by the oceans' saltiness.

Mediterranean woodland
A Mediterranean-type climate has hot, dry summers and wet, mild winters. It is most common where lands in the temperate zone are influenced by mild ocean air. Its forests are dominated by trees—such as eucalyptus—that are sclerophyll, meaning they have leathery, heat-resistant leaves.

Montane grassland and shrubland
Temperatures drop with increasing altitude, so the habitat changes in mountain regions. Forests give way to grassland on exposed slopes, which are then replaced with sparser vegetation—called montane tundra—higher up.

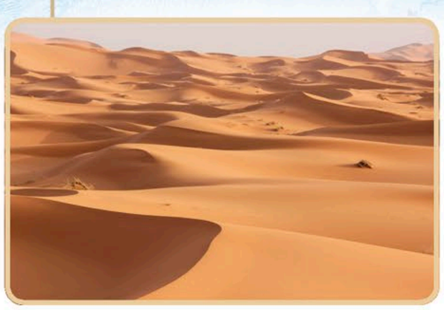


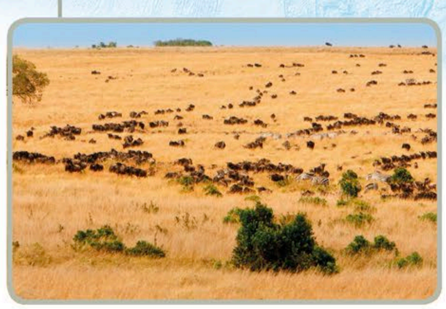




Tropical rainforest
Where temperature, rainfall, and humidity remain high all year round, Earth is covered with tropical rainforest. These are the best conditions for many plants and animals to grow, and they have evolved into more different species than in any other land biome.

Desert
In some parts of the world—in temperate or tropical regions—the land receives so little rainfall that conditions are too dry for most grasses and trees. In arid places with hot days and cold nights, succulent plants survive by storing water in roots, stems, or leaves.





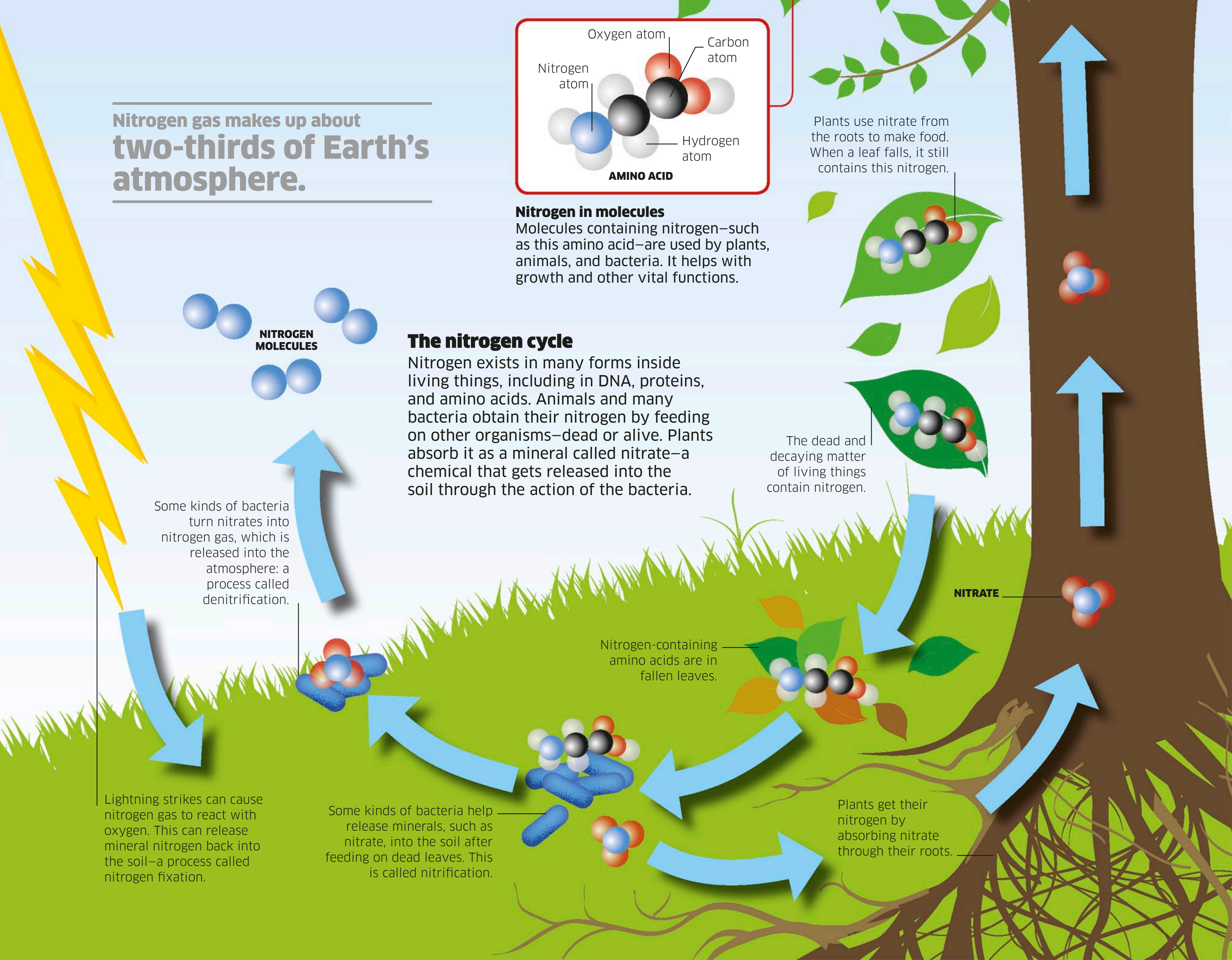
Tropical grassland
Grasslands in the tropics support some of the largest, most diverse gatherings of big grazing animals anywhere on Earth. Unlike most plants, grasses grow from the base of their leaves and thrive even when vast numbers of grazers eat the top of their foliage.

Cycles of matter

Many of Earth's crucial materials for life are constantly recycled through the environment.

All the atoms that make up the world around us are recycled in one way or another. Chemical reactions in living things, such as photosynthesis and respiration, drive much of this recycling. These processes help pass important elements like carbon and nitrogen between living things, the soil, and the atmosphere.

Nitrogen gas makes up about two-thirds of Earth's atmosphere.

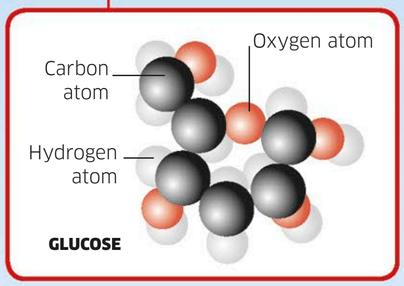


Nitrogen in molecules
Molecules containing nitrogen—such as this amino acid—are used by plants, animals, and bacteria. It helps with growth and other vital functions.

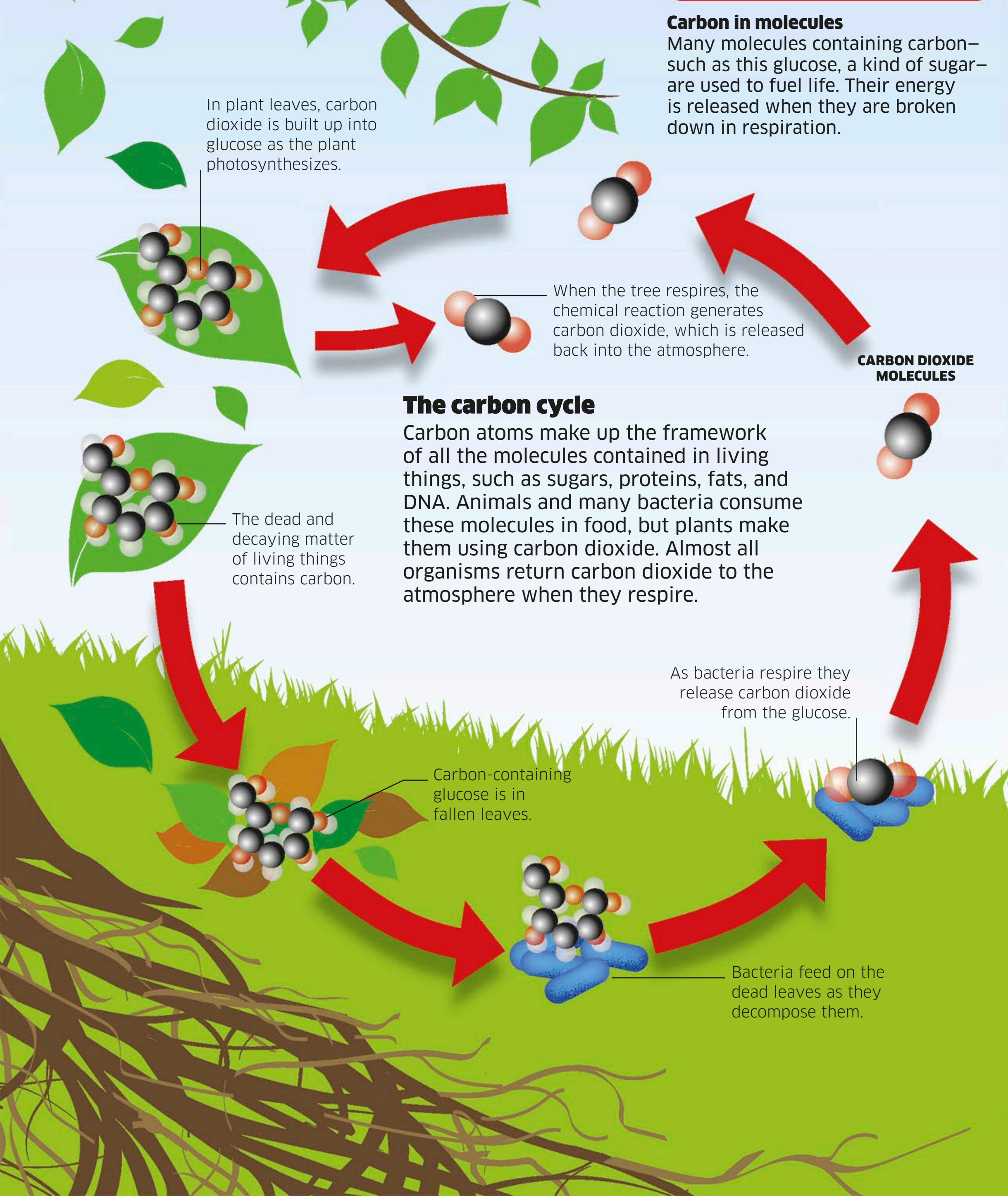
The nitrogen cycle

Nitrogen exists in many forms inside living things, including in DNA, proteins, and amino acids. Animals and many bacteria obtain their nitrogen by feeding on other organisms—dead or alive. Plants absorb it as a mineral called nitrate—a chemical that gets released into the soil through the action of the bacteria.

When a plant is dry, carbon makes up about **50 percent of its weight.**

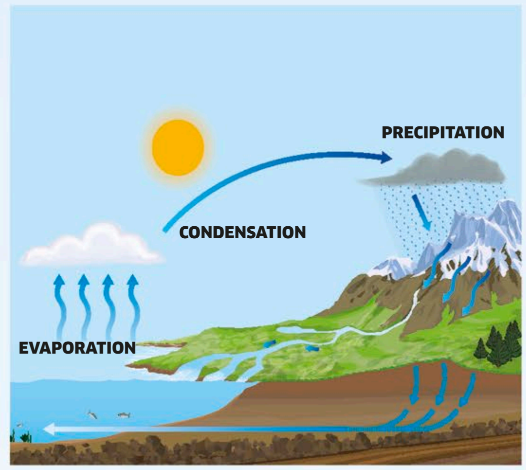


Carbon in molecules
Many molecules containing carbon—such as this glucose, a kind of sugar—are used to fuel life. Their energy is released when they are broken down in respiration.



The carbon cycle
Carbon atoms make up the framework of all the molecules contained in living things, such as sugars, proteins, fats, and DNA. Animals and many bacteria consume these molecules in food, but plants make them using carbon dioxide. Almost all organisms return carbon dioxide to the atmosphere when they respire.

Recycling water
Water is made of two elements—hydrogen and oxygen—and travels through earth, sea, and sky in the global water cycle. This cycle is dominated by two processes: evaporation and precipitation. Liquid water in oceans, lakes, and even on plant leaves evaporates to form gaseous water vapor. The water vapor then condenses to form the tiny droplets inside clouds, before falling back down to Earth as precipitation: rain, hail, or snow.

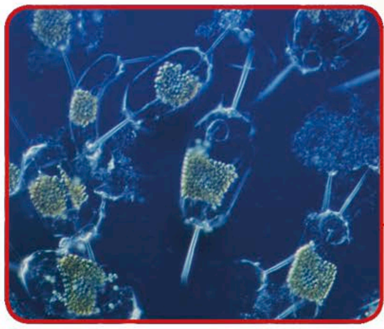


The water cycle
Recycling of water is driven by the heating effects of the sun. At it is warmed, surface water evaporates into the atmosphere, but cools and condenses to form rain or snow. Rainfall drains or runs off to oceans and lakes to complete the cycle.

The long-term carbon cycle
Carbon atoms can be recycled between living organisms and the air within days, but other changes deeper in the earth take place over millions of years. Lots of carbon gets trapped within the bodies of dead organisms either in the ocean or underground—forming fossil fuels. It is then only released back into the atmosphere through natural events such as volcanic eruptions, or when it is burned by humans in forms such as coal (see pp.36–37).

Coal mining
At this mining terminal in Australia, carbon-containing coal is extracted from the ground.

1 Sunlight
When the sun is shining brightly, a single square meter of ocean surface collects more than a thousand joules of energy every second—enough to power a microwave oven.



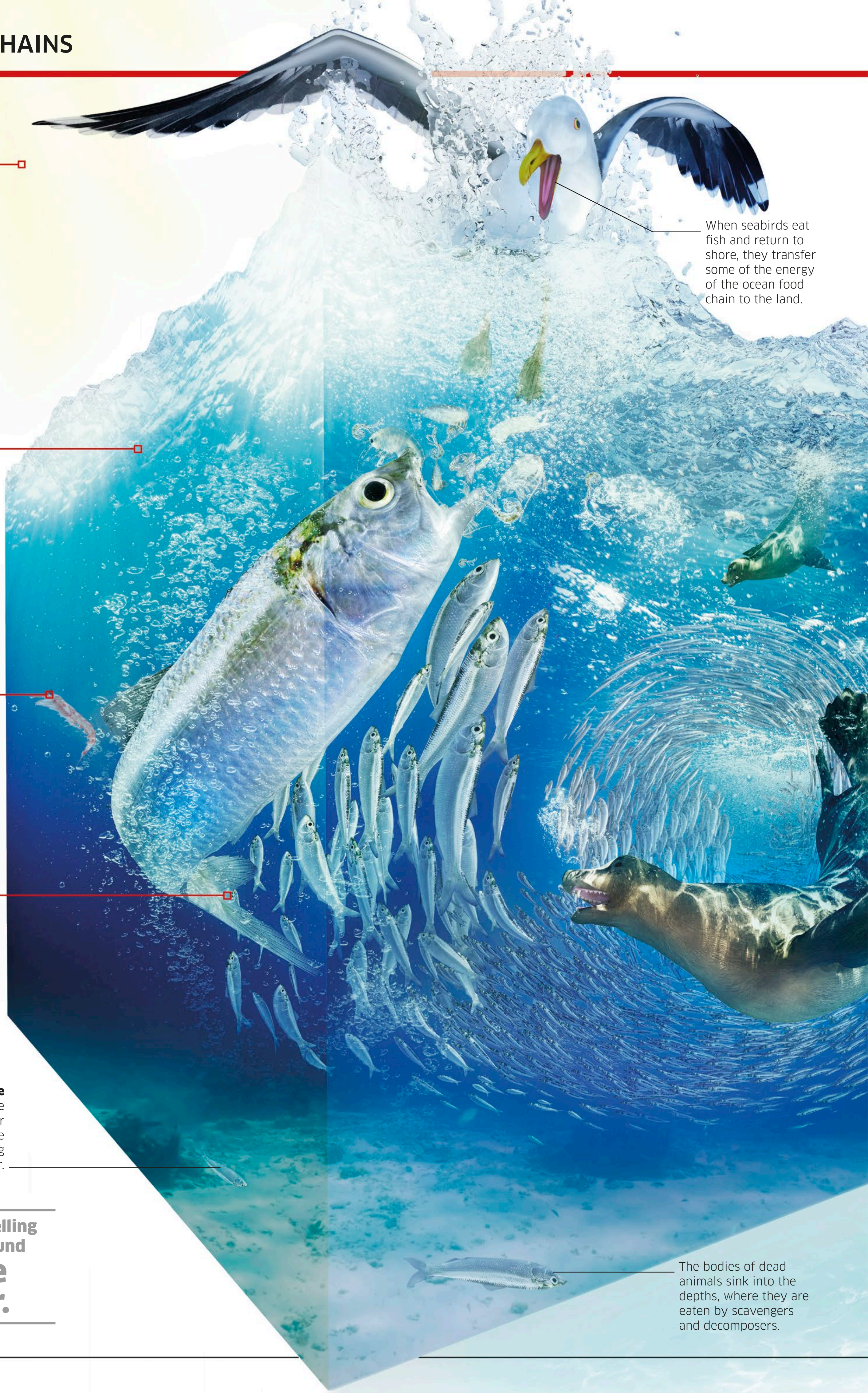
2 Phytoplankton
Plankton are tiny organisms that float in the water in billions. They contain algae called phytoplankton that make food by photosynthesis. Because they harness their energy directly from the sun, they are called the producers in a food chain.

3 Zooplankton
Tiny animals, called zooplankton, feed on the phytoplankton. Including a variety of shrimps and fish larvae, these are the primary consumers—animals that eat only algae or plants. They make up the second stage of a food chain.

4 Herring
The Pacific herring is a key link in the ocean food chain—an omnivore that eats both phytoplankton and zooplankton. It is the secondary consumer of the chain, and swims in large shoals that are easily snapped up by bigger predators.

Food waste
In deeper, darker parts of the ocean there is not enough light for photosynthesis, so food chains here often rely on dead organisms falling down through the water.

Photosynthesis by ocean-dwelling phytoplankton generates around 70 percent of the oxygen in the air.



Food chains

Living things rely on one another for nourishment. Energy in a food chain travels from the sun to plants, then animals, and finally to predators at the very top of the chain.

The sun provides the ultimate source of energy for life on Earth. Plants and algae change its light energy into chemical energy when they photosynthesize. Vegetarian (herbivorous) animals consume this food and they, in turn, are eaten by meat-eating carnivores. Energy is passed up the chain, and also transfers to scavengers and decomposers (see pp.146–147) when they feed on the dead remains of organisms.

An ocean food chain

Near the surface of the ocean, where bright sunlight strikes the water, billions of microscopic algae photosynthesize to make food. In doing so, they kick-start a food chain that ends with some of the biggest meat-eaters on the planet.

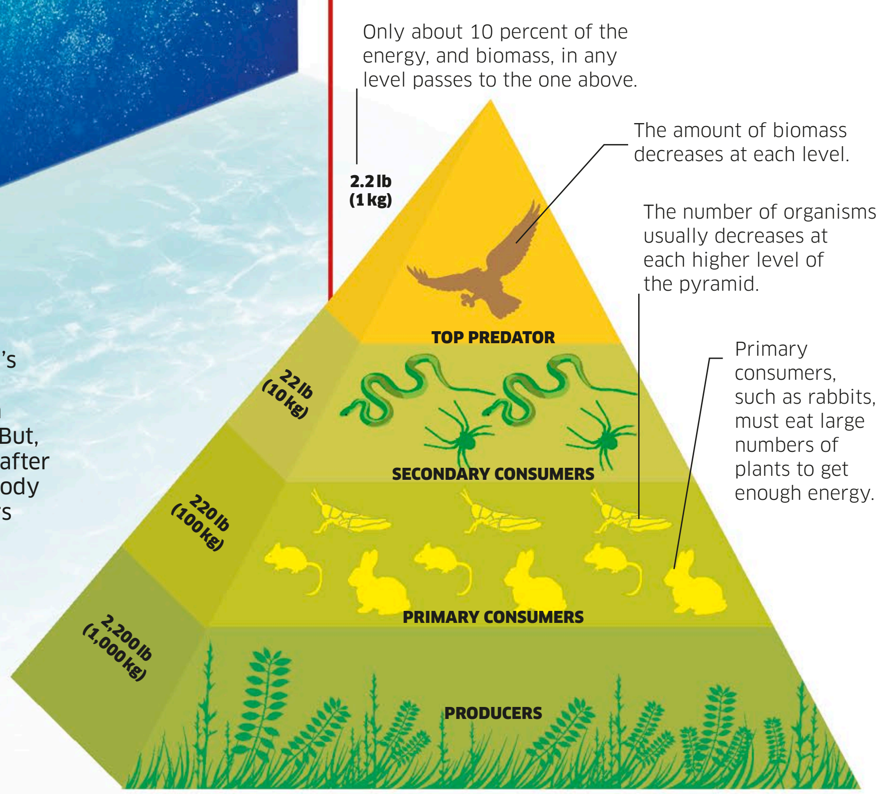
Heat production
The chemical reactions that take place in living organisms generate heat, which escapes into the surrounding water.

6 Great white shark
Being the food chain's top predator means that little else will prey on an adult great white shark. But, like all other organisms, after death the energy in its body will support decomposers that feed on its corpse.

5 Sea lion
Sea lions swim hundreds of yards from the shoreline to reach the best fishing grounds. As they hunt herring, the energy in the fish meat passes into the sea lion's body. Because their herring prey are also meat-eaters, this makes sea lions tertiary consumers.

Ecological pyramids

The levels of a food chain can be shown stacked up together to make an ecological pyramid. Plants or algae—the producers of food—form the base of the pyramid, with consumers on the higher levels. Each stage of the pyramid can also be shown as the total weight of the organisms on that level—their biomass. Both biomass and, usually, the number of animals decreases toward the top, as energy is lost at each level. Organisms use energy to stay alive and it is given off as waste and heat, leaving less to be passed on.



Threatened species

Human activities, such as habitat destruction and hunting, threaten many species of plants and animals with extinction.

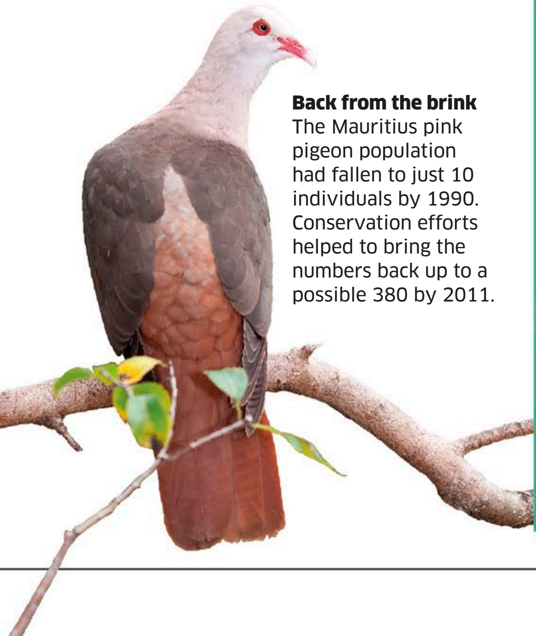
In 1964, the International Union for the Conservation of Nature (IUCN)—the world authority on conservation—started to list endangered species on the Red List. Since then, it has grown to cover thousands of species.

THE RED LIST CRITERIA

Scientists choose a level of threat for each species from among seven categories, depending on the results of surveys and other research. An eighth category includes species that need more study before a decision is made. The numbers of species on the Red List at the end of 2017 are listed below.

- **Least concern:** 30,385
- **Near threatened:** 5,445
- **Vulnerable:** 10,010
- **Endangered:** 7,507
- **Critically endangered:** 5,101
- **Extinct in wild:** 68
- **Extinct:** 844

Threatened numbers
The Red List has prioritized groups such as amphibians, reptiles, and birds that are thought to be at greatest risk. Most species—especially invertebrates, which make up 97 percent of all animal species—have not yet been assessed.

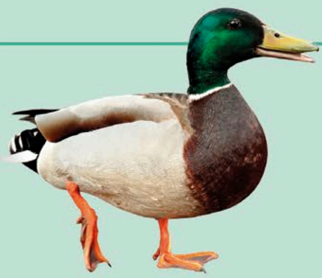


Back from the brink
The Mauritius pink pigeon population had fallen to just 10 individuals by 1990. Conservation efforts helped to bring the numbers back up to a possible 380 by 2011.

LEAST CONCERN

Widespread and abundant species facing no current extinction threat: some do well in habitats close to humans and have even been introduced into countries where they are not native.

HUMAN
Homo sapiens
Location: Worldwide
Population: 7.5 billion; increasing



MALLARD
Anas platyrhynchos
Location: Worldwide
Population: 19 million; increasing

CANE TOAD
Rhinella marina
Location: Tropical America, introduced elsewhere
Population: Unknown; increasing

NEAR THREATENED

Species facing challenges that may make them threatened in the near future: a decreasing population size increases risk.

JAGUAR
Panthera onca
Location: Central and South America
Population: 64,000; decreasing

REDDISH EGRET
Egretta rufescens
Location: Central and South America
Population: Unknown; decreasing

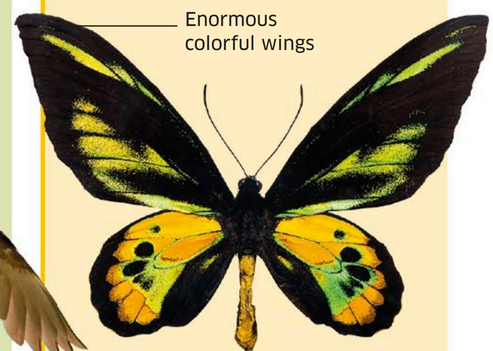
JAPANESE GIANT SALAMANDER
Andrias japonicus
Location: Japan
Population: Unknown; decreasing

PISTACHIO
Pistacia vera
Location: Southwestern Asia
Population: Unknown, decreasing

VULNERABLE

Species that may be spread over a wide range or abundant, but face habitat destruction and hunting.

HUMBOLDT PENGUIN
Spheniscus humboldti
Location: Western South America
Population: 30,000–40,000



ROTHSCHILD'S BIRDWING
Ornithoptera rothschildi
Location: Western New Guinea
Population: Unknown

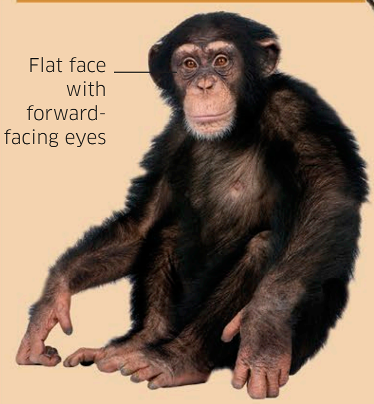
GOLDEN HAMSTER
Mesocricetus auratus
Location: Syria, Turkey
Population: Unknown; decreasing

AMERICAN PADDLEFISH
Polyodon spathula
Location: Mississippi River Basin
Population: More than 10,000

ENDANGERED

Species restricted to small areas, with small populations, or both: conservation projects, such as protecting habitats, can help save them from extinction.

WHALE SHARK
Rhincodon typus
Location: Warm oceans worldwide
Population: 27,000–238,000; decreasing



CHIMPANZEE
Pan troglodytes
Location: Central Africa
Population: 173,000–300,000; decreasing

FIJIAN BANDED IGUANA
Brachylophus bulabula
Location: Fiji
Population: More than 6,000; decreasing

GURNEY'S PITTA
Hydrornis gurneyi
Location: Myanmar, Thailand
Population: 10,000–17,200; decreasing

CRITICALLY ENDANGERED

Species in greatest danger: some have not been seen in the wild for so long that they may already be extinct; others have plummeted in numbers.

YANGTZE RIVER DOLPHIN
Lipotes vexillifer
Location: Yangtze River
Population: Last seen 2002; possibly extinct

COMMON SKATE
Dipturus batis
Location: Northeastern Atlantic
Population: Unknown; decreasing

SPIX'S MACAW
Cyanopsitta spixii
Location: Brazil
Population: Last seen 2016; possibly extinct in wild

CHINESE ALLIGATOR
Alligator sinensis
Location: China
Population: Possibly fewer than 150 in wild

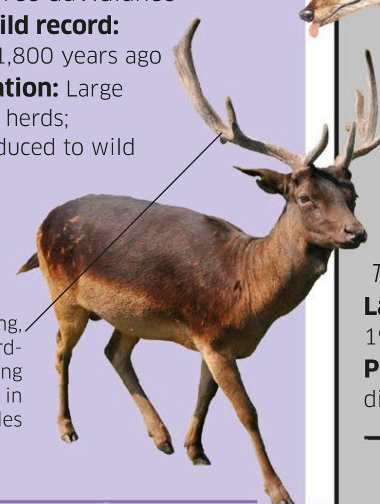
EXTINCT IN WILD

Species that survive in captivity or in cultivation: a few, such as Père David's deer, have been reintroduced to wild habitats from captive populations.

GUAM KINGFISHER
Todiramphus cinnamominus
Last wild record: Guam, 1986
Population: 124 in captivity

BLACK SOFTSHELL TURTLE
Nilssonia nigricans
Last wild record: Bangladesh, 2002
Population: 700 in artificial pond

PÈRE DAVID'S DEER
Elaphurus davidianus
Last wild record: China, 1,800 years ago
Population: Large captive herds; reintroduced to wild



WOOD'S CYCAD
Encephalartos woodii
Last wild record: South Africa, 1916
Population: A handful of clones of one plant in botanic gardens

EXTINCT

Species no longer found alive in the wild, even after extensive surveys, nor known to exist in captivity or cultivation: under these circumstances, it is assumed that the last individual has died.

GOLDEN TOAD
Incilius periglenes
Last wild record: Costa Rica, 1989
Population: Declared extinct 2004

CAROLINA PARAKEET
Conuropsis carolinensis
Last wild record: US, 1904
Population: Last parakeet died in zoo, 1918

THYLACINE
Thylacinus cynocephalus
Last wild record: Tasmania, 1930
Population: Last thylacine died in zoo, 1936

ST. HELENA GIANT EARWIG
Labidura herculeana
Last wild record: St. Helena, 1967
Population: Declared extinct 2001

REFERENCE

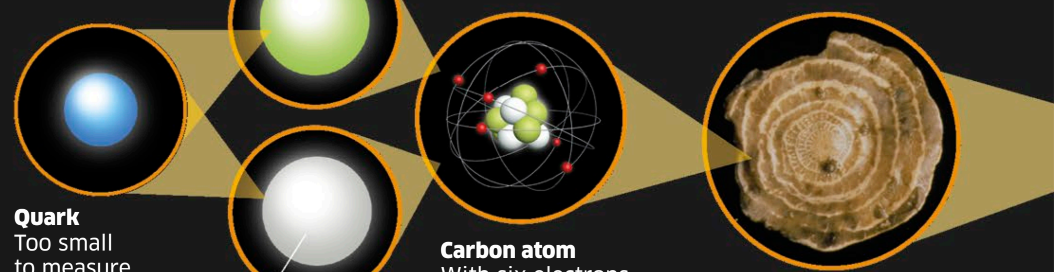
The scope of science stretches far and wide. Scientists study the vast expanse of the universe and everything within it—including the diversity of life and how it evolved. Careful observation, measurements, and experiments help scientists understand the world.

There are more **stars in the universe** than there are **grains of sand on all the beaches on Earth**.

Scale of the universe

The difference in size between the smallest and biggest things in the universe is unimaginably vast—from subatomic particles to galaxies.

No one knows how big the universe is, but it has been expanding since it formed in the Big Bang 13.7 billion years ago. The distances are so great that cosmologists measure them in terms of light-years—the distance light moves in space in a year, which is equal to 6 trillion miles (9.5 trillion kilometers)—and parts of the universe are billions of light-years apart.



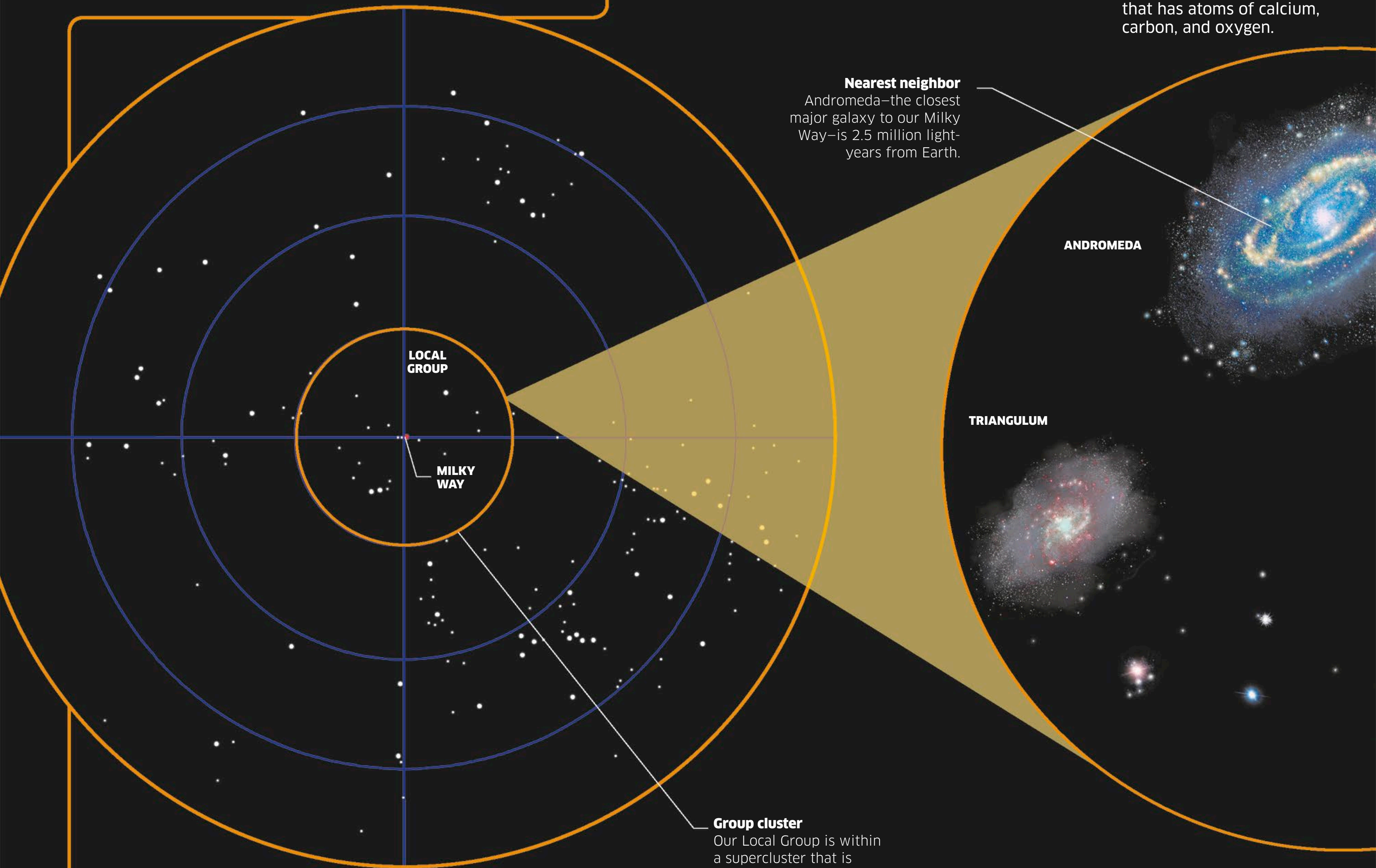
Proton
A particle in an atomic nucleus that carries a positive charge.

Quark
Too small to measure, different kinds of quarks are the subatomic particles that make up protons and neutrons.

Neutron
A particle in an atomic nucleus that carries no charge.

Carbon atom
With six electrons orbiting a nucleus of six protons and six neutrons, a carbon atom is less than a billionth of a meter across.

Limestone rock
Solid mixtures of billions of tiny fossilized shells and mineral fragments make up limestone rock, containing calcium carbonate—a compound that has atoms of calcium, carbon, and oxygen.

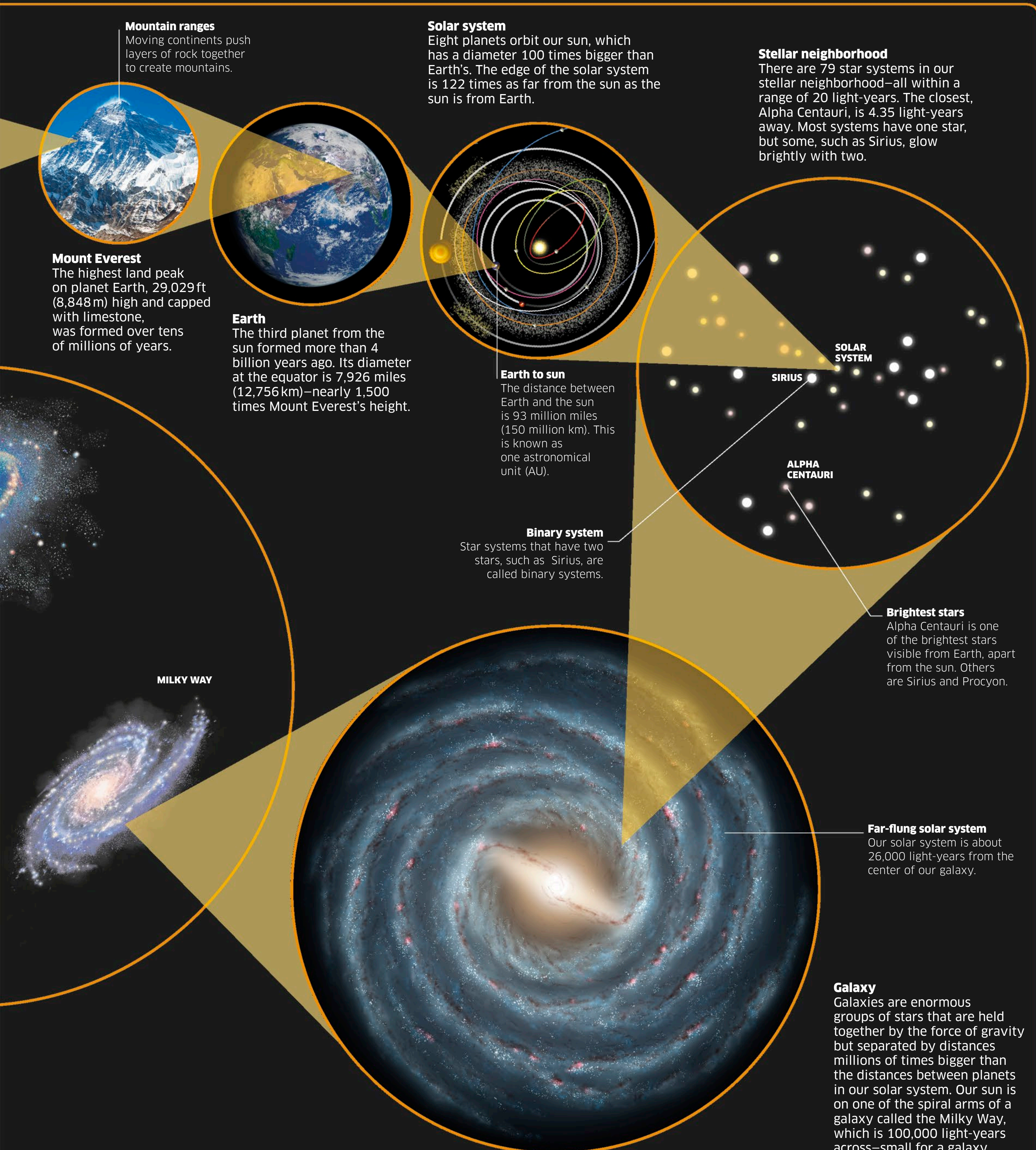


Nearest neighbor
Andromeda—the closest major galaxy to our Milky Way—is 2.5 million light-years from Earth.

Group cluster
Our Local Group is within a supercluster that is about 110 million light-years in diameter.

Supercluster
Clusters of galaxies span a region of space ten times bigger than the Local Group. Such a supercluster can contain tens of thousands of galaxies. Our Milky Way is within the Virgo Supercluster. Scientists think there are about 10 million superclusters in the observable universe.

Local Group
The Milky Way is part of a so-called Local Group of about 50 galaxies that stretch across 10 million light-years of space—that's 100 times the diameter of our Milky Way. Galaxies are millions of times farther apart than the stars that are in each one. Andromeda is the biggest galaxy in our Local Group—most others are much smaller.



Mountain ranges
Moving continents push layers of rock together to create mountains.

Mount Everest
The highest land peak on planet Earth, 29,029 ft (8,848 m) high and capped with limestone, was formed over tens of millions of years.

Earth
The third planet from the sun formed more than 4 billion years ago. Its diameter at the equator is 7,926 miles (12,756 km)—nearly 1,500 times Mount Everest's height.

Solar system
Eight planets orbit our sun, which has a diameter 100 times bigger than Earth's. The edge of the solar system is 122 times as far from the sun as the sun is from Earth.

Earth to sun
The distance between Earth and the sun is 93 million miles (150 million km). This is known as one astronomical unit (AU).

Stellar neighborhood
There are 79 star systems in our stellar neighborhood—all within a range of 20 light-years. The closest, Alpha Centauri, is 4.35 light-years away. Most systems have one star, but some, such as Sirius, glow brightly with two.

Binary system
Star systems that have two stars, such as Sirius, are called binary systems.

Brightest stars
Alpha Centauri is one of the brightest stars visible from Earth, apart from the sun. Others are Sirius and Procyon.

Far-flung solar system
Our solar system is about 26,000 light-years from the center of our galaxy.

Galaxy
Galaxies are enormous groups of stars that are held together by the force of gravity but separated by distances millions of times bigger than the distances between planets in our solar system. Our sun is on one of the spiral arms of a galaxy called the Milky Way, which is 100,000 light-years across—small for a galaxy.

Units of measurement

Scientists measure quantities—such as length, mass, or time—using numbers, so that their sizes can be compared. For each kind of quantity, these measurements must be in units that mean the same thing wherever in the world the measurements are made.

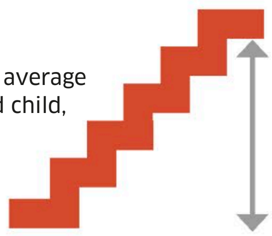
SI units
The abbreviation "SI" stands for *Système International.* It is a standard system of metric units that has been adopted by scientists all over the world so that all their measurements are done in the same way.

Base quantities

Just seven quantities give the most basic information about everything around us. Each is measured in SI units and uses a symbol as an abbreviation. The SI system is metric, meaning that smaller and larger units are obtained by dividing or multiplying by 10, 100, 1,000, etc. Centimeters, for instance, are 100 times smaller than a meter, but kilometers are 1,000 times bigger.

LENGTH
SI unit: meter (m)

One meter is about the average height of a 3½-year-old child, or five steps up a typical staircase.



- A millionth of a meter (1 micrometer) = the length of a bacterium.
- A thousandth of a meter (1 millimeter) = the diameter of a pinhead.
- 1,000 meters (1 kilometer) = the average distance an adult walks in 12 minutes.

MASS
SI unit: kilogram (kg)

One kilogram is the mass of one liter of water, or about the mass of an average-sized pineapple.

- A thousand trillionth of a kilogram (1 picogram) = the mass of a bacterium.
- A thousandth of a kilogram (1 gram) = the mass of a paper clip.
- 1,000 kilograms (1 metric ton) = the average mass of an adult walrus.

TIME
SI unit: second (s)

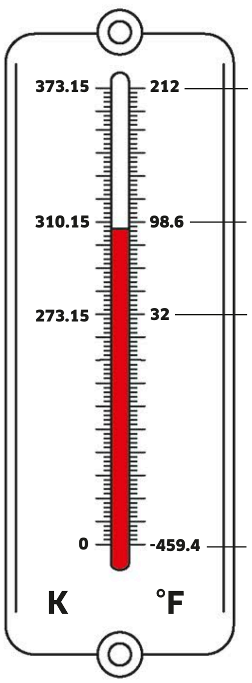
One second is the time it takes to swallow a mouthful of food, or to write a single-digit number.

- A thousandth of a second (1 millisecond) = the time taken by the brain to fire a nerve impulse.
- A tenth of a second (1 decisecond) = a blink of an eye.
- 1 billion seconds (1 gigasecond) = 32 years.

TEMPERATURE
SI unit: kelvin (K)

Just one degree rise in temperature can make you feel hot and feverish.

Temperature scales
In the USA, an everyday temperature scale uses degrees Fahrenheit (°F), where the freezing point of water is 32°F. Kelvin measures all the way down to absolute zero—where heat energy does not exist.



- 0 kelvin = absolute zero, when all objects and their particles are still.
- 1 kelvin = the coldest known object in the universe, the Boomerang Nebula.
- 1,000 kelvin = the temperature inside a charcoal fire.

ELECTRICAL CURRENT
SI unit: ampere (A)

One ampere is about the current running through a 100 W light bulb.

- A thousandth of an ampere (1 milliampere) = the current in a portable hearing aid.
- 100,000 amperes = the current in the biggest lightning strikes.
- 10 thousand billion amperes = the current in the spiral arms of the Milky Way.

LIGHT INTENSITY
SI unit: candela (cd)

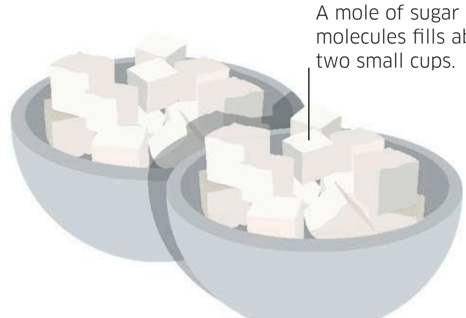
One candela is the light intensity given off by a candle flame.

- A millionth of a candela = the lowest light intensity perceived by human vision.
- A thousandth of a candela = a typical night sky away from city lights.
- 1 billion candelas = the intensity of the sun when viewed from Earth.

AMOUNT OF A SUBSTANCE
SI unit: mole (mol)

One mole is a set number of atoms, molecules, or other particles. Because substances all have different atomic structures, one mole of one substance may be very different to that of another.

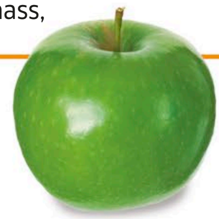

A mole of gold atoms is in about six gold coins.


A mole of sugar molecules fills about two small cups.

- A tenth of a mole of iron atoms = the amount of iron in the human body.
- 1,000 moles of carbon atoms = the amount of carbon in the human body.
- 10 million trillion moles of oxygen molecules = the amount of oxygen in Earth's atmosphere.

Derived quantities

Other kinds of quantities are also useful in science, but these are calculated from base quantities using scientific equations. For instance, we combine SI measurements of mass, distance, and time to work out an SI measurement for force. This means that force is said to be a derived quantity.



FORCE

SI unit: newton (N)

One newton is about the force of gravity on a single apple.

$$\text{Force in newtons} = \frac{\text{Mass in kilograms x distance in meters}}{\text{Time in seconds}^2}$$

- A 10 billionth of a newton = the force needed to break six chemical bonds in a molecule.
- 10 newtons = the weight of an object with mass of 1 kilogram.

PRESSURE

SI unit: pascal (Pa)

One pascal is about the pressure of one bill of paper money resting on a flat surface.

$$\text{Pressure in pascals} = \frac{\text{Force in newtons}}{\text{Area in meters}^2}$$

- A 10 thousand trillionth of a pascal = the lowest pressure recorded in outer space.
- 1 million pascals (1 megapascal) = the pressure of a human bite.

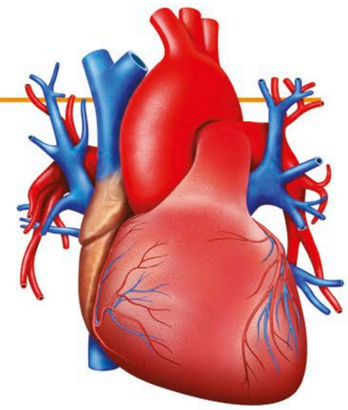
ENERGY

SI unit: joule (J)

One joule is about the energy needed to lift a medium-sized tomato a height of one meter.

$$\text{Energy in joules} = \text{Force in newtons x distance in meters}$$

- A millionth of a joule (1 microjoule) = the energy of motion in six flying mosquitoes.
- 1,000 joules (1 kilojoule) = the maximum energy from the sun reaching 1 square meter of Earth's surface each second.



FREQUENCY

SI unit: hertz (Hz)

One hertz is about the frequency of a human heartbeat: one beat per second.

$$\text{Frequency in hertz} = \frac{\text{Number of cycles}}{\text{Time in seconds}}$$

- 100 hertz = the frequency of an engine cycle in a car running at maximum speed.
- 10,000 hertz = the frequency of radio waves.

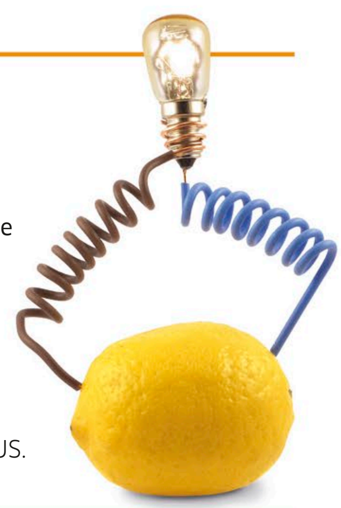
POWER

SI unit: watt (W)

One watt is about the power used by a single Christmas tree light.

$$\text{Power in watts} = \frac{\text{Energy in joules}}{\text{Time in seconds}}$$

- A millionth of a watt (1 microwatt) = the power used by a wristwatch.
- 1 billion watts (1 gigawatt) = the power used by a hydroelectric generating station.



POTENTIAL DIFFERENCE

SI unit: volt (V)

Voltage is a measure of the difference in electrical energy between two points—the force needed to make electricity move. One volt is about the voltage in a lemon battery cell.

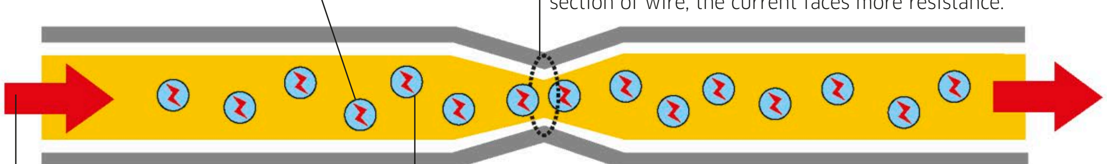
$$\text{Potential difference in volts} = \frac{\text{Power in watts}}{\text{Current in amperes}}$$

- 100 volts = the electrical grid voltage in the US.

ELECTRICAL CHARGE AND RESISTANCE

SI unit: Charge—coulomb (C)
Resistance—ohm (Ω)

The measurements relating to electricity are all interlinked. Charge is a measure of how positive or negative particles are, and can be calculated from the current and the time. Resistance is a measure of the difficulty a current has in flowing, and can be calculated from the voltage and the current.



$$\text{Resistance in ohms} = \frac{\text{Potential difference in volts}}{\text{Current in amperes}}$$

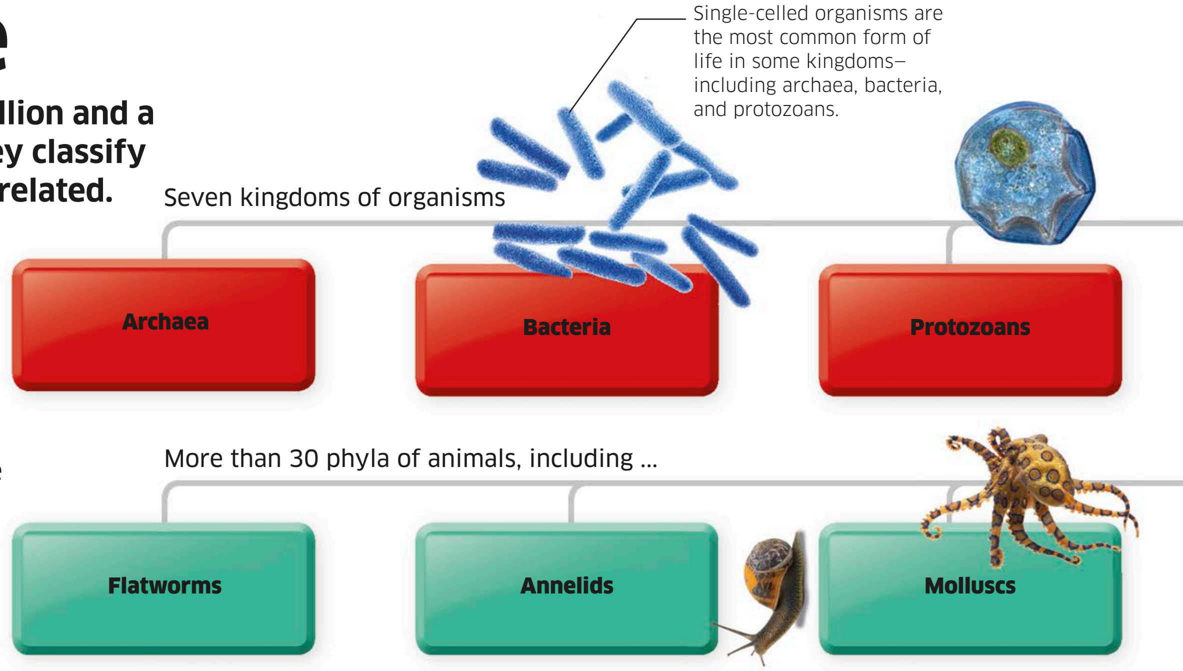
$$\text{Charge in coulombs} = \text{Current in amperes x time in seconds}$$

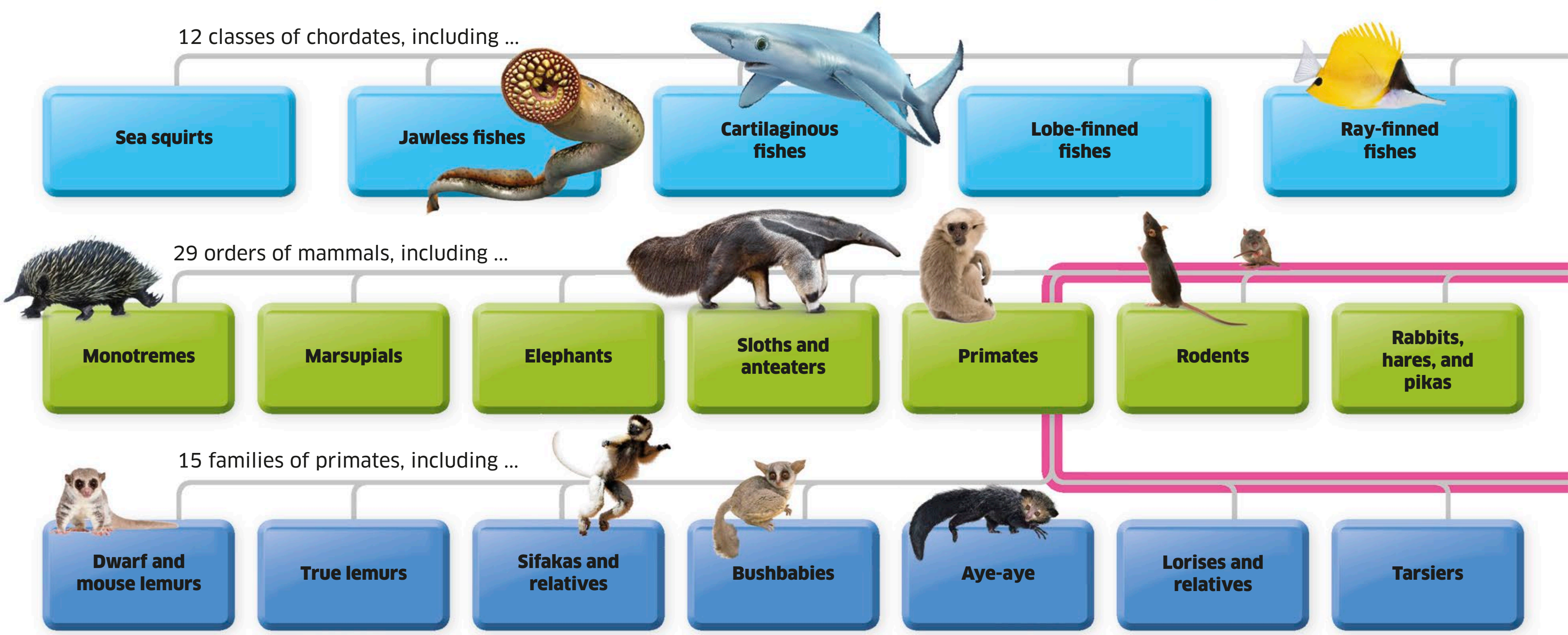
More than **half of all known animal species belong to the class of insects**, and most of these belong to one order: the beetles.

Classifying life

Scientists have described more than a million and a half different species of living things. They classify them into groups based on how they are related.

There are lots of ways of classifying organisms. Insects, birds, and bats could be grouped as flying animals, and plants could be grouped by how we use them. But neither of these systems shows natural relationships. Biological classification works by grouping related species. Bats, for instance, have closer links to monkeys than they do to birds, because they are both furry mammals that have evolved from the same mammal ancestors.



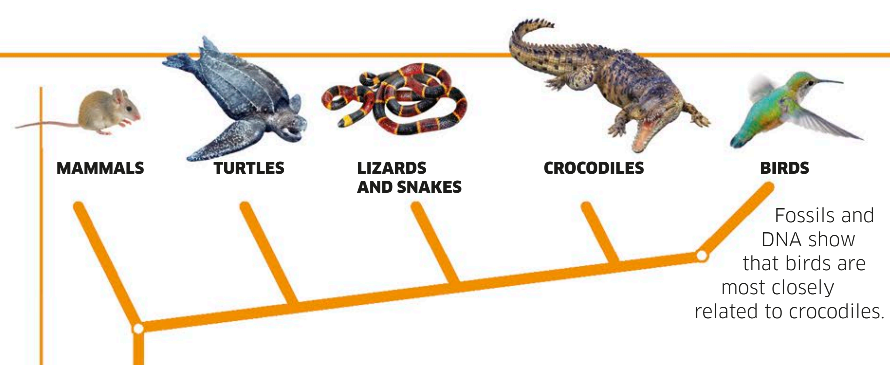


Scientific names

Every species has a two-part scientific name using Latin words that are internationally recognized in science. The first part identifies its genus group, the second its species. Lions and tigers belong to the *Panthera* genus of big cats, but have different species names.

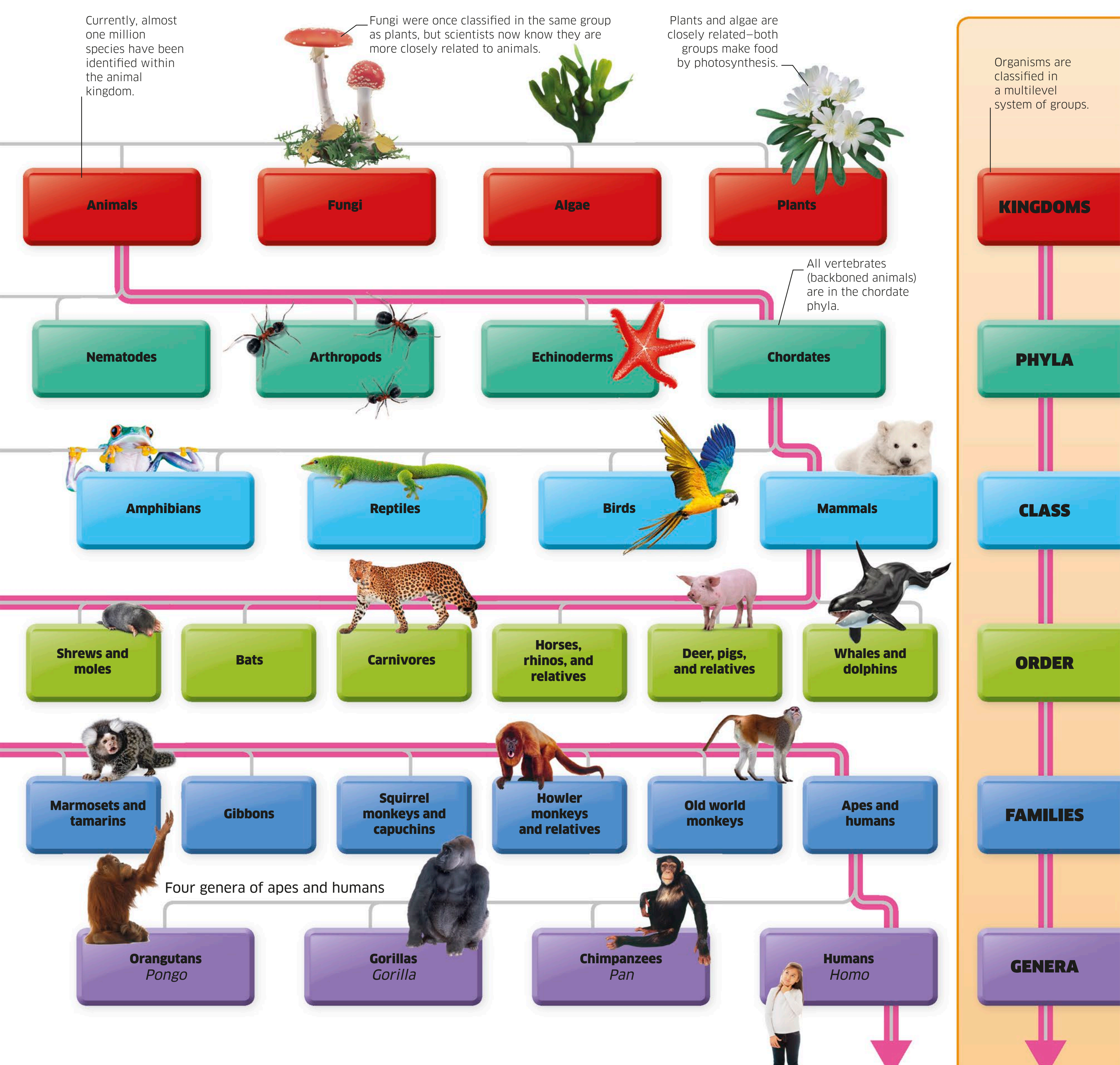
Panthera leo
Lion

Panthera tigris
Tiger



Classifying birds

Modern classification aims to show how organisms are linked by evolution. Birds and reptiles are traditionally in two separate classes. But birds evolved from reptile ancestors (see pp.136–137), so many scientists think they should be a sub-group of the reptiles.

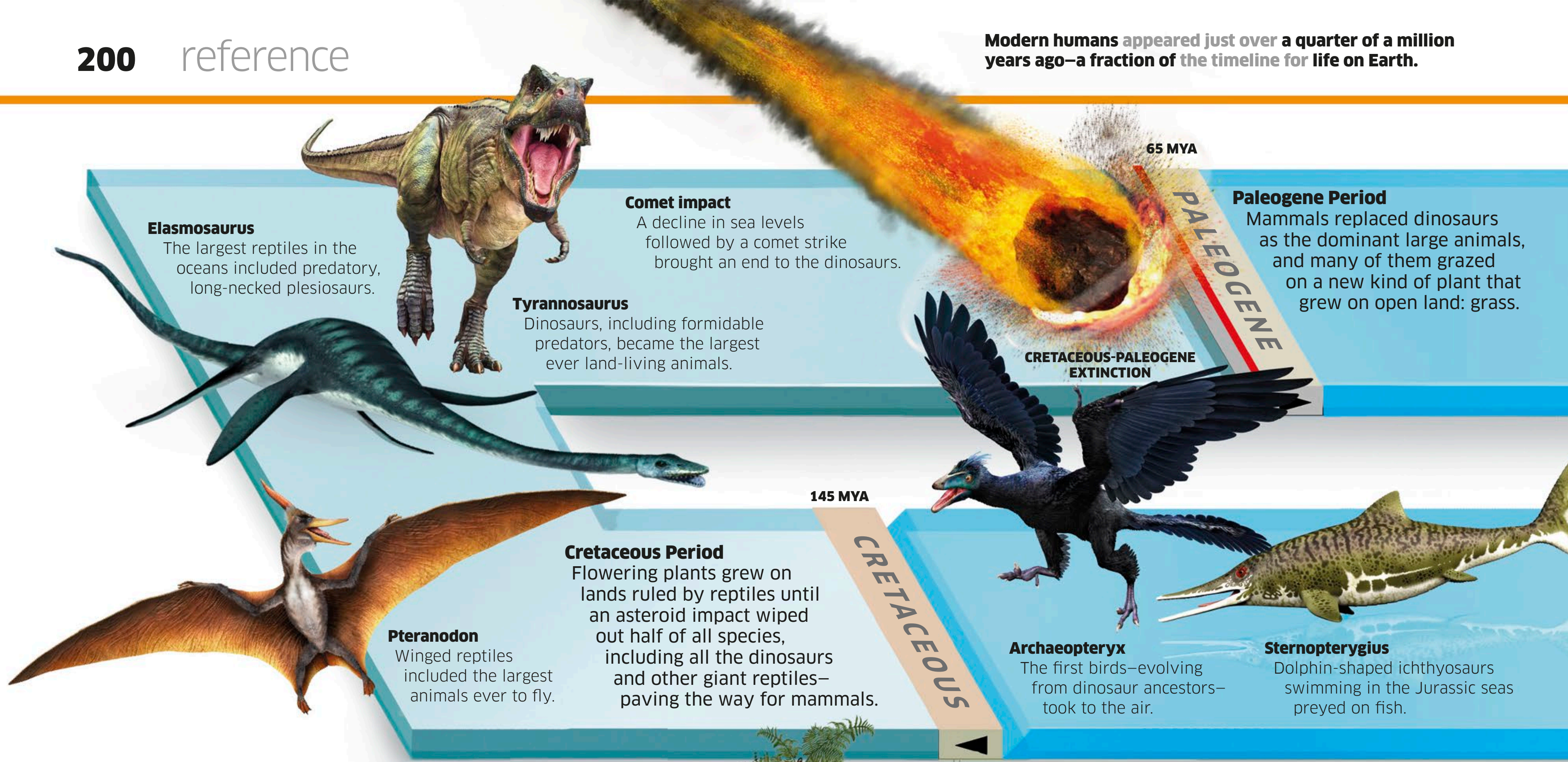


Latinized scientific names often describe an aspect of the species: **Homo sapiens means "wise man."**

Classifying humans

Every species, including our own, has its own place in biological classification. This chart shows the position of humans within the animal kingdom, next to our closest relatives—the great apes. There is only one species of human alive today, but other species of the genus *Homo* lived in the prehistoric past.

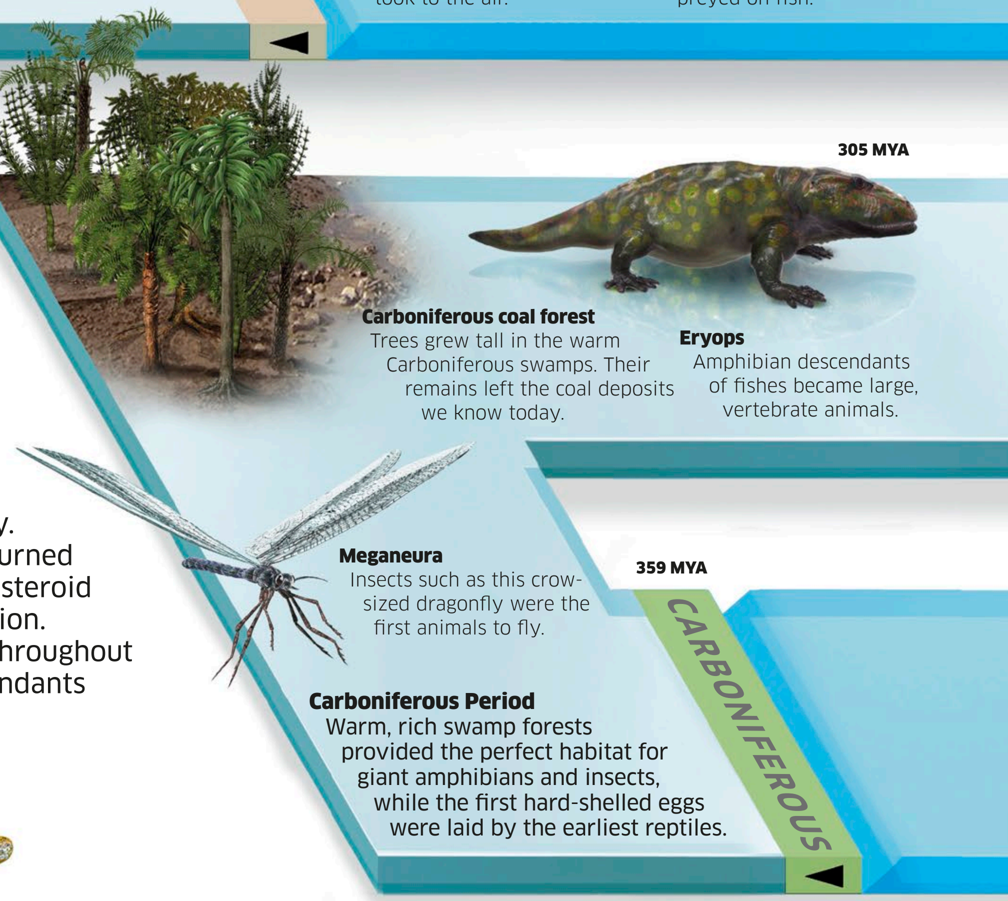
Modern humans appeared just over a quarter of a million years ago—a fraction of the timeline for life on Earth.

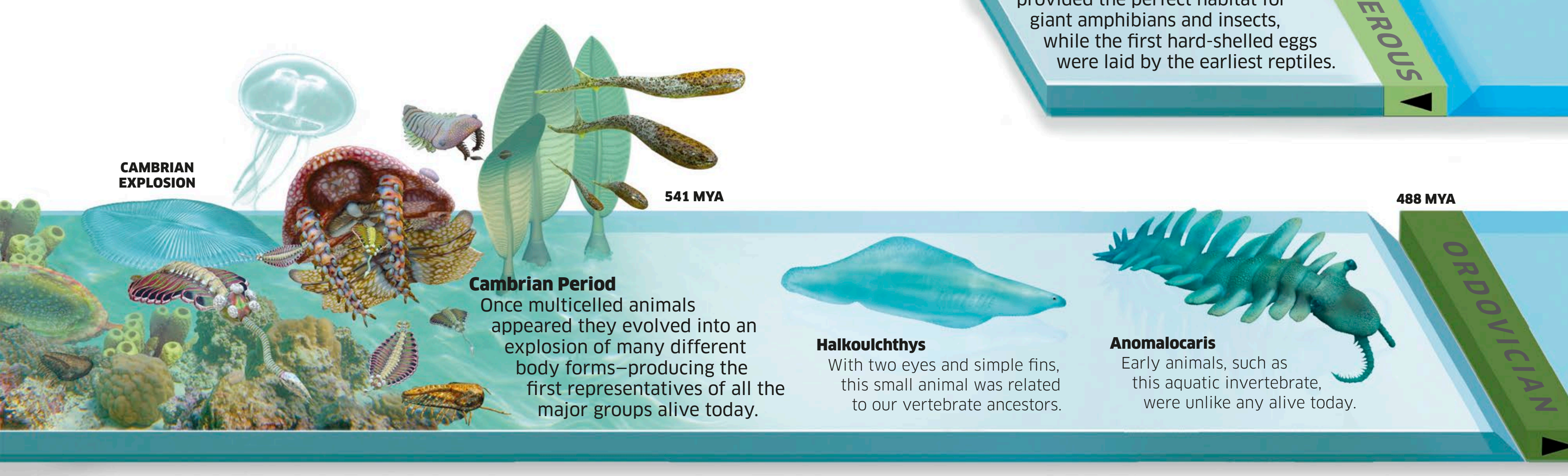


Timeline of life

Half a billion years ago the only living things were small and simple. Over time, evolution has produced a spectacular world of plants and animals.

The timeline of life is divided into periods that were dominated by particular kinds of organisms—such as invertebrates, fishes, or reptiles. As the surface of Earth changed, some organisms succeeded, while others died away. Continents shifted, seas rose and fell, and luxuriant forests turned into parched deserts and back again. Catastrophes, such as asteroid strikes or ice ages, even drove some major groups to extinction. Such events all made their mark on living things. However, throughout the history of Earth, life went on as descendants after descendants eventually led to the natural world we know today.





The earliest evidence of **single-celled fossil life** exists in rocks that are **3.5 billion years old.**

Billions of years ago, algae produced much of the **oxygen in the air today.**

Periods of time

Earth's prehistory is marked by a timescale divided up into geological periods. Each period represents a length of time that has left its mark in rocks with fossils and other evidence.

23 MYA

NEOGENE

Neogene Period
Many familiar groups of mammals, such as rodents, primates, antelopes, and cats, evolved in the Neogene, while flying birds diversified in the skies.

Megacerops
Tiny ancestors evolved into large mammals that replaced the dinosaurs.

Thylacosmilus
Predatory mammals, including saber-toothed cats, hunted grazers on the open grassland.

2.6 MYA

QUATERNARY

Quaternary Period
Mammals and birds survived Quaternary ice ages, but one species– humans– drove many others to extinction by hunting and habitat destruction, causing the biggest mass extinction of modern times.

Red lines indicate mass extinctions.

201 MYA

JURASSIC

Jurassic Period
The peak of the Age of Dinosaurs saw the evolution of giant reptiles on land and in the seas, which included the largest land animals of all time.

TRIASSIC-JURASSIC EXTINCTION

Asteroid impact
A space rock colliding with Earth wiped out a quarter of all species.

Eoraptor
The first dinosaurs, some two-legged, evolved from small reptiles that survived the Permian-Triassic extinction.

299 MYA

PERMIAN

Permian Period
Continents dried up to favor scaly reptiles over amphibians. The period ended with violent eruptions causing the biggest of all mass extinctions.

Dimetrodon
As moist-skinned amphibians declined in a drier world, reptiles such as this carnivore took over.

PERMIAN-TRIASSIC EXTINCTION

TRIASSIC

Triassic Period
New kinds of forests containing conifers and cycads were inhabited by the first dinosaurs until a possible asteroid impact brought about mass extinction.

251 MYA

LATE DEVONIAN EXTINCTION

375–360 MYA

Elginerpeton
Fishes with strong, fleshy fins—such as Elginerpeton—paved the way for the evolution of walking limbs.

Devonian Period
More kinds of fishes evolved in the oceans, while vertebrate animals and trees appeared on land. Climate change near the end of the Devonian Period caused mass extinction.

DEVONIAN

416 MYA

Climatius
This fish had a sharklike skeleton of rubbery cartilage, but bony, spiny fins.

433 MYA

Ordovician Period
The oceans of the Ordovician teemed with invertebrates and primitive fishes, but ended with an ice age that drained shallow seas and caused a mass extinction.

Orthoceras
This relative of squid had grasping arms and a body inside a long, cone-shaped shell.

ORDOVICIAN EXTINCTION

SILURIAN

Silurian Period
Jawed fishes and coral reefs appeared for the first time, while distant relatives of spiders and centipedes started to crawl onto land.

Glossary

ACID
A substance with a pH lower than 7.

ALGAE
Plantlike organisms that can make food using energy from sunlight.

ALKALI
See Base

ALLOY
A mixture of two or more metals, or of a metal and a non-metal.

ANALOG
Relating to signals or information represented by a continuously varying value, such as a wave.

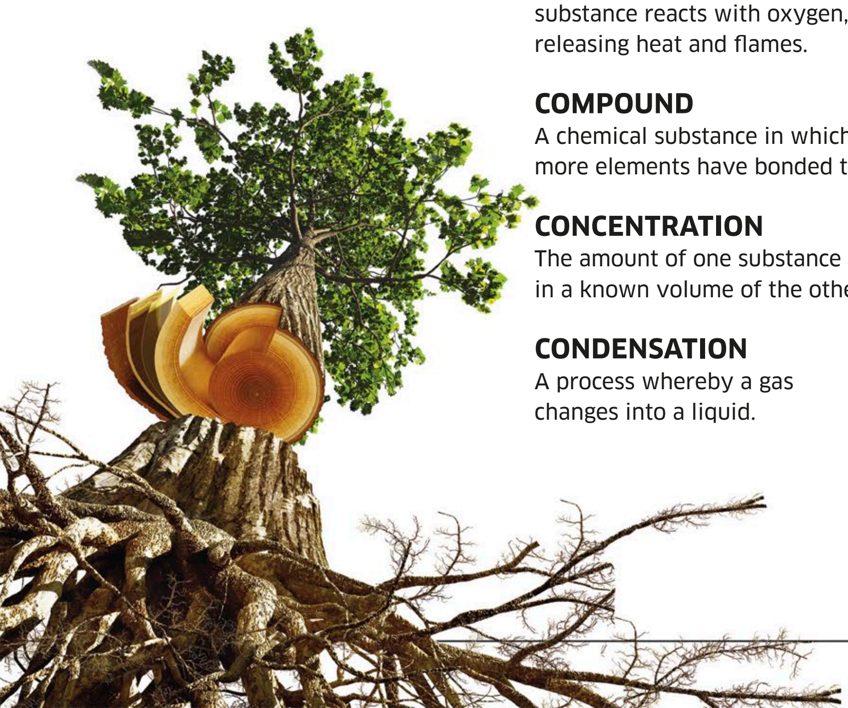
ATMOSPHERE
The layer of breathable gases, such as oxygen and nitrogen, that surrounds Earth.

ATOM
The smallest unit of an element.

BACTERIA
Microscopic organisms with a simple, single-celled form.

BASE
A substance with pH higher than 7. Bases that are soluble in water are called alkalis. Also: one of the four chemicals that make up the "rungs" of a DNA double helix.

BIOLOGY
The science of living things.



BUOYANCY
The tendency of a solid to float or sink in liquids.

CARBOHYDRATE
An energy-rich substance, such as sugar or starch.

CATALYST
A substance that makes a chemical reaction occur much more rapidly, but is not changed by the reaction.

CELL
The smallest unit of life.

CHEMICAL BOND
An attraction between particles, such as atoms or ions.

CHEMICAL REACTION
A process that changes substances into new substances by breaking and making chemical bonds.

CHEMISTRY
The science of matter and elements.

CHROMOSOME
A threadlike structure, found in the nucleus of cells, that is made up of coiled strands of DNA. Humans have 46 chromosomes per body cell.

CLIMATE
The most common weather conditions in an area over a long period of time.

COMBUSTION
A chemical reaction in which a substance reacts with oxygen, releasing heat and flames.

COMPOUND
A chemical substance in which two or more elements have bonded together.

CONCENTRATION
The amount of one substance mixed in a known volume of the other.

CONDENSATION
A process whereby a gas changes into a liquid.

CONDUCTOR
A substance through which heat or electric current flows easily.

COVALENT BOND
A type of chemical bond in a molecule where atoms share one or more electrons.

DNA
A material found in the cells of all organisms that carries instructions for how a living thing will look and function.

DRAG
The resistance force formed when an object pushes through a fluid, such as air or water.

ECOSYSTEM
A community of organisms and the nonliving environment around them.

ELECTRIC CHARGE
How positive or negative a particle is.

ELECTRON
One of the tiny particles inside an atom. It has a negative electric charge.

ELEMENT
A simple substance made of atoms that are all the same kind.

ENERGY
What enables work to be done. Energy exists in many different forms and cannot be created or destroyed, only transferred.

ENZYME
A substance produced in living organisms that acts as a catalyst and speeds up chemical reactions.

EROSION
A process by which Earth's surface rocks and soil are worn away by wind, water, or ice.

EVAPORATION
A process by which a liquid changes into a gas.

EVOLUTION
The process by which Earth's species gradually change over long periods of time, such as millions of years, to produce new species.

EXCRETION
The process by which living organisms expel or get rid of waste produced by cells of the body.

FERTILIZATION
The joining of male and female sex cells so they develop into new life.

FISSION
A splitting apart; nuclear fission is the splitting of the nucleus of an atom.

FOSSIL
The preserved remains or impressions of life from an earlier time.

FOSSIL FUEL
A substance formed from the remains of ancient organisms that burns easily to release energy.

FRICTION
The dragging force that occurs when one object moves over another.

FUSION
A joining together; nuclear fusion is the joining of two atomic nuclei.

GAS
A state of matter that flows to fill a container, and can be compressed.

GENE
One of the tiny units carried on DNA that determine what a living thing looks like and how it functions.

GLUCOSE
A simple carbohydrate, or sugar, made by photosynthesis and then used by cells as a source of energy.

GRAVITY
The force that attracts one object to another and prevents things on Earth from floating off into space.

HABITAT
The area where an animal naturally makes its home.

INHERITANCE
The range of natural characteristics passed on to offspring by parents.

INSULATOR
A material that stops heat moving from a warm object to a colder one.

ION
An atom that has lost or gained one or more electrons and as a result has either a positive or negative electric charge.

IONIC BOND
A type of chemical bond where one or more electrons are passed from one atom to another, creating two ions of opposite charge that attract each other.

ISOTOPE
One of two or more atoms of a chemical element that have different numbers of neutrons compared to other atoms of the element.

LIFT
The upward force produced by an aircraft's wings that keeps it airborne.

LIQUID
A state of matter that flows and takes the shape of a container, and cannot be compressed.

MAGMA
Hot, liquid rock that is found beneath Earth's surface.

MAGNET
An object that has a magnetic field and attracts or repels other magnetic objects.

MASS
A measure of the amount of matter in an object.

MATERIAL
A chemical substance out of which things can be made.

METAL
Any of many elements that are usually shiny solids and good conductors of electricity.

MICROORGANISM
A tiny organism which can only be seen with the aid of a microscope. Also known as a microbe.

MINERAL
A solid, nonliving material occurring naturally and made up of a particular kind of chemical compound.

MOLECULE
A particle formed by two or more atoms joined by covalent bonds.

MONOMER
A molecule that can be bonded to other similar molecules to form a polymer.

NERVE
A fiber that carries electrical messages (nerve impulses) from one part of the body to another.

NEUTRON
One of the tiny particles in an atom. It has no electric charge.

NUCLEUS
The control center inside the cells of most living organisms. It contains genetic material, in the form of DNA. Also: the central part of an atom, made of protons and neutrons.

NUTRIENT
A substance essential for life to exist and grow.

ORBIT
The path taken by an object, for example, a planet, that is circling around another.

ORGAN
A group of tissues that makes up a part of the body with a special function. Important organs include the heart, lungs, liver, and kidneys.

ORGANISM
A living thing.

PARTICLE
A tiny speck of matter.

PHOTOSYNTHESIS
The process by which green plants use the sun's energy to make carbohydrates from carbon dioxide and water.

PHYSICS
The science of matter, energy, forces, and motion.

PIGMENT
A chemical substance that colors an object.

POLLEN
Tiny grains produced by flowers, which contain the male cells needed to fertilize eggs.

POLYMER
A long, chainlike molecule made up of smaller molecules connected together.

PRESSURE
The amount of force that is applied to a surface per unit of area.

PRODUCT
A substance produced by a chemical reaction.

PROTEIN
A type of complex chemical found in all living things, used as enzymes and in muscles.

PROTON
One of the tiny particles inside an atom. It has a positive electric charge.

RADIATION
Waves of energy that travel through space. Radiation includes visible light, heat, X-rays, and radio waves. Nuclear radiation includes subatomic particles and fragments of atoms.

RADIOACTIVE
Describing a material that is unstable because the nuclei of its atoms split to release nuclear radiation.

REACTANT
A substance that is changed in a chemical reaction.

REACTIVE
A substance that is likely to become involved in a chemical reaction.

RESPIRATION
The process occurring in all living cells that releases energy from glucose to power life.

ROOM TEMPERATURE
A standard scientific term for comfortable conditions (for humans), usually a temperature of around 68°F (20°C).

SEX ORGANS
The organs of an organism that allow it to reproduce. They usually produce sex cells: sperm in males, and eggs in females.

SOLID
A state of matter in which an element's atoms are joined together in a rigid structure.

SOLUTE
A substance that becomes dissolved in another.

SOLVENT
A substance that can have other substances dissolved in it.

SYNTHETIC
Man-made chemical.

TISSUE
A group of similar cells that carry out the same function, such as muscle tissue, which can contract.

TOXIC
Causing harm, such as a poison.

ULTRASOUND
Sound with a frequency above that which the human ear can detect.

ULTRAVIOLET
A type of electromagnetic radiation with a wavelength shorter than visible light.

UNIVERSE
The whole of space and everything it contains.

VOLCANO
An opening in Earth's crust that provides an outlet for magma when it rises to the surface.

WAVE
Vibration that transfers energy from place to place, without transferring the matter that it is flowing through.

WAVELENGTH
The distance between wave crests, usually when referring to sound waves or electromagnetic waves.

WEIGHT
The force applied to a mass by gravity.

Index

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