



WOW! SCIENCE

lots of amazing things about science

The background of the image is a dense, repeating pattern of small, colorful icons representing various scientific fields. These icons include laboratory glassware like beakers and flasks, chemical structures, biological organisms, astronomical objects like planets and galaxies, and scientific instruments like microscopes and test tubes. The icons are rendered in a variety of colors including blue, orange, green, and grey, creating a vibrant and detailed texture.

WOW!
SCIENCE



**LONDON, NEW YORK,
MELBOURNE, MUNICH, AND DELHI**

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First published in Great Britain in 2011 by
Dorling Kindersley Limited,
80 Strand, London, WC2R 0RL
Penguin Group (UK)

10 987654321
001-179074-July/11

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A CIP catalogue record for this book
is available from the British Library

ISBN: 978-1-40536-427-0

Printed and bound by Leo, China

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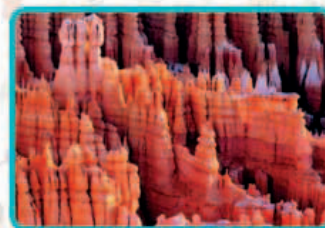
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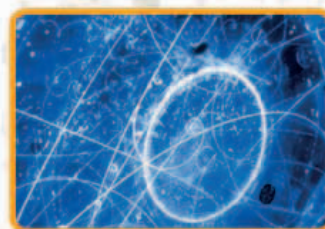
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FULL OF LIFE

A coral reef is packed with marine life. Different species of fish, crustaceans, marine plants, and mammals, as well as billions of microscopic plankton, make the waters around a coral reef their home.



The Living World

LIFE ON EARTH

Life exists in rich abundance on Earth. A species is a group of living organisms, such as humans, golden eagles, and blue whales, which share common characteristics and can breed with each other. Scientists have identified almost two million different species, although there may be many more. These are divided up into five kingdoms – plants, animals, fungi, bacteria, and single-celled organisms known as protists. All share some basic characteristics of life that enable them to survive.

▼ MOVEMENT

Living things are capable of moving part or all of their bodies. Plants may be rooted in one place, but they can grow in different directions while their flowers can open and close. This cougar (also known as a puma or mountain lion) is the largest predatory animal in the United States. It can run at speeds of more than 50 km/h (30 mph) in short sprints.



▲ FOOD ENERGY

All living things require food, which they digest for energy to fuel their movement, to maintain and repair their bodies, and for growth. Animals that eat other creatures are called carnivores, such as this osprey catching a fish. Animals that eat only plants are called herbivores, while those that eat both plants and animals are called omnivores. Plants make food through the process of photosynthesis, while fungi feed on decaying plant and animal matter.

An eagle's talons are sharp and can grip prey securely



▼ RESPIRATION

Respiration is the release of energy from food substances in all living cells. It is a chemical reaction and it can be either aerobic (with oxygen) or anaerobic (without oxygen). Animals, such as this polar bear, respire aerobically, taking in oxygen from the surrounding air or, in the case of fish, from water. The oxygen is exchanged in a land animal's lungs, a fish's gills, or an insect's tracheae, with carbon dioxide, which respiration creates as a waste product.

Cell division creates new cells essential for reproduction and growth

Powerful hind leg muscles enable cougars to leap up to 9 m (30 ft)

The cell divides into two with identical nuclei in the centre of each new cell

▲ REPRODUCTION

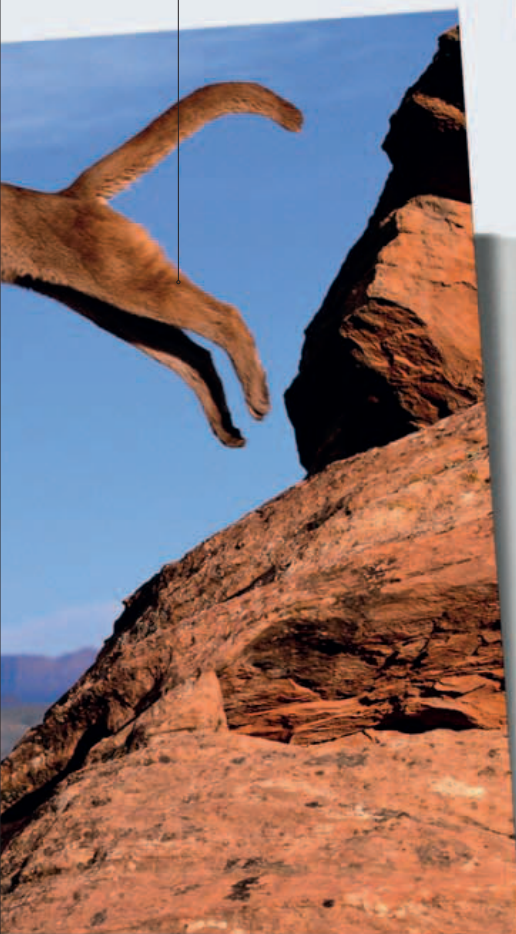
All living things reproduce to create offspring – new individuals of the species. Asexual reproduction is found in bacteria, some plants, and other creatures. It involves just one parent that may divide in two or features a part that breaks off to form an identical offspring. Sexual reproduction involves male and female parents who create a new offspring with a mixture of traits from the two parents.

▼ GROWTH

All plants and animals are capable of growth. They use food to create new cells and to increase their size. Plants grow from seedlings into mature specimens, while animals grow from young to adults. The Pacific giant kelp is one of the fastest growing organisms on Earth. It is capable of growing by as much as 50 cm (20 in) per day.

► RESPONSIVENESS

All living things have an awareness of their surroundings and are able to respond to their environment. An animal may respond to sound, heat, or light with specially adapted nerve cells sending signals from one part of the body to another. Plants are sensitive to gravity with stems growing upwards and roots growing downwards. They also respond to light by bending towards light sources. This is known as phototropism.

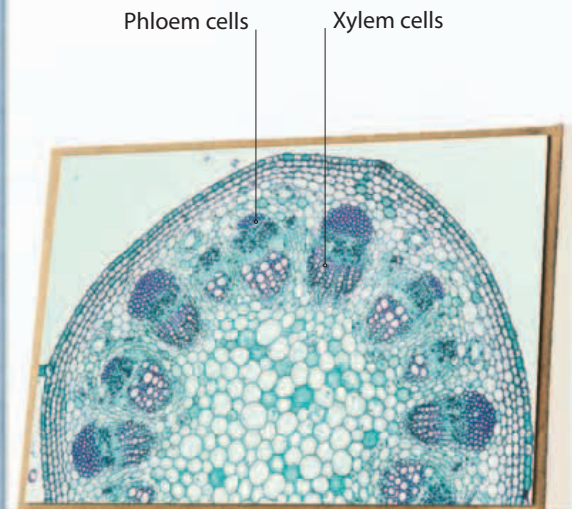


PLANT STRUCTURE

There are more than 300,000 species of plant, ranging in size from the minute species of *Wolffia* (members of the Duckweed family) to giant Sequoia trees, the largest of which stand more than 100 m (330 ft) high. Botanists divide plants into those that produce flowers and those that are non-flowering. Along with some bacteria, plants are the only living things that manufacture their own food through photosynthesis.

► TRANSPORT

Most plants are vascular, containing special cells that transport vital substances. This cross-section through a sunflower stem shows the xylem cells that transport water and some dissolved mineral nutrients from the roots up through the plant. Outside the xylem cells are phloem cells, which carry sugars created during photosynthesis around the plant.



Leaves release water and manufacture food

► PLANT STRUCTURE

Plants are also divided into vascular plants, which contain tissues that transport water, nutrients, and food around the plant (see above), and non-vascular plants, such as mosses and liverworts. A seedling of a young hazel tree already shows the parts that vascular plants share. Its roots bind it into the soil, while its stem supports its branches and leaves. Young stems rely on the pressure of water to stay upright, but gradually stiffen as the plant grows.

Stem of plant supports the branches and leaves

Growth of new branch

Root network branches out in the soil

Primary root grows downwards

Seed from which the shoot has grown up and the root has grown down

▼ LEAVES

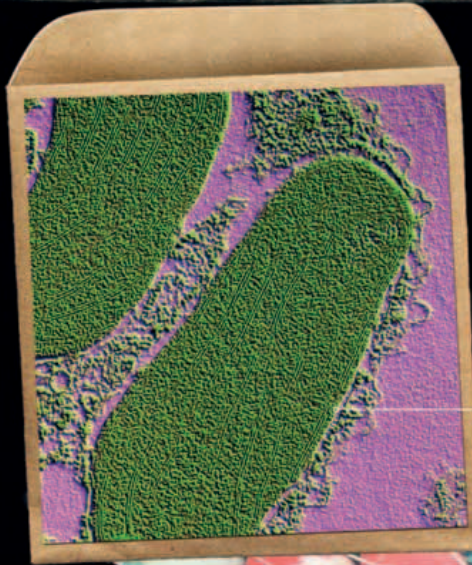
Leaves are mostly flat structures connected to a stem by a stalk, called the petiole. A network of veins runs through the leaf, carrying water and nutrients to the leaf and glucose from it to other parts of the plant. Leaves are made up of different layers of cells. The palisade layer has chloroplasts, which contain chlorophyll, a chemical that gives plants their green colour. It is in the chloroplasts that photosynthesis occurs.

Tough, waterproof outer layer called the cuticle

Epidermis layer covers outer part of leaf

Palisade layer forms upper part of mesophyll

Spongy layer forms lower part of mesophyll



◀ CONVERTING SUNLIGHT

Photosynthesis is the process where energy from sunlight is used to convert carbon dioxide and water into glucose and oxygen. Chlorophyll in a plant's leaves absorbs energy from sunlight. The energy-rich glucose is transported around the plant as food, but can also be used to form more complex chemical substances. These include cellulose, which is used to build the walls of plant cells.

Chlorophyll is stored in tiny structures called chloroplasts

▼ TRANSPIRATION

Water carried through a plant evaporates into the air through tiny openings or pores, called stomata, in the surface of leaves. This process is called transpiration. This stoma on a clover leaf is surrounded by two guard cells that open or close the pore depending on environmental conditions. Plants transpire more rapidly at higher temperatures.



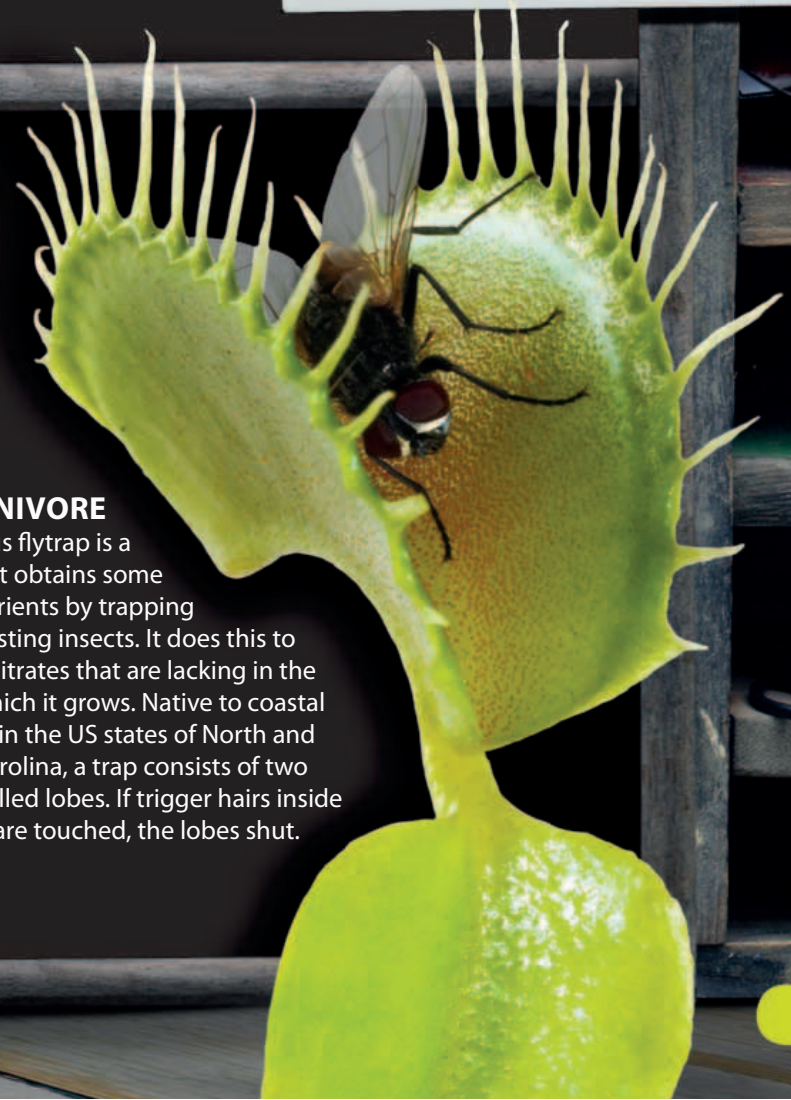
▶ ROOTS

A plant's roots help anchor it in position in the soil and support the plant's weight above the ground. Roots can branch out sideways, but their primary movement is downwards into the soil. A root of a Shepherd's tree found in Africa's Kalahari Desert was found to have reached a depth of 68 m (223 ft). Roots absorb water and nutrients from the soil. In some plants, roots store carbohydrates as food.



▶ CARNIVORE

The Venus flytrap is a plant that obtains some of its nutrients by trapping and digesting insects. It does this to replace nitrates that are lacking in the soil in which it grows. Native to coastal marshes in the US states of North and South Carolina, a trap consists of two leaves called lobes. If trigger hairs inside the trap are touched, the lobes shut.



PLANT REPRODUCTION

Plants need to reproduce for their species to survive. New plants replace those that die, increase the population numbers, and distribute a plant species to new locations. Flowering plants produce seeds that, if the temperature and conditions are suitable, will begin growing into new plants – a process called germination. Seeds are often dispersed to avoid competing for the same light, water, and soil nutrients as their parent plant.

1 FLOWERS

There are more than 250,000 different species of flowering plant. Flowers contain both a plant's male and female sex organs. Some plants, such as oak trees, produce separate male and female flowers. The female sex cells, or ovaries, lie at the base of a stalk called a pistil. At the top of the pistil lies a sticky or feathery structure called the stigma. The male sex cells, called pollen, are located on other stalks called stamen.

2 POLLINATION

For sexual reproduction to occur, male sex cells have to reach female sex cells. This process is called pollination. Some plants' flowers can self-pollinate, but most rely on cross-pollination, with pollen travelling from one plant to another. Wind transports pollen from some types of plant. Others rely on creatures, such as bees, carrying pollen from one flower to another.

3 SEEDS AND FRUITS

When pollination is successful, seeds form inside fruits. The seeds may be surrounded by a hard casing or protected by a fleshy covering. The fruit helps the seed disperse from the parent plant by rolling away when dropped or by being eaten by creatures and deposited in their droppings. Seeds contain a food store to sustain life until they germinate into plants and can produce food through photosynthesis.



4 VEGETATIVE REPRODUCTION

Vegetative reproduction does not involve flowers, pollination, and seeds. Instead, a new plant grows out from the stem or leaf of a parent plant. The Mexican hat plant, native to Madagascar, produces seeds from its flowers. It can also reproduce vegetatively by creating new plants from small buds that form along the edges of its leaves before dropping off.

5 NON-FLOWERING PLANTS

Plants without flowers do not produce seeds. Most produce spores that are surrounded by a protective casing. Ferns grow large quantities of spores in capsules called sporangia, usually under their leaves. When these capsules open, the spores are blown over long distances.

6 STUCK ON YOU

Some plant seeds have sticky hairs or hooks that attach to the bodies of animals or the clothing of humans to transport them away. Viewed under a microscope, the Cocklebur's seeds have a series of tiny hooks known as burrs. These easily tangle in the fur or hair of an animal's coat, and the animal then transports it to a new location.

7 WIND DISPERSAL

A dandelion head contains many individual seeds. Each is connected by a long filament to a parachute that catches a breeze easily, causing the seed to be carried away from the plant. Other plants, such as the sycamore tree, enclose seeds in wing-like outer husks, which drift away on air currents.

8 SQUIRTING PODS

Squirting cucumbers (pictured) are members of the gourd family of plants. They group their seeds together surrounded by an outer shell, called a pod. When it is ripe, the seed pod of the squirting cucumber releases a jet of liquid containing the plant's seeds. This makes sure that the seeds are spread far enough away from the parent plant to encourage growth.

9 WATER DISPERSAL

Plants that grow next to rivers, streams, and along coasts often rely on water to disperse their seeds. Coconuts are palm tree seeds that can survive in seawater for several months. The seed remains dormant until it encounters fresh water and begins to grow.



EVOLUTION AND EXTINCTION

Over long periods of time, living things have gradually altered as the conditions around them change. A species' strongest traits are passed from one generation to the next. This process of gradual change is called evolution. Some species fail to evolve, becoming extinct. Although millions of species are now extinct, fossil records of their previous existence remain.

► BIRD EVOLUTION

Fossil evidence of creatures that are now extinct is studied and used to show the paths that evolution has taken as species have evolved. The discovery of *Archaeopteryx*, a creature that lived about 150 million years ago, shows how birds evolved from lizards. Like lizards of the time, *Archaeopteryx* had teeth, a strong jaw, and bony-fingered claws. It also had wings and feathers.



► INTERESTING ADAPTATIONS

Creatures have evolved unusual adaptations to survive and prosper in their environment. The aye-aye lives in the forests of Madagascar. Its long middle finger can grow up to 15 cm (6 in) long. This is used for tapping trees to listen out for hollows that contain insects and larvae, the creature's main source of food.



◄ NATURAL SELECTION

The principle that the members of a species that adapt best to an environment survive, reproduce, and pass on their adaptations to the next generation is called natural selection. Over many generations, these tiny alterations can lead to major changes. Musk ox, for example, have developed thick outer coats of long hairs over a second layer of wool-like fibres to survive the freezing temperatures of the Arctic.

▶ VESTIGIAL STRUCTURES

Living in the waters of dark underground caves, the blind cave fish cannot see, yet its head still contains eyes. This is an example of a vestigial structure: a feature that once worked, but is no longer of use. Other examples are partly developed rear legs in some whales and the remains of a tail at the base of a human spine, called the coccyx.



MASS EXTINCTION ▲

Extinction is the dying out of an entire species. Extinctions have occurred regularly throughout Earth's history. At certain times, major climatic changes, catastrophic events, such as large meteorite impacts, or massive volcanic activity on Earth have caused the extinction of large numbers of species. About 65 million years ago, the Cretaceous-Tertiary extinction event saw about three-quarters of all species, including the dinosaurs, die out.

▶ RECENT EXTINCTIONS

Hunting, habitat destruction, pollution, and introducing competing species are four major ways in which humans have helped bring about or speed up extinctions. The dodo was a large, flightless bird from Mauritius that became extinct in about 1680. Its extinction was caused by hunting and by dogs introduced to the island by traders.



Siberian tiger

Mountain gorilla

◀ ENDANGERED

Thousands of species are at risk of extinction despite the efforts of conservation groups. These include the Siberian tiger and the mountain gorilla. Fewer than 700 of both creatures are believed to still live in the wild. The Iberian lynx is also endangered due to habitat destruction and deaths caused by rabbit traps.

Iberian lynx



INSECTS AND ARACHNIDS

There are more species of insect than any other creature. Within this incredible diversity, nearly all insects share common features. All are invertebrates (creatures without backbones). They have a hard outer covering, called an exoskeleton, which supports their bodies and is segmented into three parts: the head, thorax, and abdomen. Insects have six jointed legs and most insects have wings, although some, such as the silverfish, do not. Arachnids have an abdomen, head, thorax, and eight legs.

▼ BUTTERFLIES AND MOTHS

Butterflies, such as this white admiral, are usually active during the day. They have large, flat wings and long tubular mouthparts with which they feed on nectar. Moths are similar to butterflies, but tend to be most active at night and rest with their wings open rather than closed. There are more than 150,000 species of butterfly and moth.



▲ METAMORPHOSIS

Many insects lay eggs that go through dramatic stages of development, known as metamorphosis, before becoming adults. Butterflies and bees are among those insects that hatch from eggs as larvae. Once reaching full size, the larvae enter a pupating stage inside a protective structure, during which their bodies are broken down and then reassembled to emerge as adults.



▲ FLIES

True flies include house flies, gnats, mosquitoes, and crane flies. They are insects that have just one pair of wings with their second, rear pair reduced to knob-like structures, called halteres. The halteres help them to balance during flight.

Flies are among the fastest and most manoeuvrable insects in flight. They have compound eyes that contain many lenses, which give extremely accurate 3-D vision.



◀ ORTHOPTERA

Grasshoppers, crickets, katydids, and locusts are all *orthoptera* insects. From eggs, they undergo incomplete metamorphosis as their larvae are much like adults, only they lack an adult's two pairs of wings. Adult *orthoptera* can make a distinctive sound by rubbing body parts together.

Pincers used to hold prey

Grasshoppers communicate by rubbing their hind legs against their wings

▶ SCORPIONS

Scorpions are a type of arachnid. Their bodies feature two large pincers and, at the rear, a segmented tail. Their tails have a stinger supplied with venom by two sacs. Scorpions mostly live in warm and dry tropical regions and are nocturnal, hunting at night for insects and spiders as their prey.

Stinger used to paralyse or kill prey

◀ SPIDERS

Like scorpions, spiders are arachnids. They have eight legs, each with seven jointed parts and more than 30 muscles. Their bodies are divided into an abdomen and a head and thorax fused together, which contains the spider's brain and stomach. Spiders are carnivorous and most kill their prey with venom.

◀ ANTS

Ants form specialized colonies containing just one or a handful of queens – the only females capable of reproduction. Leafcutter ant colonies can contain eight million members. Leafcutter ants have powerful vibrating jaws that can slice rapidly through leaves. They can carry leaf material weighing 20 times their body weight.

▶ HEMIPTERA

The group of insects known as true bugs, or *hemiptera*, includes aphids, cicadas, stink bugs, and pondskaters (right). They have beak-shaped mouthparts that pierce then suck up liquid food, such as the sap from plants. Some, like the pondskater, are carnivorous and feed on other insects.

BEES AND WASPS ▲

Bees and wasps are related to ants. Bees pollinate large numbers of flowering plants as they feed on nectar. Wasps feed their young on insects. Only female bees and wasps have powerful stings at the tips of their abdomens. Many species of wasp and most bees are social and live in large nests or hives.

◀ BEETLES

More than 350,000 species of beetle have been identified, more than any other type of insect. A beetle's front wings, called elytra, are hardened and can be closed over the top of the abdomen protecting the rear pair of wings. The biggest species of beetle is the South American longhorn, which can grow up to 16 cm (6 in) in length.



Tree frogs are amphibians who spend most of their lives in trees

REPTILES AND AMPHIBIANS

Reptiles are land-dwelling creatures with tough skins covered with scales. All reptiles are vertebrates (they have backbones) and most have four legs, although snakes and worm lizards do not. For about 200 million years, giant reptiles, called dinosaurs, were the world's largest creatures. Amphibians were the first vertebrates to move from water up onto the land.

► COLD BLOODED

Reptiles and amphibians are ectothermic, or cold blooded. They are unable to generate their own body heat and so cannot regulate their own body temperature. Instead, they bask in the sun to warm up and dip their bodies in water to cool down. Some collared and frilly lizards run just on their hind legs to produce a cooling breeze around themselves.

A common lizard basks in the sun to warm its body up. Its ideal internal temperature is around 30°C (86°F)

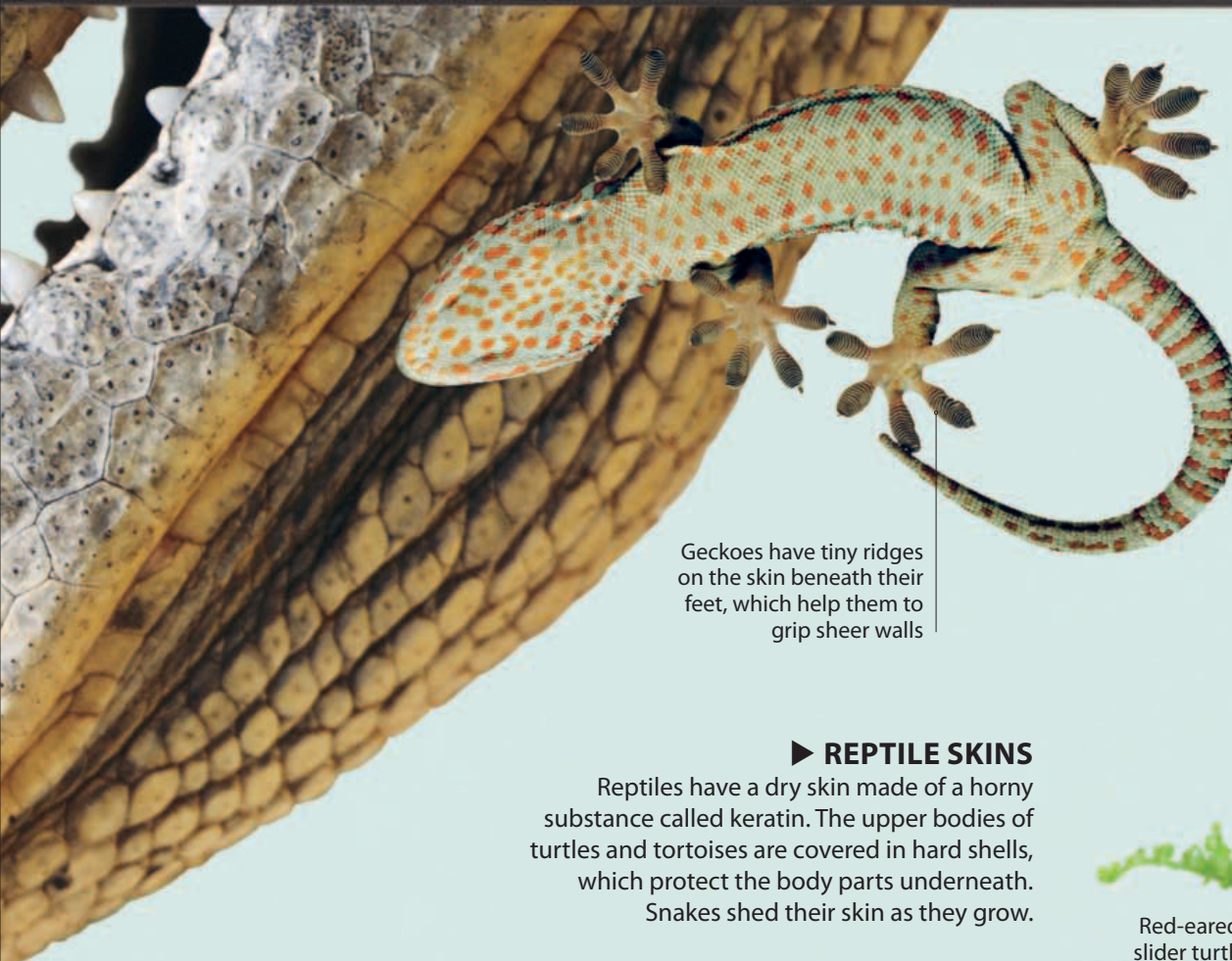
► REPTILE LIFECYCLE

A small number of reptiles, including the slow worm and the adder snake, give birth to live young. However, most reptiles lay hard or leathery shelled eggs that hatch into live young. The Nile crocodile digs a nest in a river bank before laying up to 80 eggs, which are then covered with sand. The female will guard the nest before the eggs begin to hatch.

Adult female Nile crocodiles carry their young to a nursery area in the water

Baby Nile crocodiles measure around 30 cm (12 in) long when they hatch

Frog eggs surrounded by jelly



Geckoes have tiny ridges on the skin beneath their feet, which help them to grip sheer walls

▼ AMPHIBIAN SKINS

Instead of a covering of hair, fur, or scales, an amphibian's skin contains a network of tiny blood capillaries. These enable an amphibian to take in water and oxygen through its skin. For this to work efficiently, the skin needs to be kept moist. Most amphibians secrete a slimy layer of mucus, which protects the skin from drying. In some amphibians this layer is poisonous to deter potential predators.



Couch's spadefoot toad

Red-eared slider turtle

► REPTILE SKINS

Reptiles have a dry skin made of a horny substance called keratin. The upper bodies of turtles and tortoises are covered in hard shells, which protect the body parts underneath. Snakes shed their skin as they grow.

► AMPHIBIAN LIFECYCLE

Most amphibians lay their eggs in water. Some species of frog and toad lay thousands of eggs and abandon them. Others lay fewer eggs but guard them. Amphibian eggs are soft and many species' eggs are surrounded by a jelly-like substance to stop them drying out. A frog's eggs hatch to form tadpoles that develop gills on the outside of the body to breathe and a tail. Tadpoles undergo a major change in body shape as they develop into an infant frog.



Adult frog

Infant frog with tail



Tadpoles

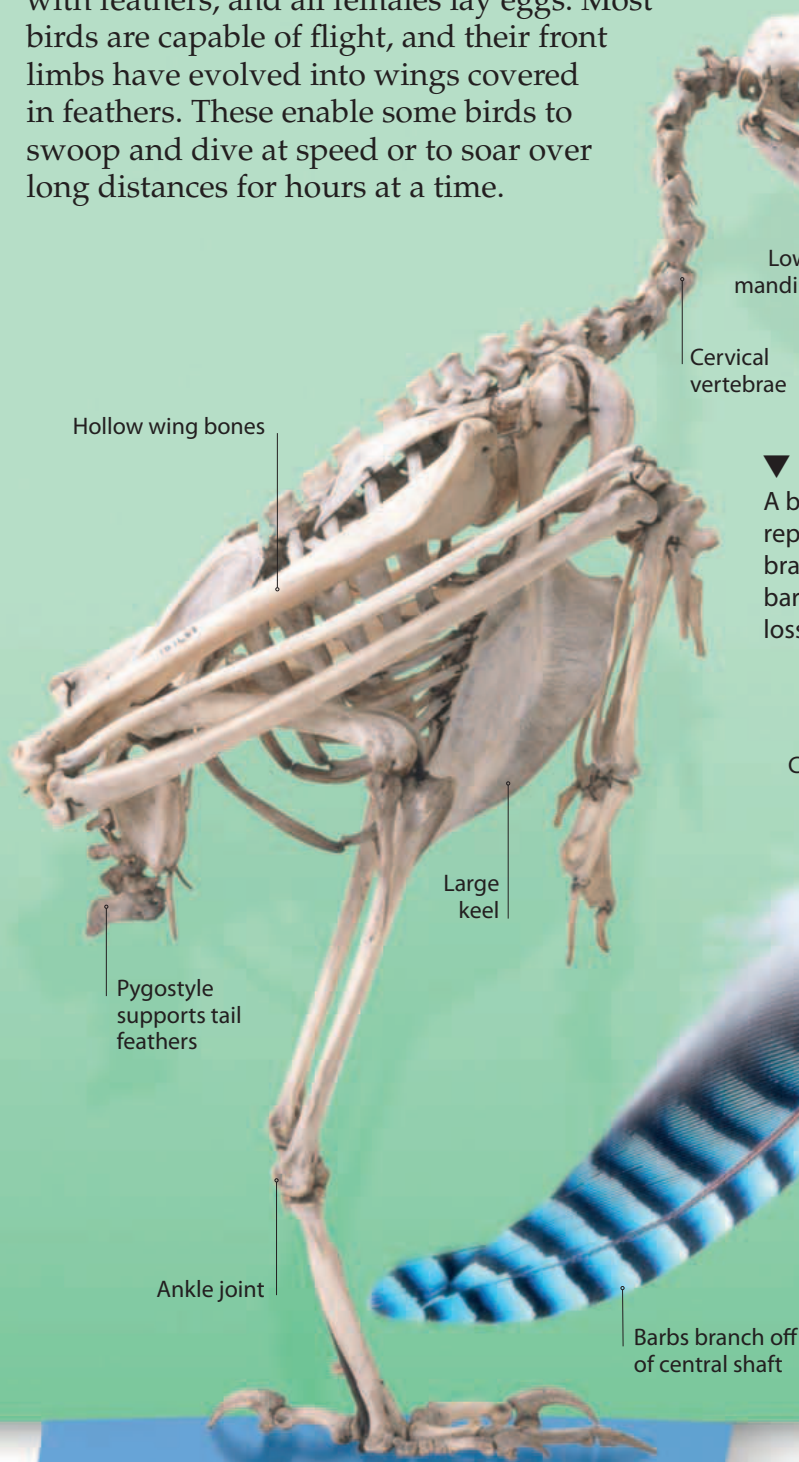
► ESTIVATION

Some reptiles and amphibians, such as this Cane Toad from Australia, can enter a period of inactivity when water is scarce. This is called estivation and is a survival mechanism. Estivating creatures head underground where it is cooler and where some moisture may be found. They lower their heart rate and conserve water in their bodies.



BIRDS

There are more than 9,600 species of bird distributed over every continent. They are the only vertebrates with feathers, and all females lay eggs. Most birds are capable of flight, and their front limbs have evolved into wings covered in feathers. These enable some birds to swoop and dive at speed or to soar over long distances for hours at a time.

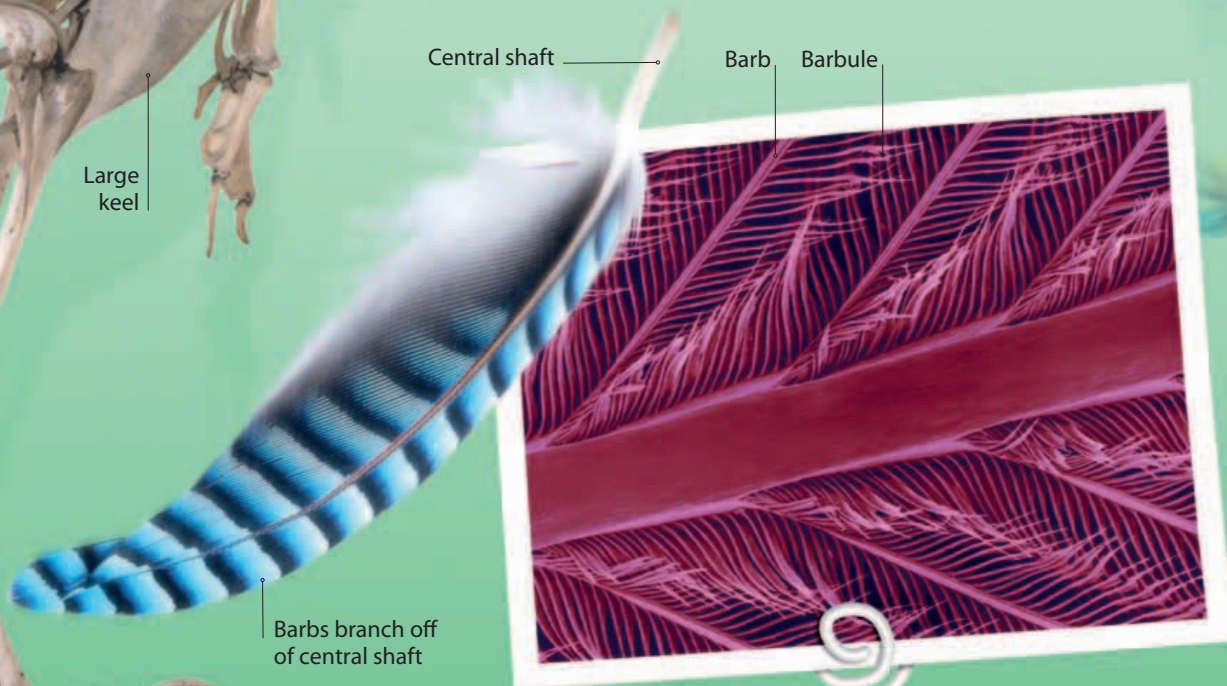


◀ SKELETON

Most birds are very light for their size – for example, Australia's wedge-tailed eagle has a wingspan of up to 2.5 m (8 ft), but may weigh only 4.5 kg (10 lb). Part of the secret is in their bones, a number of which are hollow and may be reinforced with internal struts. A bird's skeleton has to be light, but strong enough to fly.

▼ FEATHERS

A bird can have between 800 and 20,000 feathers, which grow and are replaced throughout its life. Feathers consist of a central spine, side branches called barbs, and many smaller branches from the barbs, called barbules. Feathers enable flight, help to insulate against water and heat loss, and, for some birds, act as camouflage or are used to attract a mate.



◀ FLYING MUSCLES

A male great bustard can weigh up to 19 kg (42 lb), making it the heaviest flying bird in the world. Birds rely on powerful breast muscles attached to a developed part of the sternum (breast bone), called the keel. These muscles must generate enough power to become airborne. The downstroke of each wing beat pushes the air down and the bird up and forwards.





A toucan's giant bill can grow to one-third of the bird's length.

◀ FLIGHT AGILITY

Many birds exhibit extraordinary flying agility or speed – for example, a diving peregrine falcon can reach 320 km/h (200 mph).

Kestrels can hover in mid-air, seeking out prey on the ground below. A hummingbird can also hover, allowing it to remain in front of a flower as it feeds on plant nectar. Its wings can beat up and down 90 times every second.

▶ FLIGHTLESS BIRDS

Over thousands of years, some bird species have lost their ability to fly.

These include seabirds, such as penguins, whose wings are used like flippers to swim. Flightless birds range in size from the 17-cm (7-in) long Inaccessible Island rail to the ostrich, the largest living bird. Male ostriches can be 2.5 m (8 ft) tall and can run at speeds of 70 km/h (43 mph).

Kingfisher's dagger-like beak catches fish and other prey

▲ BEAKS

All birds have some form of bill, or beak. Birds use their beaks to preen their feathers, build nests, and feed their young. Beaks show great variety and adaptation for a bird's habitat – for example curlews, sandpipers, and other wading birds, have long, thin beaks for probing sand and mudflats for food. Eagles and other birds of prey have hooked beaks for tearing meat.

Clutch of eggs

Nest of twigs and other plant matter

▲ FUEL

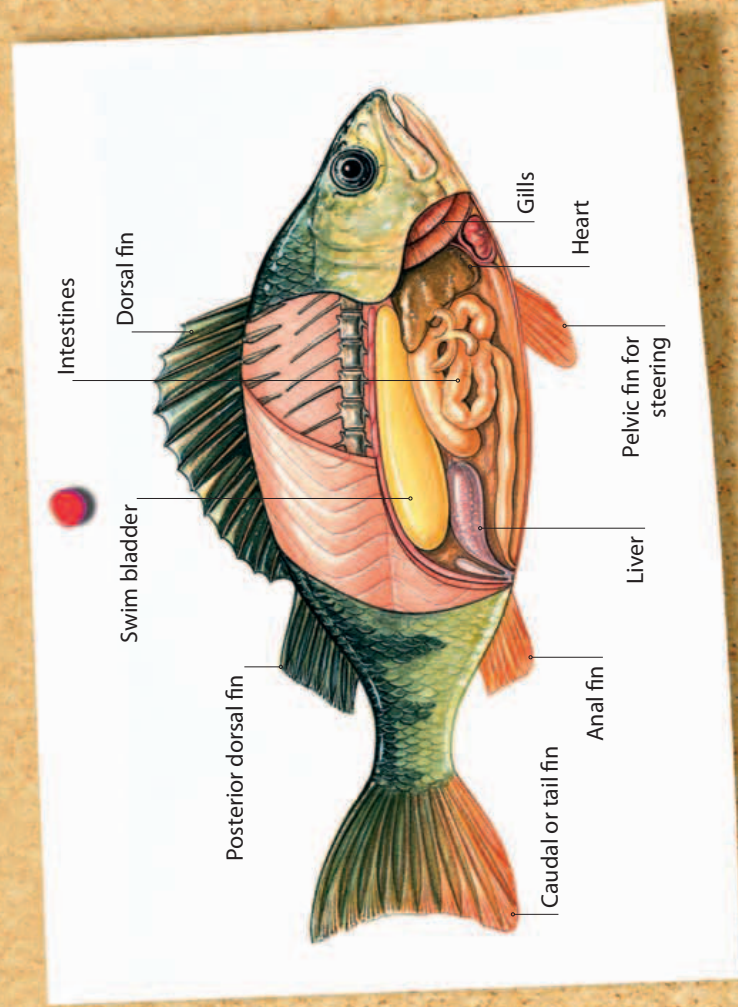
Birds eat food sources that are rich in protein and energy. Kingfishers are one of many species that plunge into water to capture fish, insects, or small amphibians. Other species, such as parrots, eat fruits and nuts. As they do not have teeth, birds use a part of their stomach called the gizzard to crush and grind down seeds and bony parts.

▲ EGGS AND NESTING

All birds lay eggs, which are kept warm either by being buried, or incubated by the parents sitting on them. Nests offer protection from predators and can be as simple as a shallow hollow in the ground or a mixture of mud and plant matter. Cuckoos are an example of parasitic breeders who lay their eggs in other birds' nests.

UNDERWATER LIFE

Earth's rivers, lakes, seas, and oceans teem with life. More than two-thirds of the planet's surface is covered in water. In deep oceans, most marine life exists in the top 100 m (330 ft) or so, as this is where light and vast quantities of microscopic organisms, called plankton, are most abundant. Plankton is crucial as it forms the basis of marine life diets. All underwater life either feeds directly on plankton or preys on creatures that do.



▲ FISH

Fish live in water and have a protective covering of scales on their outer bodies. They breathe by absorbing dissolved oxygen in the water using organs called gills located at the back of their heads. Most fish have an array of blades projecting on their body called fins. These give the fish stability in water and help control the fish's direction of movement.



▼ CARTILAGINOUS FISH

Skates, rays, and sharks, such as this great white, are all cartilaginous fish. They lack a true backbone, but have a structure made of gristly cartilage. They also lack swim bladders and must maintain their depth by swimming. Most species of shark are predators. Rays are flattened fish that live on the seabed where they hunt smaller fish.



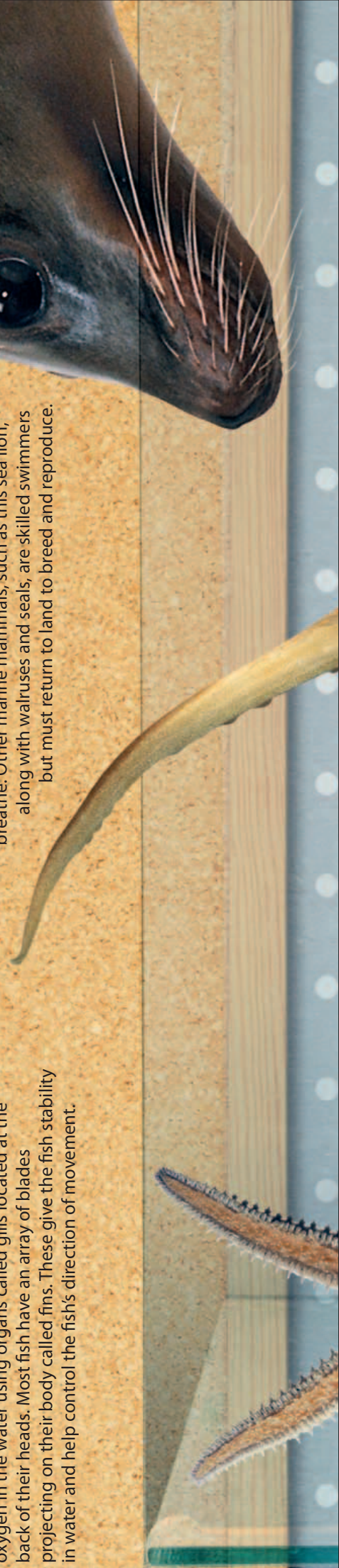
▲ BONY FISH

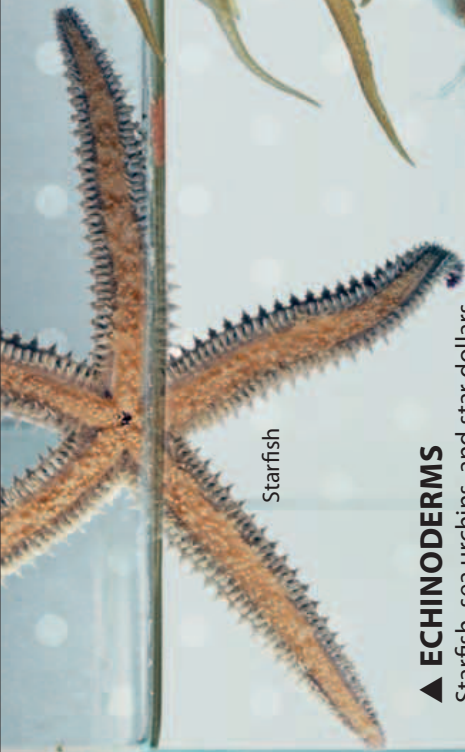
Every species of bony fish has a skeleton of bones with a flexible spine, or backbone, running the length of the body. An organ called the swim bladder enables a constant buoyancy, regardless of the changing water pressure. This ocean sunfish is the heaviest bony fish – some weigh as much as 2,000 kg (4,400 lbs).

▶ MARINE MAMMALS

Some mammals (see pages 24–25) spend most or all of their lives in water. These include many species of whale, porpoise, and dolphin, and plant-eating dugongs and manatees. All of these creatures that stay in the water must surface to breathe. Other marine mammals, such as this sea lion, along with walrus and seals, are skilled swimmers but must return to land to breed and reproduce.

Sea lion





Starfish

▲ ECHINODERMS

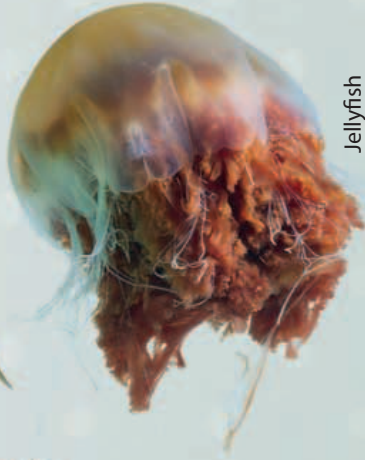
Starfish, sea urchins, and star dollars are all echinoderms. Their skeletons are made of chalky plates that are sometimes covered in small spines. All echinoderms' bodies are divided into five parts. Starfish, for example, all have five arms and five sets of digestive and reproductive organs. If an arm breaks off, it will grow back.



Octopus

◀ CNIDARIANS

Jellyfish, sea anemones, and coral are all cnidarians. These creatures have no brains or central nervous system. They tend to have a bell-shaped or hollow body and a mouth ringed with tentacles. The mouth contains stinging cells, called nematocysts, which can disable prey. Some jellyfish are harmful to humans – for example, an Australian box jellyfish sting can kill within minutes.



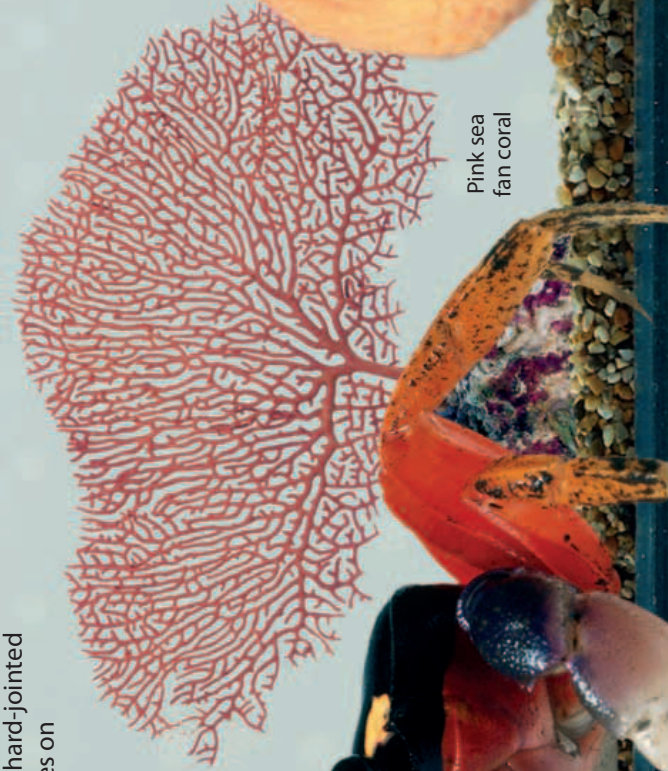
Jellyfish

▼ CORAL

Coral are made up of individual, small creatures called polyps. They are part of the cnidarian group. Their vivid colours come from bright algae that grow in the coral's tissue. As coral dies, its hard outer casing falls and, over long periods of time, builds up to form coral reefs.

▼ CRUSTACEANS

This group of more than 40,000 species of invertebrates ranges from tiny water fleas no more than 0.1 mm in size up to the Japanese spider crab with a leg span in excess of 3.7 m (13 ft). Crustaceans include shrimps, lobsters, and crabs. They all have hard-jointed shells as well as gills, eyes on stalks, and four or more pairs of jointed legs.



Pink sea fan coral

▲ CEPHALOPODS

Molluscs that lack a complete hard outer shell but have tentacles are known as cephalopods. These include cuttlefish, squid, and species of octopus. An octopus has eight arms, a well-developed brain, and good eyesight. It can react quickly to danger, squirting out a jet of water to propel itself away.

▼ SPONGES

There are as many as 10,000 species of sponge. Sponges are simple, invertebrate creatures. They are found mostly in saltwater habitats although some freshwater species exist. Sponges attach to rocks and feed on tiny food particles that flow through openings called ostia.

▼ MOLLUSCS

Most molluscs are soft-bodied creatures covered in a shell. These shells are made from calcium carbonate secreted by a body part called the mantle. The giant clam can live for up to 100 years. It can grow to more than 1.2 m (4 ft) across. However, most molluscs (including snails, oysters, and mussels) are much smaller.

Orange puffball



Giant clam

Crab



MAMMALS

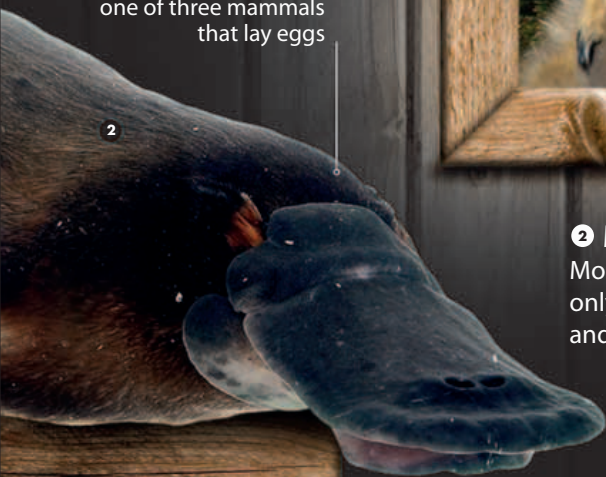
About 220 million years ago, mammals evolved from a group of reptiles called therapsids. Early mammals were shrew-like creatures that survived partly because their warm-blooded bodies enabled them to be active at night (nocturnal). Today, there are more than 5,000 species of mammals distributed worldwide. These range in size from the lightest, the Etruscan shrew, which weighs less than 2 g (0.07 oz), to the heaviest, the blue whale, which weighs more than 150 tonnes.

1 LIVE YOUNG

Nearly all mammals give birth to live young. Some, such as this wildebeest, can stand and move within minutes of being born. Species of marsupials, in contrast, are born alive but not fully developed. They are then kept safe in their mother's marsupium, or pouch, where they feed on her milk until they are more developed. Kangaroos, koala bears, and wallabies are all marsupials.



Duck-billed platypuses are one of three mammals that lay eggs



3 MOTHER'S MILK

Female mammals feed their newborn young on nutritious milk from their mammary glands. This milk is rich in fats and proteins that promote growth. It also contains antibodies that protect against disease. Young mammals suckle by clasp onto teats or nipples with their mouths, which open as they draw in milk. Human beings have two nipples while pigs have 16.



2 MONOTREMES

Monotremes are mammal exceptions. They are the only mammals that lay eggs. Found solely in Australia and New Guinea, there are only three species of monotremes – two types of echidna, or spiny anteaters, and the duck-billed platypus. Monotremes do not suckle. Instead they lick milk that runs over the belly of their mother.



Adult male giraffes can be more than 5 m (16 ft) tall

4 PARENTING

Mammals are among nature's most hands-on parents. The young of many species are taught not only feeding and survival skills, but also how to behave within their social group. Meerkats live in social groups called mobs, where the young are mentored by the adults. When meerkats forage or dig for food, they are vulnerable to attack, so one or more of the mob keeps watch, standing on its hind legs.



5 VERTEBRATES

All mammals are vertebrates. This means that their body is supported by an internal skeleton, including a backbone made of individual vertebrae bones. The neck of almost all mammals contains seven vertebrae. In the case of giraffes, each of the seven vertebrae is about 25 cm (10 in) long and flexible.

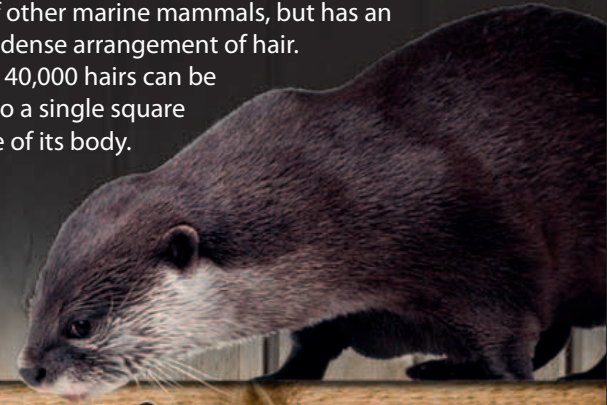


6 INSULATION

Most mammals have layers of fat underneath their skin to help insulate from cold. Mammals that live in colder climates often have thicker fat layers. Marine mammals, such as these walrus, which live in the Arctic, have a layer of fat called blubber that can reach thicknesses of 15 cm (6 in). An adult walrus can weigh up to 1.6 tonnes.

7 FUR AND HAIR

A mammal's skin is covered in hair or fur for some or all of its life. The strands of fur and hair trap air and help to keep the animal warm. The sea otter lacks the thick layer of blubber of other marine mammals, but has an extremely dense arrangement of hair. More than 40,000 hairs can be packed into a single square centimetre of its body.



A beaver's front incisor teeth can chop through tree trunks and branches



8 WARM-BLOODED

Mammals are warm-blooded and so are able to maintain a constant temperature. While their sweat glands release perspiration, they also adopt certain behaviour to cool down. This includes resting in the shade, as the leopard above.

9 LOWER JAW

Mammals have a single lower jawbone and most have a number of different types of teeth that are specialized for different tasks. Incisors snip and bite, canines pierce and tear, premolars slice materials, and molars crush and grind foods.

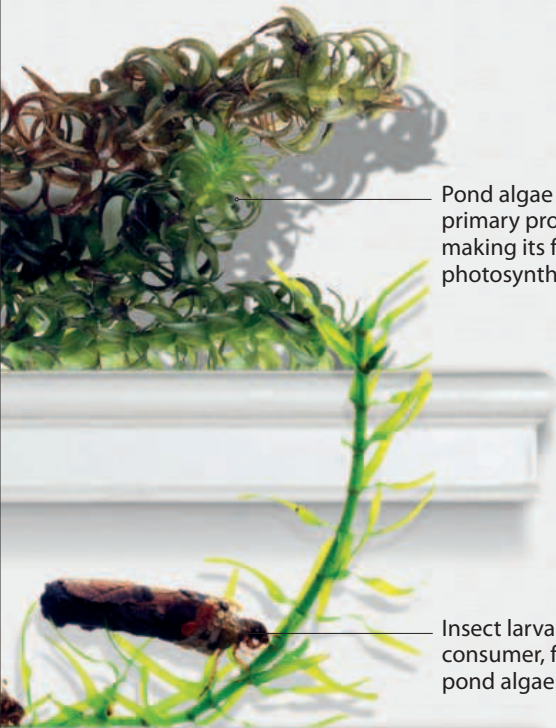
10 SUPER SENSES

Mammals have highly developed senses. For example, the star-nosed mole has 22 tentacles around its nose. These are sensitive to touch. They enable the mole to identify insects and other prey without using sight.



ECOSYSTEMS

Ecosystems are complete communities of different living things, together with their environment including the climate. An ecosystem can be as small as a pond or a single rotting tree stump, or as large as a tropical rainforest. Ecosystems are treated as separate units as this makes them easier to chart and study. In reality, they are rarely closed systems, and food and energy may flow from one ecosystem to another.



Pond algae is a primary producer, making its food via photosynthesis



Frog is a secondary consumer, using rapid movement of its sticky tongue to catch larva

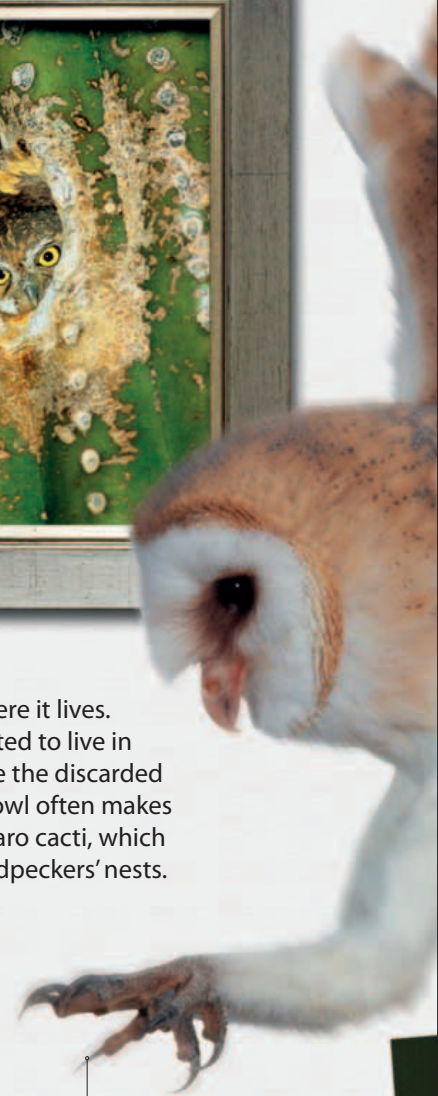
◀ FOOD CHAINS

Food chains are a simple way of describing the flow of food and energy through an ecosystem. Plants, which make their food from sunlight by photosynthesis, are known as primary producers. Animals cannot make their own food, so they must consume either these plants or creatures that eat plants. Those that eat plants are primary consumers, and they are eaten by secondary consumers. At each level of consumption, known as a trophic level, large amounts of energy consumed by one living thing are lost. Only a fraction of the energy it used is passed on when it is eaten by another creature.



▲ HABITATS

A creature's habitat is where it lives. Some animals have adapted to live in unusual habitats or to use the discarded homes of others. The elf owl often makes its home in holes in saguaro cacti, which were previously gila woodpeckers' nests.



Barn owl swoops to kill and eat the snake



Small grass snake feeds on frogs as well as insects and other pond life



◀ DECOMPOSERS

Fly agaric mushrooms grow among rotting plant matter on a forest floor. Mushrooms, toadstools, moulds, and other fungi, along with bacteria and some worms, recycle dead matter through decomposition. As they feed, decomposers break down dead plant and animal matter into fibrous humus and valuable minerals and nutrients that enrich the soil.



This sea anemone is carried around on the shell of a hermit crab



◀ MUTUALISM

A relationship where both species benefit is called mutualism. For example, bees gain nectar from the flowers they pollinate, and bacteria living in the guts of cows aid digestion and receive nutrients as a result. This red-billed oxpecker bird feeds on ticks on a hippopotamus. In doing so, it gains food while removing pests.

▲ COMMENSALISM

Many different species have close relationships with one another in an ecosystem. Commensalism is when one species benefits, while the other is not significantly harmed. Epiphytic plants, such as orchids, bromeliads, and some ferns and mosses, live on taller plants to gain more access to sunlight.



◀ PARASITISM

When one species benefits while harming another, called the host, it is known as parasitism. Aphids are parasites that feed on plants, sucking the sap from stems and foliage. They can distort a plant's growth, transmit viruses, or encourage the growth of damaging moulds.

Some parasites, such as tapeworms, live inside their hosts. Others are carried from one host to another, such as malaria, which is carried by mosquitoes.

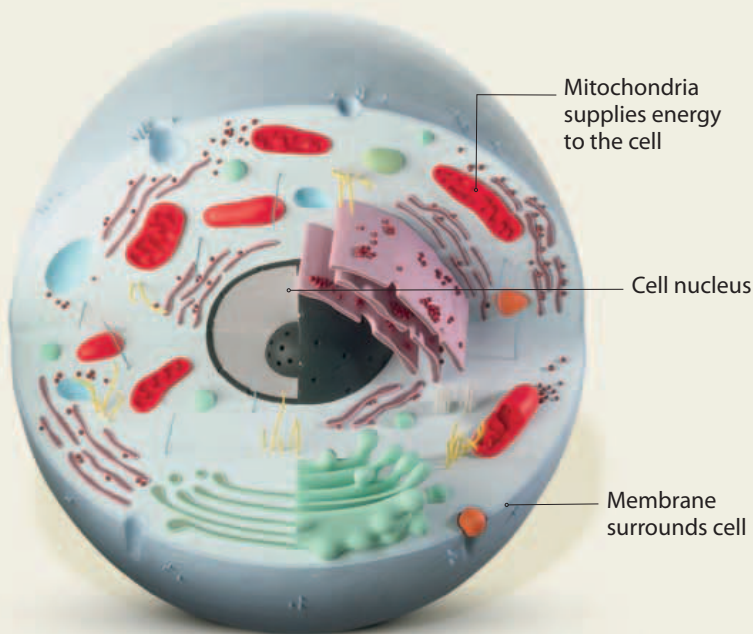
▶ BALANCING ACT

A thriving ecosystem has a balance between producers and consumers and the environment they live in. The introduction of new species into an ecosystem is just one way that this balance can be disturbed. In 1935, just over 100 cane toads were introduced to Australia in an effort to combat beetles that ate sugar cane crops. Cane toad numbers have since grown to more than 100 million. They are a danger to native animals with their poisonous skin and voracious feeding habits.



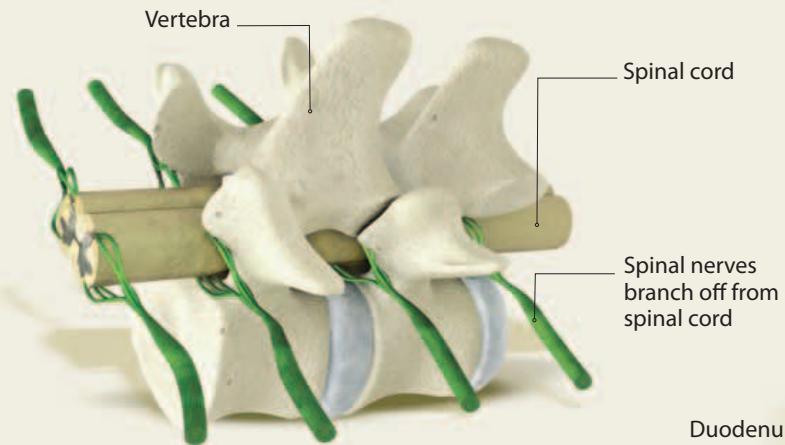
▼ CELLS

There are some 200 different types of cells in the body, from adipose cells, which act as stores of oils or fat, to mammary gland cells, which can secrete milk in female breasts. Although they perform different functions, cells tend to have the same basic structure, with a nucleus and jelly-like cytoplasm contained within a thin outer membrane.



HUMAN BODY

The human body's building blocks are some 100 trillion cells. Many of these microscopic units are grouped together to form tissues. An organ, which performs one or more key functions, consists of two or more types of tissue and often works along with other cells, tissues, and organs in a system. The human body relies on 12 major systems, including the lymph system and the circulatory system.

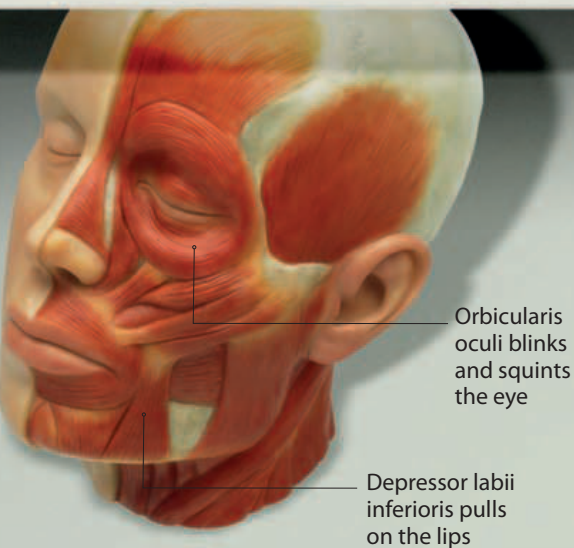
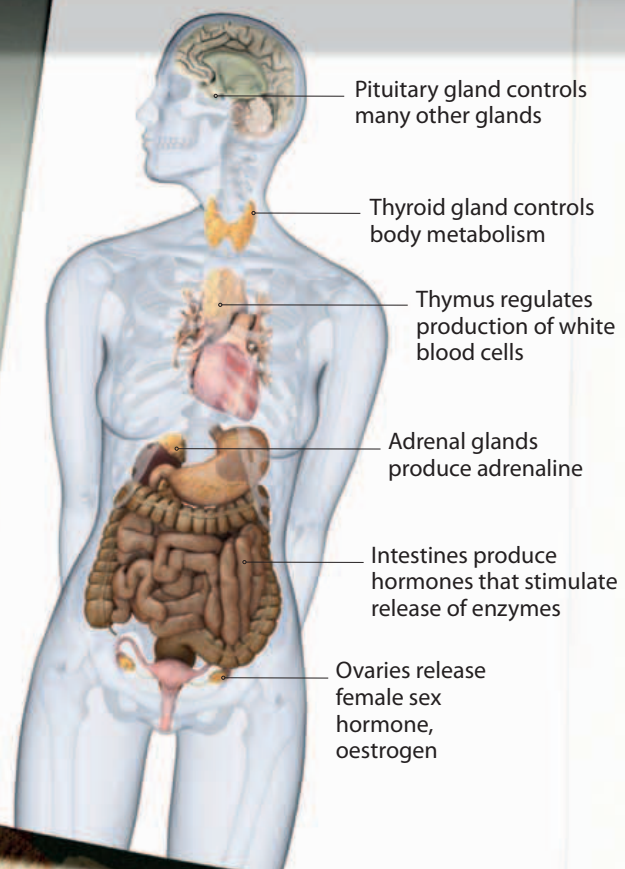


▲ NERVOUS TISSUE

Networks of long cells carry electrical signals through the body to and from the brain. As well as the individual nerves, nervous tissue forms the brain inside the skull and the spinal cord that runs through the vertebrae of the backbone.

► ENDOCRINE SYSTEM

This system is made up of glands that produce and secrete hormones. These chemical messengers influence and help control various body functions, including growth and reproduction. Most are released into the bloodstream and are designed to work slowly over time.



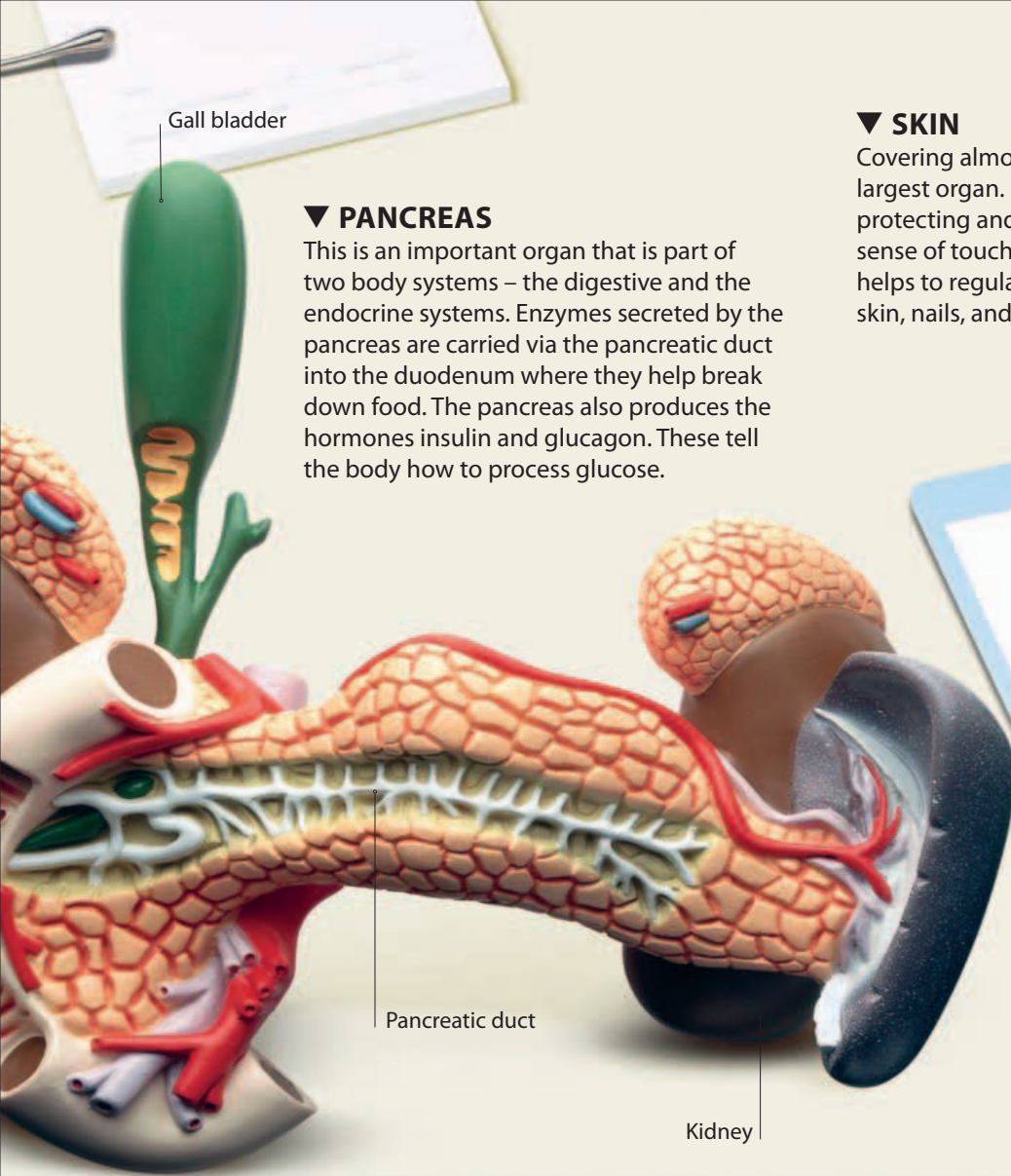
▲ MUSCLE TISSUE

The cells in muscle tissue, when stimulated by nerves, contract to pull a body part and generate movement. Anchored to the skull, more than 30 facial muscles work to generate different facial expressions, from surprise to happiness or anger. Other muscles attached to the skull control eye movement or power the movement of the lower jaw.

Gall bladder

▼ PANCREAS

This is an important organ that is part of two body systems – the digestive and the endocrine systems. Enzymes secreted by the pancreas are carried via the pancreatic duct into the duodenum where they help break down food. The pancreas also produces the hormones insulin and glucagon. These tell the body how to process glucose.

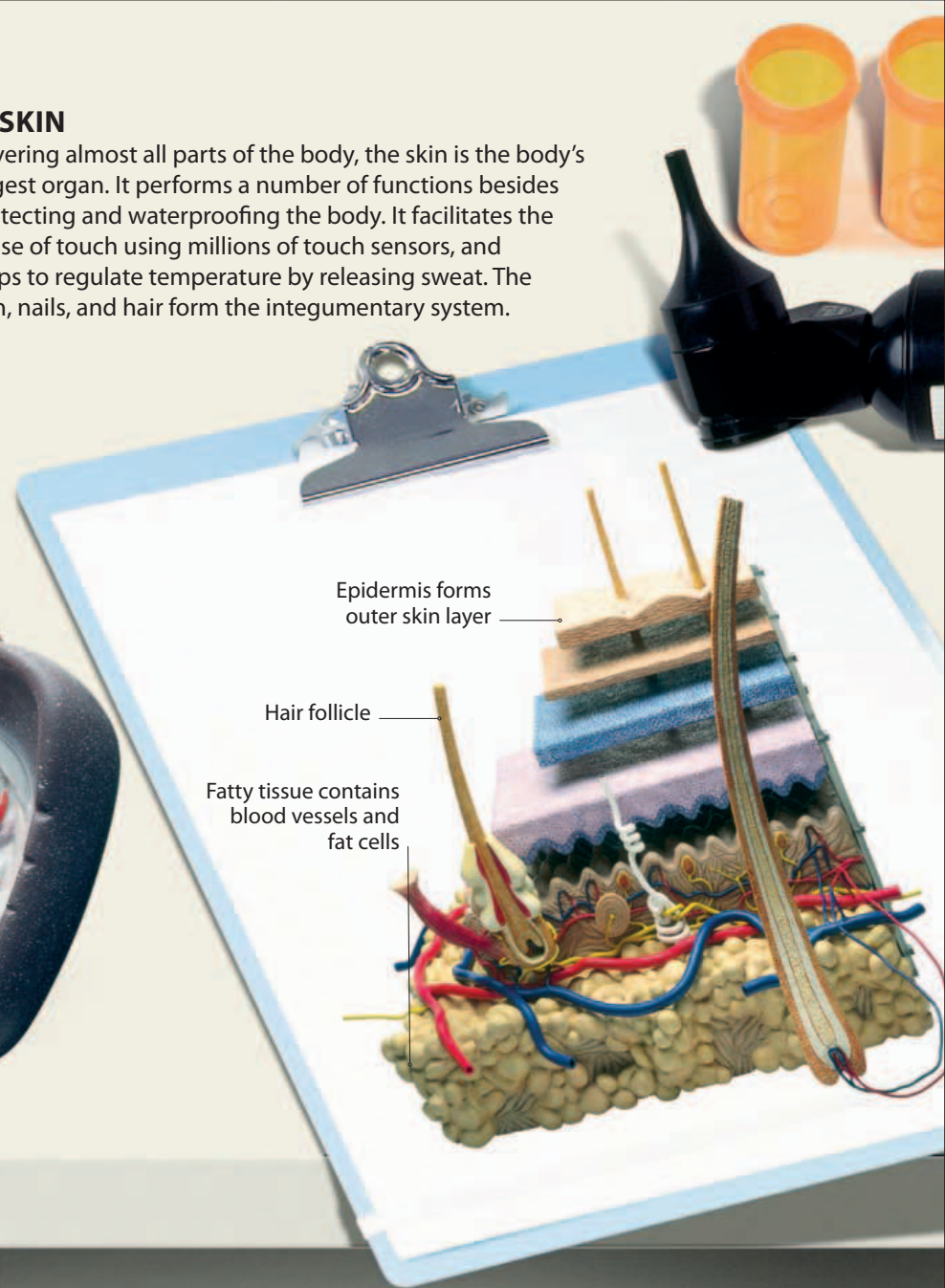


Pancreatic duct

Kidney

▼ SKIN

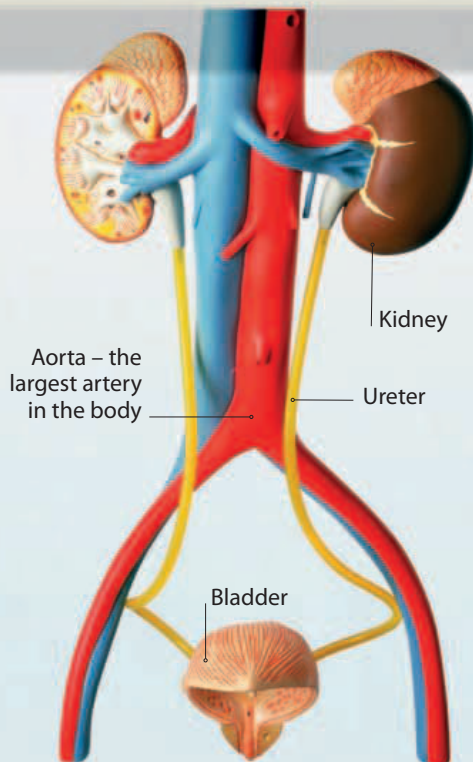
Covering almost all parts of the body, the skin is the body's largest organ. It performs a number of functions besides protecting and waterproofing the body. It facilitates the sense of touch using millions of touch sensors, and helps to regulate temperature by releasing sweat. The skin, nails, and hair form the integumentary system.



Epidermis forms outer skin layer

Hair follicle

Fatty tissue contains blood vessels and fat cells



Kidney

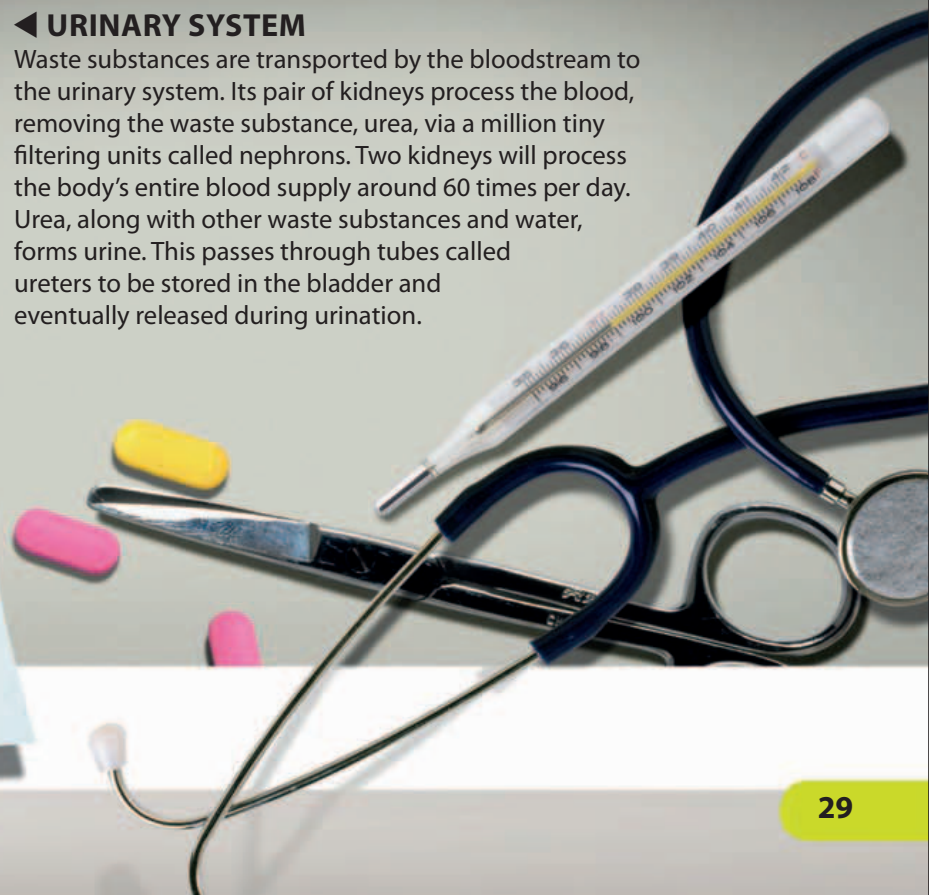
Ureter

Bladder

Aorta – the largest artery in the body

◀ URINARY SYSTEM

Waste substances are transported by the bloodstream to the urinary system. Its pair of kidneys process the blood, removing the waste substance, urea, via a million tiny filtering units called nephrons. Two kidneys will process the body's entire blood supply around 60 times per day. Urea, along with other waste substances and water, forms urine. This passes through tubes called ureters to be stored in the bladder and eventually released during urination.

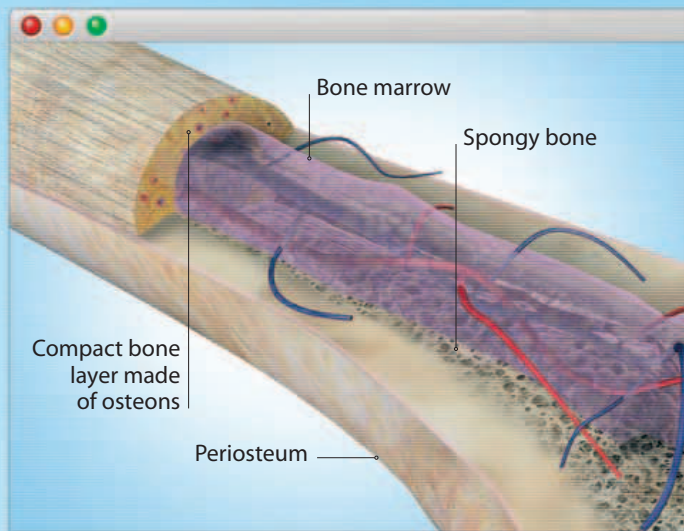


SKELETON AND MUSCLES

The human body has 206 lightweight but strong bones. They provide protection, support, and a framework that anchors the body's many muscles. Bones range in size from the tiny stapes in your ear to your femur or thigh bone, which is the longest. Some, such as the ribs that form the ribcage and your skull, act as protective bowls or cages for delicate internal organs.

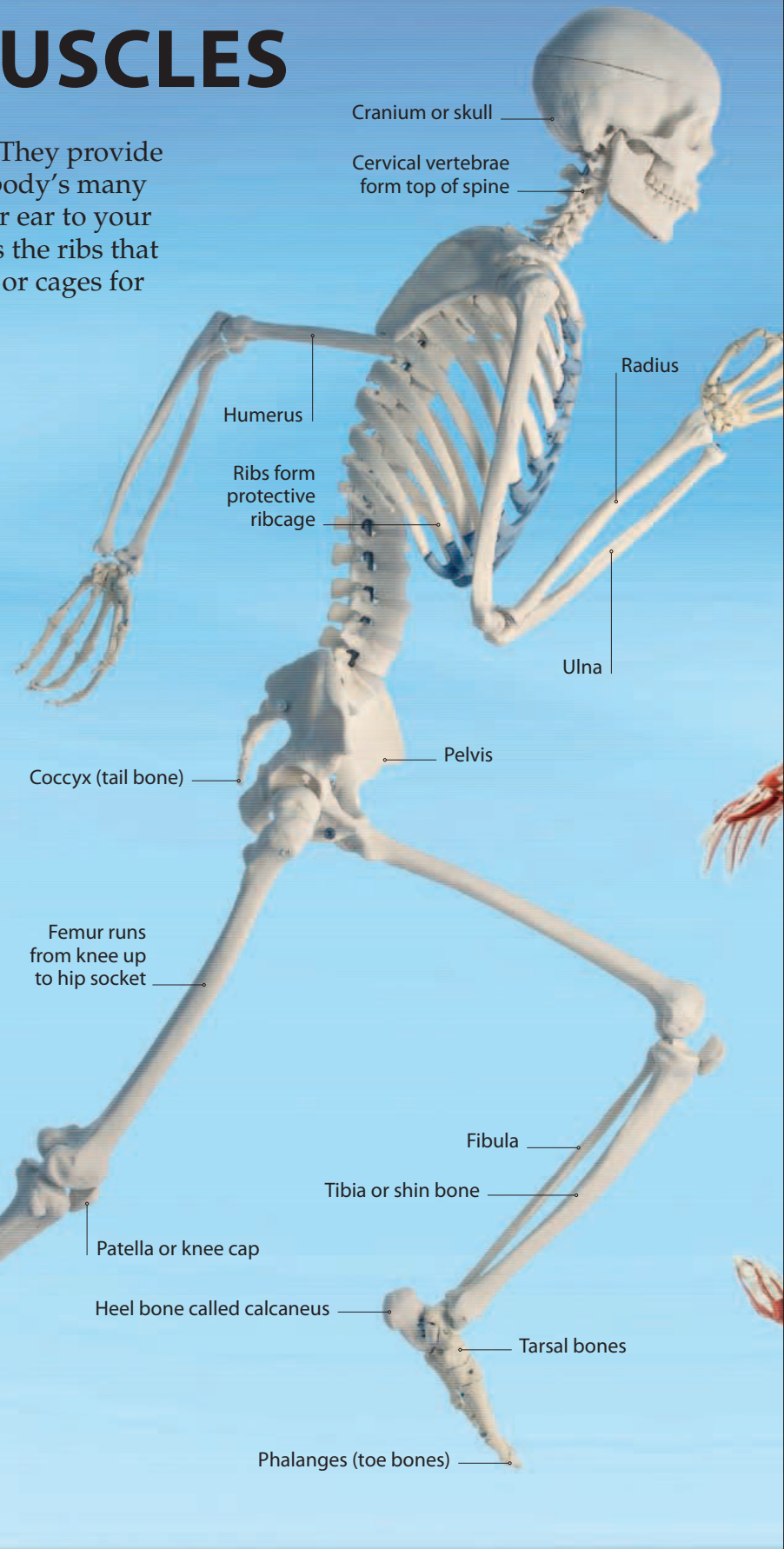
► SKELETON

The skeleton can be divided into two parts – the axial and the appendicular. The axial skeleton consists of the skull, the vertebral column, the ribs, and the sternum or breastbone at the front of the chest. The appendicular skeleton is the bones in the arms and legs as well as the shoulder and hip girdles, which attach the limbs to the axial skeleton.



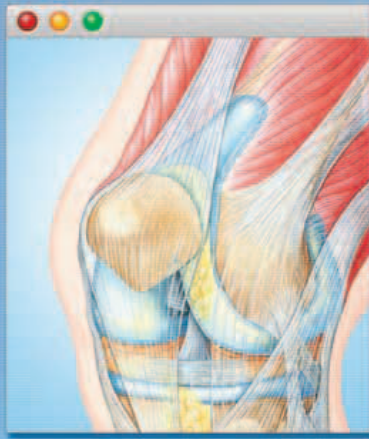
▲ INSIDE BONES

This cutaway of the humerus (upper arm bone) shows the hard compact bone layer made of tubes called osteons and a lighter layer called spongy bone. At the centre is bone marrow, which in long bones stores fat and in some flat bones, such as ribs, sees new red blood cells made. Blood vessels provide the bone with nutrients and oxygen.



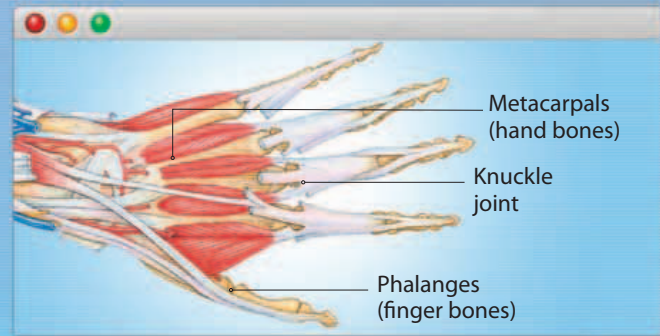
► SYNOVIAL JOINTS

Joints are the points at which two or more bones meet. Synovial joints, such as the knee, offer large amounts of movement. The ends of the bones are covered in cartilage and separated by a cavity filled with synovial fluid, which reduces friction.



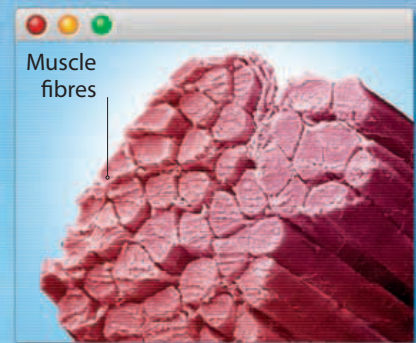
▼ RANGE OF MOVEMENT

Some bone joints are immovable, such as the plates that form the skull, or are slightly flexible, such as the vertebrae in your spine. Others are extremely flexible. The joints in the fingers and hands allow us to grasp large objects or manipulate small ones.



◀ MUSCLES

The human body has three types of muscles. Cardiac muscle is found in the heart. Smooth muscle is found inside organs, such as the intestines. Skeletal muscles cover the skeleton, giving the body its shape, and are connected to bones by cords called tendons.

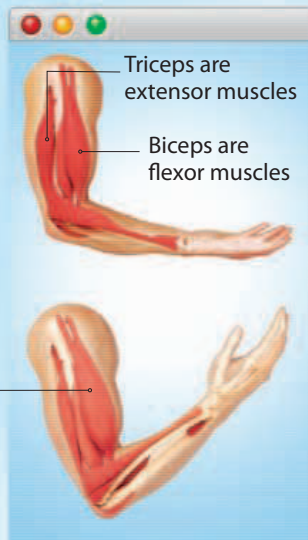
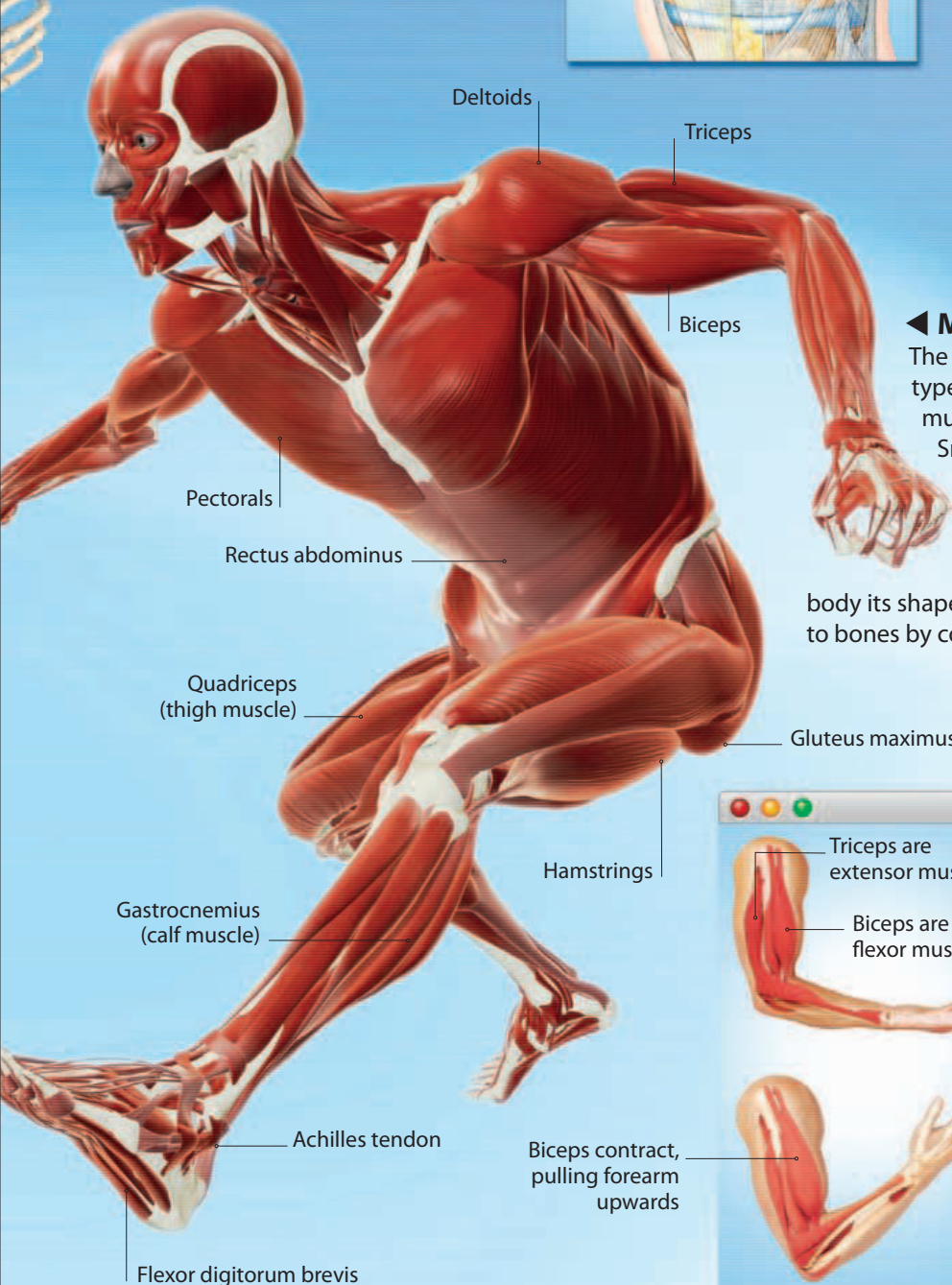


▲ SKELETAL MUSCLES

Skeletal muscles are full of long fibres containing tiny strands called myofibrils. Blood vessels run through muscles, supplying oxygen and nutrients, while nerve endings carry impulses from the brain and central nervous system. Muscle cells contract in response to nerve signals.

◀ MUSCLE MOVEMENT

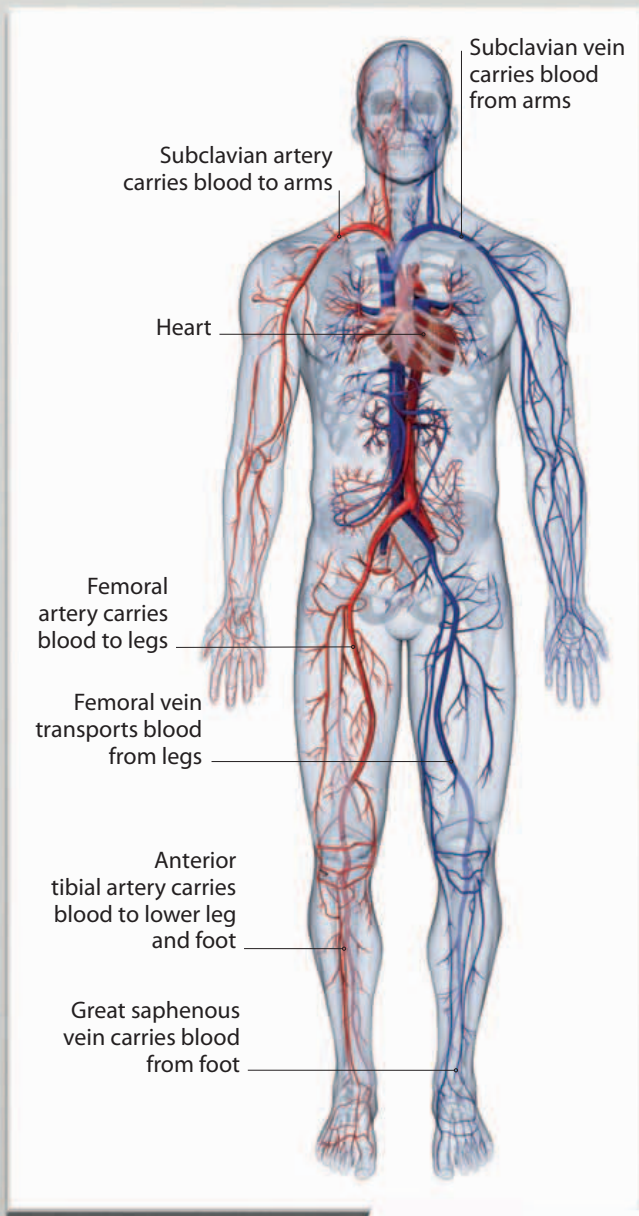
Muscles perform work by contracting and pulling a body part in one direction. Muscles cannot push, so an opposing muscle group is required to pull the body part back to its original position. Muscles that bend a joint are called flexors and those that straighten it are called extensors.



BLOOD AND BREATHING

Every second, the circulatory system delivers oxygen and nutrients to body cells. At the centre of the system is the heart, a muscular pump that drives blood around the body through a massive network of blood vessels. If laid end to end, these would stretch a distance of 150,000 km (93,000 miles).

This network is divided into arteries, which transport blood away from the heart, and veins, which carry blood back to the heart.

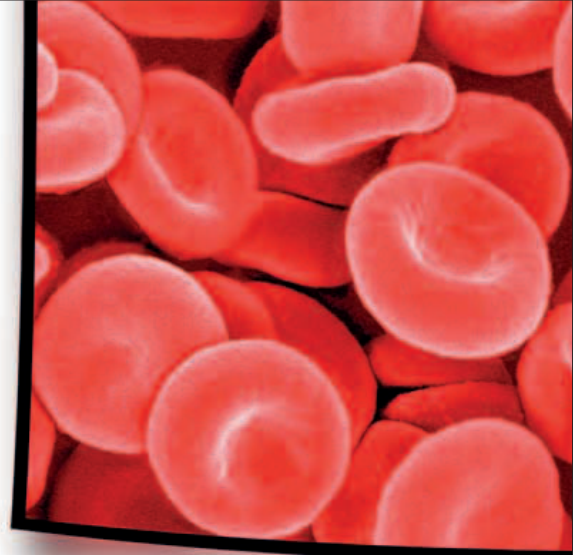


◀ THERE AND BACK

Blood travels twice through the heart on each cycle of its journey around the body. Deoxygenated (oxygen poor) blood is carried back from the body to the heart in veins. It is then pumped into the lungs. There, gaseous exchange takes place and the resulting oxygen-rich blood travels back into the heart, before it is pumped out through arteries around the body.

▼ BLOOD COMPOSITION

A human body contains about 5–6 litres (9–11 pints) of blood. Blood consists of a liquid called plasma and three types of cells. Red cells are oxygen-carriers, while white cells fight diseases. Small cell fragments called platelets clump together to seal leaks in blood vessels when damage occurs.

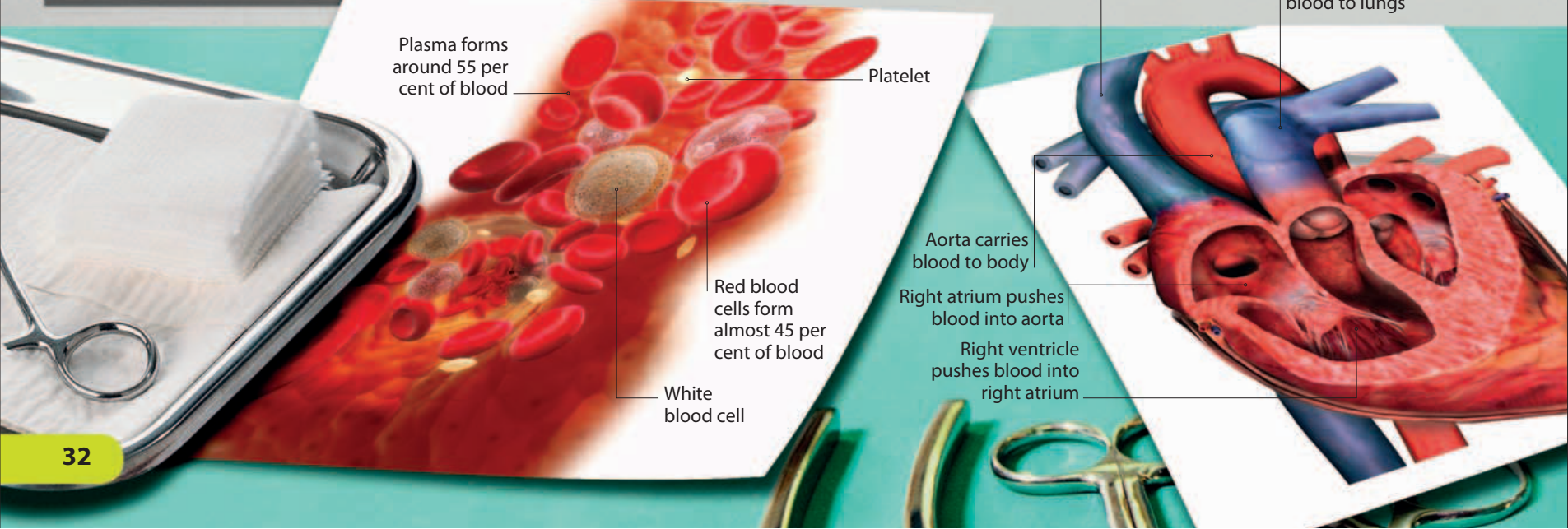


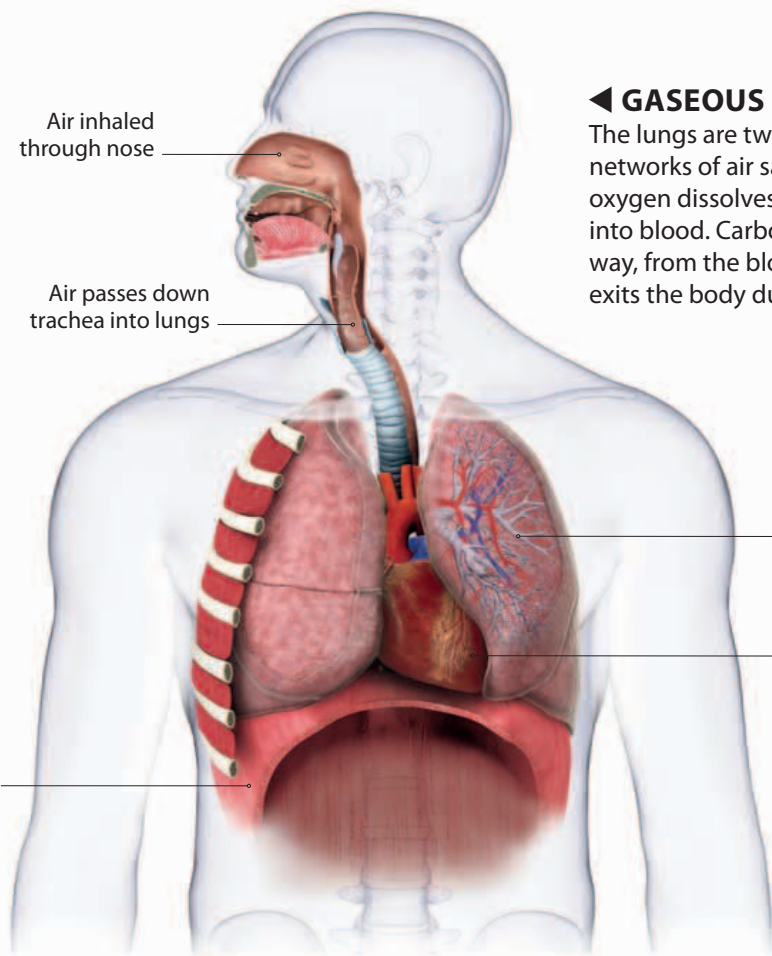
▲ BLOOD

Blood is the body's delivery system. It carries chemical hormones, infection-fighting cells and antibodies, and many other crucial substances. Blood plasma transports dissolved food and nutrients around the body as well as carrying waste substances away. Red blood cells contain haemoglobin, which transports oxygen to and waste carbon dioxide away from body cells. A red blood cell can carry one billion oxygen molecules.

▼ THE HEART

The heart is divided into four chambers – a right and left atrium and two lower ventricles. A human heart beats on average about 70–75 times per minute, and will pump blood an estimated 2.5 billion times in a person's lifetime. The muscular walls of the atria and ventricles contract to push blood through and out of the heart.





Air inhaled through nose

Air passes down trachea into lungs

Muscular diaphragm contracts and relaxes during breathing

◀ GASEOUS EXCHANGE

The lungs are two sacs containing branching networks of air sacs called alveoli. Inhaled oxygen dissolves in the alveoli and passes into blood. Carbon dioxide travels the other way, from the blood into the lungs, and then exits the body during exhalation (breathing out).

Oxygen and carbon dioxide exchanged in the alveoli

Heart pumps oxygen-rich blood around body

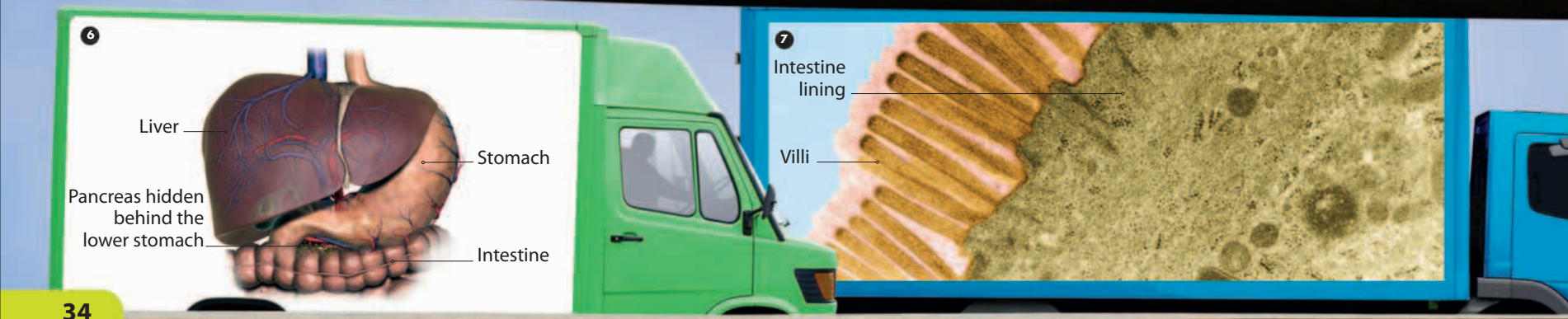
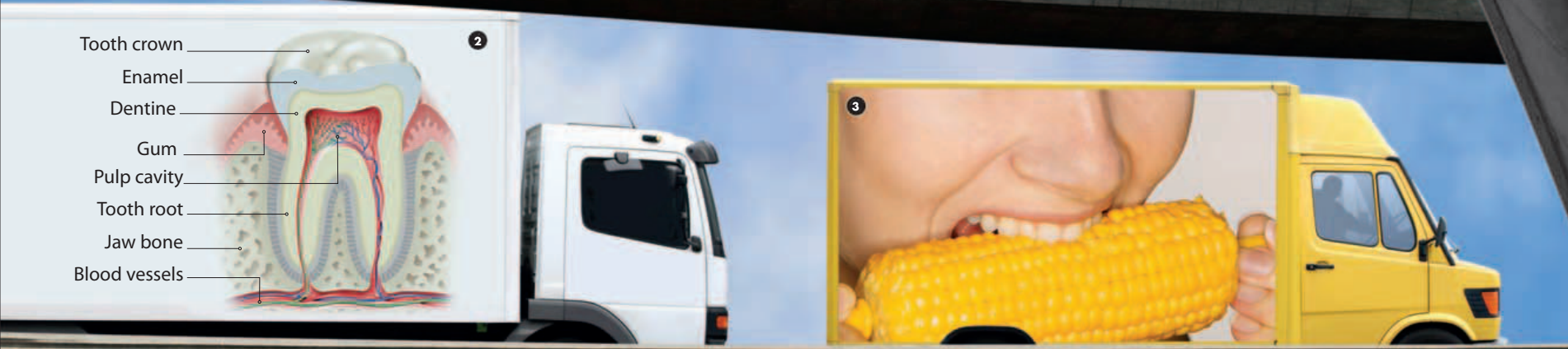
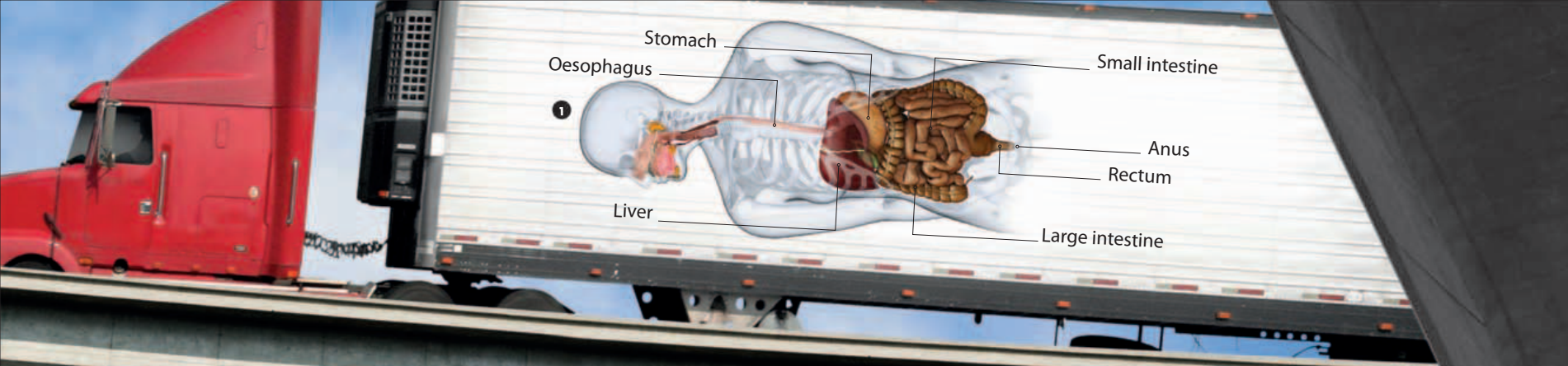
▼ CAPILLARIES AND VENULES

Blood travels from large arteries through smaller arteries and arterioles and into capillaries. These microscopic vessels infiltrate the body's tissues. Their walls are permeable – substances can pass in and out. This allows the transfer of nutrients and oxygen into cells. Waste products enter the blood in return. The blood then flows from capillaries into small venules which join to form veins.

▼ CARDIOVASCULAR DISEASE

A number of different conditions can affect the ability of the heart and circulation system to perform efficiently. Atherosclerosis is the build up of fatty deposits called plaque inside arteries. This causes the arteries to narrow and they will struggle to deliver enough oxygen to the heart. This can lead to a heart attack.





THE DIGESTIVE SYSTEM

The nutrients the human body needs from food are locked up in large food molecules. Digestion is the process of breaking down foods into substances that can be absorbed by the bloodstream and cells. Once in the cells, the energy and nutrients from food are used as fuel for movement, and cell and tissue growth and repair. The digestion process begins even before food enters the mouth, with the smell of it stimulating the salivary glands.

1 DIGESTIVE SYSTEM

The digestive system in humans is about 9 m (30 ft) long and is called the alimentary canal. Food takes 24 hours or longer to complete a journey that begins in the mouth and ends with waste matter passed out of the anus opening. Along the way, food is broken down by different parts of the digestive system before it is absorbed.

2 TAKE A BITE

An adult human has 32 teeth in the gums and jaw bones. The crown of the tooth (the part above the gum) is covered in a hard layer of enamel that protects the bone-like dentine underneath. Front incisor teeth cut and slice food, while the block-like molars at the back grind the food down.

3 CHEWING

The lips and front teeth pull food inside the mouth where cheek muscles drive the jaws in a chewing motion. The muscular tongue presses food against the teeth. Three pairs of ducts inject saliva, which lubricates the food as it is crushed. It also contains the enzyme ptyalin, which begins to break down starch in the food.

4 SWALLOWING

Once the food is a soft, moist mass called a bolus, it is pushed to the pharynx at the back of the mouth by the tongue and enters the oesophagus. This muscular tube contracts and relaxes in a wave-like sequence called peristalsis, which carries the food on a 6-second journey to the stomach.

5 IN THE STOMACH

The stomach expands to accept food through a ring of muscle called the oesophageal sphincter. Layers of muscle in the stomach's walls contract about three times per minute to crush and churn food. The stomach makes gastric juices that contain enzymes that break down the food. At the other end of the stomach, the pyloric sphincter stops food from entering the intestines.

6 LIVER AND PANCREAS

The stomach content, called chyme, is stored for 2–6 hours. After this, the pyloric sphincter opens and the chyme is pushed into the small intestine. Here, the chyme is made less acidic, while bile from the liver breaks down fats, making them easier to digest. Pancreatic juice breaks down food into simpler units.

7 SMALL INTESTINE

Enzymes continue their work in the small intestine. Its walls are covered in vast numbers of finger-like projections called villi, which absorb food. Proteins are changed into amino acids, fats into fatty acids, and carbohydrates into sugars. These now pass through the walls of the intestine into the bloodstream.

8 LARGE INTESTINE

The watery remains of undigested food and juices leave the small intestine and enter the 1.5–1.8 m (5–6 ft) long large intestine, where they spend 12 to 24 hours. Here, large amounts of water and some minerals are absorbed, while more than 400 different types of bacteria in the large intestine, such as these saccharolytic bacteria, break down and absorb further nutrients. The remaining matter, called faeces, is stored in the rectum and pushed out of the anus.



BRAIN AND SENSES

Humans rely on their senses to obtain information about the world around them. Data from the sensory organs continually bombards the brain. This organ monitors and regulates the body's unconscious actions, such as breathing and digestion, as well as conscious thought and movement. The brain sends instructions and receives sensory information as electrical signals via the nervous system.

▼ THE BRAIN

The brain is the body's control centre. Weighing about 1.5 kg (3.5 lbs), it consumes more than 20 per cent of the body's energy as it receives feedback from the body's senses. It also makes decisions and sends instructions to the rest of the body. The brain consists of about 100 billion brain cells called neurons, which form enormous networks with each other.

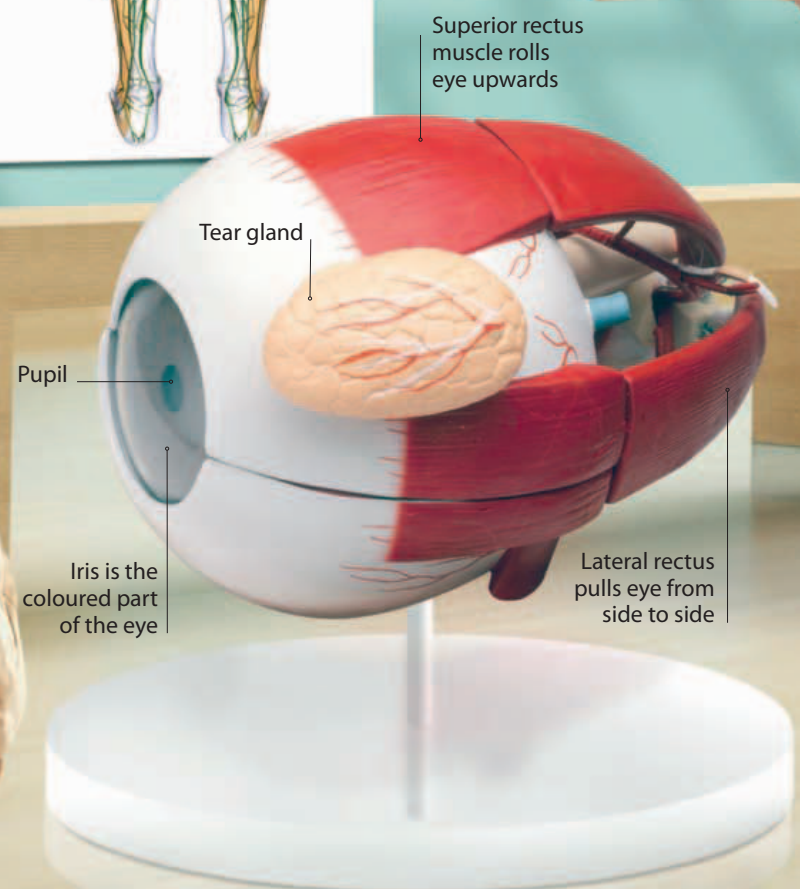
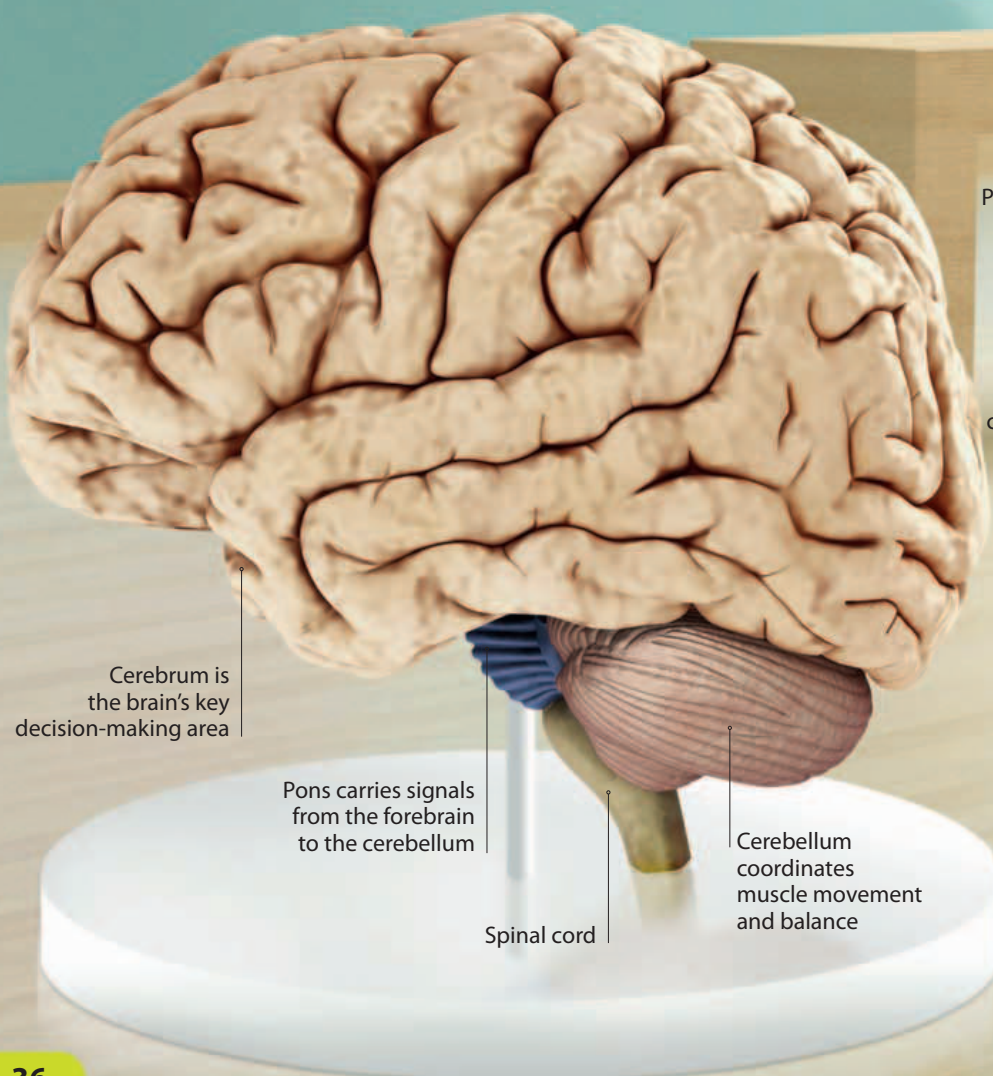
► THE NERVOUS SYSTEM

The central nervous system consists of the brain and spinal cord. Branching off are the many millions of neurons that form the peripheral nervous system, which extends throughout the body. Sensory neurons carry information to the central nervous system, while motor neurons carry instructions from the central nervous system to move muscles.



TOUCH ▼

The sense of touch provides data about the body's immediate surroundings. Different receptors in the skin respond to light touch, pressure, vibrations, temperature, and pain. The receptors are all over the body, but they are not distributed evenly. Certain parts, such as the lips and fingertips, are more sensitive as they contain a great number of receptors.



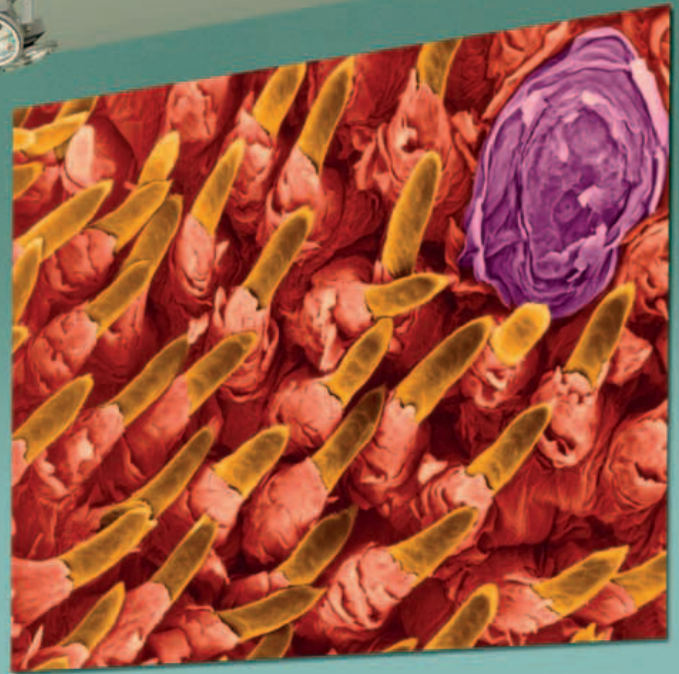
▲ SIGHT

Eyeballs are protected by a bony socket, with tear ducts to wash the eyeballs' surface every few seconds. Light enters the eye through the clear cornea and an opening called the pupil. A lens focuses the light so it falls on the retina at the back of the eye. The retina contains millions of photoreceptor cells. These are rods, which "see" in black and white, or cones, which "see" in colour.



▲ SMELL

The human nose can distinguish between about 10,000 different smells. This enables people to enjoy food and scents and to detect danger signs, such as smoke. Air breathed in contains odour molecules. Some of these dissolve in the layer of mucus that coats the inside of the nose. Smell receptor cells detect them and send nerve impulses to the brain.

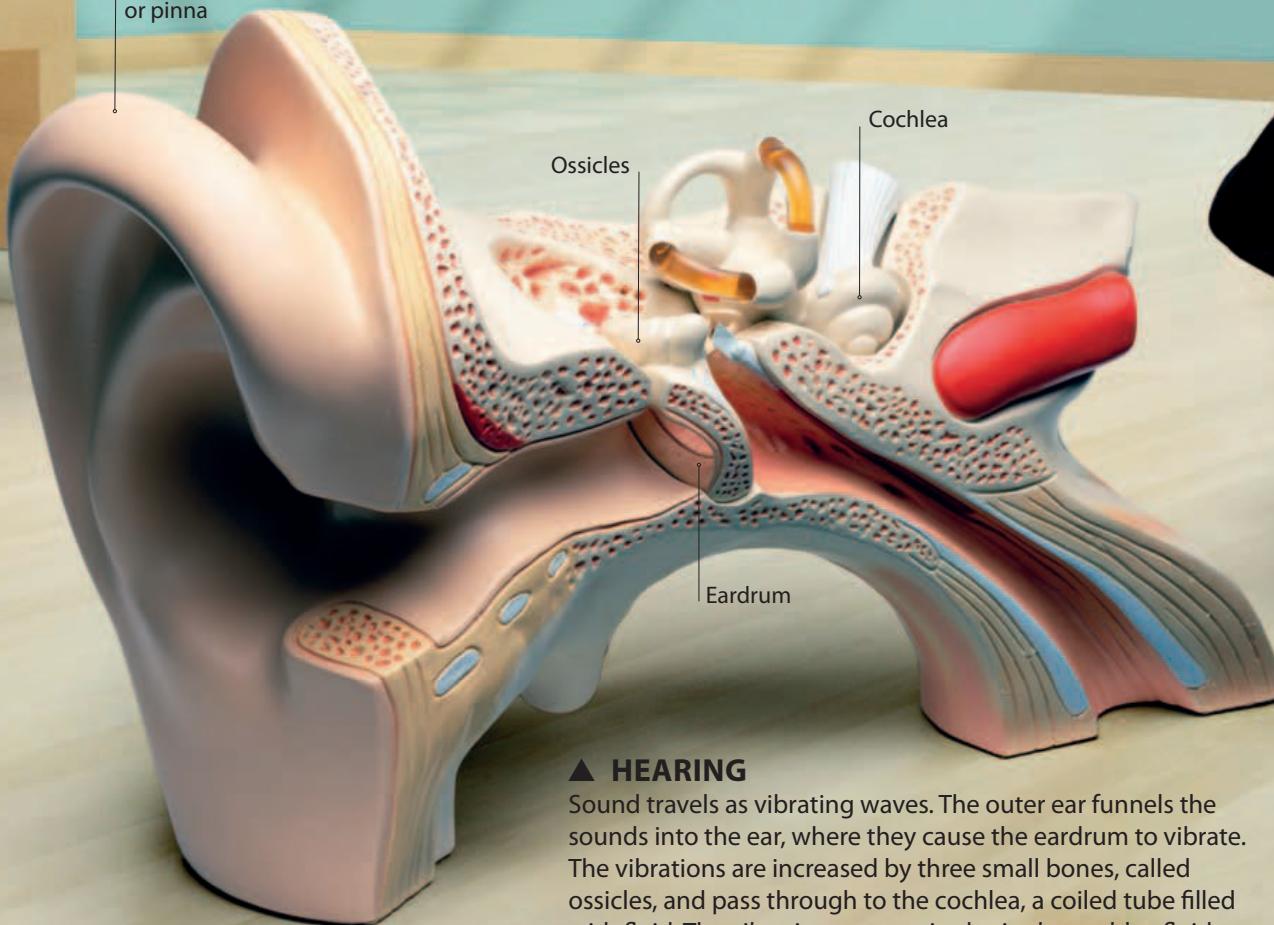


▲ TASTE

The human mouth has about 10,000 taste buds (top right of image) located on the surface of the tongue, the roof of the mouth, and the entrance to the pharynx. These can differentiate between five basic tastes: sweet, sour, bitter, salty, and umami, a savoury taste found in meats, cheeses, and mushrooms. Nerve fibres in taste buds transmit signals directly to the brain.

Fingertips packed with touch receptors

Outer ear or pinna



▲ HEARING

Sound travels as vibrating waves. The outer ear funnels the sounds into the ear, where they cause the eardrum to vibrate. The vibrations are increased by three small bones, called ossicles, and pass through to the cochlea, a coiled tube filled with fluid. The vibrations create ripples in the cochlea fluid and these ripples bend tiny hairs that line the inside of the cochlea. These hairs send signals to the brain and these signals are interpreted as sounds.

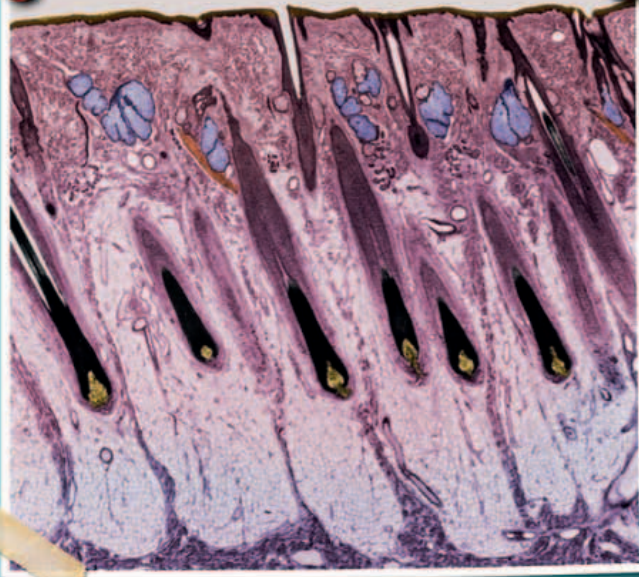


▲ PROPRIOCEPTION

Proprioception is the body's ability to know the location and position of its parts, including the direction of movement of the arms and legs and the position of joints. Proprioception enables a person to touch their nose with their eyes shut, as the body senses the finger's movement and its position relative to the face.

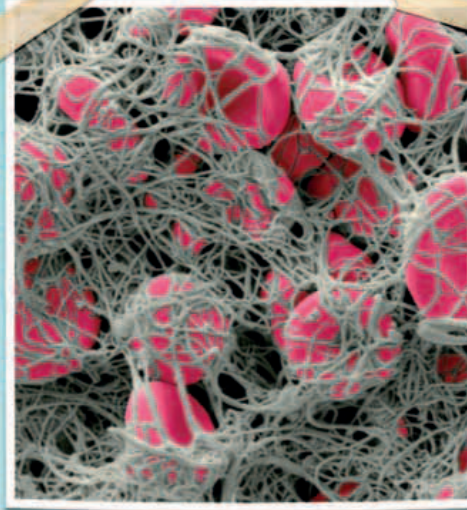
BODY REPAIR

The human body has a remarkable capacity for regrowth, repair, and regeneration. Processes within the body help sustain and maintain many of its parts during life. In an adult human, somatic stem cells are unspecialized cells that can be harnessed by the body and turned into certain types of blood, bone, or nerve cells. When the human body cannot repair a body part, medical science has found ways to help.



▲ CONSTANT REPLACEMENT

Some types of cells in the human body are replaced in a continual process. Red blood cells last a matter of months before being replaced, while human liver cells are regenerated every 300–500 days. Cells on the skin's surface (pictured above) rub and flake off steadily. They are replaced by cells in the deepest layer of the epidermis. These divide into new cells, are pushed towards the surface, die, and form a protective barrier.



◀ HEALING WOUNDS

When a cut occurs, red blood cells clump together with a mesh of a protein called fibrin (shown as grey fibres), forming a clot. Wounds can allow harmful substances into the body. Some white blood cells produce antibodies that fight any infection caused by these substances. Others perform the process of phagocytosis – surrounding and consuming bacteria. Blood capillaries grow into the area and, over time, new tissue forms around and over the wound.

Blood fills swelling around fracture

A cartilage callus holds bone parts in place

Fibrous network forms

Bony callus replaces cartilage

Blood vessels broken by fracture

Bone remodels itself forming permanent patch of fracture

Blood vessels re-grow through fracture area

▲ BROKEN BONES

Bones can break or fracture in different ways. Simple, or closed, fractures occur internally, while compound or open fractures see the skin surface break, often revealing part of the bone. A doctor may put the arm or leg in a cast or splint to let the bone's healing process continue smoothly. Simple fractures, if rested and not put under strain, usually take five to eight weeks to heal.

▼► REPLACEMENT JOINTS

Wear and tear, injury, or disease can all seriously affect the smooth working of load-bearing joints, such as the hip, knee, or ankle. The joint cartilage, which reduces friction between the moving bones, can wear away causing pain, swelling, and lack of movement. Major surgery can replace the natural joint with artificial parts.



Replacement knee joint



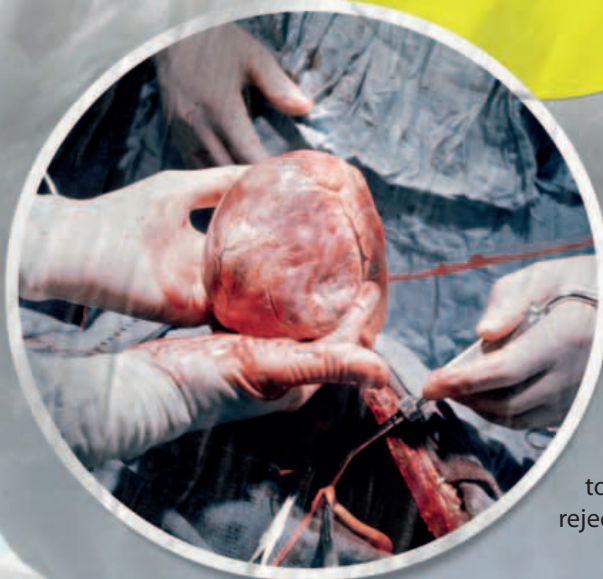
Artificial hip joint with ball fitted into hip socket

PROSTHESES ▼

An artificial substitute for a damaged, diseased, or missing body part is called a prosthesis. Modern prosthetic arms and legs offer wearers high levels of function and mobility. South African track athlete Oscar Pistorius wears prosthetic legs made of carbon fibre, which flex on impact with the track.

◀ TRANSPLANTS

Living tissue and organs can be surgically removed from one person (the donor) and transplanted into the body of another. Some transplant organs, including hearts, are from healthy donors who died suddenly. Others, such as a single kidney, can be taken from a living donor. In all cases, drugs to suppress the body's natural defences are required to help prevent the body rejecting the transplant.



GENETICS

Genetics is the scientific study of genes – the instructions that govern a person's growth, development, and health. These are passed down from parents to children via sexual reproduction. Each cell in the human body has more than 20,000 genes stored in the cell's nucleus. They provide the entire genetic code for a person and vary so that, apart from identical twins, each person has slightly different genes and has their own unique set of features.



Chromosome forms four-armed shape just before a cell divides

▲ CHROMOSOMES

DNA is packaged into 23 pairs of chromosomes inside a cell. Twenty-two of these pairs are similar in men and women. The 23rd pair are the sex chromosomes. These consist of two X chromosomes in females (XX) and one X and one Y chromosome in males (XY). Male and female sex cells (sperm and eggs) contain just one of the two sex chromosomes. A male child develops if the sperm contains the Y chromosome.

▶ DNA

Genes are found contained within long ribbon-like strands of deoxyribonucleic acid (DNA) molecules. Pairs of DNA molecules wind round in what is called a double helix. They are linked by chemical substances called bases, which are found in pairs. Long sequences of base pairs form genes. DNA can copy itself when cell division occurs so that a precise copy of the DNA is present in the new cell.

2



▲ INHERITANCE

Three generations of the same family share many similar features as a result of a parent and child sharing 99.95 per cent of the same DNA. A child inherits half of their chromosomes from their father and half from their mother. Sometimes, the genes from each parent, such as hair colour, do not match. In these cases, the dominant gene wins and is inherited by the child.

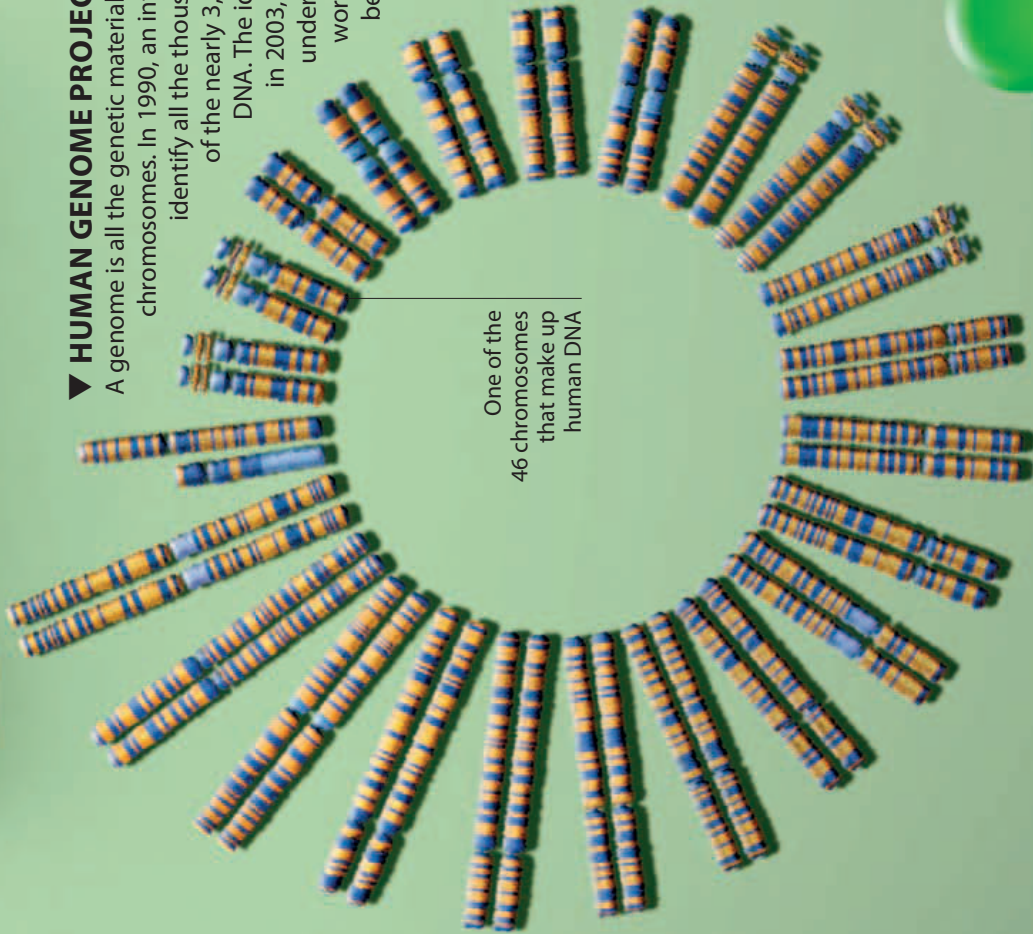




▼ HUMAN GENOME PROJECT

A genome is all the genetic material contained in a full set of chromosomes. In 1990, an international project began to identify all the thousands of genes and the sequences of the nearly 3,100 million base pairs in human DNA. The identification was completed in 2003, but research continues to understand more about how genes work and how gene therapy might be able to replace faulty genes.

One of the 46 chromosomes that make up human DNA



CC was the first cat cloned in 2001

4



Dolly became the first cloned sheep in 1996

5



6

▲ CLONING

Scientists are able to produce copies of individual genes, cells, and, in some cases, entire organisms, in processes called cloning. Scientists have cloned many animals, including sheep and cats. These creatures were created using somatic cell nuclear transfer. This is where the cell nucleus from an adult animal is placed inside an egg cell that has had its own nucleus removed.

8

9

► DNA FINGERPRINTING

Crime-fighting agencies use DNA fingerprinting to trace identities of criminals and victims. A DNA fingerprint is constructed by first taking a sample of DNA from a person's blood, hair, or a swab inside their mouth. A complex series of processes sees DNA extracted from the nucleus of a cell, cut into smaller pieces, processed, and imaged using X-ray photography. New DNA samples can be compared to those already held in order to try to find a match.



SPIKES OF ROCK

These rock formations are called hoodoos and are found at Bryce Canyon National Park in the US state of Utah. The spires of sedimentary rock have been created over millions of years of erosion.



Earth

EARTH'S ORIGINS

Earth is around 4,600 million years old. It is a slightly squashed sphere, measuring 12,756 km (7,973 miles) in diameter at the equator – the line running around the planet's middle an equal distance from the North and South poles. The planet spins on its axis and makes a complete revolution once every 23 hours, 56 minutes. Earth is the only planet in the Universe that is known to support life.

▼ EARTH FORMATION

Around 5 billion years ago, the Sun began life as a protostar, pulling dust and gas into its centre, becoming hotter, and then sending out a swirling mass of gas and dust. Over hundreds of millions of years, these materials would group together, collide, heat, and cool to form the objects found in the Solar System, including Earth.

1 Dust and rock Dust grains and small pieces of rock orbiting the Sun were pulled together by their own gravity. Heat generated by the collisions welded the rock together, forming larger clumps. This process is called accretion.

2 Ball of fire Early Earth was bombarded with rocky debris, generating intense heat. This, along with radioactive reactions, melted the planet and helped create its different layers.

3 Cooling crust Heavier, iron-rich materials moved towards the centre of Earth, forming its core. Lighter materials began to cool and form the planet's mantle and the outer crust.

4 Seas and oceans The cooling Earth allowed water vapour released into the planet's early atmosphere to fall back to the surface to form early oceans.

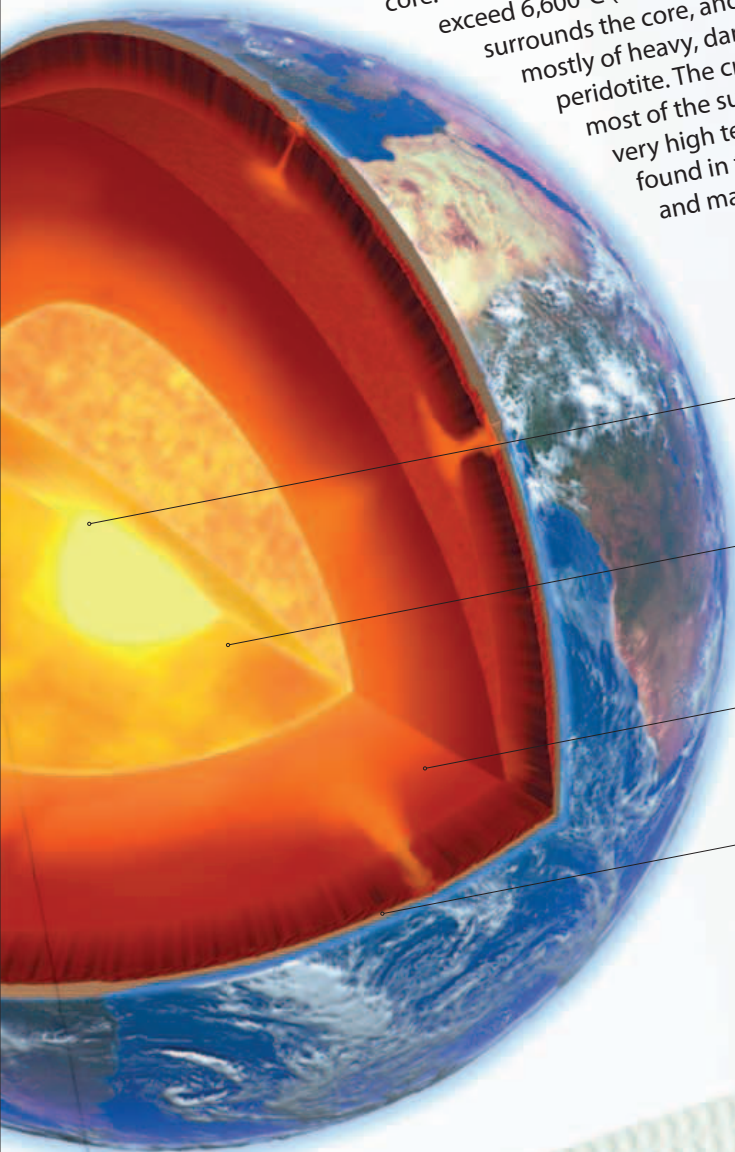
5 Moving land The continental crust once formed one giant landmass called Pangaea. About 200 million years ago, the separate continents that we know today were formed.

6 The planet today Earth today has an oxygen-rich atmosphere and other conditions capable of supporting a huge diversity of life.



▼ INSIDE EARTH

Earth consists of three main layers – a core, the mantle, and a rocky crust. The core is divided into a solid inner core, made of iron and nickel, and a molten outer core. Temperatures in the inner core may exceed 6,600°C (11,900°F). The mantle surrounds the core, and is made up mostly of heavy, dark rock called peridotite. The crust insulates most of the surface from the very high temperatures found in the core and mantle.



Inner core is 1,300 km (815 miles) in diameter

Outer core is roughly 2,200 km (1,400 miles) thick

Mantle is 2,900 km (1,800 miles) deep

Oceanic crust is up to 5 km (3 miles) in depth

▼ BUBBLING UNDER

In certain areas, water descends deep into the crust where it is heated by contact with hot rocks. Much of the water remains in geothermal reservoirs below the surface. Some, however, circulates back to the surface, forming thermal springs and jets of hot water and steam called geysers. Here, a group of Japanese macaque monkeys gain welcome relief from the cold Japanese winter by bathing in a hot spring.



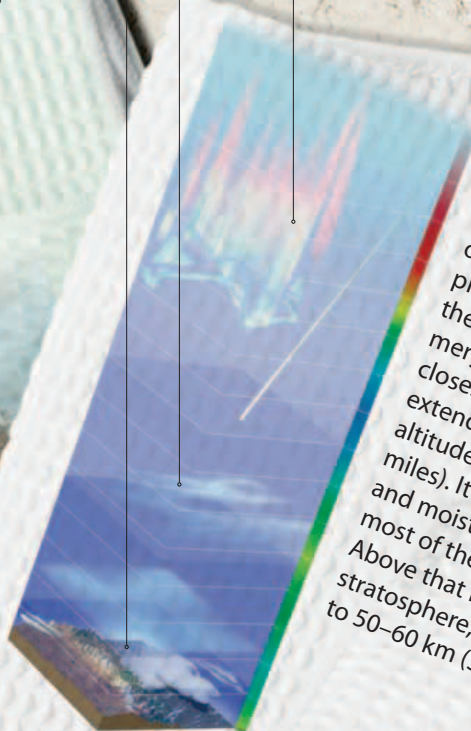
▲ LIFE ON EARTH

Precisely how life began on Earth remains unclear. It is believed, though, that life started after the planet had cooled enough for bodies of water to form. Scientists have found fossilized single-celled micro-organisms in rocks that date to approximately 3.5 billion years ago. This cyanobacterium is an example of the blue-green algae bacteria thought to be one of the earliest forms of life.

Troposphere

Stratosphere

Exosphere



▲ ATMOSPHERE

Earth's atmosphere is a cocoon of gases that surround the planet and extend upwards, with the outer layer, the exosphere, merging into outer space. The closest layer, the troposphere, extends from sea level up to an altitude of around 15 km (10 miles). It contains circulating air and moisture, which creates most of the planet's weather. Above that is the drier stratosphere, which extends up to 50–60 km (30–40 miles).

PLATES AND FAULTS

Earth's crust is not one single piece. It is made up of a number of gigantic slabs, called plates, which float on the surface of Earth's mantle. Heat generated by radioactivity deep within Earth causes convection currents to run through the mantle. The plates glide on these currents, moving 1–20 cm (0.5–8 in) per year. They come together or pull apart, generating volcanic and earthquake activity and creating new landforms.

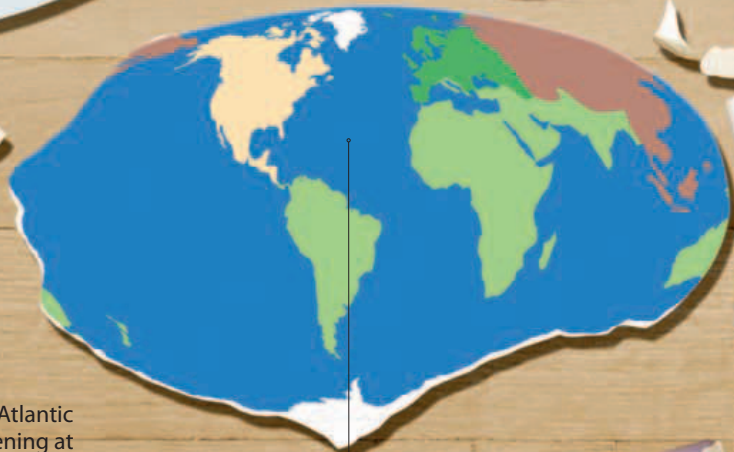
▼ CONTINENTAL DRIFT

In the distant past, the continents were in quite different locations. Around 250 million years ago, they were all clumped together as one supercontinent called Pangaea. The different plates of crust then moved apart in stages in a process called continental drift. North America, for example, separated from Europe as the Atlantic Ocean started to form around 150 million years ago.

170 million years ago, South America and Africa were slowly drifting apart



Today, the Atlantic Ocean is widening at a rate of about 2.5 cm (1 in) per year



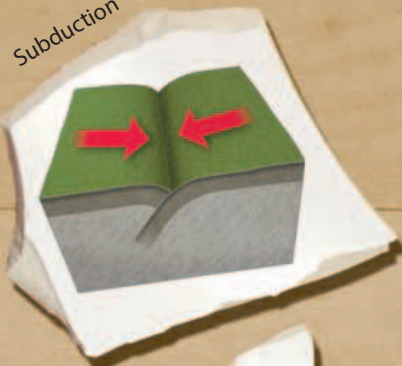
Lava spews up at Krafla in Iceland, which lies on the mid-Atlantic ocean ridge



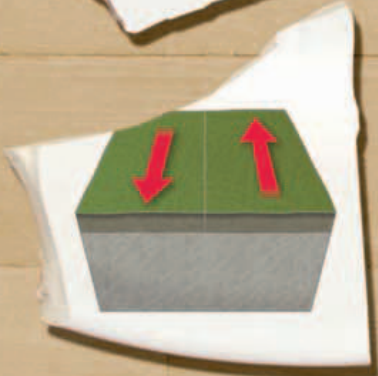
► OCEAN SPREAD

New oceanic crust is created at giant rifts in the middle of the oceans, called mid-oceanic ridges. As plates pull apart, pressure beneath the oceanic crust decreases, allowing molten rock (magma) from deep in Earth's mantle to rise towards the surface. Vast mountain and volcano chains form on the ocean floor, some of which may emerge above the ocean's surface as islands.

Subduction



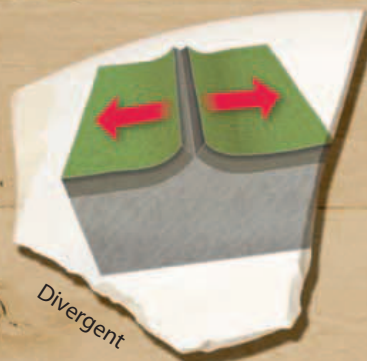
Transform



Collisional



Divergent



◀ PLATE BOUNDARIES

Boundaries are where two or more plates meet. At divergent boundaries, plates pull apart. At subduction boundaries, one plate slips underneath another. Transform boundaries see the plates slide and grind past each other. At collisional boundaries, two continental crust plates crunch into one another. Rock is often driven upwards at boundaries to form mountain ranges. The Himalayas are formed by the collision of the Eurasian and Indo-Australian plates.



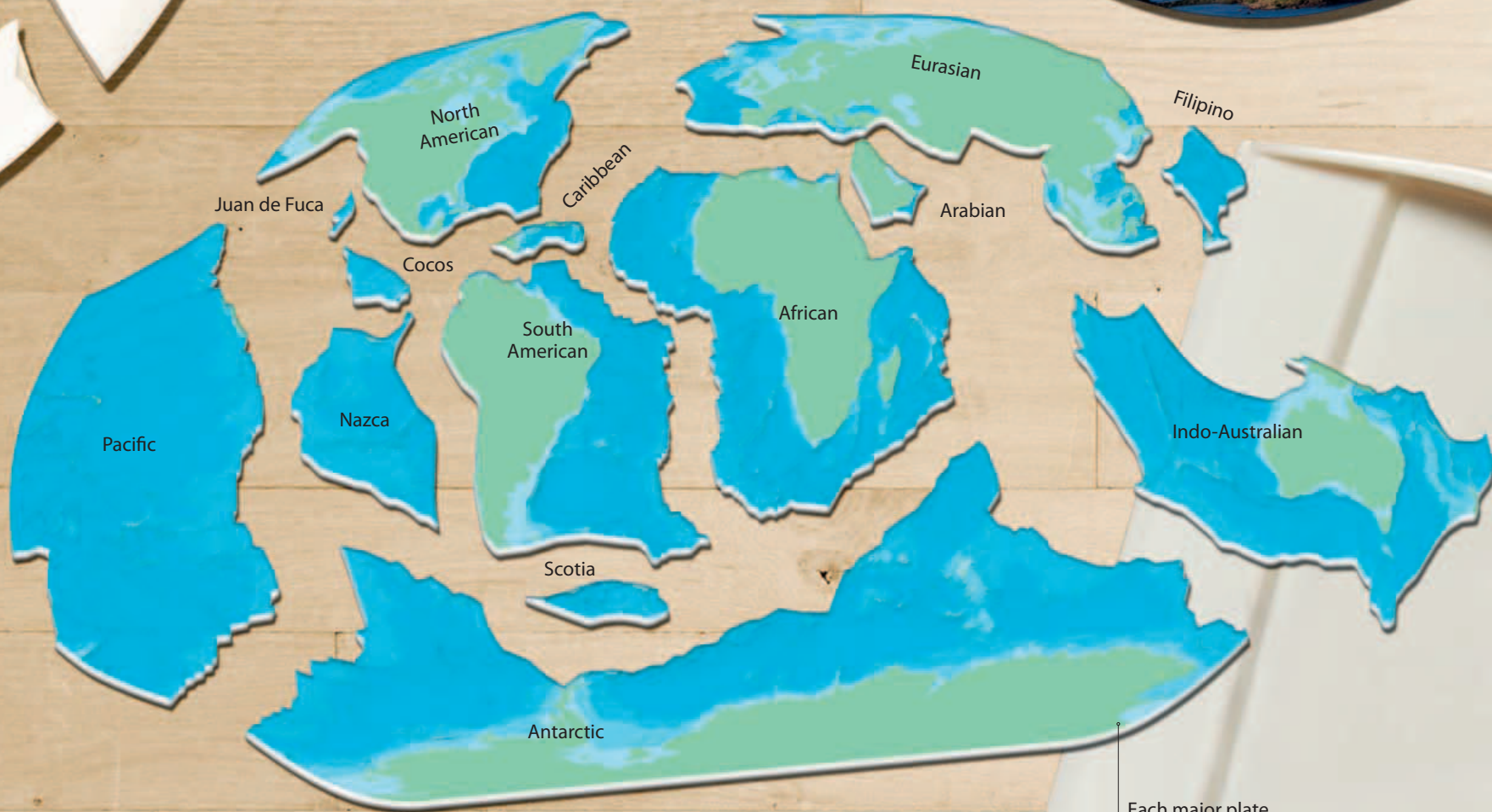
◀ FAULTS

A large crack in Earth's crust, where the rocks either side have moved, is called a fault. There are thousands of faults, but the largest tend to be the result of plate movement squeezing and stretching the crust. The San Andreas Fault (shown here) is caused by the movement of the Pacific and North American plates. These have struck and slipped past each other at a rate of about 4–6 cm (1.5–2.5 in) per year.



▶ MAKING MOUNTAINS

Plate movements, especially along the boundaries between plates, generate enormous forces that can fold and uplift rock to create high mountains. The Andes in South America are made up of mountain ranges and highland areas running the length of South America, with more than 50 peaks at least 6,000 m (20,000 ft) high. They were formed by the Nazca and Antarctic plates sliding beneath the South American plate.



▲ PLATES

There are seven major plates – the African, North American, South American, Eurasian, Indo-Australian, Antarctic, and Pacific plates. In addition, there are a number of smaller, minor plates, including the Nazca plate to the west of South America and the tiny Juan de Fuca plate, a mere 200 km (120 miles) long, positioned on the Pacific coast of the United States between the Pacific and North American plates.

Each major plate is made up of smaller plates, called tertiary plates

EARTHQUAKES AND VOLCANOES

Volcanoes and earthquakes tend to happen most where Earth's crust is under enormous stress and strain, such as where plates grind up against each other, pull apart, or one plate subducts, sliding underneath another. Earthquakes usually occur near faults, where the movement of rocks leads to a great build-up of energy. A sudden release of this energy sees waves travel through the crust, reaching the surface as powerful tremors.



◀ QUAKE!

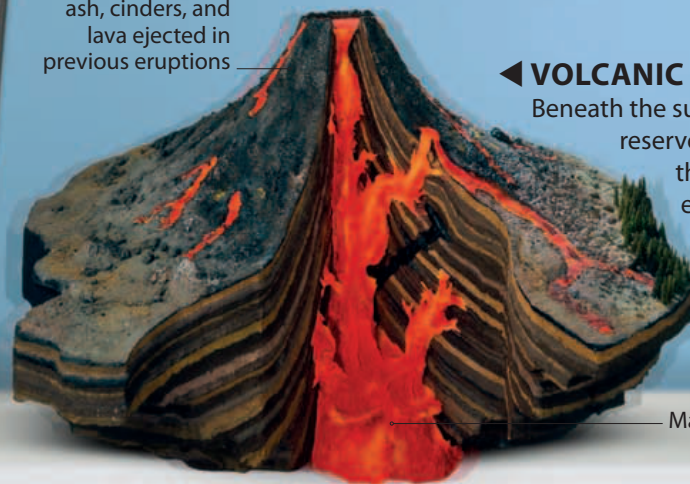
An earthquake begins at a point underground called the hypocentre or focus. The released energy radiates outwards in a series of seismic waves. These weaken in strength the further they travel. As they move, the waves distort the rocks as they release their energy. An earthquake may be followed by further tremors called aftershocks.

▶ EPICENTRE

The point on the surface directly above the focus is called the epicentre. This is usually the area at the surface where the greatest force of the quake is felt. Major quakes can be devastating. The earthquake that struck Haiti in 2010 killed more than 220,000 people.



Cone forms from ash, cinders, and lava ejected in previous eruptions



◀ VOLCANIC ACTIVITY

Beneath the surface, molten rock, called magma, can form in reservoirs called magma chambers. Less dense than the surrounding rock, the magma rises and, if enough pressure builds, may reach the surface through weak areas of the crust. These volcanic eruptions vary from a gentle oozing above ground through to explosive eruptions.

Magma chamber

◀ LAVA

Lava is magma that has reached the surface. It will eventually cool and solidify to form a volcanic igneous rock such as basalt, andesite, or rhyolite. Lava can be thin or thick and viscous. This river of molten hot lava flowing from Mount Etna is relatively thin, allowing gases to escape and the lava to flow longer distances. Thin lava will often form gently sloping shield volcanoes.



▶ TSUNAMI

Earthquakes and volcanic activity underwater can generate giant ocean waves called tsunamis. The Sumatra-Andaman earthquake in 2004 generated powerful tsunamis that devastated the coasts of Indonesia, Thailand, Sri Lanka, and India. Waves caused by the earthquake travelled as far as Struisbaai, South Africa, some 8,500 km (5,300 miles) from the epicentre.

Tsunamis can be highly destructive if they strike land



► LAVA BOMB

Lava bombs are chunks of molten lava ejected from a volcano during an eruption. They can vary from something the size of a golf ball to more than 5 m (17 ft) across. The 1992 eruption of Mount Spurr in Alaska saw lava bombs 1 m (3.5 ft) in size ejected up to 3 km (2 miles) from the volcano.

SANTORINI ▼

Some time during the period 1600–1650 BCE, a gigantic eruption occurred on the Greek island of Santorini (also known as Thera). The eruption emptied the volcano's magma chamber and this collapsed forming a giant crater called a caldera, which flooded with water. Santorini is still the site of volcanic activity and the volcano last erupted in 1950.

▼ MOUNT ETNA

Lying on the boundary between the African and Eurasian plates of Earth's crust, Mount Etna stands more than 3,300 m (11,000 ft) tall and is Europe's largest active volcano. It has a long history of activity, with five major eruptions in the 20th Century alone.

EXPLOSIVE ERUPTION ▼

When magma is thick and viscous, gases find it hard to escape and pressure can build. In addition, the surface opening of a volcano may be plugged with previously erupted lava. Eruptions in these situations can often be explosive, sending vast amounts of lava, rock, and ash high into the atmosphere.

Anak Krakatau has grown from the ocean floor to a height of 300 m (1,000 ft) since 1927

▼ EXTINCT

Volcanoes can die out. Extinction can occur when Earth's plates move so that the volcano is no longer positioned above a magma chamber. Mount Kilimanjaro is a giant stratovolcano in Tanzania. It consists of three separate volcanic peaks, two of which (Mawenzi and Shira) are extinct, while one (Kibo) is classed as dormant.

► DORMANT

A dormant volcano is one that has not been active for a long period of time, but may erupt in the future. Mauna Kea is a dormant shield volcano and is the highest mountain in the Hawaiian Islands, with a height of 4,205 m (14,015 ft). It started building up from the Pacific floor around 1 million years ago and last erupted about 4,500 years ago.

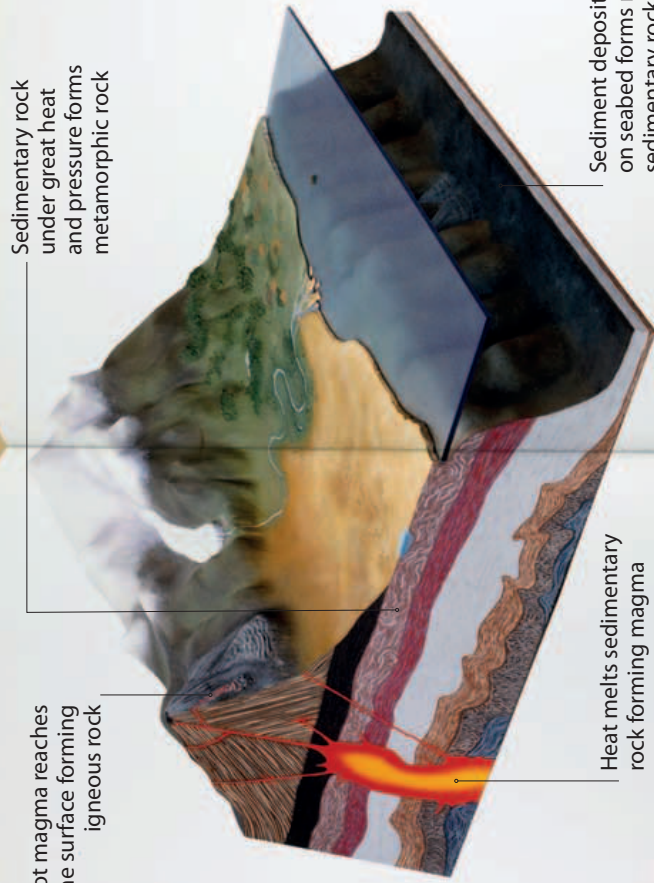
ROCKS AND SOIL

▼ ROCK CYCLE

The rock cycle shows how rocks can be transformed from one type to another. Sedimentary rock, for example, can be transformed into metamorphic rock through great heat and pressure. Heat can also transform sedimentary or metamorphic rock into igneous rock. Rocks can be worn away, creating particles that are transported and deposited as sediment. This settles and hardens to form new sedimentary rock.

Our planet's crust is formed of many different types of rocks. These materials are made up of chemical compounds called minerals. Some minerals are elements, such as the metals silver and copper. Others are compounds or mixtures, such as silicates containing oxygen, silicon, and other substances. Rocks are classified into three groups – igneous, metamorphic, and sedimentary. Over long periods of time, rocks alter their structure and can change from one group to another in a process called the rock cycle.

Hot magma reaches the surface forming igneous rock



Sediment deposited on seabed forms new sedimentary rock

Heat melts sedimentary rock forming magma

▼ IGNEOUS ROCKS

Igneous rocks form when molten rock cools and solidifies. The texture of igneous rocks is determined by how quickly they cool. Those that form on or near the surface tend to cool rapidly, giving the rock a fine grain, such as basalt, the most common rock on the ocean floor. Those igneous rocks that form deep below the surface tend to cool more slowly and, as a result, tend to be tough with a coarse grain, such as granite (shown here).

▼ IGNEOUS INTRUSIONS

When magma cools and turns solid before it reaches the surface, it forms an igneous intrusion. Intrusions can form thin or narrow dykes between cracks in other rocks, or large deep-seated mounds under the surface called batholiths. Over millions of years, rocks above intrusions may wear away exposing the intrusions at the surface.

Trosky Castle in the Czech Republic sits on top of an igneous intrusion

▼ SEDIMENTARY ROCKS

Sedimentary rocks, such as sandstone, are formed from tiny particles of rock or, in the case of limestone and chalk (shown here), the skeletons, shells, and other hard body parts of creatures. This material is transported and deposited by rivers, oceans, winds, or glaciers as a layer of sediment. Over time, layers build up, heaping pressure on layers below, which compact together to form solid rock.



► REGIONAL METAMORPHISM

Metamorphic rocks can be created over large areas, through the heat and pressure of rocks folding and bending under enormous forces, created by the movement of plates. The sedimentary rock shale, for instance, can be changed through this regional metamorphism, into slate. The slate can itself be transformed by further heat and pressure into a tough metamorphic rock called gneiss (shown here).

▲ ON THE SURFACE

Rivers carry vast amounts of sediment. The Amazon carries and discharges more than 1.3 million tonnes of sediment into the Atlantic Ocean every day. Deposition and compaction of sediment takes place close to Earth's surface. This is why some 75 per cent of rocks visible on the surface are sedimentary rocks. However, only five per cent of Earth's crust is made of sedimentary rocks.

▲ METAMORPHIC ROCKS

Marble is a metamorphic rock. All metamorphic rocks started life as a different form of rock, before they were transformed by great heat or a combination of heat and pressure. Thermal or contact metamorphism is where hot igneous rocks or magma enter an area and bake the surrounding rock. In this way, limestone can be transformed into marble (shown here) and sandstone can be changed into quartzite.

► SOIL

This is a layer of loose matter that covers large areas of land and is essential for plant growth. Soil is formed from the remains of rock that have been broken down by weathering into tiny fragments, and mixed with decaying animal and vegetable matter, known as humus. Soil contains moisture, air, and mineral-rich nutrients taken up into plants by their roots. Soils vary greatly in composition – from thick, sticky clays to loose, dry sandy soils.

WEATHERING AND EROSION

Rock formations are continually under attack from water, wind, ice, chemical reactions, and changes in temperature. Weathering is the gradual breaking down of exposed rock. It can be caused by chemical changes or physically, when rock shatters or is broken down into smaller fragments. Erosion is the removal of weathered material from its original location. Common agents of erosion are water, wind, and ice.

► BIOLOGICAL WEATHERING

Living things can weather rocks. Plant roots growing between cracks widen rock fissures and split rocks apart. Some creatures, such as limpets, scrape away grains of rock surfaces or burrow into rock. Other living things, such as lichens and bacteria, secrete chemicals that can dissolve rock.

Roots of a Jeffrey pine enlarge crack in granite rock



◀ PHYSICAL WEATHERING

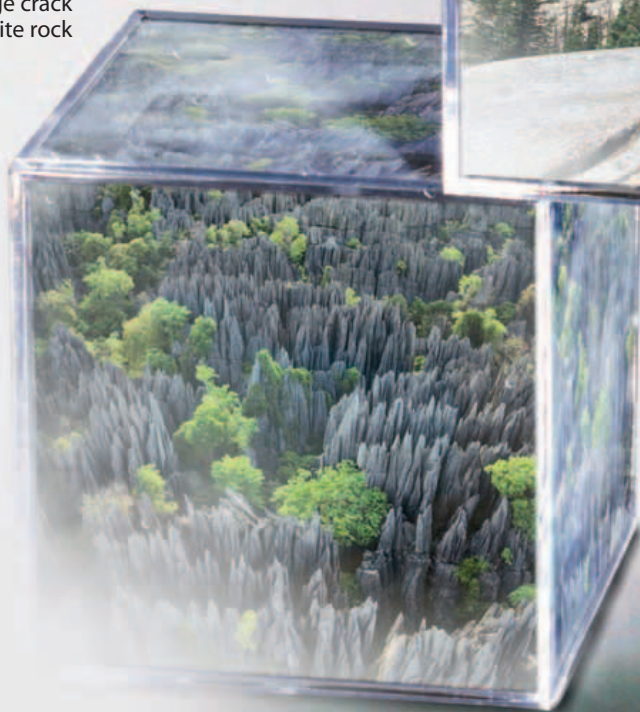
Changes in temperature see rocks expand when heated and contract when cold. These changes cause most physical weathering. Freeze-thaw occurs when water seeps into cracks, freezes, and expands, breaking rocks apart. Salt weathering occurs when evaporating water leaves salt behind in rock holes and cracks. This salt expands when heated, pushing the rocks apart.

Holes caused by salt weathering from sea spray



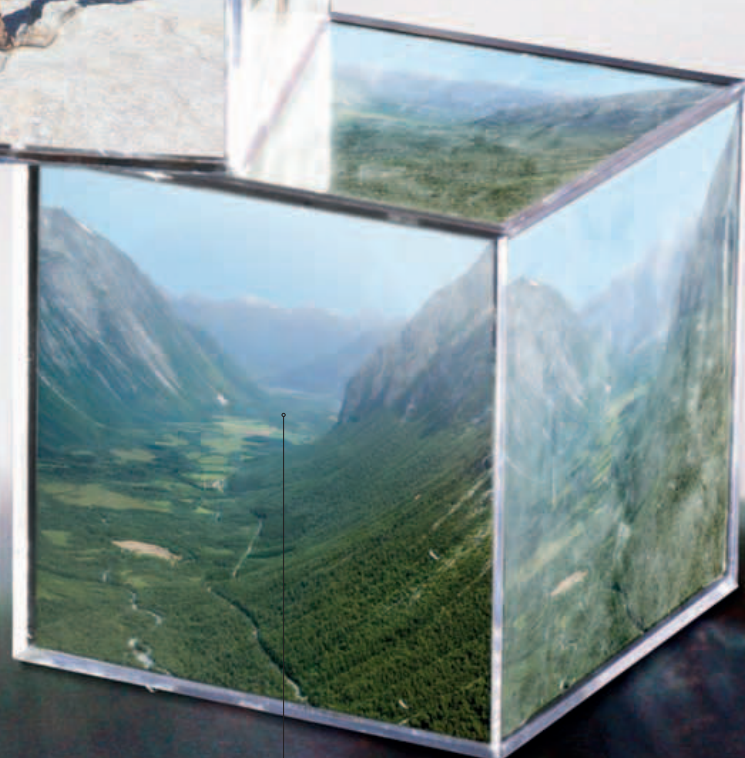
▼ GLACIATION

Glaciers can have a dramatic impact on the landscape. They gouge, grind, and scrape out the rock as they move past, creating highland features, such as jagged peaks and sharp ridges, and producing wide U-shaped valleys. When such valleys extend to the coast and are flooded with water, they are called fjords.



▲ KARST

When certain rocks, such as marble, dolomite, gypsum, and limestone, are eroded by chemical reactions with rainwater, they form Karst landscapes. Rain combines with carbon dioxide in the air to form a weak carbonic acid. Over time, this can dissolve away rock, creating large forests of rock pinnacles, or infiltrate joints in limestone formations to create caves.



The U-shaped Romsdal Valley in Norway

► WIND EROSION

Winds pick up large amounts of sand and other gritty particles, and blast rock surfaces. This can erode and cut grooves through softer layers of rock and sometimes round and polish harder rock. The dramatic arch of the Sipapu Bridge in the US state of Utah was originally formed by water erosion, but has been shaped subsequently by wind erosion.



Sipapu Bridge is 67 m (225 ft) high and 82 m (275 ft) long

This meandering loop is Horseshoe Bend on the Colorado River, USA

► MOVING WATER

A river's waters erode and transport vast quantities of material as sediment. Along their length, rivers cut into the surrounding land, eroding the river banks and beds, forcing water into cracks and breaking loose rock into smaller particles. When a river flows in a bend, the water current is fastest on the outside and erodes the outer bank more than the inner.



▼ COASTAL EROSION

Ocean waves erode by pounding the coastal rock with stones, sand, and other particles, which act as a powerful abrasive on the rock surface. In addition, sea water, which is mildly acidic, can dissolve limestone and chalk. Coastlines may be formed of rocks of different hardnesses and these will erode at different rates. Soft rock forming these cliffs in Chesapeake Bay in the US state of Maryland has been eroded rapidly, leaving abandoned houses teetering on the cliff edge.

Water drops a height of 82 m (275 ft)



▲ WATERFALLS

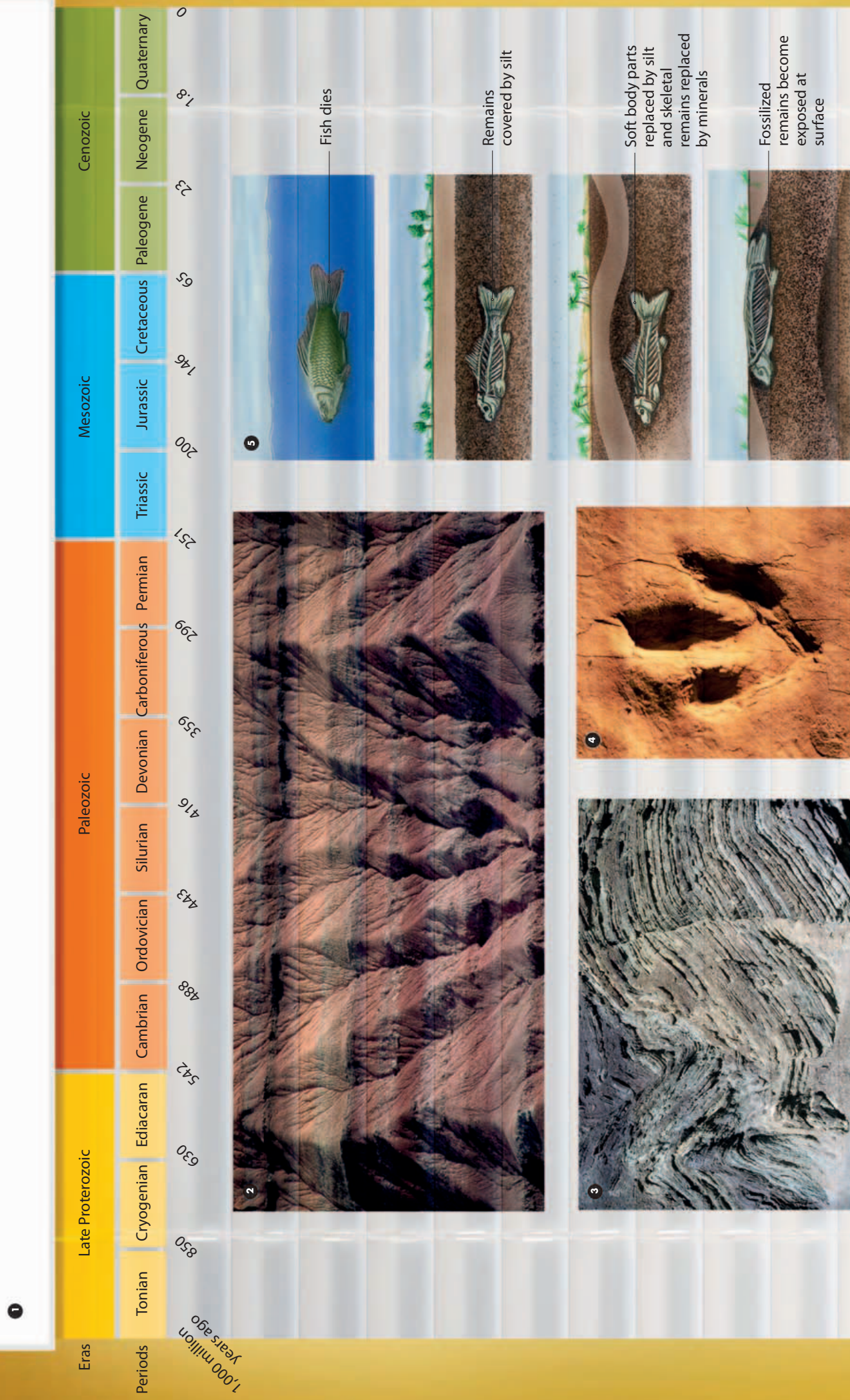
The Iguazu Falls in South America consists of 275 separate waterfalls called cataracts over a stretch of the Iguazu River. Waterfalls often form when different hardnesses of rock span a river bed. The water erodes softer layers creating a steep ledge, over which the water flows. Over longer periods of time, the waterfall erodes the harder rock as well, so the falls retreat upriver.

FOSSILS AND STRATA

Rock formations provide varying branches of geology (the study of rocks) and palaeontology (the study of prehistoric life) with clues to the distant past. Fossils can lie buried for tens or hundreds of millions of years until rock movement or erosion reveal them. Earth has a 4,600-million-year long history. To deal with the enormous time spans involved in rock and fossil history, scientists use the concept of geological time.

1 GEOLOGICAL TIME
Earth's history is divided into four major eras of geological time – the Proterozoic, Paleozoic, Mesozoic, and Cenozoic. The Cenozoic era stems from 65 million years ago to the present day. Each era is split into periods, which are subdivided into epochs. We are currently living in the Holocene epoch, which began 10,000 years ago.

2 LAYER ON LAYER
These rock formations in Arizona's Painted Desert show layers or strata of sedimentary rocks. Over long periods of time, sedimentary rocks form layers on top of each other. In an undisturbed rock formation, the oldest layers are at the bottom. Geologists can investigate strata to build up a picture of the geological history of an area.

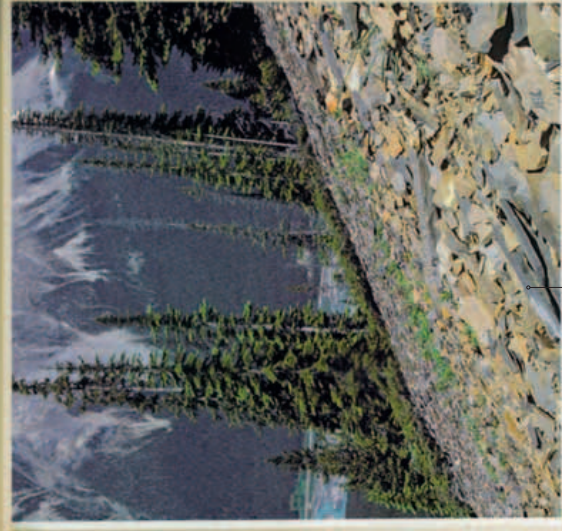
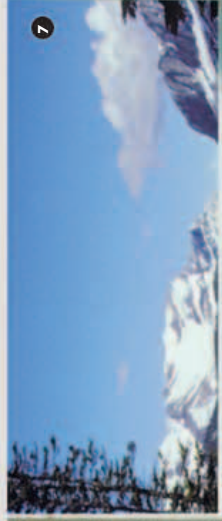
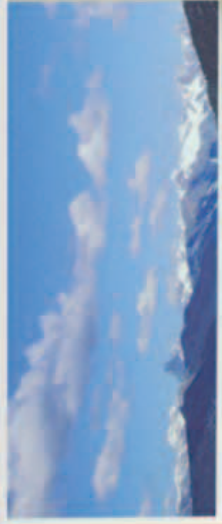


6 FAULTING AND BENDING

Many rock formations do not remain undisturbed for millions of years. Movements in the crust can cause rock strata to snap and move. Less violent pressure and heat can deform rocks over long periods of time. This can bend and fold rock strata. This image shows an anticline fold – an upwards pointing fold with its oldest rocks furthest from the surface.

4 FOSSILS

Fossils are any physical evidence of former prehistoric life. This means that ancient faeces that has been preserved or a dinosaur footprint are fossils, as well as complete skeletons of dinosaurs or the outer shell of a prehistoric marine animal. Fossils form in a number of different ways, including insects being trapped in sticky resin from trees that hardens to form amber.



Models of mammoths caught in La Brea Tar Pits

5 FOSSILIZATION

This diagram shows how a prehistoric fish can become a fossil. A dead fish's soft body parts rot away, but its bones and other hard body parts remain and can be infiltrated by minerals. These harden as layer upon layer of sediment covers the remains. Erosion and movements in the crust can expose the fossil.

6 PRESERVING IN TAR

The remains of some prehistoric creatures were well preserved when they fell into pits of thick tar or asphalt. The La Brea Tar Pits in Los Angeles, California, are world-famous for preserving thousands of fossils that are up to 40,000 years old. These fossils include the remains of mammoths and sabre-toothed tigers.

7 FOSSIL FINDS

Many sites have become renowned for their rich haul of discovered fossils. Canada's Burgess Shale formation was discovered in 1909. Dating back to the Middle Cambrian period 520–512 million years ago, the area was part of an ocean where frequent mudslides preserved the remains of marine creatures.

8 FOSSIL REMAINS

Scientists interpret fossils to build up a picture of prehistoric life, climate, and the geography of regions millions of years ago. Certain species that evolved rapidly and were distributed widely around the planet are called index fossils. Rocks containing these fossils date the rock to that time.



Dragonfly fossil from the Mesozoic era (251–65 million years ago)

WATER

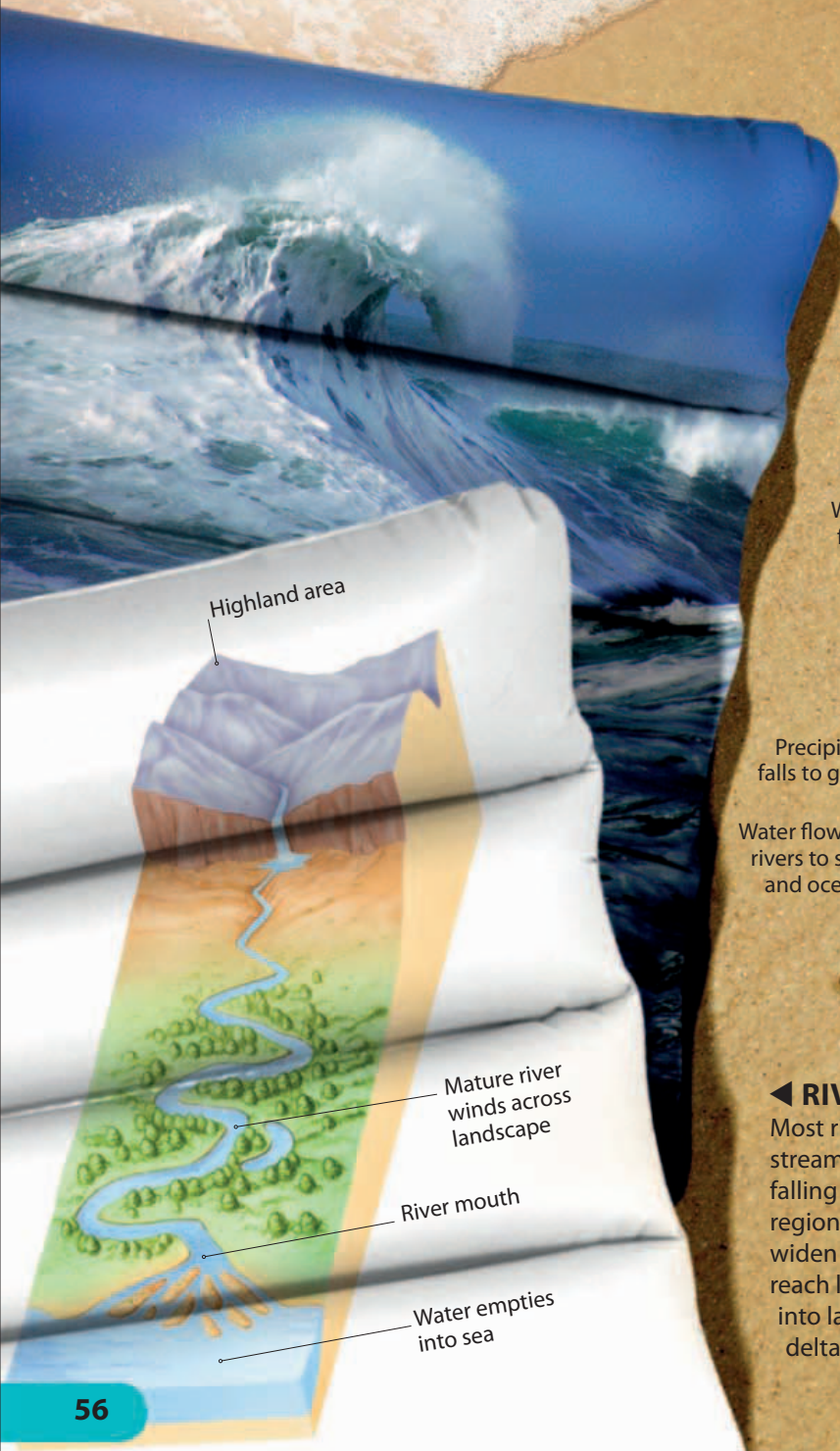
Water is essential to life. It makes up more than 50 per cent of the weight of all living things, and few organisms can survive for long without it. There is an estimated 1.45 billion cubic km (0.4 billion cubic miles) of water on the planet existing in solid, liquid, and gaseous states. The total amount of water found on Earth never changes, but it moves from place to place and state to state in a continuous process called the water cycle.

▲ ICE CAPS

Less than three per cent of the world's water is fresh water. Most of this is locked up as solid ice in glaciers and in the giant ice sheets that cover parts of the Arctic and much of the continent of Antarctica. The Antarctic ice sheet is enormous. It has an area of almost 14 million square km (5.5 million square miles) and extends down in places to depths of 2,500 m (8,200 ft).

◀ SEAS AND OCEANS

Seas and oceans cover almost three quarters of the planet's surface. Together, they hold more than 97 per cent of all the water on Earth. Seawater is saline (salty), typically three per cent salt and 0.6 per cent other elements, such as potassium, fluoride, and calcium. The planet's oceans are all interconnected and water is pushed around by ocean currents.



◀ RIVERS

Most rivers are fed by smaller rivers and streams called tributaries as well as by falling rain and melting ice from highland regions. They slow in speed and tend to widen and meander in bends as they reach lowland areas. Eventually, they flow into lakes, fan out into wetlands and deltas, or empty into the sea.

▲ THE WATER CYCLE

The Sun powers the water cycle. It evaporates liquid water into water vapour in the atmosphere. Water vapour is also sent into the atmosphere by plants through transpiration. Winds transport the water vapour around before it falls as rain, snow, hail, and other forms of precipitation.



◀ CLOUD FORMATION

Clouds form when warm air containing water vapour rises, cools, and the vapour condenses to form millions of small water droplets. As these droplets collide, they form larger drops, which become too heavy for the air to support. These droplets may fall to Earth as rain or, if it is cold enough, as snow, sleet, or hail.



▶ TOO LITTLE WATER

Droughts are long periods with no rain or far lower than average rainfall. As a result, an imbalance occurs in water supplies, with reservoirs and wells drying up and crops failing. Droughts cause soils to harden, crack into lumps, and crumble into dust that may be blown away. This great loss of soil can leave regions in crisis even when rain returns.




▶ WETLANDS

Areas of land that are saturated with water, where still or slow-moving water is present, are called wetlands. This water forms marshes, lagoons, swamps, and bogs. Wetlands, such as the Okavango Delta in Botswana, form very rich habitats. Fed by annual floodwaters, the Okavango can swell to cover an area of up to 15,000 square km (6,000 square miles).



▼ TOO MUCH WATER

Many floods occur regularly and predictably. Some, such as the flooding of the Nile River in Egypt, can be very useful as the floodwaters deposit rich, fertile sediment that is good for crop growing, while much of the water is stored for irrigation. Unexpected flooding, however, can be devastating. It can destroy towns, crops, and animal habitats.



The Okavango is the world's largest inland delta

Floodwaters swamp the town of Fenton, Missouri, USA

WEATHER

Air in the atmosphere is always on the move, carrying clouds, rain, and snow around the globe. The weather is generated by air currents that circulate through the atmosphere, driven by the heat of the Sun. These currents carry areas of cold and warmer air at different pressures. Weather describes the day-to-day state of the atmosphere over an area. A region's climate is the general weather conditions it experiences over a long period of time.

1 Snow Water droplets can freeze into ice crystals in clouds. These collide with each other, sticking together to form snowflakes. Most melt on the way to the ground and fall as rain. If the air close to the ground is cold enough, some will fall as snow. Snowfall can be light or severe. Thompson Pass in Alaska, USA, once received 160 cm (63 in) of snowfall in a day.

2 Humidity This is a measure of the amount of moisture (water vapour) in the air. In general, the hotter the air, the more moisture it can hold. Humid conditions mean that sweat from bodies cannot evaporate so quickly. This is why a very humid day can feel hotter and more uncomfortable than a dry day with the same temperature.

4 Fog When water vapour clouds form at or near ground level and reduce visibility at ground level to less than 1 km (0.6 miles), they are known as fog. It can be a safety issue for road traffic, aircraft, and shipping. In areas with significant air pollution from coal burning and vehicle emissions, smoke can react with fog to form photochemical smog containing substances that are harmful to health.

3 Hailstones These are pieces of ice that form inside storm clouds. Hail forms when ice crystals descend through a cloud, picking up a layer of moisture on their outer surface. Strong air currents sweep them back up through the cloud, where this moisture freezes to add a new layer of ice. Successive cycles create large hailstones containing many layers, which then fall to Earth. A hailstone recovered in Aurora, Nebraska, USA, in 2003 had a diameter of 18 cm (7 in) and weighed 680 g (1.5 lbs).

1

2

3

4



Golf ball-sized hailstone that fell in Texas, USA

5 Wind Differences in temperature and air pressure cause the streams of moving air that we feel as wind. Different parts of the world receive different amounts of the Sun's heat. Colder air from the poles tends to sink and move towards the equator close to the surface of Earth. Warm air from the equator rises and moves towards the poles high in the atmosphere because it is less dense.

Updraughts (upward-rising air currents) in storm clouds can travel at more than 130 km/h (80 mph)



Air surrounding lightning can reach temperatures of 20,000°C (36,000°F).

Weather maps show the positions of the fronts of warm and cold air masses as red and blue lines

6 Lightning When a huge electrical discharge is released from the atmosphere during a storm, we see a flash of lightning. Colliding ice crystals in storm clouds build up positive and negative electrical charges. As these charged particles move to equal themselves out, they can cause a giant spark of lightning. Thunder is created by hot air around lightning expanding rapidly and violently.

7 Storms Cumulonimbus storm clouds have their base close to the ground but extend upwards into the atmosphere more than 12 km (7.5 miles). Storms are disturbances in the atmosphere often caused where warm and cold air masses meet. Winds build in speed and moisture falls as rain, snow, or hail. A 2005 storm over the city of Mumbai, India, brought 944 mm (37 in) of rainfall in a single day.

8 Hurricanes Also known as typhoons or cyclones, hurricanes develop over tropical oceans. They are giant storms often measuring more than 600 km (400 miles) in diameter and with winds circulating at speeds up to 300 km/h (200 mph) around a relatively calm centre called the eye. Hurricanes can cause immense destruction. Hurricane Felix struck Central America in 2007, causing more than 130 deaths.

9 Weather map Meteorologists, or weather experts, map existing weather patterns and forecast future weather. Weather balloons, weather stations dotted around the globe, and satellites send data to powerful computers to track conditions in the atmosphere, the strengths of winds, and the build-up of storms. However, forecasts can often be inaccurate as weather conditions can change suddenly.



NATURAL RESOURCES

The Earth provides humankind with a wide range of resources. A river, for example, provides not only drinking and cleaning water, but also potentially rich food sources and a transport system for boats and shipping. Similarly, forests offer shelter, foods, fuel, medicine, and valuable raw materials for construction, paper, and other industries. However, these resources have to be used carefully. Overuse can deplete stocks and reduce the supply of a resource, while careless use of methods and chemicals can damage the environment or even destroy a resource completely.



1 Farming About 10,000 years ago, humans learnt how to cultivate wild plants and rear animals to supply food. Today, farming is an enormous industry. In 2009 alone, 682 million tonnes of wheat was produced worldwide. However, farming requires an enormous amount of land and this needs to be cleared of forests, grasslands, and other native environments.

5 Mining and ores Mining can be performed deep underground or in an open pit on the surface. Mines are dug to obtain coal, gemstones, metals, and minerals, such as feldspar and potash. Many of the most useful metals on the planet, including iron, aluminium, and copper, are found in the Earth's crust in rocky ores. These have to be processed to extract the metal from the ore.

2 Riches from the sea Commercial fishing employs more than 35 million people worldwide. Its catch, ranging from tiny crustaceans to tuna weighing more than 200 kg (440 lbs), provides foods that are rich in protein and nutrients. Overfishing in certain areas, however, has seen a drastic reduction in fish stocks. This has led to many governments introducing limits on how much fish can be caught.

6 Fossil fuels Natural gas, coal, and oil are all fossil fuels. These are the remains of dead organisms that have changed into energy sources. Power stations that burn fossil fuels produce 60 per cent of our electricity. However, fossil fuels are a limited resource and humans are having to go to more extreme lengths to find new sources. These include deep beneath the oceans or under the polar ice caps.

3 Forestry Millions of tonnes of wood are cut down every year for use in the timber industry. Apart from timber, the world's forests are rich in other resources, including medicinal plants and foods. In industry today, a range of substances is extracted from wood. These include cellulose used in textiles and paints, and other chemicals used as fragrances and food flavourings.

7 Hydroelectric power This is a form of renewable energy that has been used to power watermills and waterwheels for centuries. Today, it is used to turn turbines to produce electricity. Around one-fifth of the world's electricity is produced this way. Hydroelectric dams, such as the Hoover Dam, create huge lakes behind them. These lakes can flood entire towns or areas of environmental importance.

4 Rocky raw materials Many rocks and minerals are used in a whole range of industries from cosmetics (clays) to food preparation (rock salt). Limestone and granite are quarried as building stone or, in the case of limestone, crushed to make types of cement. Among sand's many uses is the manufacture of glass, while clay and shale are used to make bricks and ceramics.

8 Sun, wind, and sea Renewable energies also include wind power, solar power, and wave and tidal power. Wind turbines, for example, generate turning movements to power electricity generating turbines. Around two per cent of the world's electricity is generated by windpower, but in some countries, the amount is far higher – 20 per cent in Denmark and 14 per cent in Spain.

HUMAN IMPACT

Polluted water runs into wetlands, destroying habitats and life

In 1900, the estimated world human population was around 1.6 billion. Just 100 years later, it had increased more than four times, passing 6.9 billion in 2010. This phenomenal boom in the number of people has put the planet under increasing strain as a rapidly growing human population demands food, clothing, land, shelter, electricity, and other resources. Poor management of resources and the generation of large amounts of air, water, and land pollution threaten the environment and wildlife.

▼ AIR POLLUTION

Every day, millions of tonnes of pollutants, including carbon monoxide, carbon dioxide, sulphur dioxide, and tiny solid particles, are pumped into the atmosphere. The main culprits are motor vehicles, industrial emissions, and power stations that burn fossil fuels, such as coal and oil.

▶ ACID RAIN

Sulphur dioxide, nitrogen oxides, and other pollutants from factories, coal-fired power stations, and vehicle emissions can enter the atmosphere and mix with water vapour. Blown some distance from where they were released, these pollutants fall back to Earth in acid rain. This can kill trees, dissolve and wash away nutrients and minerals in the soil, destroy life in lakes and rivers, and erode stone.

Tree damaged by acid rain in the US state of North Carolina

WATER POLLUTION ▲

Water is one of the most fundamental resources for life and it is abundant over the planet as a whole. Yet more than 800 million people lack a clean water supply and have to drink unsafe water that carries deadly diseases. Human and animal sewage flushed into streams and rivers without being treated damages clean water supplies. Further pollution of seas, oceans, lakes, and rivers comes from industry, chemical and oil spills, and where rain washes pesticides and fertilizers off farmland into rivers and streams.

▼ WASTE DISPOSAL

Vast amounts of waste are generated every day. In 2008, the United States alone produced more than 250 million tonnes of waste. Much of this waste is burned in incinerators, releasing further air pollution, buried in landfill sites, or left to decay in open mounds. Water run-off from landfill can carry poisonous substances that pollute water sources above and below ground.

A pile of logs stacked up in a forest clearing

◀ DEFORESTATION

At least a third of the world's rainforests have disappeared in the past century. The trees have been cut for timber or fuel, or the land cleared for farmland or settlements.

This deforestation has destroyed incredibly rich habitats, threatening many plant and animal species with extinction and reducing the planet's ability to absorb carbon dioxide through the leaves of trees.

▼ DESERTIFICATION

Deforestation, soil erosion, overgrazing, and climate change are all factors in the increasing amount of land turning into dust bowls unsuitable for cultivation. Desertification is a widespread problem in Africa, Central and Latin America, Central Asia, and China. Every year some 12 million hectares (30 million acres) of land, an area larger than the country of Portugal, become too desert-like to grow crops.

▼ CLIMATE CHANGE

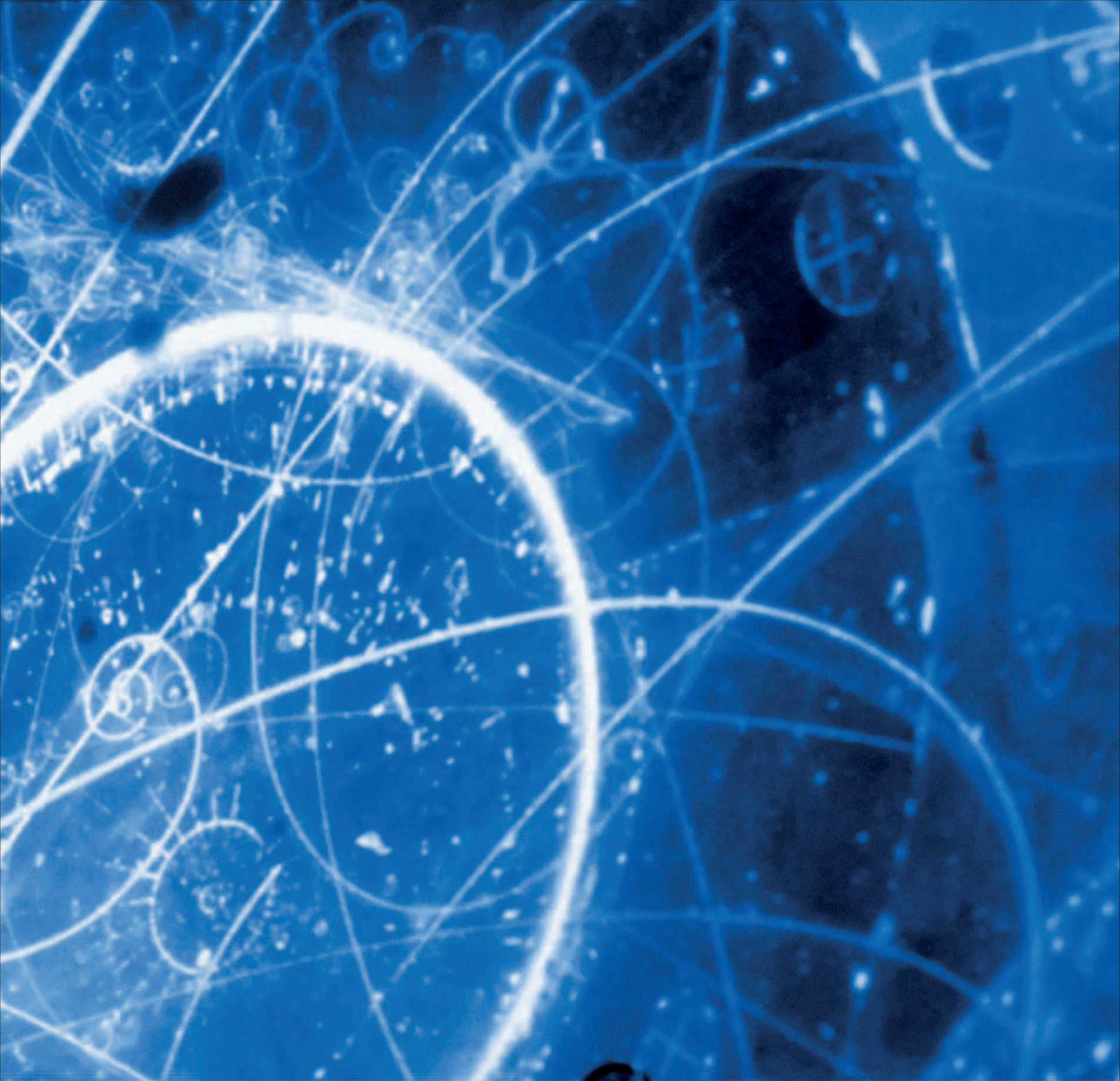
Earth's atmosphere has always contained carbon dioxide, methane, and other "greenhouse" gases that trap heat and warm the planet's surface. In recent years, however, it is believed that an increase in greenhouse gases in the atmosphere, caused by human activity, is leading to a general increase in world temperatures. Climate change could lead to rising sea levels, melting ice caps, changing weather patterns, and the extinction of many species.

Coral bleaching caused by rising sea water temperatures



SUBATOMIC PARTICLES

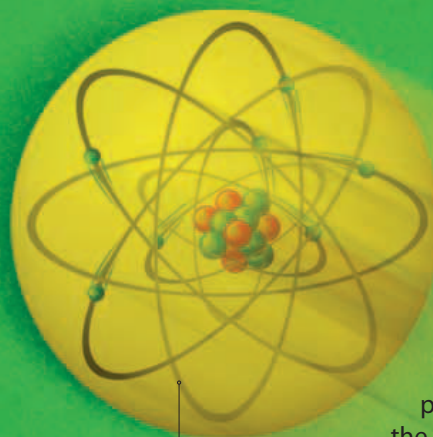
A detector screen at the Fermi National Accelerator Laboratory in Chicago captures the trails made by electrons and other particles created in a single nano-second (one billionth of a second).



Matter and materials

BUILDING BLOCKS

All matter, from our bodies and the air we breathe to the ink, paper, and cover that make up this book, consists of atoms. An atom, from the ancient Greek word for indivisible, is the smallest amount of a substance that can exist and retain the properties of that substance. Each different type of atom is called an element, and more than 100 exist. A typical atom has a radius of just one tenth of a billionth of a metre.



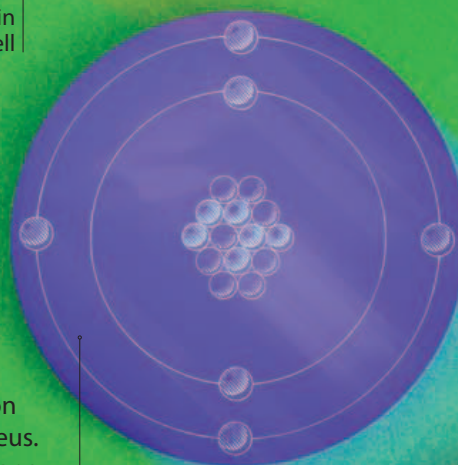
Electron orbit in outer shell

◀ ATOMIC STRUCTURE

An atom is mostly empty space. At its centre is a nucleus made up of particles with a positive electric charge called protons and electrically neutral neutrons. Orbiting the nucleus are electrons – atomic particles with a negative electrical charge. The pull between the charges of the electrons and protons sees the electrons orbit the nucleus arranged in different layers, or shells. An atom of nitrogen (see left) has a nucleus with seven protons and seven neutrons. Seven electrons orbit the nucleus in two shells.

ISOTOPES ▶

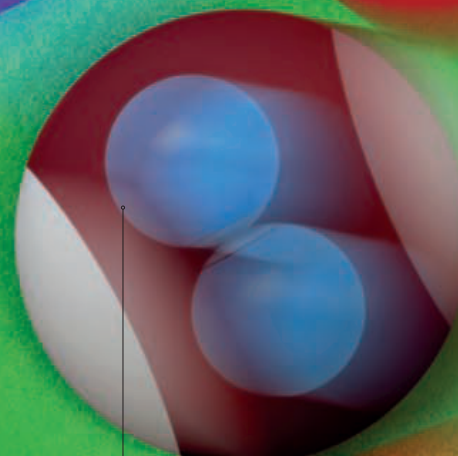
In some cases, atoms of the same element can have different numbers of neutrons in their nucleus. Each of the possible versions of an element is known as an isotope. In its most common form, hydrogen is the one element with no neutrons in its nucleus. Two isotopes of hydrogen exist, however – deuterium, with one neutron, and tritium, with two. The most common form of carbon has six neutrons but the isotope carbon 14 has eight neutrons.



Carbon 14 has equal numbers of protons and electrons (six), but eight neutrons

MOLECULES – OXYGEN ▶

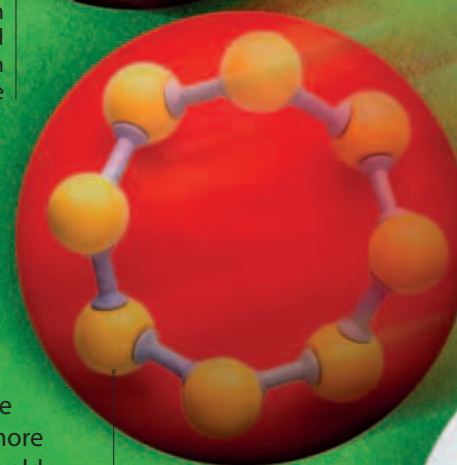
It is relatively rare for atoms to be found on their own. They tend to combine with other atoms, either of the same type or of other elements to form a molecule. A molecule has chemical bonds between its atoms and can be shown by a chemical formula – a combination of letters and numbers that show the types of atoms and their proportion in a molecule. Oxygen has the chemical symbol O, but oxygen molecules are diatomic – they contain two atoms. So an oxygen molecule's chemical formula is O₂.



Oxygen atom chemically bonded to another to form oxygen molecule

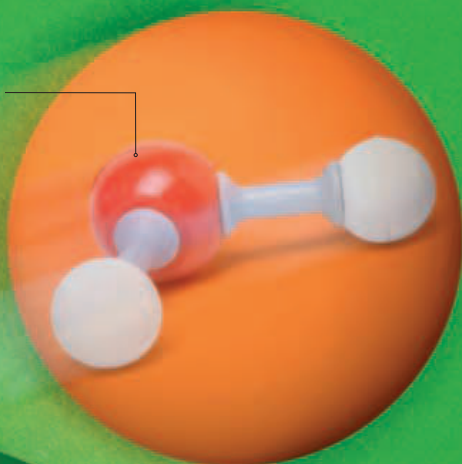
MOLECULES – SULPHUR ▶

Eight sulphur atoms bond in a ring to form a molecule of this yellow solid. Sulphur reacts with many other elements to form a wide range of compounds (combination of two or more elements). It reacts with all metals except gold and platinum. There are some 30 different isotopes of sulphur, only a few of which are stable and do not react easily with other substances. Sulphur is used in the process of making substances such as fertilizers, gunpowder, and many medical drugs.



Sulphur (S₈) molecule made of eight sulphur atoms

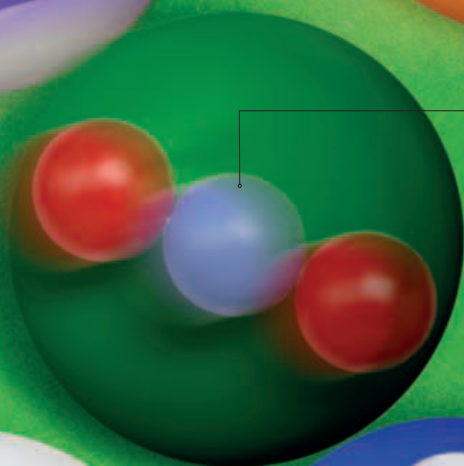
Oxygen atom in water molecule



◀ MOLECULES – WATER

Ancient philosophers thought of water as one of the four or five fundamental elements that made up the Universe. Today, we know that water is itself composed of two different elements. Two atoms of hydrogen combine with one atom of oxygen to form a molecule of water (H_2O). Water can be split back into its constituent elements by the process of electrolysis.

Carbon atom in a carbon dioxide molecule

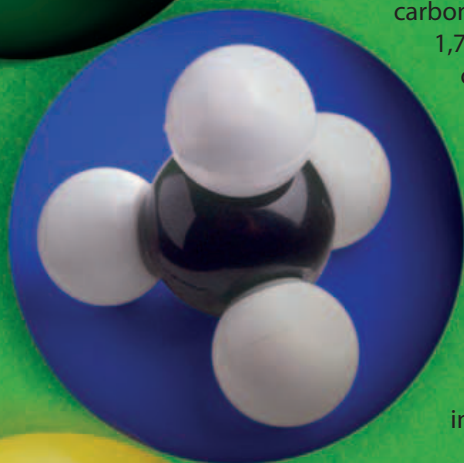


◀ MOLECULES – CARBON DIOXIDE

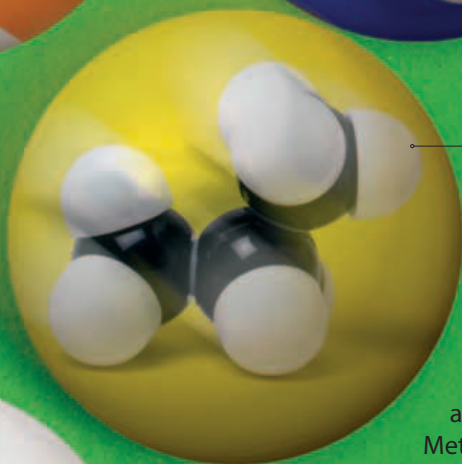
Carbon dioxide (CO_2) is found in the atmosphere as a gas and is used by plants during the process of photosynthesis (see pages 10–11). It consists of one carbon atom that is joined to two oxygen atoms by double covalent bonds. This means that each oxygen atom shares two pairs of electrons with the carbon atom. When heated to temperatures above $1,700^\circ C$ ($3,000^\circ F$), it splits into oxygen and carbon monoxide (CO).

◀ MOLECULES – METHANE

Methane has the chemical formula CH_4 and has the molecular structure of four hydrogen atoms all joined to one carbon atom. Methane is colourless and odourless and is a major constituent of natural gas found in reserves on Earth. It is also common in the atmospheres of the planets Neptune, Jupiter, Uranus, and Saturn. Recent increases in the levels of methane gas in the atmosphere may be a significant cause of global warming.



Propane's chemical formula is C_3H_8



◀ MOLECULES – PROPANE

Substances whose molecules consist only of hydrogen and carbon atoms are known as hydrocarbons.

Methane and propane are hydrocarbons.

Propane is a colourless gas that can be readily turned into a liquid for transportation and storage. It is separated in large quantities from natural gas, crude oil, and oil refinery gases. It is used as a fuel and is also an important raw material in the chemicals industry.

▼ SPLITTING ATOMS

Atomic science has developed techniques for nuclear fission – splitting the nuclei of certain atoms to generate enormous amounts of power. This can be used for destructive purposes in bombs or to generate superheated steam in nuclear power stations to drive turbines to generate electricity. In a nuclear power station, neutrons bombard uranium-235 atoms, splitting nuclei and releasing more neutrons. These start a chain reaction by splitting more nuclei and releasing yet more neutrons.



A detonated atomic bomb produces a giant mushroom cloud in the atmosphere

THE PERIODIC TABLE

Elements consist of one type of atom. They are pure substances and they cannot be broken down into simpler substances. For example, water contains both hydrogen (H) and oxygen (O) atoms, so it is not an element, but hydrogen is. Each element has a different atomic number – the number of protons in the atom's nucleus. Ninety of the first 92 elements by atomic number occur naturally. Hydrogen is the lightest and most abundant element in the Universe and it has the atomic number one.

1 PERIODIC TABLE

Based on the work of Russian scientist, Dmitri Mendeleev (1834–1907), the periodic table is a list of all elements. The elements are arranged in columns called groups and horizontal rows called periods. Each element to the right of another in the same period has an extra electron in its atoms. Elements in the same group tend to share similar chemical properties.

2 ALKALI METALS

The first group in the periodic table includes lithium, potassium, and the most abundant alkali metal, sodium. They are so named as they react with water, forming alkaline solutions as a result. In the case of caesium (Cs) and rubidium (Rb), their reaction with water is an explosive one. Alkali metals are soft, white-coloured, and rarely found in their pure form in nature.

21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co
39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh
	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir
	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu
89 Ac	90 Pa	91 Pa	92 U	93 Np	94 Pu	95 Am

3 ALKALINE-EARTH METALS

Calcium, magnesium, barium, and radium (Ra) are all alkaline-earth metals, found in compounds in Earth's crust. Beryllium (Be), for example, is found in gemstones, such as beryl and emeralds. Alkaline-earth metals react with water, albeit less intensely than alkali metals, and with oxygen. Magnesium burns a bright white in air and is used for flares and fireworks.

Lithium (Li)



2

Sodium (Na)



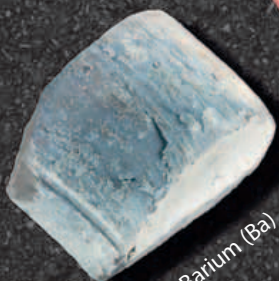
Potassium (K)



Calcium (Ca)



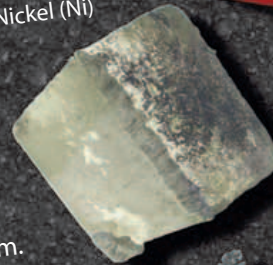
Barium (Ba)



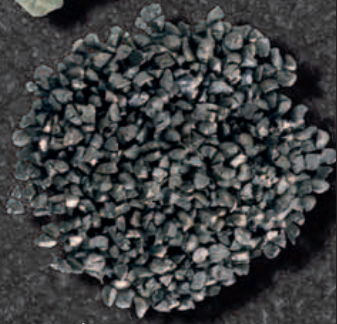
Magnesium (Mg)



Nickel (Ni)



Iron (Fe)



4 TRANSITION METALS

This large group of elements includes some of the most common metals, such as copper and chromium. They include elements that can create a magnetic field, such as nickel and iron, and the most dense naturally occurring element, osmium (Os). While mercury (Hg) is a liquid at room temperature, transition metals tend to have high melting points. They also tend to be hard and their outer electrons are capable of flowing, making them good conductors of heat and electricity.



Copper (Cu)



Chromium (Cr)

						2 He		
	5 B	6 C	7 N	8 O	9 F	10 Ne		
	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar		
28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn

6 NOBLE GASES

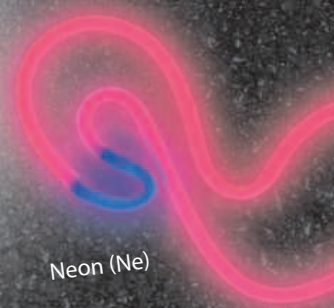
These gases are colourless and odourless and largely unreactive, but that does not mean they lack useful applications. Helium is the second lightest gas after hydrogen, but does not burn, making it safe for use in deep-sea diving and airships. With the exception of helium, all noble gases emit light if electricity is passed through them and so are used for lighting.



Helium (He)



Argon (Ar)



Neon (Ne)

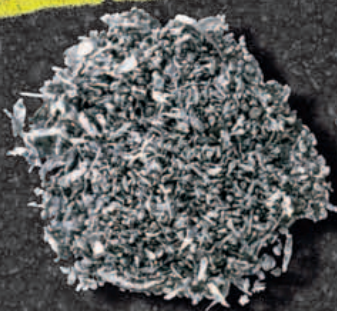
7 NON-METALS

Non-metals include common gases in the atmosphere, such as nitrogen and oxygen, as well as sulphur (S) and carbon. Non-metals tend to be poor conductors of heat and electricity and are brittle when solid. Halogens, such as chlorine (Cl), are a type of non-metal that form salts with other elements.

64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

8 POOR AND SEMI-METALS

Lead, tin, aluminium, and bismuth (Bi) are all poor metals. These are softer and have lower melting points than transition metals. Most poor metals are at their most useful when mixed with another metal in an alloy such as bronze (an alloy of copper and tin). Semi-metals, such as arsenic (As), antimony (Sb), boron (B), and silicon (Si), possess some, but not all, properties of metals.



Aluminium (Al)



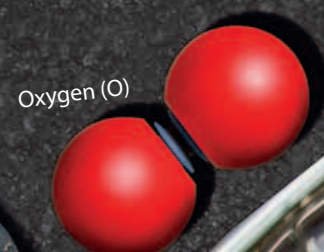
Lead (Pb)



Tin (Sn)



Carbon (C)



Oxygen (O)

Nitrogen (N)



STATES OF MATTER


Matter exists in different physical states – solid, liquid, water, and plasma. A substance or element can change its physical state, but still retains the same chemical make-up. Oxygen, for example, is a gas at room temperature, but can be cooled to form a liquid and it still remains oxygen. Water is unusual as it is found on Earth in three states – solid ice, liquid water, and gaseous water vapour. Solids usually change state into liquids, but frozen carbon dioxide, known as dry ice, can change state directly into a gas. This process is called sublimation.

❶ EVAPORATION

Evaporation is the process by which a liquid changes its state into a gas. The opposite change of state from gas to a liquid is called condensation. Evaporation occurs when some molecules in a liquid have enough energy to escape the liquid's surface as a gas. Liquid water on pavements or in wet clothes evaporates into the atmosphere as water vapour. Liquids evaporate more quickly as they heat up, such as when water is boiled in a kettle.

❷ LIQUIDS

Molecules in a liquid are very close, but can slip over each other to change position. Liquids have a definite volume, but no definite shape. They can be pushed along a pipe, but they cannot be compressed to occupy less space. Liquids can flow and take on the shape of the container they occupy. Viscosity is a measure of how easily a liquid flows. Liquids with a high viscosity, such as thick syrups and shampoos, flow less freely.



Boiled in a kettle,
water changes state
and rises as steam

Fruit juice has
low viscosity and
flows freely

3 SOLIDS

Atoms and molecules are packed tightly together in solids, sometimes in a regular lattice. The particles in a solid still move but their movement is a small vibration. As a result, solids have a definite shape from a long, thin piece of copper wire to a round china saucer or square shaped piece of toast. Solids also have a defined volume and occupy a definite space.

4 GASES

The molecules in a gas are far apart and can move freely and rapidly. As a result, gases can expand to fill a container and have a low density. Gases do not have a fixed shape or volume so they can be compressed, reducing the space between their particles. Most gases are invisible. Steam rising from a hot cup of coffee is only visible as it starts to condense and forms a mist of water droplets.

5 MELTING

Matter melts when it changes state from a solid to a liquid. Increased temperature can cause the particles in a solid to vibrate more and more quickly. Eventually, they are able to slip over each other and form a liquid. The temperature this happens at is called the melting point. The metal tungsten has an extremely high melting point of approximately 3,420°C (6,190°F).

6 FREEZING

Freezing occurs when substances change from liquids to solids, such as solid ice forming from liquid water or liquid wax running down a candle and hardening into solid wax. Different substances have different freezing points, the point below which they will turn from a liquid to a solid. Pure water has a freezing point of 0°C (32°F), while mercury's freezing point is -38.8°C (-37.8°F).

7 PLASMA

Plasma is the fourth state of matter. It is found throughout the Universe, but rarely on Earth. It is a gas-like state caused when either radiation or extremely high temperatures strip electrons away from atoms. This creates a gaseous cloud of positive ions and negative electrons. Plasma conducts heat and electricity extremely well and is found around stars like the Sun and in the natural light displays in the sky called auroras.

Aurora Borealis lights shine in the night sky of the northern hemisphere

Butter has a low melting point of between 22°C (72°F) and 45°C (113°F) depending on its fat and water content

Solid ice cubes melt slowly in water



PROPERTIES OF MATTER

All materials and substances have a wide range of different characteristics called properties. These describe attributes ranging from appearance – colour, lustre (whether something is shiny or not), and smell – to chemical properties, such as a substance's ability to dissolve in liquids, its acidity, and whether it will combust or not. This information is used in industry and by scientists and engineers to select the right material or substance for a particular task.

► HARDNESS

The property of hardness is a measure of how easy or difficult it is permanently to scratch or shape a substance. Different measurements of hardness are made. One common method is the Mohs scale, which places ten minerals on a scale of softness and hardness and measures how well one substance will resist scratching by another.

◀ MASS AND DENSITY

Density is how heavy something is for its size. It is calculated by dividing the material's mass by its volume. Dense materials, such as lead and brass, are used for weights, while materials with low density, such as wood, float in water. These air-filled plastic foam pellets have very low density and are used to protect electronic goods and other delicate items.

▼ FLEXIBILITY AND ELASTICITY

Some materials are more flexible and able to bend more than others. Elasticity is the ability of a material to absorb force and bend or stretch in different directions, before returning to its original position. Some materials have an elastic limit. If stretched beyond this, they do not return to their original size and shape.



Air-filled foam pellets have less than a tenth of the density of water

Talc is rated one – the softest mineral on the Mohs scale

Diamond can scratch talc, corundum, and all other minerals on the Mohs scale

A rubber band is both flexible and elastic. It can be bent and stretched before returning to its original shape

Corundum is a very hard mineral and can scratch anything except for diamond

◀ CONDUCTING ELECTRICITY

Materials with good electrical conductivity allow an electric current to flow through them easily. Metals are all excellent conductors. Copper, especially, is used in electrical wiring. Glass, ceramics, and plastics are poor conductors of electricity. They are used as insulators, preventing electricity flow where it is not wanted, such as isolating a pylon carrying high-voltage electricity from a power station to homes.

Ceramic discs insulate pylons from the electricity-carrying cables

This red-hot iron bar would have to be handled with thick gloves

▲ THERMAL CONDUCTIVITY

Heat moves through materials at differing rates depending on the material and how thermally conductive it is. If a metal spoon is placed in a cup of water that is heated from below, the spoon handle quickly becomes hot. This is because both water and most metals are excellent conductors of heat. Materials that are poor thermal conductors, like glass and plastics, are usually excellent insulators and resist the flow of heat through them.

▼ FLAMMABILITY

Flammability describes how easily a material ignites (catches fire) and then combusts (burns). Some materials are highly flammable and burn readily, producing heat. Nearly all motor vehicles rely on liquid gasoline's flammability to burn inside engine cylinders to drive pistons. A material that does not burn is said to be non-flammable.

▶ SOLUBILITY

Some materials are soluble and can dissolve in water or other liquids to form a solution. Water is sometimes called the universal solvent as many substances can dissolve in water. A carbonated soft drink consists of soluble sweeteners, flavourings, and carbon dioxide to give the drink its fizz, all dissolved in water.

Gold is very malleable and can be beaten into thin sheets called gold leaf

▲ PLASTICITY

Plasticity is the ability of a material to be shaped or deformed permanently. There are different forms of plasticity including ductility, the ability of a material to be drawn into thin wires, and malleability, whether a material can be beaten into thin sheets.



CHEMICAL REACTIONS

A chemical reaction occurs when the bonds between atoms and molecules in substances are broken and then reformed into different chemical substances. The original substances are called reactants and the results of the reaction are called products. Where a substance contains two or more elements, it is called a compound. Chemical reactions can be sudden, such as in an explosion, or can take place over many years, such as the tarnishing of silver in contact with air.

1 REDOX REACTIONS

These involve both oxidation and reduction reactions. Oxidation occurs when substances combine with oxygen or lose hydrogen. At the same time, other substances are undergoing a reduction reaction, losing oxygen or gaining hydrogen. Metal corrosion is a redox reaction. Corrosion sees metals lose their shine and their structure may break down, such as when rust eats through metal.

2 REVERSIBLE REACTIONS

Most reactions only go one way. They are irreversible, as the reactants are used up to form new products. In a small number of reactions, though, some of the reactants remain and the reaction can reverse. Molecules of ammonia gas and hydrogen chloride gas are formed when solid ammonium chloride is heated. Some of these gases immediately react with each other to form ammonium chloride again.

3 DISPLACEMENT REACTIONS

Some reactions see one element replace another in a compound (a substance where two or more elements have combined chemically). The more reactive element displaces the less reactive element. Galvanizing is a method of rustproofing iron or steel objects, such as a dustbin. A thin layer of zinc coats the iron or steel object. If the iron is exposed and iron oxide rust threatens, the zinc will displace the iron, forming zinc oxide.

4 EXOTHERMIC REACTIONS

Reactions that give off energy to their surroundings, usually in the form of heat, are called exothermic reactions. Neutralization reactions between acids and alkalis give off energy, as do combustion reactions. These are a type of rapid oxidation reaction where fuel combines with oxygen, generating heat and, sometimes, light energy. The burning of hydrocarbons, such as oil or coal, are combustion reactions that provide us with the energy to power our cars and homes.

Red iron oxides (rust) form when iron reacts with water and oxygen in air

1

Ammonia molecule contains one nitrogen and three hydrogen atoms

2

3

5 ENDOTHERMIC REACTIONS

During some reactions, more energy is needed to break molecular bonds than is released when new bonds are made. These reactions take in energy, usually in the form of heat, from their surroundings. This leaves the surrounding area cooler as a result. An ice pack used to treat a sprain or bruising contains water and ammonium chloride. When the pack is activated, the barrier between the two substances is broken and the substances mix and react, drawing in heat and making the pack ice-cold.

Bunsen burner combusts methane, producing carbon dioxide and water

6 RATE OF REACTION

The speed of chemical reactions can change depending on factors such as temperature, the size of the particles, or the amount of light. Most reaction rates increase if the temperature is higher, as the particles move more rapidly. Solids tend to react more quickly if they are broken up into smaller pieces as the pieces then have a greater total surface area than when they were a single piece. This fork is made of a biodegradable plastic derived from corn. It decays in just 45 days compared to the many years regular plastics can take to decay.

7 CATALYSTS

A catalyst is a substance that is used to alter the rate of a chemical reaction. Some catalysts, known as inhibitors, slow the rate of a reaction. They are used to prevent bread going stale or rust occurring inside iron radiators. Most catalysts speed up the rate of reaction. Platinum, palladium, and rhodium in a car's catalytic converter react with the toxic emissions from a petrol engine to convert nitrous oxides and carbon monoxide into carbon dioxide and harmless nitrogen and oxygen.



MIXTURES AND COMPOUNDS

Mixtures are physical combinations of substances, such as soil, muddy water, or ink. The atoms, molecules, or particles of the different substances are mingled thoroughly with each other, but have not chemically bonded to form different substances. Compounds are also made up of several different atoms. However, they are made from two or more elements that have chemically reacted with each other and are held together by chemical bonds.

1 COMPOUNDS

The elements found in a compound are usually in fixed proportion to each other, so a beaker of water (below) contains molecules that each have two hydrogen atoms and one oxygen atom. Compounds cannot be separated by physical means.

It takes a chemical reaction to break the bonds between its molecules. Compounds often possess quite different properties from their constituent elements.

Sodium chloride is white, granular common salt, but it is made up of a silvery metal, sodium, and a gas, chlorine.

2 POLYMERS

Polymers are compounds that form long repeating chains of molecules. Some polymers exist in nature, such as hair fibres, DNA, and cellulose (shown below), which forms the walls of plant cells. Others are synthetic polymers, such as polyvinyl chloride (PVC) and nylon. A single polythene molecule consists of just two elements, carbon and hydrogen, but may contain up to 200,000 carbon atoms.

4 SOLID SOLUTIONS

A solid solution is formed when atoms of one substance are distributed throughout those of another. Metal alloys can be solid solutions with the various metals melted and then allowed to solidify. Duralumin is a solid solution formed of 90 per cent aluminium with copper, manganese, and magnesium. It is used in the aerospace industry because it is lightweight and very strong.

3 MIXING IT UP

Solutions are uniform mixtures, where two or more substances are mixed together evenly. The substance present in the greatest amount is known as the solvent. Other substances, called solutes, dissolve into the solvent. Air is a gaseous solution of oxygen and other gases dissolved in nitrogen. Most solutions are gases or solids dissolved in a liquid. A standard saline drip (right) contains a solution of 0.9 per cent sodium chloride dissolved in sterile water. It is given to hospital patients to prevent dehydration.



5 SEPARATING MIXTURES

Many techniques have been developed to separate mixtures. Iron filings can be separated from sand by running a magnet over the mixture. This attracts the iron away from non-magnetic sand. A centrifuge spins test tubes of material at high speed. Centrifuging relies on substances in a mixture possessing different densities. This causes different densities of liquid to separate into layers.

Centrifuge rotor spins, throwing the most dense substances to the bottom of the tubes

6 DISTILLATION AND CHROMATOGRAPHY

When a liquid mixture is heated, the liquid with a lower boiling point becomes a vapour and can be hived off, leaving the other liquid behind. This is called distillation and it is used, for instance, to separate alcohol from water. Paper chromatography is used to separate mixtures of coloured compounds, such as dyes or inks. Molecules in these substances have different properties and, when a solvent is applied, they travel at different speeds along paper, separating out.

The different substances show up as bands of different colours

7 EVAPORATION

Evaporation is the process through which a liquid changes its state to a gas or vapour. It can be used to remove liquid from a solution, usually leaving behind a solid. The water in copper sulphate solution can be evaporated away to leave behind copper sulphate crystals. Cooking salt is produced in many warm regions by trapping seawater in large shallow pools. The water evaporates, leaving behind the salt, which is raked together into large mounds.

Salt pile from evaporated seawater. A litre of seawater contains around 30 g (1 oz) of salt.



ACIDS, BASES, AND SALTS

Acids and bases are chemical opposites, but they are closely related. Acids are substances that produce positively charged particles of hydrogen, called hydrogen ions (H^+) when dissolved in water. Bases are substances that can accept these hydrogen ions as they produce an excess of negatively charged particles called hydroxide ions (OH^-) in water. A base that is soluble in water is known as an alkali. Acids and bases are highly reactive with one another. They can be combined to produce many useful substances in the food, chemical, and metal industries.

1 Indicators Different indicators can be used to measure how acidic or basic a substance is. Litmus paper turns red if it comes in contact with an acid and blue if it encounters an alkaline substance. A popular homemade indicator is red cabbage juice, which contains a substance called flavin. A strong base will turn the liquid greenish-yellow, while a strong acid will turn the liquid red.

2 Acids – sulphuric acid Sulphuric acid (H_2SO_4) is highly corrosive – capable of eating through metals. It is used as a drying agent to chemically remove water from many substances and is one of the most widely produced industrial chemicals in the world. This is because of its large number of uses, helping to produce fertilizers, dyes, drugs, paints, and dozens of other chemical products.

3 Acids – vinegar The word acid comes from the Latin word *acidus*, meaning sour or sharp. Most acids, such as vinegar (shown here), yoghurt, and lemon juice, have a strong, sour taste. Table vinegar is mostly water, but gets its sour taste from about 4–8 per cent of its volume being acetic acid.

4 pH scale pH stands for “power of hydrogen” and is a numbered scale running from close to zero (extremely acidic) to 14 (very heavily basic). It is a measure of the concentration of hydrogen ions in a substance. Pure water has a pH value of seven, which is neutral – it is neither an acid nor a base. Each whole pH number on the scale is ten times more acidic or basic than the previous number.

5 Bases and fats Bases tend to feel slippery and react with fats, such as butter, breaking them down so that they can be more easily washed away. As a result, bases are often used in strong household cleaners. For example, sodium hydroxide ($NaOH$), also known as caustic soda, is a powerful base used in the paper industry and is often the main active ingredient in drain unblockers and cleaners.



Butter can be broken down by bases

Acetic acid in vinegar is derived from ethanol

Lemon juice contains 4–7 per cent citric acid and has a pH of between two and three

Hazard label for corrosive substances

Pure water has a pH level of seven

6 Acids – citric acid The sharp, tangy taste in some processed foods and soft drinks is due to the presence of a small amount of citric acid. Found naturally in citrus fruits, such as oranges, lemons, and limes, citric acid is used in the food industry and in many bathroom and kitchen cleaners. It is also found in water softeners that enable soaps to lather better.

7 Saponification Reactions between certain acids and bases can result in the formation of soaps – a salt that comes from a fatty acid. This process is called saponification. Certain acidic substances, such as animal fats or olive oil (shown here), come from fatty acids. These can be hydrolysed (broken down) by a strong base, such as sodium hydroxide to form hard soaps or potassium hydroxide to form soft soaps.

8 Batteries Both acids and bases can conduct electricity. The stronger the acid or the base, the better it conducts electricity. Both acids and bases are used widely in making batteries. One of the key substances inside an alkaline battery is the base, potassium hydroxide (KOH). Alkaline batteries tend to offer longer life than zinc chloride batteries of the same size.

9 Salts – mercury sulphide Mercury sulphide (HgS) is a salt composed of mercury and sulphur. It is found in nature in two forms, as a coarse, black powder called black mercuric sulphide, or as a fine, bright-scarlet powder called red mercuric sulphide. The latter is used mainly as a colouring in art, where it is known as vermilion.

10 Salts – potassium permanganate Potassium permanganate (KMnO_4) is a salt that dissolves in water to create intense purple-coloured solutions. It is also soluble in sulphuric acid. It has a wide range of applications, including use in water treatment, as a disinfectant, a fungicide, and as an industrial cleaner and bleacher.

11 Salts – copper sulphate Some acids and bases can react with each other to cancel out their acidic and basic properties – a reaction called neutralization. A neutralization reaction tends to produce a salt and water. An insoluble metal oxide can react with an acid to form a soluble salt. Sulphuric acid, for example, can react with copper(II) oxide to produce copper(II) sulphate with its distinctive blue colour.

12 Bases – sodium bicarbonate A mild base with a pH of around eight, sodium bicarbonate (NaHCO_3) is used in cooking where it reacts with acidic substances such as cocoa, yoghurt, lemon juice, and buttermilk to generate carbon dioxide, which helps make dough rise. It is also found in many indigestion tablets to neutralize excess acid in the stomach.



MATERIALS SCIENCE

Humans have been working with materials for thousands of years, learning how to push them to their limits. Early civilizations discovered how to work clays into ceramics, make glass, and melt and work certain metals, such as iron, silver, tin, and copper. Modern scientists continue to develop more efficient methods of production or new uses for old materials, as well as producing new materials with useful properties and applications.

► PROCESSING NATURAL MATERIALS

Many materials extracted from nature are in forms that require processing before use. For example, crude oil is heated in giant fractional distillation columns. Inside the columns, the crude oil separates into substances with different boiling points. These substances are called fractions. The fractions with the lowest boiling points, such as petroleum, rise to the top of the column, while those with higher boiling points, such as lubricating oil and bitumen, remain near the bottom.

More than 80 per cent of all petroleum produced is used as fuel

► BITUMEN

Bitumen is the heaviest fraction of crude oil produced by fractional distillation. It is a thick oily substance with a boiling point of more than 525°C (977°F), and is used in many different waterproofing materials, including roofing felt. Bitumen asphalt is used in road surfacing where it is rolled to form a smooth, hardwearing surface.

◀ PETROLEUM

When crude oil is processed using fractional distillation, one of the lightest fractions produced – petroleum – is also the most highly sought after. This liquid is consumed as a fuel for motor vehicles, but it has many other uses. It is also used to make detergents and many plastics. In the United States, 18,686,000 barrels – each barrel containing 159 litres (35 gallons) – of petroleum was consumed in 2009 every day.

▲ METAL ALLOYS

A metal alloy is a mixture of two or more metals, or a metal and other substances. Carbon is mixed with iron to form the world's most commonly used metal alloy, steel. Alloys have different properties from the original materials. Aluminium, for instance, is light in weight but relatively soft. It can be made harder by alloying it with other metals, such as copper.

▼ PLASTICS

Plastics produced from fractions of oil are one of the most common and versatile groups of materials. Most plastics will not react with other substances, making them useful as containers for potentially reactive liquids. Plastics can be produced that are light, waterproof, and good electrical and heat insulators.

They can be formed into almost any shape, from thin sheet layers to complicated parts.



▼ GLASSMAKING

Glass consists of silica from sand along with soda ash, limestone, and other substances. These are heated in a furnace during the manufacturing process. Glass can be shaped in many ways. It can be poured into moulds, rolled into large, flat sheets, or blown into shape. Small amounts of other materials can be added to give glass different properties. When boron is added, it makes glass ovenproof, while the addition of lead can make glass more transparent.

Glass blowers shape the red-hot glass by blowing through a long tube

▼ MIXING IT UP

Composites combine the useful properties of two or more materials into one material. Tiny carbon fibres are set into polymers, such as epoxy, polyester, and nylon. This creates materials that are extremely strong, but also lightweight. They are used extensively in the aerospace industry. The Model 281 Proteus is a high-altitude research aircraft built almost entirely of strong but light composite materials.

Carbon nanotubes can measure less than 1/50,000th the width of a human hair

The Proteus has a wingspan of 22 m (73 ft) but weighs just 2,676 kg (5,887 lbs)

NANOTECHNOLOGY ▲

This involves producing and working with materials measured in nanometres, where a nanometre equals one billionth of a metre. Scientists have managed to produce graphene – a layer of densely packed carbon atoms bonded together to form a sheet just one atom thick. Graphene can be rolled to form nanotubes.

These are very strong materials that may have wide future applications in electronics and microscopic nanomachines.

Cutlery made from stainless steel, a steel alloy with chromium and nickel added

► SHAPE MEMORY ALLOYS

Advanced materials engineering has created metal alloys that remember their original shape after they have been bent, deformed, or stretched by heat. Shape Memory Alloys (SMAs) have many applications. For instance, more than half of all vascular stents (artificial tubes used in medicine to keep blood flowing through a blood vessel) are made from the SMA Nitinol.

◀ RECYCLING

Collecting and reprocessing discarded materials to make new products and materials is called recycling. Aluminium drinks cans, old glass bottles, and paper are commonly recycled. Every year, millions of worn-out car tyres are discarded. Many are recycled by being shredded to produce a rubber crumb material. This can be used to produce shoe soles or playground surfaces.



IN A SPIN

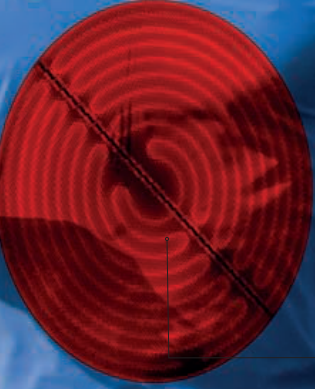
A rollercoaster transports thrill-seekers on a stomach-churning ride through multiple loops and spins. Different forces act on the carriages and riders as they race along the twisting and turning track.



Energy and forces



1



Cooker ring converts electrical energy into heat and light energy

2



A tennis racket's strings, stretched by the ball, have potential energy

3



1 CHANGING FORMS

These road runners are converting the chemical potential energy from food into kinetic energy (see below) as they run. Their movement also generates heat and sound energy. Many devices utilize electrical energy. This can be converted into kinetic energy in an air fan, light in a lamp, or sound in a door bell.

ENERGY

Energy is the ability to perform work. All living things need energy to survive and prosper. They obtain energy from food, which they digest and convert into substances that power their activity. Energy cannot be destroyed. It can, however, be transferred from one object to another, such as when a kicking foot transfers energy to a ball and moves it, or changed from one form of energy to another, such as when the physical movement of a strummed guitar string generates sound energy.

2 KINETIC ENERGY

The energy something has because it is moving is known as kinetic energy. A stunt motorcyclist flying through the air has kinetic energy. The kinetic energy of an object depends on its speed and its mass. The greater an object's mass or the faster it moves, the more kinetic energy it has.

3 POTENTIAL ENERGY

Energy stored as a result of an object's chemistry, position, or state is potential energy. An object that is squashed, such as a spring, has potential energy. So does a tennis ball hit into the air. Its position above the ground, which required energy to achieve, gives it gravitational potential energy. As the ball falls, its potential energy changes back into kinetic energy.



4

4 ELASTIC ENERGY

Elastic energy is potential energy stored in a compressed, stretched, or bent object. A pole vaulter in the middle of a vault grips a long flexible pole. It is almost bent double due to its absorption of some of the athlete's kinetic energy from the run down the runway. As the pole straightens, its stored energy is released as kinetic energy, propelling the athlete upwards and over the bar.

5

Burning coal releases chemical energy originally created by prehistoric plants

6

Powerful fusion reactions occur in the Sun's core

7

An atomic bomb releases the same amount of energy as millions of tonnes of high explosive

5 CHEMICAL ENERGY

Much energy is stored in substances that can only release their energy as a result of a chemical reaction. Examples include the metabolism of foods eaten by living things, the combustion of wood to generate heat and light, and the reaction of the chemicals in a battery to produce electrical energy.

6 FUSION

Nuclear fusion is the joining together of the nuclei of atoms, which releases vast amounts of energy. It is how the Sun generates its energy. Research into nuclear fusion reactors promises a renewable form of energy where 1 kg (2.2 lbs) of hydrogen isotope fuel would generate the same amount of energy as 10 million kg (22 million lbs) of fossil fuels.

7 FISSION


Splitting the nuclei of atoms apart, a process called nuclear fission, can release enormous amounts of energy. This has been used both as a devastating weapon and as a method of electricity generation. In a nuclear power station, the nuclei of uranium-235 atoms are split to produce energy that drives electricity generators.

FORCES


From an apple falling to the ground to a car rolling to a halt, forces are constantly at work around us. Forces are pushes and pulls that act on an object. They can cause it to move or stop, speed up or slow down, or to change shape. Forces can be small and act locally or cause effects over vast distances, such as Earth's gravitational pull, which holds the Moon in its orbit at a distance of 384,400 km (238,900 miles).

▼ FRICTION

When two things rub together, they create a force that opposes their movement. This is called friction. It occurs because no surfaces are perfectly uniform and smooth. This means that surfaces catch on each other. Friction allows shoes and bicycle tyres to grip and push off the ground when moving. It also slows moving things down, can cause objects in contact to wear, and generates heat.



Friction of brake blocks pressed onto wheel rim slows bike wheel down




The Moon is 3,476 km (2,173 miles) in diameter and has much less mass than Earth

▲ GRAVITATIONAL PULL

The force of attraction between two objects is called gravity. When the objects have little mass, there is no noticeable effect, but when one object has great mass, such as Earth, its gravity pulls objects to its surface. Objects dropped from a height accelerate at the same speed towards Earth – 9.8 m (32.7 ft) per second per second – regardless of their mass. To lift an object, you must apply more force than the gravitational pull.

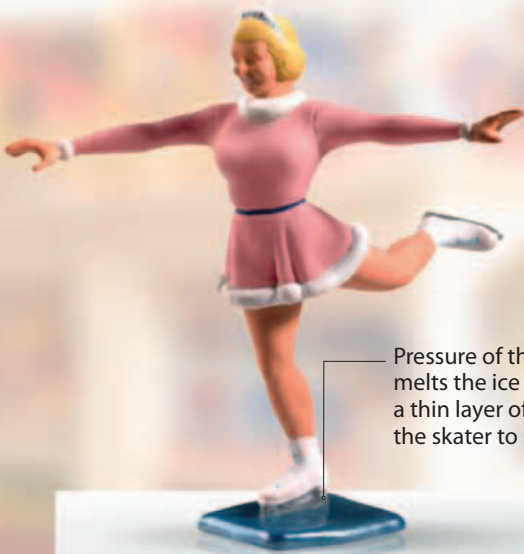
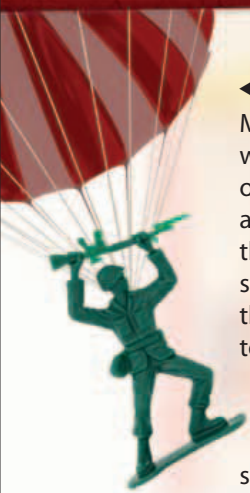
OVERCOMING FRICTION ▼

Friction can be reduced in several ways, including covering two moving surfaces with a thin layer of oil or powder – a process called lubrication. Rolling movement also reduces friction. A marble moves easily because a round surface constantly lifts off a flat surface so that less of their surface areas rub against each other.



◀ COMBINED FORCES

More than one force is often at work on a moving object at any one time. When two forces pull an object in opposite directions, the resultant force is found by subtracting the smaller force from the larger. A parachutist is pulled towards the ground by the force of gravity. As he travels through the air, his parachute creates large amounts of air resistance that slows his descent to the ground.



Pressure of the skate melts the ice creating a thin layer of water for the skater to slide on

▲ FEEL THE SQUEEZE

Pressure describes force applied over a particular area. The amount of pressure generated depends on both the size of the force and the size of the area. A force acting over a small area will have a higher pressure than the same force acting over a larger area. The force of an ice skater's body weight is applied over the small area of the skate blade, which cuts into the ice.



Helicopter rotor blades generate lift as they sweep through the air

▲ BALANCED FORCES

When you sit down on a chair, the force of your bodyweight is counteracted by the force of the chair pushing upwards. The forces are balanced and you are said to be in equilibrium. Forces that are balanced cause no change in an object's speed or direction. A helicopter can hover in mid-air by balancing the forces of lift generated by its rotor blades with the force of gravity pulling it downwards.



▼ AIR RESISTANCE

Also known as drag, air resistance is the pushing of air against a moving object. Air and the object rub together, slowing the object down or making it use more energy to reach a certain speed. The faster an object moves, the greater the air resistance it encounters. Fast vehicles such as sports cars and jet aircraft are designed to be streamlined, so reducing drag.

Pointed nose helps to channel air around vehicle



MOTION

Motion or movement is a change in location or position of an object over time. When an object moves, one or more forces are at work. Forces are measured in newtons (N), named after the British physicist Sir Isaac Newton (1642–1727). He formulated three laws of motion, which helped to explain the principles of momentum, inertia, and how for every action there is an equal and opposite reaction.



1 SPEED AND VELOCITY

The average speed for a sports car is determined by the distance it travels divided by the time taken. So, if the car completed a lap of 2.4 km (1.5 miles) in one minute, its average speed would be 144 km/h (90 mph). Velocity is a measure of speed in a particular direction. It changes if either the speed or direction of movement alters.

2 ACCELERATION

As a car increases its straight-line speed and pulls away from a vehicle behind, it is said to accelerate. Acceleration is a change in velocity over time. Acceleration can be either an increase or decrease. Negative acceleration is sometimes called deceleration.

3 INERTIA

Objects tend to move at the same speed and direction or, if at rest, stay at rest. A force has to be applied to overcome this inertia. A cyclist at a standstill must pedal hard to overcome the inertia that he and his bicycle possess. An object's inertia is determined by its mass. A supertanker has more inertia than a single-seat dinghy because it has greater mass and so will require greater force to get it moving.

4 MOMENTUM

When forces are balanced, a moving object keeps moving until another force stops it. The object is said to have momentum, which is measured as the velocity of an object multiplied by its mass. A soccer ball's momentum can be halted abruptly by a goalkeeper's hands exerting force to stop the ball.



5 EQUAL AND OPPOSITE REACTION

Newton's third law of motion states that when one force acts on a body, there must be an opposite action of equal force occurring. This is known as the reaction force. The jet engines on an airliner produce a powerful stream of hot gases flowing backwards. These produce a reaction force of thrust that propels the airliner forwards.

6 TURNING FORCES

A pivot is a point, such as the hinges of a door, around which turning motion occurs. A turning force (also called a moment) is measured as the amount of force multiplied by the force's distance from the pivot point. The further from the pivot the force is applied, the greater the turning force at the pivot. This is why a wrench spanner is able to undo a tight nut and bolt with ease.



SIMPLE MACHINES

Simple machines are devices with a single part or a handful of parts that make it easier to perform work. Some simple machines, such as a pair of tweezers, allow people to be more precise when applying a force. Many simple machines enable people to apply a force greater than their muscles can generate on their own. For example, a pole or tree branch can be used as a simple machine called a lever to move a heavy rock.

❶ INCLINED PLANES

An inclined plane, or ramp, is a simple machine consisting of a sloping surface. Like this builder's ramp up into a skip, inclined planes are often used to help carry heavy loads. They can reduce the force required to raise an object by increasing the distance it travels. Some inclined planes, such as waterslides, work by allowing people and other objects to descend safely with less force than a vertical drop.

❷ WHEELS

One of humankind's greatest inventions, the wheel has enabled many forms of land transport and machinery to flourish. A wheel turns around a shaft called an axle. When an axle is turned, the wheel turns with it. As the wheel is much larger, it covers a greater distance than the axle. When the reverse is true, such as with a screwdriver, where the handle is the axle, the blade moves less distance than the axle, but with greater force.

Load carried in wheelbarrow's hopper



Axle of the chainwheel is turned round by pedals

❸ GEARS

Gears are toothed or grooved wheels that transmit a force from one place to another, or change the size or direction of a turning force. A bicycle chain allows the force of the turning chainwheel gear to be transmitted to a rear wheel gear.

A smaller rear wheel gear in relation to the chainwheel turns more times than the chainwheel, but requires more force to turn it, so is used for high speeds.



Jib acts as lever to raise and lower loads

5

5 PULLEYS

A pulley is a wheel on an axle around which runs a rope, cable, cord, or wire. A single pulley working on its own alters the direction of movement, such as when a rope running over a pulley is pulled down to lift up an object to which the rope is tied. Multiple pulleys work together to increase the distance the rope or chain has to travel, reducing the amount of force required to lift a load.

Hoist mechanism contains pulleys to increase the load that can be lifted by a crane

Fulcrum of seesaw is placed in the centre, about which either end turns

7 COMPLEX MACHINES

Compound or complex machines are collections of simple machines all working together. The wheelbarrow, for example, is a lever and a wheel and axle. A tower crane (left) combines pulleys and the long lever of its horizontal arm, or jib, to lift large loads. The hoist is wound up and down by a motor that features gears, while a large, wheel-like turntable at the base allows the crane to turn to its left and right.

4

4 LEVERS – WHEELBARROW

A lever is a bar, rod, or pole that turns about a point, called the fulcrum or pivot, to move a load. The positions of the effort, load, and fulcrum of the lever vary and give rise to three groups of levers, called classes. A wheelbarrow is an example of a class-two lever because the load (of bricks) sits between the effort (lifting the handles of the barrow) and the fulcrum (the wheel).

6

6 LEVERS – SEESAW

A seesaw is a class-one lever as the fulcrum lies between the load and the effort. A seesaw is unusual in that the load and effort are approximately the same distance away from the fulcrum, allowing the children to move up and down using their weight as effort. Most class-one levers, such as scissors, magnify force by moving the point of effort a greater distance away from the fulcrum than the load.

8

Load is lifted by a shovel using left hand as pivot

8 LEVERS – SHOVEL

This builder is using a shovel as a class-three lever. His right hand and arm are lifting a load on the shovel's blade. The shovel pivots around the handle held with his left hand. A class-three lever has the effort close to the load and on the same side of the fulcrum as the load. Your lower arms are class-three levers as the effort is provided by your biceps, the load is your hand, and the fulcrum is your elbow joint.

ELECTROMAGNETIC SPECTRUM

The colours you can see make up the visible light spectrum. Visible light, though, is just one of a number of forms of energy that travel in waves at a speed of 300,000 km (186,000 miles) per second.

This is the speed of light. These differing forms of energy, from radio waves to gamma rays, are together called the electromagnetic spectrum.

All, bar visible light, are invisible to the naked eye, but their effects can be observed and studied. Some carry more energy than others, and the different wavelengths of energy exhibit different properties. They all have been harnessed and put to work in a variety of applications.

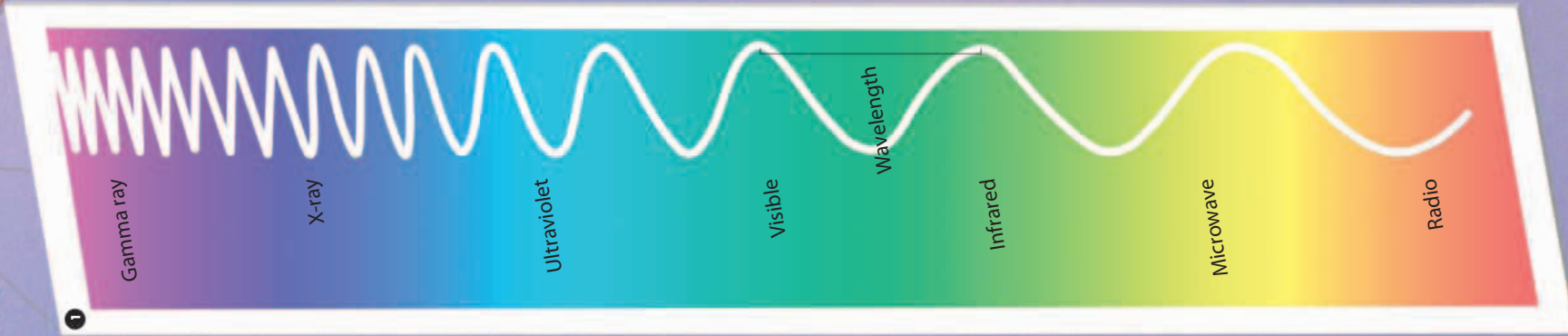
1 WAVELENGTH

Each type of wave in the electromagnetic spectrum has its own wavelength. This is the distance between two identical parts of a wave, such as two peaks or two troughs. Wavelengths range from many metres for long radio waves down to one billionth of a metre for gamma rays. Frequency is the rate at which waves pass a given point. Visible light frequencies range from 430 trillion waves per second for the colour red up to 750 trillion waves per second for violet.

2 GAMMA RAYS

Created through the radioactive decay of atoms, gamma waves have the shortest wavelength of all electromagnetic waves, often smaller than single atoms, and possess extremely high energy. Harmful to humans in large quantities, their controlled use is deployed to sterilize medical instruments and to attack cancers. Scanners using gamma rays can see through metals to check for cracks and faults in aircraft bodies or to search metal cargo containers for stowaways and security risks.

Gamma rays are used in this security scan of a truck at a border crossing



A 16th-century painting X-rayed by art restorers yields clues to how it was produced

3 X-RAYS

Since they were first discovered by accident in a laboratory experiment by German scientist, Wilhelm Conrad Röntgen (1845–1923), X-rays have been investigated and used heavily in medicine. X-rays can penetrate flesh but are absorbed by more dense substances such as bone, teeth, and metals. They allow images of the inside the body to be taken for diagnosis. X-rays are used to examine pipelines for defective joints and to discover paintings hidden under other artworks.

4 ULTRAVIOLET

With a wavelength just shorter than the visible light spectrum, ultraviolet (UV) rays have various uses. When UV rays fall on certain substances, the substances fluoresce, or emit visible light. UV watermarks on these bank notes (right) help prevent forgery, while police and forensics teams use ultraviolet lighting to detect small amounts of blood.

5 INFRARED RAYS

Between visible light and microwaves on the spectrum exists infrared radiation. It is given off by all warm things, from stars to the heat lamps used to treat sports injuries. Infrared photography builds up a heat picture and is used to detect defects in electronics. Infrared with wavelengths close to red in the spectrum give off little heat and are used in many short-range remote controls.

6 RADIO WAVES

This model buggy is remote-controlled using radio waves to send and receive signals. Radio waves have the longest wavelength in the spectrum from about 10 cm (4 in) up to hundreds of metres or longer. They are used for a wide range of wireless communication, including TV, radio, and Wi-Fi wireless computer networking.

7 VISIBLE LIGHT

The visible light spectrum consists of electromagnetic waves that human beings can see. A rainbow, caused by sunlight striking moisture in the air at certain angles, depicts all the colours of visible light. Each colour has a different wavelength with red possessing the longest and violet the shortest. When all the waves are seen together, they make white light.

8 MICROWAVES

Very short radio waves called microwaves are used for a wide range of communication uses, from sending and receiving global positioning system (GPS) signals to transmitting radar. Hands-free receivers (left) use microwaves to enable wireless mobile phone communication. A microwave oven bombards food with rays. This makes the water molecules in the food vibrate, generating heat that cooks the food from the inside out.

Hands-free earpiece receives microwaves from a mobile phone



SOUND

When you hit a drum, you generate energy waves that vibrate and travel away from the source of the sound, gradually losing their force as they ripple outwards. A sound needs a source to generate it, and a medium – a substance that carries sound. It also needs a receiver, such as the human ear, to detect the sound. Sounds above the level of human hearing are called ultrasound. This is used in medicine, for example, where ultrasound scanners provide diagnostic images of the body's internal organs.



A humpback whale's song can travel more than 100 km (60 miles) through water.



A Space Shuttle lift-off generates a sound level of 180 decibels.

▲ SPEED OF SOUND

The speed at which sound travels varies and depends on the density of the medium. At sea level, sound travels through air at a speed of 340 m/s (1,115 ft/s). This speed drops to 300 m/s (980 ft/s) at an altitude of 10,000 m (33,000 ft), where air is less dense. In a dense medium, such as the closely packed molecules of water, sound travels faster – at about 1,500 m/s (3,800 ft/s).

▲ AMPLITUDE

The measure of a sound's intensity – how much energy it has – is called amplitude. The more energy a sound wave has, the greater the peaks in its wave, and the louder the sound will seem. The decibel scale is used to describe the loudness of sounds, from a quiet whisper of about 30 decibels to a jackhammer digging up roads at about 115 decibels. Each rise of 10 decibels on the scale means the sound is ten times louder.

▼ FREQUENCY AND PITCH

A sound's frequency is measured in hertz (Hz) – the number of vibrations the sound makes in one second. The greater the frequency of a sound, the more vibrations it makes per second and the higher the pitch of the sound. Human hearing has a broad range, from low sounds of 20 Hz up to high-pitched sounds of 20,000 Hz (20 kHz). As we get older, our range of hearing decreases. Some animals, such as dogs, can detect sounds higher than 45 kHz, while bats can detect sounds up to 120 kHz.



The hole behind the strings provides an opening to the guitar's soundbox.

▲ GOOD VIBRATIONS

The sound waves from many musical instruments vibrate through a solid material, such as wood, and the air. The strings of an acoustic guitar, for example, create sound waves in the air. The strings do not disturb a great deal of air and so, by themselves, do not create a loud sound. But the vibrations also travel through the guitar's body – the soundbox. This amplifies the sound before it leaves via the soundhole.



◀ REFLECTING AND ABSORBING

Smooth, hard surfaces tend to reflect sound, making the waves change direction. An echo – when a sound is made, then reflected back – has a delay because the sound waves have to travel outwards and back. Echoes are often fainter because only some of the sound waves are reflected – the remainder are absorbed by the material. Certain soft materials, such as foam, are good at absorbing sound waves.

▶ MICROPHONE

A microphone converts sounds into electrical signals. These can then be recorded, processed, or sent to an amplifier to have the sound's amplitude increased before being broadcast. There are various types of microphone. Inside this condenser model, sound waves vibrate a flexible diaphragm. The diaphragm is part of an electrical component called a capacitor. This generates a variable electrical signal depending on the position of the diaphragm.

▼ LOUDSPEAKER

Electrical signals from an instrument or a stereo reach a loudspeaker's metal coil, turning it into an electromagnet that produces a fluctuating magnetic field. This field causes a diaphragm joined to a paper or plastic cone to move back and forth. The vibrating movement creates sound waves that reproduce and amplify the original sounds. A loudspeaker cabinet often contains more than one speaker, with a tweeter to reproduce high sounds and a woofer for low-pitched sounds.

▼ RESONANCE

Most solid objects have a natural frequency or group of frequencies at which they vibrate. This is their resonant frequency. If a sound of the same frequency is made near the object, it can pick up energy from the sound wave and vibrate itself. A crystal wine glass can vibrate at its resonant frequency to the point that the glass bends too far, then cracks and shatters.

Wine glass shatters when a loud sound is equal to its resonant frequency

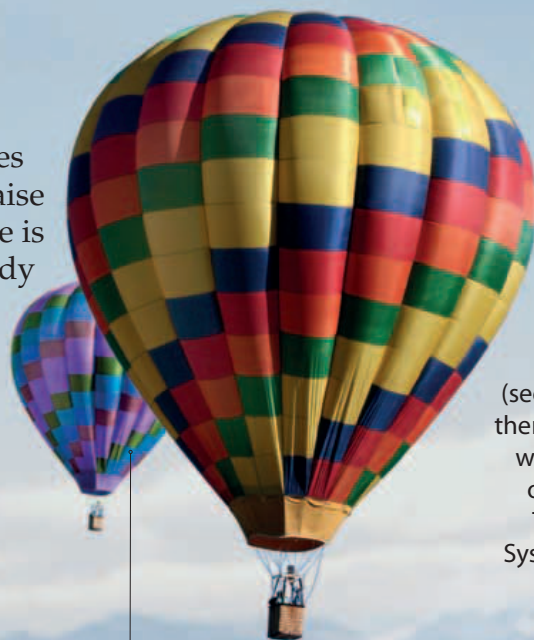


Acoustic foam helps absorb sound waves and is used in recording studios.



HEAT

Heat is a form of energy. It is often measured in calories or joules. A calorie is the amount of heat required to raise the temperature of 1 gram of water by 1°C. One calorie is equal to 4.1855 joules. Heat is transferred from one body to another because of a difference in temperature. Heat tends to move from a warmer area to a colder one. Heat can also alter the state a substance is in. If enough heat is applied to a solid, for example, it begins to melt and change state into a liquid.



▲ RADIATION

Energetic particles travelling in waves transmit energy by radiation (see pages 92–93). Infrared radiation is thermal (heat) radiation transmitted by warm and hot objects. The hotter the object, the more energy it gives out. The hottest object of all in our Solar System, the Sun, warms Earth through vast amounts of infrared radiation.

▲ EXPANDING AND CONTRACTING

Increasing heat can cause substances to expand in volume. Air heated by a hot air balloon burner expands to fill the balloon's envelope. The hot air is less dense than the surrounding cold air. As a result, the hot air rises, carrying the balloon with it. A decrease in heat sees substances contract. Large structures, such as bridges, contain expansion joints to buffer the expansion and contraction of the structure's materials that occur as the temperature changes.

Balloon envelope is filled with hot air so balloon rises

▼ MEASURING HEAT

Temperature is a measurement of how fast the molecules in an object are moving. Thermometers measure temperature. Some rely on liquid mercury in a small reservoir, which expands and rises up a graduated scale when warmer and contracts and drops down the scale when cooler. Others are electronic, using thermistors to measure electrical resistance, which increases with a rise in temperature. Temperature can be described using one of several different temperature scales.



The Celsius scale measures temperature in 100 units between the freezing point (0°C) and boiling point (100°C) of water

120°F on the Fahrenheit scale is equal to 48.89°C



Hang-gliders soar on circulating convection currents of warm air

◀ CONVECTION

Heat can be transferred through the process of convection, where it is carried through a liquid, air, or another gas. If air is heated, its molecules spread out, it lowers in density and, as a result, rises. Cooler air flows in to take its place and will become warmed itself, while the warmer air will lose its heat and begin to sink. This pattern of warming and cooling creates circulating convection currents in the air.

Warm clothes, like this down jacket, trap layers of warm air close to the body, slowing heat loss

◀ INSULATORS

A substance that does not let heat travel through it easily is known as an insulator. In many situations, we want to trap heat and stop or slow its flow. Plastic, rubber, and wood are good insulators and are often used for saucepan handles to stop heat from the pan flowing up to burn the cook's hand. Air is also a good insulator. Animal fur traps warm air close to the creature's skin to keep it warm.

Heat conducts easily and evenly through a metal saucepan to boil water quickly

◀ CONDUCTION

This is the transfer of heat through matter from particle to particle, molecule to molecule. Solids tend to be better conductors than gases as their molecules are more closely packed together. As the molecules nearest the heat source gain energy and increase their vibration, they pass on some of their energy to neighbouring molecules. Metals are very good heat conductors and are used in saucepans, soldering irons, and heating elements in cookers.

LIGHT

Lying between infrared and ultraviolet waves on the electromagnetic spectrum, visible light consists of electromagnetic waves mostly emitted by warm objects such as the Sun or a light bulb. Some chemical reactions, such as combustion, can also generate light. Nothing travels faster than light, which moves in straight lines, spreading out over an increasingly large area, and diminishing in power over distance. Unlike sound waves, light can travel through a vacuum.

▲ LETTING LIGHT THROUGH

Some materials, such as the glass of this window, are transparent. They let almost all light through. Opaque materials, such as wood and metals, are those that do not let light through. Translucent materials, such as some camera lens filters and tissue paper, let some light through, but scatter the waves in all directions.

▼ REFRACTION

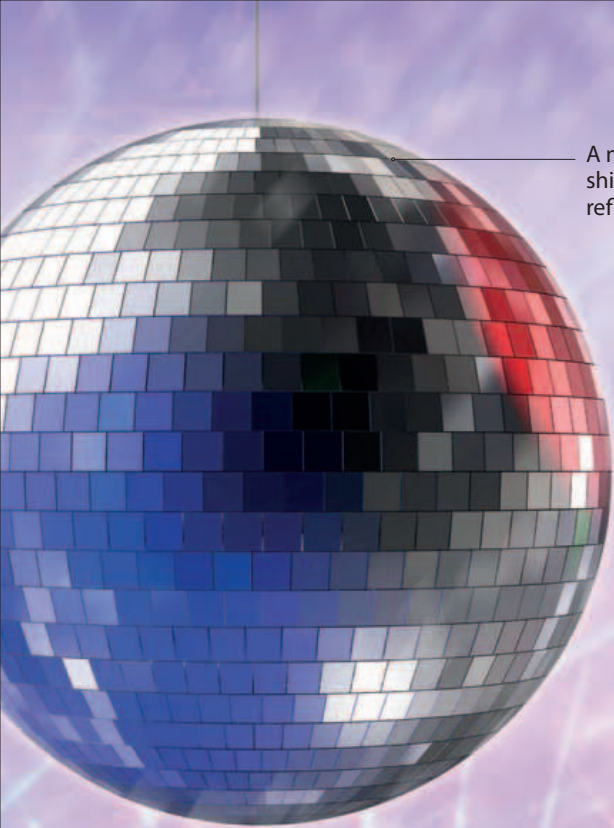
Light travels through different materials, or media, at different speeds. For example, it travels a little more slowly through water and glass than through air. Refraction occurs where light bends as a result of changing speed as it passes from one medium to another. Swimming pools, for example, tend to look more shallow from the side than they really are. The light from the bottom of the pool bends as it leaves the water.

▲ LASERS

When the atoms inside a laser are excited by an energy source, they give off photons (particles of light). All the photons have the same amount of energy, which means that lasers produce a highly concentrated beam of light of just one wavelength. Laser light can travel great distances with little weakening or spreading. Lasers are used in a huge range of applications, from concert lighting to satellite communications.

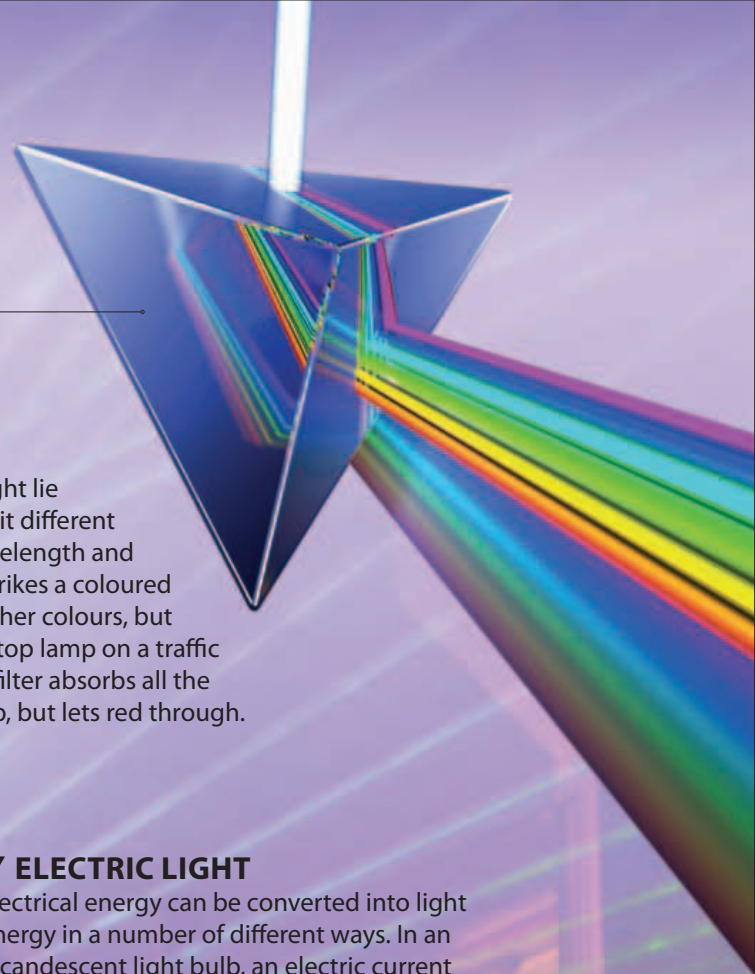
Refraction of the light means that the straw looks bent where it enters the water

Concave spectacle lenses help correct myopia (short-sightedness)



A mirrorball's flat shiny mirrors reflect light

White light passing through a transparent prism separates out into differing colour wavelengths



COLOUR ►

Within the spectrum of visible light lie different wavelengths that exhibit different colours. Red has the longest wavelength and violet the shortest. When light strikes a coloured object, the object absorbs the other colours, but reflects its colour back. The red stop lamp on a traffic light glows red because the red filter absorbs all the other colours from its white lamp, but lets red through.

▲ REFLECTION

When light strikes an object, its rays can be either absorbed or reflected. A solid black object absorbs almost all light, while a shiny, smooth surface, such as a mirror, reflects almost all light back. When reflected off a flat mirror, light bounces off at an angle equal to the angle it struck the object. A rough surface tends to bounce rays off at different angles, scattering the light.

▼ ELECTRIC LIGHT

Electrical energy can be converted into light energy in a number of different ways. In an incandescent light bulb, an electric current passes through a thin filament, often made of tungsten, which is heated and glows, producing light. Incandescent bulbs are gradually being replaced by more reliable and efficient lights including Compact Fluorescent Lamps (CFLs). When electricity passes through the gases in a CFL, they give off ultraviolet light, which causes the lamp's phosphor coating to glow.



◀ LENSES

Transparent, curved, polished surfaces called lenses alter the direction of light waves. A wide range of applications in optics and photography use lenses. Convex lenses have thicker centres than edges. Waves passing through a convex lens converge (come together). Convex lenses are used to magnify images. A concave lens has a thinner centre than its edges, and spreads out, or diverges, light passing through it.

ELECTRICITY

Few forms of energy have a greater impact on our lives than electricity. All materials consist of positive and negative charges. These are normally balanced out in most atoms, leaving the atom electrically neutral. Electricity is made when electrons are free to jump from one atom to another, while the nucleus of the atom remains still. This can occur in lightning, electrical gadgets, and through nerves racing between your eye and brain as you read this.

► CURRENT ELECTRICITY

An electric current is a flow of electric charge. Unless there is a continuous, unbroken loop for electrons to flow through, an electric current cannot be sustained. An electrical switch in a circuit can break or complete a loop, stopping a current or allowing it to travel through a circuit. The number of electrons that pass a given point in an electrical circuit at one time is measured in amperes, or Amps.

► INSULATORS

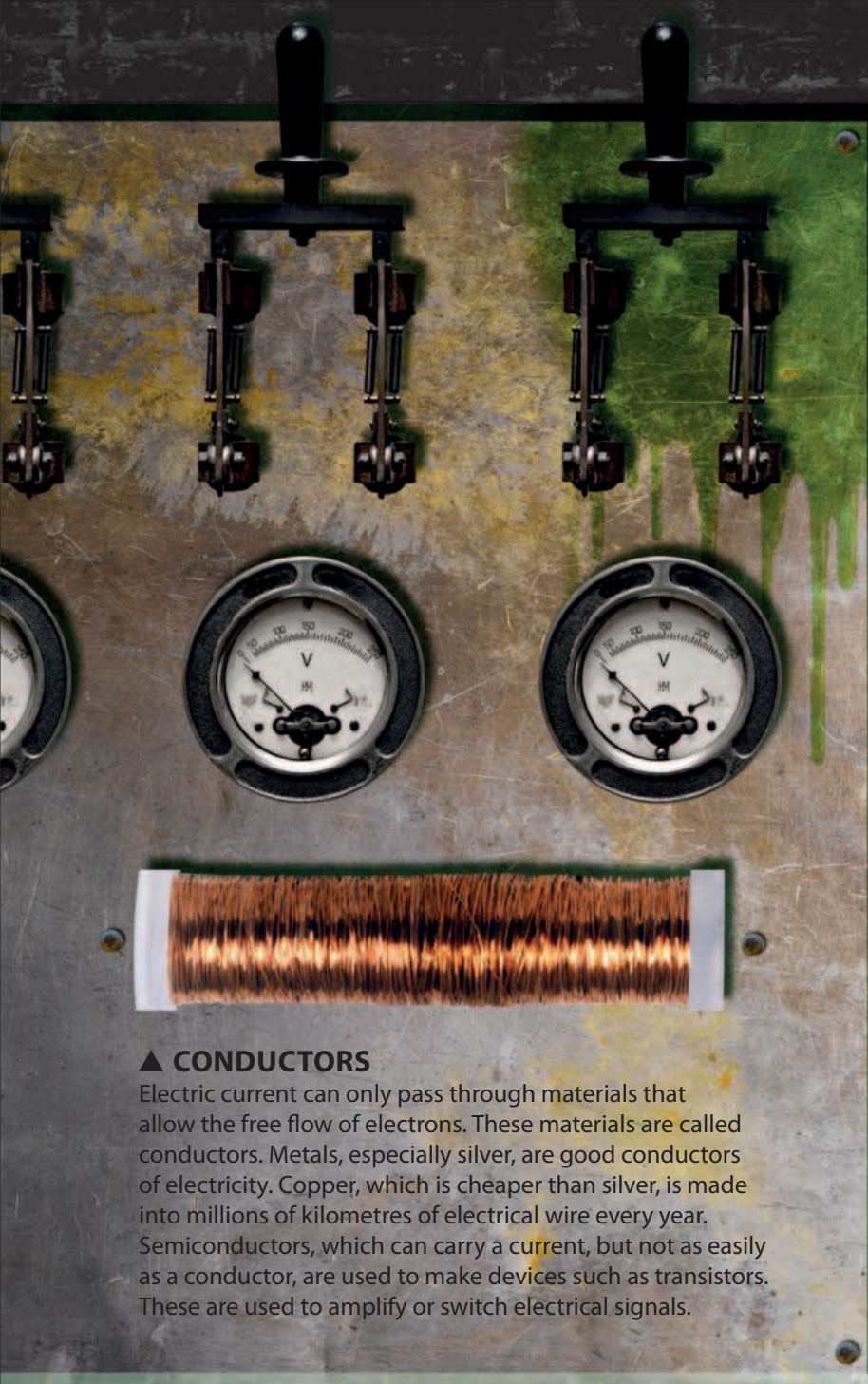
Electrical insulators are the opposite of conductors. Their electrons are tightly bound in their atoms and are not free to roam and flow from one atom to another. Common electrical insulators are glass, rubber, plastic, wood, and ceramics. Plastic coatings cover most electrical wires in appliances, while ceramic and rubber insulation may be used in power lines to protect people from the danger of high voltage electricity.

◀ STATIC

When substances have a surplus of positive or negative charges, they will attempt to stay balanced by attracting one another. If you rub hands on a balloon, for example, a surplus of electrical charges builds up on the surface of the balloon and on your body. The charges remain static (still) until they find a way to escape. If static charge builds up on the surface of your hair, it will stand on end. The hairs all have the same charge, which makes them repel each other.

Static electricity build up causes hairs to stand on end





▲ CONDUCTORS

Electric current can only pass through materials that allow the free flow of electrons. These materials are called conductors. Metals, especially silver, are good conductors of electricity. Copper, which is cheaper than silver, is made into millions of kilometres of electrical wire every year. Semiconductors, which can carry a current, but not as easily as a conductor, are used to make devices such as transistors. These are used to amplify or switch electrical signals.



▼ RESISTANCE

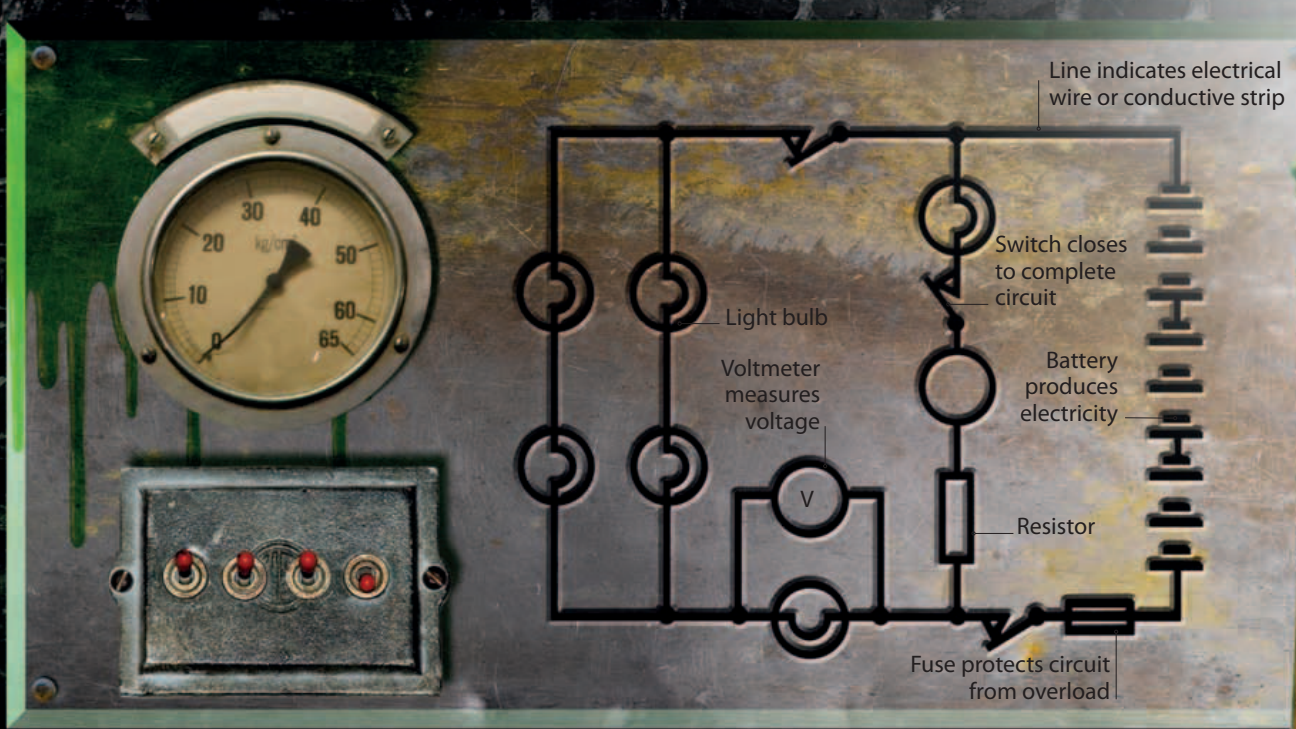
A measure of how much something resists the free flow of electric current is called resistance. Good conductors have low resistance, while insulators have very high resistance. Resistors add a deliberate amount of resistance to an electrical circuit. They can be fixed – set at a particular resistance – or variable. A variable resistor changes the amount of resistance when, for example, a person adjusts a control.

Volume control attached to a variable resistor



▼ CIRCUIT DIAGRAMS

When an electrical power source, such as a battery, is attached to a complete circuit, electrons flow from its negative terminal round the circuit to the battery's positive terminal. An electrical circuit channels or modifies the flow of electricity to perform a task, with some components converting electrical energy to heat, light, sound, or movement.



MAGNETISM

Magnetism is a force that can attract (pull towards) or repel (push away) some materials. Certain elements, such as cobalt, iron, and nickel, are strongly attracted by a magnetic force and are called ferromagnetic. These materials' atoms line up readily in the same direction. Elements that are attracted by magnets can also be turned into magnets. A steel rod stroked repeatedly with a magnet will generate its own magnetic force.

► ELECTROMAGNETS AT WORK

This giant electromagnet fitted to a crane can lift and drop waste metal around a scrapyard at the press of a button. Electromagnets are found in many devices, from magnetic door locks to loudspeakers. Magnetic levitation (maglev) trains use the repelling power of magnets to keep a train hovering about 10 mm (0.4 in) above its track. With no friction between moving parts, maglev trains can move at very high speeds.

Heavy steel girder
lifted high by
electromagnet



► REPEL AND ATTRACT

The two ends of a magnet are called its north and south poles. If a long bar magnet is cut in half, each half becomes a complete magnet, with a north and south pole. When a north and a south pole from two magnets face each other, they are attracted towards each other. When like poles of two magnets are placed close to one another, they repel or push away from each other.

The same poles of two bar magnets repel each other

► MAGNETIC FIELDS

The area of space around a magnet where magnetism is detected is called a magnetic field. The poles are where the magnetic field is at its strongest. The larger and more powerful the magnet, the greater its magnetic field. A wire carrying an electric current generates a magnetic field around the wire.

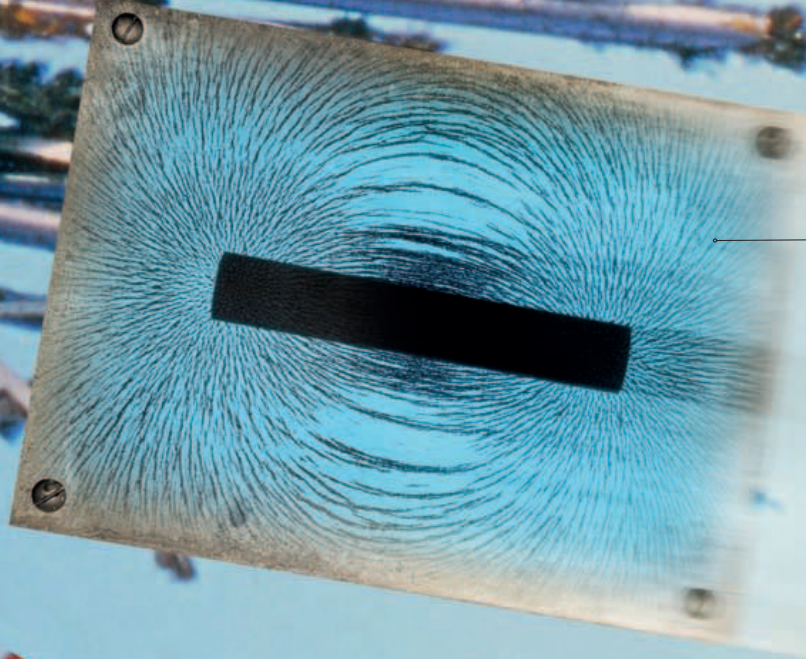
Compass needle points north allowing navigation



◄ MAGNETIC EARTH

Electric currents in Earth's core generate a magnetic field. It is at its strongest at the magnetic North and South poles (which are near to but not at the geographical North and South poles). This magnetic field extends out into space, where it is known as the magnetosphere. A compass uses a magnet on a pivot whose north-seeking pole points to magnetic north.

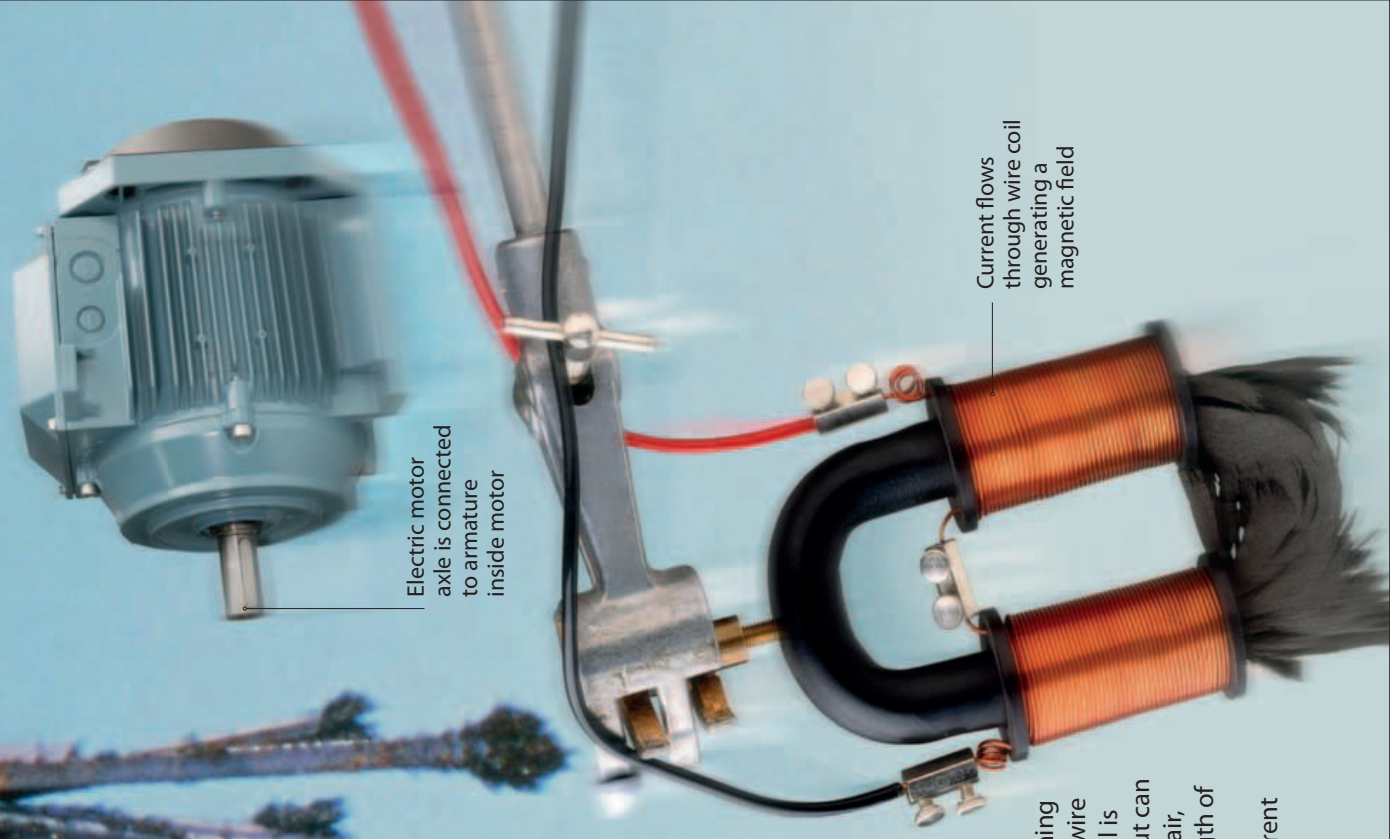
Iron filings show the pattern of a magnetic field around a bar magnet



▼ ELECTRIC MOTORS

Electricity flows through the armature coil of a simple electric motor, turning the armature into an electromagnet with its own north and south poles. These interact with one or more fixed magnets around the inside of the motor's case, called the stator. As the armature repeatedly moves to align its magnetic poles with the other magnets, it rotates, turning the motor's axle.

Electric motor axle is connected to armature inside motor



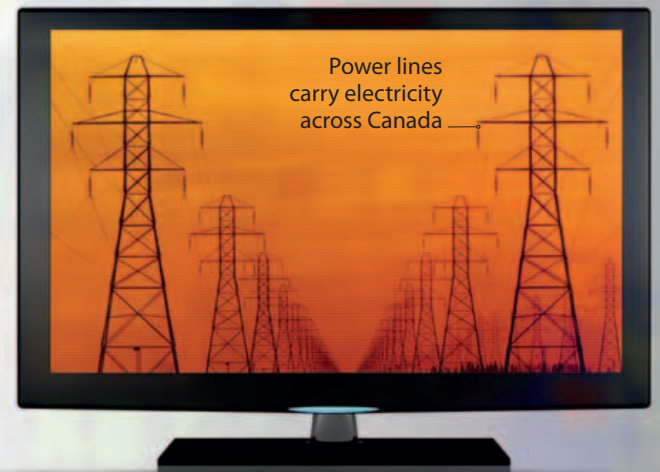
Current flows through wire coil generating a magnetic field

► ELECTROMAGNETISM

An electromagnet is created by running an electric current through a coil of wire to generate a magnetic field. The coil is often wound around an iron core, but can be doughnut-shaped with a core of air, which is called a solenoid. The strength of an electromagnet can be altered by changing the amount of electric current that flows through it.

USING ELECTRICITY

Electricity powers our world. Its great importance stems from its versatility. It can be stored in battery form, sent along wires and cables to where it is needed, and converted into many other forms of energy including heat, light, and physical movement. In addition to powering a huge range of electrical goods, electricity is used in many chemical and industrial processes, including electrolysis, in which a compound is broken down into the elements it is made from.



Power lines carry electricity across Canada

▲ POWER TRANSMISSION

From a power station, electricity is distributed through power lines to local substations and on to individual buildings. Some loss of energy occurs during this transmission, mainly in the form of heat. To minimize energy loss, electricity is carried at extremely high voltage, and this is converted to a lower voltage before it enters our homes.

◀ POWER STATIONS

Electricity is generated in large power stations fuelled in a range of ways. Fossil fuel-fired power stations are the most common type. However, the burning of fossil fuels releases polluting gases into the atmosphere, and other sources of energy, such as solar, wind, and nuclear power, are increasingly being used.



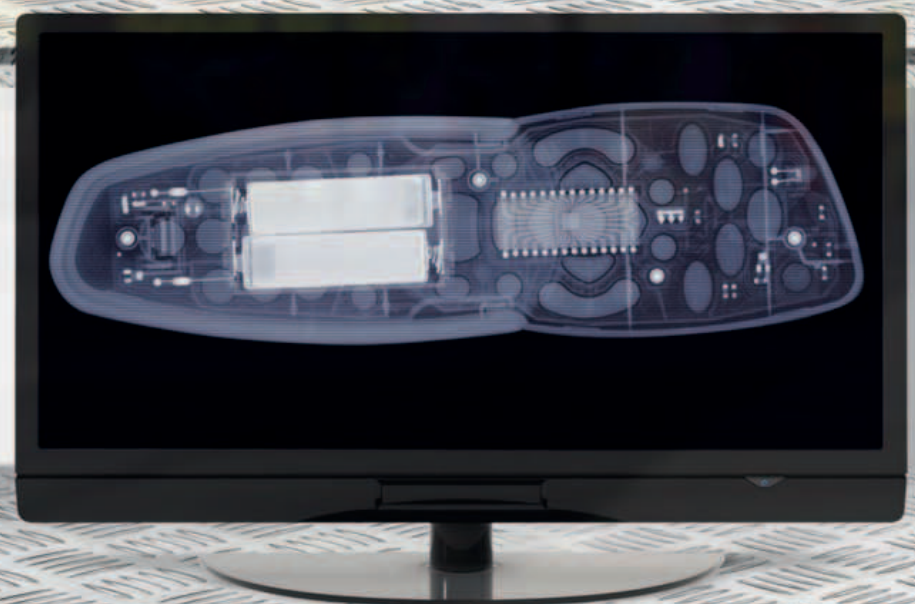
Big Bend power station in Tampa, Florida, generates electricity by burning coal



A fuse in an electric plug has to be replaced once it has blown

▲ FUSES AND CIRCUIT BREAKERS

Fuses and circuit breakers are safety devices placed in an electric circuit to prevent a surge of current passing through the circuit and damaging electrical components. A fuse contains a thin piece of wire that breaks if a surge in electric power occurs. A circuit breaker performs a similar function. It is a switch that turns the circuit off and can be reset rather than replaced.



▲ BATTERIES

Batteries are stores of chemical energy that, when connected to an electric circuit, can power it by converting chemical to electrical energy. Secondary cells can accumulate electricity and are rechargeable, while primary cells must be discarded once their chemicals are exhausted. The primary cell batteries that power this remote control contain a positive end and a negative end that are separated by a paste made of aluminium chloride.



Torch is powered by a dynamo driven by turns of the handle

► TRANSFORMERS

A transformer converts current from one voltage to another. Step up transformers are used at a power station to increase the voltage of the electricity to be distributed. At the other end of the journey, step down transformers reduce the voltage for use in factories and homes.



▼ AC AND DC

The electric current from a battery is direct current (DC), meaning that it only flows in one direction. The current in mains electricity supplies in homes is alternating current (AC). Here, the flow of electrons switches direction 50–60 times per second. Many electrical devices, such as this hair dryer, can only work with DC electricity. They contain an adaptor that converts the AC from the mains into DC.

▲ GENERATORS

A generator converts mechanical energy into electrical energy. Generators can be giant devices, such as those powered by moving gases or water in a power station, or small, such as a dynamo turned by a bicycle wheel to power lights. Inside most generators, a wire or coil is moved through a magnetic field which, through the principle of electromagnetic induction, generates an electric current.



Spoon electroplated with a thin layer of silver

▲ ELECTROPLATING

To prevent corrosion, many objects are coated with a thin layer of metal in a process called electroplating. The object to be coated is placed in a bath containing a solution of the metal coating. Electricity is passed through the object, which acts as a negative electrode and attracts positive ions of the coating.

► ELECTRIC VEHICLES

This electric car is connected to a charging spot. Electric vehicles use a collection of large rechargeable batteries to drive electric motors. They waste no energy when idling or stuck still in traffic and generate no direct air pollution, so are well suited to short journeys through cities.





CLOUDS OF CREATION

Gigantic clouds of gas and dust, the raw materials for building new stars and creating new solar systems, form the beautiful Orion Nebula, which lies some 1,500 light years from Earth.



Space

THE UNIVERSE

The Universe contains everything. It includes all known matter, from the smallest atomic particle to the largest galaxy. Scientists estimate that there are some 10^{21} (1,000,000,000,000,000,000,000) stars in the Universe. Yet most of it comprises vast distances of space between celestial bodies. Cosmology is the study of the Universe, how it began, how it developed, and what might happen to it in the future.

THE BIG BANG ▶

No one knows for certain how the Universe originated or what, if anything, came before. The current theory is that about 13.7 billion years ago, the Universe, space, and time expanded very rapidly out of a single point. In the merest fraction of a second, cosmic inflation saw the Universe grow at an unbelievably fast rate. Within minutes, radiating energy turned into particles of matter.

▶ COOLING DOWN, HEATING UP

Over a period of about 300,000 years, the Universe continued to expand and cool. Near the end of this period, the first stable atoms formed from hydrogen and helium nuclei, joining with protons and electrons. Gravity pulled gases into clouds that heated up, binding particles together, and forming the earliest stars and galaxies.



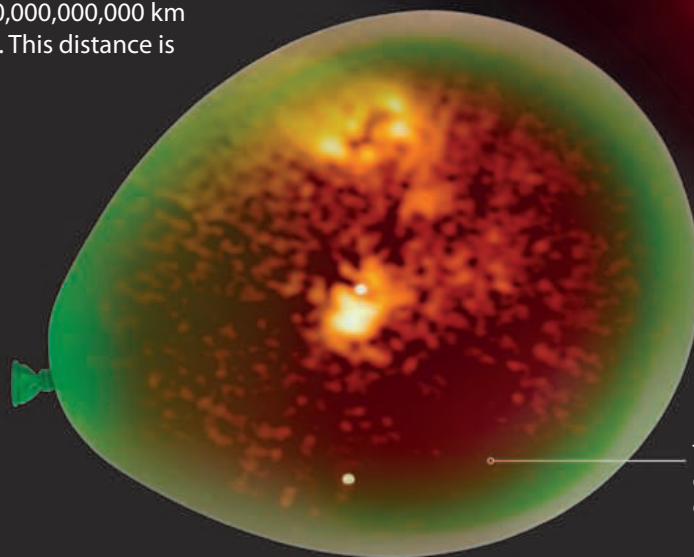
◀ LIGHT YEARS

Astronomers need larger measurements than miles and kilometres to convey the immense distances in space. Light travels at about 300,000 km (186,000 miles) per second. So the distance it travels in a year is 9,500,000,000,000 km (5,900,000,000,000 miles). This distance is called a light year.

Proxima Centauri is the nearest star to our Solar System. It is about 4.22 light years away

▶ SEEING THE PAST

When astronomers observe an object at huge distances, they are looking back deep into the past because of the millions of years it takes light to travel across the Universe. A galaxy viewed at a distance of 2 billion light years is seen as it was 2 billion years ago. In 2010, galaxy UDFy-38135539 (right) was detected. It is more than 13 billion light years away.



This galaxy is the most distant and earliest ever observed

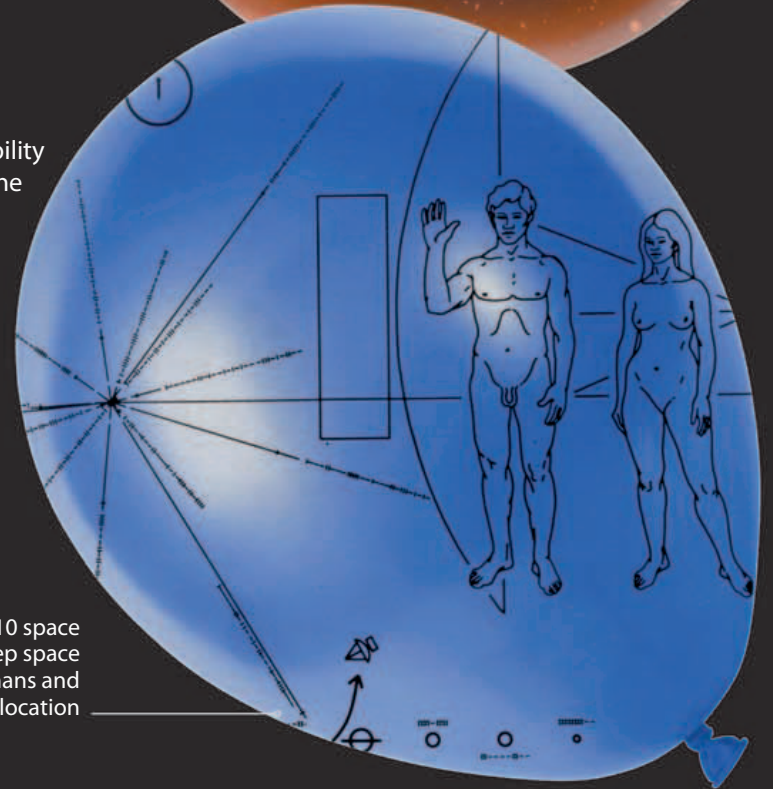
In a few trillionths of a second, the Universe expanded from a single point to the size of a galaxy

► THE UNIVERSE TODAY

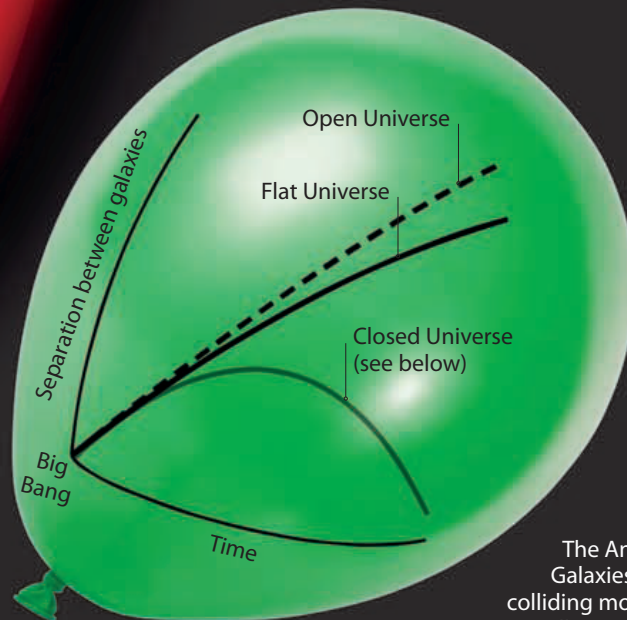
The Universe today is still expanding and is believed to be more than 90 billion light years in diameter. What astronomers can detect using scientific instruments is only part of the story. Much of the Universe is hidden from us as dark energy and dark matter. These mysterious phenomena are invisible to telescopes but their effects, such as their gravitational pull on stars, galaxies, and light can be observed.

► LIFE ELSEWHERE?

Humans are fascinated by the possibility of life elsewhere in the Universe. The vast distances of space prevent a physical search far beyond our Solar System – the Pioneer probe launched in 1972, for example, will take about two million years to reach the star Aldebaran. Instead, astronomers use telescopes to find exoplanets (planets outside the Solar System).



Plaque on Pioneer 10 space probe sent into deep space depicts adult humans and Earth's location



◀ FATE OF THE UNIVERSE

No-one is sure how the Universe will end. The open Universe theory is that it will continue to expand for ever, with the stars and galaxies dying out and space becoming a cold, dark waste. The flat Universe theory proposes that its expansion will slow to a point where the forces of expansion and gravity are balanced. The third theory, the closed Universe, is explained below.

The Antennae Galaxies began colliding more than 700 million years ago and are merging into one large galaxy

► WHEN GALAXIES COLLIDE

The closed Universe theory suggests that the Universe will stop expanding and will start to pull back on itself. This would see galaxies collide and condense inwards, until the entire Universe had shrunk into one unimaginably large black hole – the so-called Big Crunch. Whether the Universe is expanding or contracting, the forces of gravity will cause galaxies to collide.



GALAXIES AND STARS

Stars are fiercely burning balls of gas with powerful nuclear reactions at their cores. Around 5,000 stars are potentially viewable from Earth with the naked eye, but billions more exist, many of which have been catalogued and classified by astronomers. Despite the vast distances separating most stars from each other, they are bound by gravity into massive systems called galaxies. Galaxies also include star remains, gas, and dust. There are at least 125 billion galaxies in the Universe and potentially many more.

► STARS

Astronomers group stars into seven spectral types based on the temperature they burn at. Type O are the hottest, followed by B, A, F, G, K, and M, the coolest. The Sun is a type G star, while Rigel (right) is a type B star some 700–900 light years away from Earth. Rigel shines many thousands of times more brightly than the Sun.

► THE MILKY WAY

The Solar System resides in the Orion arm of the Milky Way galaxy. The Milky Way is a spinning barred spiral galaxy about 100,000 light years in diameter, but only between 1,000 and 4,000 light years thick. Our Sun lies some 25,000 light years from the centre of the galaxy and is just one of between 200–500 billion stars that are found in this galaxy.

► SPIRAL GALAXIES

Shaped like a disc, spiral galaxies often have a bulge in the centre and curved arms that spiral outwards as the galaxy rotates. The Milky Way is a type of spiral galaxy, as is NGC 1309 (right), a galaxy three-quarters the size of the Milky Way and about 120 million light years away. Even bigger is the Andromeda Galaxy. It is 220,000 light years in diameter and may contain a thousand billion stars.

◀ MAGNITUDE

Astronomers measure and classify stars in a number of ways. One of the most basic measures is apparent magnitude – the brightness of a star as viewed from Earth. The Sun, as the brightest object in the sky, has an apparent magnitude of -26.8, while the next three brightest stars are Sirius (-1.6), Canopus (-0.7), and Alpha Centauri (0.1). The least bright stars viewed with an optical telescope from Earth have a magnitude of around 30.

▶▶▶ GALAXY TYPES

Astronomers classify galaxies by their overall shape. Many galaxies are oval-shaped ellipticals, or spirals, like Andromeda (right). Lenticular galaxies are flat discs often with a central bulge. They are believed to contain few newborn stars and mainly older, mature stars. NGC 5886 (left) is a lenticular galaxy some 45 million light years away and is viewed edge on from Earth. Around one in four galaxies are classed irregular as they appear to lack a particular shape or form. This may be due to gravity from neighbouring galaxies pulling them out of shape. Most irregular galaxies contain a lot of dust, gas, and infant stars. NGC 4449 (above) is an irregular galaxy 12 million light years from Earth. Its reddish areas are star-forming regions.

▶ GALAXY CLUSTERS

Galaxies often exist as part of a collection known as a cluster. The Milky Way exists in a cluster called the Local Group along with Andromeda, Canis Major Dwarf, Triangulum, Pisces, and more than 40 other galaxies. A number of the members of the Local Group are dwarf galaxies that have only been discovered in recent years. The Local Group is estimated to have a diameter of around 10 million light years.

▶ SUPERCLUSTERS

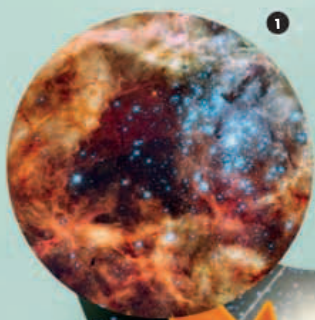
A supercluster is a number of galaxy clusters grouped together. Our local supercluster, the Virgo Supercluster, contains as many as 100 galaxy clusters, making it a staggering 100 million light years in size. Other superclusters, such as Perseus-Pisces, over 180 million light years away, are thought to be three times larger.

STAR LIFE AND DEATH

Stars are born, develop, flourish, and die over periods of millions or billions of years. The mass of the star will often determine its end as stars change and die in different ways. Their deaths leave behind different phenomena, all of which, from white dwarfs to black holes, fascinate astronomers.

1 STAR BIRTH

Most stars are born in enormous star nurseries, known as nebulae. A nebula consists of giant clouds of gas, mostly hydrogen and helium, and dust. Gravitational pull in denser parts of the nebula, sometimes caused by nearby stars or explosions, sees matter clumping together, increasing in mass and temperature, and generating its own gravity.



2 PROTOSTARS


As a large clump of gas shrinks and grows hotter, it is labelled a protostar. This is a potential star in the making. Eventually, most protostars get dense and hot enough to trigger off nuclear reactions deep inside them and the stars start to shine. This initial burst of energy blows away dust and gas surrounding these early stars.

3 MAIN SEQUENCE

The main sequence is a long period, usually lasting billions of years, in which a star generates energy through nuclear fusion, turning hydrogen into helium in its core. For stars up to three times the mass of our Sun, the main sequence comprises about 90 per cent of their life span. The Sun has been in its main sequence for more than 4 billion years.

4 GIANTS AND SUPERGIANTS

When a star of the Sun's size has used up most of the hydrogen fuel in its core, it swells up to become a red giant. When more massive stars, eight or more times greater in mass than our Sun, start to swell, they become supergiants. Betelgeuse (also known as Alpha Orionis) is a red supergiant. It is so huge that if it replaced the Sun in our Solar System, its outer atmosphere would extend past the asteroid belt.

A photograph of a binary star system, showing two stars of different colors (one blue, one white) orbiting each other. The stars are labeled 'A' and 'B'.

4 BINARY STARS

Some stars, such as Sirius A and B or Albireo A and B (pictured), are a binary pair of stars orbiting around their common centre of mass. The Albireo stars are about 380 light years from Earth.

6 FADE AWAY

Some protostars do not have enough mass to trigger nuclear reactions and become stars. Instead, they generate smaller amounts of energy through continuing contraction. These failed stars are known as brown dwarfs. They will radiate their remaining heat out into space, slowly fading until they have no energy left, at which point they are known as black dwarfs.

7 PLANETARY NEBULA

After completing their main sequence, stars that are a similar size to the Sun start to collapse, increasing in density and temperature. The stars then swell to enormous size, before throwing off their outer layers as giant clouds of gas. The clouds cool to form a planetary nebula, surrounding the star's remains, known as a white dwarf. Since the discovery of the Dumbbell Nebula in 1764, more than 3,000 planetary nebulae have been observed.

8 WHITE DWARFS

A white dwarf may have run out of hydrogen or helium fuel to burn in its core, but it will continue to shine for many millions of years. White dwarfs can range in colour from hot white through to cool red. Scientists estimate that a typical white dwarf is so dense that a teaspoonful of its matter would weigh about 5 tonnes. As with a brown dwarf, white dwarfs fade over time to become black dwarfs.

9 SUPERNOVA!

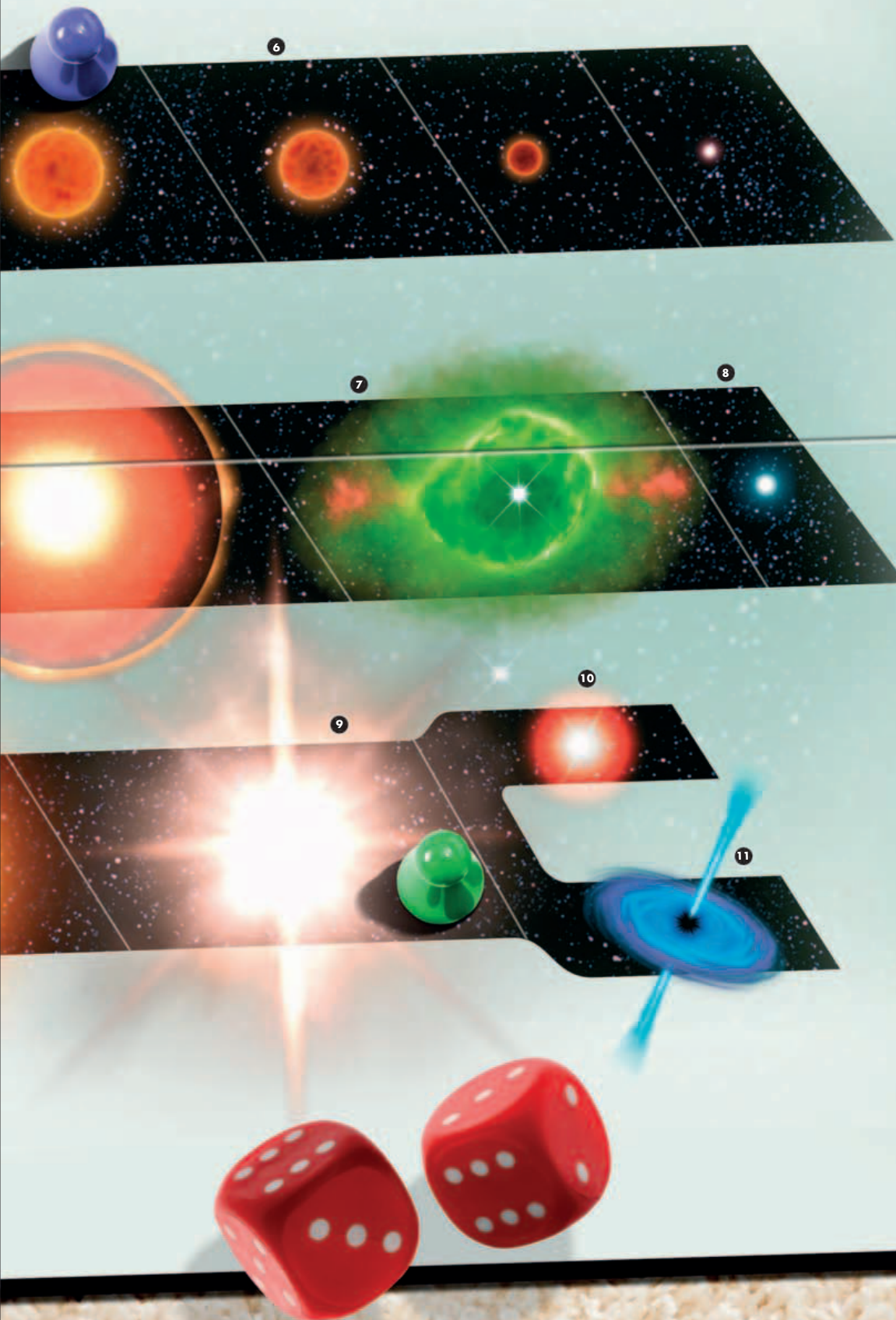
As some massive stars die, their cores contract sharply and temperatures rise by millions of degrees. The core absorbs more and more energy before erupting in a gigantic explosion. In the first 10 seconds of a typical supernova explosion, 100 times more energy is produced than the Sun will generate during its entire lifetime.

10 NEUTRON STAR

Some massive star deaths result in the core collapsing in on itself to form a neutron star – the smallest, densest stars known in the Universe. Neutron stars may be under 20 km (12 miles) in diameter yet contain the same mass as the Sun. Rapidly spinning neutron stars send out radio waves that we can pick up on Earth. These stars are known as pulsars.

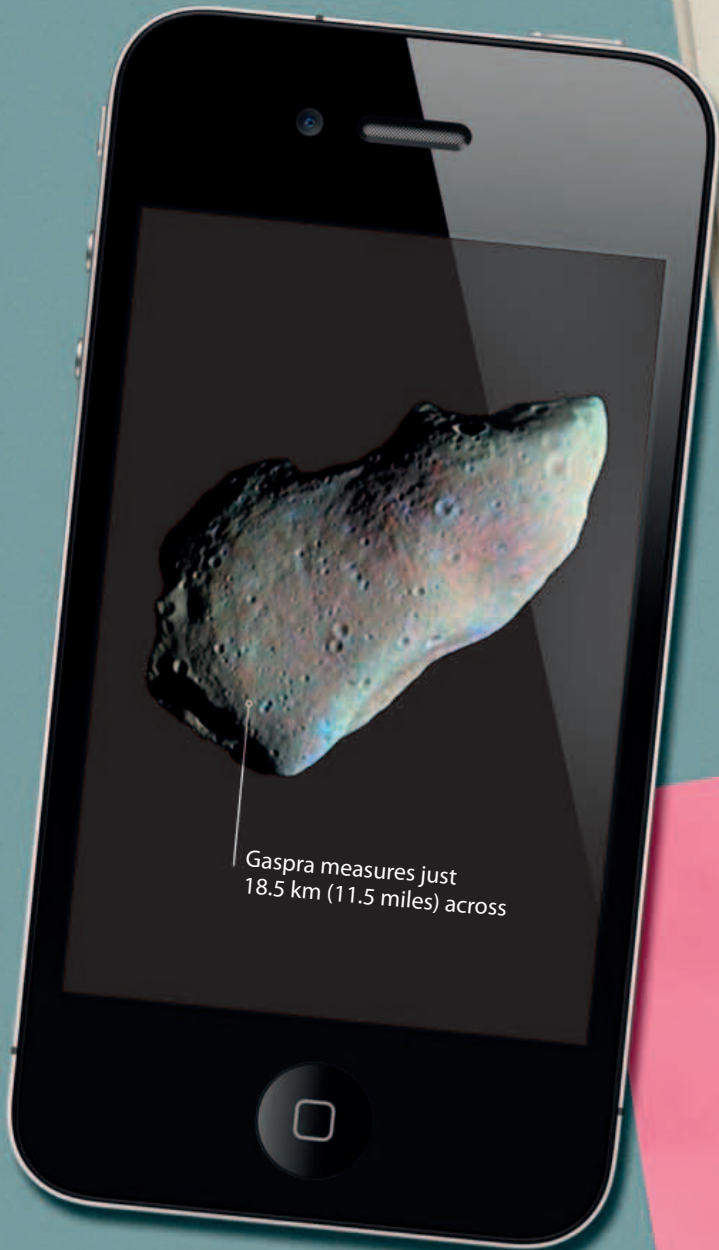
11 BLACK HOLE

Some stars collapse even further, into a dense point called a singularity. The space immediately around a singularity is called a black hole. It is so dense and the pull of gravity so strong that nothing, not even light, can escape from it. Astronomers cannot observe a black hole directly, only its effects on nearby objects, such as the pull of gas into the hole, which can release powerful X-rays.



THE SOLAR SYSTEM

Our Solar System is dominated by a fiery star at its centre, the Sun. This contains 99.8 per cent of the entire system's mass. Asteroids, planets, and other objects, drawn by the Sun's great gravitational pull, travel on elliptical paths around it, taking varying periods of time to complete an orbit. The dwarf planet Pluto takes 248 Earth years to complete a circuit of the Sun, while Mercury orbits the Sun in just 88 Earth days.



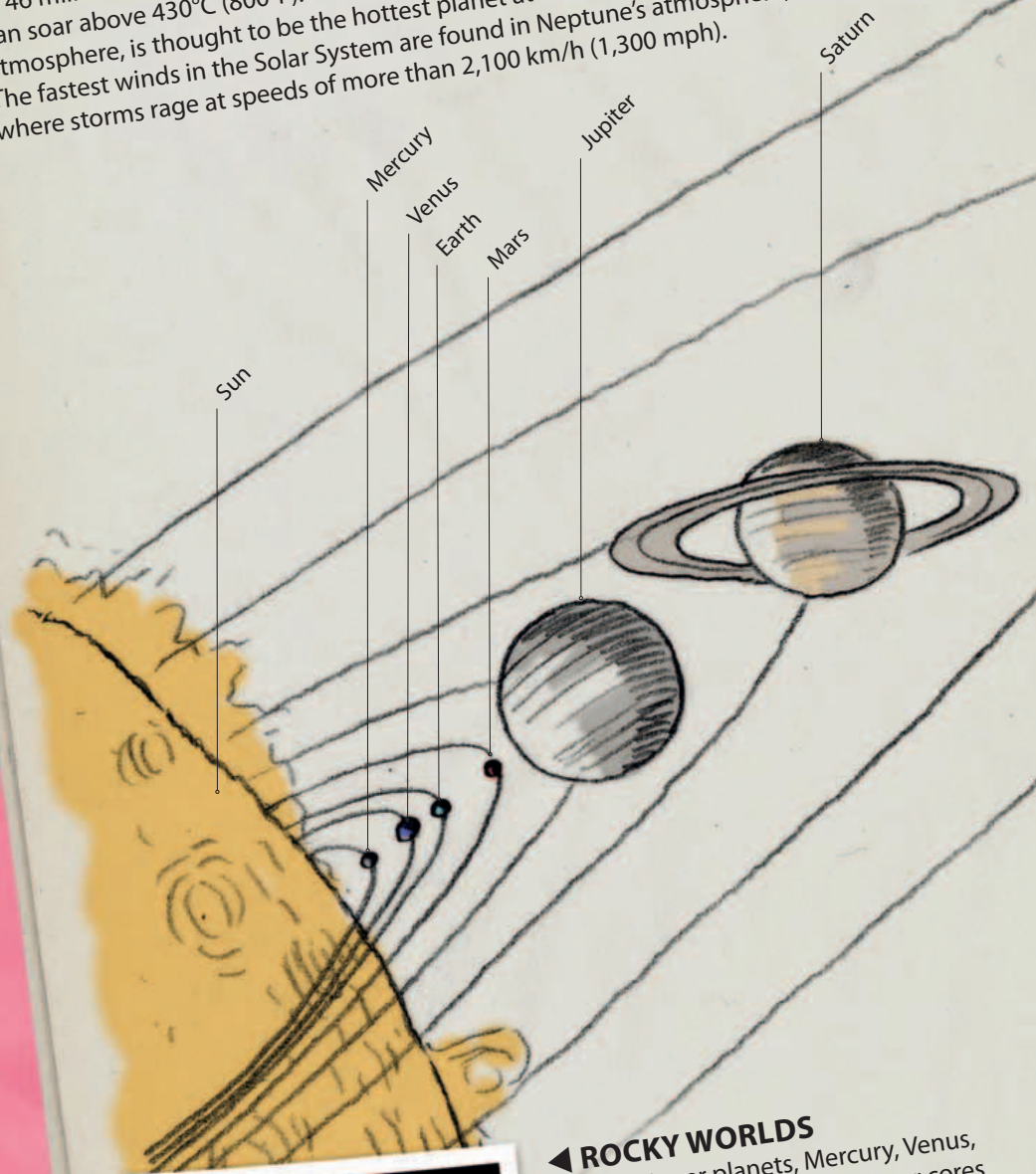
Gaspra measures just 18.5 km (11.5 miles) across

▲ ASTEROID BELT

Asteroids are chunks of rock and metal that orbit the Sun. More than nine out of ten asteroids are found in a belt lying between Mars and Jupiter. Many astronomers believe they are the remains of a planet that failed to form. The largest asteroid, Ceres, measures 974 km (609 miles) in diameter, but the vast majority are much smaller.

▼ THE PLANETS

Eight major planets orbit the Sun. Neptune is the farthest away, as far as 4.54 billion km (2.84 billion miles). Mercury, the smallest planet, is the closest at 46 million km (29 million miles). As a result, temperatures on its surface can soar above 430°C (800°F). Yet Venus, shrouded in its thick insulating atmosphere, is thought to be the hottest planet at around 465°C (870°F). The fastest winds in the Solar System are found in Neptune's atmosphere, where storms rage at speeds of more than 2,100 km/h (1,300 mph).



◀ ROCKY WORLDS

The four inner planets, Mercury, Venus, Earth, and Mars, have metal inner cores and rocky crusts. Mars's red colour (left) comes from its soil, which is rich in iron oxide. The Venusian atmosphere consists mainly of carbon dioxide with some sulphur dust and sulphuric acid droplets. Like our Moon, the surface of Mercury is heavily cratered.

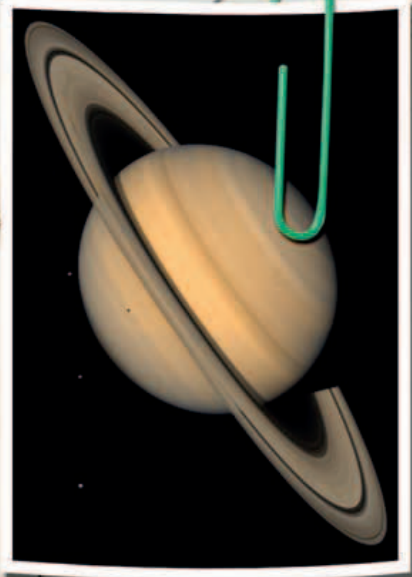
The dwarf planet Eris, with the Sun in the distance

Uranus

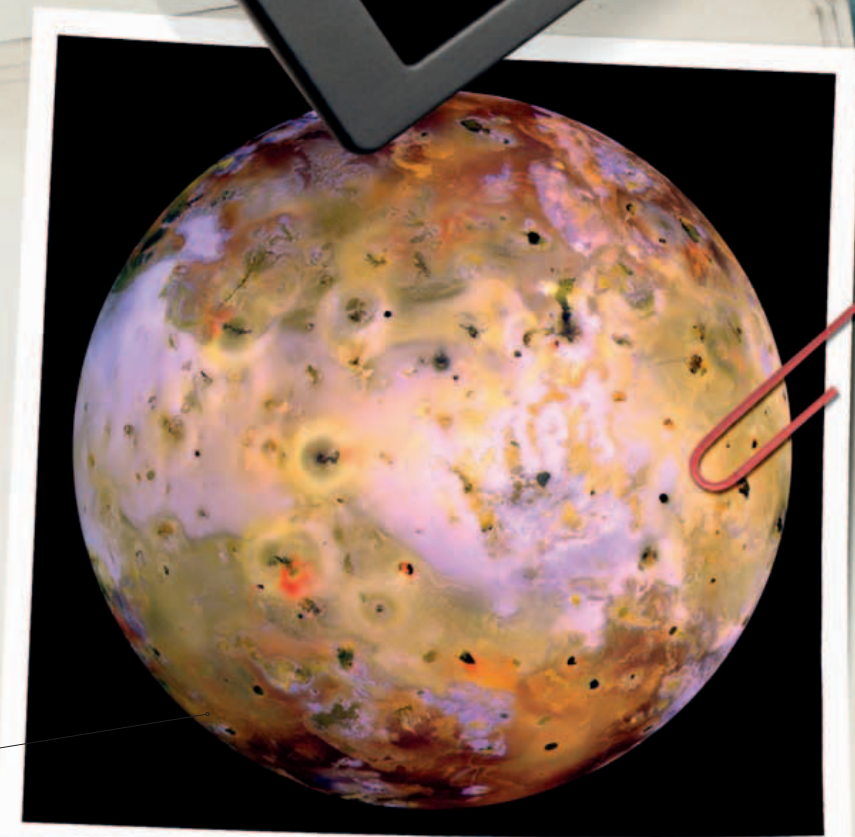
Neptune

▼ GAS GIANTS

All four of the outer planets are giant balls of gas. They lack a solid outer surface, but are believed to possess a solid core. These gas giants dwarf the four rocky planets. The largest, Jupiter, is 142,984 km (88,846 miles) across – more than 11 times the diameter of Earth. All four gas giants have rings of matter, although Saturn's (below) are the most pronounced.



Io's surface is covered with the scars of volcanic eruptions



▲ NATURAL SATELLITES

More than 160 natural satellites or moons exist in the Solar System, each orbiting a planet. Mars has two, Phobos and Deimos, while Saturn and Jupiter both have more than 60 moons. Ganymede, which orbits Jupiter, is the largest at 5,268 km (3,293 miles) in diameter and is bigger than the planet Mercury. A number of moons interest astronomers greatly. These include Io (above), which is the most volcanically active body in the Solar System, and Triton, Neptune's largest moon, which has a crust of solid frozen nitrogen.

◀ KUIPER BELT

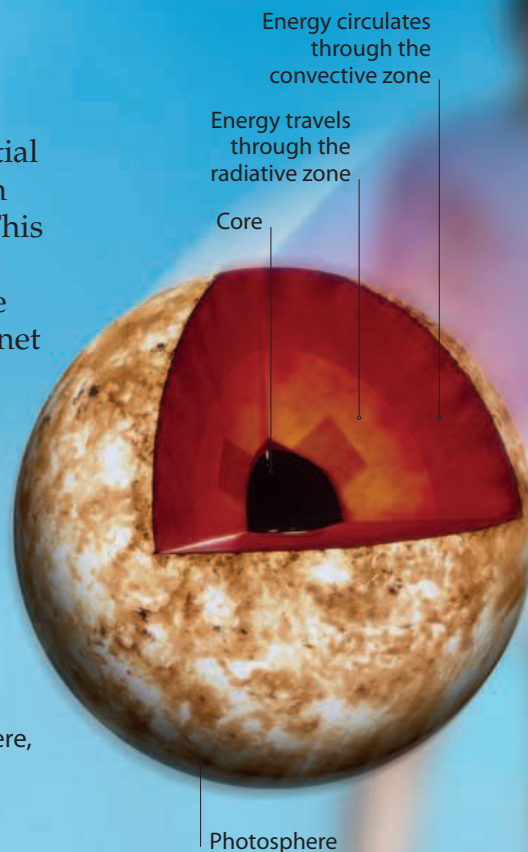
The Kuiper belt stretches out like a giant disc past Neptune and deep into space. It contains thousands of rocky or icy objects, many of which are 50–100 km (30–60 miles) in diameter. It includes dwarf planets such as Pluto. A new dwarf planet, Eris, was discovered in the belt in 2005. Measuring approximately 2,500 km (1,550 miles) across, its current location places it on an orbital path roughly three times farther away from the Sun than Pluto.

SUN AND MOON

The Sun is our closest star and the Moon is our nearest celestial neighbour. The Sun has a diameter of about 1.392 million km (865,000 miles), more than 109 times the diameter of Earth. This giant sphere of intensely hot gases generates phenomenal amounts of energy at its core. The energy travels through the Sun's layers and out into the Solar System, warming our planet and enabling life to flourish.

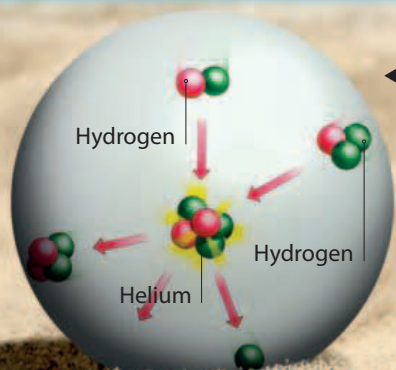
► SUN STRUCTURE

The Sun consists of a number of layers, beginning with an extremely dense yet still gaseous core, which spans about a quarter of the Sun's diameter. Energy passes through and around the convective and radiative zones of the Sun before reaching the photosphere, which has a thickness of about 500 km (300 miles). This is the Sun's surface, where temperatures average 5,700°C (10,300°F). Beyond the photosphere lies the hotter inner atmosphere, or chromosphere, and finally the corona, the outer atmosphere.



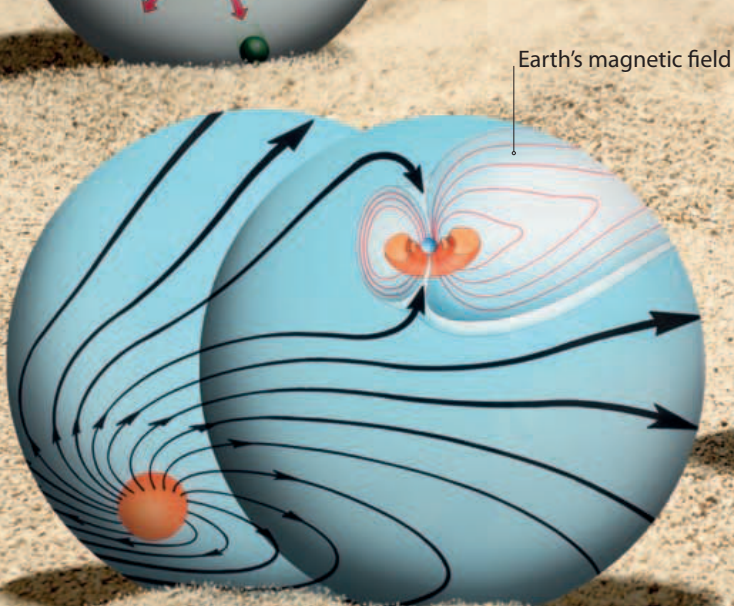
◀ SOLAR FURNACE

Hydrogen makes up almost three-quarters of the mass of the Sun. The rest is mostly helium. Vast pressures and temperatures of millions of degrees in the core cause mass nuclear fusion reactions. These convert hydrogen atoms into helium – with incredible amounts of energy generated as a result.



▼ SPOTS AND FLARES

Sunspots are areas of the Sun's surface that are cooler than the surrounding regions and are caused by interference from the Sun's own magnetic field. The sunspot recorded in 2003 (below, bottom) was the diameter of 15 Earths. A solar flare is an enormous explosion of energy from the Sun's surface.

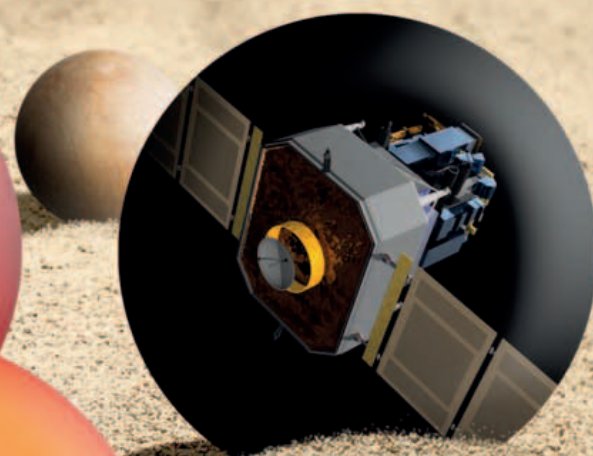


▲ SOLAR WIND

A stream of particles is continually ejected from the Sun. These carry strong electrical and magnetic fields as they billow out across the Solar System. Earth's own magnetic field (above) is shaped by the solar wind, extending away from the Sun in a teardrop shape.

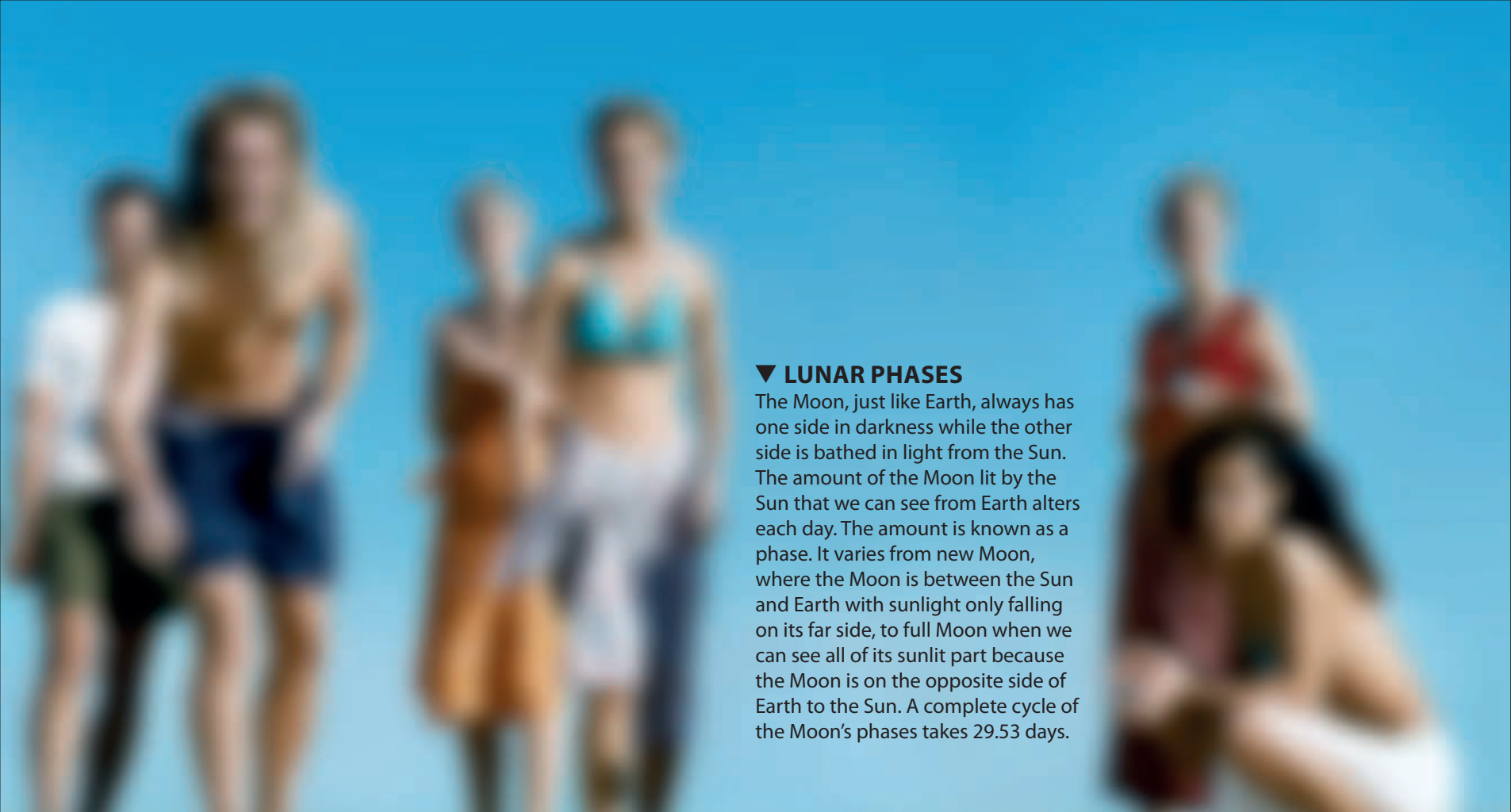


Largest sunspot seen by SOHO probe



▲ STUDYING THE SUN

One of the most successful solar probes has been SOHO – the Solar & Heliospheric Observatory (above). Launched in 1995, its 12 major scientific instruments are still studying the Sun's structure and provide regular data, allowing solar astronomers back on Earth to predict patterns of solar activity.



▼ LUNAR PHASES

The Moon, just like Earth, always has one side in darkness while the other side is bathed in light from the Sun. The amount of the Moon lit by the Sun that we can see from Earth alters each day. The amount is known as a phase. It varies from new Moon, where the Moon is between the Sun and Earth with sunlight only falling on its far side, to full Moon when we can see all of its sunlit part because the Moon is on the opposite side of Earth to the Sun. A complete cycle of the Moon's phases takes 29.53 days.

► THE MOON

The Moon orbits Earth at an average distance of 384,400 km (238,900 miles). It has a diameter of about one-quarter that of Earth. The Moon lacks an atmosphere, contains no surface water, and temperatures range from searing by day to frozen by night. Much of its surface is covered in a blanket of soil several metres thick and rising to 10 m (33 ft) in depth in some mountainous regions.



The Moon waxes as the phases grow larger, and wanes as they grow smaller

▼ TIDES

While Earth's gravitational pull ensures the Moon stays in orbit around the planet, the Moon's own gravity has effects on Earth. Water in the planet's oceans is pulled to the Moon. Its gravity creates two bulges in the water on either side of the planet. As Earth rotates on its axis, the bulges move round the planet causing the rise and fall in the ocean level. These are tides.

Generally, there are two high tides each day



LUNAR SURFACE ►

As the Moon travels in its orbit around Earth, it also rotates on its axis. It takes as long to complete a full rotation as it does to encircle Earth, which is why it always presents its same face to us. This nearside of the Moon features many plains called maria, deep valleys called rills, and hundreds of impact craters. The largest, Bailly, is more than 295 km (180 miles) wide. The far side of the Moon was a mystery until space probes began photographing its surface in 1959.

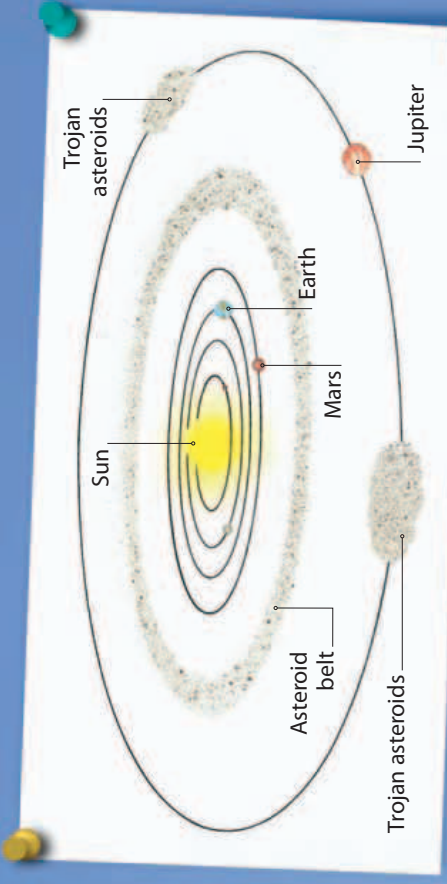
ASTEROIDS, METEORITES, AND COMETS

The planets and their moons are not alone in the Solar System. There are many other bodies orbiting the Sun. Some, such as the millions of small meteoroids, are less than a metre across. Others, like the largest asteroids, Ceres, Pallas, and Vesta, can measure hundreds of kilometres in diameter, while the tail of a comet can extend millions of kilometres behind its nucleus. Many of the asteroids in the Solar System are believed to be the remains of a planet that failed to survive.

▼ ASTEROIDS

Asteroids are chunks of rock or rocky-metals. More than 210,000 have been identified and more than 15,000 have been named, but only a handful have been studied up close by space probes. Vesta, the third-largest asteroid in the asteroid belt, is the one asteroid bright enough to see with the naked eye.

Eros asteroid is 34.4 km
(21.5 miles) long



▲ THE ASTEROID BELT

About 90 per cent of all asteroids are found in a broad belt between Mars and Jupiter, 248–598 million km (154–392 million miles) from the Sun. The vast majority of these asteroids are less than a kilometre across, but some are much larger. In 2009–10, two asteroids in the belt – 65 Cybele and 24 Themis – were found to have ice on their surface. There are also two groups of asteroids, called the Trojans, orbiting in the same path as Jupiter.



▲ METEORS

Meteors are small pieces of rock, dust, and metal that enter Earth's atmosphere. Most are fragments of asteroids, but some are small pieces of debris from Mars, the Moon, or comets. Most meteors burn up in the atmosphere in seconds, melting and forming streaks of light in the night sky known as falling or shooting stars.

A collection of meteors, called a shower, light up part of the night sky



Comet Hale-Bopp could be viewed from Earth for 18 months (1995–97)

◀ COMETS

A comet consists of a solid nucleus surrounded by a cloud of dust and gas called the coma. The nucleus is often called a dirty snowball, and consists of frozen water, rock, metal, and carbon. As a comet approaches the Sun, heat evaporates or sublimates some of the ice into gas, increasing the size of the coma, which lengthens to become the comet's tail.

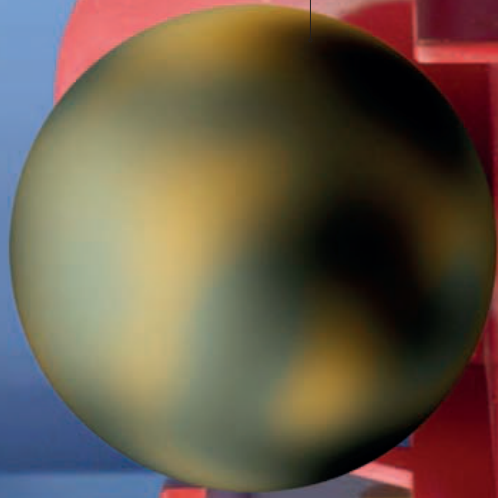
▲ PERIODIC COMETS

Comets have highly elliptical orbits around the Sun. Some take many thousands of years to complete an orbit. Much of what we know about comets comes from short-period comets such as Halley's Comet, which completes an orbit every 76 years.



▼ DWARF PLANETS

In 2006, Pluto was relegated from one of the nine major Solar System planets to the status of dwarf planet. These are bodies that are basically spherical in shape and orbit the Sun and not another planet, but are not large enough for their gravitational pull to clear their orbital path of debris. Also classified as dwarf planets are Makemake, Eris, and Haumea, which lie inside the Kuiper Belt, and Ceres, the largest of the asteroids.



Pluto, as seen by the Hubble Space Telescope

IMPACT! ▶

When a meteorite or comet strikes Earth, it leaves an impact crater. Due to the high speed of impact, the resulting crater is often far larger than the body that crashed into the ground. Meteor Crater in the US state of Arizona (right) was formed around 50,000 years ago. It is 1.2 km (0.75 miles) wide, but was created by an asteroid that was only 30 metres (100 ft) wide.



METEORITES ▼

Some larger meteors survive transit through the atmosphere and fall to Earth where they are known as meteorites. Compared to meteors, meteorite occurrence is relatively rare, with around 400–900 impacts reported each year. Most surviving meteorites are fist-sized, but larger examples have been discovered. The biggest was found in Hoba West, Namibia, and weighed more than 60 tonnes.



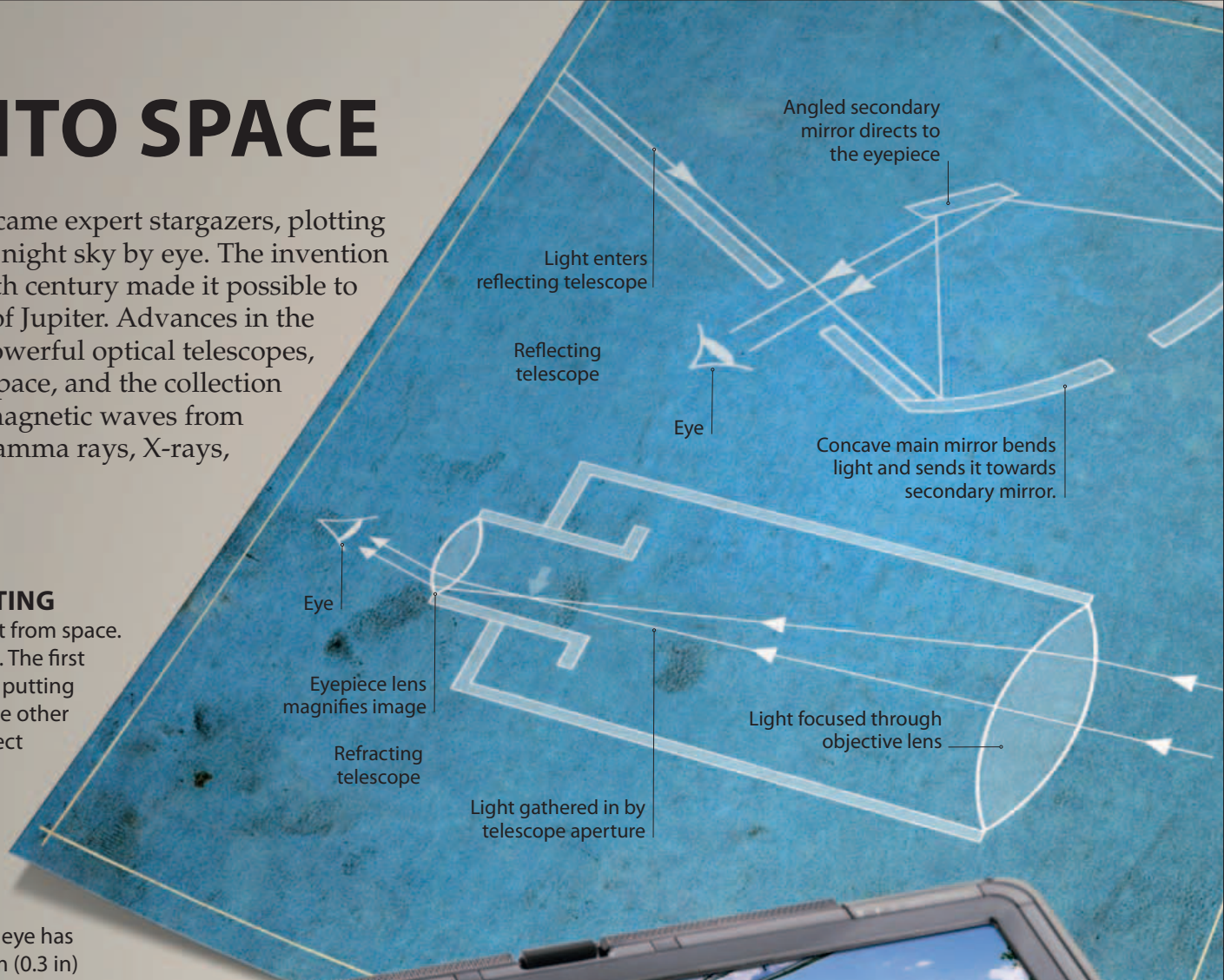
SEEING INTO SPACE

Many ancient civilizations became expert stargazers, plotting the paths of bodies across the night sky by eye. The invention of optical telescopes in the 17th century made it possible to see more, such as the moons of Jupiter. Advances in the 20th century brought more powerful optical telescopes, observatories launched into space, and the collection and analysis of other electromagnetic waves from space, such as radio waves, gamma rays, X-rays, and infrared.

► REFLECTING AND REFRACTING

Optical telescopes capture visible light from space. They are either refracting or reflecting. The first telescopes were refractors, created by putting two spectacle lenses one in front of the other in a tube. Refractors use lenses to collect and bend light to create a magnified image. Lenses are harder to build to a large size and suffer from chromatic aberration, creating coloured fringes around an image. Instead, reflecting telescopes use large, extremely smooth mirrors. While your eye has an aperture, or opening, of up to 7 mm (0.3 in) to let in light, reflecting telescopes can have apertures measured in metres.

Arecibo radio telescope's dish measures 305 m (1,015 ft) in diameter



▲ RADIO TELESCOPES

Radio waves from space can be gathered, amplified, and studied as electronic images. Radio astronomy began in 1932 with Karl Jansky's discovery of radio static coming from the Milky Way. Since that time, bigger radio dishes or arrays of a number of dishes linked together have discovered pulsars (see page 113), detected radio waves from quasars and exploding stars, and explored the cosmic microwave background radiation.

Chandra image of the remains of an exploded supernova

► INVESTIGATING OTHER WAVES

Electromagnetic waves, such as ultraviolet and X-rays, are also collected by astronomical instruments on the ground or in space. The Chandra Observatory was launched into space in 1999 and is still collecting imagery from the remains of exploded stars, and the gases around pulsars and black holes.

▼ INFRARED ASTRONOMY

This modified Boeing 747SP carries SOFIA, the largest airborne observatory in the world. In 2010, SOFIA began studying infrared sources from space. Many objects in the Universe are too cool and faint to be detected in visible light, but can be observed using infrared telescopes. Infrared astronomy has revealed many bodies previously unseen.

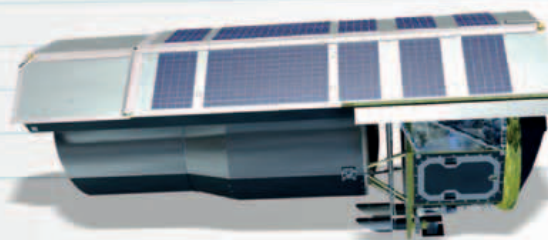


Aircraft houses a 2.5-m (8-ft) wide infrared telescope.



▲ OBSERVATORIES

Telescopes and other electronic astronomy devices are located in purpose-built observatories. Many observatories are sited in isolated places away from the light pollution generated by large cities, and in regions with a dry climate with few clouds to obscure viewing. The Mauna Kea Observatory in Hawaii is perched more than 4,200 m (13,800 ft) above sea level.

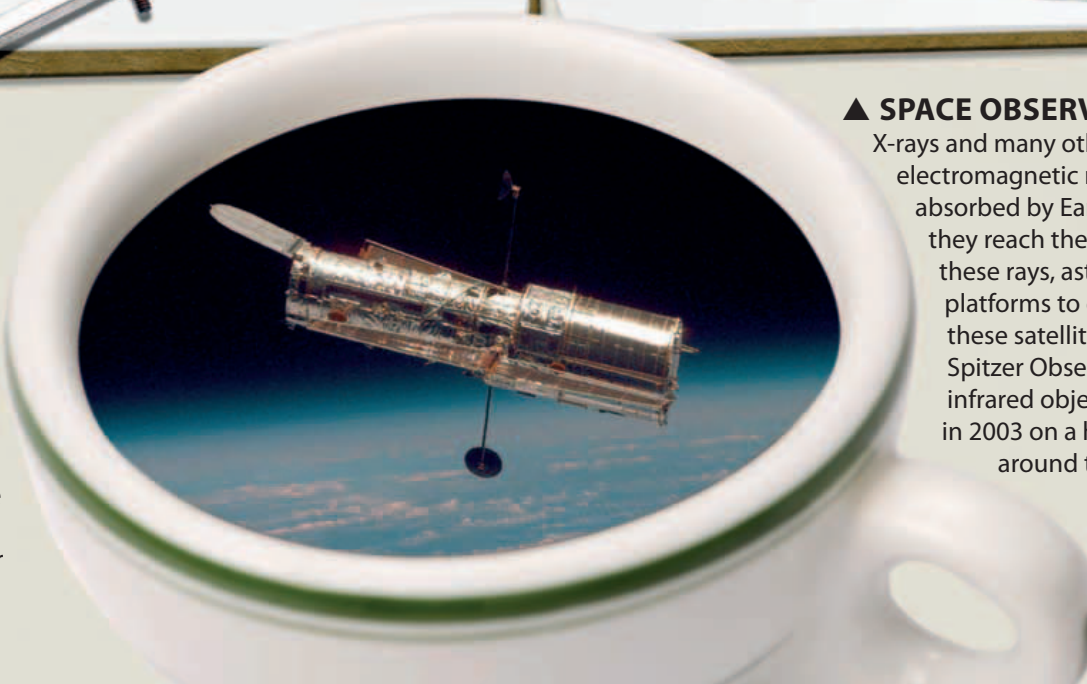


▲ SPACE OBSERVATORIES

X-rays and many other wavelengths of electromagnetic radiation from space are absorbed by Earth's atmosphere before they reach the planet's surface. To gather these rays, astronomers use satellites as platforms to carry telescopes. Most of these satellites orbit Earth. However, the Spitzer Observatory, which investigates infrared objects in space, was launched in 2003 on a heliocentric orbit, travelling around the Sun.

► THE HUBBLE

Launched in 1990 and expected to operate until 2014, the Hubble Space Telescope (HST) has helped to establish how the early Universe worked by peering back to galaxies some 10 billion light years away. Its 2.4 m (8 ft) diameter reflecting telescope has studied newborn stars, planets orbiting stars in other galaxies, and comet impacts.





▲ LIFT OFF

Rockets are chemical engines that mix fuel and oxygen, before burning this mixture in a combustion chamber. The hot gases accelerate out of the rocket's nozzle, while an equal and opposite force propels the rocket upwards. The thrust produced by a rocket is enormous. Each of this Saturn V's five F1 engines generated 691,818 kg (1.5 million lbs) of thrust, and in just 150 seconds they had propelled the rocket 68 km (42 miles) above Earth's surface.



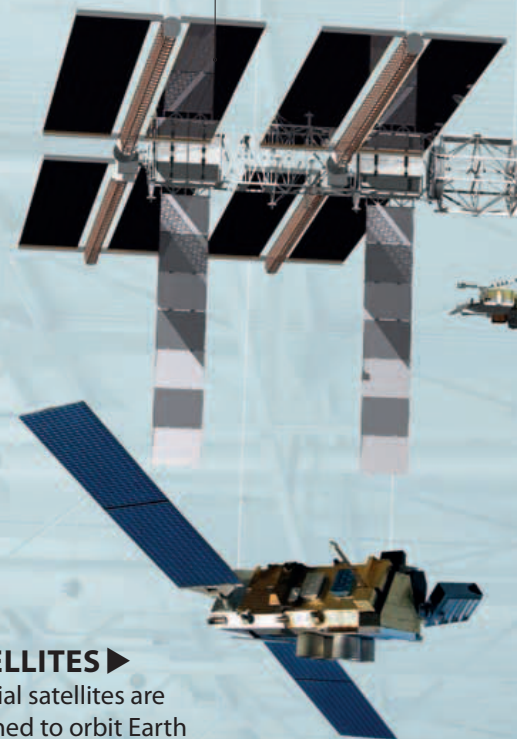
▲ LIFE IN SPACE

When astronauts leave Earth, they have to be orderly and methodical. Everyday tasks, such as eating, washing, and sleeping, need to be managed carefully in a weightless environment. Inside the pressurized and air-conditioned cabins of the Space Shuttle and ISS, astronauts work in shirtsleeves and use footholds and straps to stay in one place.

► SPACE STATIONS

Orbiting at an altitude of between 278 and 460 km (172 and 288 miles) above Earth's surface, the International Space Station (ISS) is the largest construction in space. Produced by the collaboration of 16 nations, the ISS was assembled in modules over the course of more than 50 spaceflights and 120 spacewalks. Since 2000, the 110-m (360-ft) long space station has provided a place for astronauts to work, live, and conduct a wide variety of long-term space-science experiments.

Solar array wing contains 32,800 solar cells



SATELLITES ►

Artificial satellites are launched to orbit Earth or other celestial bodies. Some satellites are in a geostationary orbit. This means that they orbit Earth at exactly the same speed as Earth turns, keeping the same position above the planet's surface. Geostationary satellites are used to predict the weather, for communications, and for navigation systems.

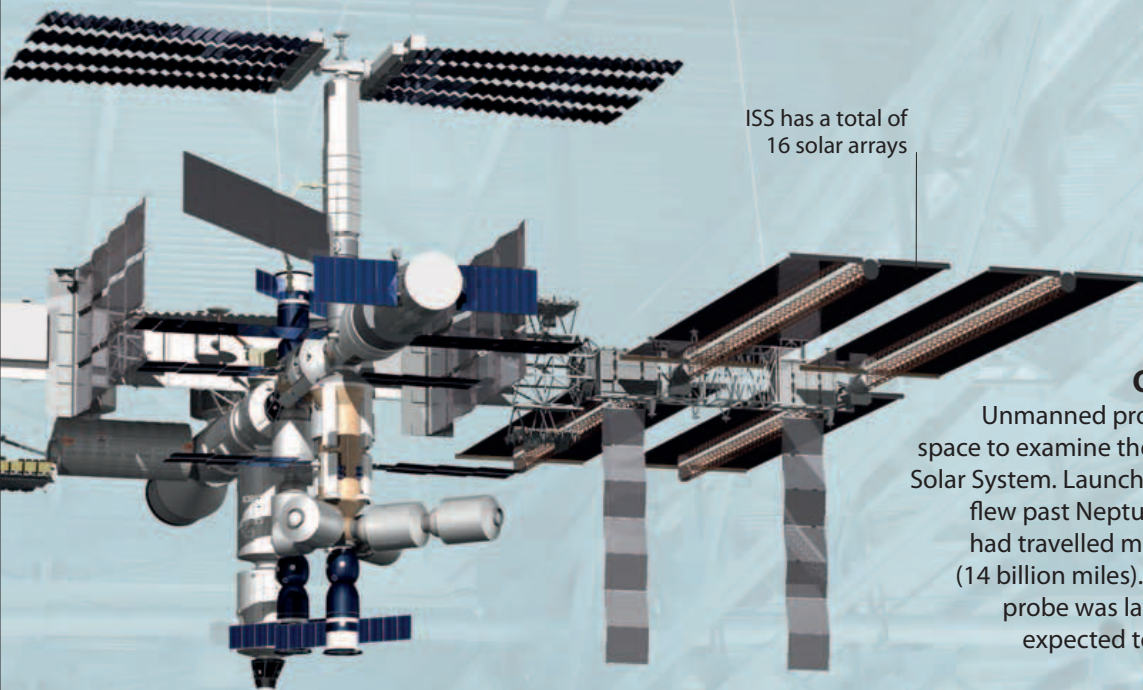


► SPACESUITS

For journeys to and from Earth and for spacewalks, specialized spacesuits are worn. NASA's EMU suit has 14 layers, with the outer layer able to repel small particles of rock that would rip through other materials. The suit contains a life support system. This keeps the suit pressurized and temperature controlled, providing oxygen and transporting waste gases and liquids away.

SPACE EXPLORATION

Sending people, probes, and scientific instruments into space has taught us much about the Solar System and Universe, as well as about our own planet. Manned space exploration is complex and costly, as large amounts of equipment, supplies, and life support systems are required. A method of returning astronauts to Earth safely is also needed. In contrast, unmanned space probes are expendable and can be sent on missions into space with no plans for their return.



ISS has a total of 16 solar arrays

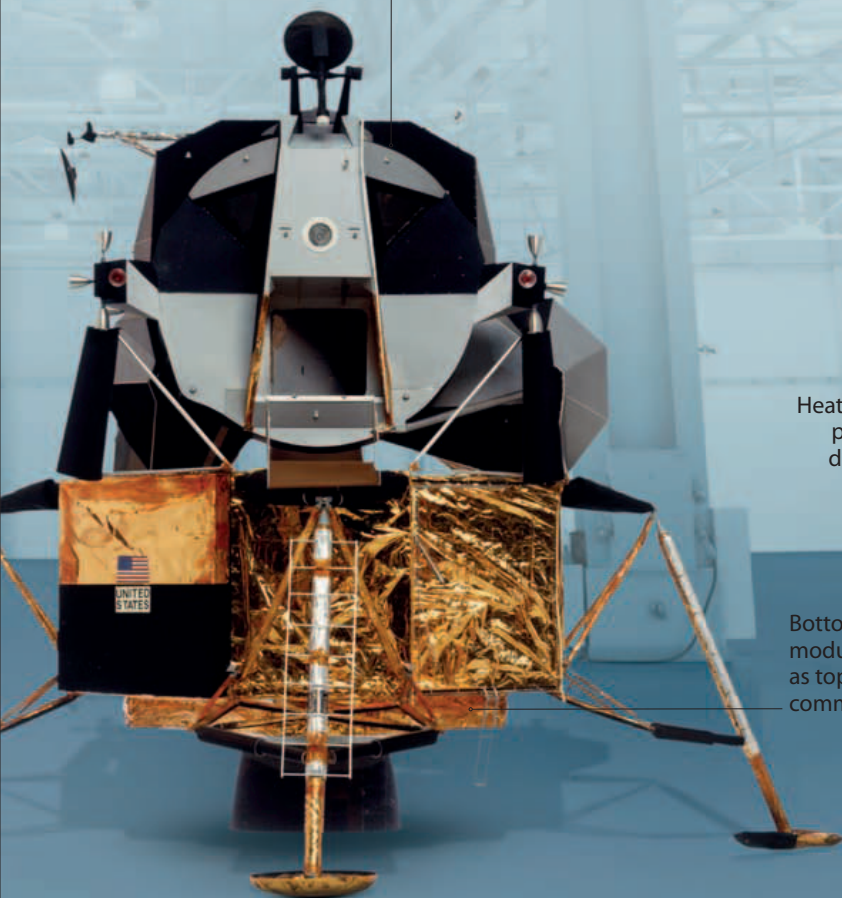
New Horizons instrument, called Ralph, provides heat maps and colour images from space



ON THEIR WAY ▶

Unmanned probes can travel across space to examine the outer planets of the Solar System. Launched in 1977, Voyager 1 flew past Neptune in 1989. By 2010, it had travelled more than 22 billion km (14 billion miles). NASA's New Horizons probe was launched in 2006 and is expected to reach Pluto by 2015.

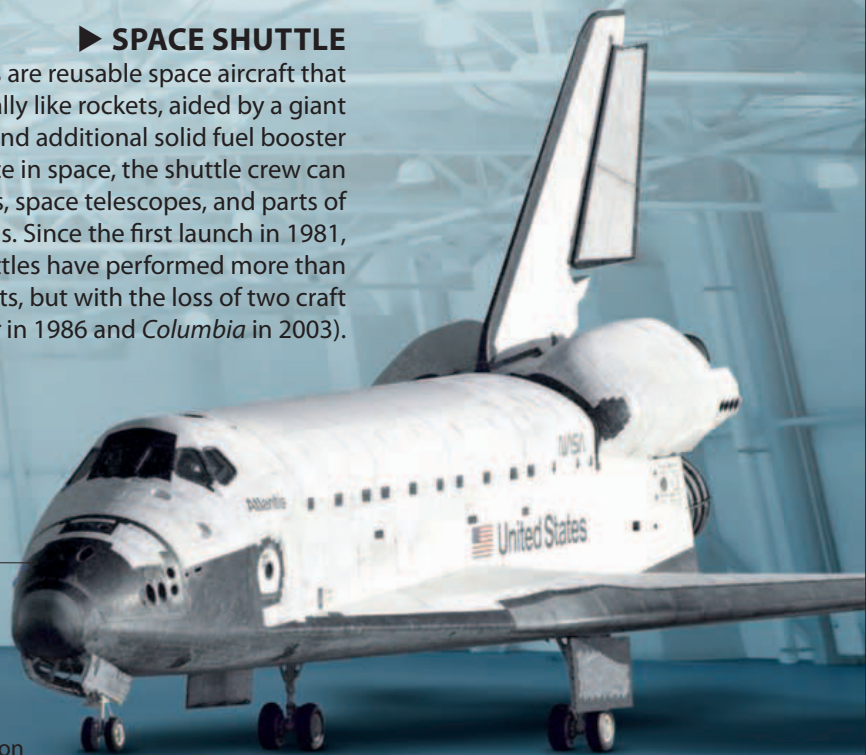
Top half of the lunar module left the Moon to dock with command module in lunar orbit



▶ SPACE SHUTTLE

Space shuttles are reusable space aircraft that launch vertically like rockets, aided by a giant fuel tank and additional solid fuel booster rockets. Once in space, the shuttle crew can deliver satellites, space telescopes, and parts of space stations. Since the first launch in 1981, NASA's five shuttles have performed more than 130 flights, but with the loss of two craft (*Challenger* in 1986 and *Columbia* in 2003).

Heat-resistant tiles protect Shuttle during re-entry

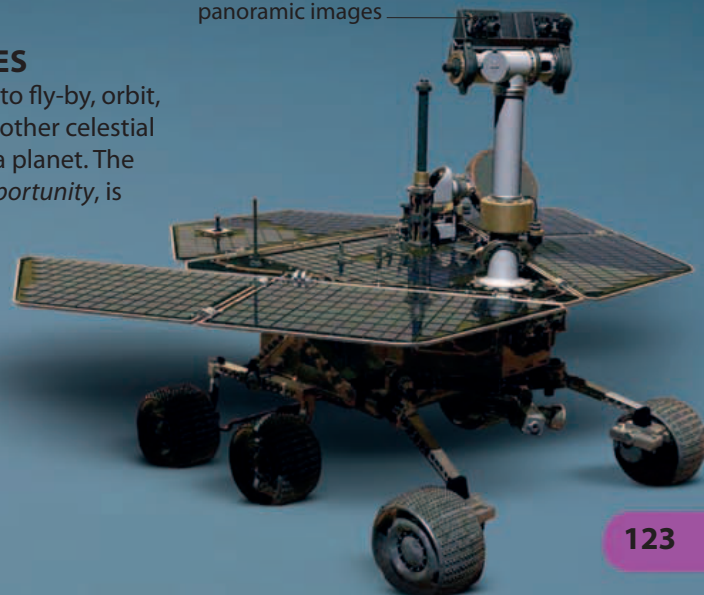


Bottom half of the lunar module remained on Moon as top half flew back with command module

Cameras mounted on rotating mast to take panoramic images

▶ PLANETARY PROBES

Space probes are designed to fly-by, orbit, or land on the surface of another celestial body, such as the Moon or a planet. The Mars Exploration Rover, *Opportunity*, is solar powered and has six independently driven wheels. It has exceeded its original target of 600 m (2,000 ft) of movement across the Martian surface. By 2010, it had reached the 24 km (15 mile) mark.



▲ MOON LANDINGS

The Apollo programme in the 1960s and early 1970s sent 24 men to the Moon. Of the 24 men, 12 actually set foot on the lunar surface. The very first was Neil Armstrong from the Apollo 11 mission on 20 July 1969. The Apollo 15, 16, and 17 missions carried lightweight, battery powered lunar rovers, which travelled 90 km (56 miles) exploring the lunar surface.

Glossary

ACID RAIN

Rain and snow that contains poisonous or harmful chemicals, such as sulphur dioxide, which are created by the burning of fossil fuels.

AMPHIBIANS

Creatures, such as frogs and toads, that are able to live on land or in water.

ANTENNA

A long, sensory structure found on creatures such as insects.

ARTERY

A thick-walled blood vessel that carries blood away from an animal's heart.

ATMOSPHERE

The layer of gases that surrounds a moon, planet, or star.

ATOM

The smallest particle of a chemical element.

BACTERIA

Microscopic single-celled life forms. Bacteria are the most abundant living things on Earth.

BIG BANG

A massive event from which scientists believe the Universe expanded and formed about 13.7 billion years ago.

CARBON DIOXIDE

A gas that is found in the atmosphere and is a waste product of energy release in cells.

CELL

A tiny unit of living matter. Cells are the building blocks of all living things.

CENTRAL NERVOUS SYSTEM

The control centre of the nervous system that consists of the brain and the spinal cord.

CHLOROPHYLL

The green-coloured chemical that traps the sunlight energy plants use to make their food.

CHROMOSOME

A thread-like structure in a cell's nucleus. Chromosomes are made of DNA and contain genes.

COMET

A small body made of ice, dust, and rock particles that orbits the Sun and can grow a large tail when nearing the Sun.

COMPOUND

A substance containing two or more elements formed by a chemical reaction that bonds their atoms together.

COMPOUND EYE

A type of eye, found in insects and crustaceans, made up of many smaller units.

CONDENSE

To change from a gas to a liquid.

CONVECTION

The transfer of heat by movement – for example, when warm gas rises and cooler gas sinks.

CRUSTACEAN

A creature with a hard-shelled body, jointed legs, and two pairs of antennae.

DEFORESTATION

The cutting down of large numbers of trees for fuel or timber, or to clear the land for settlements or farming.

DENSITY

A measure of how tightly the mass of an object is packed into its volume.

DEOXYRIBONUCLEIC ACID (DNA)

The long molecules found in a cell nucleus that contain the coded instructions to build and operate a cell.

DIGESTION

The breaking down of food so that it can be absorbed and used by the body.

EARTHQUAKE

A large, sudden movement of Earth's crust.

ECOSYSTEM

A community of interacting living organisms and the environment.

ECTOTHERMIC

Describes an animal whose internal body temperature varies with its surroundings.

ELECTROMAGNETIC RADIATION

A range of energy waves that travel through space and include gamma rays, ultraviolet, infrared, visible light, and radio waves.

ELEMENT

One of just over 100 different types of atom, such as gold, hydrogen, iron, and silicon, which form all substances.

ELLIPTICAL

Shaped like an ellipse – an elongated circle or sphere.

ENDOTHERMIC

Describes an animal whose internal body temperature remains the same. It also refers to a reaction that takes in energy from its surroundings.

ENZYME

A substance that controls the rate of chemical reactions, including the breakdown of food molecules during digestion.

EQUATOR

The imaginary line drawn around the centre of Earth an equal distance from the South and North poles.

EROSION

The wearing away and transportation of rock through natural forces, such as wind or flowing water.

EVAPORATION

The process where a liquid changes into a gas. The warming of the air by the Sun causes water to evaporate and change into water vapour.

EVOLUTION

The process by which species change over many generations and long periods of time to give rise to new species.

EXOPLANET

A planet that orbits around a star other than our Sun.

FAULT

A fracture or crack in Earth's crust where blocks of rock slip past each other.

FOOD CHAIN

The links between different animals that feed on plants and each other. Food chains show how energy is passed up through the chain.

FOSSIL FUEL

A type of fuel, such as coal, gas, or oil, that formed underground over millions of years from the remains of plants and animals.

FRICTION

The resistance created by the rubbing of one moving object or material against another object or material.

FUNGI

A group of living organisms that includes mushrooms.

GALAXY

An enormous grouping of stars, planets, gases, and dust that is held together by gravity.

GENE

One of the instructions stored inside cells required to build and operate a creature's or plant's body. Genes are passed on from parents to their offspring.

GLACIER

A mass of ice formed from compacted snow that may flow slowly downhill.

GRAVITY

A force of attraction between objects found throughout the Universe. The greater the object's mass, the greater its gravitational pull.

HABITAT

The natural home of a species of animal or other living organism.

HEMISPHERE

One of the halves of Earth created by the equator.

HORMONE

A substance released by a gland into the bloodstream that acts as a chemical messenger. Some hormones help control certain body processes, such as the rate of body growth.

IGNEOUS ROCK

A rock formed from the cooling and hardening of hot liquid magma or lava.

INSECT

A hard-shelled creature with a three-part body, six legs, and, usually, two pairs of wings.

INVERTEBRATE

An animal without a backbone, such as an insect.

JOINT

A part of the skeleton where two or more bones meet, for example the elbow.

KERATIN

A tough, waterproof substance found in nails, hair, and the outer layers of skin.

LAVA

Magma that reaches Earth's surface through a volcanic vent or fissure.

LIGHT YEAR

A unit of distance equal to the distance light travels through space in one year. One light year is equal to 9.5 million million km (5.9 million million miles).

MAGMA

Hot liquid rock that lies beneath Earth's surface.

MAMMAL

An endothermic vertebrate, such as a dog or horse, that has fur or hair and feeds its young with milk.

MANTLE

The rocky middle layer of Earth that lies between its core and outer crust.

METAMORPHIC ROCK

A type of rock formed when igneous or sedimentary rock is altered by great heat or pressure, or both.

METEOR

A short-lived streak of light, which is produced by a small piece of rocky material from space travelling through Earth's upper atmosphere.

METEORITE

A piece of rock or metal that lands on the surface of a planet or moon.

MOLECULE

A group of atoms that are bonded together. For example, oxygen and hydrogen atoms are bonded together in a water molecule.

NERVE

A bundle of long, specialized cells that relay signals rapidly from one part of the body to another.

NUCLEAR FISSION

The splitting of the nuclei of atoms to generate enormous energy for use in power stations or as a weapon.

NUCLEAR FUSION

The fusing, or combining, of atoms of two elements to create a heavier element.

ORBIT

The path that a natural body, such as a moon, or an artificial object, such as a space probe, makes around a larger body.

ORE

A type of mineral that contains useful metals, such as iron, that can be extracted.

ORGANISM

An individual form of life, such as a single-celled bacterium, an animal, or a plant.

PHOTOSYNTHESIS

The process by which plants use energy from sunlight to produce food.

PLATE TECTONICS

The process in which the large plates that form Earth's crust are constantly moving together or apart.

POLLUTION

Waste products or heat that damage the environment in some way.

PRECIPITATION

Any form of water, such as rain, snow, sleet, or hail, that falls from the atmosphere to the surface of Earth.

PRESSURE

The force felt when something presses against a surface.

PREY

An animal that is killed and eaten by another animal, the predator.

PRODUCER

An organism, such as a plant, that makes its own food using sunlight energy and provides nutrients and energy to any animals that eat it.

PROTOSTAR

A very young star in its early stage of formation before nuclear reactions begin in its core.

RADIATION

Energy travelling as electromagnetic waves, such as infrared or visible light.

RESERVOIR

A natural or artificial store of liquid, usually water.

RESPIRATION

A chemical process in which food is broken down to release energy.

SEDIMENT

The solid that settles at the bottom of a liquid.

SEDIMENTARY ROCK

A type of rock formed from sediment that is compressed over time to form a solid.

SOLUBLE

Capable of being dissolved.

SPECIES

A set of organisms that can be grouped together due to their similarity and their potential ability to breed with each other.

SPECTRUM

The rainbow band of colours that is produced when light is split.

STEM CELL

An unspecialized cell that divides repeatedly, giving rise to specialized cells, such as nerve cells or muscle cells.

STRATA

Layers of sedimentary rock.

SUPERNOVA

A star that explodes and leaves a remnant behind that may become a black hole, pulsar, or neutron star. The plural of supernova is supernovae.

SYSTEM

A set of linked organs inside an animal's body, such as the nervous system or digestive system, which carries out a specific set of functions.

TOXIC

Poisonous or harmful.

TRIBUTARIES

Streams or small rivers that flow into larger rivers.

TRILLION

One million million (one followed by 12 zeros).

VEIN

A blood vessel that carries blood from an animal's tissues back to its heart.

VERTEBRATE

An animal that has a backbone. Fish, mammals, amphibians, birds, and reptiles are all vertebrate animals.

VISCOUS

Refers to a liquid and how slowly it runs.

VOLUME

The amount of space an object occupies.

WATER CYCLE

The continual flow of Earth's water from the atmosphere to Earth and back.

WAVELENGTH

The distance between the peaks or troughs in waves of energy.

WEATHERING

The gradual breaking down of rocks and minerals into sand and soil.

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Acknowledgements

DK would like to thank:

Chris Bernstein for preparing the index.

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