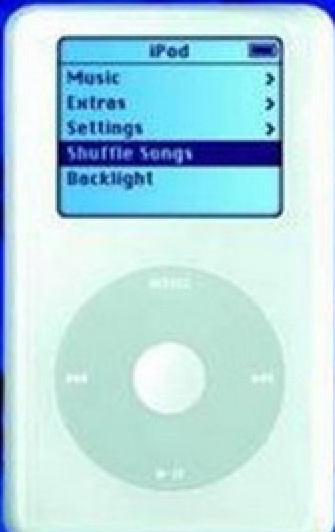
HOW COOL STUFF WORKS



HOW

COOL STUFF

WORKS

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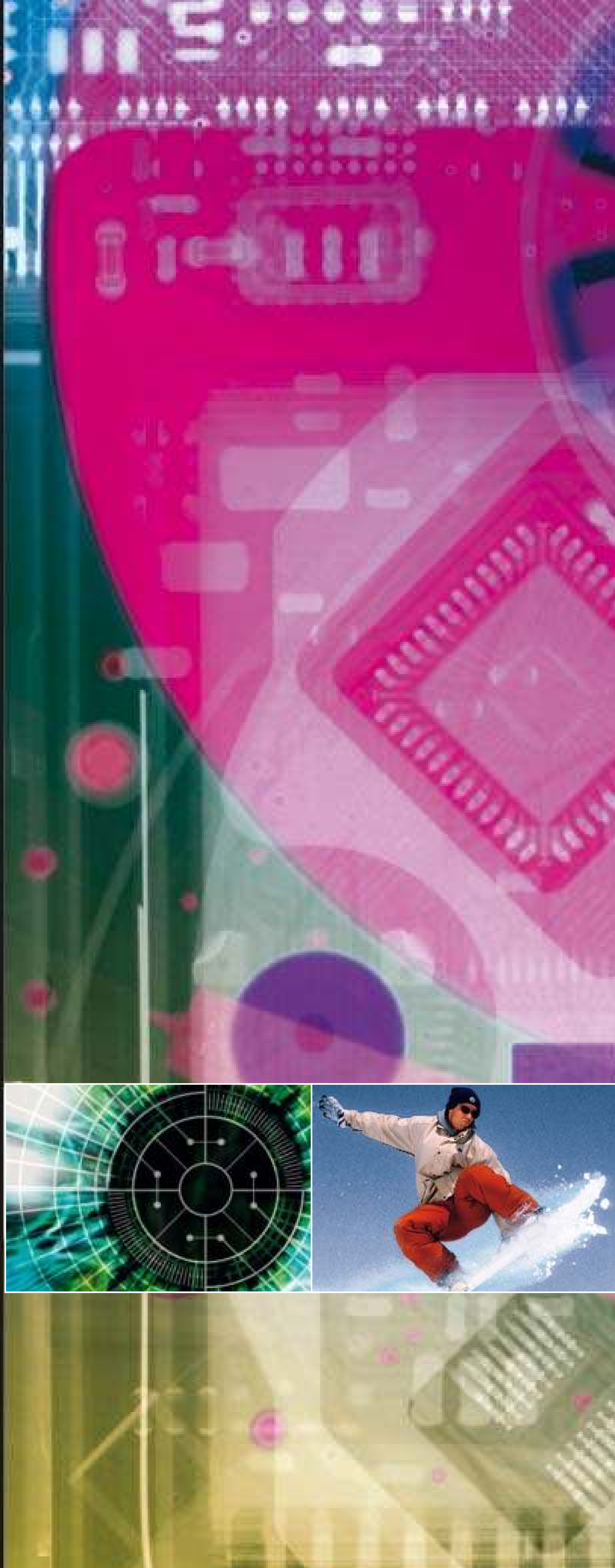

HOW COOL STUFF WORKS

Written by Chris Woodford, and Luke Collins,
Clint Witchalls, Ben Morgan, James Flint

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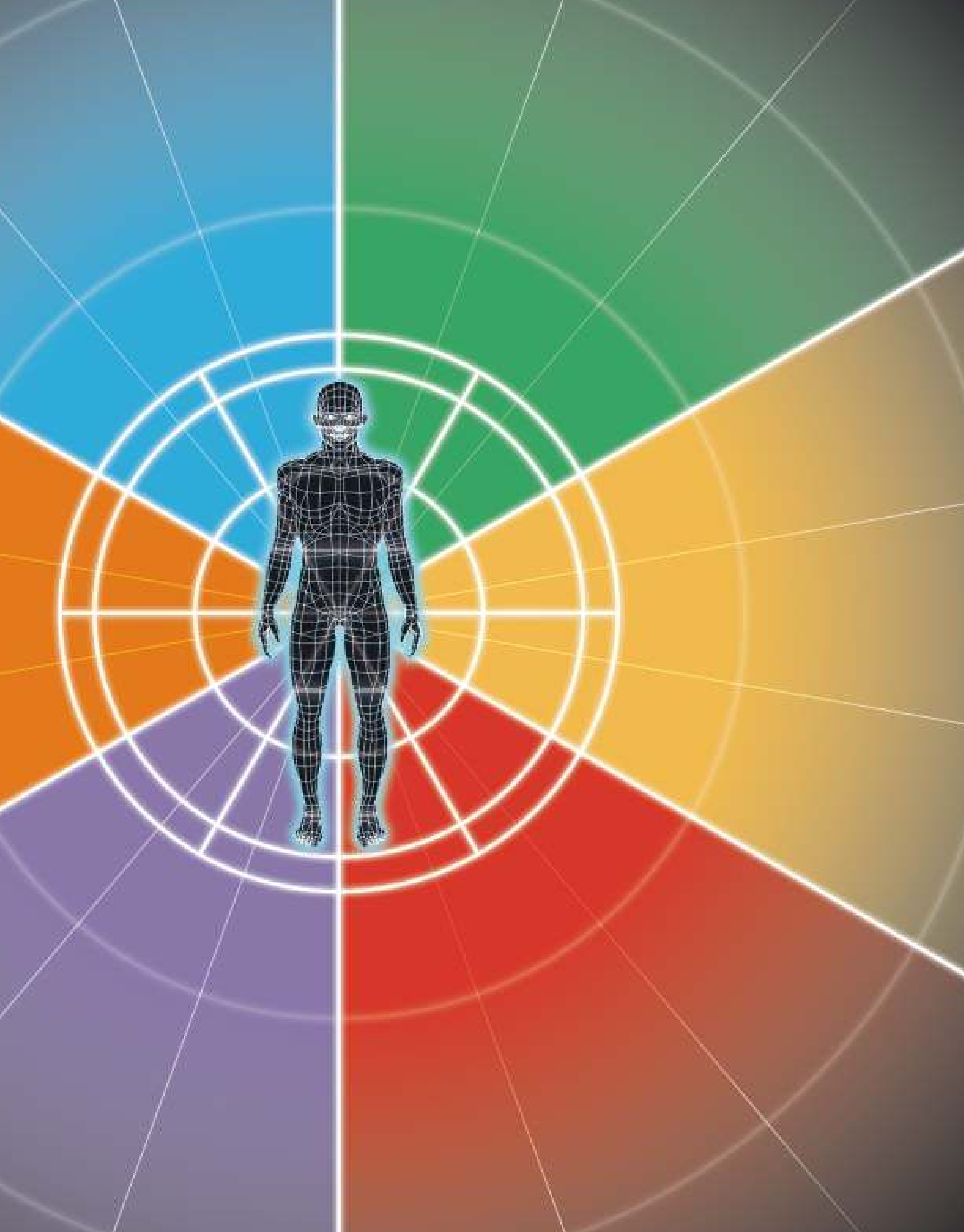

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MOVE

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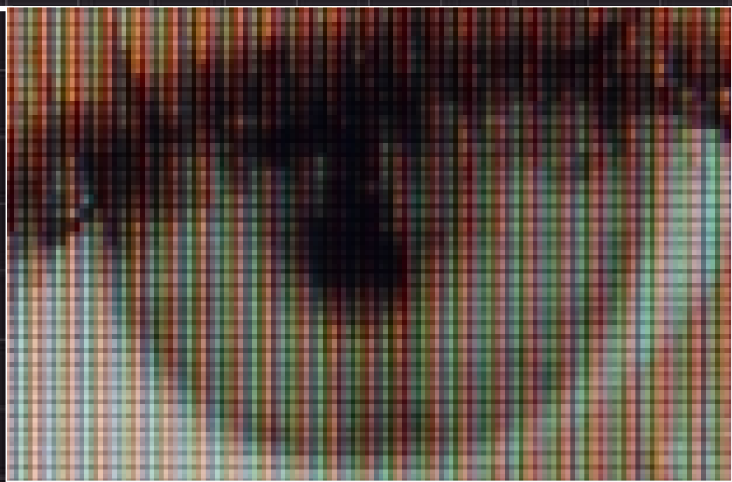
REFERENCE

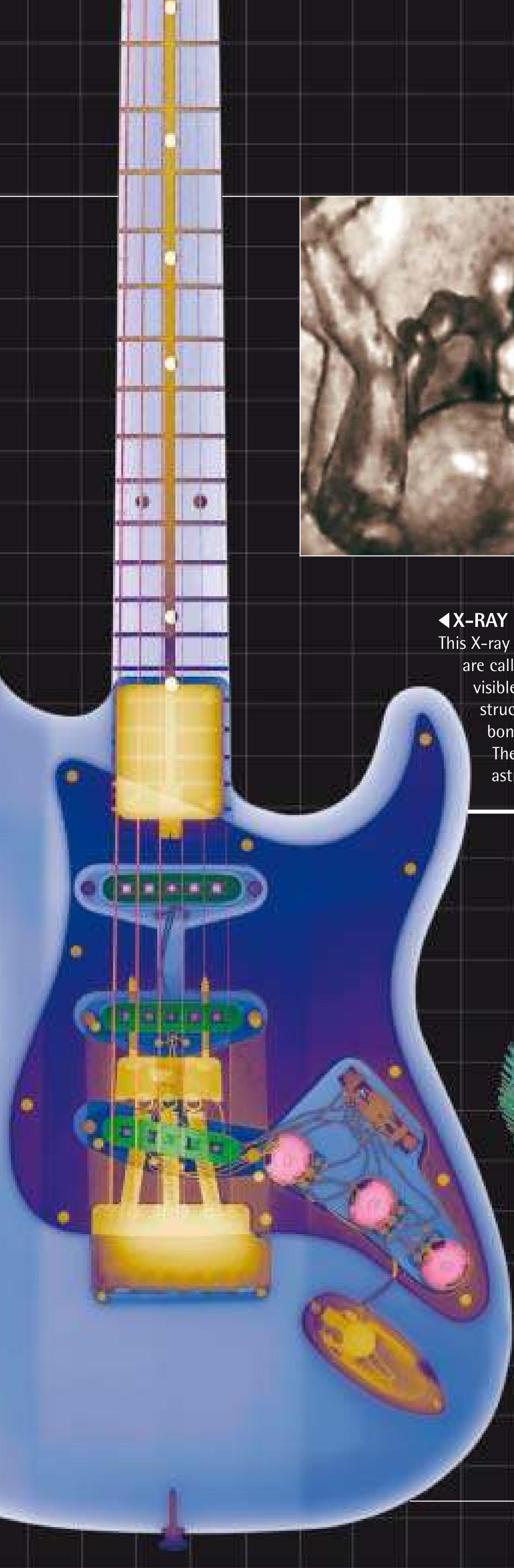
Imaging techniques

Over the last century, successive breakthroughs in imaging technology have transformed the way we see the objects that surround us. From medicine to engineering to weather forecasting, worlds invisible to the naked eye can now be observed. There are microscopes that can take pictures of individual atoms, the building blocks of matter. These are so small that they have to be magnified 100 million times to become visible. At the other end of the scale, the almost perfect mirrors inside the Hubble Space Telescope capture images of dying stars in distant galaxies.



▶ MACROPHOTOGRAPHY
Macrophotography makes a small subject, such as this image of a human eye on a liquid crystal display (LCD) screen, appear life-size or greater. A special camera lens with powerful magnification lets the photographer focus from just a few centimetres away. Macrophotography can reveal details that are very difficult, or impossible, to make out with the naked eye. It is often used to make extreme close-up pictures of plants and insects. Scientists can also attach cameras to microscopes to capture objects in even greater detail. This technique is called photomicrography.

◀ DOPPLER RADAR
Doppler radar helps meteorologists to track storms, tornadoes and, as pictured here, hurricanes. Doppler radar measures an object's speed and direction of movement. A transmitter sends out radio waves into the sky. These travel at the speed of light until they reach their target – usually water droplets in clouds – then they bounce back. By calculating the time it takes for the echoes to bounce back, a computer can work out where clouds are. It can also work out how much water a cloud contains from the strength of the reflected echo beam. In this way, a detailed picture of weather events can be made.



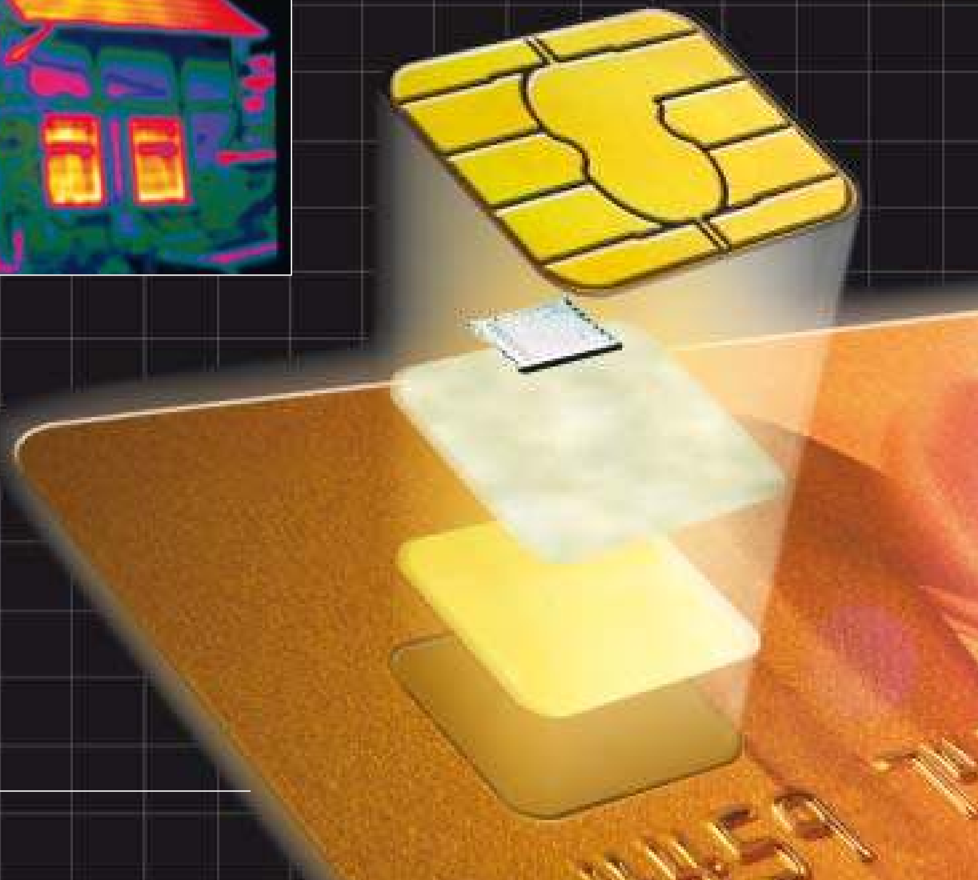
◀ ULTRASOUND
Ultrasound is a medical imaging technique often used to check a baby's development in its mother's womb. A probe sends out millions of pulses of high-frequency sound waves – at least 100 times greater than those within the range of human hearing – into the body each second. By measuring the time it takes for the echoes to return to the probe, a detailed image is produced on the screen of the ultrasound machine. To produce three-dimensional (3D) images, such as this one, many scans are taken and combined by a computer.

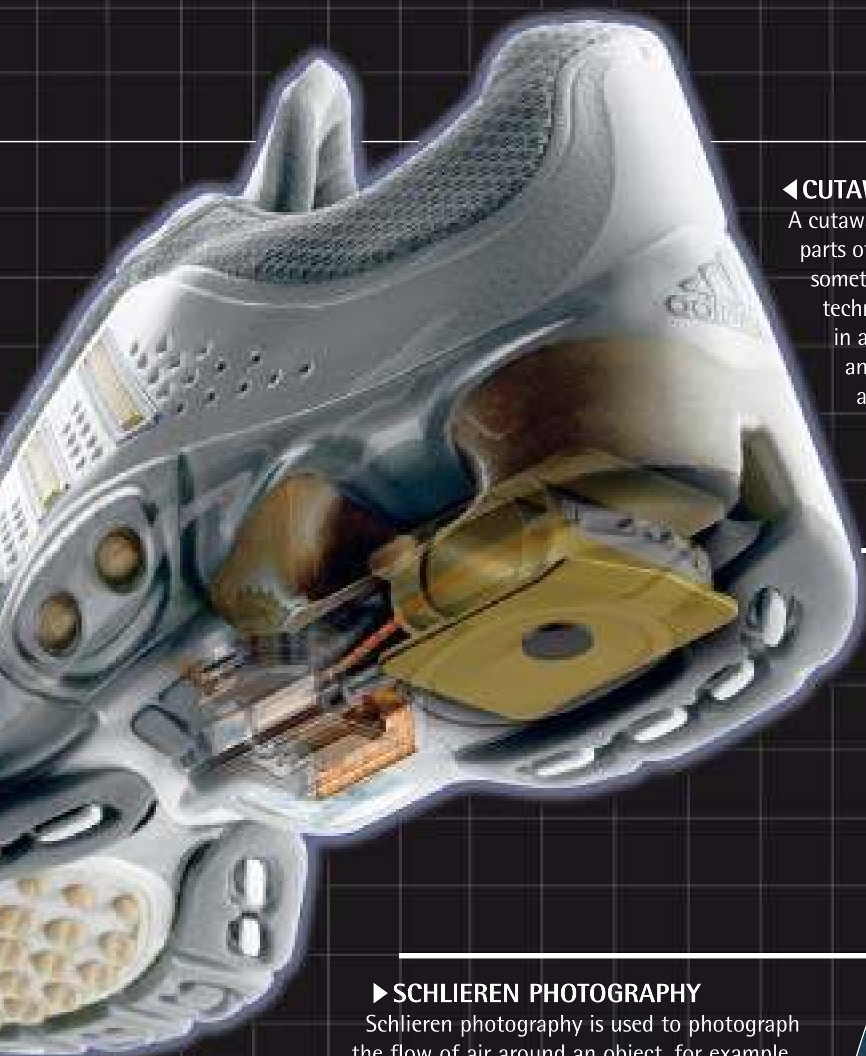
◀ X-RAY MACHINE
This X-ray of a guitar's components has been enhanced with colour. Images like this are called false-colour X-rays. X-ray machines work like cameras, but instead of visible light they use X-rays, which can penetrate soft materials to reveal the hard structures inside an object. They are most commonly used to diagnose broken bones, but high doses can damage living tissue, so they must be used sparingly. They are also used by engineers to detect tiny flaws in metal structures, by astronomers to observe distant stars, and by airport security to scan luggage.

▲ MAGNETIC RESONANCE IMAGING
Magnetic Resonance Imaging, (MRI), allows doctors to explore the body's structures, such as the brain's network of nerve connections, shown here. An MRI scanner bombards the body with radio waves that cause vibrations in atoms held in position by the scanner's powerful magnets. These tiny movements produce the information for a computer to build up a very detailed three-dimensional image. MRI helps doctors diagnose serious conditions, and provides clues about the workings of the brain.

▲ SCANNING ELECTRON MICROSCOPE
A Scanning Electron Microscope (SEM) reveals tiny organisms and viruses that are invisible to the naked eye. It can also make images of objects that are difficult to see, such as these tiny hairs on an electric shaver. An SEM works by focusing a stream of electrons into a narrow beam that sweeps the object. The electrons bounce off the object and are converted into an electrical signal by a detector. The signal is used to create a photograph-like image on a TV screen that has a very high resolution, or level of detail. The image is photographed to make a black and white image, but can be coloured digitally – false-coloured – by a computer.

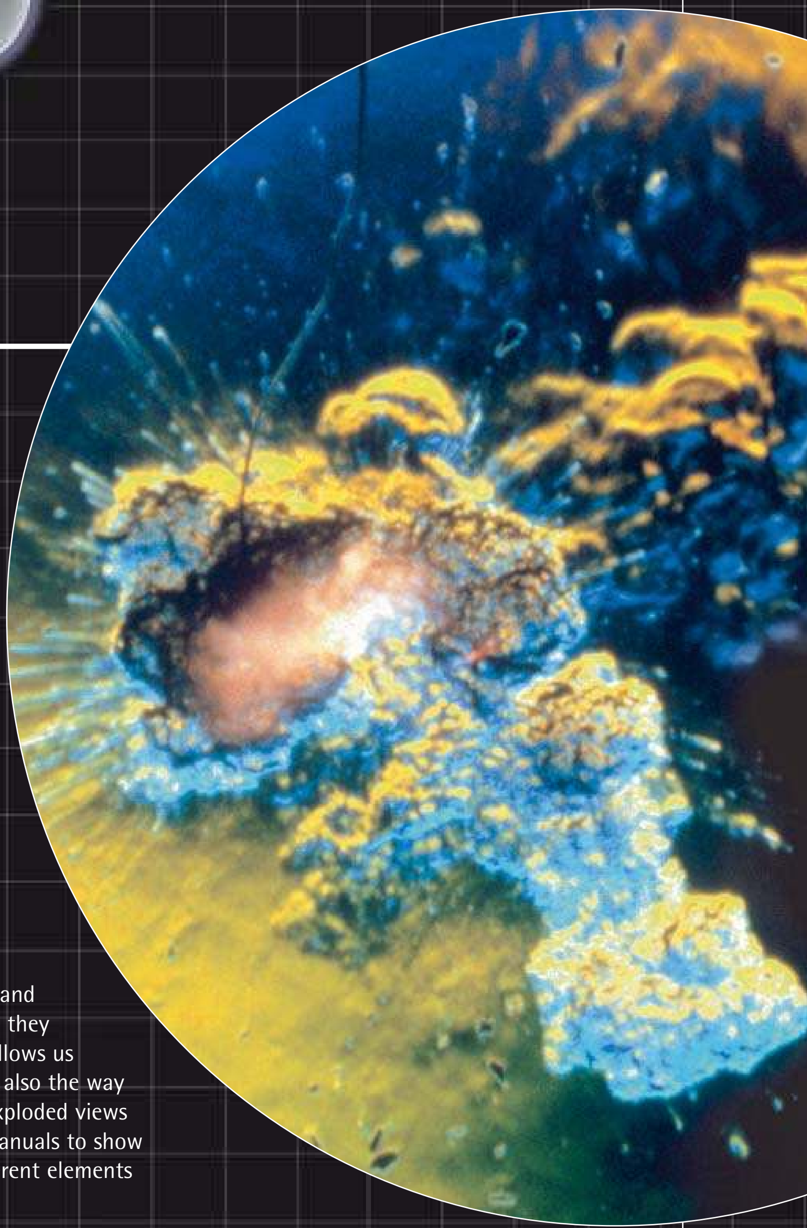
▲ INFRARED THERMOGRAPHY
Infrared thermography is a technique that uses a special camera to see heat. Every object, even very cold ones such as ice cubes, releases infrared, or heat, radiation. In a heat picture, or thermogram, higher temperatures show up as brighter areas. Although the images are black and white, they can be coloured to provide as much information as possible. Thermography has many uses including medical diagnosis, search and rescue operations, and monitoring the energy efficiency of buildings.





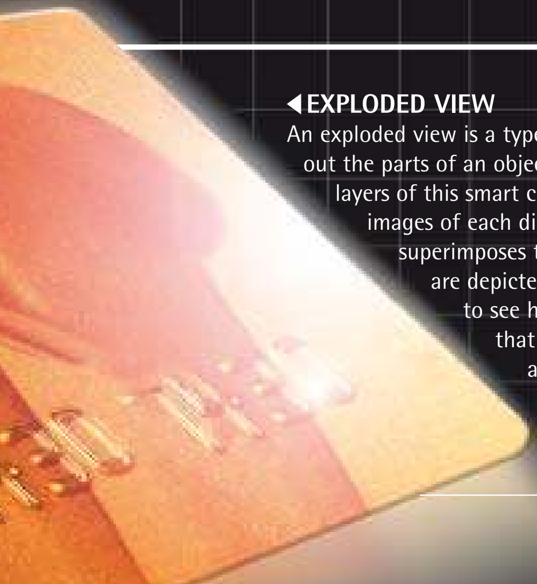
◀ CUTAWAY

A cutaway is an illustration technique that reveals the internal parts of an object. This technique is often used to show how something works, usually in 3D, for example the cushioning technology in a high-tech trainer, or the position of an engine in a car. Cutaways were originally drawn on paper by hand, and were very time consuming. Today, technical illustrators are more likely to create cutaways on a computer screen. With digital imaging software and 3D graphic tools, an artist can create a realistic illustration of an object by superimposing some layers on an image and making others transparent.



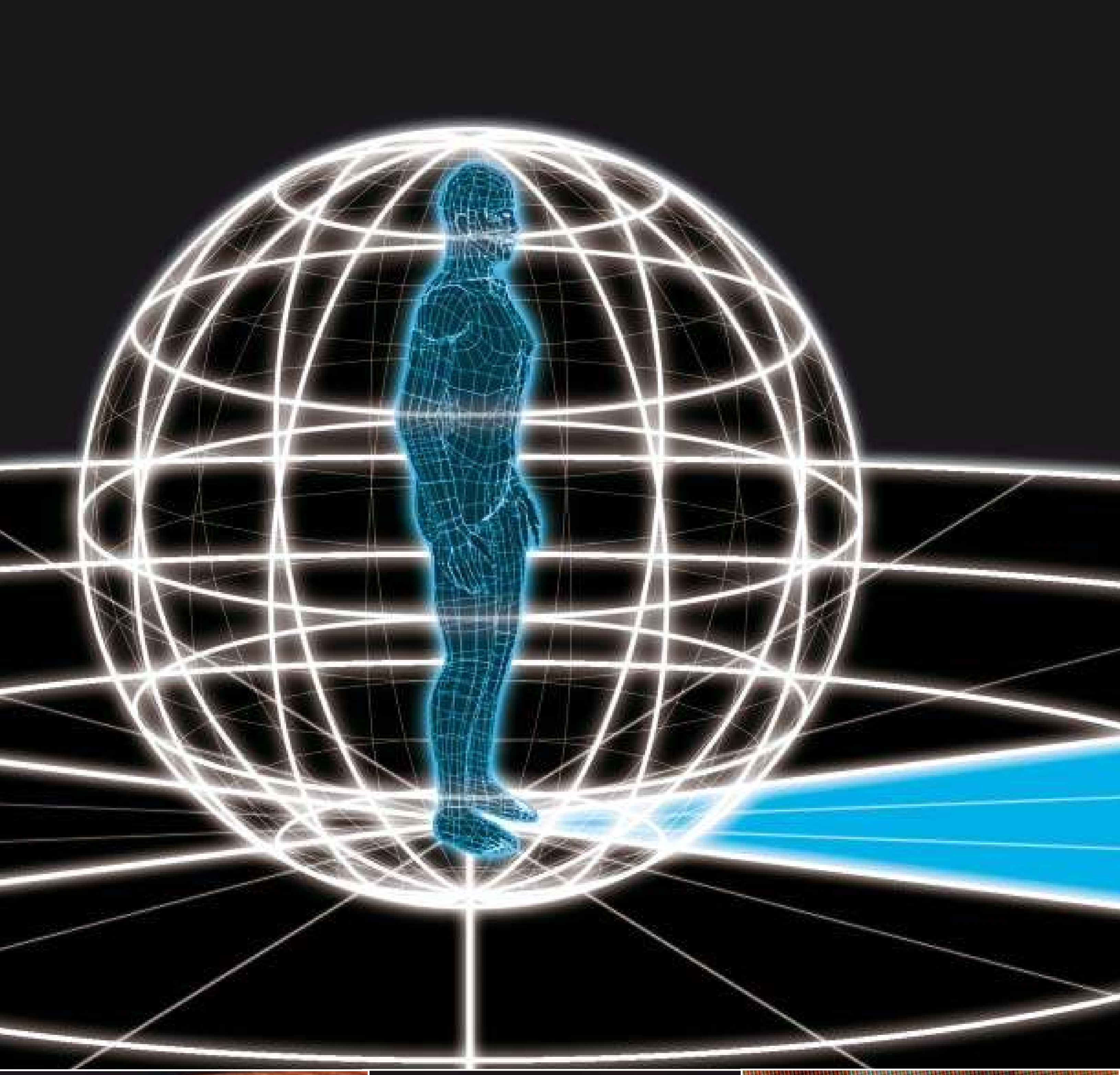
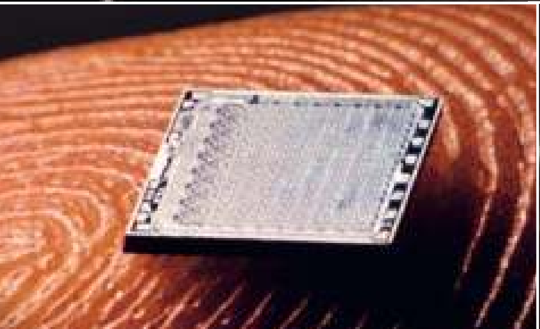
▶ SCHLIEREN PHOTOGRAPHY

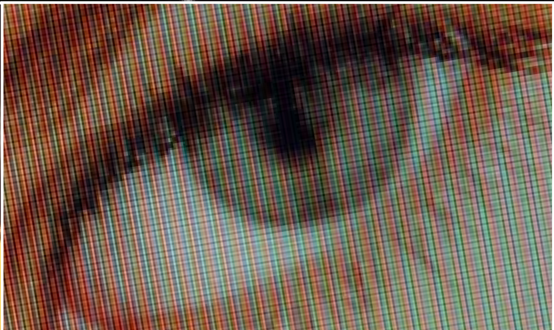
Schlieren photography is used to photograph the flow of air around an object, for example, an aircraft in a wind tunnel. In this image the technique has been used to capture the shockwaves caused by an exploding firecracker. Schlieren photography works because a fast moving object disturbs the air, squashing it in some places and stretching it in others. This causes changes in air pressure and density. When light passes through the air, the differences in density make it refract (bend), causing the image to become lighter or darker where this happens. Colour is added to the image with the use of filters.



◀ EXPLODED VIEW

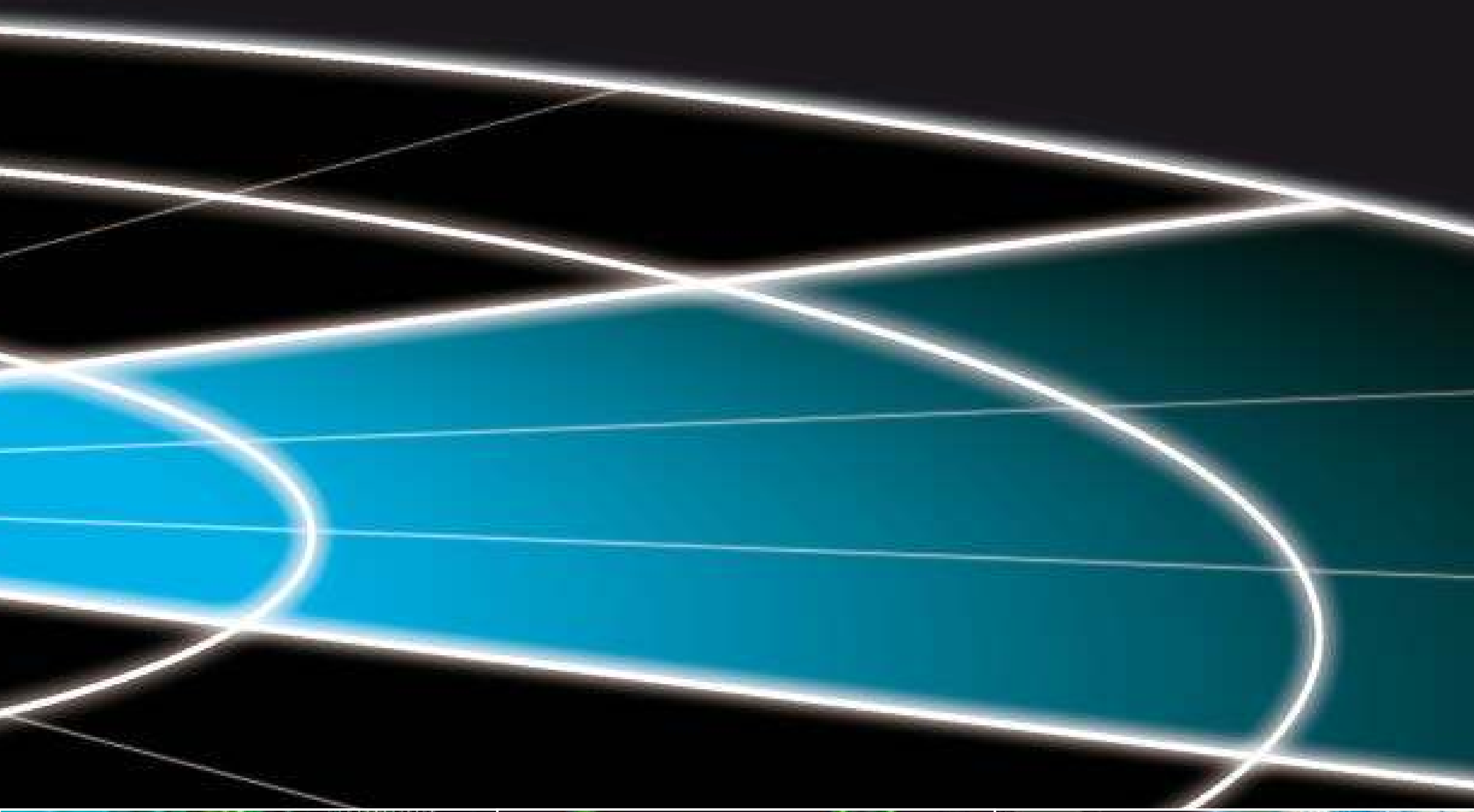
An exploded view is a type of illustration that separates out the parts of an object, for example the different layers of this smart card. A computer uses separate images of each different element of the object and superimposes them on a main image so that they are depicted in their correct order. This allows us to see how the parts fit together and also the way that they relate to one another. Exploded views are often found in technical manuals to show the order in which the different elements need to be assembled.



>>CONNECT

Microchip >> Mobile phone >> Fibre optics >> Digital radio >> LCD TV >> Voice recognition >> Pet translator >> Iris scan >> Neon >> Internet >> Video link >> Satellite



Communication systems have existed for thousands of years. A postal system, with relays of riders to deliver messages, was used in Ancient Persia (now Iran) as long ago as the 6th century BC. Until the 1800s, sending post in this way was the only method of long-distance communication. The time it took for a message to be received depended on the speed of the carrier.

REMOTE CONTROL

The electric telegraph was widely used by the mid-1800s and this meant that, for the first time, messages made up from a special code could be sent and received without delay. With the invention of the telephone in 1876, people could have conversations with each other even if they were hundreds, and later thousands, of kilometres apart.

Today, digital technology has revolutionized the way we communicate. Digital means turning information – images, words, sounds, as well as text – into streams of ones and zeros that can be read by digital devices such as computers or mobile phones. Digital technology allows millions of telephone calls, text messages, and emails to be sent instantly around the world. None of this would be possible without computers and fibre-optic cables which can carry 100 billion ones and zeros per second at the speed of light.

When digital computers were developed soon after World War II, they took up whole rooms and were no more powerful than a digital watch is today. This might seem puny compared to today's computers, but even so, in 1969, a computer was able to make the calculations that helped astronauts land on the Moon.

Since then, computers have become much smaller. As they have reduced in size and cost, they have also become much more powerful and user friendly. The processing power of a computer is found in its microchip, or electronic brain. A microchip has millions of tiny switches, or transistors, made chemically on the surface of a wafer of silicon, a chemical element most commonly found in sand. These electronic switches allow computers to carry out mind-boggling numbers of calculations every single second.

> "We can share information, exchange ideas, and form online communities with people thousands of miles away."

Two or more computers connected together form a network. From tree roots to spiders' webs to our own brains, networks are everywhere. By linking many simple units, very complex structures can be formed. The Internet connects hundreds of millions of computers together worldwide so they can access the World Wide Web – the part of the Internet that provides information in the form of websites. In 1993 there were only 50 sites. Today, there are more than eight billion. This immensely powerful network of computers gives us instant access to a vast amount of knowledge. You can also log on to email a friend on the other side of the world, book a holiday, buy or sell goods, or download music. The Internet has transformed the computer into the ultimate communications device, and shrunk the world to a global village.

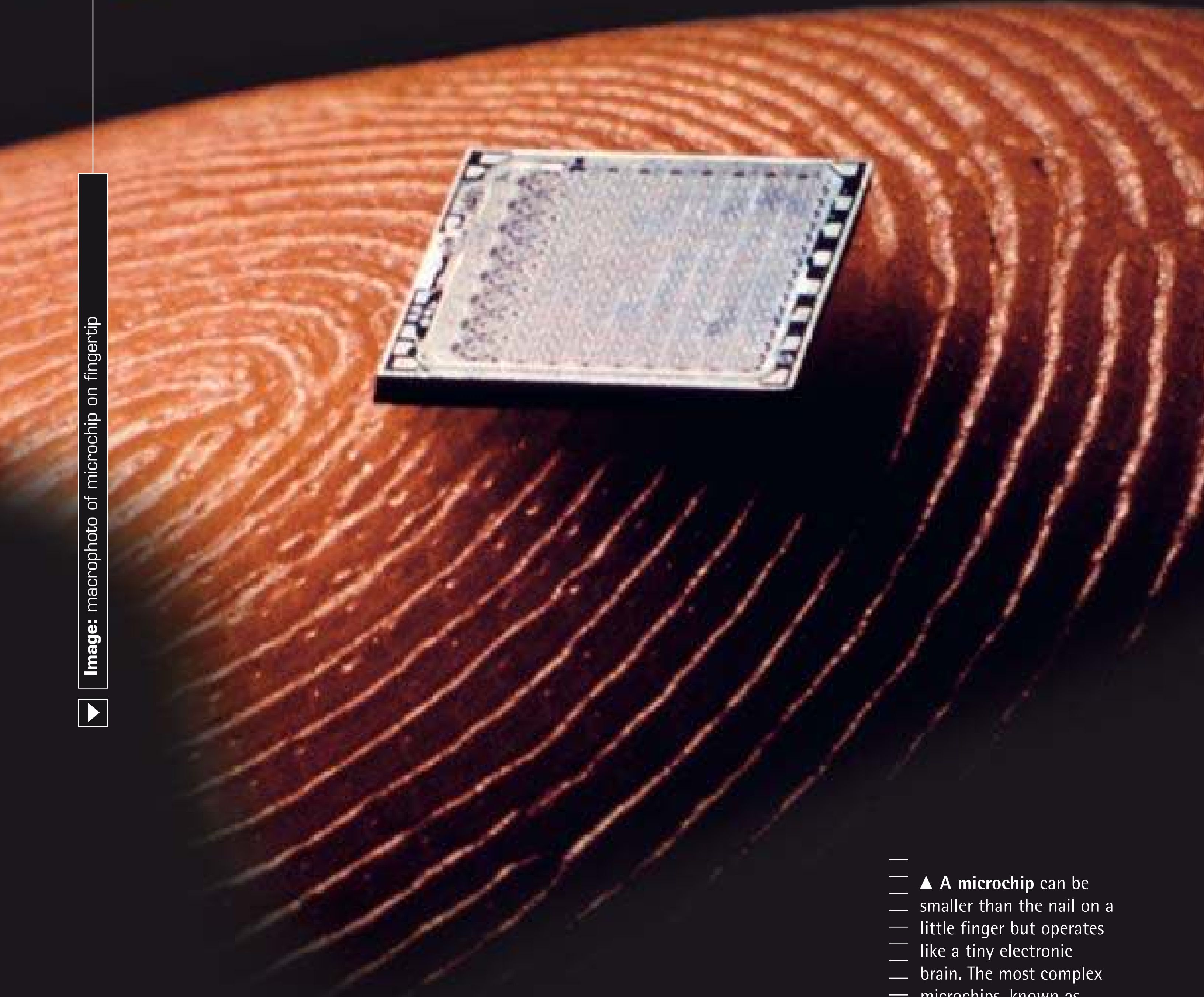


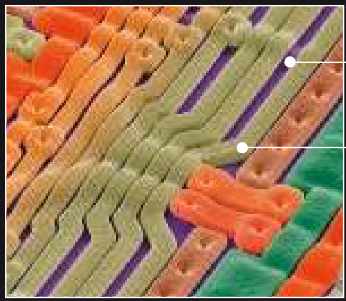
Image: macrophoto of microchip on fingertip

▲ **A microchip** can be smaller than the nail on a little finger but operates like a tiny electronic brain. The most complex microchips, known as microprocessors, can pack the processing power of an entire computer onto a single chip.

MICROCHIP

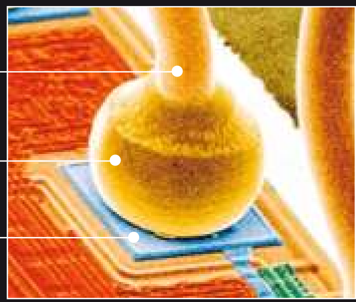
Microchips used in the latest computers can processs about 10,000 million instructions every second. Since 1971, the number of transistors that can fit on a single chip has increased from over 2,000 to a staggering 500 million.

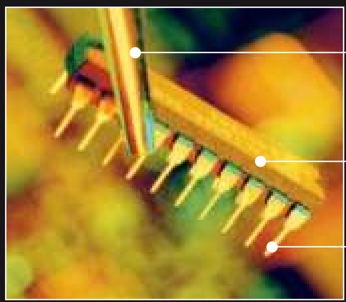
MICROCHIP: KEY FEATURES



1. A microchip reveals its secrets when magnified almost 1,200 times. Transistors (purple) are built up in layers on the chip, with metallic connecting tracks positioned above them. These tiny transistors switch on and off to control electronic signals, processing thousands of pieces of information a second.

2. Gold microwires – magnified here almost 300 times – link tiny, electrical contact points at the edge of the chip to metal legs on its casing. Although gold is expensive, it is an excellent conductor of electricity, and helps to prevent the microchip from overheating.





3. A microchip is so small and fragile that it has to be protected in a casing made of plastic or ceramic. Each of the casing's metal legs, which extend from the contact points inside the chip, can be soldered into a larger electronic circuit to connect the chip to other components.

BACK

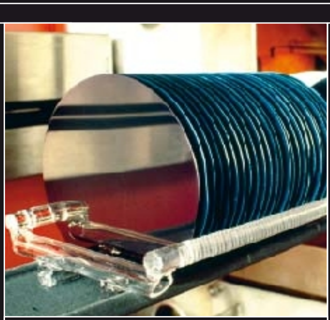
In 1958, the invention of the integrated circuit – a method of shrinking entire circuits onto microchips – led to more affordable electronic goods.

FORWARD

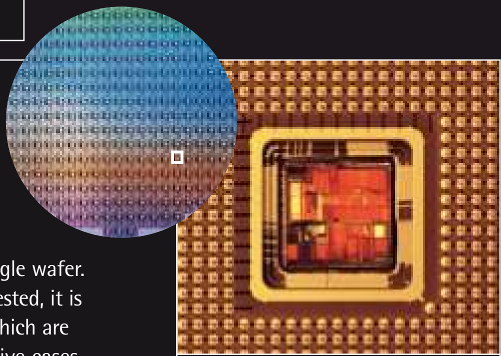
Scientists are developing a microchip implant for the eye that stimulates cells around the retina. This may help blind people to see again.

Making a silicon chip

▶ Microchips are made from an element called silicon. They start life as crystals, which are grown from molten silicon to become cylinders over 1 m (3 ft) long and up to 30 cm (1 ft) in diameter. Each cylinder is then sliced into discs called silicon wafers.


Silicon wafers

▶ The silicon wafers are heated in a furnace and etched with chemicals, which form the tiny tracks and transistors on their surface. Hundreds of chips can be made on a single wafer. Once the wafer has been tested, it is cut into individual chips, which are then mounted into protective cases.


Silicon wafer and single chip

▶▶ See also: Microprocessor p246, Motherboard p170, Smart card p182, Trainer p50

MOBILE PHONE

Image: close-up of Motorola Moto Razr V3

Mobile phones let you make or take calls wherever you happen to be. A quarter of the world's population now make their phone calls this way and around 800 million mobile phones are in use worldwide.

Powerful loudspeaker can work as an earpiece or speaker-phone.

Screen has a 176 x 220 pixel (colour dot) display that can show photos taken by the built-in camera. A graphic accelerator chip allows it to play films, music videos, and games.

Ultra-thin keypad is a third of the thickness of a conventional phone keypad. Its built-in blue light glows so that numbers are visible in the dark.

This mobile phone is a handheld personal communications centre, with email, Web browser, and state-of-the-art video and games player. It has a built-in camera and two colour screens (one on the inside of the case and another seen when the case is closed). It weighs just 95 g (3.35 oz).

BACK

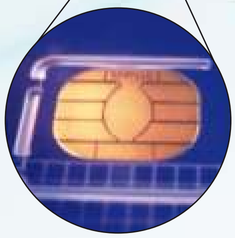
The first mobile phone network, Advanced Mobile Phone System (AMPS), appeared in Chicago, USA in 1978. It used a system of ten cells to link 2,000 customers.

All mobile phones will have built-in multimedia players that can stream (simultaneously download and play) music and video from the Internet.

FORWARD

Digital camera has a zoom lens that can magnify up to four times. Photos taken are stored in the phone's memory and can be sent to other people's phones.

Internal aerial is built into the phone's hinge.



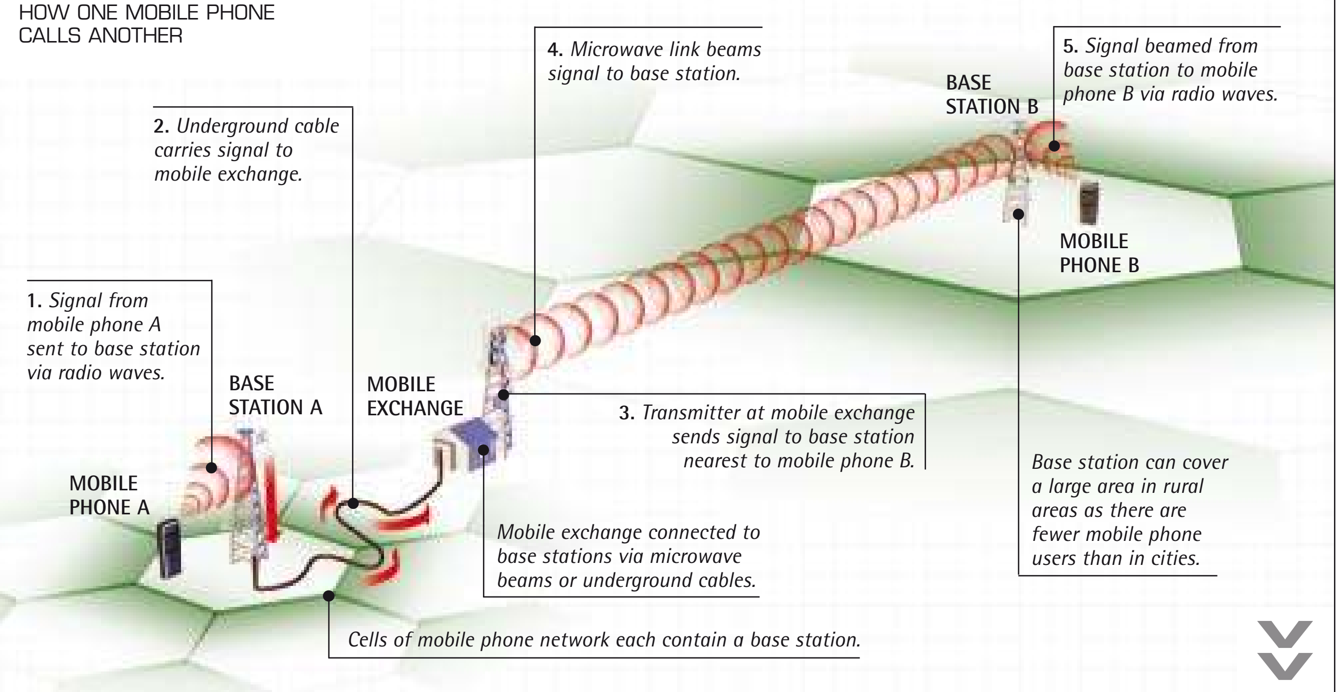
SIM (Subscriber Identity Module) contains a microchip that stores your personal details and can be swapped from phone to phone.

ACTUAL SIZE OF PHONE

▶▶ See also: Battery p94, Digital radio p22, Internet p38, Voice recognition p28

HOW MOBILE PHONES WORK

HOW ONE MOBILE PHONE CALLS ANOTHER



Mobile phones operate within a network of cells – areas covered by a radio transmitter mast known as a base station. Cells vary in size but overlap slightly, so that when you move from one cell to another your call can be handed off (passed without interruption) from one cell to the next. A central mobile exchange links the cells; it also connects one mobile network (usually operated by one company) to other mobile networks and to the landline (wired-phone) network.

Mobile phones send and receive calls as streams of digital data. This has many advantages over the analogue technology still used in many landlines. There is less interference and better sound quality. Digital calls can be encrypted (scrambled) to prevent eavesdropping. Mobiles also send and receive voice, fax, text, and Internet data. Mobile networks can carry more digital calls than landline networks. Some send information using packet switching (known as GPRS), just like the Internet.

◀ **Bluetooth**® headset with built-in microphone and earpiece speaker, lets you answer calls and talk to people without touching the phone itself. Bluetooth® is a method of controlling electronic devices, without wires, over short distances. Signals are sent via short-range radio waves.

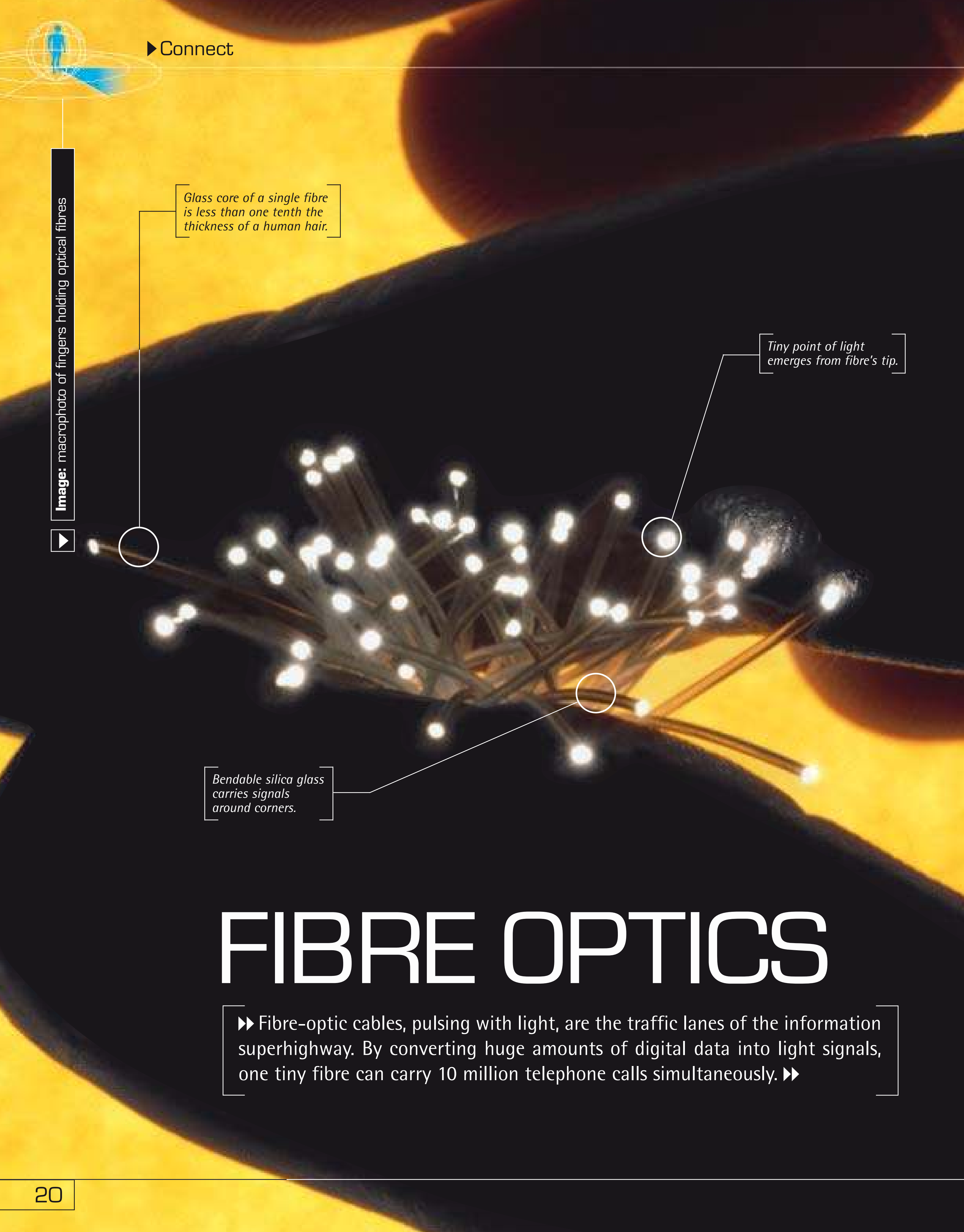


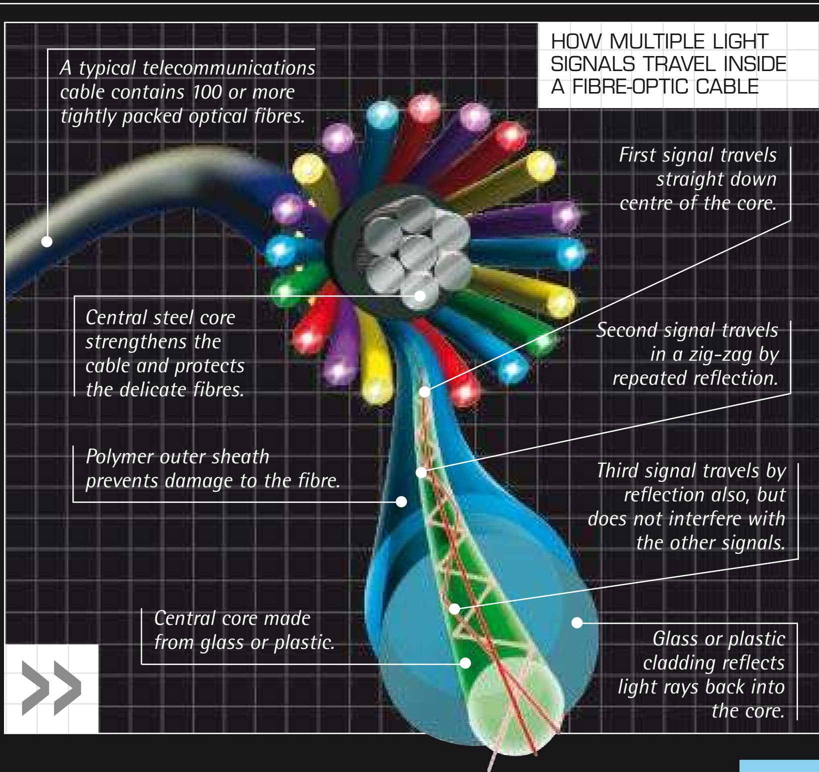
Image: macrophoto of fingers holding optical fibres

FIBRE OPTICS

Fibre-optic cables, pulsing with light, are the traffic lanes of the information superhighway. By converting huge amounts of digital data into light signals, one tiny fibre can carry 10 million telephone calls simultaneously.

HOW FIBRE OPTICS WORK

Information transmitted by fibre optics starts out as an electric current carrying a stream of digital data. A light source, often a laser, turns the current into pulses of light and fires them into the cable. At the receiving end, a photodiode (light-detecting device) receives the light pulses and turns them back into an electric current that re-creates the original stream of data. Light pulses travel down the fibre's core via different paths, known as modes, by reflecting off the surrounding cladding. In multiplexing (shown right), different streams of information are sent through the core of the fibre at the same time using a slightly different wavelength of light for each stream. Light can travel in zig-zags for short-range communications, but for longer distances, much thinner fibres are used that send light signals via the more direct route, straight down the fibre's centre.



Optical fibres are hair-thin strands of glass, or sometimes plastic, that transmit digital information at the speed of light – fast enough to circle Earth seven times a second. They cost less and carry more signals than the copper wires that they are replacing. International phone calls and high-speed Internet connections are now much cheaper thanks to fibre-optic cables.

Making optical fibres

The glass core of an optical fibre starts as a thick, solid rod known as a preform. This is made by pumping two gases, silicon dioxide and germanium dioxide, into a hollow tube mounted on a slowly turning lathe. A burner travels up and down the tube, heating it from below until a solid glass core has completely formed inside it.


Burner heating preform in lathe


Pulling and shaping thin fibres

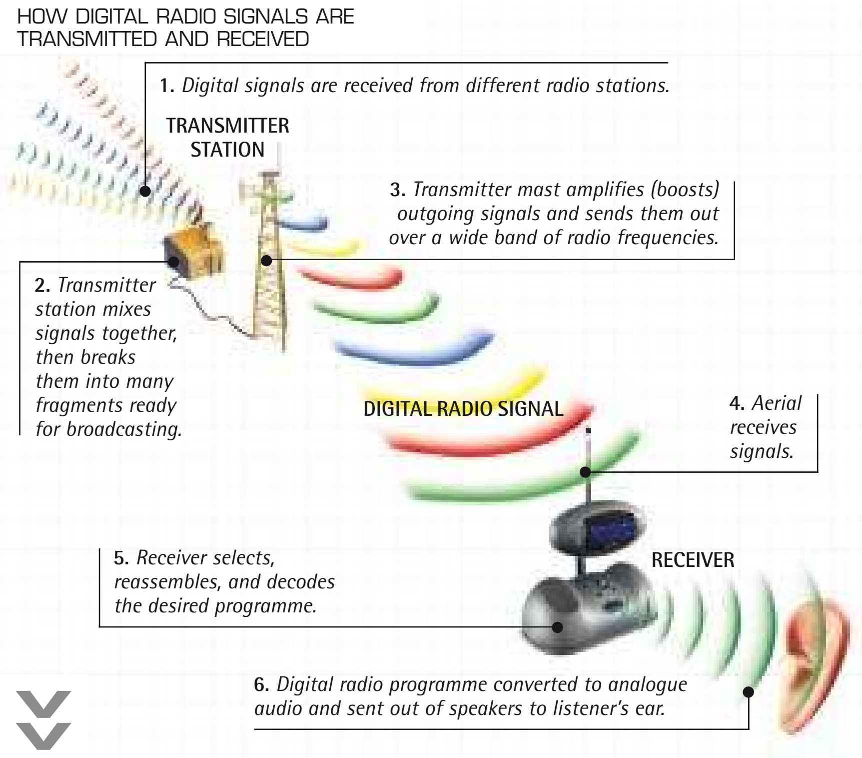
The preform is lowered into a tower at 1,900°C (3,500°F). As the vertically hung glass melts, it stretches under its own weight. A machine at the base of the tower pulls and shapes the molten glass into thin cylindrical fibres. A laser measures the fibres and the machine speeds up or slows down to keep their diameter constant.

See also: Camera capsule p212, Mirror p90, Video link p40

DIGITAL RADIO

Digital radio sends programmes through the air as numeric codes. Unlike analogue radio, which can be affected by buildings and other obstacles, digitally coded signals deliver clear sound even if you're in a moving car or far from a transmitter.

HOW DIGITAL RADIO WORKS



In analogue radio, each radio station beams signals through the air on a separate, narrow band (range) of radio waves. As the signal travels, buildings, hills, and electrical equipment can interfere with it. Some radio waves never arrive, causing gaps in transmission; others are distorted, and the listener hears hiss, crackle, and stations leaking into each other's frequencies. With digital radio, programmes are turned into digital codes (long strings of zeros and ones), each of which represents a fraction of a second of music or speech. The strings of numbers are broken into fragments, and then transmitted over a wide band of radio waves. Each fragment is sent more than once, at slightly different times, and over slightly different radio frequencies. Even if some fragments are lost along the way, the radio can piece together enough to form a clear and complete programme.

This digital radio, called The Bug, has a built-in memory chip that records incoming radio signals. At the push of a button, you can pause and even rewind live programmes. Unlike an analogue radio, it displays the title and singer of a song being played. The display also shows the station name, which makes it easier to tune.

Speaker on each side allows for clear stereo sound.

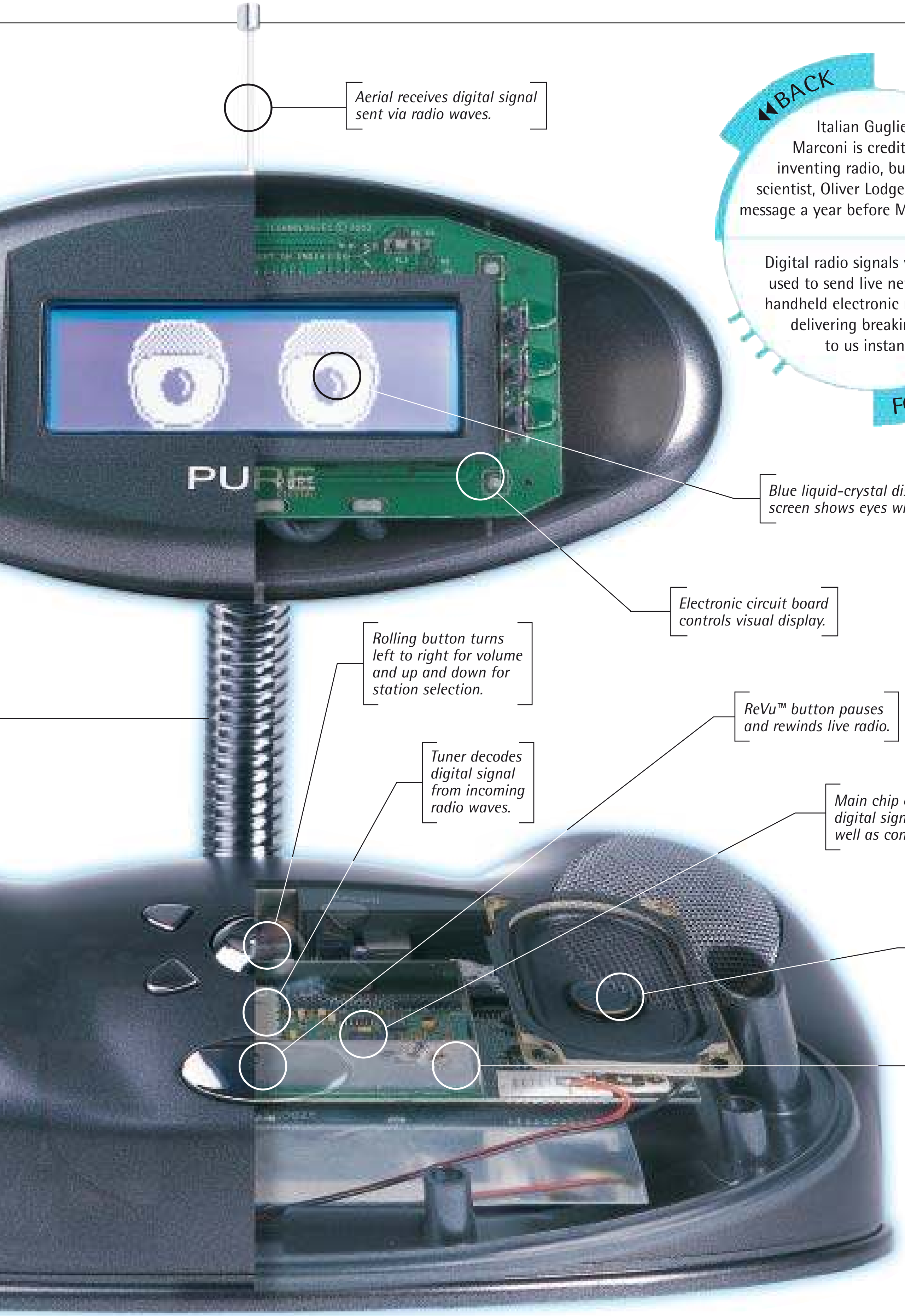


Image: cutaway of PURE Digital's Bug radio

◀◀BACK

Italian Guglielmo Marconi is credited with inventing radio, but a British scientist, Oliver Lodge, sent a radio message a year before Marconi in 1894.

Digital radio signals will soon be used to send live news feeds to handheld electronic newspapers, delivering breaking news to us instantly.

FORWARD▶▶

▶▶ See also: Headphones p74, LCD TV p24, MP3 player p70, Radio waves p249

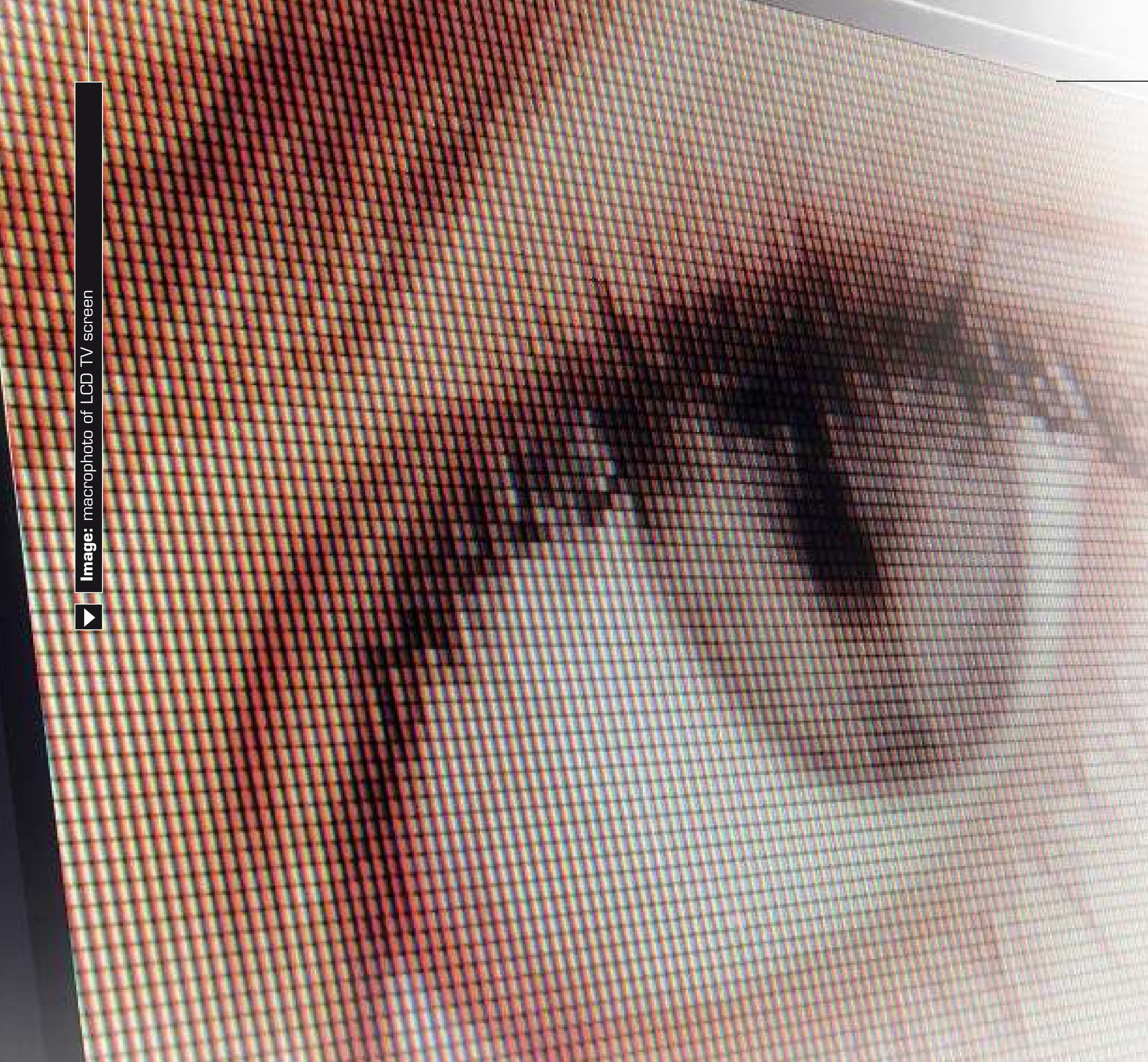


Image: macrophoto of LCD TV screen

▲ **Tiny coloured squares** known as pixels make up the images on a TV screen. LCD (liquid-crystal display) screens, such as this one, are used in an ever-increasing number of televisions. They are also used in computer monitors, mobile phones, and digital music and movie players.

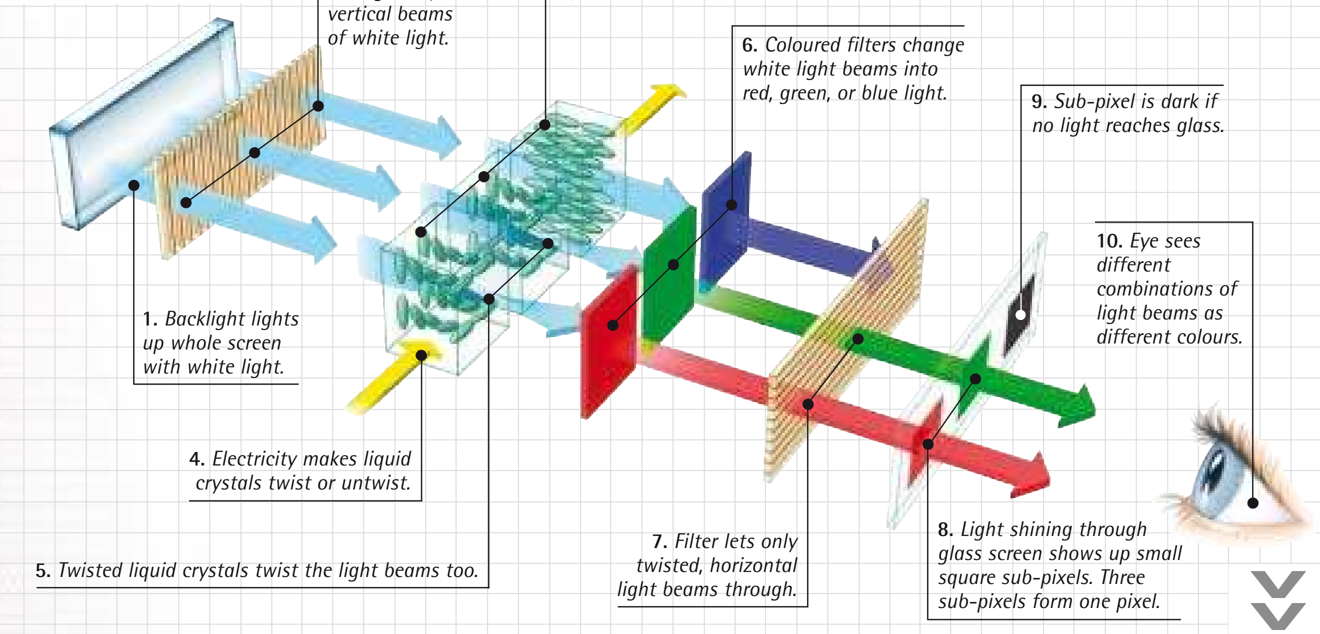
LCD TV

There are an estimated 1.5 billion television sets in the world today – one for every four people on the planet. LCD TVs are now the flattest, lightest, most reliable, and energy-efficient TVs around.

See also: Camera p62, Games p64, Laptop p168, Light p246

HOW AN LCD TELEVISION WORKS

HOW LIQUID CRYSTALS CONTROL PIXEL COLOURS



An LCD screen is made up of several million tiny squares called pixels, each containing a red, green, and blue sub-pixel. Each sub-pixel is controlled by a group of microscopic liquid crystals positioned behind it. Electronic circuits inside the TV work out which pixels need to be switched on and off to make a picture. They pass tiny electric signals through the liquid crystals so that their molecules twist and untwist, acting like tiny light switches to turn each sub-pixel on and off.

As their name suggests, liquid crystals have certain things in common with both liquids and solids. In solids, molecules are largely fixed in place. In liquids, molecules can move more freely. When electricity flows through liquid crystals, the molecules twist or untwist, but stay in much the same place. Their twisting can be precisely controlled by adjusting how much electricity flows through them. This makes them perfect for controlling the pixels of an LCD television.

BACK

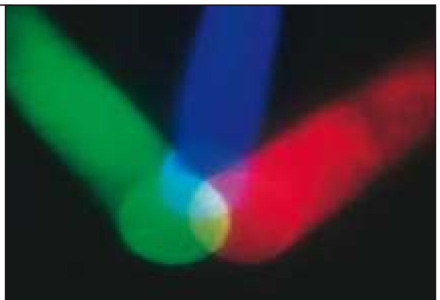
Austrian botanist Friedrich Reinitzer discovered liquid crystals in 1888. LCD screens were first used in the early 1970s for wristwatches and calculators.

Liquid-crystal displays may soon be fitted to windows to replace blinds or curtains. At the flick of a switch they will block out light to darken a room.

FORWARD

Mixing light

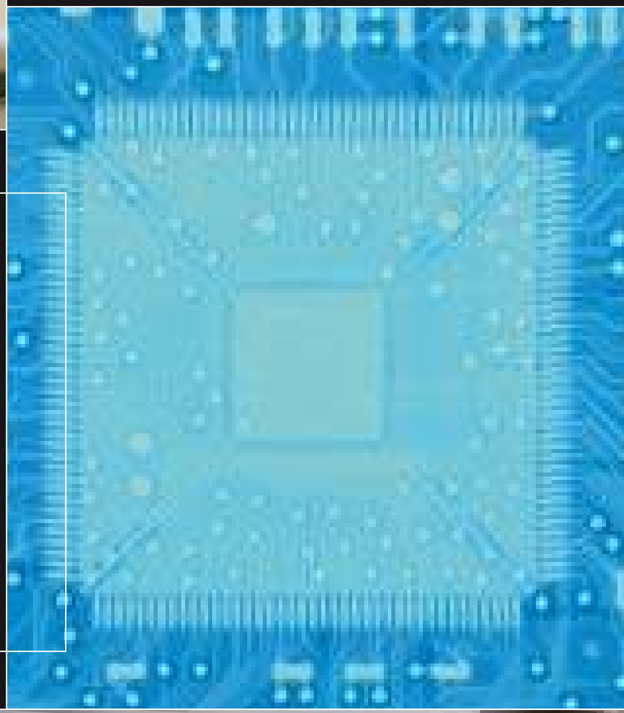
It is possible to make any colour by mixing together red, blue, and green light. Red and blue mix to form a bright purple called magenta. Blue and green lights combine to make a bright blue known as cyan. Yellow is made where red and green overlap. When all three colours shine equally, they make white light or shades of grey (depending on their brightness). Black occurs if no light shines.



Mixing green, blue, and red light

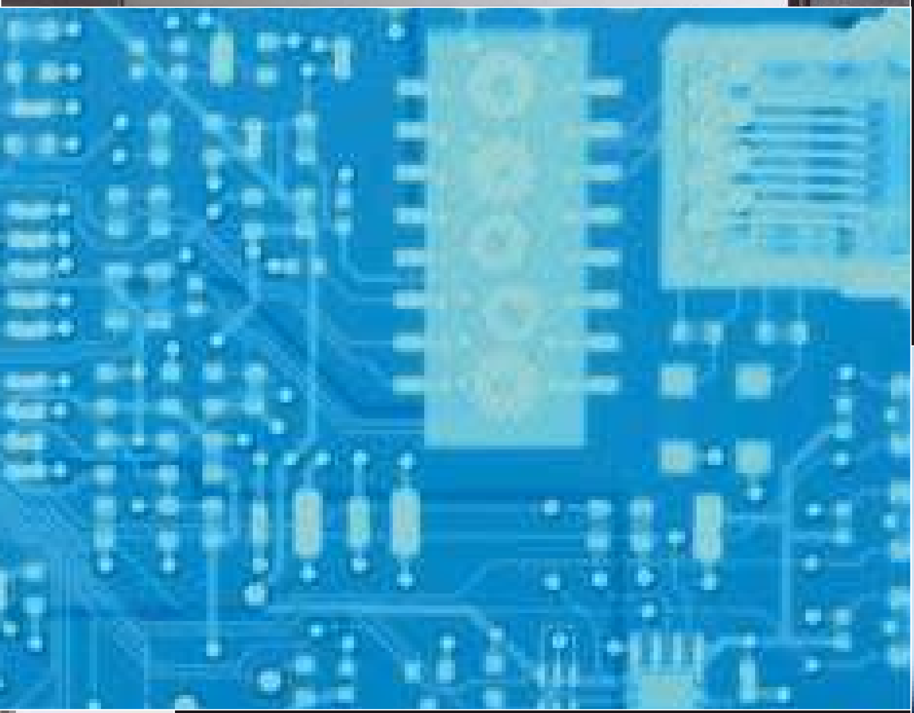
TOYS

Web cam
Computers can become videophones using a camera the size of a golf ball. A Web cam is a digital camera that plugs into a computer, captures around 30 still pictures every second, and sends them across the Internet so that they play like a video on another person's computer screen. If two computer users have Web cams they can see each other while chatting.



Wi-Fi card
Wireless Fidelity, or Wi-Fi, connects a computer to the Internet using invisible radio waves instead of cables. Plugging this credit-card-sized circuit board into a laptop computer allows Internet access at Wi-Fi hotspots – places with equipment to send and receive radio signals from your Wi-Fi computer.

Electronic toys are being developed to make our lives easier and more fun. People can communicate while on the move, talk face-to-face over the Internet, and watch TV programmes where and when they want.



Digital television

With interactive features and access to more channels, digital televisions are gradually replacing older analogue TV sets. Some digital TVs contain hard-drive memories similar to those in a computer. They can record, store, and play back hours of TV programmes and can also pause live television so not a second is missed.

Sat-Nav PDA

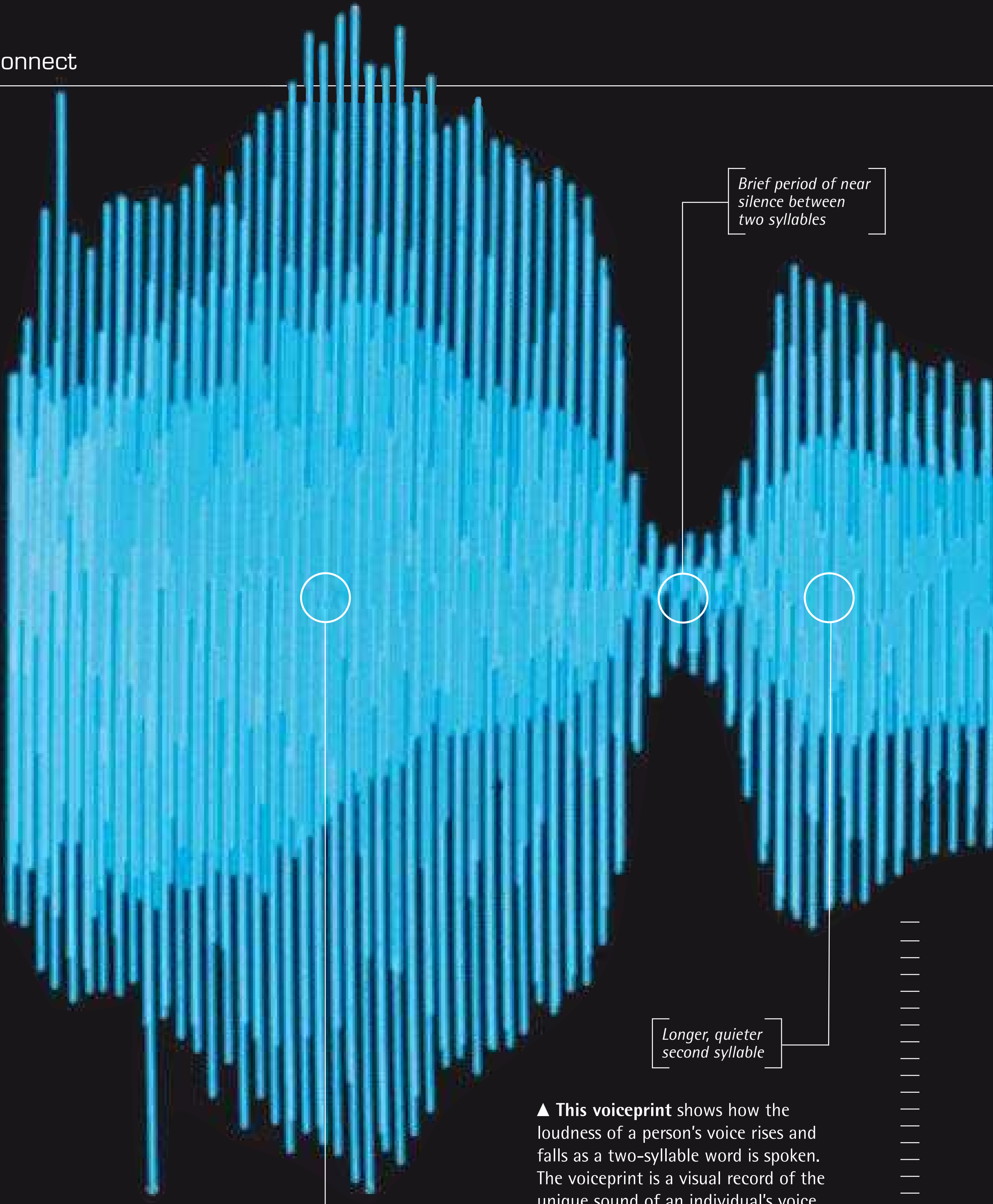
This palm-sized computer is known as a personal digital assistant (PDA). It is fitted with a satellite navigation (Sat-Nav) receiver that uses signals from orbiting satellites to pinpoint its location. Its colourful screen can then display 3D maps of the surrounding area, and it can even speak directions. Touching the PDA's screen with the stylus pen can select menu options and also make notes, which are stored digitally.

MP4 player

Millions of people already own hand-held digital music players that store and play tunes in a computer file format called MP3. But MP4 players take digital technology a step further – they make movies portable too. This MP4 player stores up to 16 hours of films on its 20GB hard drive and plays them on a crystal-clear 9 cm (3.5 in) LCD TV screen.

See also: Laptop p168, LCD TV p24, MP3 player p70, Navigation p154

VOICE RECOGNITION

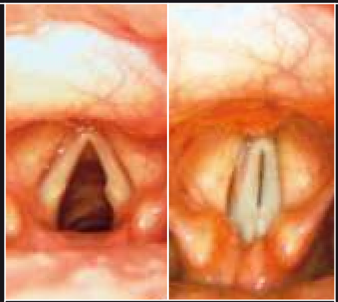


▲ **This voiceprint** shows how the loudness of a person's voice rises and falls as a two-syllable word is spoken. The voiceprint is a visual record of the unique sound of an individual's voice. Voice recognition systems analyse voiceprints to identify the person speaking or the words being said.

Your voice is unique – no one else sounds like you. Voice recognition systems can tell one voice from another. Not only that, they can identify up to 50,000 different spoken words.

The human voice

Our voices are made by vocal cords, two folds of elastic tissue that stretch either side of the throat's larynx (voice box). As air moves up from our lungs, muscles tighten or loosen the cords to create higher- or lower-pitched sounds. Women have short, tight vocal cords so often have higher voices than men.



Vocal cords open and closed

The sounds made by our vocal cords are amplified (made louder) by the larynx. Opera singers have precise control over the volume and pitch of their voices. If they sing one musical note at the right pitch for a long time, they can make a glass vibrate so much that it shatters.

The human voice can shatter glass

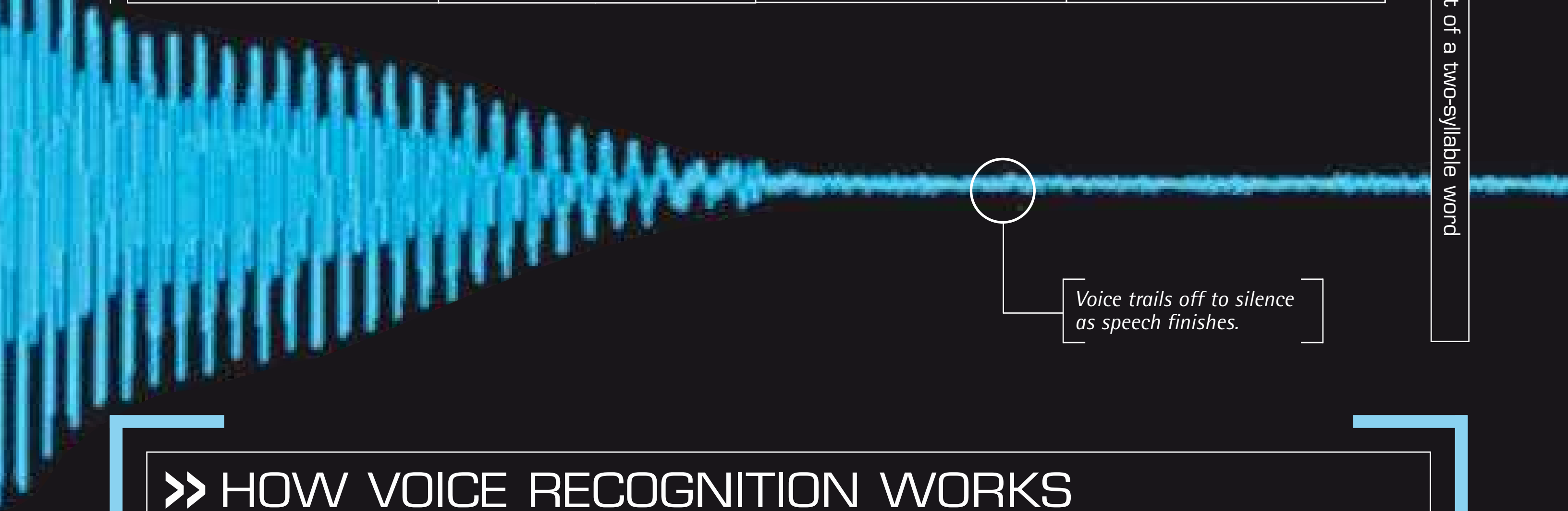
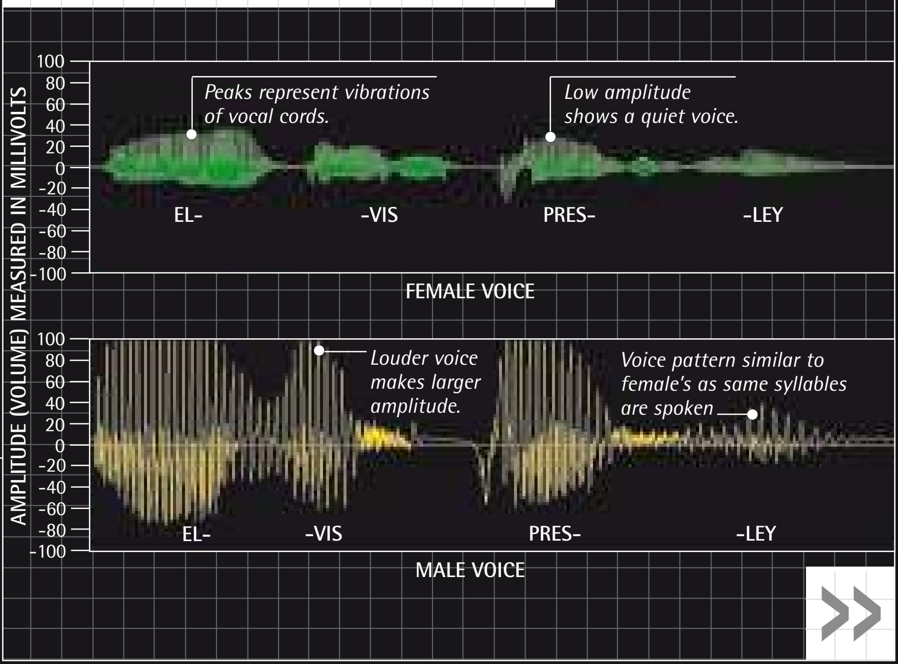


Image: computerized voiceprint of a two-syllable word

HOW VOICE RECOGNITION WORKS

COMPARING THE VOICEPRINTS OF TWO PEOPLE SAYING THE SAME WORDS



Although everyone's voice sounds different, all voices make similar patterns of sound energy when they say the same words. These simple graphs show how amplitude (volume) changes in the voices of two people, a female and a male, in the few seconds it takes to say two words. Speech patterns like this are used in computer voice-recognition systems, where people speak words or commands into a microphone instead of typing them into a keyboard. Before the computer can recognize words, it has to be trained by listening to the voices of hundreds of different people saying many different words. Then, when it hears an unfamiliar voice saying one of these words, it matches the pattern of sound energy to the voice patterns in its memory to find out what the person has said.

See also: MP3 player p70, Pet translator p30, Sound wave p250

Image: close-up of Takara's Meowlingual pet translator handset

PET TRANSLATOR

Sound wave formed by cat's meow travels towards handset's built-in microphone.

Liquid-crystal display (LCD) screen shows translations as picture icons and words.

BACK

Dr Matsumi Suzuki helped to invent pet translation after matching the sounds made by dogs, cats, and dolphins to the behaviour he observed.

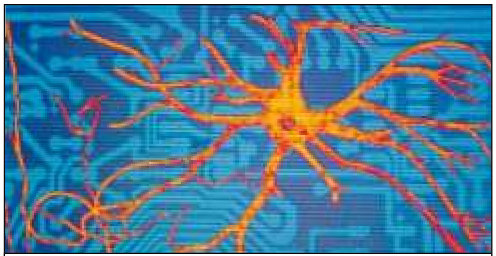
One day, all pets may be implanted with a satellite-navigation tracking chip to help their owners locate them if they get lost.

FORWARD

▲ **A pet translator,** such as this Meowlingual for cats or Bowlingual for dogs, reveals an animal's moods in many different ways. Apart from translating basic noises, it can monitor changes in an animal's behaviour, help with training, and even reveal the early signs of illnesses.

Handheld pet translators capture meows and barks and translate them into picture icons and words. They use voiceprint technology to reveal the secret thoughts of cats and dogs.

Neural networks

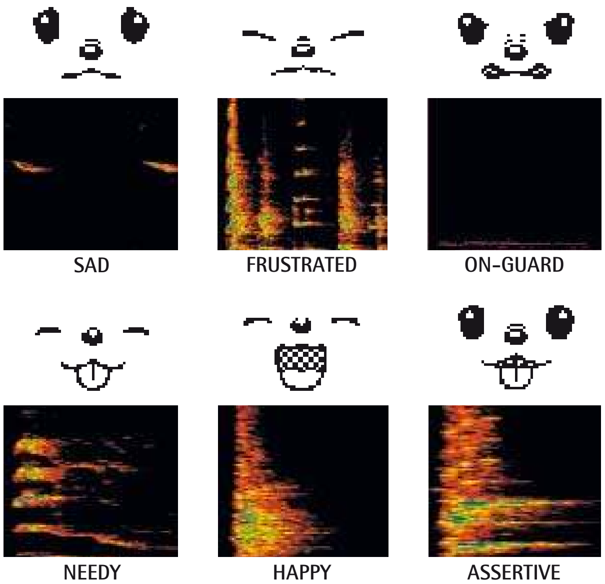


Brain cell (red) and electronic circuit (blue)

▲ Networks of brain cells allow us to recognize other voices. Some computers are programmed to work in the same way. These programs, called neural networks, helped scientists to develop pet translation. After learning to recognize many different animal sounds and their meanings, the neural network is able to decipher new sounds.

PET TRANSLATIONS

Bowlingual's collar and handset work together to capture a dog's bark. A microphone on the collar picks up the bark, which is then turned into a digital signal and beamed through the air via radio waves to the handset. The handset then matches distinctive features of the digital bark to patterns stored in its database.



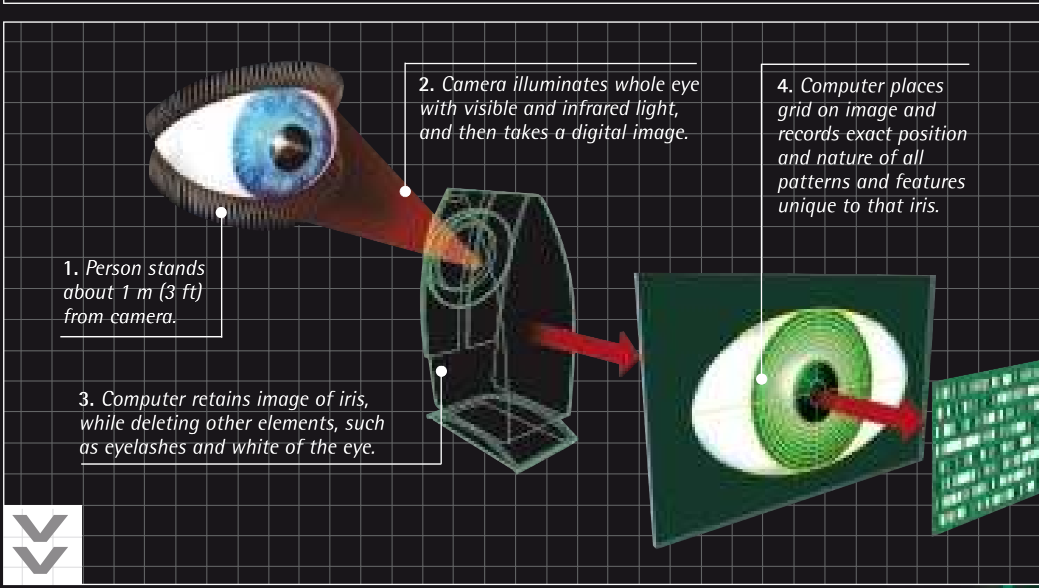
Dogs can produce many different barks and sounds, which all look very different when viewed as digital voiceprints. Bowlingual's handset stores details of 200 different barks, in the form of voiceprints, in a similar way to a human voice recognition system. Although different breeds make different sounds, the translator can usually match a bark to one of six moods. A sad bark involves brief, high-pitched noises, while an angry (on-guard) bark is a mixture of lower-pitched, growling noises that last up to five times longer. Once matched, the handset displays the appropriate face and word translation of the bark.

▶▶ See also: Digital radio p22, LCD TV p24, Voice recognition p28

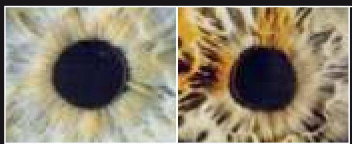
IRIS SCAN

Iris recognition systems are the quickest, most reliable method of identifying individuals so far devised.

HOW IRIS SCANNING WORKS



MAPPING THE IRIS, FROM CAMERA TO DIGITAL CODE



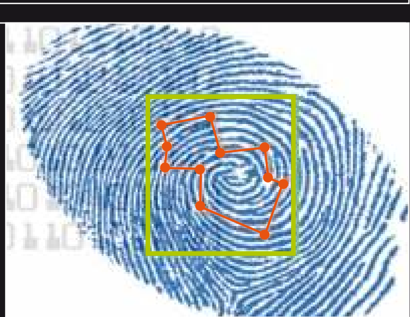
Iris colours, like skin tones, depend on a pigment (colouring) called melanin. Lots of pigment gives a brown iris; less means eyes are blue, green, or grey.

Swirling, coloured iris patterns make all eyes unique – even identical twins have different patterns. A computerized system that recognizes people by their iris patterns is the latest and most accurate method of biometric identification – the science of identifying people by recording their unique biological features. Iris recognition systems are already in use in high-security buildings, such as airports.

The first time a person uses the system, there is a two-minute process in which their eyes are photographed. The resulting image is converted into a digital IrisCode and stored in a database. The next time the individual passes through the system, their iris is scanned again. The system searches for a match on its database of IrisCodes. Within two seconds a match can be found and the person identified.

Fingerprint ID

In this picture, a computer has outlined the central area of a fingerprint in green and highlighted key ridges with red dots. By measuring the dots and the angle of the ridges, the computer turns the fingerprint pattern into a digital code that can be compared with other stored codes. Although fingerprinting is an effective method of identification, the iris recognition system is 1,000 times more accurate.



Computerized fingerprint analysis

BACK

In 1994, British computer scientist John Daugman invented the mathematical process for turning iris patterns into digital codes.

Iris recognition is so reliable that it might completely replace passports and credit-card PIN numbers at cash machines in the future.

FORWARD

▶▶ See also: Camera p62, ID p180, Laser surgery p206, Smart card p182

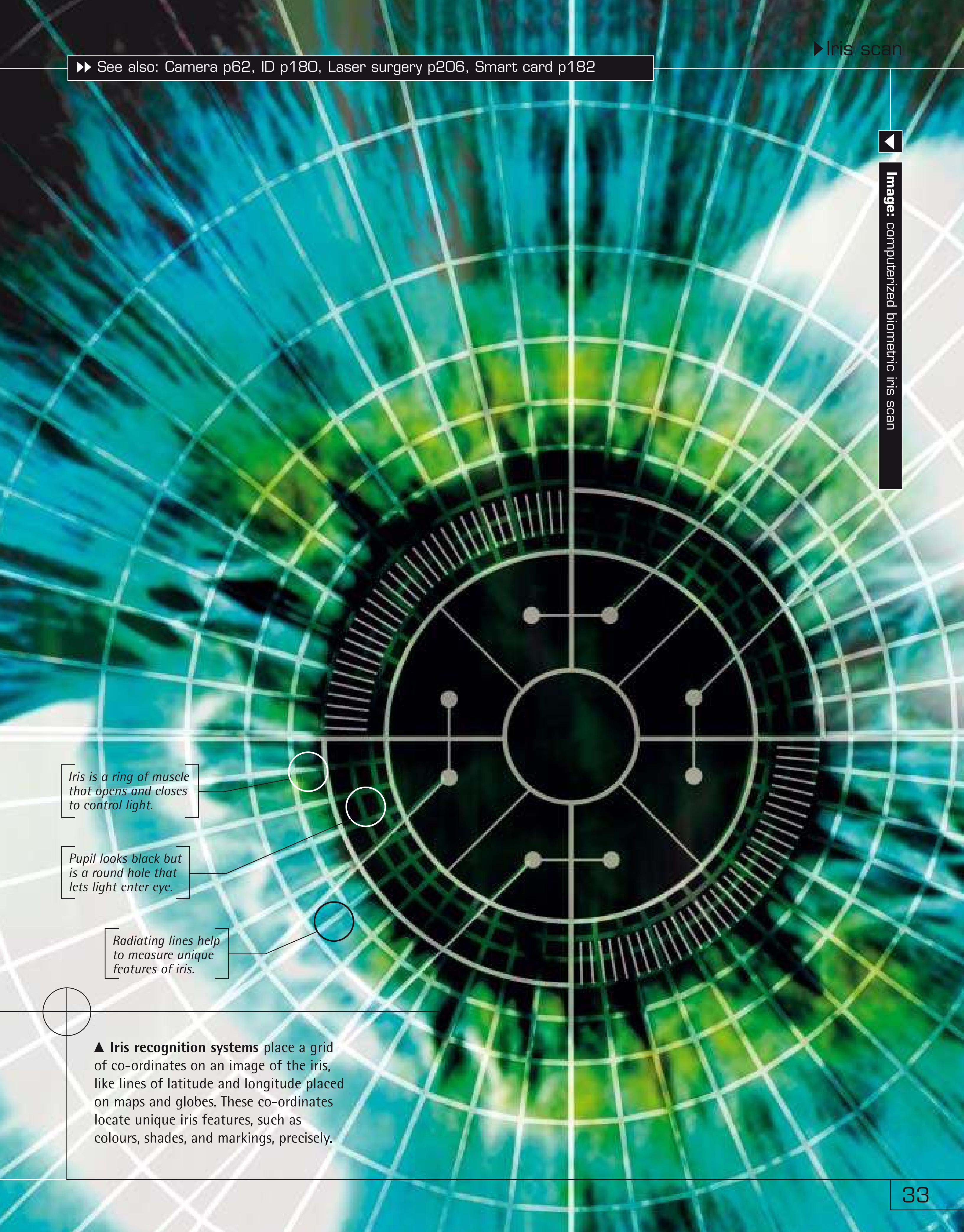


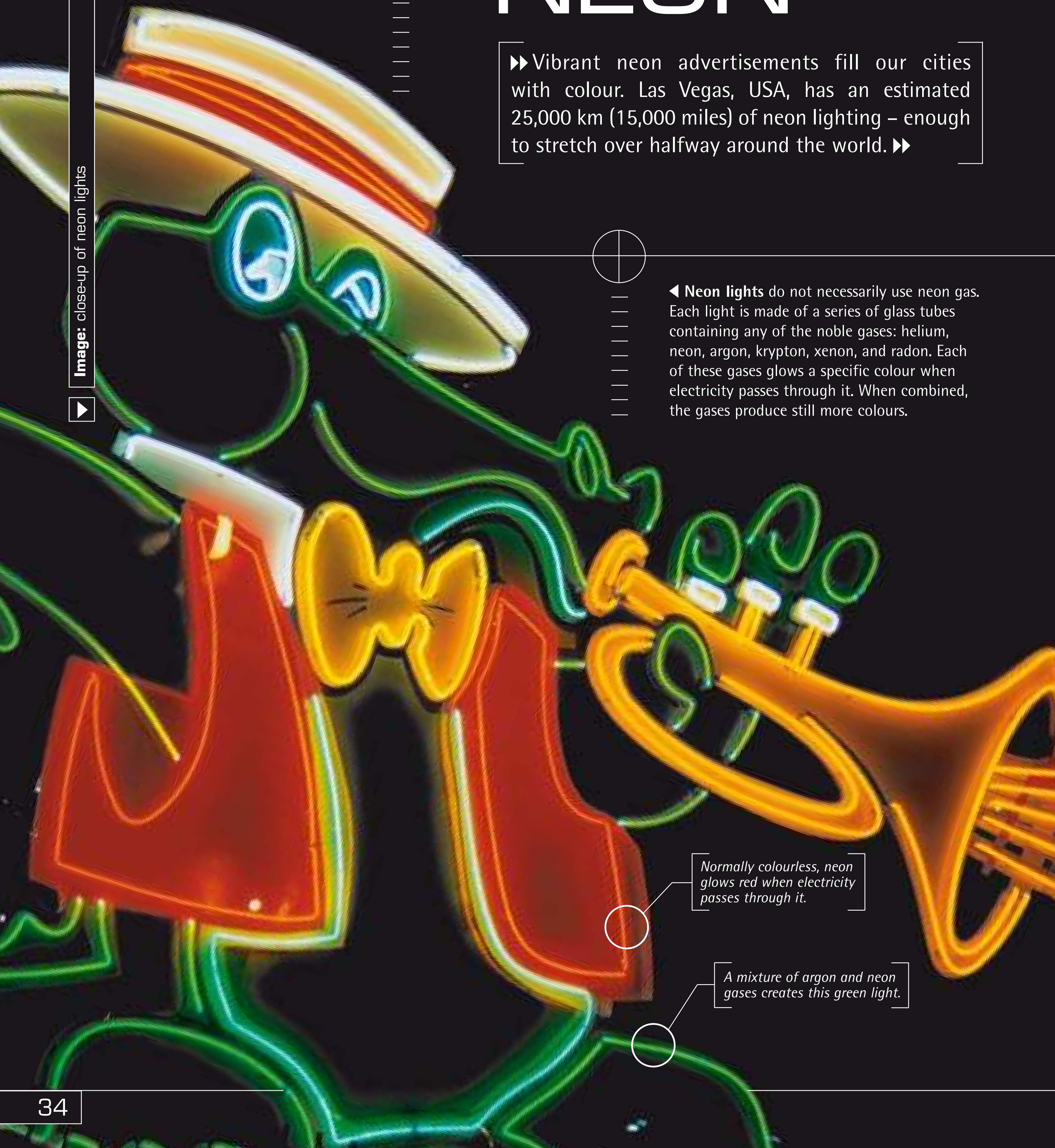
Image: computerized biometric iris scan

▲ **Iris recognition systems** place a grid of co-ordinates on an image of the iris, like lines of latitude and longitude placed on maps and globes. These co-ordinates locate unique iris features, such as colours, shades, and markings, precisely.

NEON

Vibrant neon advertisements fill our cities with colour. Las Vegas, USA, has an estimated 25,000 km (15,000 miles) of neon lighting – enough to stretch over halfway around the world.

Image: close-up of neon lights



Neon lights do not necessarily use neon gas. Each light is made of a series of glass tubes containing any of the noble gases: helium, neon, argon, krypton, xenon, and radon. Each of these gases glows a specific colour when electricity passes through it. When combined, the gases produce still more colours.

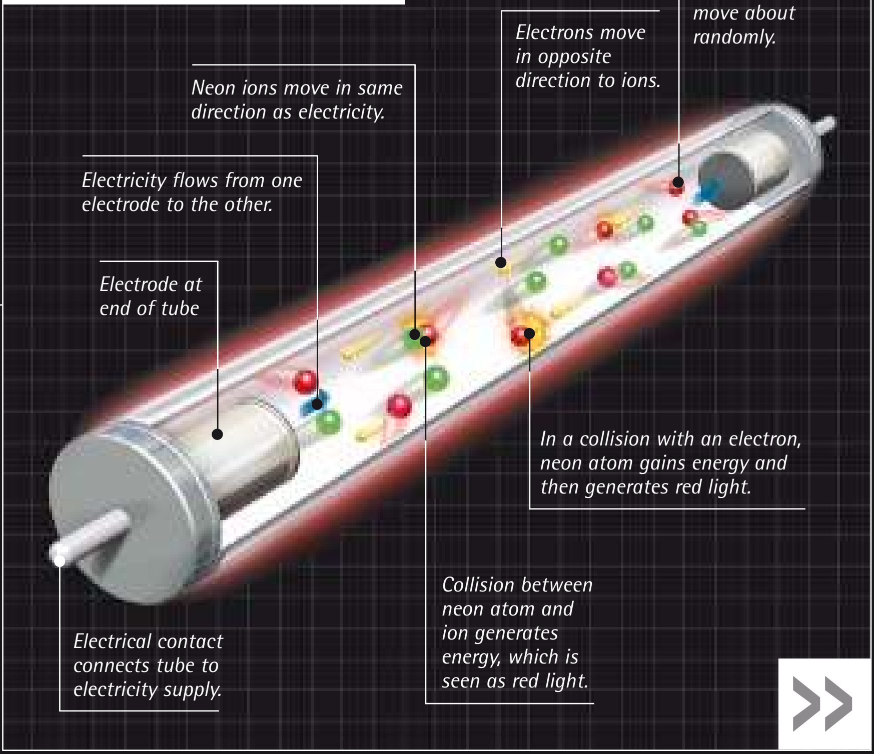
Normally colourless, neon glows red when electricity passes through it.

A mixture of argon and neon gases creates this green light.

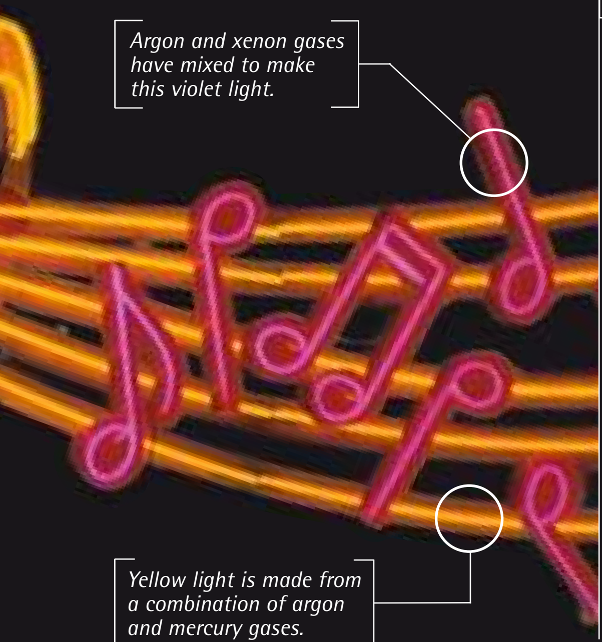
▶▶ See also: Fireworks p78, Light bulb p88, Noble gases p247

HOW A NEON LIGHT WORKS

HOW COLLISIONS INSIDE A NEON TUBE CREATE RED LIGHT



A neon light is a sealed tube filled with neon gas at low pressure. The gas consists of millions of neon atoms, whizzing around randomly. When a high electric voltage (up to 15,000 volts) is applied to the metal electrodes at either end of the tube, it ionizes the gas: some neon atoms lose electrons and become ions. The atoms, ions, and electrons hurtle around the tube in different directions. All these moving particles have kinetic energy (energy of movement). If an atom or ion is involved in a collision, it can absorb some of the kinetic energy. This makes it unstable, however, so it quickly tries to get rid of the energy by giving off particles of light called photons. With neon gas, the light produced appears red. With other noble gases, the photons appear as light of other colours. The noble gases in these tubes also exist in the air around us. They make up about one per cent of every breath we take.



Bioluminescence

▶Living creatures that glow produce light inside their bodies through a process called bioluminescence. This firefly is making bright yellow flashes in its tail through a reaction that turns chemical energy into light. The reaction takes place in its lower body, where a protein called luciferin reacts with oxygen from the air. Fireflies glow to attract mates or to warn off predators.

Night-time flight of a firefly

Warning flash of a jellyfish

◀Jellyfish make light in different ways for different reasons. Some scare off predators with bright warning flashes. Others release thousands of glowing particles to distract enemies. Some even make a luminous slime that sticks to predators to make them visible to other attackers. In the deepest, darkest parts of the ocean, over 90 per cent of marine creatures are bioluminescent.

LINKS

Complex communication networks across Earth and in space are evolving and expanding all the time. These links allow people to contact one another in many different ways, quicker than ever before.

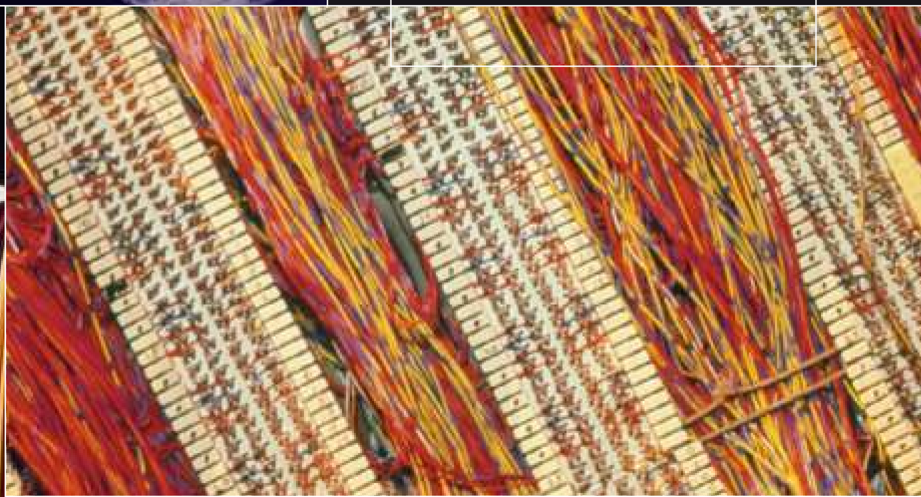
Television links Every television station has a master control room. This uses computers to combine signals from many live and recorded programmes to provide a continuous broadcast. These signals are then sent along cables or transmitted via radio waves to reach our television sets.

Computer networks This diagram shows the US National Science Foundation's computer network. It links scientists' computers throughout the USA, but is just one of the many networks that can link one computer to another. Computer networks can be internal links within private companies, public systems that span entire nations, or the global web of the Internet.

See also: Internet p38, Mobile phone p18, Satellite p42

Satellites From their position high above Earth, communication satellites work together to bounce TV and radio signals around the world. Satellite phones can also enable people in remote areas without landline or mobile phone networks to make calls, putting people on opposite sides of the globe in touch.

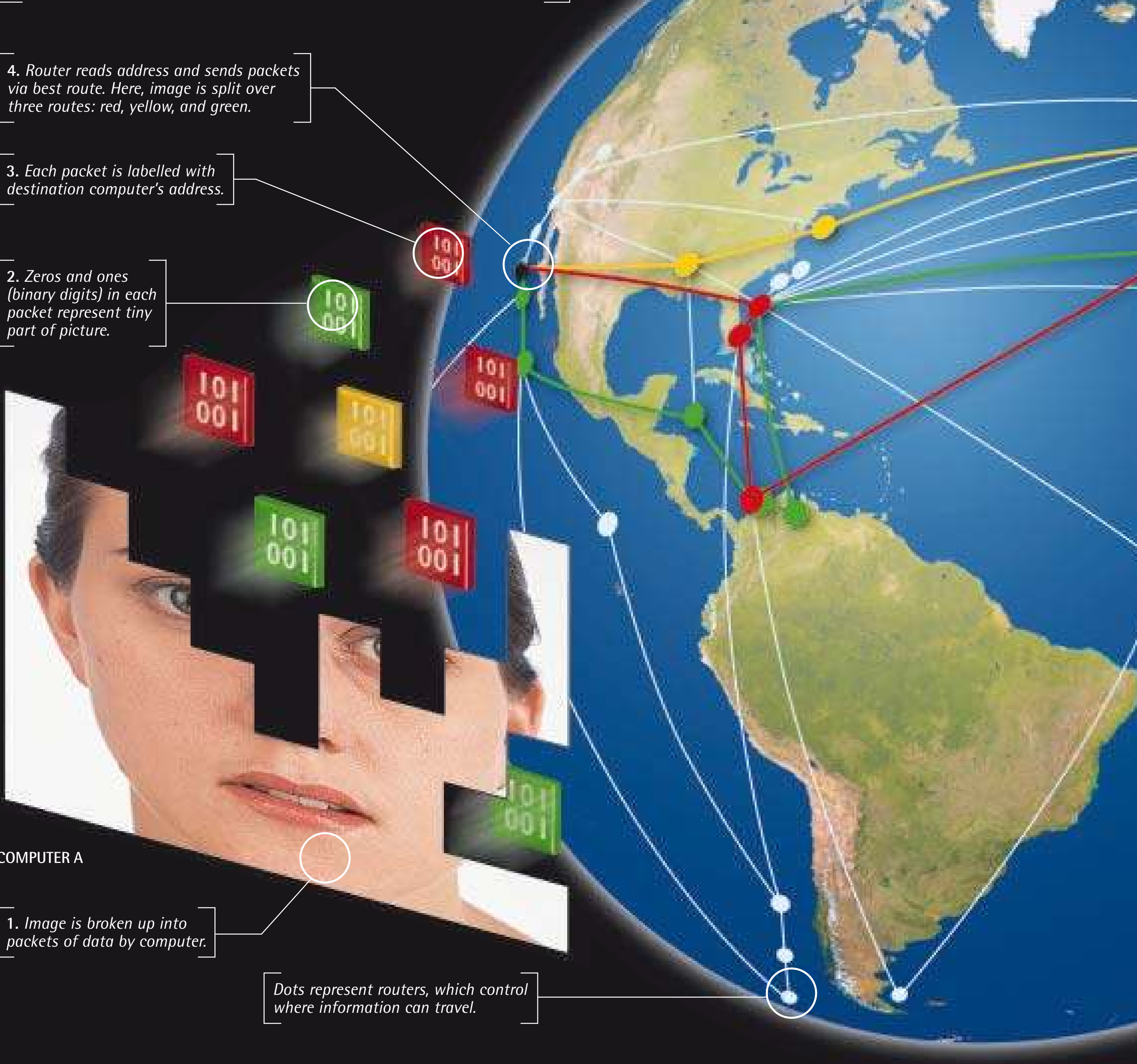
Telephone cables Lifting a handset or pressing the call button causes an electrical signal to be sent from your phone to a local telephone exchange. These local exchanges use circuits and wires, such as these, to route the signal to its destination and connect the call. Telephone signals can be transmitted via copper or fibre-optic cables, or by radio waves, and may be relayed by satellites.



Microwave mast These tall towers, with transmitter and receiver dishes mounted on them, are microwave relay stations. They receive signals sent through the air via microwaves (a type of radio wave), and then route them to the next relay station. Microwaves can carry TV and radio signals, telephone calls, images, and fax-machine data almost instantaneously.

INTERNET

The Internet is a computer network linking more than 200 countries. Hundreds of millions of people now use it to send information to one another instantly.



See also: Laptop p168, Links p36, Packet p248, Toys p26

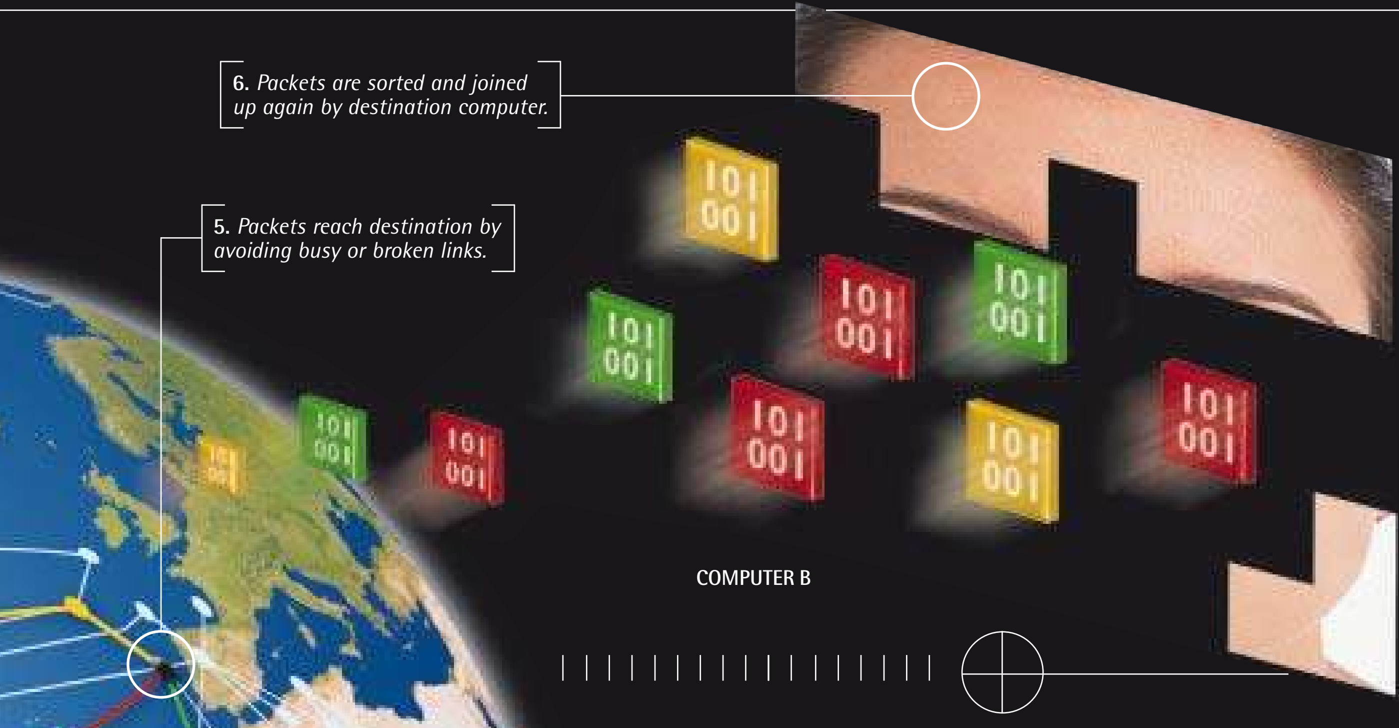


Image: computer graphic of information travelling across the Internet

The Internet began in the 1960s when a group of academics launched a project to link together large computer systems at four US universities. Now it has grown into a global network that links millions of home computers and LANs (local-area computer networks) in schools, corporations, and governments. Most people use the Internet for sending emails, but it can carry other information too, including music files, TV and radio programmes, instant messages, and phone calls. Information travels across the Internet in packets of data, known as packet switching. A user-friendly Internet application known as the World Wide Web, or WWW, lets us view pages of information and create our own. We can now share information, exchange ideas, and form online communities with people thousands of miles away thanks to the Internet's global village.

Networks in nature


Strands of a spider's web

A spider's web is a dense framework of silky strands linking at many points. The Internet's World Wide Web is also highly interconnected. Its pages are connected by electronic cross-references called links. Using links, people can explore Web pages in different ways and different orders to follow their own interests.

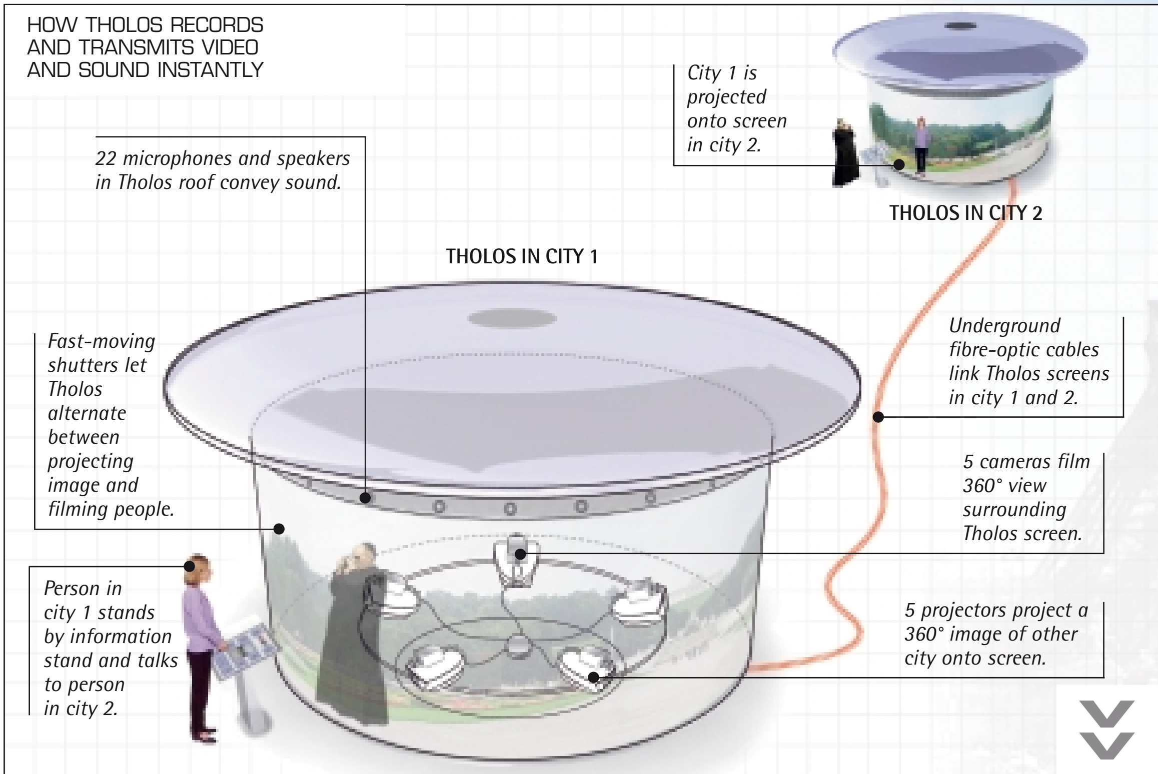
When moles make underground burrows, they build many different entrances and exits and a complex network of paths in between. If part of the burrow collapses, the animals can still travel down other routes. The Internet can survive failures in the same way. In computing, this idea is known as redundancy.


Cross-section of mole burrows

VIDEO LINK

Giant Tholos video pods allow people in Paris or Brussels to communicate face-to-face with other people in Moscow or Rome. These pods can transmit sound and life-sized images from city to city in less than half a second.

HOW THOLOS VIDEO LINKS WORK



Most people communicate with friends and colleagues in other countries by telephone, fax, or email, without seeing the other person's face. But a new invention, called Tholos, could change all that. Its giant video-link pods send sounds and images from one city to another and back again, allowing users to talk face-to-face despite being huge distances apart. The system works by transforming moving pictures and sound into digital signals, which travel along fibre-optic cables from one Tholos pod to another, almost instantly.

In ancient times, people could make contact over long distances only by carrying written messages. More than 2,000 years ago, the Greeks used carrier pigeons and marathon runners to transmit news, while the Romans set up the first postal system using horse riders. In the 19th century, the telegraph was invented, which could transfer written messages instantly. Telephone, invented soon afterwards, allowed two people to hold a conversation. Tholos marks a new age in communication: people far apart can talk to each other as if they are side by side.

See also: Digital technology p243, Fibre optics p20, Links p36, Mobile phone p18, Toys p26

▶ **Giant Tholos pods** are soon to arrive in cities throughout Europe. Here, Paris in France is linked to Pisa in Italy. Apart from letting people chat to one another, the large TV screens can display advertising, graphics, and text messages. A central studio monitors and controls the network of pods.

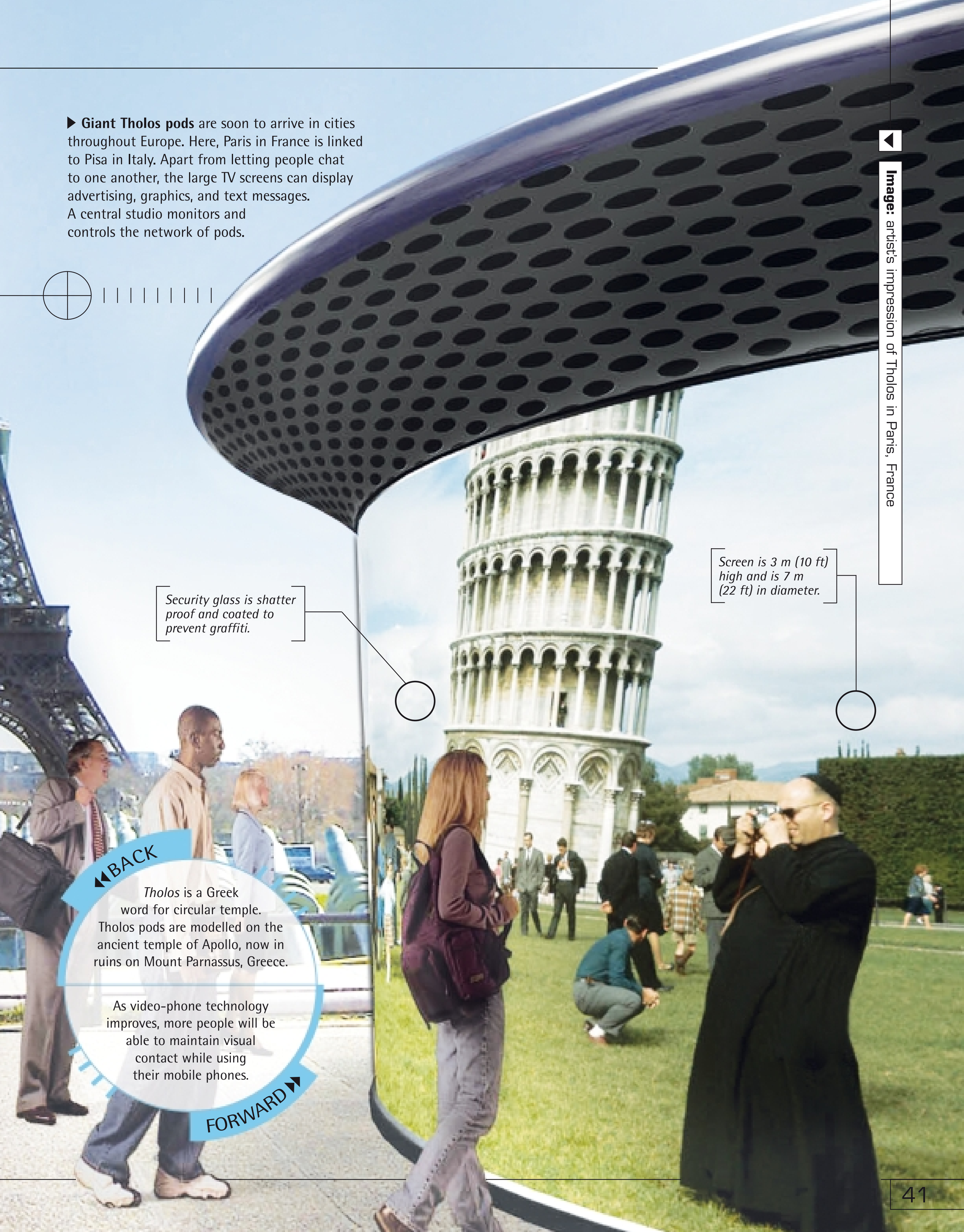


Image: artist's impression of Tholos in Paris, France

◀◀ BACK

Tholos is a Greek word for circular temple. Tholos pods are modelled on the ancient temple of Apollo, now in ruins on Mount Parnassus, Greece.

As video-phone technology improves, more people will be able to maintain visual contact while using their mobile phones.

FORWARD ▶▶

▲ In 2004 *Superbird-A2*, a Japanese communications satellite, was launched from a 25 m- (82 ft-) long Atlas rocket. Over a period of 30 hours it performed a series of manoeuvres to place itself into the correct position. *Superbird* will stay above Earth for 13 years, relaying satellite TV and Internet traffic across the Asia-Pacific region until it is replaced.

SATELLITE

▶▶Turning 36,000 km (22,500 miles) above Earth, communications satellites can bounce radio signals from one side of our planet to the other in just a quarter of a second. ▶▶

Launching satellites

▶Most satellites travel into space on rockets, but some are launched from the Space Shuttle. Large craft are hoisted into position using a long robotic arm. Smaller satellites are launched from a rotating turntable inside the cargo bay, as shown here. The turntable spins the satellite before springs push it into orbit. The spinning motion (known as gyroscopic stability) makes the satellite follow a steady path. When it has cleared the shuttle, its rocket boosters fire to set its orbiting speed.

Launch in space

◀◀BACK

Writer Arthur C. Clarke dreamed up the idea of communications satellites in 1945. The first such satellite, *Echo I*, was launched 13 years later.

Scientists are worried that obsolete satellites and other space junk could cause a catastrophic collision with rockets or space stations.

FORWARD▶▶

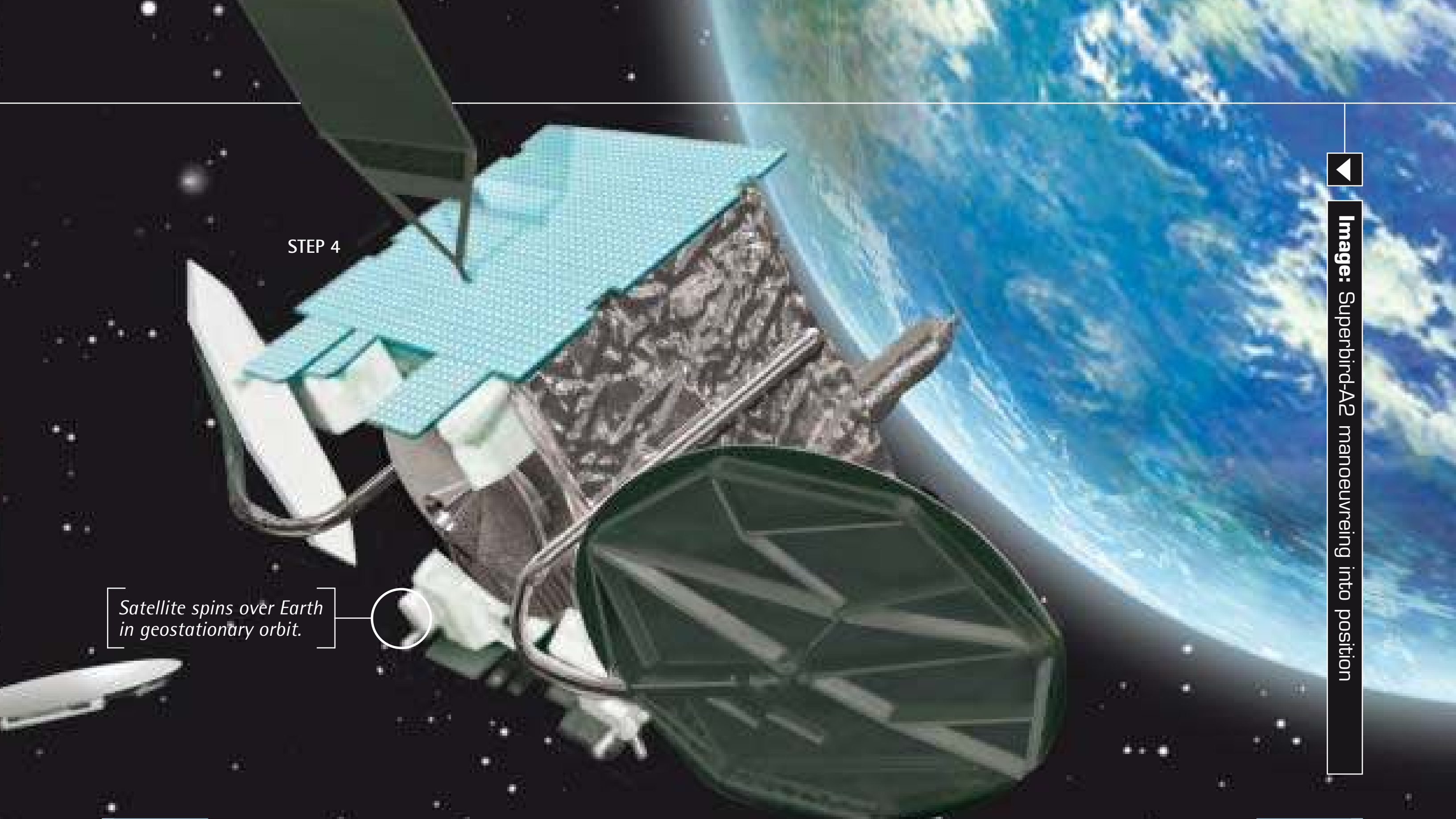
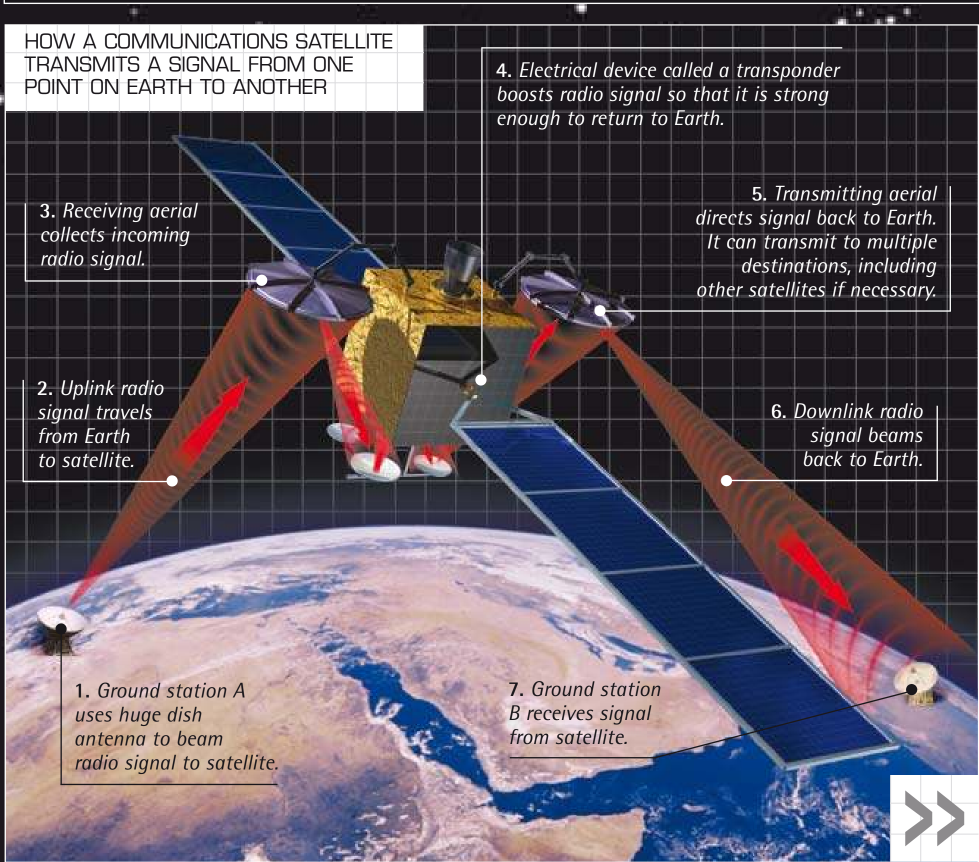


Image: Superbird-A2 manoeuvreing into position

HOW A COMMUNICATIONS SATELLITE WORKS



A communications satellite has to send and receive, or relay, thousands of phone calls and TV programmes across Earth simultaneously. It does so by catching and relaying microwave (high-energy radio wave) signals that are transmitted from the ground. These signals travel through space at the speed of light in narrowly focused beams.

Most communications satellites orbit the Earth in the same direction and at the same speed as the Earth rotates. They are always over the same point on the Earth, making them appear stationary. This is called geostationary orbit (GEO). Several hundred of these communications satellites are in geostationary orbit.

See also: Links p36, Mobile phone p26, Radio waves p249, Space Shuttle p156

Today, computers and communication devices are light enough for us to carry around wherever we go. The next phase will see them getting smaller still. In the long-term, the development of quantum and DNA computing technology will result in machines that work a billion times faster than current silicon-based computers.

In the next decade, most electronic devices will become connected to the World Wide Web by high-bandwidth fibre optics. When you are on the move, computers fitted into your clothing will be able to link with navigational satellite systems to tell you your precise location, and enable you to download information on local services.

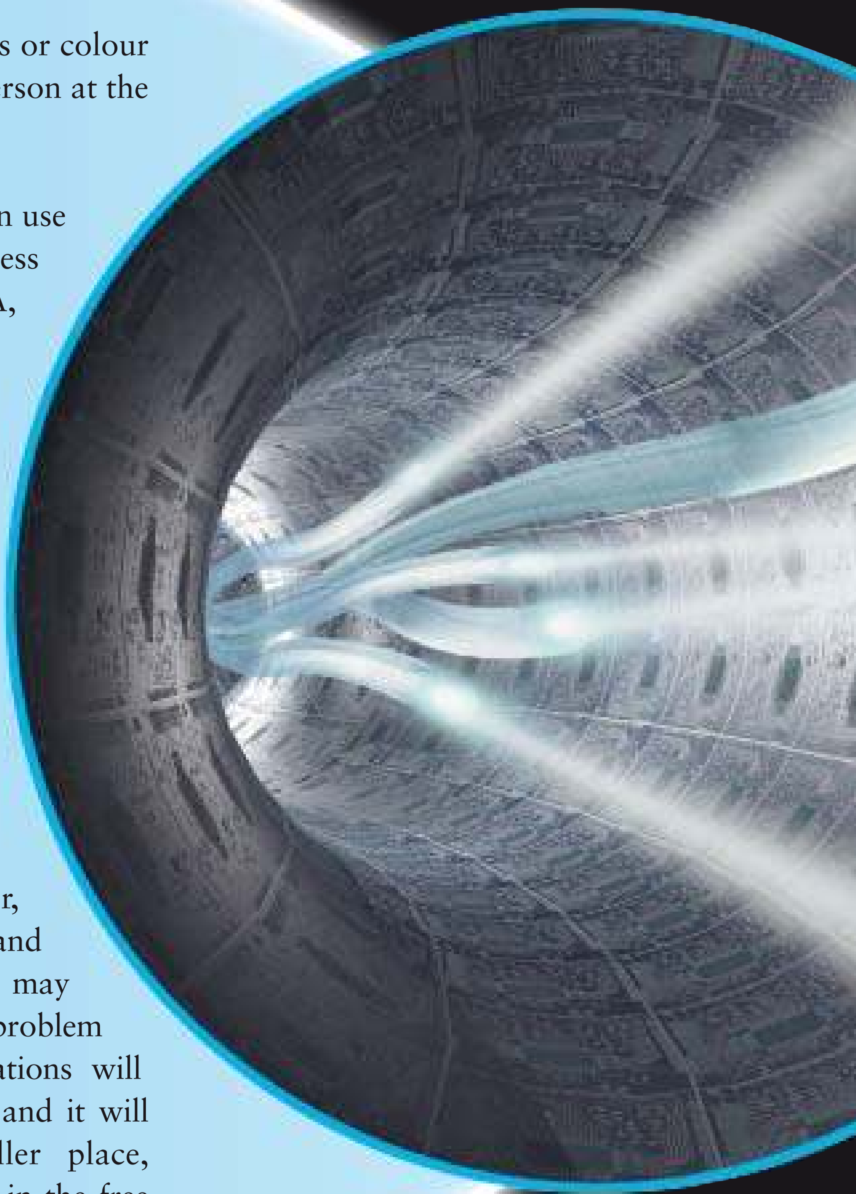
> "Computers that harness the incredible storage power of human DNA will perform calculations at unimaginable speed."

Invisible sensors embedded in public spaces, from city centres to art galleries, will recognize and respond to your presence. These areas, called "intelligent environments", will be able to provide information according to your needs and preferences, such as showing the way to a parking space or directing you to an artwork that particularly interests you. The technology may also be used to sell products: as you pass by a digital advertising hoarding, the display might change automatically to show items tailored to your own lifestyle.

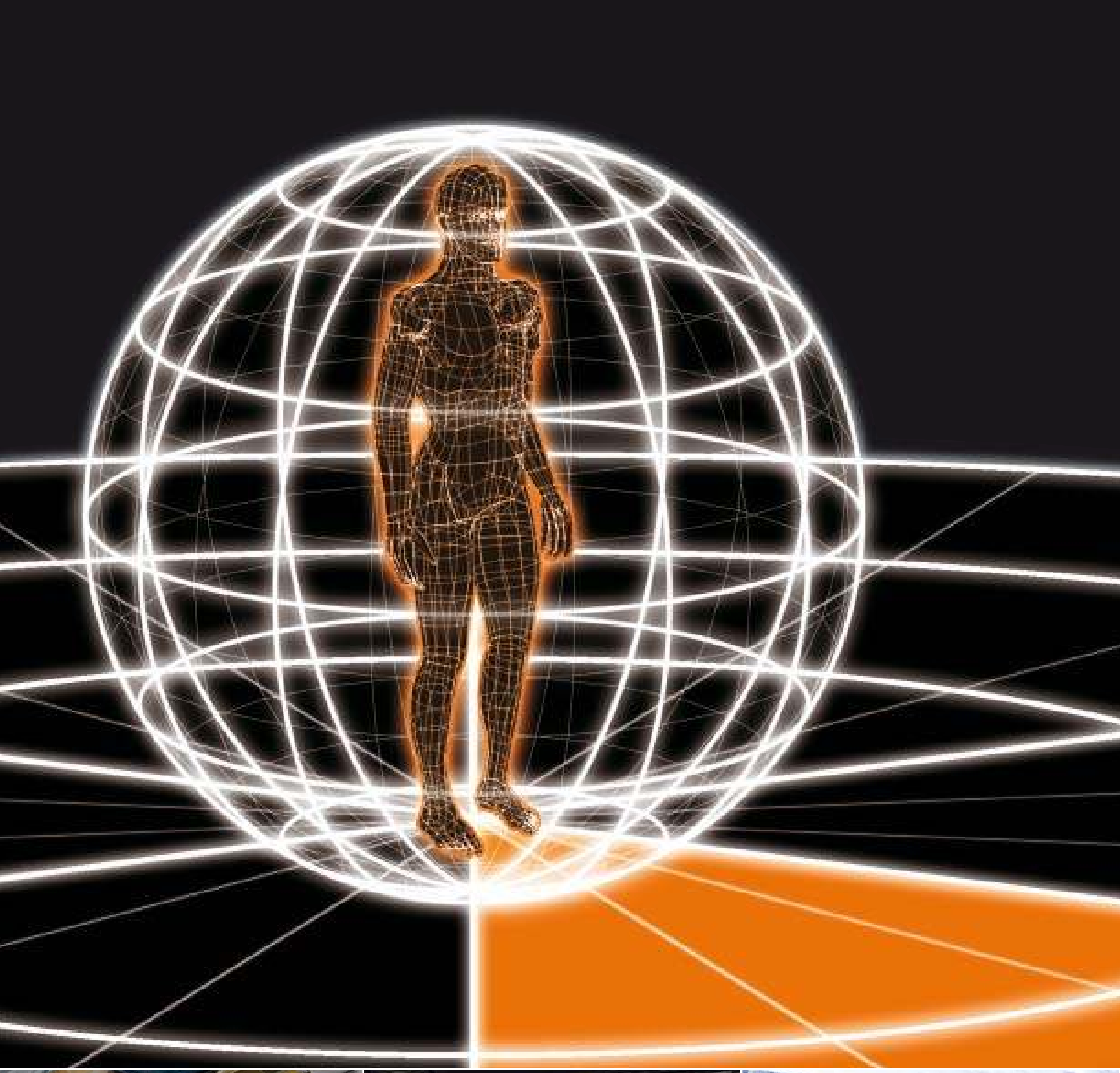
Sensors will play a central role in the development of "affective computing". This technology will enable computers to gauge moods and respond to them. Cars will be able to detect when you are stressed or angry and slow down automatically to reduce the risk of accidents. Chairs will know when you are bored, tired, or frustrated and shift their position to make you feel more relaxed or alert. Phones will be able to register whether you are happy or sad while you are speaking, and create emotions or colour feedback patterns to communicate this to the person at the other end of the line.

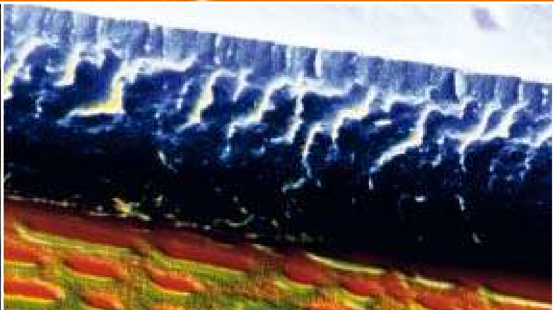
Future generations of computers may not even use silicon-based technology. Computers that harness the incredible storage capacity of human DNA, found in our genes, could one day perform calculations at speeds unimaginable today. Quantum computing will use atoms and molecules to perform vast numbers of calculations simultaneously.

Communication technologies will bring new benefits and past obstacles will disappear. For example, instant translation technology will allow you to speak in English into your mobile phone and be heard in Japanese by the person you are phoning in Tokyo. On the other hand, with our mobile phones and computers constantly communicating with one another, satellites surveying our positions from space, and sensors monitoring us on the ground, privacy may become impossible. Some people fear that this problem outweighs the benefits that better communications will bring. But the information age is here to stay, and it will continue to make the world feel a smaller place, and to be one in which everyone can take part in the free exchange of ideas and information.



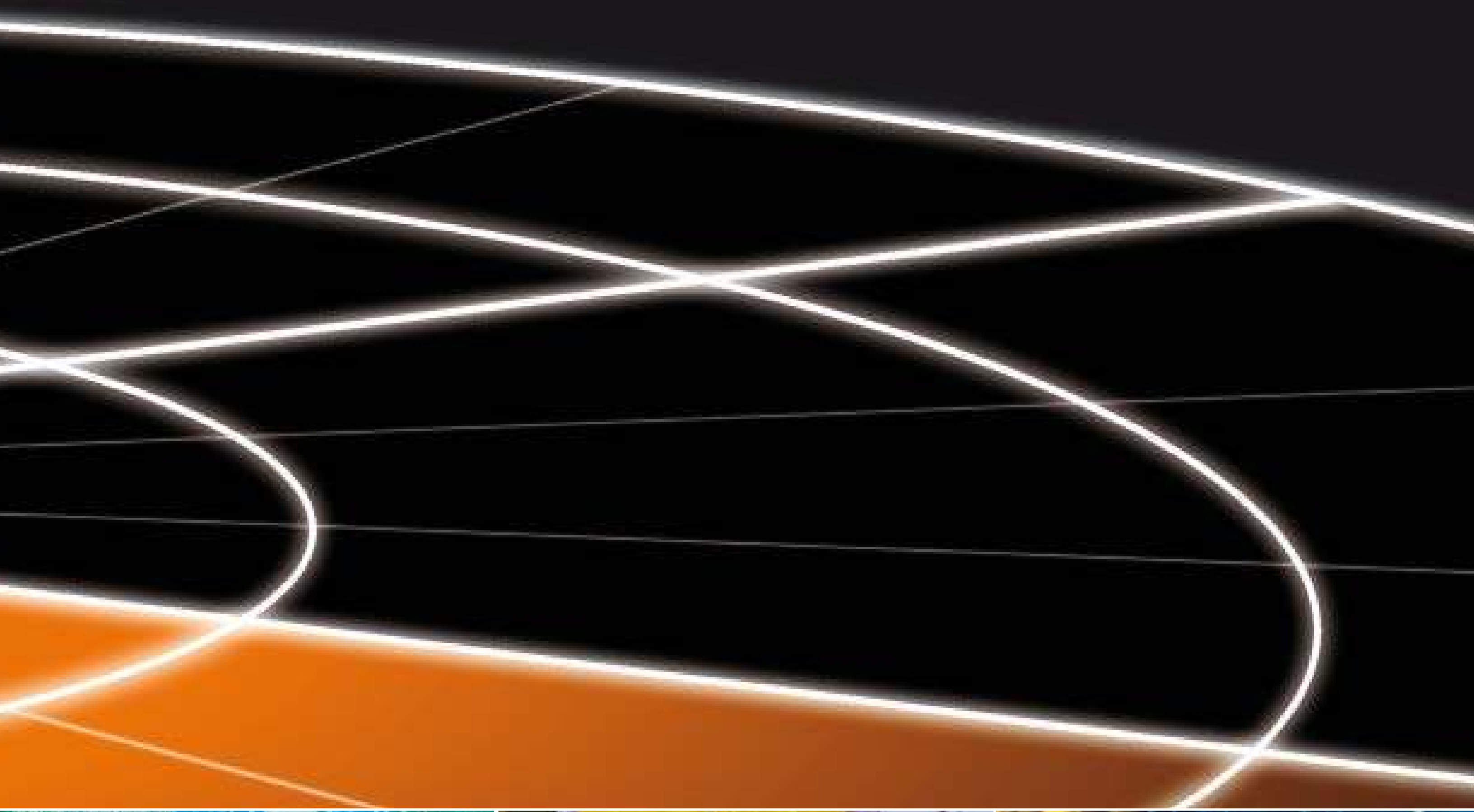
FIBRE OPTICS

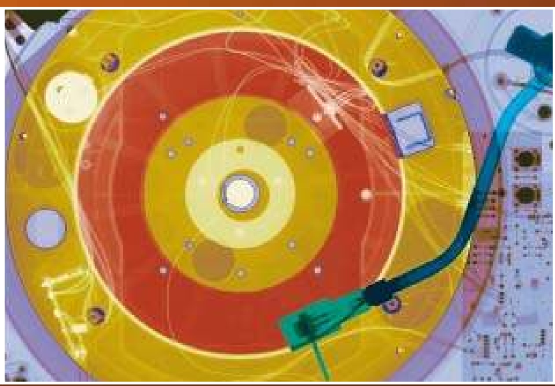


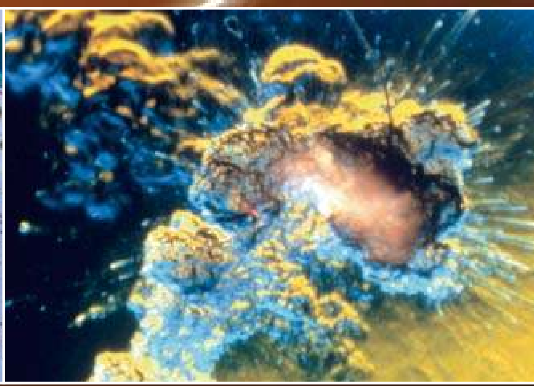



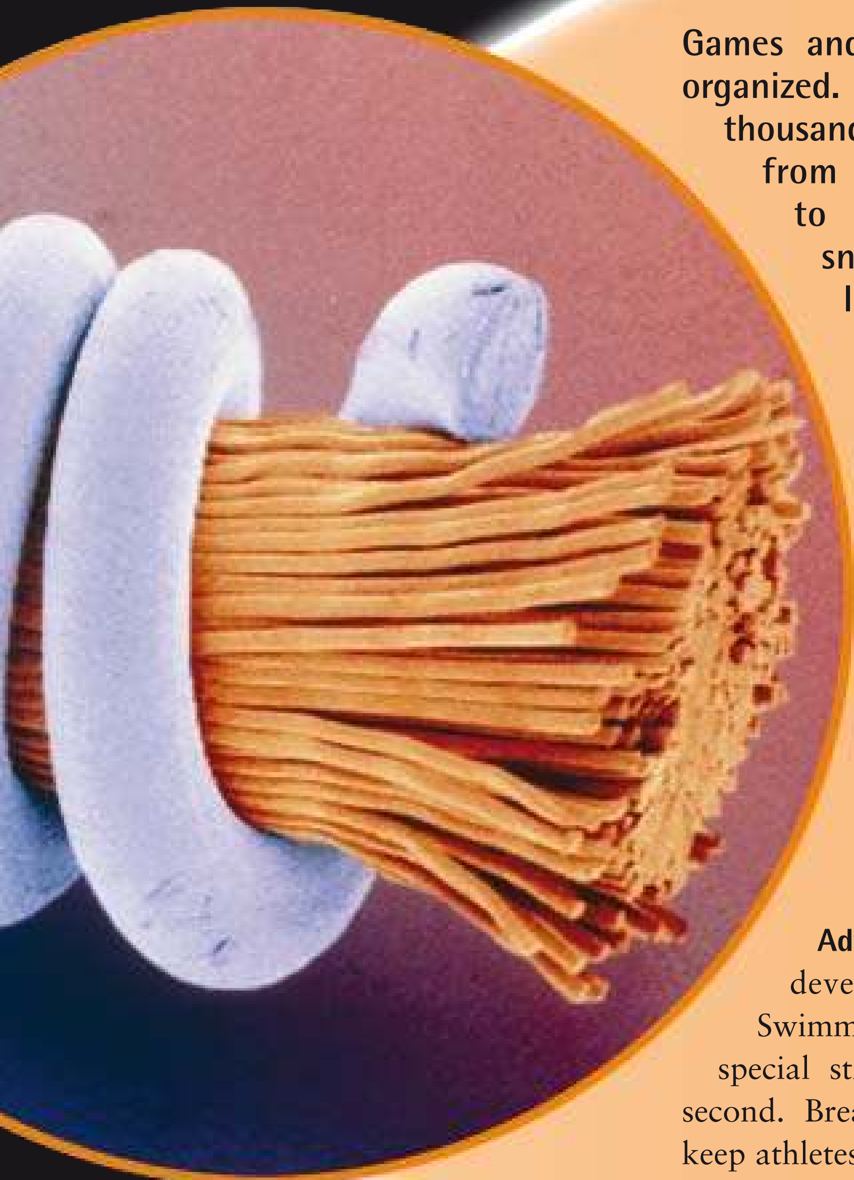
>>PLAY

Trainer >> Football >> Racket >> Snowboard >> Bike >> Camera >> Games >> Guitar >> Compact disc >> MP3 player >> Headphones >> DJ decks >> Fireworks









SEM OF GUITAR STRING

Games and sports are ways of making play more organized. Throughout history people have invented thousands of different kinds of activities, ranging from ancient board games such as chess to athletics and extreme sports such as snowboarding and skateboarding. Over the last few decades, digital technology has added another dimension to the way we choose to spend our leisure time.

In a world where sport has become increasingly competitive, technology can make all the difference between winning and losing. With the help of computer-aided design and modelling, the equipment used for many sports is constantly improving. Tennis racquets are becoming more responsive and powerful, footballs lighter and more effective, and running shoes more supportive and better at absorbing impact.

Advances in fabric technology have led to the development of high-performance sportswear. Swimmers, for example, can wear swimsuits with special streamlining that can save vital fractions of a second. Breatheable fabrics' special venting systems help keep athletes cool and dry. Skiers and mountaineers can stay warm with lightweight but extremely well insulated jackets.

Sports, of course, are not the only way we play. Computer games have had a global impact and are familiar to millions of people. The first video game was invented in 1958. It was called Tennis for Two, and it was played on an oscilloscope – a device for measuring sound waves. The first video game that you could play on a television was called Pong and introduced in 1975. It involved two players hitting a ball back and forwards across the screen – another tennis game! Today's console games are both far more sophisticated in their design and more challenging to play. From building and running imaginary cities to re-creating realistic battle scenes, the games are so complex that they can cost as much to make as a movie.

> "In 2004, the Athens Olympics was seen on TV by four billion people – two-thirds of the planet's population."

Digital technology has also opened up a world of creative opportunities. Before the advent of affordable digital video cameras and simple-to-use film editing software, film-making was a specialized activity. Now that the technology is so widely available, creating a movie is within everyone's reach. It is a similar story with making music. Just as the introduction of the electric guitar in the 1950s revolutionised popular music, digital technology is now having a similar impact. You do not need specialist training to compose music – computer-aided composition tools can provide most of the necessary skills.

The way our entertainment is delivered to us is also changing. Most homes have a range of devices including televisions, audio systems, DVD players, or video recorders. But now it is possible to have all these devices in one unit. Thanks to wireless communication and high-speed internet connections the personal computer is becoming a digital centre, or hub, for the many different forms of entertainment that are available.

TRAINER

Today's running shoes use state-of-the-art microchip technology to maximize performance while also making serious style statements.

BACK

The first sports shoe was known as the plimsoll, because the line around the sole resembled the Plimsoll waterline painted on a ship.

FORWARD

With new advances in materials technology, trainers will be so light and comfortable that you'll hardly notice you're wearing them.

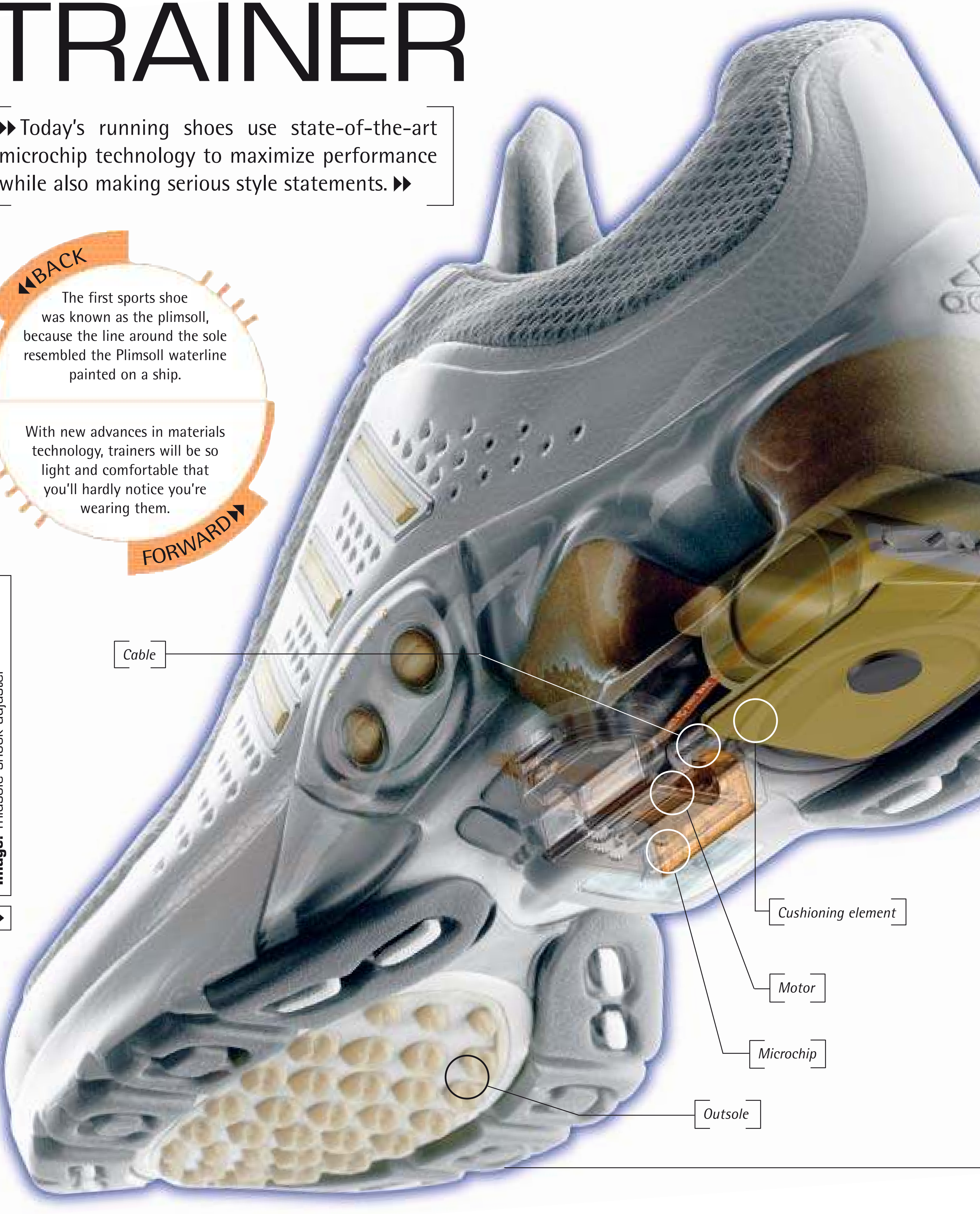
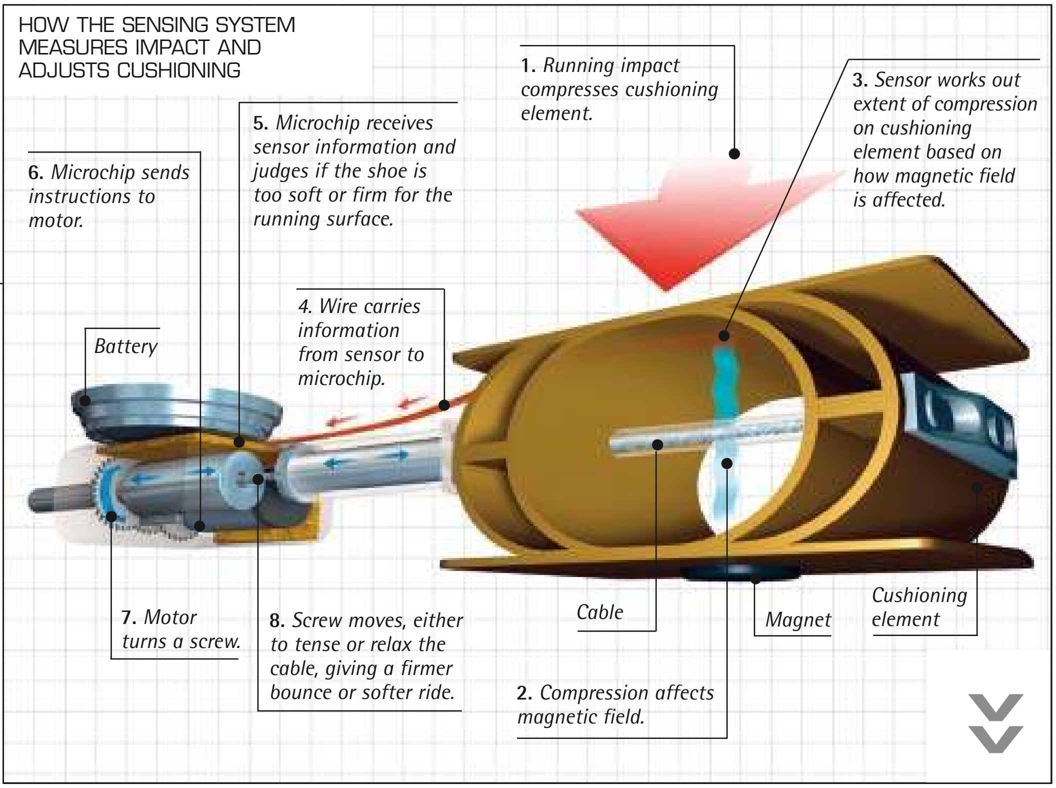


Image: midsole shock adjuster

◀ **This hi-tech** running shoe contains an automatically adjusting cushioning system in its midsole. This allows it to adapt continually to changing running surfaces and individual running styles, giving optimum performance during a run.

» HOW THE SENSOR WORKS



Every owner of a pair of running shoes has an individual running style and body weight. In addition, running conditions are never the same – soft grass, gravel, and hard pavements are all very different surfaces to run on. This remarkable running shoe has a microchip and an adjustable cushioning element in its midsole that adjusts the shoe to give optimum performance for each individual and on any running surface. Once the person has started running, a sensor takes one thousand readings every second. The information it receives triggers continual changes to the shoe's cushioning. These changes happen in such a subtle way that all the runner notices throughout the run is how comfortable the shoes are.

Shock absorption

▶ When people run, their bodies absorb four times their weight with each step. This image is colour-coded to show areas of pressure: red indicates the most pressure, followed by yellow, green, and blue. Trainers help protect the feet by absorbing shock in all these areas.

Imprint of bare foot

▶ In a running shoe, the job of the midsole is to provide shock absorption and stability. The outsole, on the undersurface, provides traction, or grip. This treaded layer has a studded design that enhances traction on different surfaces.

X-ray of outsole

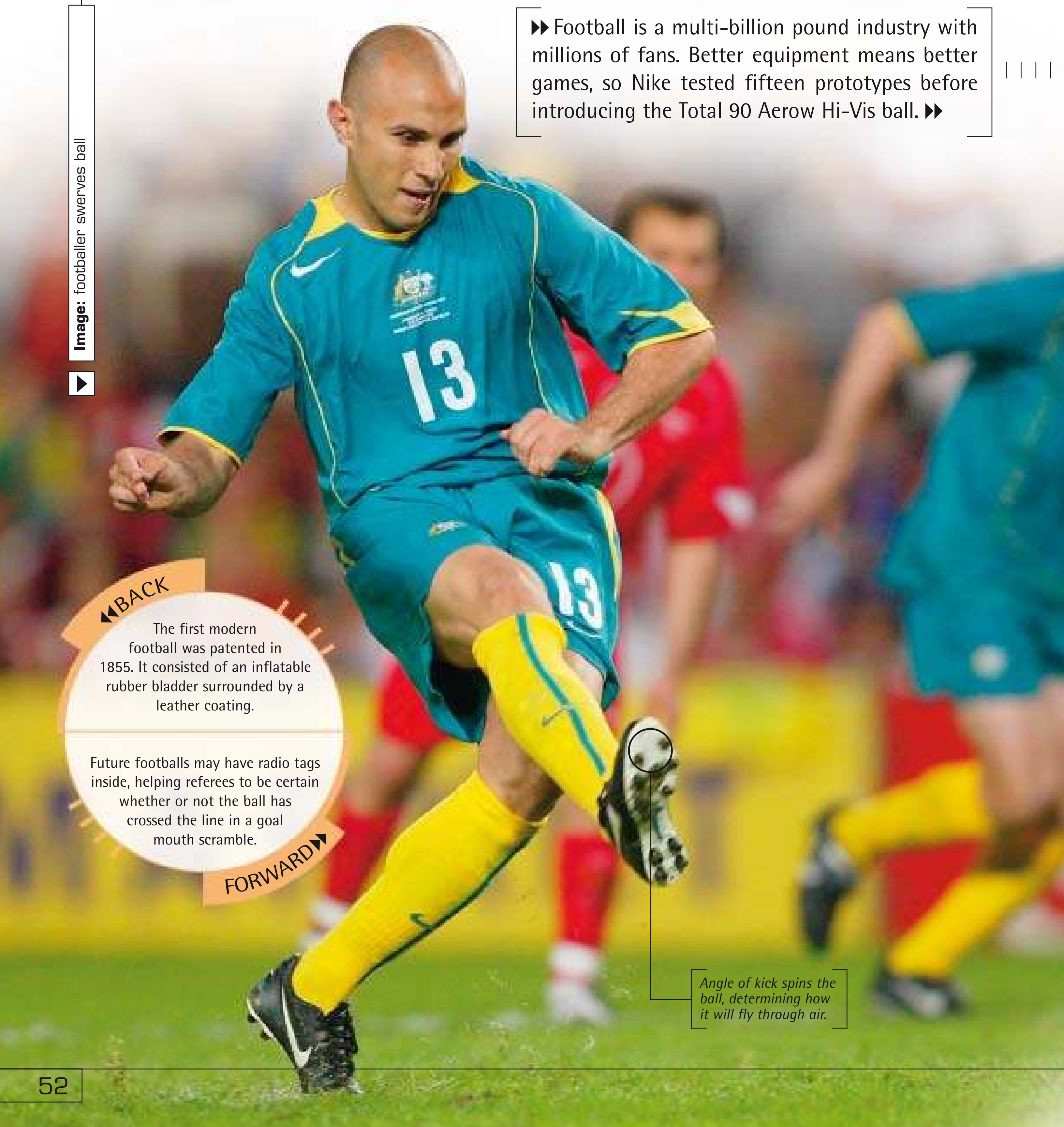
▶▶ See also: Fabric p60, Microchip p16, p246, Sensor p250

See also: Arenas p72, Racket p54, Trainer p50

FOOTBALL

Football is a multi-billion pound industry with millions of fans. Better equipment means better games, so Nike tested fifteen prototypes before introducing the Total 90 Aerow Hi-Vis ball.

Image: footballer swerves ball



BACK

The first modern football was patented in 1855. It consisted of an inflatable rubber bladder surrounded by a leather coating.

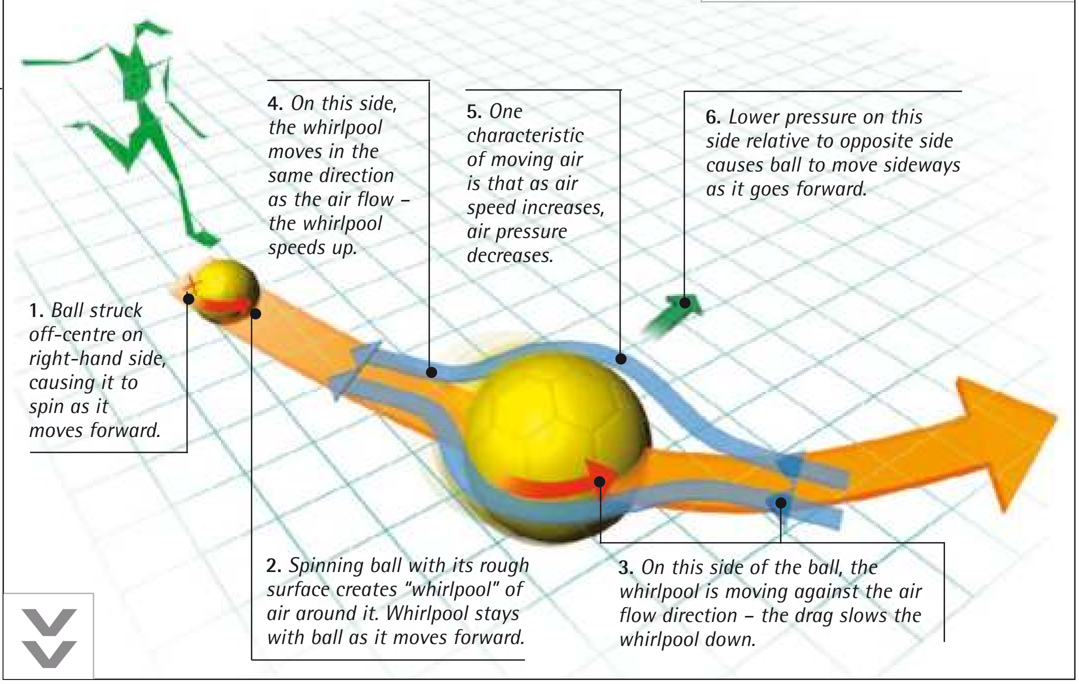
FORWARD

Future footballs may have radio tags inside, helping referees to be certain whether or not the ball has crossed the line in a goal mouth scramble.

Angle of kick spins the ball, determining how it will fly through air.

HOW A BALL GETS ITS SWERVE

HOW AERODYNAMICS MAKE A FOOTBALL SWERVE THROUGH THE AIR AFTER BEING KICKED



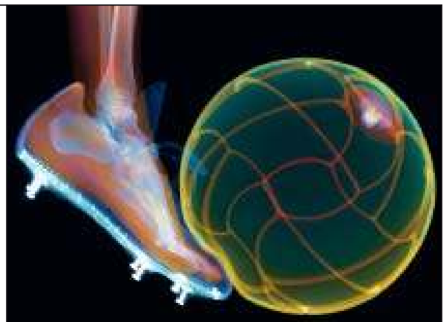
Some top footballers are able to make a football dip and swerve dramatically as a result of hundreds of hours of practice. This means a free kick can rise high over a defensive wall, but then dip suddenly under the crossbar at the last second. Spinning the ball has become easier as lighter, more sophisticated footballs have been produced. The original leather balls were heavy to kick and became heavier still when they absorbed moisture from a wet pitch.

Modern footballs have carefully designed surfaces made of lightweight materials, so the same strength of kick makes them go further. It is not just the balls that have improved. Pitches with an artificial surface have been developed. They are most useful in winter, when it is often too wet to play on real grass. The first artificial pitches were very bouncy, making ball control difficult, but recent artificial pitches act much more like the real thing.

Footballer Marco Bresciano kicks the Nike Total 90 Aerow Hi-Vis, a football that has been designed to fly more quickly and accurately than other balls on the market. It uses a six-layer casing to make it durable and quick to react to a kick, and a special pattern and coating to make it fly accurately over long distances.

Changing shape

A football deforms when kicked because it is not rigid, although it is impossible to see in the actual instance of a kick. In this image, we see a depression in the ball's lower left side caused by impact pressure from the kicking foot. When a football deforms, the air inside it acts like a spring. The ball and the air inside it absorb some of the energy from the kick. They then release this energy to create the ball's bounce.



False-colour X-ray of foot and football

Image: cutaway of HEAD® Intelligence™ racket

◀◀BACK

First introduced in 1874, tennis was known as Sphairistike. Fortunately, this was soon replaced with the more pronounceable name of Lawn Tennis.

The fastest serve in a championship match reached 246.2 km/h (153 mph), in 2004. The HEAD® Intelligence™ racket may help beat this record.

FORWARD▶▶

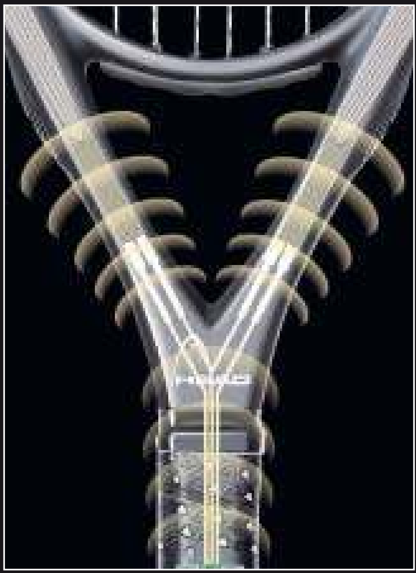
▶ The key to playing tennis is hitting the ball with power and control. This racket helps acheive that by ensuring that as much of the energy from the player's stroke is transferred to the ball as possible, and in a controlled way. This means that the player can make the ball move faster and position it more accurately, so that it is harder to return.

RACKET

▶▶ Tennis has evolved from a game played in long trousers or heavy skirts to a fast and furious competition in which players use the latest technology to gain the edge. ▶▶

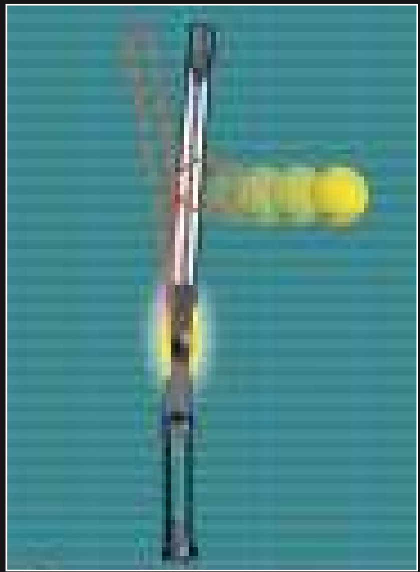
▶▶ See also: Crash test p134, Guitar, p66, Piezoelectricity p248

HOW THE RACKET WORKS



1. When a racket hits a ball, the racket bends, absorbing some of the energy. Ideally, all that energy would flow back into the ball as the racket straightens out. With a standard racket the energy is wasted through vibrations in the racket head and the player's arm. This intelligent racket has a way of harnessing the energy of these vibrations, shown here travelling from the racket's head to its throat.

2. The vibrations stretch piezoelectric fibres in the racket's throat (shown below). The fibres convert the mechanical energy into electrical energy. This travels in the form of an electrical current to a microchip in the handle of the racket, which stores it up and then sends it back to the fibres. The fibres stiffen enough to stifle the vibrations and return the original mechanical energy to the ball.



3. When the racket stiffens as a result of the piezoelectric fibres, the ball is propelled back sooner than it would otherwise be. A standard racket – here superimposed in red – is still being bent backwards when the stiffened one has already straightened. The faster return gives the player a greater advantage over his or her opponent who will need to move very quickly to reach the ball.

What is the piezoelectric effect?

Close-up of quartz crystals

When you squeeze a piezoelectric material such as quartz, it gives out a spark. This is how the racket's fibres produce electricity when they receive vibrations from the racket head. The piezoelectric effect also works the other way around, so if you apply electricity to a piezoelectric material, it changes shape. This is how the racket's fibres stiffen the racket head when they receive electricity from the microchip.

Image: snowboarder performing jump

▲ **A boarder "catches air"** as he performs an impressive jump. Board shapes have evolved to match different terrains and riding styles. Boarders can compete in cross-country, downhill, and trick-riding contests to test their strength, skill, stamina, and speed.

BACK

The earliest snowboards were marketed as Snurfers. They had ropes for steering and looked like a cross between a sledge and a ski.

FORWARD

There could be more people riding snowboards than using skis by 2015, according to some market forecasts.

SNOWBOARD

What started as an alternative to skiing and sledging is now one of the fastest-growing of alpine sports. Snowboarders can compete in competitions held on the slopes or in snow parks.

See also: Arenas p72, Bike p58

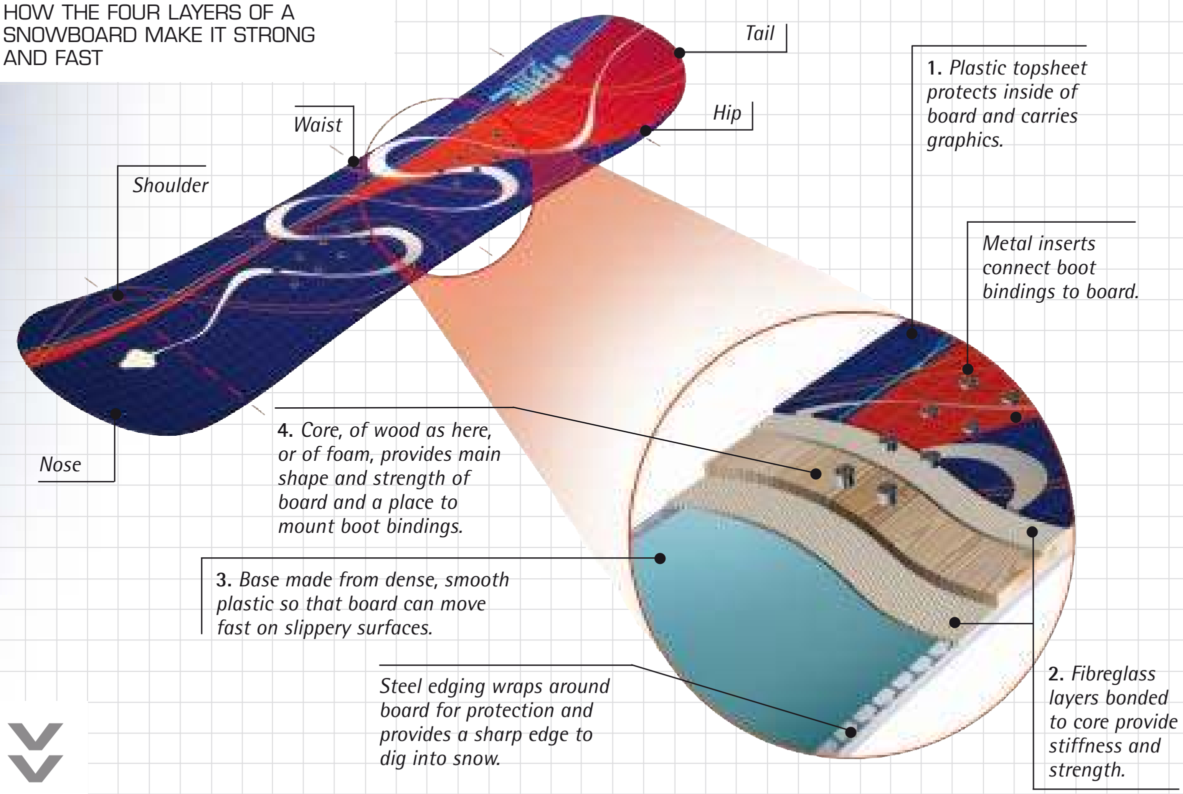
HOW A SNOWBOARD WORKS

Freestyle
The short, wide, symmetrical shape of freestyle boards allow riders to perform tricks and to ski with either foot in front.

Freeride
These boards are often used by beginners as they work in most conditions, but with practice they can also be used for jumps and tricks.

Freecarving
Also known as alpine, or racing, boards, these are long and narrow for making high-speed turns on a zig-zagging slalom track.

HOW THE FOUR LAYERS OF A SNOWBOARD MAKE IT STRONG AND FAST



First, surfboards started the craze for surfing on waves, then skateboards made urban surfing on pavements possible. Now surfers ride on snow with a snowboard. The most popular snowboarding competitions are freeriding events, where riders tackle downhill slopes as fast and with as much style as possible, and freestyle events, where they can show off their tricks using ramps to twist and turn in the air.

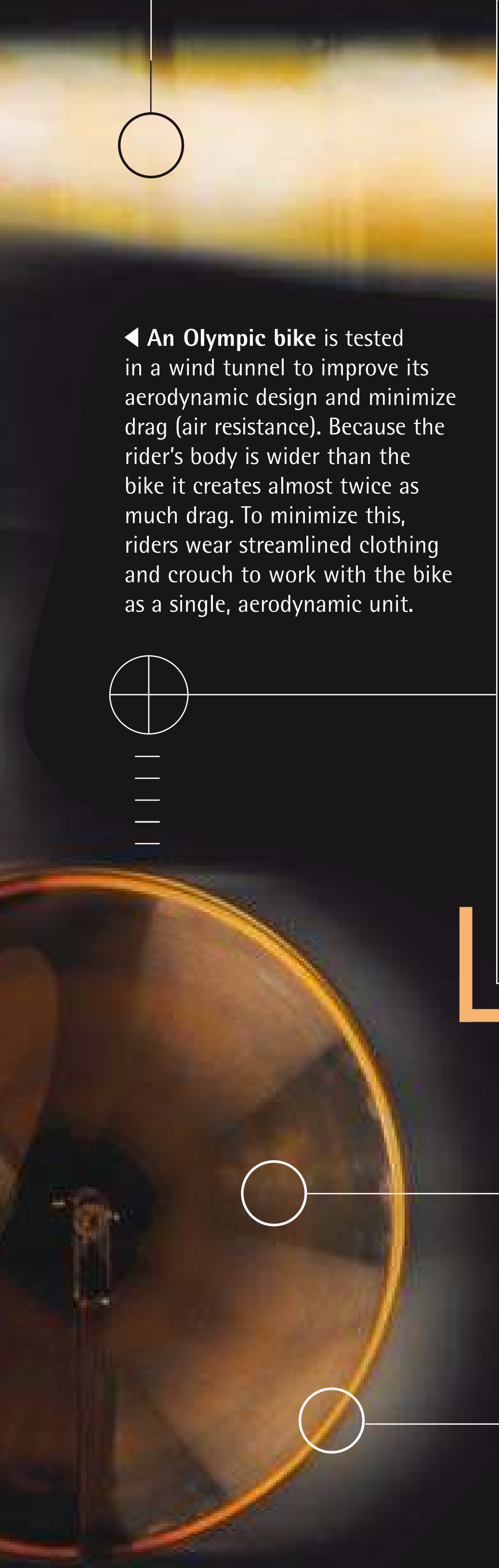
Snowboarders wear soft boots strapped into plastic connective straps called bindings, which are mounted diagonally across the board. Riders control the board as gravity pulls them downhill by shifting their weight between heel and toe and from one foot to the other. This makes the edges of the board dig into the snow, causing it to turn. Pushing down hard on both heels or toes turns the board sharply so that it stops.

BIKE

Olympic cyclists need to ride as fast as possible against the clock or each other. So their bikes are lighter and more aerodynamic than normal bikes, often with only one gear and no brakes.

Image: Olympic bike test in wind tunnel

See also: Air resistance p240, Motorbike p126, Parts p132, Wind tunnel p148

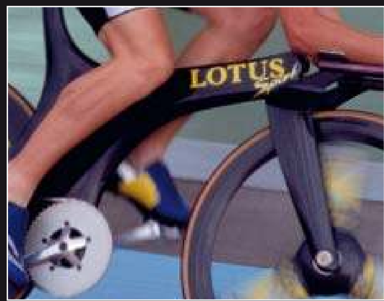


An Olympic bike is tested in a wind tunnel to improve its aerodynamic design and minimize drag (air resistance). Because the rider's body is wider than the bike it creates almost twice as much drag. To minimize this, riders wear streamlined clothing and crouch to work with the bike as a single, aerodynamic unit.

OLYMPIC BIKE: KEY FEATURES

The front of a moving object usually creates the most drag. On a normal bike, wide handlebars force the rider to sit with arms apart, creating lots of drag. To solve this, an Olympic time-trial bike has two sets of handlebars positioned side by side. The narrow pair in the centre can be gripped to reduce drag when the bike is travelling straight; the wider pair on the outside is used only for steering and braking.

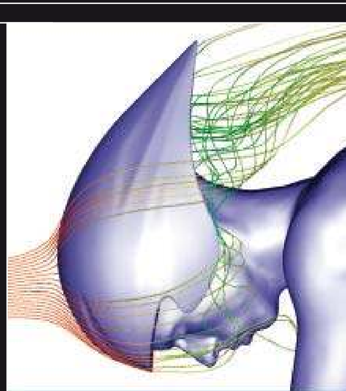
The bike's frame has to withstand huge stresses from the rider's weight as well as twisting forces when turning corners. An Olympic superbike has a frame made from a single piece of tough, carbon-composite material. This spreads forces evenly throughout and is reinforced in key places with super-strong titanium. The frame's sides are curved like the surface of an aeroplane wing so that air travels smoothly around it to reduce drag.



Wheels move faster than other bike parts, so can create lots of drag. To avoid this, the front wheel has flattened, aerodynamic blades that can be easily steered into a moving airstream. A bladed wheel is weaker than an ordinary bike wheel with spokes, so it is strengthened with a thick rim. The rear wheel does not need to steer so is an even more aerodynamic solid disc. These bikes are often made without brakes. At the end of a race, the rider pedals more slowly to gradually stop the bike.

Computer-aided design

Instead of using wind tunnels, engineers can use lasers to scan the shape of the bike and rider to create a 3D computer model. They can then test different aerodynamic bike and helmet designs to find those that create the least drag. This pointed aerodynamic helmet, designed by computer, allows air to flow smoothly around it.

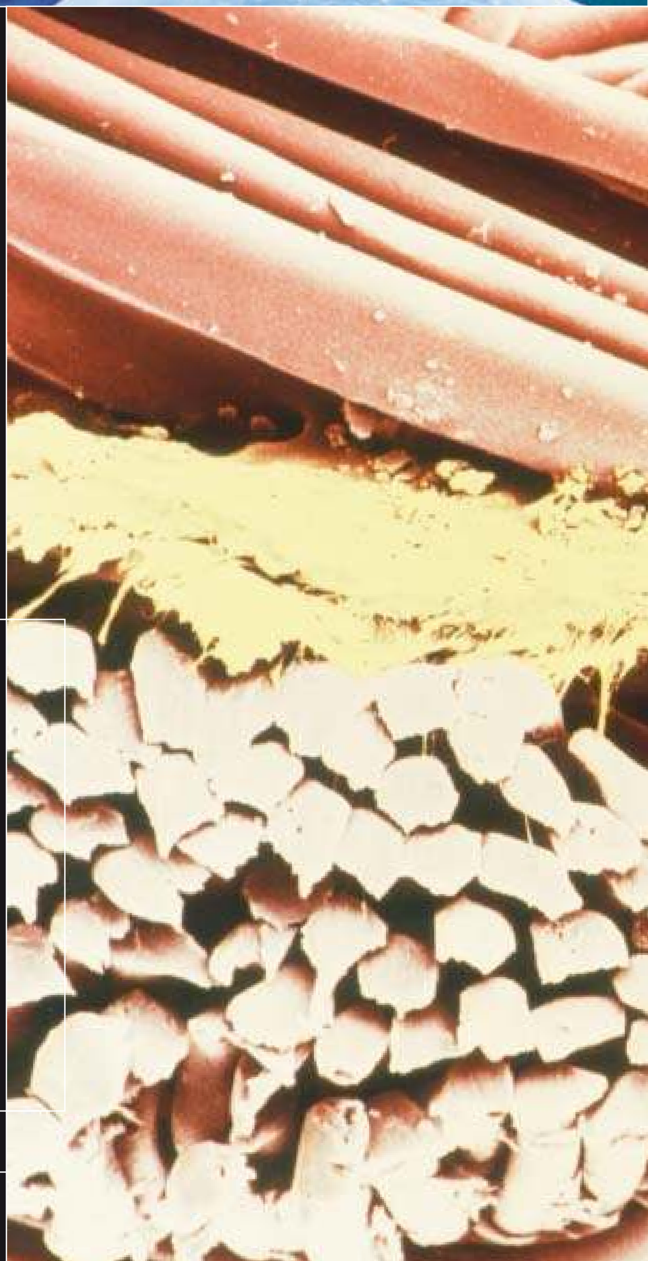


3D computer model of helmet

FABRIC

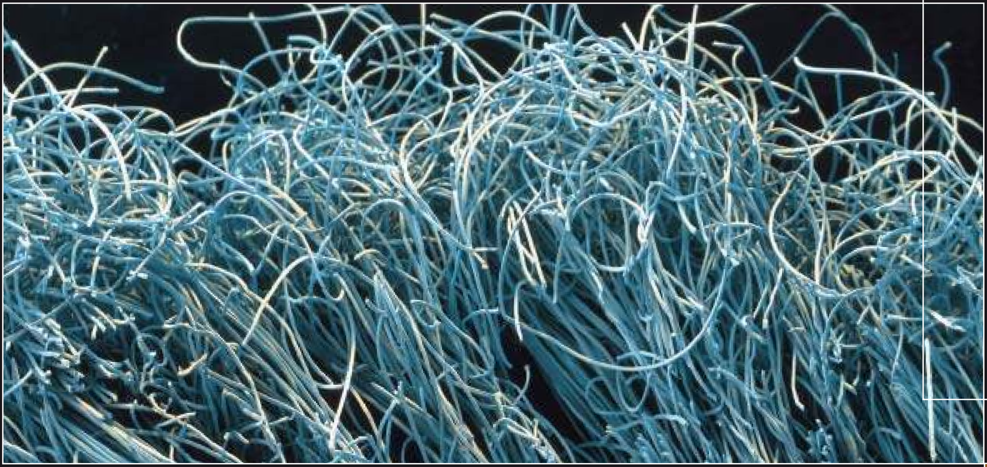
New technology has helped to create fabrics that keep us warm in winter and cool in summer, absorb perspiration, and keep us dry when it rains. Here is how a few of these fabrics work.

Aqua shift
As soon as swimmers hit the water, they create drag – resistance caused by the turbulence from their movements. They have to use up energy to swim against it. To combat drag, swimsuits are made of clinging fabric that helps streamline the body. This swimsuit's horizontal bands redirect the flow of water around the body, further reducing drag.



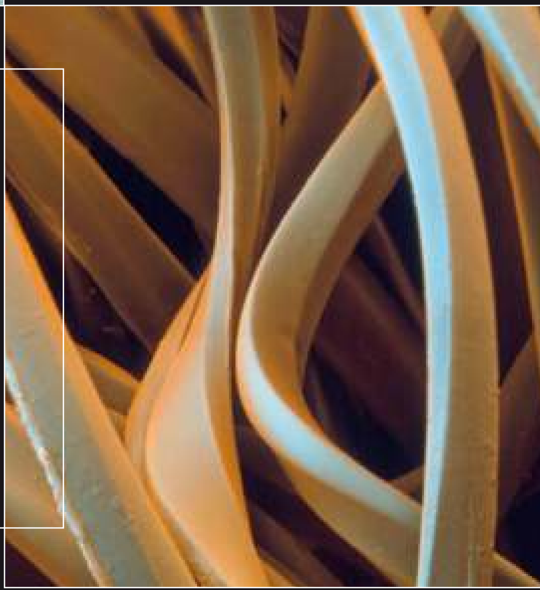
Breathable fabrics
These are used to make wet-weather clothing. Breathable fabrics combine more than one layer of nylon (seen here, in pink) with a porous inner layer (yellow). The inner layer contains tiny holes – smaller than raindrops but bigger than individual water molecules. This lets sweat out but prevents rain getting in. The outer layers are wind-resistant, keeping the wearer warm.

See also: Bike p58, Parts p132



Fleece

This is a soft material valued for its light weight and excellent insulating properties. It is used for outdoor clothing. Fleece is made from long, felt-like fibres, closely interwoven with one another. Air is trapped between the fibres, and is heated by the body.



Sweat absorbers

Fabrics that absorb sweat can help make clothes more comfortable. These fibres are coated with two different substances that prevent the fabric becoming wet during wear. One of the substances absorbs the body's moisture and the other transfers the moisture to the outside.

Lycra®

Lycra® is a strong, highly elastic fibre that is often used to make close-fitting but flexible clothing such as sports wear. This magnified image shows Lycra® and nylon fibres in a pair of cycling shorts: the thin, criss-crossing red and yellow lines are Lycra® and the other parts of the weave are layers of nylon.

CAMERA

A digital camera allows you to see your pictures moments after they have been taken, and makes it easy to store, share, and print them.

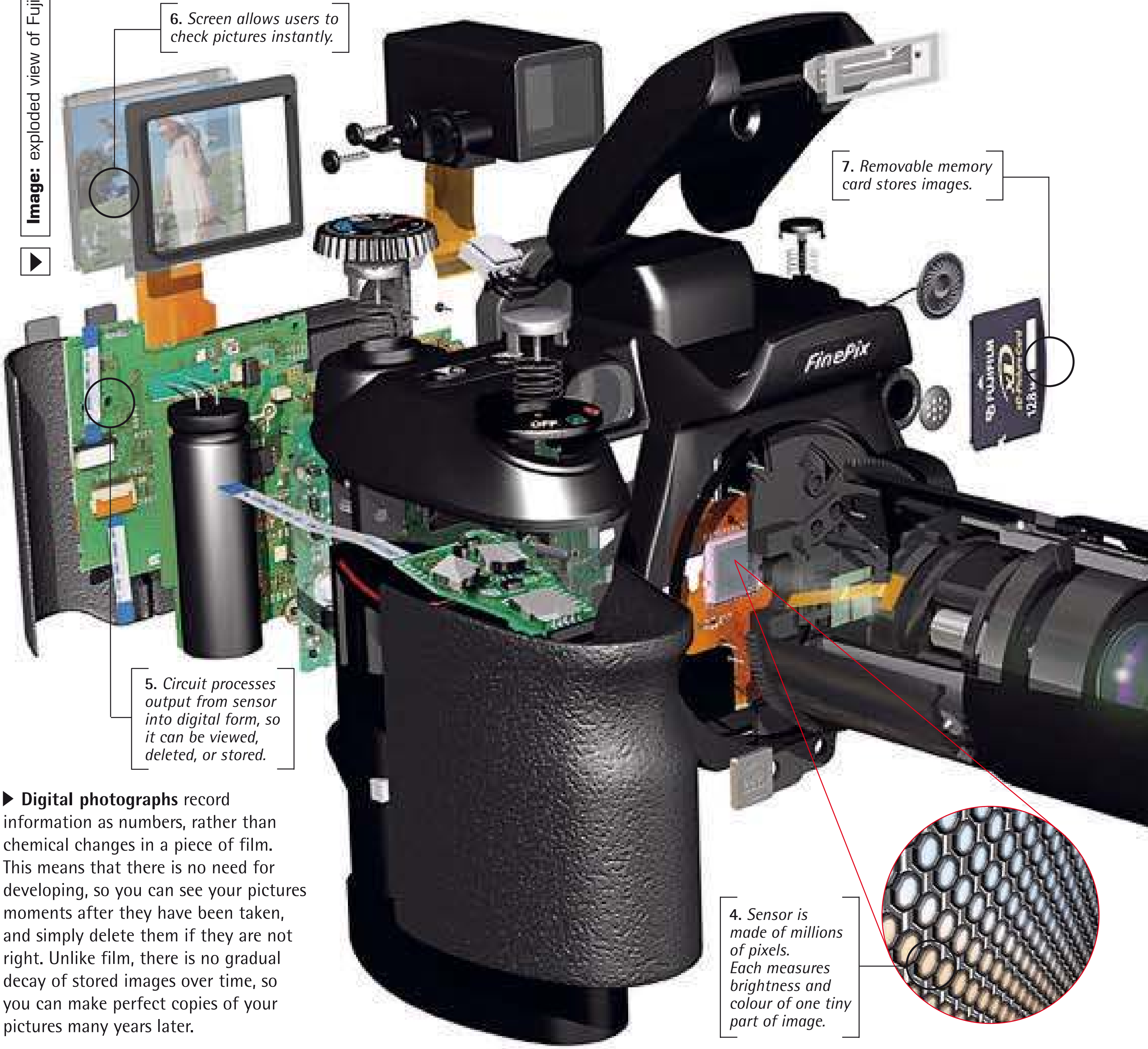


Image: exploded view of Fuji S5000

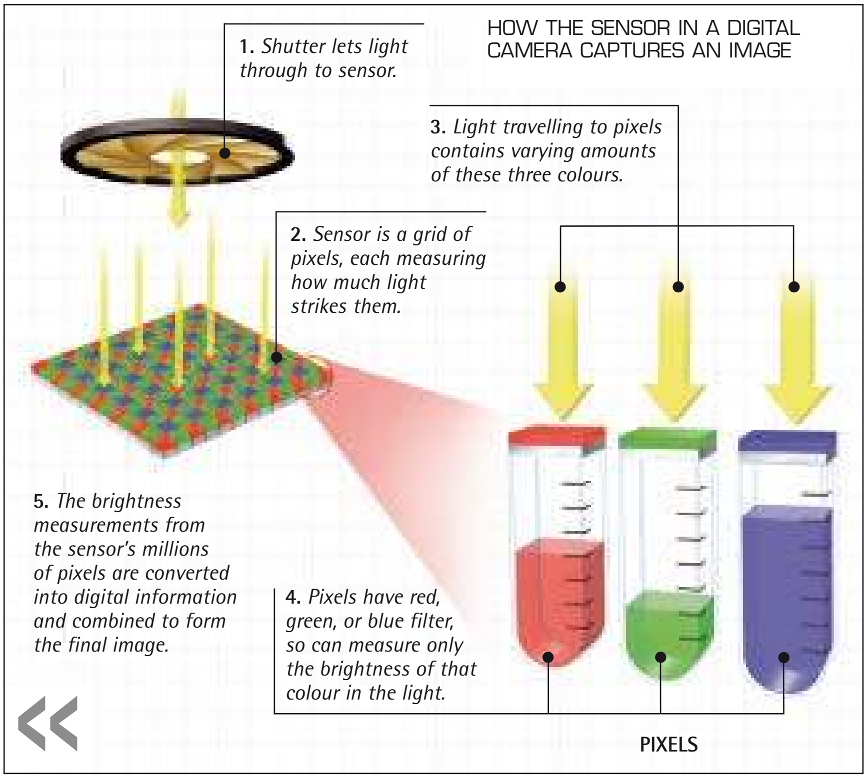
Digital photographs record information as numbers, rather than chemical changes in a piece of film. This means that there is no need for developing, so you can see your pictures moments after they have been taken, and simply delete them if they are not right. Unlike film, there is no gradual decay of stored images over time, so you can make perfect copies of your pictures many years later.

See also: Digital technology p243, Iris scan p32, LCD TV p24, Microchip p16, Sensor p250

HOW THE SENSOR WORKS

Digital cameras use lenses to focus the image onto an electronic sensor rather than a strip of film. When a picture is taken, the sensor converts the light striking it into an electrical charge. The charge is then sent to a circuit inside the camera, which measures it and gives it a digital value. Computer chips process the data to construct the image, which is then stored on a memory card.

The images in the card can be taken to a professional developer for high-quality prints, or downloaded to your computer. This is done either by connecting the camera to a computer with a cable, or by removing the memory card and putting it into the computer's card reader. The images can be printed, emailed, and manipulated using computer software, or loaded onto the web. The speed with which images can be retrieved, and the creative possibilities that follow, have revolutionized photography.



BACK

The first digital camera prototype was made by Kodak in 1976, but a consumer version – the Apple QuickTake 100 – was not introduced until 1994.

Digital cameras may use lenses made from liquid, making them incredibly small, flexible, and shatterproof.

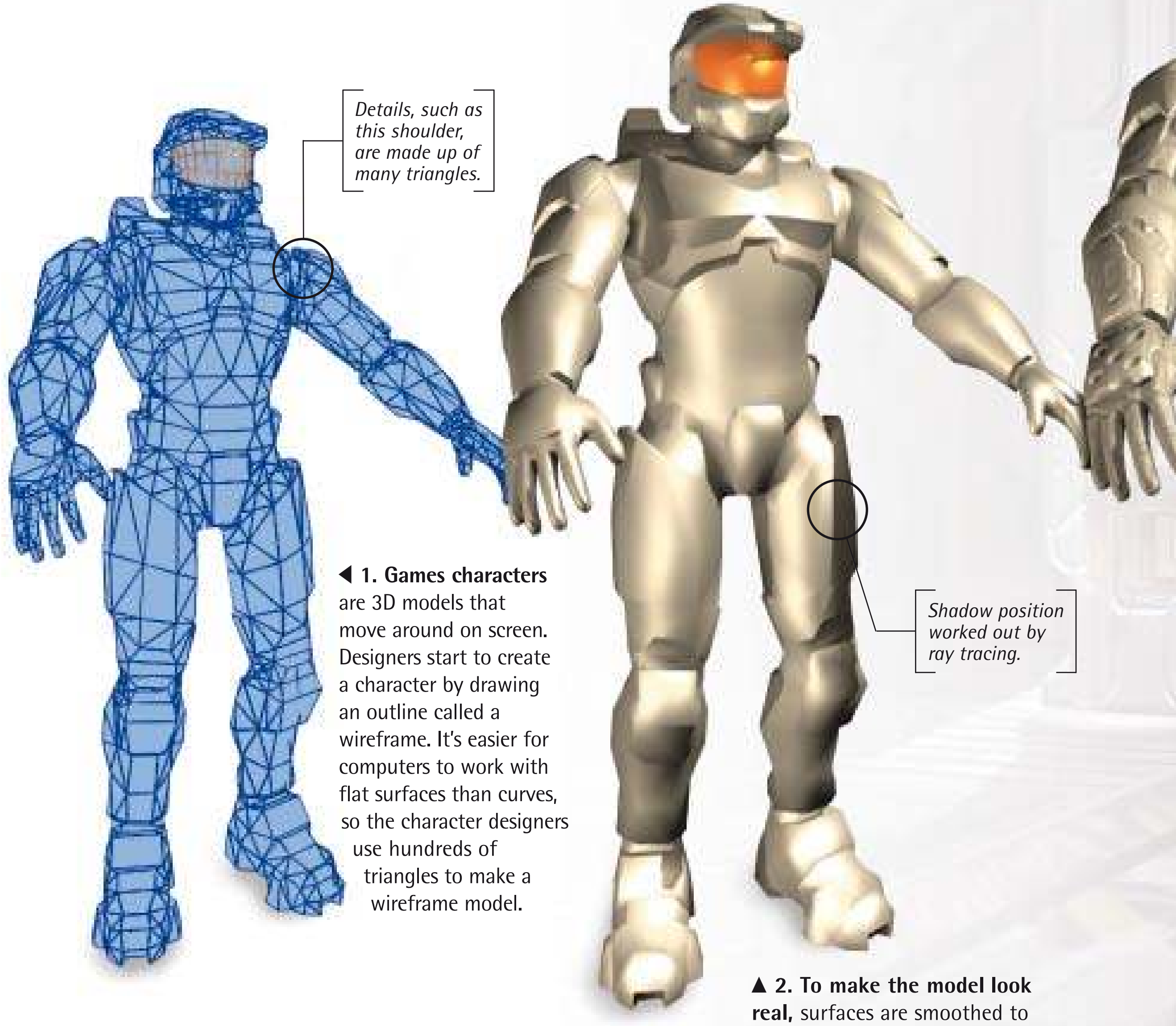
FORWARD

GAMES

Powerful processors

Games have become more elaborate since the first basic computer games. Today's games consoles are powerful computers that use a microprocessor chip and a 3D graphics controller to run the game. The microprocessor works out where the characters are and what they are doing, and tells the 3D graphics controller. The graphics chip inside the controller calculates what those characters should look like on screen. Both chips do billions of calculations each second to produce a realistic-looking game.

Pacman, an early video game



1. Games characters are 3D models that move around on screen. Designers start to create a character by drawing an outline called a wireframe. It's easier for computers to work with flat surfaces than curves, so the character designers use hundreds of triangles to make a wireframe model.

2. To make the model look real, surfaces are smoothed to take away the angular look of the wireframe. Light and shadow are added in a process called ray tracing, which works out how light would be reflected off the character at different angles.

Games consoles can put you in the driving seat of a rally car, let you pilot a 747, or allow you to become a fantastic creature moving through a mythical world.

▶ **4. Final colour detail** is added, then the last step is to put the model into its environment. As the figure may be moving quickly around the scene, each change of position and view of the background must be calculated separately.

Visor colour is applied in layers to give depth.

Image: background and character from Halo 2

Detail is added to leg.

◀◀BACK
The first videogame console, the Magnavox Odyssey, was produced in 1971. Plastic sheets were placed over the screen to provide background graphics.

Sony, Toshiba, and IBM have developed a new chip called Cell. Its designers predict it will make games consoles run ten times faster.
FORWARD▶▶

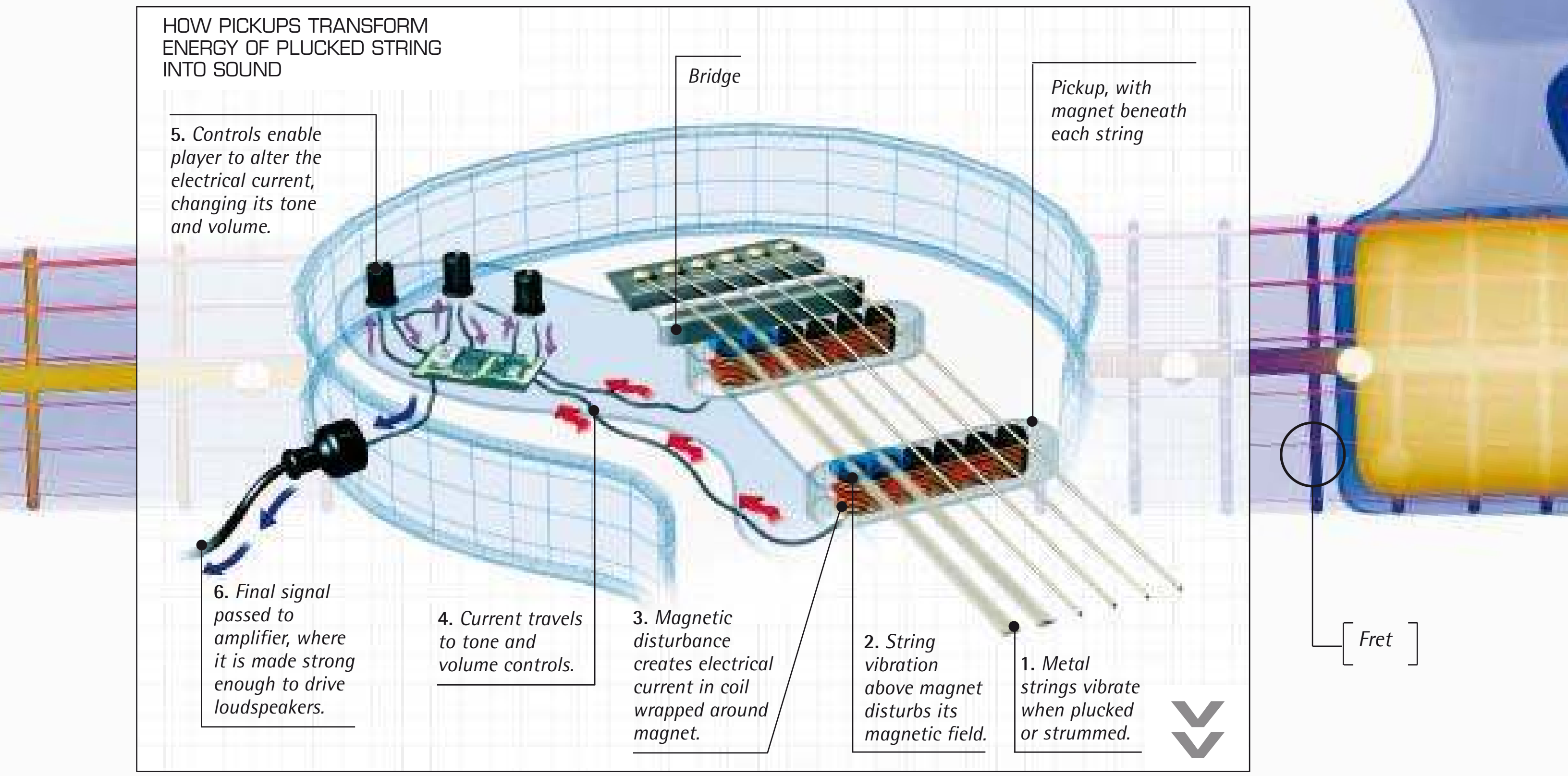
▲ **3. Surface detail** is applied to the model. In this case, the computer mimics the way that metal armour reflects light and applies this to the figure.

▶▶ See also: Arenas p72, Microchip p16, Microprocessor p246, Toys p26

GUITAR

The electric guitar started out as a way of making an ordinary guitar sound much louder, but has now become an established instrument with its own place in history.

HOW AN ELECTRIC GUITAR WORKS

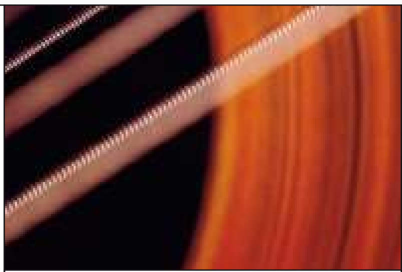


Guitars use a set of six strings of different thicknesses and stretched to different tensions. When played together, they produce a set of notes, known as a chord. The strings don't make much sound on their own, so they need to be amplified. In an acoustic guitar, the vibration of the strings sets the air in the guitar's hollow body vibrating as well, making the sound louder. However, an electric guitar amplifies the sound in a different way. The vibration of the strings is converted by a device called a pickup into an electrical signal. Loudspeakers then turn this electrical energy back into sound waves. The first electric guitar, called the Vivi-tone, was invented in 1933 but it was not a success. It was not until the rise of popular music in the 1950s that guitars became widely used. Since then, guitars such as the Gibson® Les Paul and the Fender Stratocaster® have become mass-selling classics, each renowned for producing a very particular sound. Some modern guitars are now used to control electronic synthesizers, giving guitarists access to a new palette of sounds.

See also: Headphones p74, Racket p54, Sound wave p250, Vibration p251

Thickness and vibration

When a string is plucked, it vibrates very fast. The speed of this vibration is called its frequency. Different frequencies produce different musical notes, and are determined by the length, thickness, and tension of the plucked string. The thicker the wire, the slower the vibration, and the lower the note that is produced.



Guitar strings vibrating

All guitars rely for their sound on controlling how strings vibrate. The guitar is tuned by changing the tension in each string. Different notes can be played on a string by pressing it against frets on the guitar's neck, shortening its effective length and so playing a higher note.

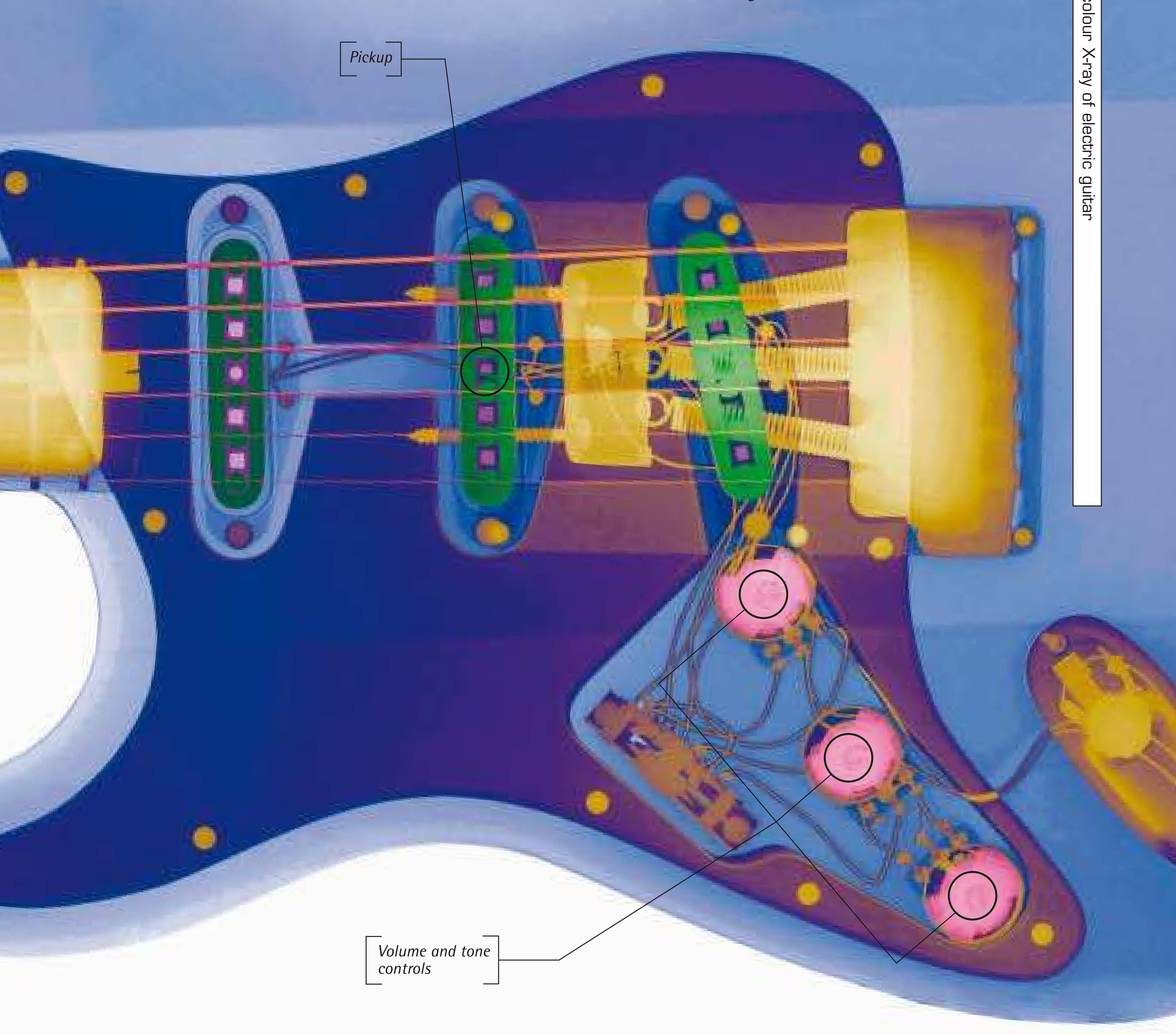


Image: false-colour X-ray of electric guitar

COMPACT DISC

▶▶ CDs spin around hundreds of times a minute while a glowing beam of laser light reads their data. The spiral track that holds all the information is almost 5 km (3 miles) long. ▶▶

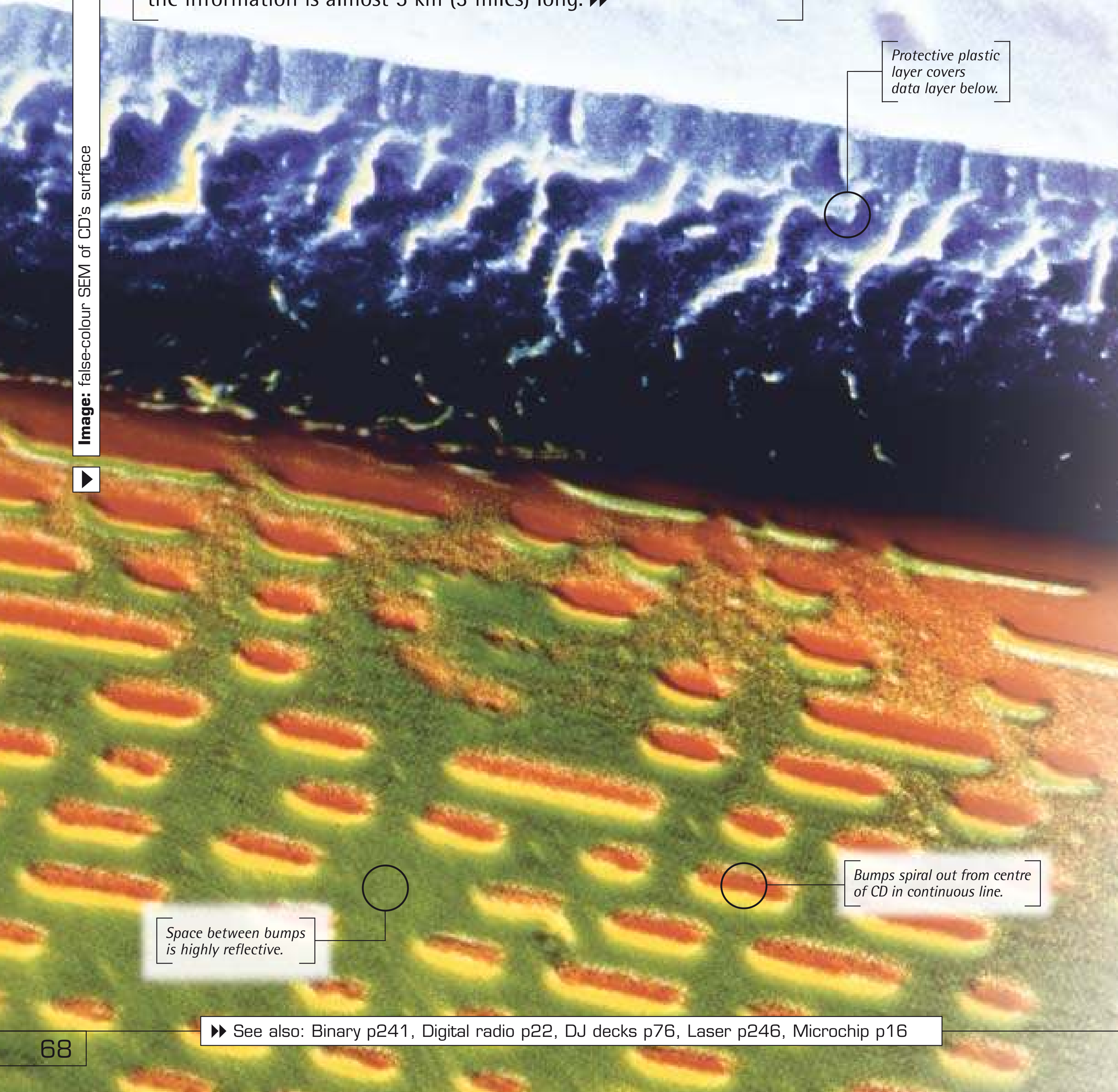
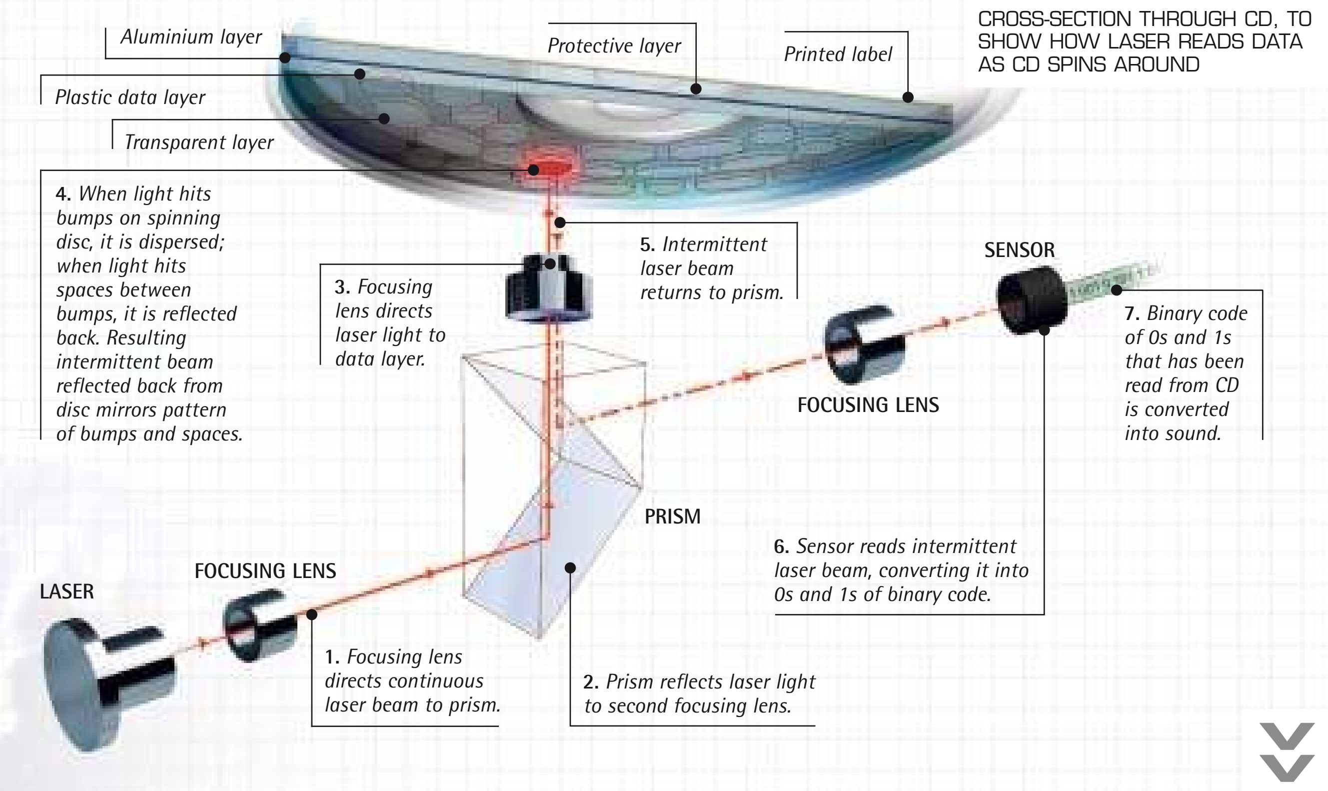


Image: false-colour SEM of CD's surface

▶▶ See also: Binary p241, Digital radio p22, DJ decks p76, Laser p246, Microchip p16

HOW A COMPACT DISC IS READ



In a digital recording, sound is converted into a long series of 0s and 1s – binary code. These are then represented as bumps and spaces on a tiny spiral track under a CD's surface. A CD is made up of layers. The bottom layer is transparent and carries the data layer where the information is stored. The data layer is covered with a layer of shiny aluminium, and topped with a layer of plastic that protects it, gives the CD strength, and carries the label. Music information is read from the CD using a laser beam focused through the transparent layer onto the spinning spiral track. Bumps disperse the laser light, but if there is no bump, the laser hits the shiny aluminium and is reflected back strongly. A sensor picks up the intermittent reflections from the disc as it spins and turns the signal back into 0s and 1s, which in turn are converted back into sound.

The tiny bumps that can be seen in this SEM of a CD's surface are no more than 500 nm wide – nm stands for nanometre, which is just one thousand-millionth of a metre. Their minuscule size means that a CD contains millions of bumps. These bumps are how a CD stores its digital data – 0s and 1s – that a CD player converts back into sound.

Master disc

CDs can be made cheaply by stamping them out using a mould. The master mould is made of metal, because it has to be extremely accurate and durable. The master carries the opposite pattern to that needed on the final CD, so a bump on the master forms a pit on the CD. One very expensive master can stamp out thousands of low-cost plastic copies.

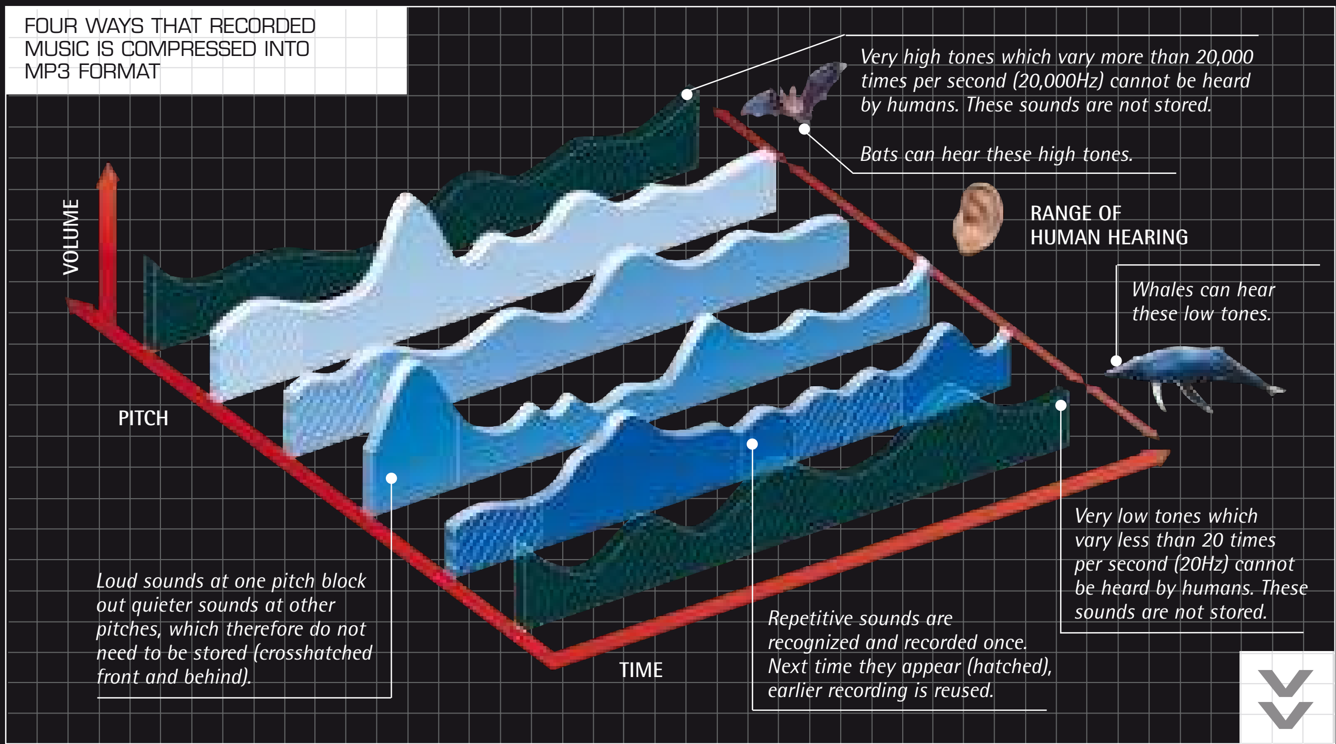

Manufacture of a master compact disc

MP3 PLAYER

MP3 players are portable music machines that can store and play thousands of songs. Most will fit in your pocket, some are small enough to be built into mobile phones and even sunglasses.

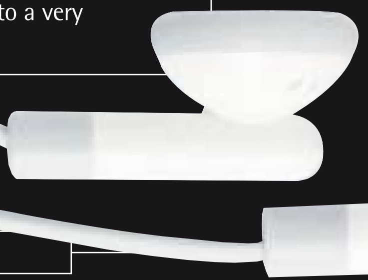
This MP3 player is the size of a pack of cards. It consists of just three main elements, a hard disk, circuit board, and battery. The hard disk stores thousands of tracks as digital data, the circuit board translates data into sound, and the battery provides power.

HOW MP3 COMPRESSION WORKS



Just as the size of a book depends on how many words are in it, the more information a digital file contains, the larger it is. MP3 players can be small because their software records only the sounds that we can hear, saving valuable storage space. The software identifies four ways it can avoid recording certain sounds, detailed above. In addition, it only records the left and right channels when they are actually different.

Together, these techniques reduce the amount of information that needs to be stored when music is recorded by ten or twelve times. Similar data compression techniques are used in all digital media. They are used to squeeze multiple phone calls down international telephone lines, to shrink the size of picture files so that they are easier to email, and to make digital television and radio possible by squashing lots of information into a very limited section of the airwaves.



See also: Compact disc p68, DJ decks p76, Headphones p74, Toys p26

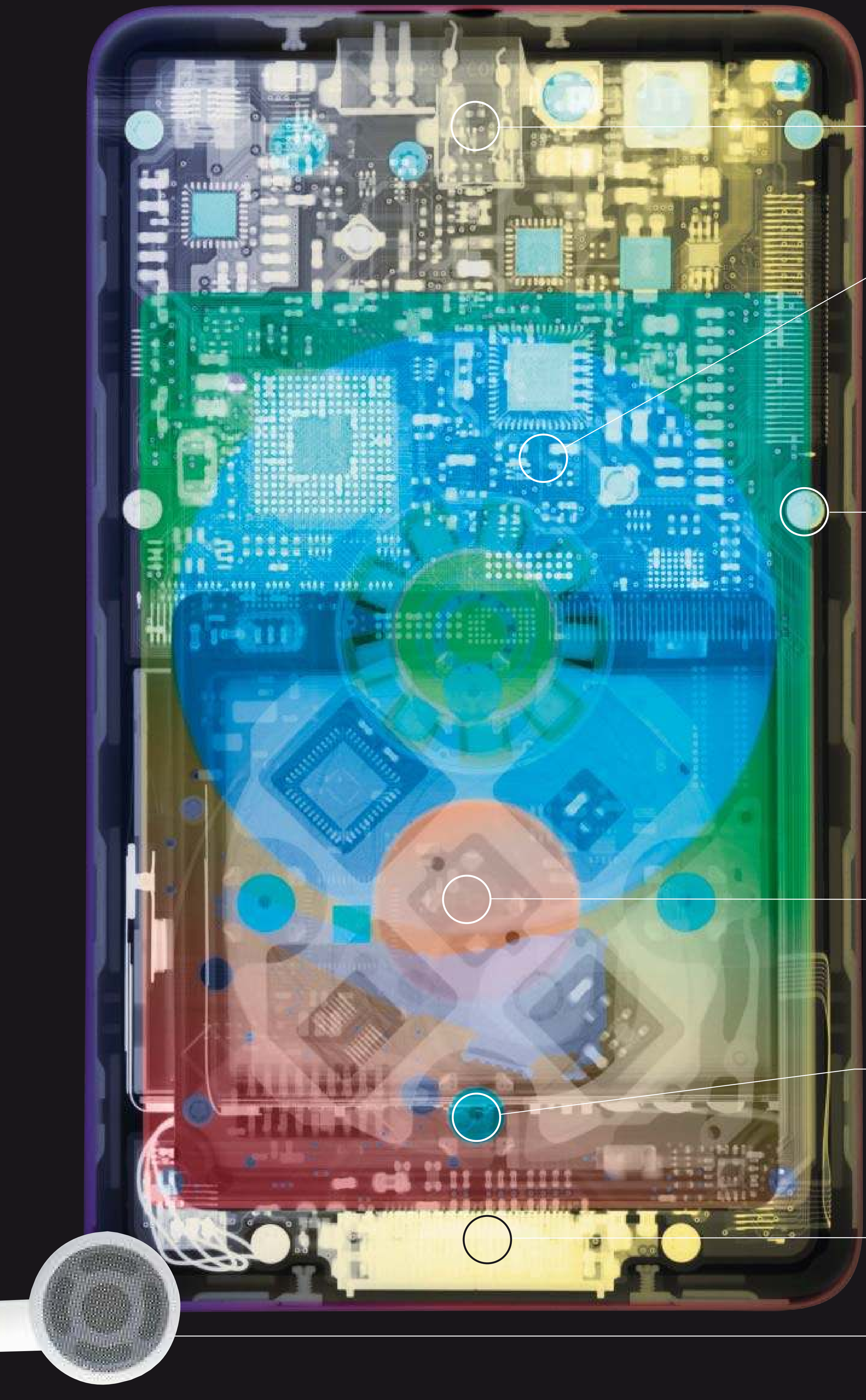
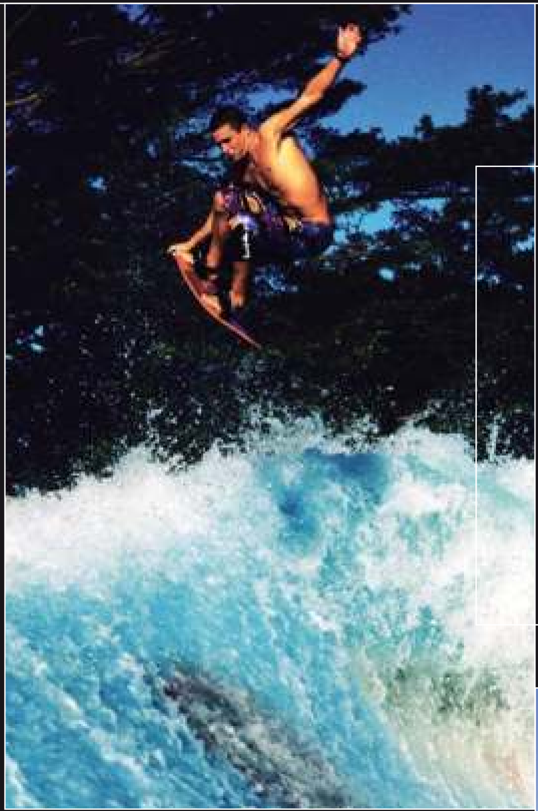


Image: false-colour X-ray of iPod mobile digital device

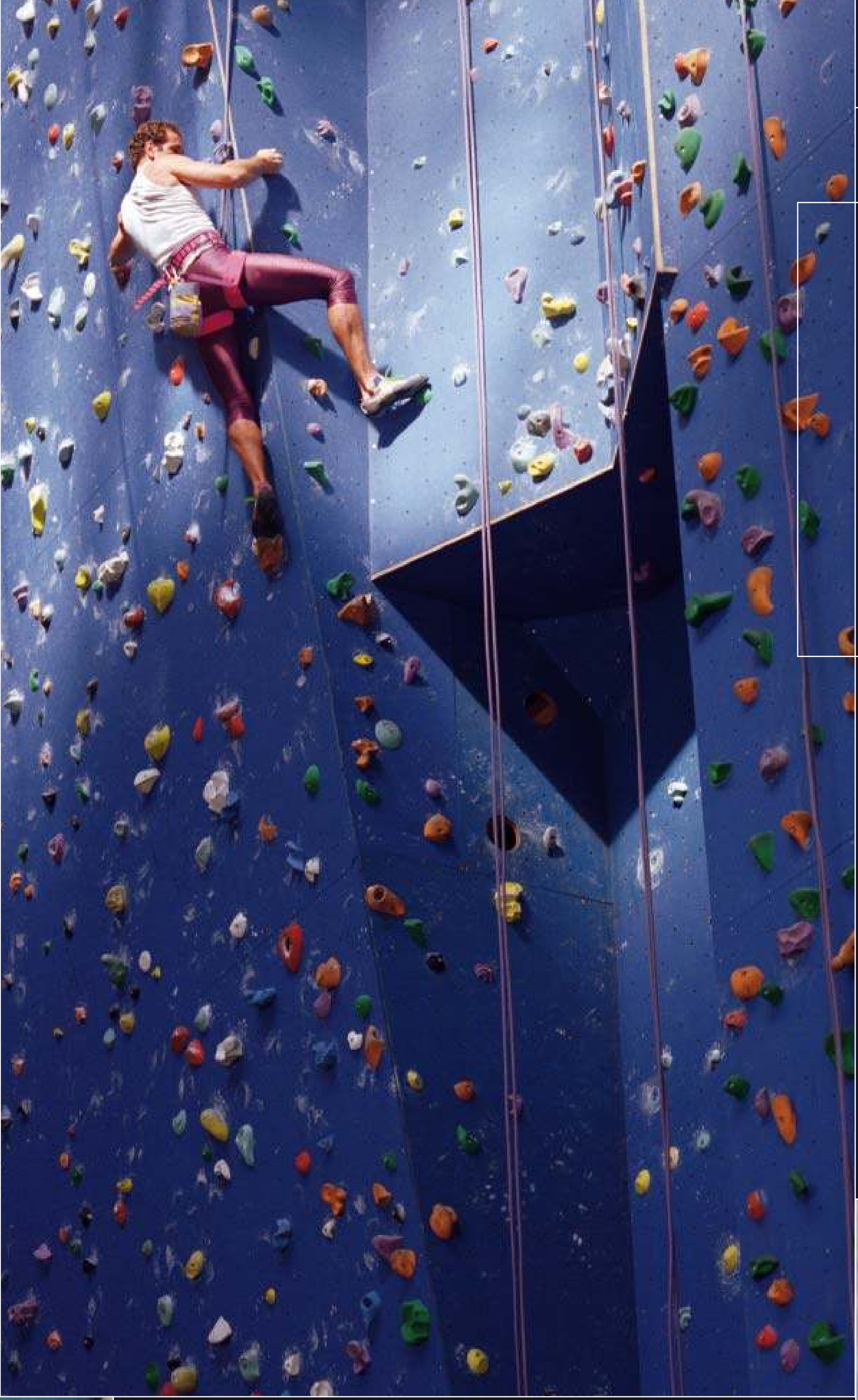
ARENAS



Wave simulator Surfers can spend hours waiting in the water for the perfect wave to ride into the shore. Indoor wave pools can provide a sequence of waves so that they can practise without the wait. Wave pools can be programmed to simulate the wave types found in different parts of the world.

Artificial turf Golf courses take up a lot of land, so are expensive in built-up areas. But putting greens, on which players practise their putts (rolling the ball into the hole), need only be small. Here, artificial turf has been laid on a skyscraper's roof, allowing golfers to practise their putts in a city centre.

Arenas enable climbers, surfers, cyclists, and other sports enthusiasts to train all year round. Technology creates outdoor conditions, such as snow and waves, even where they do not occur naturally.



Climbing wall

Using indoor climbing walls, climbers can work on their skills, strength, and stamina in the comfort and safety of a sports hall, whatever the weather. Then, when the summer climbing season comes around, they're fit and ready to go. Climbing walls are made of concrete, embedded with a combination of real rocks and artificial handholds and footholds. Climbers use a harness attached to a rope so that they can try out daring moves without risk of injury.

Velodrome

How do you make a long-distance event like cycling into a spectator sport? Wrap the long track into an oval and put it indoors. Velodromes (named after velocipedes, an early name for bicycles) have banked tracks and a staggered start so each rider cycles the same distance, whether they are on the inside or outside of the oval. Riders use the banking to gain position and attack the race leaders, creating a game of tactics and cunning.

Inside a snowdome

Skiing and snowboarding do not have to be winter sports. Snowdomes contain slopes of different heights so that beginners can learn the basics, and the more experienced can brush up on their skills, before heading for the real slopes. Snowdomes are kept very cold and manufacture their own snow to create a true alpine experience, even at the height of summer.

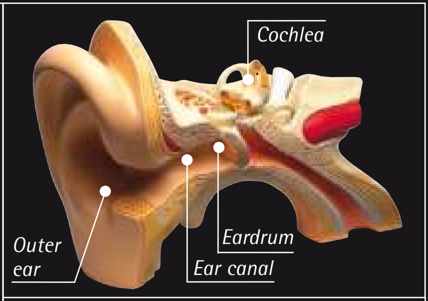
See also: Bike p58, Snowboard p56

HEADPHONES

Headphones allow you to enjoy music without disturbing anyone else. Some headphones are pads that enclose the ear, others are buds worn inside it.

Sound and the ear

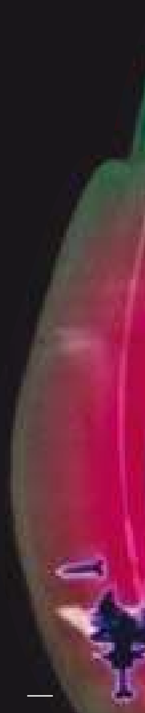
The outer ear directs sound waves into the ear canal, where they meet the eardrum. There, sound waves are turned into vibrations, and transmitted to the cochlea, a curled tube filled with fluid. The vibrations make the fluid move. This movement is sensed by tiny hairs within the cochlea, which turn it into electrical signals that are sent to the brain.



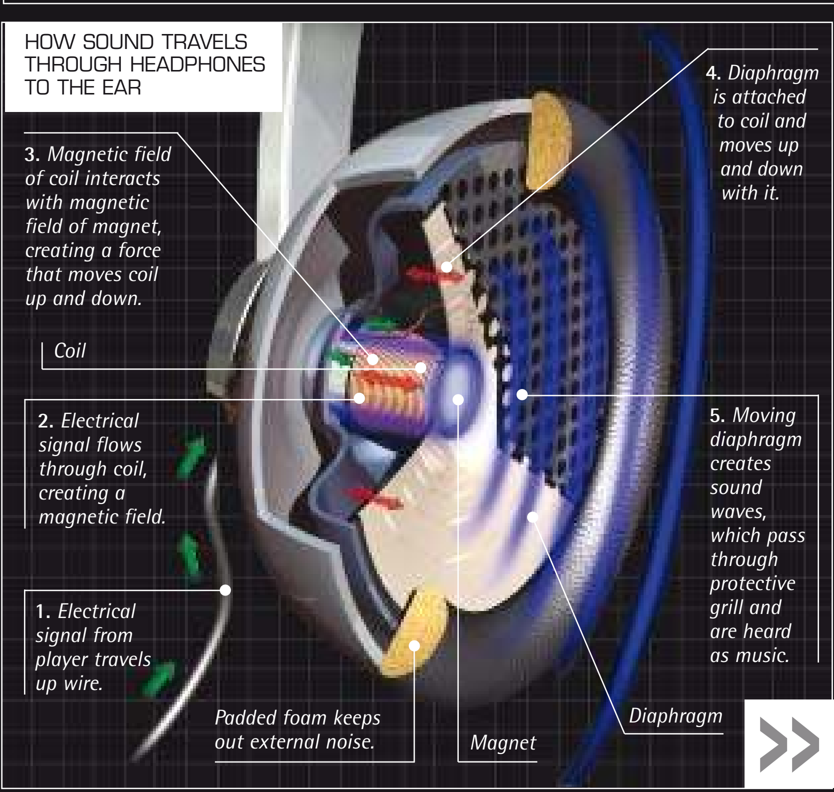
Anatomy of the ear

BACK The first hi-fi stereo headphones were launched in 1958 by the American company Koss and were designed to be used with a record player.

Some companies are developing wireless headphones that can be linked to portable music players, so you can listen without a tangle of wires. **FORWARD**



HOW HEADPHONES WORK



Headphones channel sound to both ears, and each earpiece is connected to the source by a wire. A signal is transferred through the wire to a coil wrapped around a tube that encloses a cylindrical magnet. When the signal flows through the coil, it creates a changing electromagnetic field. This interacts with the magnet's own field to create a force that moves the coiled tube up and down. This in turn moves the diaphragm. The sound waves are created by the diaphragm, which pushes the air in front of it, reproducing the sound from the source.

Pilots need to hear information and instructions over the roar of aeroplane and helicopter engines. Headphones have been developed that can cancel out a lot of this external noise, so only the sound fed to the headphones is heard.

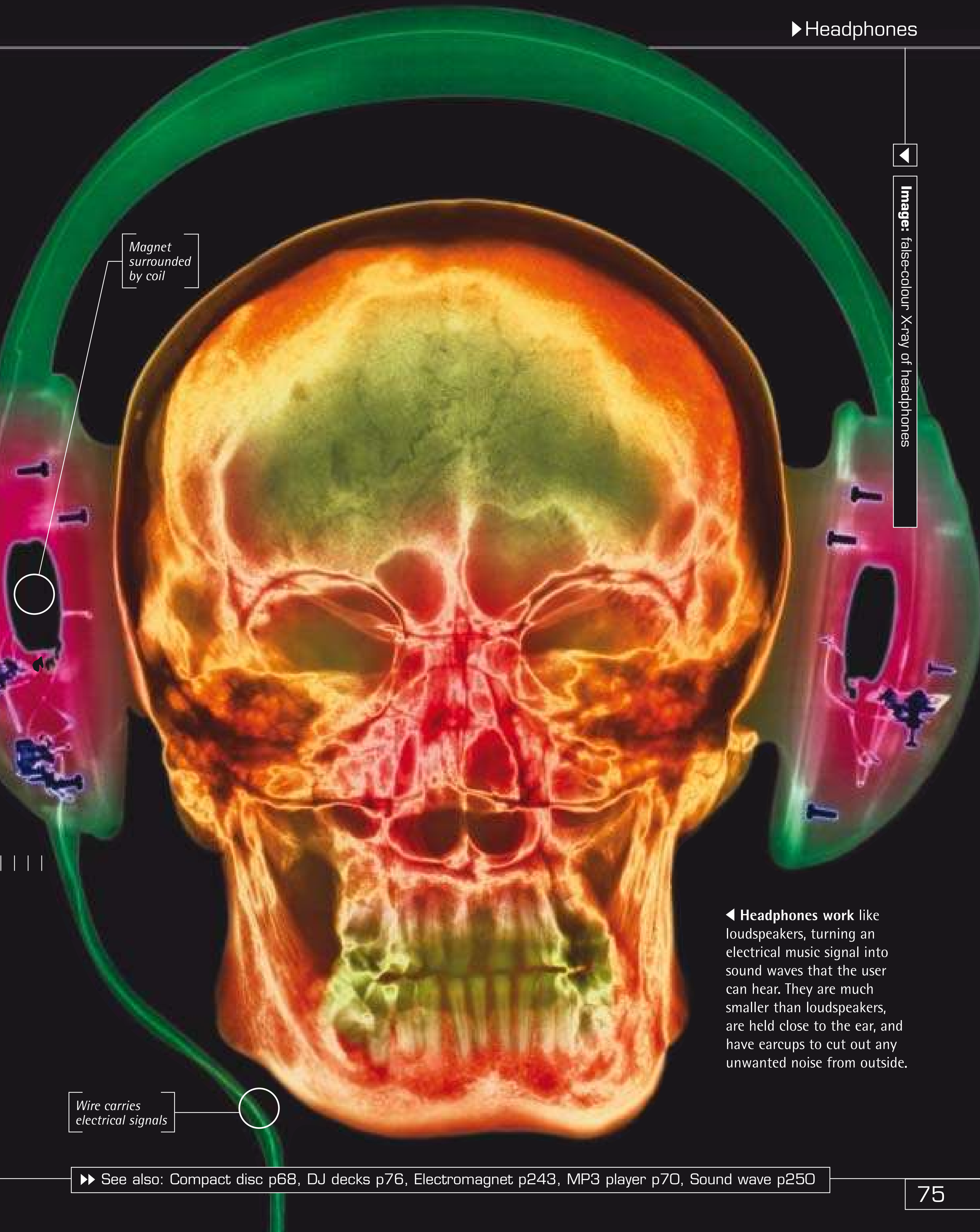
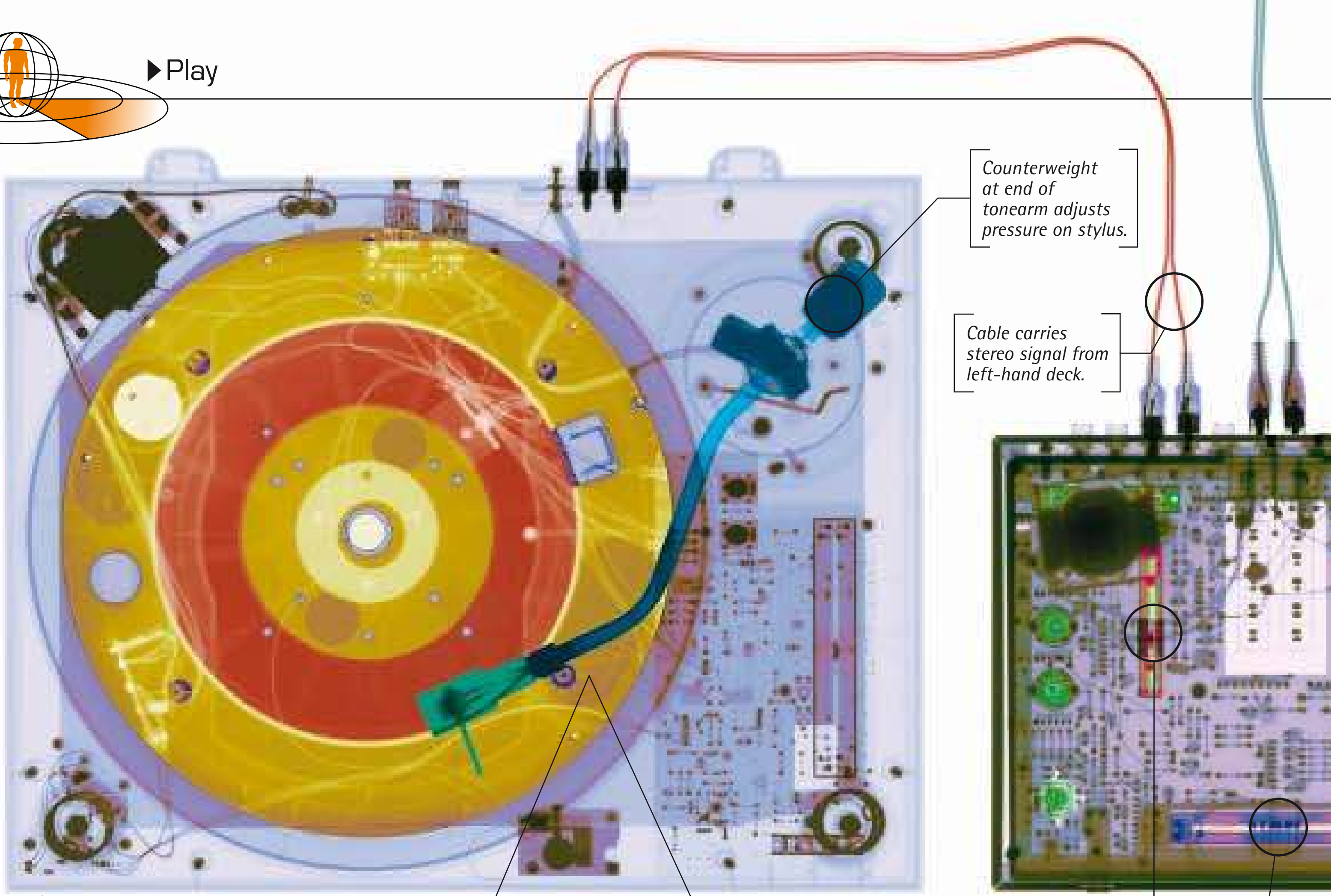


Image: false-colour X-ray of headphones

Headphones work like loudspeakers, turning an electrical music signal into sound waves that the user can hear. They are much smaller than loudspeakers, are held close to the ear, and have earcups to cut out any unwanted noise from outside.

See also: Compact disc p68, DJ decks p76, Electromagnet p243, MP3 player p70, Sound wave p250



▼ **DJs play vinyl records** on a pair of decks and a mixer. Using two decks, they can swap between records without interruption, and stop, rewind, and replay part of a record by pushing it backwards and forwards with a fingertip. The mixer allows the DJ to combine sounds from the two records. In this way, DJs make their own music from other people's recordings.

◀ **A vinyl record** is stamped with a long spiral groove that holds the musical information. The record is placed on a rotating metal disc called a platter. The stylus, which picks up the music from the groove, is held in place by the tonearm. The tonearm enables the stylus to follow the groove as the spiral leads it into the record's centre.

DJ DECKS

▶▶ Radio disc jockeys, or DJs, used to use two record decks and a mixer to change between songs on their shows. It wasn't long before club DJs started using this technology to make crowd-pleasing music of their own. ▶▶

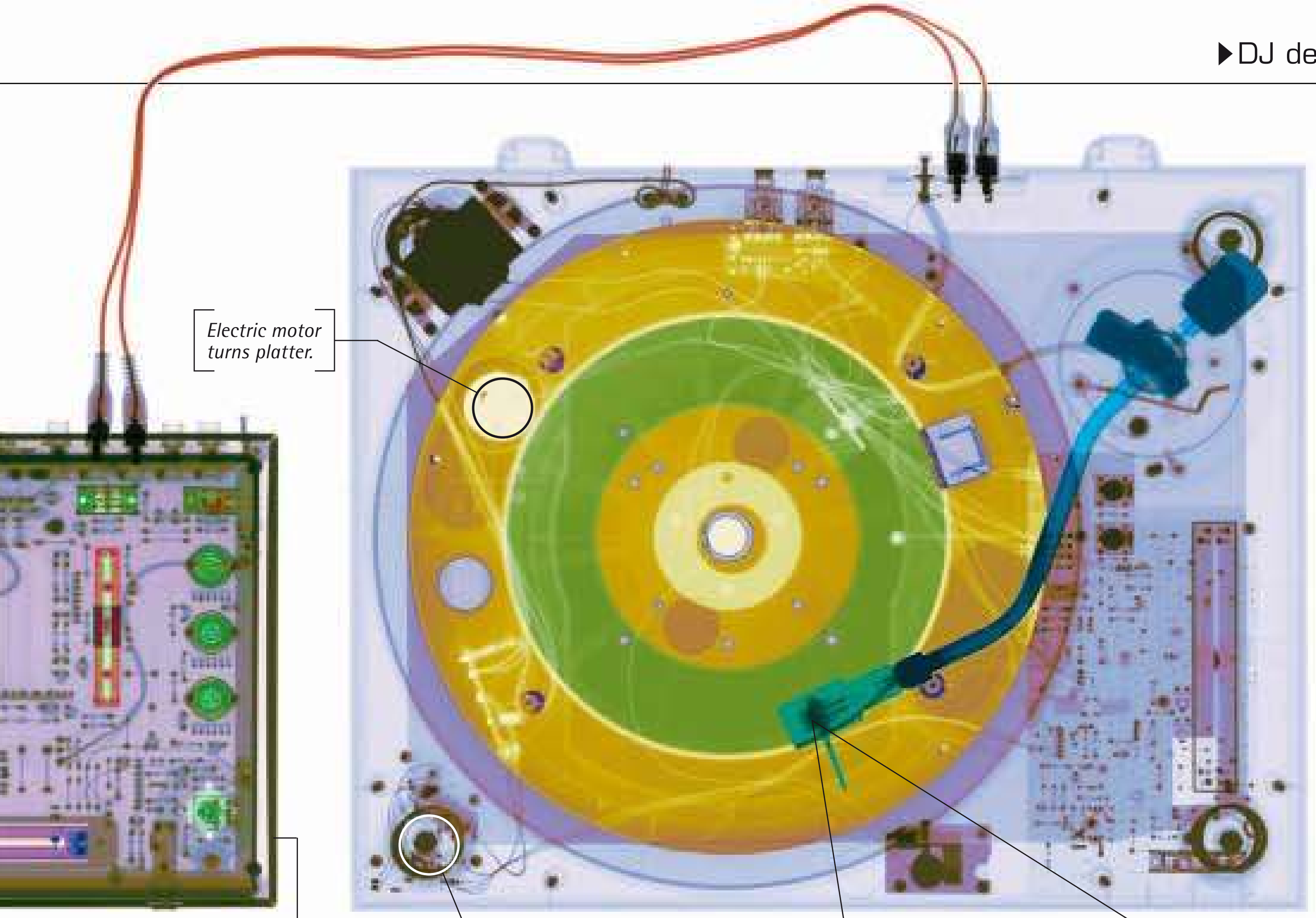


Image: false-colour X-ray of DJ decks and mixer

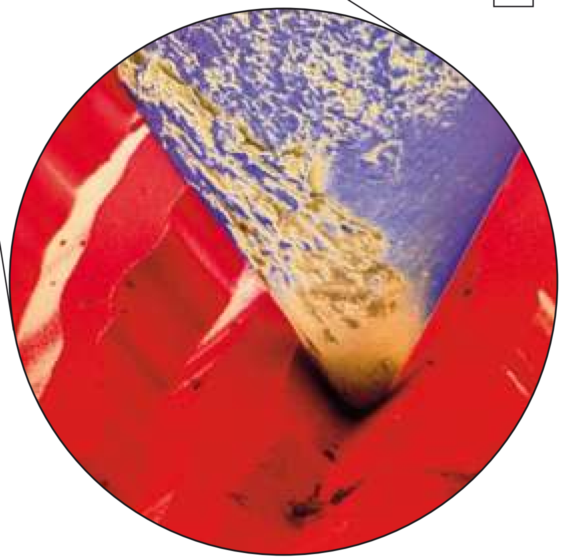
▲ **The mixer is the heart** of the DJ's art and the crossfader its most important control. DJs use the crossfader to mix sounds from one record with another. For example, a violin solo from a classical record could be mixed with drum and bass beats. Other controls adjust the amount of bass and treble in the music, and the volume for each deck, giving DJs some of the control that studio mixing desks offer.

◀◀BACK

The man renowned for first hooking two turntables together was DJ Kool Herc, a Jamaican who moved to New York in the early 1970s.

Computers can be used to mix records together, adjusting their sounds and speeds, but it is difficult to replicate the hand control DJs have with decks.

FORWARD▶▶



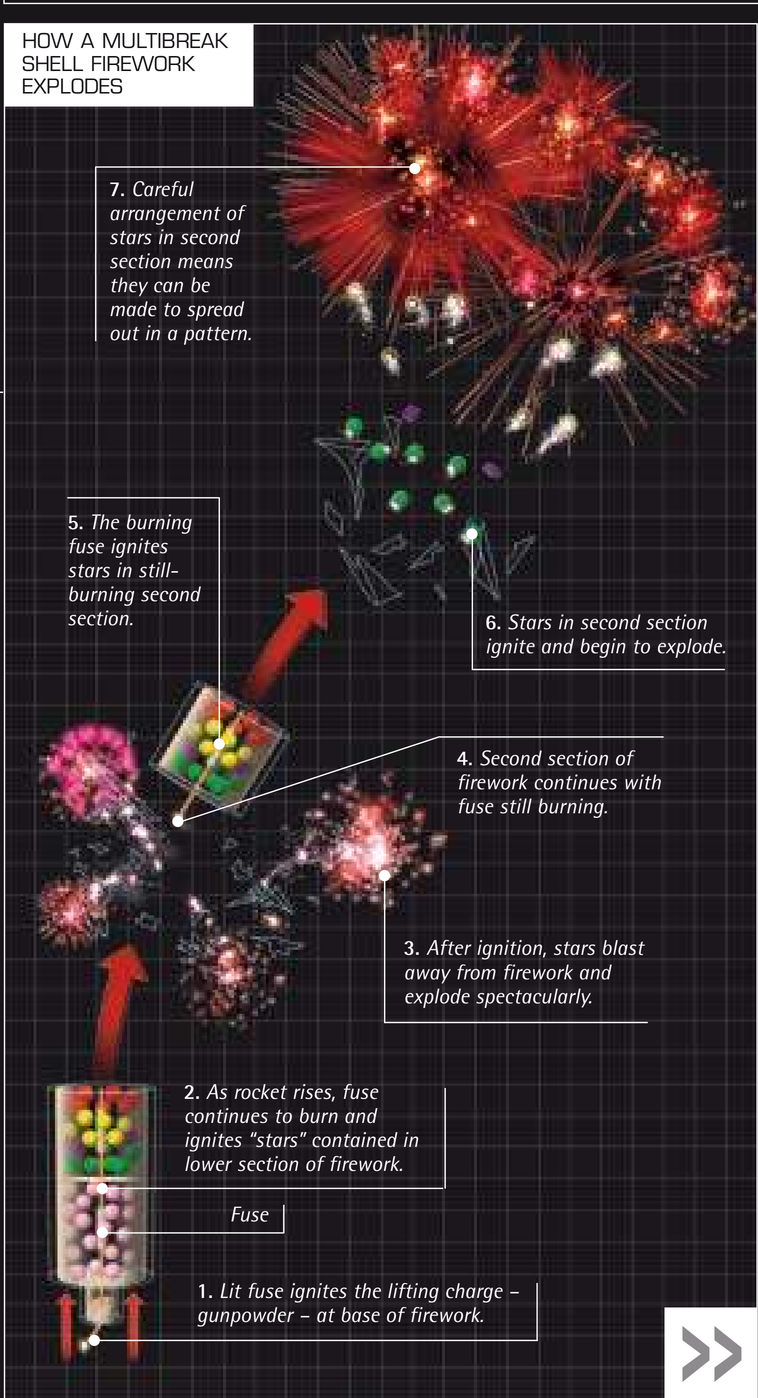
▲ **This false-colour SEM** shows a diamond stylus in the tiny V-shaped groove of a record. As the record spins, the stylus vibrates, picking up the musical signal pressed into the groove as microscopic hills and valleys. The stylus is connected to mechanisms in the tonearm that turn the vibrations into electrical signals so that they can be amplified and heard as sound.

▶▶ See also: Compact disc p68, Headphones p74

FIREWORKS

A firework is a device in which gunpowder and other chemicals explode to produce colour, sparks, smoke, and sound. Firework displays can paint the sky with multicoloured designs in time to music.

HOW FIREWORKS EXPLODE



Fireworks were developed in the second century BC by the ancient Chinese for use in religious ceremonies. From this peaceful beginning, they were turned into weapons of war. In the Middle Ages, rockets were used to set fire to opponents' camps. Later, rockets were made to deliver packets of gunpowder, exploding on impact. In 1605, a group of conspirators led by Guy Fawkes made an attempt to blow up London's Houses of Parliament with gunpowder. In Britain, their failure is celebrated with annual firework displays. Today, firework displays around the world use sophisticated blends of explosive and colour chemistry to produce cascades of colour and sound. They are co-ordinated by automatic firing mechanisms.

The brilliant colours that fireworks make are produced by a mixture of chemicals. Magnesium and aluminium burn to produce white light, sodium salts produce yellow, strontium nitrate or carbonate produces red, and barium nitrate produces green. Copper salts produce blue, and various forms of carbon, including charcoal, produce orange.

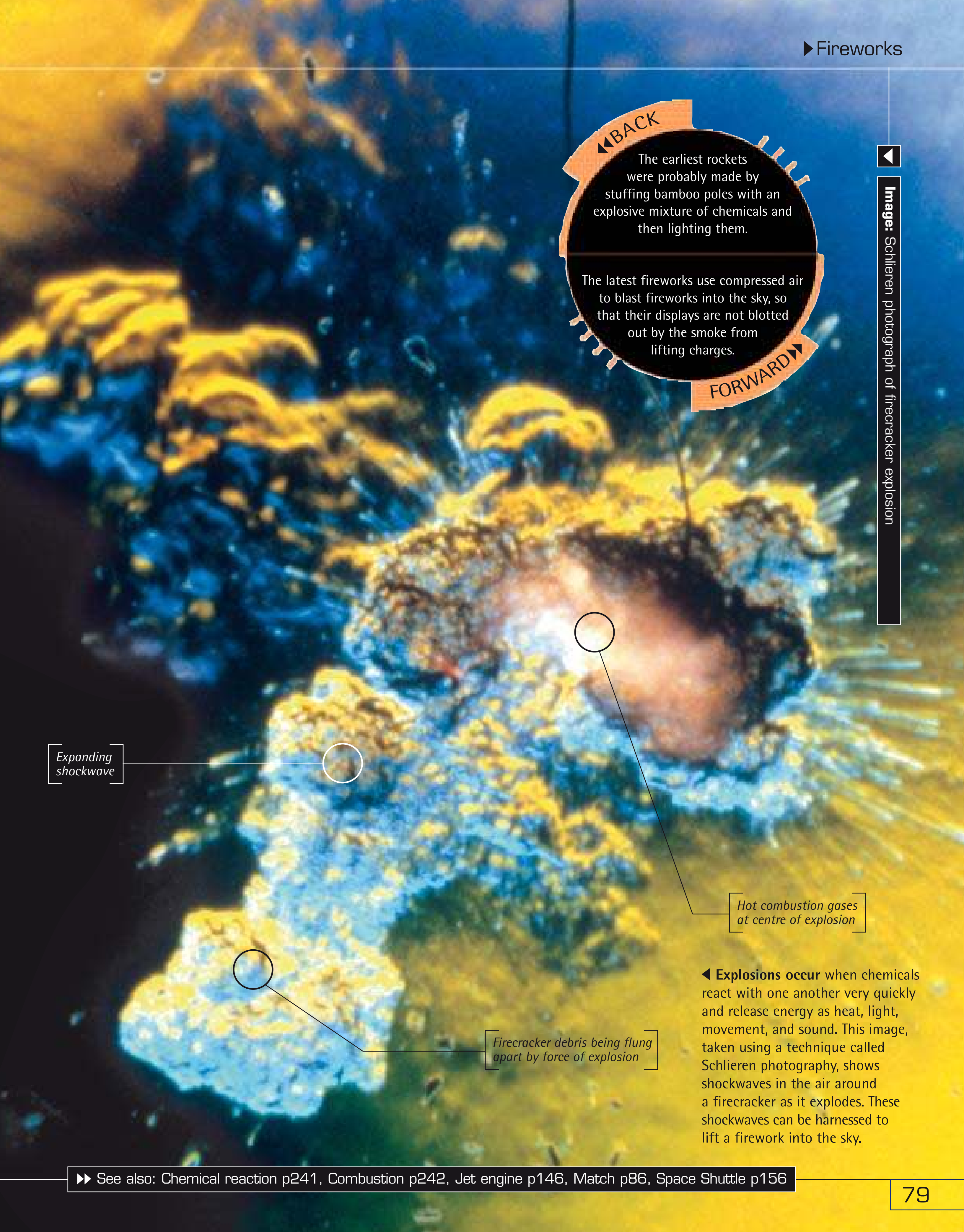
◀◀ BACK

The earliest rockets were probably made by stuffing bamboo poles with an explosive mixture of chemicals and then lighting them.

The latest fireworks use compressed air to blast fireworks into the sky, so that their displays are not blotted out by the smoke from lifting charges.

FORWARD ▶▶

Image: Schlieren photograph of firecracker explosion



◀ **Explosions occur** when chemicals react with one another very quickly and release energy as heat, light, movement, and sound. This image, taken using a technique called Schlieren photography, shows shockwaves in the air around a firecracker as it explodes. These shockwaves can be harnessed to lift a firework into the sky.

▶▶ See also: Chemical reaction p241, Combustion p242, Jet engine p146, Match p86, Space Shuttle p156

Computer games will increasingly become a more shared experience with other people. Wireless communications and high-speed connections will result in more networked games, which will allow you to play against players who may be located anywhere on the planet rather than just pitting you against computer-generated opponents. There will also be exciting developments in the way we control and interact with computer games. Control buttons and joysticks will disappear to be replaced with sensors and cameras that read your body movements and facial expressions. Advanced speech recognition will instantly react to voice commands.

> "A head-mounted display will allow you to superimpose computer-generated images and sounds onto the real world."

The explosive growth in computer power could mean that by 2010 it will be difficult to distinguish between digitally created images and what is real. New display technologies will narrow the gap even further. In the 1990s, the advent of virtual reality gave people the opportunity to immerse themselves in a virtual world by putting on a pair of goggles with computer images projected on the inside. The next step is likely to be head-mounted displays that beam images directly onto the retina inside the eye. Augmented reality will blur the boundaries even further by allowing you to see the real world through your head-mounted display and superimposing computer-generated images, sounds, and even smells.

While some of these worlds will remain strictly in the realms of fantasy, others will immerse you in role-playing experiences much closer to home. So-called epistemic games will enable you to act out the challenges facing a real-life person such as a surgeon, architect, pilot, or soldier. These games already form part of the training for people who intend to follow these careers, and will become increasingly detailed and realistic.

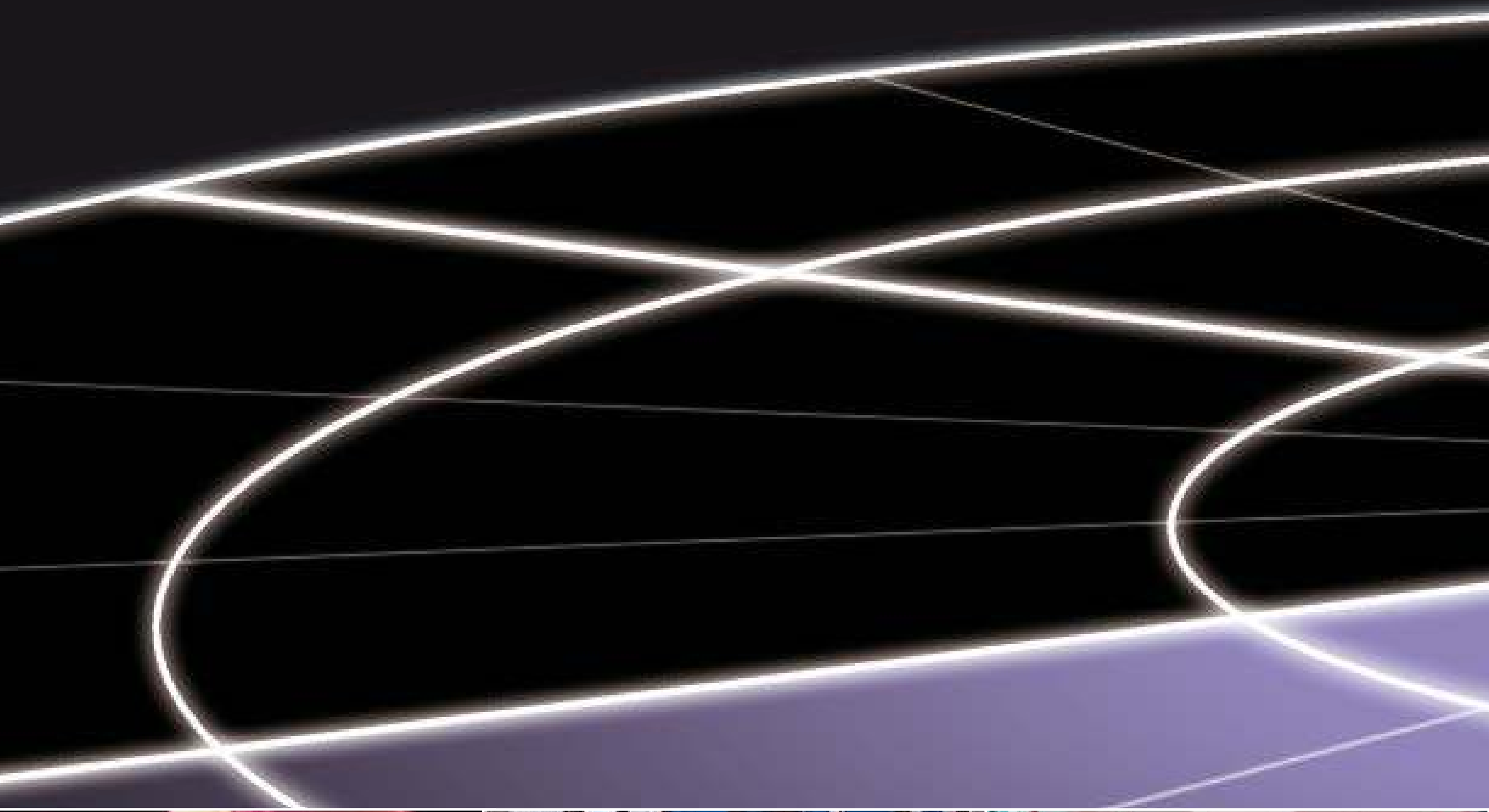
Back in the real world, spectators attending sporting events, from athletics to football matches, will be able to have a much more interactive experience from the stands. Wireless handheld devices will provide fans with on-demand instant action replays from different cameras positioned around the stadium. There will also be access to all kinds of information from complex rules to statistics about individual players or teams.

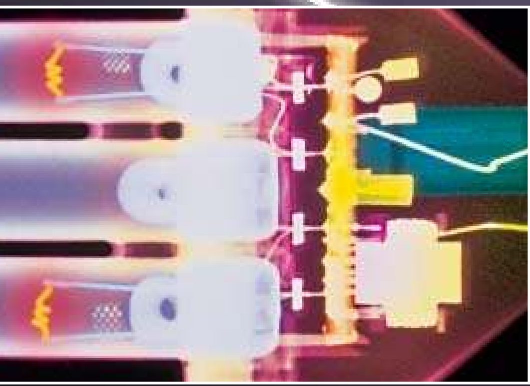
As space flight becomes more accessible, people dream of playing zero-gravity sports beyond Earth's atmosphere. Lunar golf was first played in 1971, when astronaut Alan Shepard hit a golfball on the Moon. In years to come, we may be able to race spacecraft fitted with solar sails. These giant mirrored sails are pushed through Space by light energy from the Sun. Because the spacecraft do not have to carry their own fuel supplies, they can travel at much greater speeds. So, who knows – maybe the sky is no longer the limit.

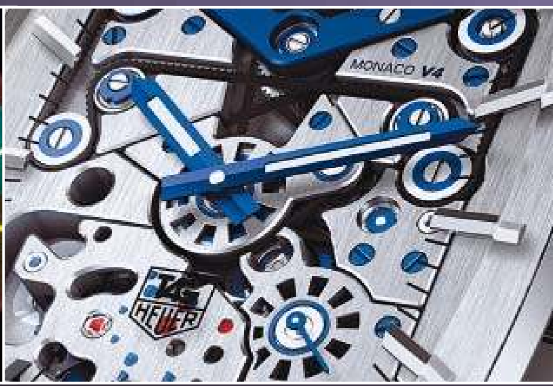
WATERPROOF SPORT FABRIC

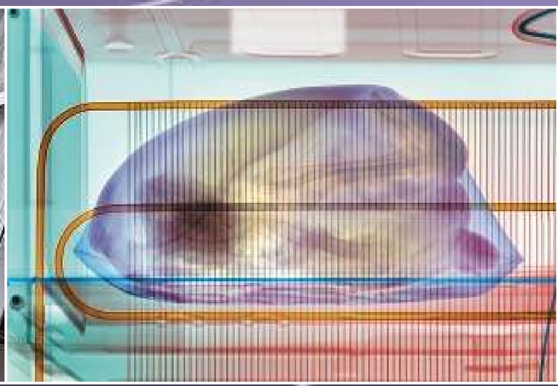
>>LIVE

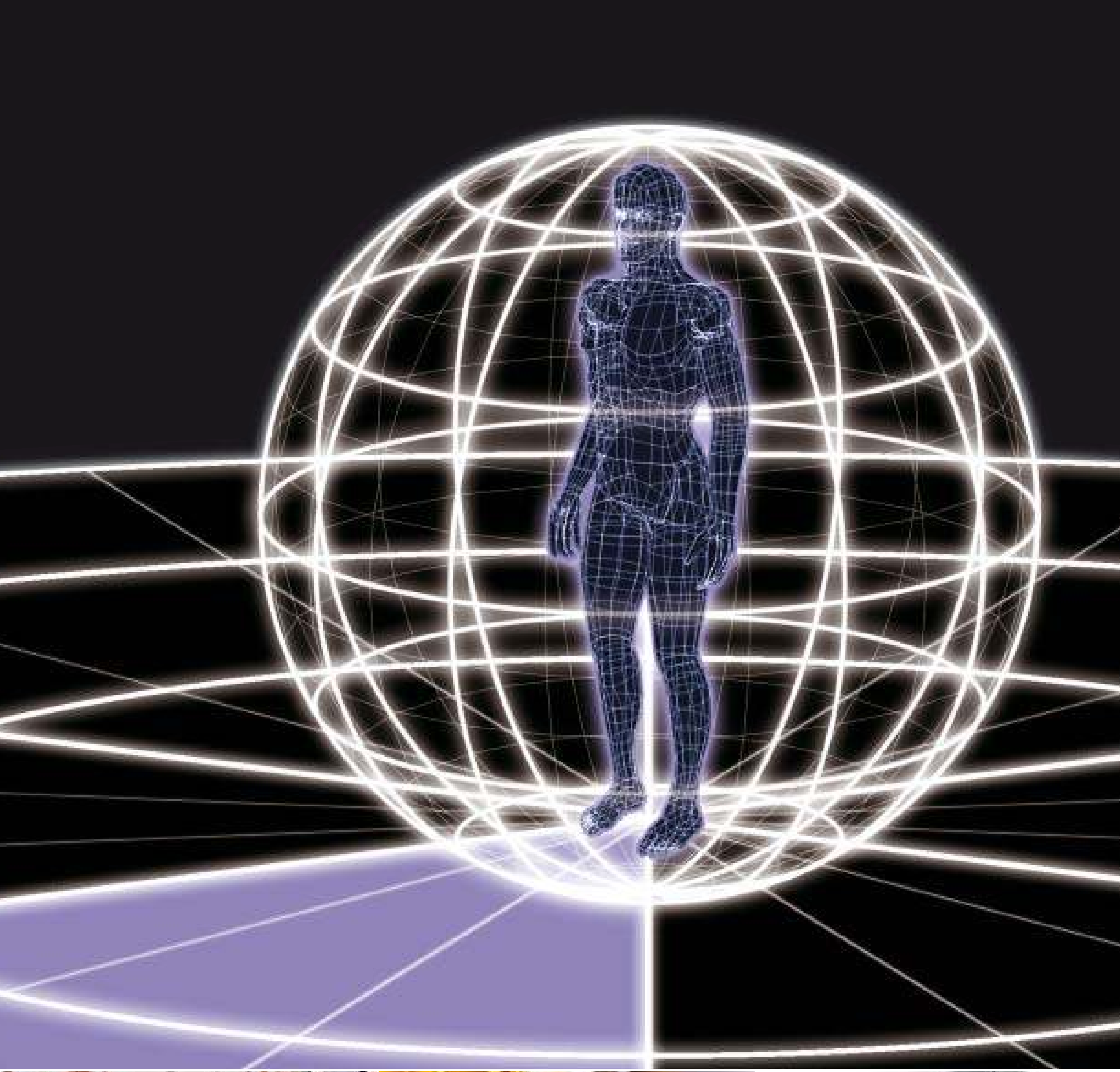
Match >> Light bulb >> Mirror >> Watch >> Battery >> Solar cell >> Microwave >> Fridge >> Aerogel >> Lock >> Shaver >> Aerosol >> Washing machine >> Vacuum >> Robot helper

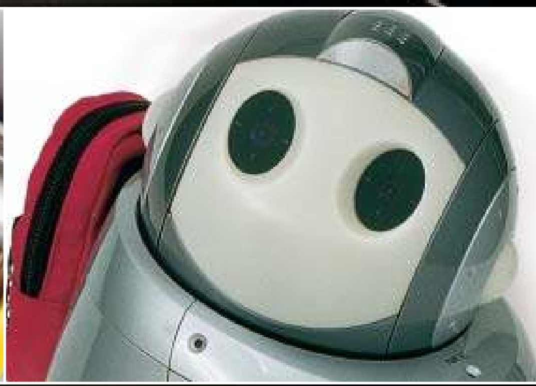










CLOSE-UP OF AIR VENT

Today, most of us in the industrialized world can cook a meal in minutes using a microwave oven, or programme a washing machine to clean and dry our clothes and a dishwasher to wash our kitchen utensils while we are out of the home. Just 150 years ago, there were very few labour-saving devices of any kind.

Without gas or electricity, household tasks had to be done by hand and were very time-consuming. To wash dirty laundry, for example, wood had to be chopped, a fire lit to heat the water, and clothes had to be scrubbed and wrung out by hand. Each day of the week was usually reserved for a particular chore such as washing, ironing, baking, or cleaning the house. Most of the work involved was physically very demanding and left little time for other activities.

The arrival of electricity in homes during the late 19th and early 20th centuries resulted in the invention of a range of domestic devices designed to make life easier, from the electric shaver to the electric toaster. Small, high-speed electric motors made the development of effective washing machines, refrigerators, and lightweight vacuum cleaners possible. Housework became less of a daily struggle and homes became cleaner, healthier environments.

In the second half of the 20th century, new technologies continued to have a big impact on the domestic scene. The magnetron, a vacuum tube used in radar systems, led to the development of the microwave oven. By the end of the century, many household appliances, including ovens and dishwashers, had timers and programming devices controlled by microprocessors. Food could be prepared quickly and easily. Many tasks could now be carried out automatically and simultaneously, simply at the push of a button or two.

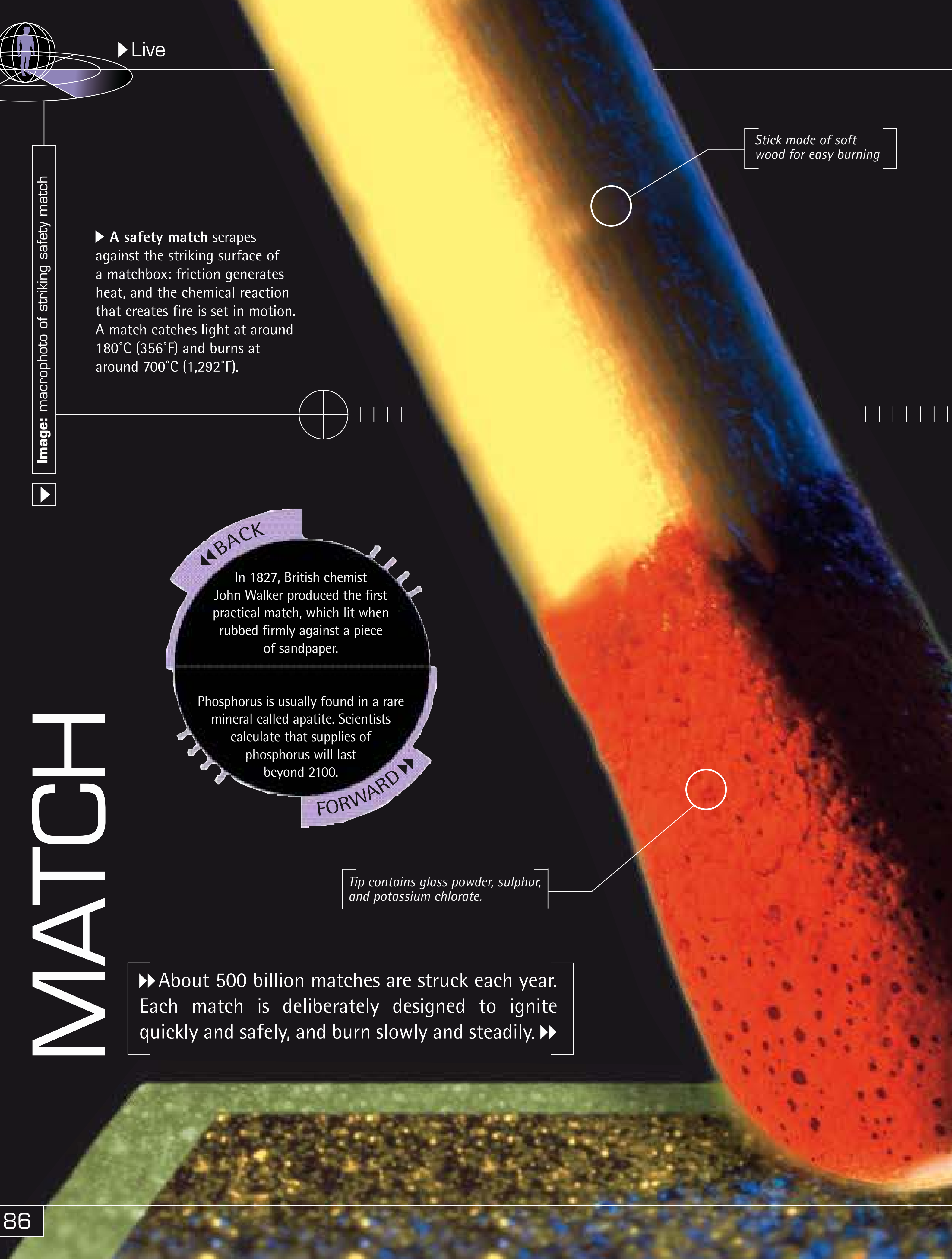
> "Previously time-consuming and physically demanding tasks can today be carried out at the push of a button."

The way we live has been revolutionized by domestic appliances. The time needed for household chores has been dramatically reduced and leisure time has increased. But it has come at a cost. Older refrigerators contain chemicals called chlorofluorocarbons (CFCs), which damage the ozone layer, the planet's natural defence system against harmful radiation from the Sun. Most of the electricity that powers our household appliances comes from burning oil, coal, or gas in power stations. Burning these fuels, however, releases gases into the atmosphere that are responsible for climate change – one of the main threats facing our planet during the 21st century.

One of the ways to cut down on the amount of electricity that we consume is to make our homes and household devices more energy-efficient. By making washing machines that use less water and houses that retain heat effectively, we can cut down on the amount of power that we use. Technologies that harness alternative sources of power, such as solar cells and wind turbines, are being developed too. Coupling energy-efficient devices with clean power will make a real difference to the planet's future.

MATCH

Image: macrophoto of striking safety match



A safety match scrapes against the striking surface of a matchbox: friction generates heat, and the chemical reaction that creates fire is set in motion. A match catches light at around 180˚C (356˚F) and burns at around 700˚C (1,292˚F).

BACK

In 1827, British chemist John Walker produced the first practical match, which lit when rubbed firmly against a piece of sandpaper.

Phosphorus is usually found in a rare mineral called apatite. Scientists calculate that supplies of phosphorus will last beyond 2100.

FORWARD

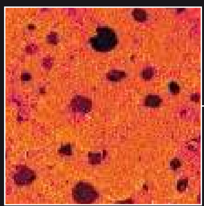
About 500 billion matches are struck each year. Each match is deliberately designed to ignite quickly and safely, and burn slowly and steadily.

See also: Combustion p242, Fire suit p190, Friction p244, Heat p98

HOW A MATCH WORKS

When a match strikes, friction between glass powder in the match tip and the striker on the box produces a small amount of heat. This converts the red phosphorus on the box striker into a cloud of white phosphorus gas. The white phosphorus ignites in air and makes the potassium chlorate and sulphur in the match tip react together. This reaction happens at a high enough temperature to set fire to the wood.

BEFORE

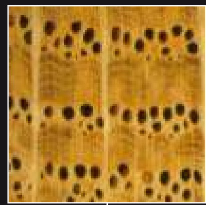


The match tip contains potassium chlorate and sulphur.

AFTER

Most of this easily burned material has been consumed by the fire.

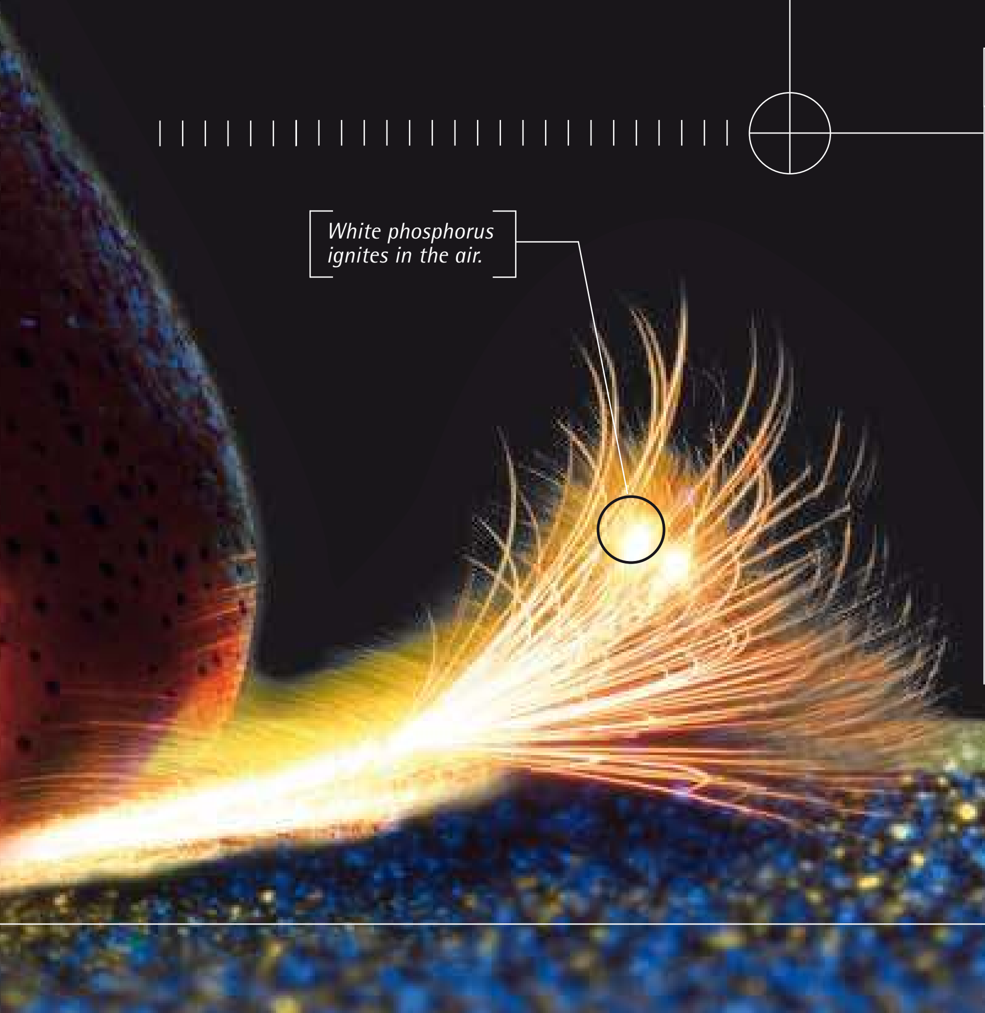
BEFORE



Wood is made from compounds that contain carbon, hydrogen, and oxygen.

AFTER

Carbon does not burn easily. It is left behind and makes the match stick dark and crumbly.



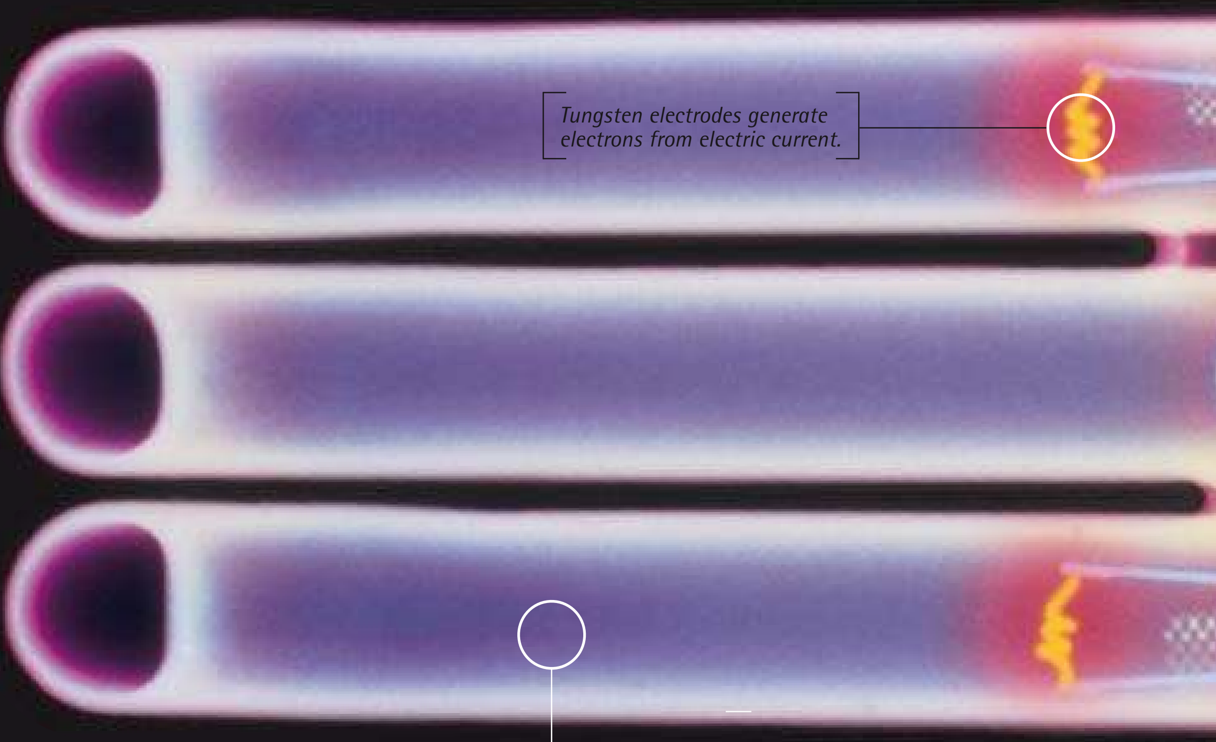
White phosphorus ignites in the air.

Making fire

A natural fire in woodland

▲ Fire needs three key ingredients: fuel, heat, and oxygen. When fuel, such as wood, is heated to a high enough temperature, a chemical reaction takes place – it catches fire. Carbon-based molecules in the wood react with oxygen in the air. We see the reaction as flame, and its products as charred wood and smoke. The fire will continue until it is either extinguished or the available fuel runs out.

LIGHT BULB



At the flick of a switch, the gas in a fluorescent tube buzzes with energy, converting electricity into cool, bright beams of light.

▲ **An energy-saving light bulb** makes light by passing electricity through a glass tube filled with gas. Unlike a traditional bulb, very little energy is wasted as heat. This makes a fluorescent tube much more energy efficient than a traditional one.

Incandescence and fluorescence


Close-up of a glowing filament

Ordinary light bulbs work by incandescence: they make light by creating heat. They pass electricity through a thin coil of wire known as a filament, which heats up to around 2,500°C (4,532°F). The filament glows white hot and gives off light. Around 90 per cent of the energy it emits is wasted as heat.

Energy-saving light bulbs work by fluorescence: they make light at a much lower temperature than incandescence without using heat. Glow-worms, luminous watches, and light-sticks used by climbers all make light by fluorescence: they glow when chemicals inside them absorb or make energy, then give off that energy as light.


Test tube containing fluorescent chemical

BACK

The modern fluorescent bulb was patented in 1936 by George E. Inman. The best-selling model was made for industry, and was a massive 122 cm (48 in) long.

Future bulbs may use high-power light-emitting diodes (LEDS), like the lights used on electrical equipment. They last five times longer than fluorescent bulbs.

FORWARD

See also: Fluorescence p244, Heat p98, Incandescence p245, Neon p34

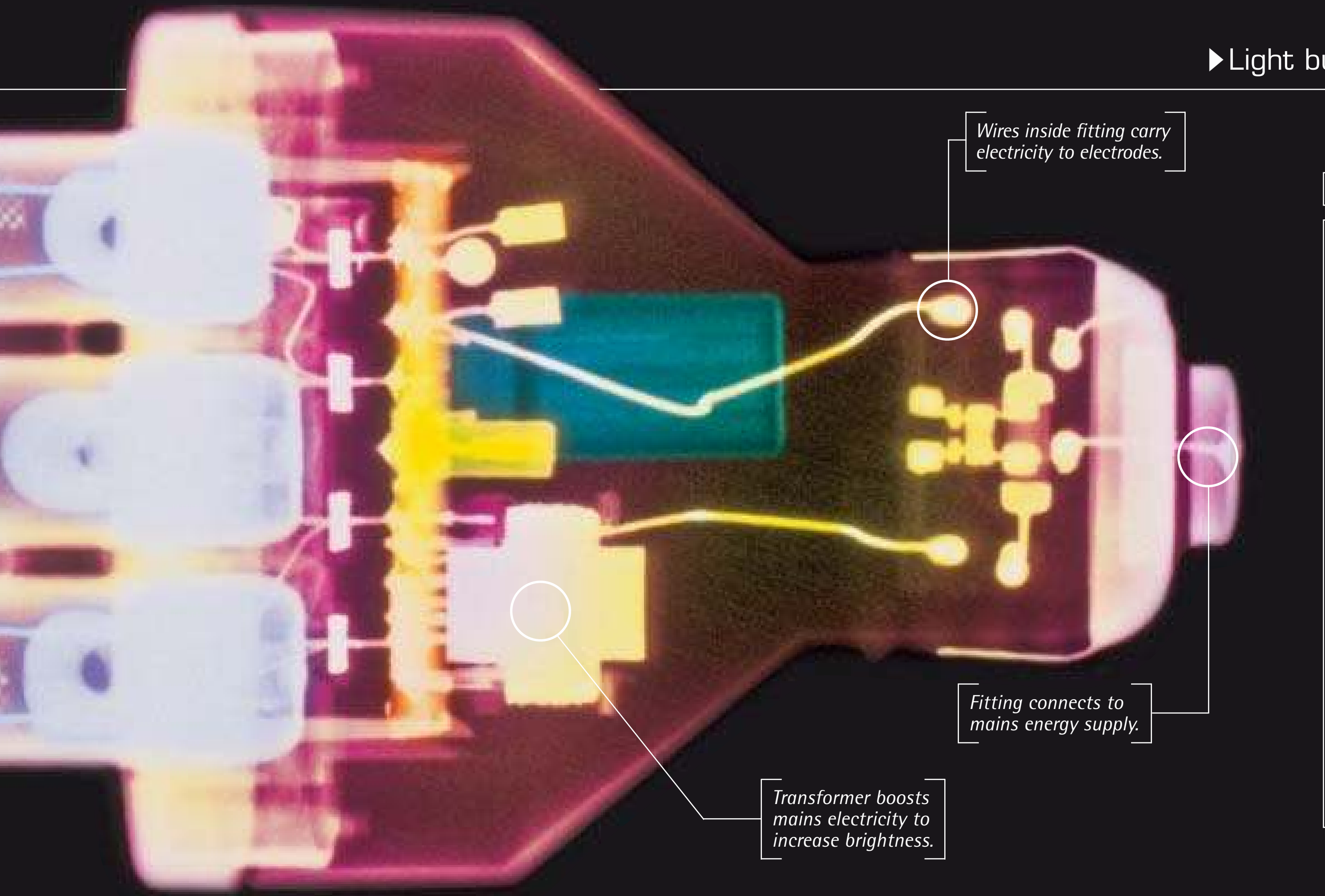
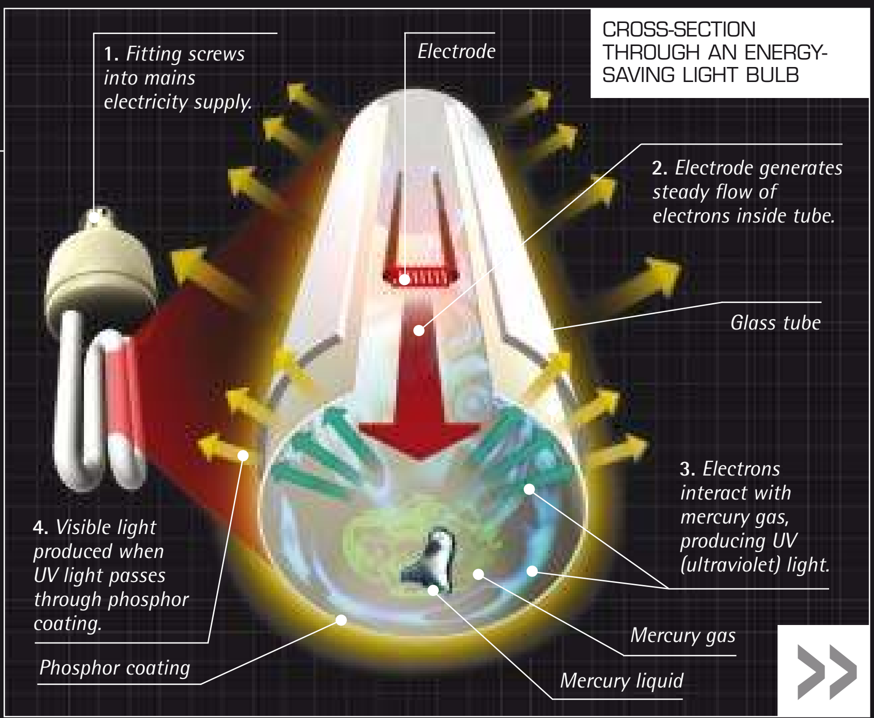


Image: false-colour X-ray of energy-saving light bulb

HOW AN ENERGY-SAVING LIGHT BULB WORKS



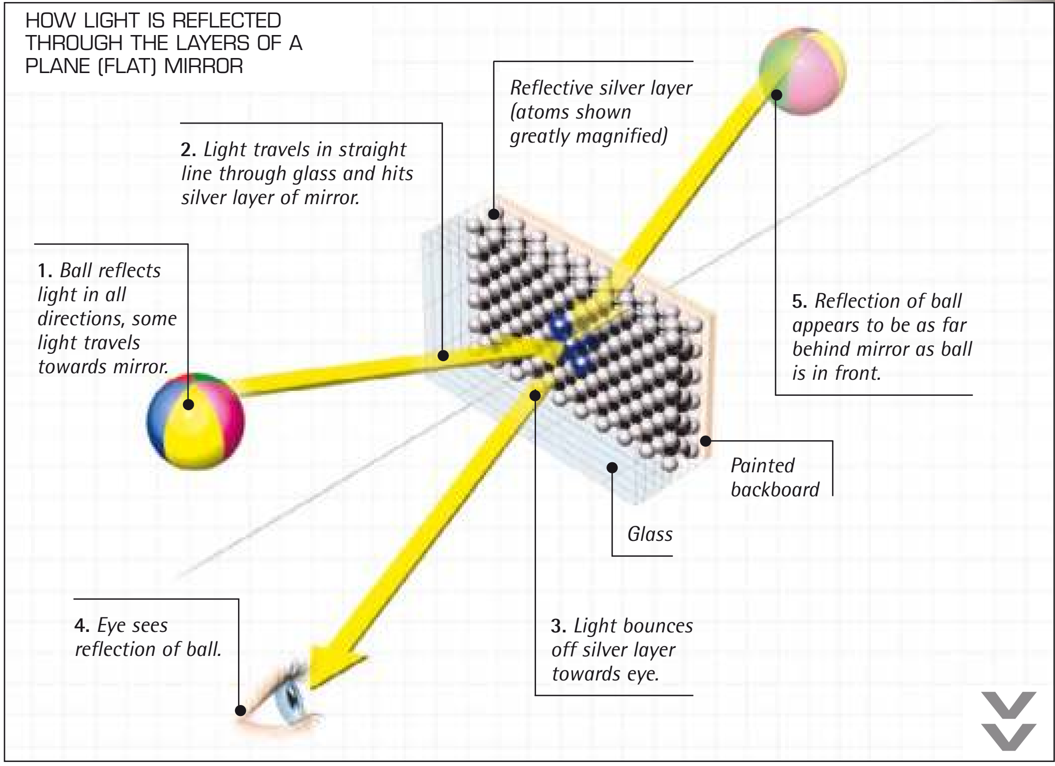
Modern, energy-saving light bulbs are a big improvement on the traditional incandescent light bulbs. Incandescent light bulbs have a white-hot filament that gives off light, but they lose a lot of energy through heat radiation. Energy-saving light bulbs pass electricity through gases in their tubes to create fluorescence with virtually no heat loss. Energy-saving light bulbs are also an improvement on traditional fluorescent strip lights because they are more compact. A device called a transformer boosts the electrical voltage to a higher level than in normal fluorescent lights, maximizing the light that is created. Compact, energy-saving bulbs also flicker less than older fluorescent lights because their electrical circuits increase the speed by which current pulses from the mains to the bulb.

MIRROR

Atoms in a mirror absorb light and reflect it back. An ordinary piece of glass reflects only eight per cent of the light that falls on it; a polished mirror reflects up to ninety five per cent.

Curved mirrors reflect the world in surprising ways. This unusual reflection was made by a giant, stainless steel sculpture in Chicago, USA, known as Cloud Gate. People can walk underneath it; as they do, their distorted reflections swim about on its highly polished surface.

HOW A MIRROR WORKS



The Moon, a ball, the words on this page – all these are visible to our eyes because they reflect light that falls on them. When you hold an object up to a mirror, some of the light bouncing off it travels towards the mirror. Light contains packets of energy called photons. When the photons reach the mirror, they are absorbed by atoms in the mirror's silvered layer. The atoms become unstable and try to return to their original, stable state. They do this by giving off new photons of light that travel back out of the mirror, creating the reflection that you see. Mirrors can be shaped for many uses. Convex (outward curving) mirrors make objects look smaller but also give a wider field of view. They are commonly used on the side of vehicles and in shop security mirrors. Concave (inward curving) mirrors magnify objects so that they look bigger and closer. Shaving and make-up mirrors are often concave to help people see what they are doing in more detail.

See also: Compact disc p68, Laser printer p176, Reflections p249

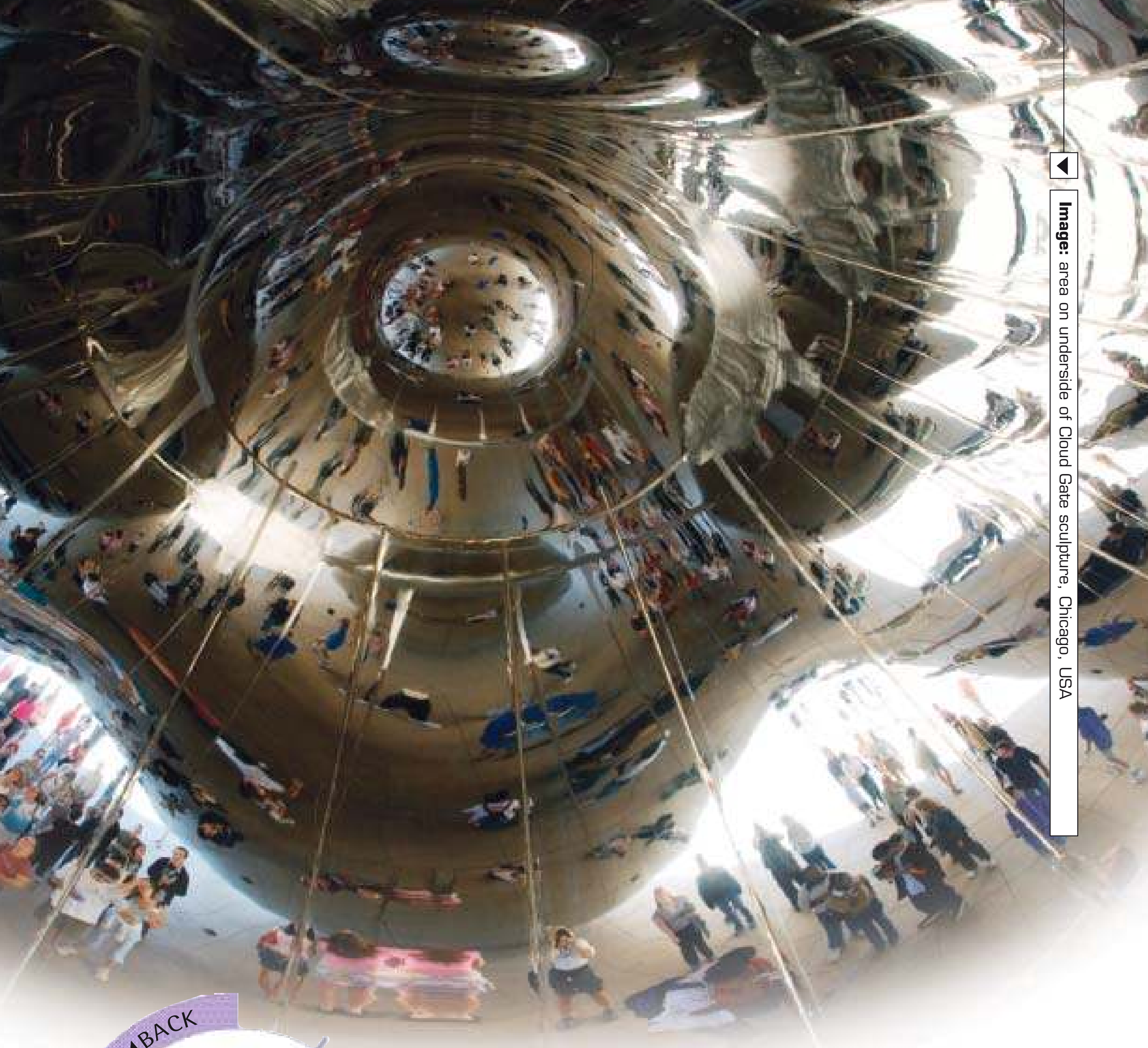


Image: area on underside of Cloud Gate sculpture, Chicago, USA

◀◀BACK

The first mirrors were used by the ancient Chinese. They checked their reflections in clay pots filled with water, called jians.

Mirrors are an important component of large space telescopes. The OWL space telescope will have a mirror 100 m (300 ft) wide on its completion in 2018.

FORWARD▶▶

Why silver?

▶Silver is one of the best materials for making mirrors. It can be polished to a smooth finish that will reflect light of all colours, in perfectly straight lines, to give a sharp image. These silver crystals, magnified 800 times, have flat faces, so when light reflects on them, each face behaves like a tiny mirror within the mirror. Silver tarnishes in air, so mirrors are usually covered in glass for protection.

Magnified silver crystals

WATCH

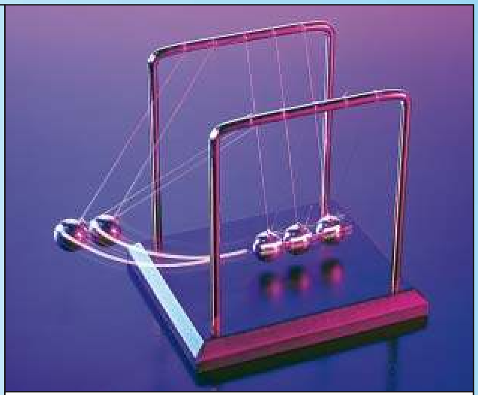
As the hands of this watch sweep around its face, the belts and wheels inside are constantly whirring with motion. These moving parts vibrate exactly 18,000 times an hour, helping to keep perfect time.

Image: cutaway of a TAG Heuer Monaco V4 watch

◀ **Unlike other watches,** the TAG Heuer Monaco V4 wristwatch is not driven by a battery or a mechanical winder. Instead it has a heavy platinum ingot inside it that oscillates – slides back and forth. The ingot generates power each time the wearer moves their wrist, providing energy to keep the hands moving.

Storing energy

▶ Mechanical objects can store energy for some time. This Newton's cradle consists of a series of heavy balls hanging from a frame. As the balls swing back and forth, energy is passed from one ball to the next. The cradle can store energy for several minutes, which is evident because the balls keep moving. In the TAG Heuer watch, the sliding metal ingot passes energy to its four barrels (spring wheels). Unlike a Newton's cradle, the watch can store energy for many hours.



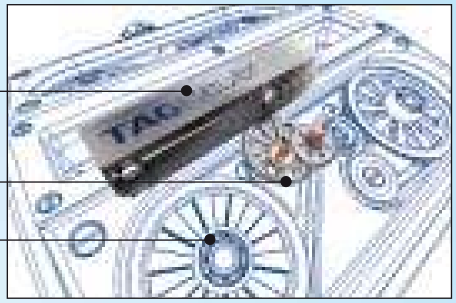
Energy transferred and stored in desk toy

HOW THE WATCH WORKS

BACK OF WATCH

The energy generated by the ingot's movement is stored in four barrel wheels. Each wheel has a tight, spiral-shaped spring at its centre. When the wheel is turned one way by the sliding ingot, the spring tightens up and stores energy; when it rotates the other way, the spring loosens and releases energy. The four wheels act like the batteries found in other watches.

This oscillating platinum ingot is the engine that powers the watch. Weighing about 4.5 g (⅕ oz), it is the watch's heaviest component. There are rows of teeth along the lower edges of the ingot. As it slides to and fro, these teeth turn a gear system, which is a series of cogs that transfers the ingot's energy to the barrel wheels.



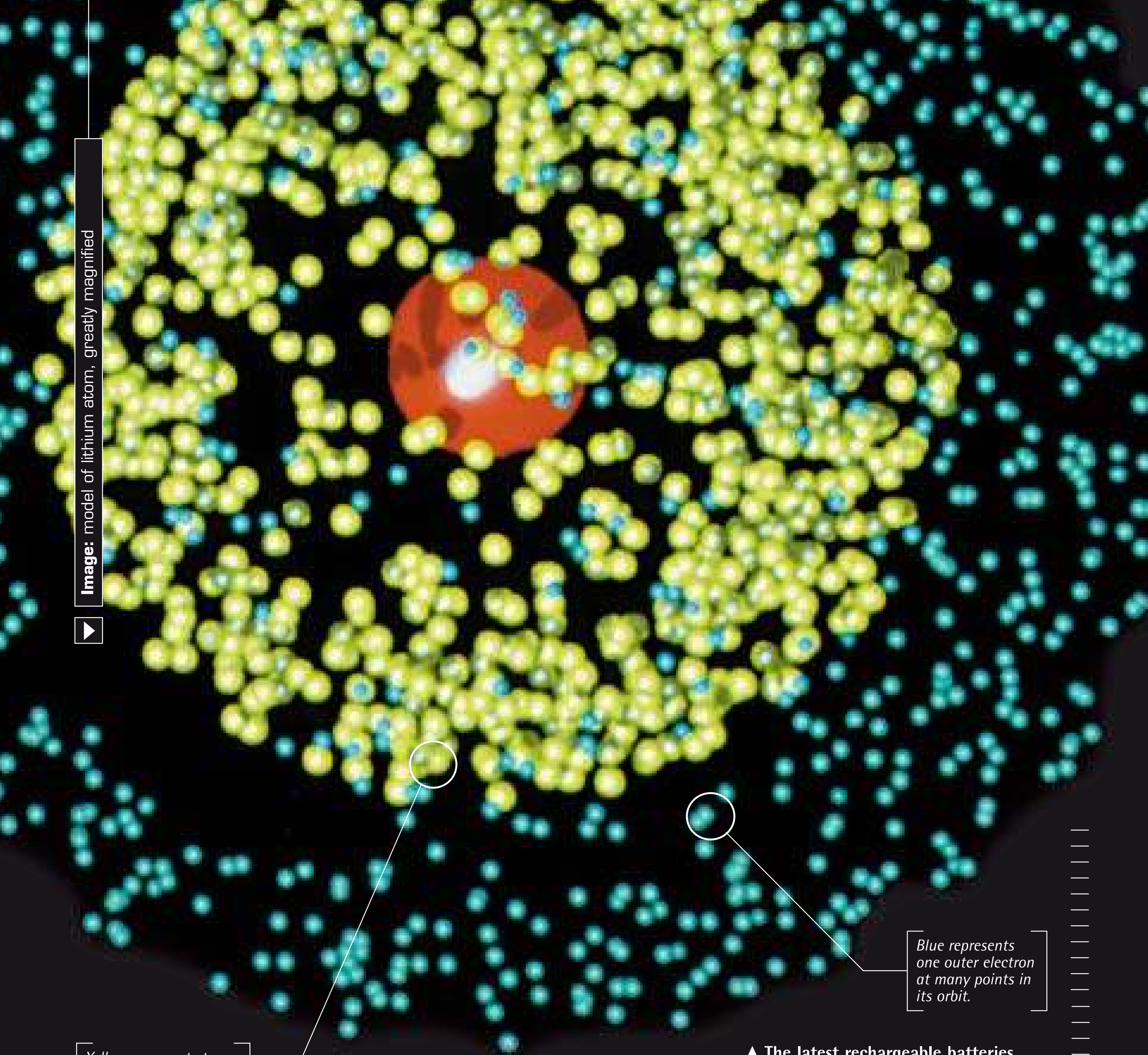
INSIDE BACK OF WATCH

INSIDE FRONT OF WATCH

The four wheels transfer energy to belts, which move the hands of the watch around the dial at different speeds. In other watches, this job is done by miniature gear wheels that mesh together. Using belts is more efficient because less energy is wasted overcoming friction. This watch uses 13 separate belts. Each one has tiny notches cut deep into it to stop it from slipping as it turns around.

▶▶ See also: Energy p244, Gear p244, Navigation p154, Oscillation p248

Image: model of lithium atom, greatly magnified

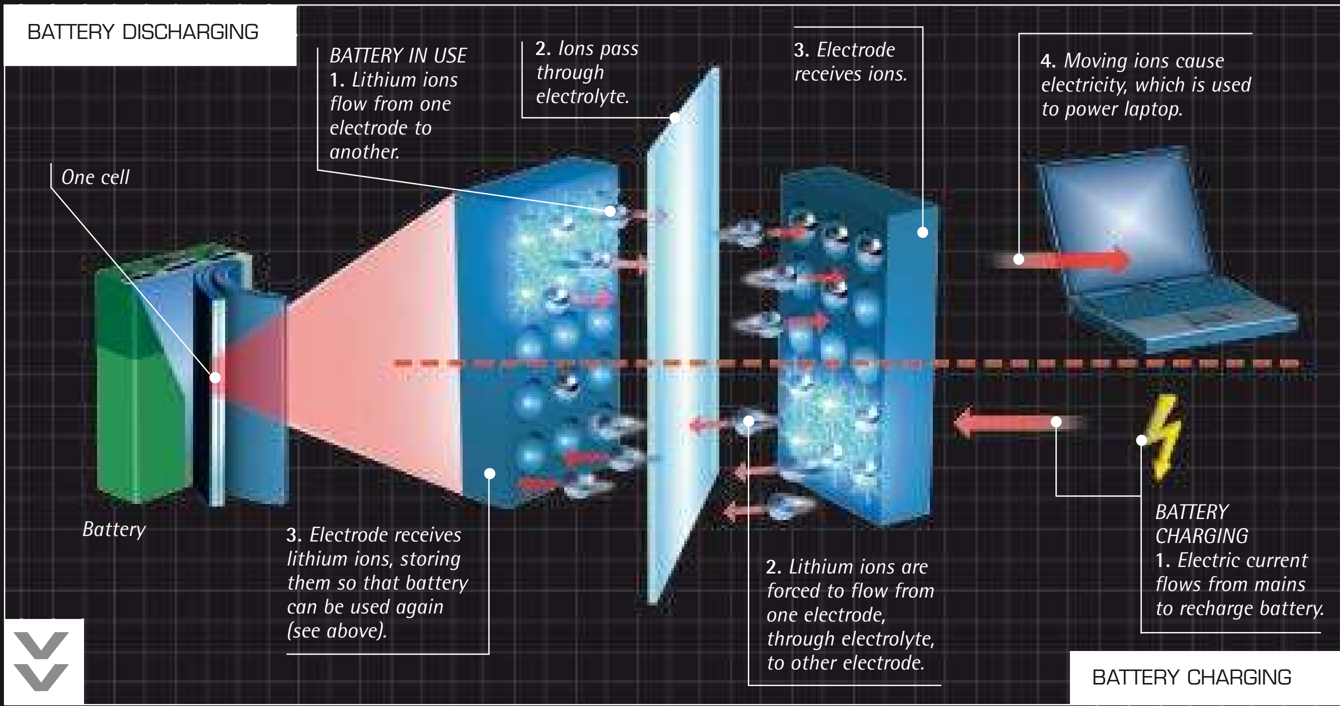


▲ **The latest rechargeable batteries** contain a chemical called lithium. This image shows the structure of one lithium atom. The centre of the atom, its nucleus (red), is orbited by two inner electrons (yellow) and one outer electron (blue). When lithium is used in a battery, the blue electron is removed from each lithium atom, creating something called a lithium ion. Lithium ions can store an electric charge in a battery.

BATTERY

▶▶ A rechargeable battery is a portable chemical power pack you can use again and again. An average rechargeable battery lasts around 10 years and can be reused 1,000 times. ▶▶

HOW A RECHARGEABLE BATTERY WORKS



The battery inside a laptop contains one or more separate power-generating compartments, called cells. Each cell contains two electrodes separated by an electrolyte. During charging, lithium ions are forced from one electrode to the other, where they are stored. When the battery is connected to a circuit – when the laptop is switched on – the ions immediately begin to move back to the other electrode. This movement is electricity. As the ions flow through each cell, the battery gradually loses power. In batteries that are not rechargeable, this process happens only once. When all the ions have flowed from one electrode to the other, the battery is dead. In a rechargeable battery, the charging and recharging process can happen over and over again. Once all the ions have flowed from one electrode to the other, the battery can be recharged, forcing the ions back to the electrode they came from, thereby storing up power again.

BACK

The first battery, made in 1800, was called a voltaic pile. It was made from a sandwich of paper, soaked in salt water, and pieces of metal.

Batteries may be replaced by environmentally friendly fuel cells, which convert hydrogen and oxygen into water to produce electricity.

FORWARD

Battery graveyard

Collection of disposable batteries

More than 5 billion disposable batteries are thrown away every year. They are a major cause of environmental pollution: some contain extremely toxic chemicals such as mercury and cadmium, which leak in landfills, polluting land and watercourses. Although some rechargeable batteries contain harmful chemicals, they last much longer, so far fewer are thrown away.

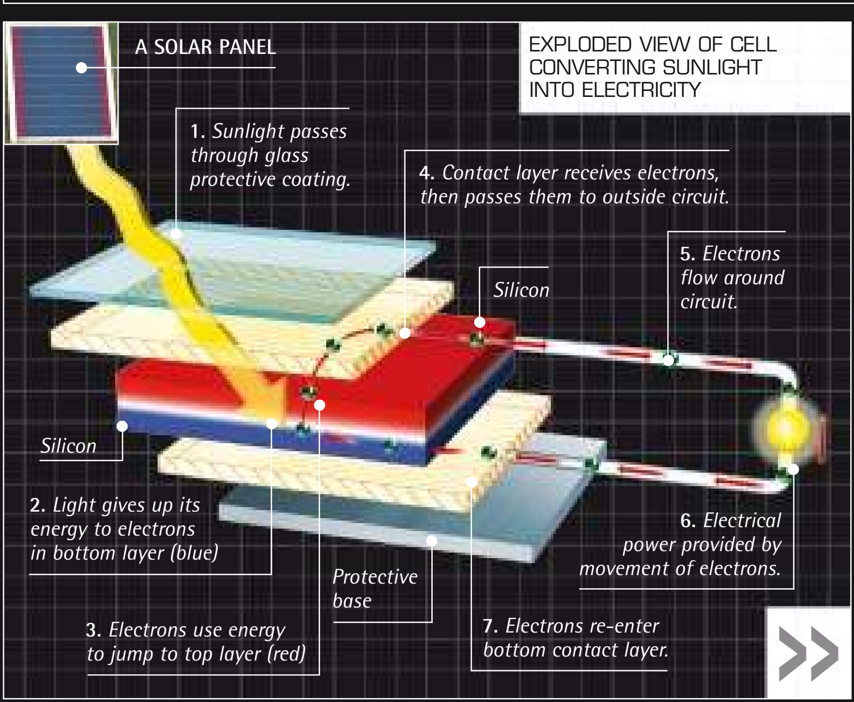
See also: Electrode p243, Fuel-cell car p128, Ions p245, Laptop p168, Solar cell p96

See also: Fuel-cell car p128, Homes p106

SOLAR CELL

One second of the Sun's energy, if it could be harnessed, would power the world for a thousand years. Solar cells tap this massive energy source to give us clean, free power.

HOW A SOLAR CELL WORKS



There are two types of solar power. Solar thermal power means collecting the Sun's heat through roof panels that have water pumped through them, providing the house with hot water. Solar electric power means converting the sunlight into electricity using a solar (or photovoltaic) cell. This is made from two layers of silicon, a chemical element extracted from sand. The bottom layer (blue) is chemically treated so that it has slightly too few electrons; the top layer (red) is treated to have slightly too many. When light falls on the cell, the energy it contains energizes the electrons in the lower layer. This causes them to jump up to the top layer, and then continue around as a steady flow of electrons – electricity – until they return to the bottom layer; an electrical circuit has been created.

Where photovoltaic cells are used

One tiny solar cell can power a pocket calculator. When solar cells are joined to form solar panels, they can help power a house. Photovoltaic panels like these are coloured blue to absorb as much light as possible. They feed their energy into rechargeable batteries, which charge up during the day and release their power at night.

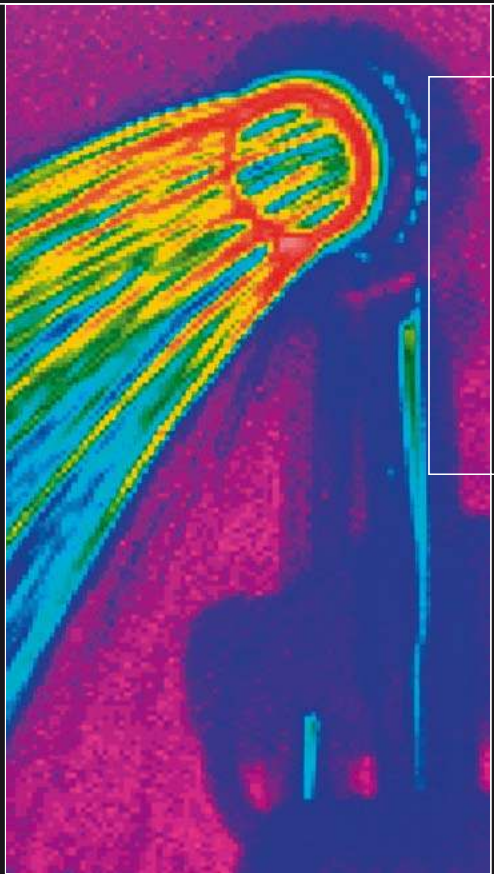
Photovoltaic panels on house roof

A solar cell is chemically treated silicon that converts sunlight into electricity. A solar panel is made of many circular cells like this one, each the size of a compact disc. A typical panel on the roof of a house would be made up of around 36–100 cells.

Image: macrophoto of silicon cell in cross-section

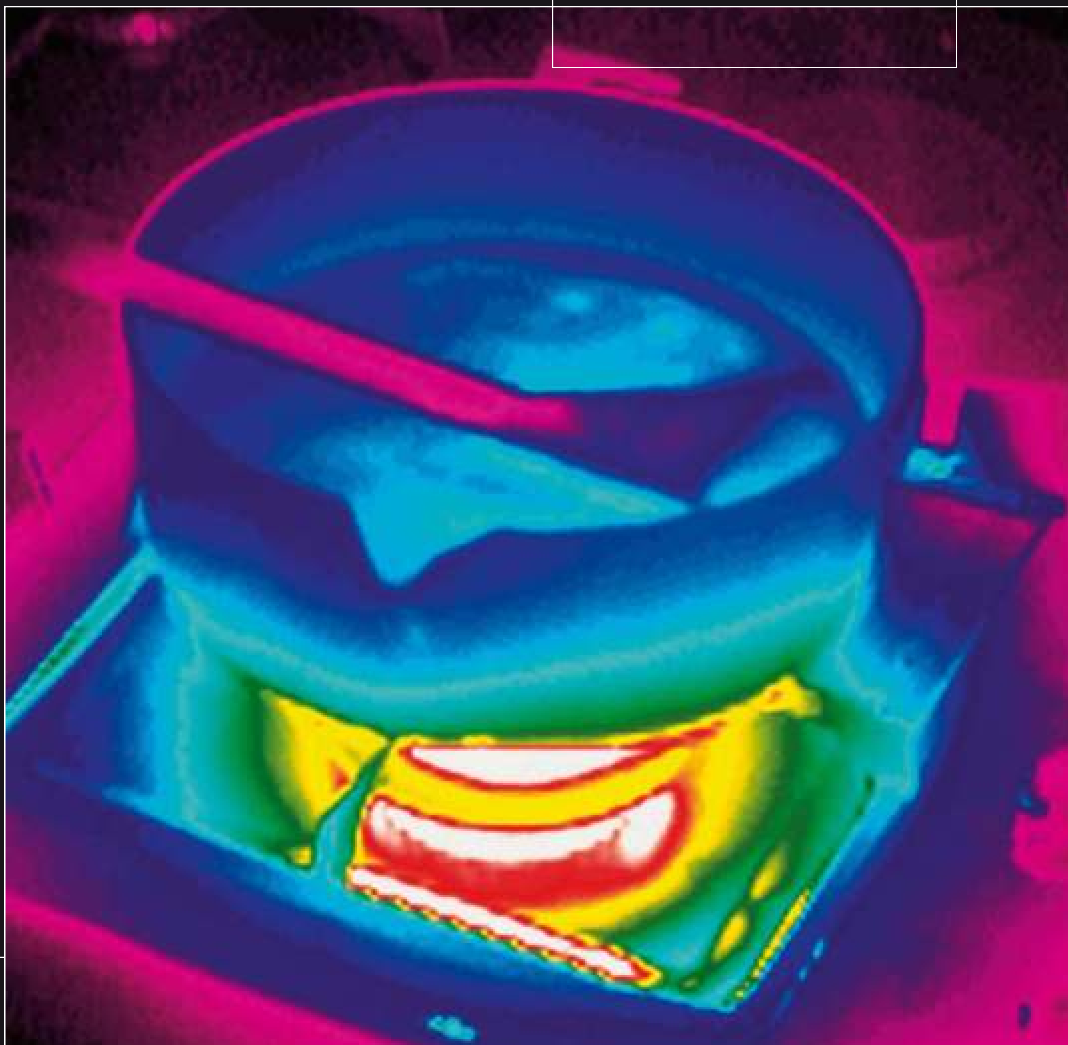
HEAT

Heat is essential for our warmth, comfort, and wellbeing. The images on this page show how household objects, and even our homes, gain, lose, and transfer heat.



Thermogram A detailed temperature pattern called a thermogram records the infrared light that all objects give out. This thermogram shows a hot shower's water changing from red (hot), through yellow and green to blue (coldest) as it hits the cold air.

Hotting up Here we can see heat transferred through different materials. The burning gas is the hottest (white). Eventually, it heats the metal pan and the soup to the same temperature, but they start off cool (blue). The wooden spoon stays cool.



Converting electricity to heat

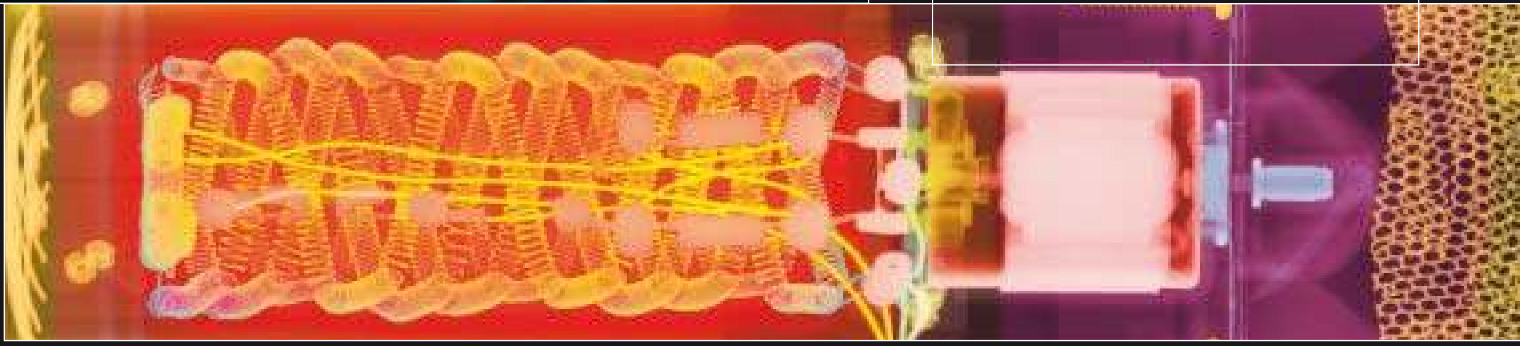
The toaster in this X-ray works by changing electrical energy to heat energy. Elements made of thin metal wire are heated by the electrical current until they glow orange. Once the selected time has elapsed – enough to brown your toast – a switch turns off the element and releases a spring to pop up the toast.

Heat loss

This thermogram shows how heat leaks out in an average home. The roof and the windows (yellow) are poorly insulated and are losing the most heat. The solid walls (red, purple, and green), which have the greatest insulation, are losing the least heat. Typically, up to 25 per cent of the heat generated in a house is lost through poor insulation.

Hairdryer

This coloured X-ray shows the heated element inside a hairdryer. An electric fan at the back of the device blows air over the filament, which heats it and blows the hot air out through the nozzle. The element is made of nichrome, which does not rust when heated to high temperatures.



See also: Conduction p242, Fridge p102, Light bulb p88, Microwave p100

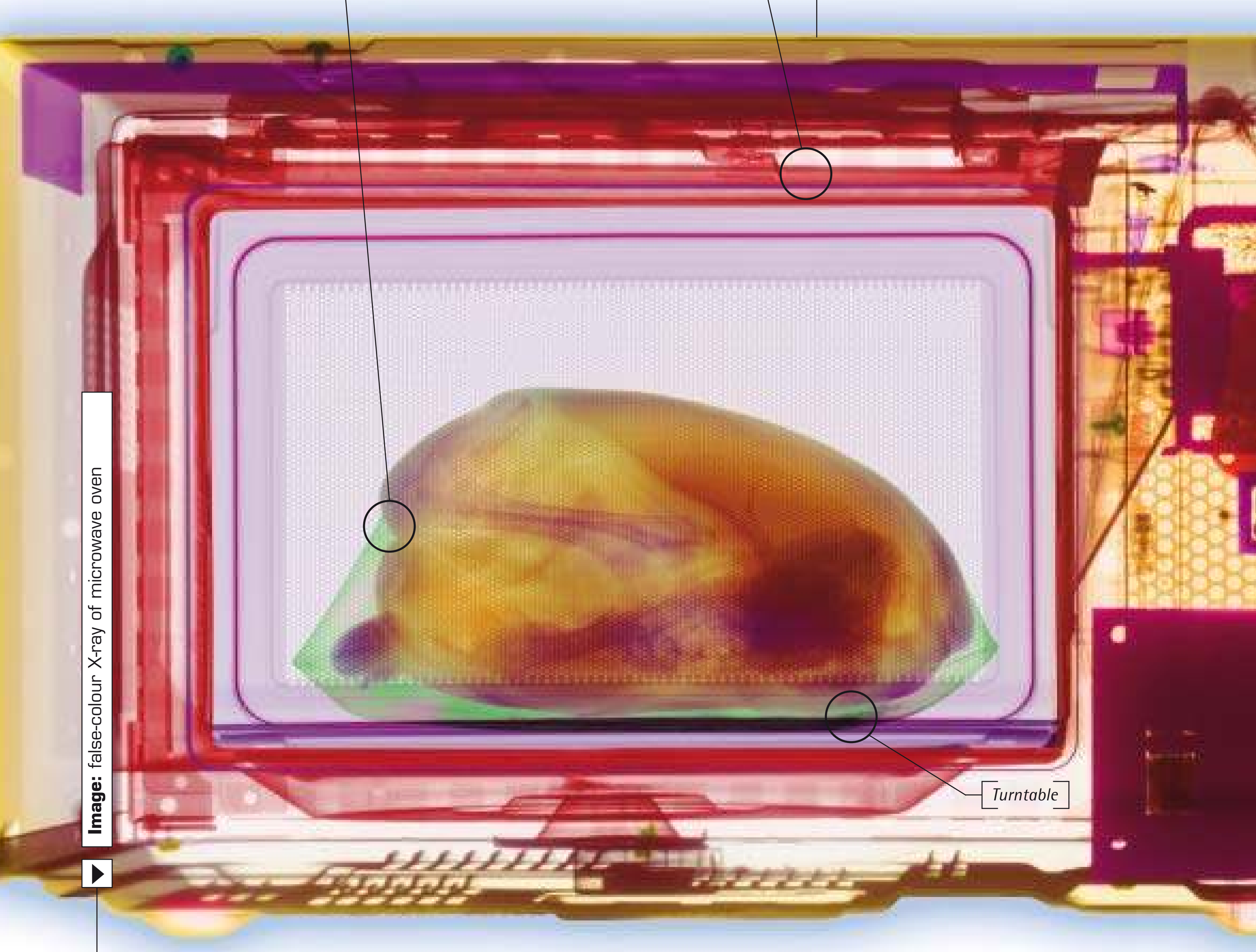
MICROWAVE

Invisible rays of microwave energy, zapping through the air, can heat food in a matter of minutes. A microwave oven can cook a joint of meat six times faster than a normal oven.

▼ **A microwave oven** cooks much more quickly than a conventional oven, but is much noisier. The humming noise of the oven is the sound of the transformer vibrating as it converts power, and the whirring noise is the sound of the fan cooling the electronic components.

Special cooking bag makes chicken skin brown and crisp.

Metal grill on door and metal seal stop microwaves leaking.

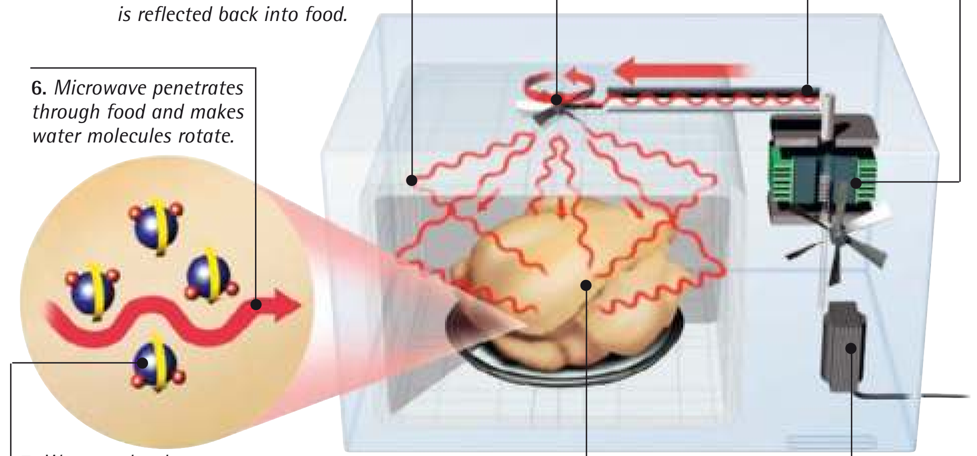


Turntable

Image: false-colour X-ray of microwave oven

See also: Electromagnetic spectrum p250, Heat p98, Microwaves p247, Mobile phone p18

HOW A MICROWAVE WORKS

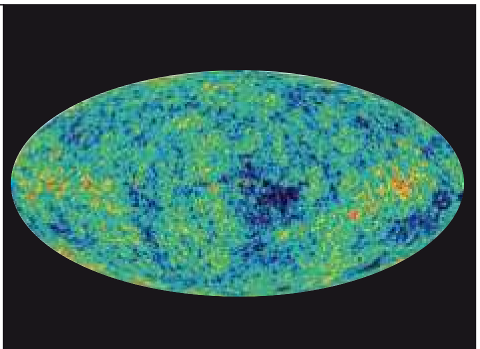


Microwaves are very short radio waves that carry a lot of energy. The food in a microwave oven cooks when these waves transfer their energy to the water molecules inside the food. Microwaves cook food quickly because they set all the water molecules vibrating at once. But in a conventional oven, heat energy transfers to food slowly from the outside in.

Microwaves are a type of electromagnetic radiation, as are light and X-rays. They are made when electricity and magnetism move back and forth and carry their energy through the air. Like other electromagnetic waves, microwaves travel in space at the fastest speed possible: the speed of light (300,000 km/s or 186,000 miles per second).

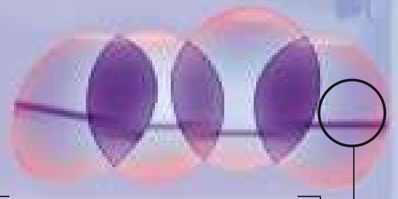
Microwaves all around us

▶ Intense microwaves are harmful to living things. But smaller doses have bounced around the Universe since time began and surround us all the time. Scientists use this background radiation to make important discoveries about the Universe. This microwave map shows how the Universe looked soon after it formed, 13.7 billion years ago. Red and yellow areas are hottest and show matter clumping to form stars and galaxies.



Microwave map of the Universe

FRIDGE

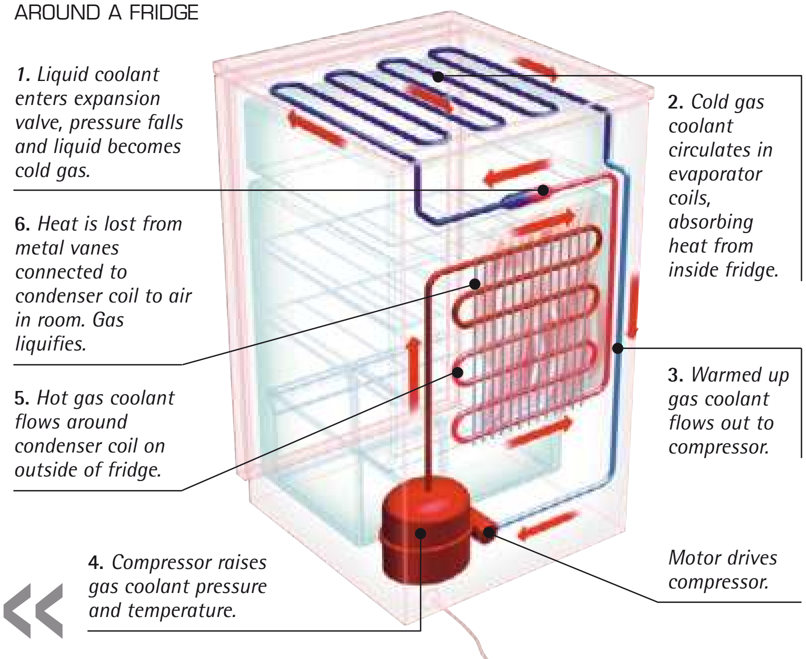


▶▶ A fridge is a heat extraction machine that keeps food fresh. The latest fridges use an Internet connection to reorder food when supplies get low. ▶▶

›› HOW A FRIDGE WORKS

The clever part of a fridge is a small length of pipe known as an expansion valve, fixed to the outside of the plastic food compartment. The coolant – the chemical that circulates around the fridge in coils – enters the narrow opening at one end of the expansion valve as a high-pressure liquid. The expansion valve becomes wider along its length, so the pressure of the coolant falls as it travels through. The drop in pressure causes the coolant to evaporate and become a cold, low pressure gas, which is pumped into the evaporator coils inside the fridge. The cold gas in the coils now absorbs heat from inside the fridge, resulting in the gas warming up, and the inside of the fridge cooling down. The warmed up gas then flows to the condenser coil outside the fridge, where the heat is lost into the air of the room.

HOW COOLANT FLOWS AROUND A FRIDGE



▶▶ See also: Heat p245, Homes p106, Internet p38

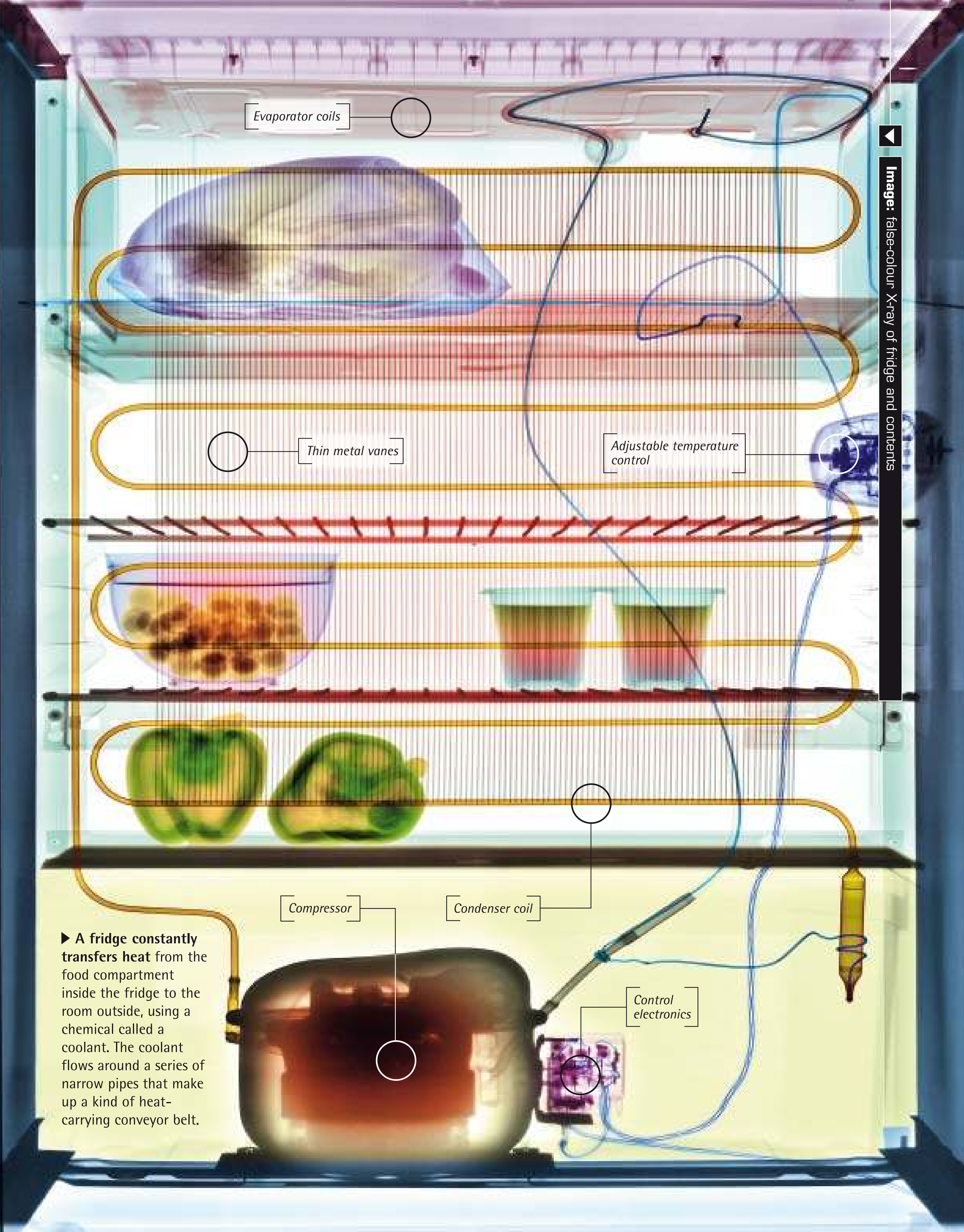
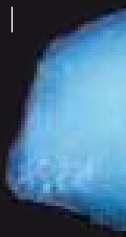


Image: false-colour X-ray of fridge and contents

▶ **A fridge constantly transfers heat** from the food compartment inside the fridge to the room outside, using a chemical called a coolant. The coolant flows around a series of narrow pipes that make up a kind of heat-carrying conveyor belt.

AEROGEL

A ghostly substance called aerogel is the lightest solid known. It is also incredibly strong. A piece of aerogel the size of a man weighs less than 1 kg (2.2 lb), but it could still support the weight of a car.

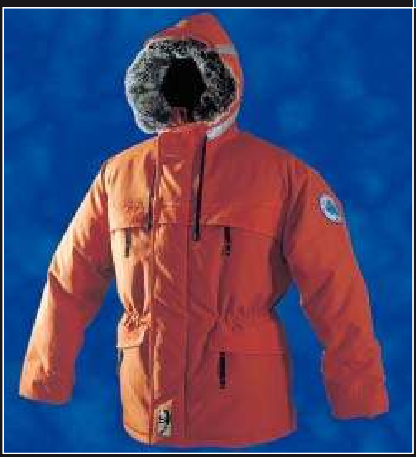


USES AND APPLICATIONS

The Stardust space probe collects cosmic dust (minute specks of matter from space) with a tennis racket-shaped arm, packed with aerogel. Passing dust zooms into the aerogel at vast speed, forming a trail, which reveals where it came from. This dust may reveal much about the formation of the Universe.

Oil is transported through very long pipelines from rigs at sea to refineries on land. When it leaves the seabed the oil is hot and fluid. But chilly temperatures in oil-rich places, for example the North Sea, cause the oil to thicken making it harder to pipe ashore. Aerogel is now wrapped around the pipes to insulate them, so that oil stays warm.

Packed with fuel for long journeys, aeroplanes are at risk of catching fire. Because aerogel is fire-resistant, it is used to line the passenger compartments of planes to stop a potential fire from spreading so easily. Aerogel is also used to insulate plane engines so that they give off less heat. It also helps to make engines less noisy.



Clothing made with aerogel is excellent at keeping people warm. This insulated jacket is made from Spaceloft™, a fabric with a built-in layer of aerogel. A jacket only 3 mm (1/10 in) thick keeps people warm in temperatures as low as -50°C (-58°F).

Aerogel is transparent and lets little heat pass through it, so it is perfect for making windows. It is also very fragile, so the aerogel has to be protected in a sandwich of ordinary glass.

See also: Fabric p60, Fire suit p190, Heat p98, Insulator p245, Space probe p158

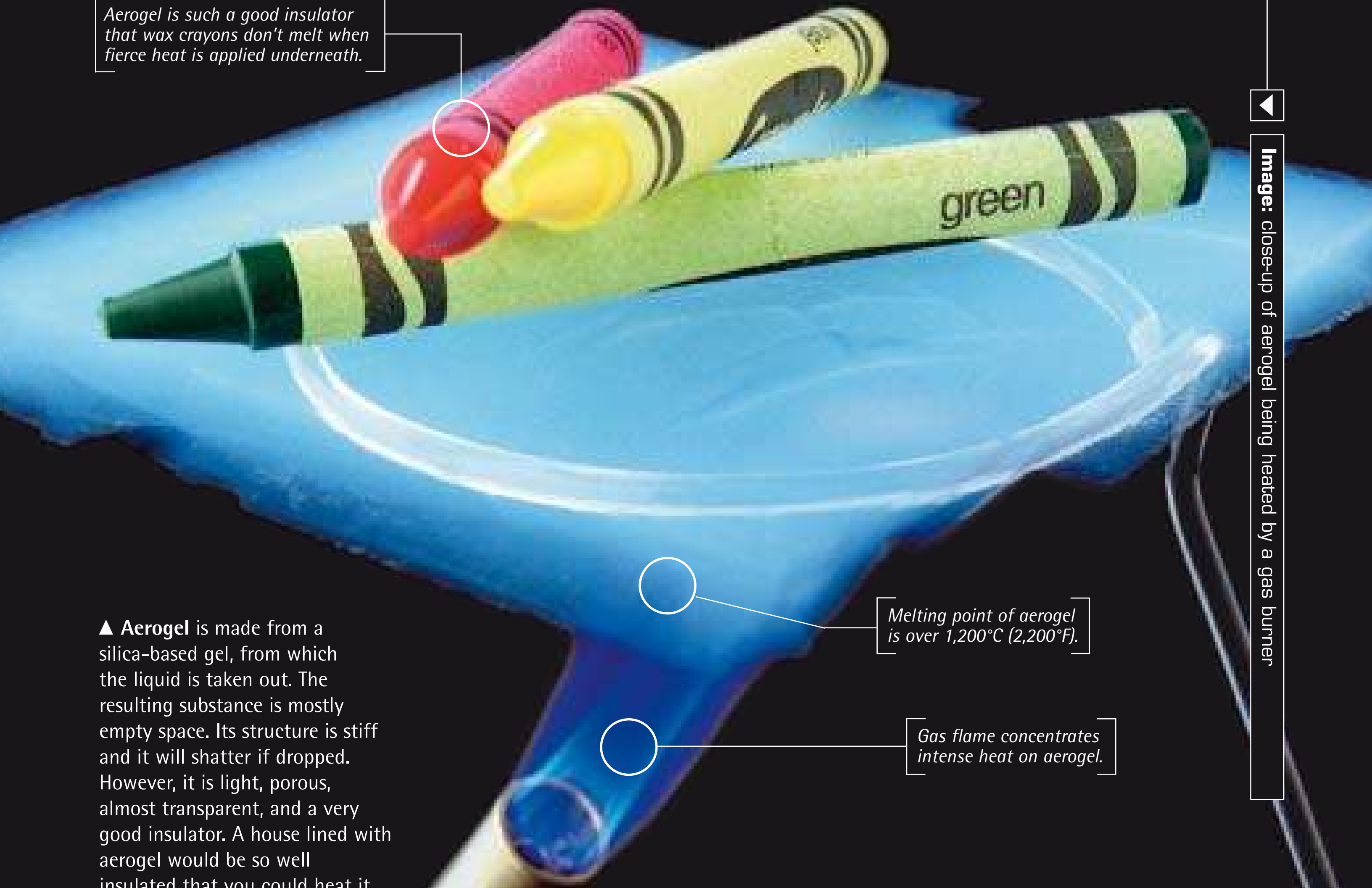


Image: close-up of aerogel being heated by a gas burner

▲ **Aerogel** is made from a silica-based gel, from which the liquid is taken out. The resulting substance is mostly empty space. Its structure is stiff and it will shatter if dropped. However, it is light, porous, almost transparent, and a very good insulator. A house lined with aerogel would be so well insulated that you could heat it with a candle and it would still be too hot to live in. New uses for aerogel are emerging all the time.

Making aerogel

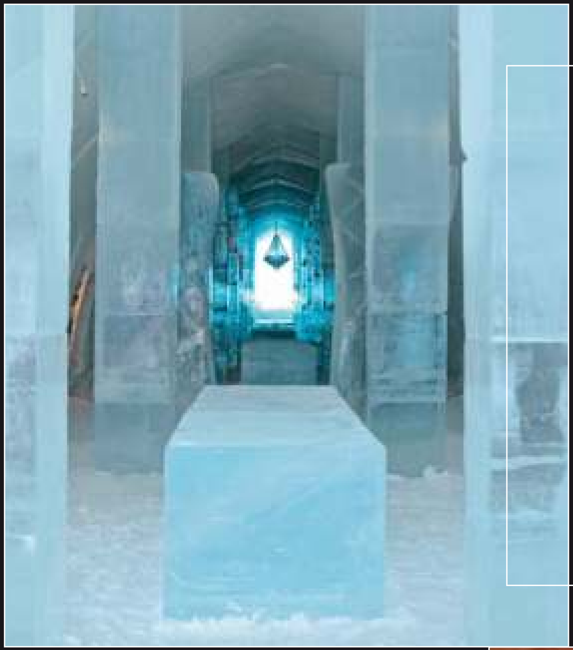
Technician analysing material using microprobe

▲ American chemist Steven Kistler made the first aerogel in 1931. The complicated process for making the solid involves very high temperatures and pressures. The first production plant for making aerogel was based in Sweden. Today it is manufactured throughout the world.

See also: Heat p98, Insulator p245, Solar cell p96

HOMES

Made from local or recycled materials, generating their own power, and using resources wisely, eco-friendly buildings help protect the environment.



Ice homes

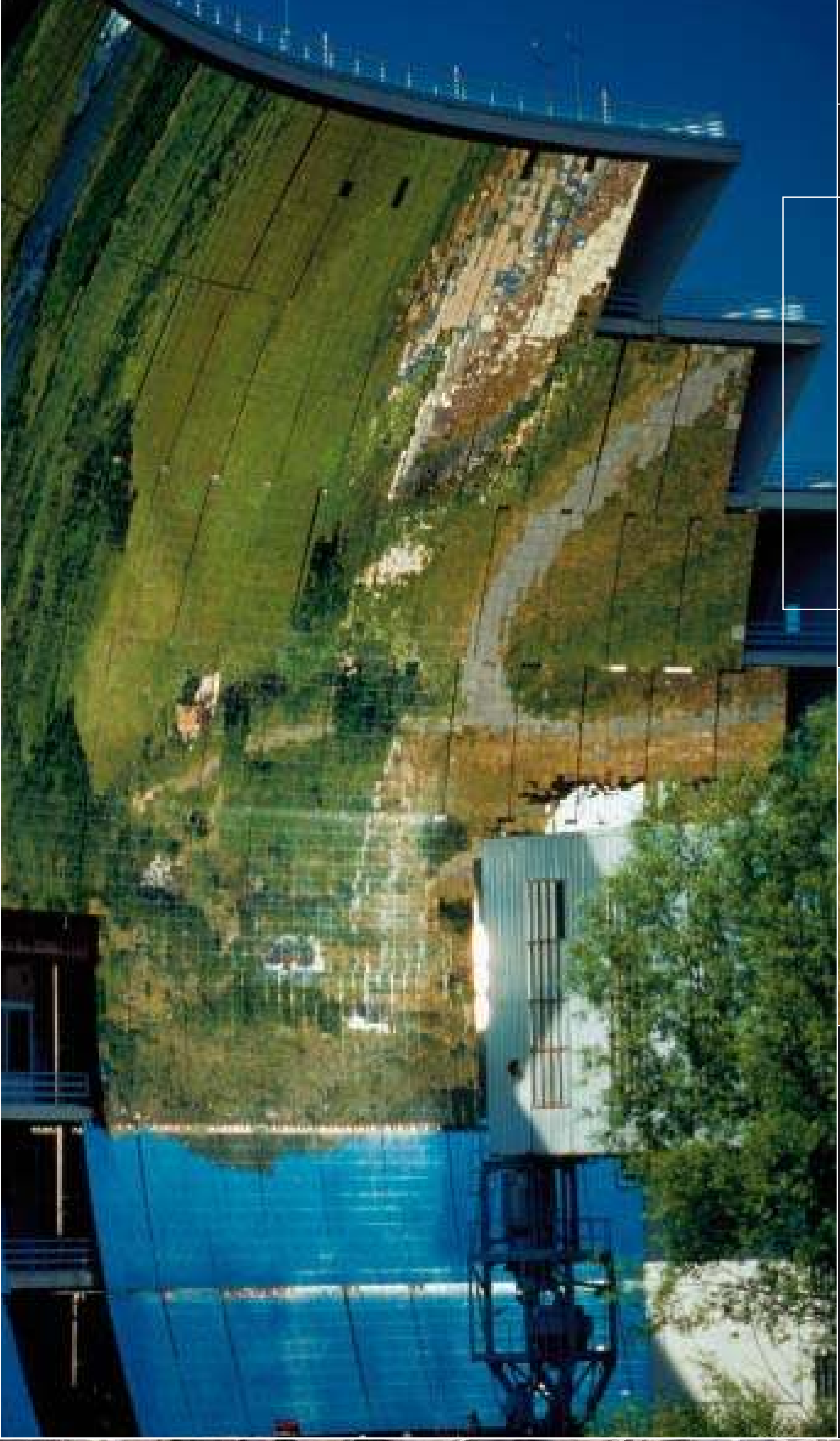
Ice is a traditional Arctic building material. It is free, easy to shape, and melts away when summer comes. Ice is used most famously for igloos, the historic home of the Arctic people. This ice hotel in Lapland is made from thousands of tons of ice and snow. Even the beds are made from blocks of ice, with soft mattresses and reindeer hides piled on top.

Straw insulation

The walls of this eco-home are made from a cheap, natural material: straw. The heavy straw bales are stacked like gigantic bricks, and strengthened by a wood-and-steel framework coated outside with plaster. The bales are packed tightly to make the walls sufficiently fireproof. The thick walls cut heating costs by up to a quarter.

Recycled materials

Each day, millions of tons of building materials are dug out of quarries, and millions of tons of household rubbish are buried in landfills. Building eco-homes from recycled materials helps tackle both these environmental problems. This wall is made from drinks cans and car tyres buried in plaster, and will last a long time as the materials are weather-resistant.



Solar collectors
This is the world's biggest solar furnace at a solar research centre in the French Pyrenees. The two-storey mirror focuses sunlight on the small tower in front, making useful energy that is carried away by hot water pipes. Some eco-homes generate electricity and heat water using the Sun's energy collected from solar panels. Solar energy is free and does not pollute the environment. One day, every home may have its own solar panel.

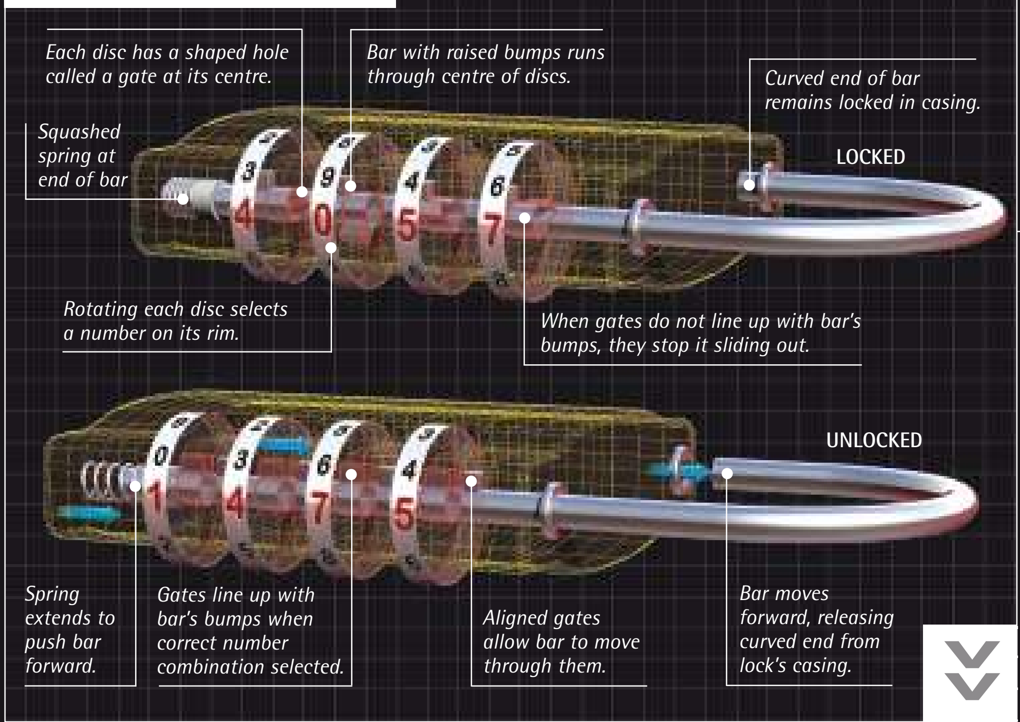
Turf roof
Grass roofs are good insulators. In winter, the thick mat of grass, roots, and soil traps heat inside the building. In summer, the growing grass absorbs sunlight and keeps the building cool. A plastic sheet under the turf keeps the roof waterproof. Roofs like this last more than 50 years.

LOCK

Gold, money, and jewels are often kept safe by nothing more than the intricate metal mechanisms inside locks. A typical bank safe has around 10 billion combinations.

HOW COMBINATION LOCKS WORK

INSIDE A COMBINATION LOCK, FROM LOCKED TO UNLOCKED



Combination locks come in all shapes and sizes. Some need keys to open them. Others, including these, have combination dials instead. Small combination locks are often built into briefcases. Large D-locks (combination locks with much bigger hoops) are used to secure bicycles.

A combination lock has a strong metal bar running through its middle that stays in place when locked and moves slightly when unlocked. The mechanism that unlocks the bar varies from lock to lock. In most combinations, the bar is released by wheels with notches, or gates, cut into them. Combination locks are far more secure than key locks because they cannot be picked open with a wire through a keyhole.

A safe lock is more complex. It has a numbered dial at the front that you turn to select the combination. Stacked behind the dial is a series of wheels, one for each number in the combination. As you turn the dial, a metal pin fastened to its back fits through notches in the wheels behind. When the notches line up, the wheels turn together, and the safe opens. If you don't know the correct number, the safe will not open.

See also: Radio ID tag p184, Smart card p182

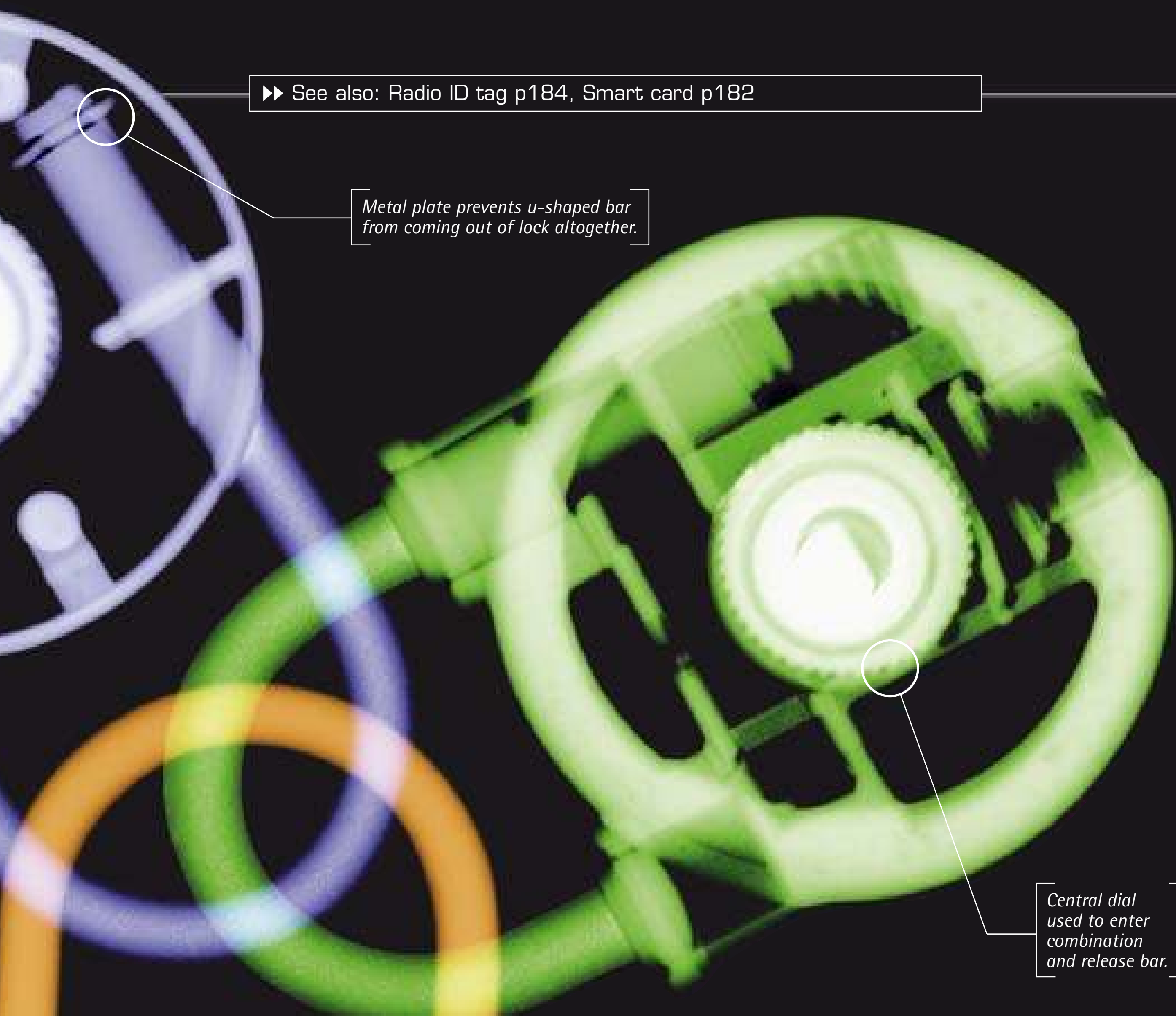


Image: false-colour X-ray of combination locks

Microscopic locks

Micro-mechanical gears in close-up

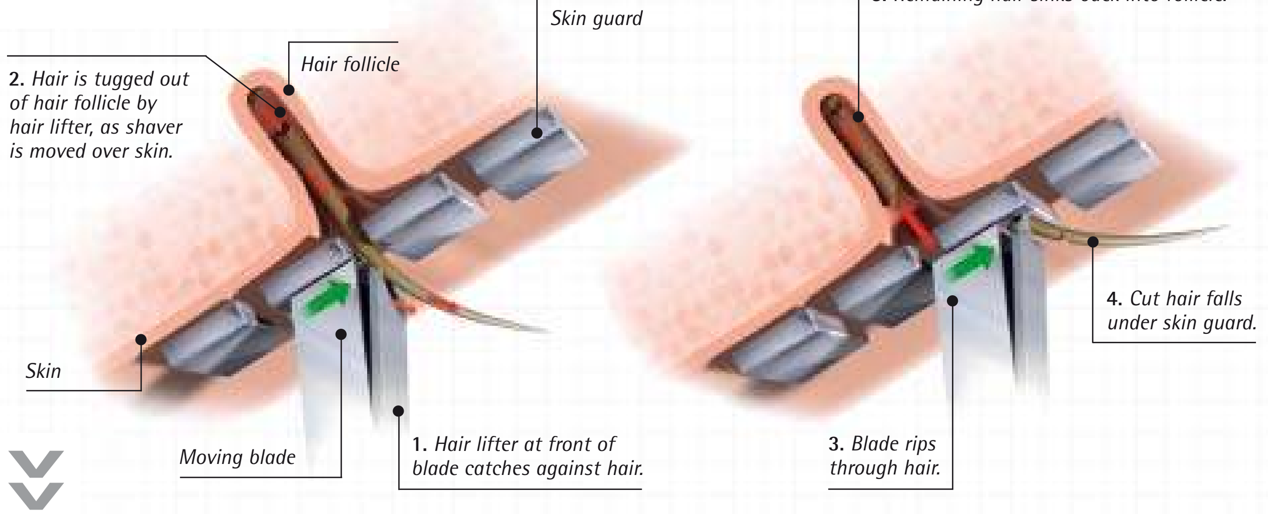
▲The best locks are very large and intricate. In the future, micro-mechanisms (extremely small moving parts) could make locks more compact and much easier to manufacture. These micro-mechanical gears, magnified 2,200 times by an electron microscope, could be used to make a hi-tech lock smaller than a fingernail. The mechanism would be so tiny that it would be almost impossible to tamper with and so much more secure than a normal-sized lock.

SHAVER

The average man grows 9 m (30 ft) of beard in his lifetime. Many use electric shavers. These tiny motor mowers are driven across the face, chopping hairs quickly and painlessly.

HOW A SHAVER WORKS

THE LIFT AND CUT MECHANISM IN AN ELECTRIC SHAVER



Hair is made of keratin, a strong protein that is also found in nails and the outer layer of skin. The metal blade of a razor is strong enough to chop through the structure of hair. Electric shavers have blades that are mounted on wheels and spin around under skin guards. As the blades whizz along, they rip through the hairs, but do not touch the skin. This makes them quick and safe to use. They were also designed to work on a dry face with no soap. A manual shaver works much like a knife blade. Wetting the face and using soap makes the hairs softer, so the sharp blade of a manual razor can slice through hairs easily. However, this process takes much longer and does not protect the skin from cuts.

Skin guard provides barrier between blades and skin.

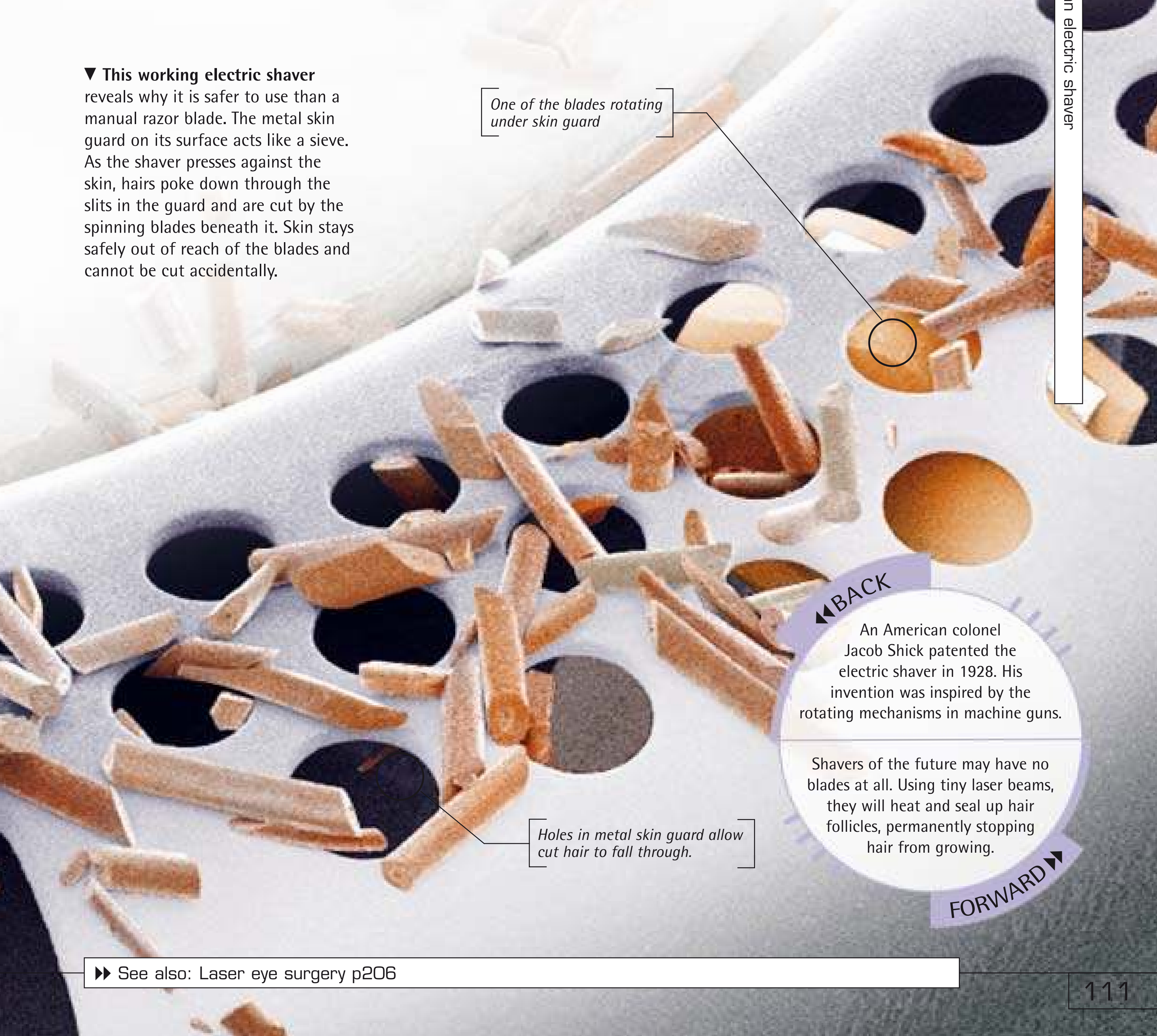
Image: magnified image of an electric shaver

Why razor blades wear out

Blades and cutting instruments are made from strong, hard materials, for example diamonds and metals. These can cut through softer materials, like hair. But even hard materials, such as this steel razor blade, eventually become blunt. Each time the blade shaves, hairs leave tiny scratches on its surface. A rough, old blade is less able to slice through hair than a smooth, new one, so it cuts less well.

Worn edge of a steel razor blade

This working electric shaver reveals why it is safer to use than a manual razor blade. The metal skin guard on its surface acts like a sieve. As the shaver presses against the skin, hairs poke down through the slits in the guard and are cut by the spinning blades beneath it. Skin stays safely out of reach of the blades and cannot be cut accidentally.



One of the blades rotating under skin guard

Holes in metal skin guard allow cut hair to fall through.

BACK

An American colonel Jacob Shick patented the electric shaver in 1928. His invention was inspired by the rotating mechanisms in machine guns.

Shavers of the future may have no blades at all. Using tiny laser beams, they will heat and seal up hair follicles, permanently stopping hair from growing.

FORWARD

See also: Laser eye surgery p206

AEROSOL CAN

At the press of a button, an aerosol can releases a burst of pressurized liquid and sprays it evenly over a wide area. Aerosol cans hold many things, including air fresheners and hairspray.

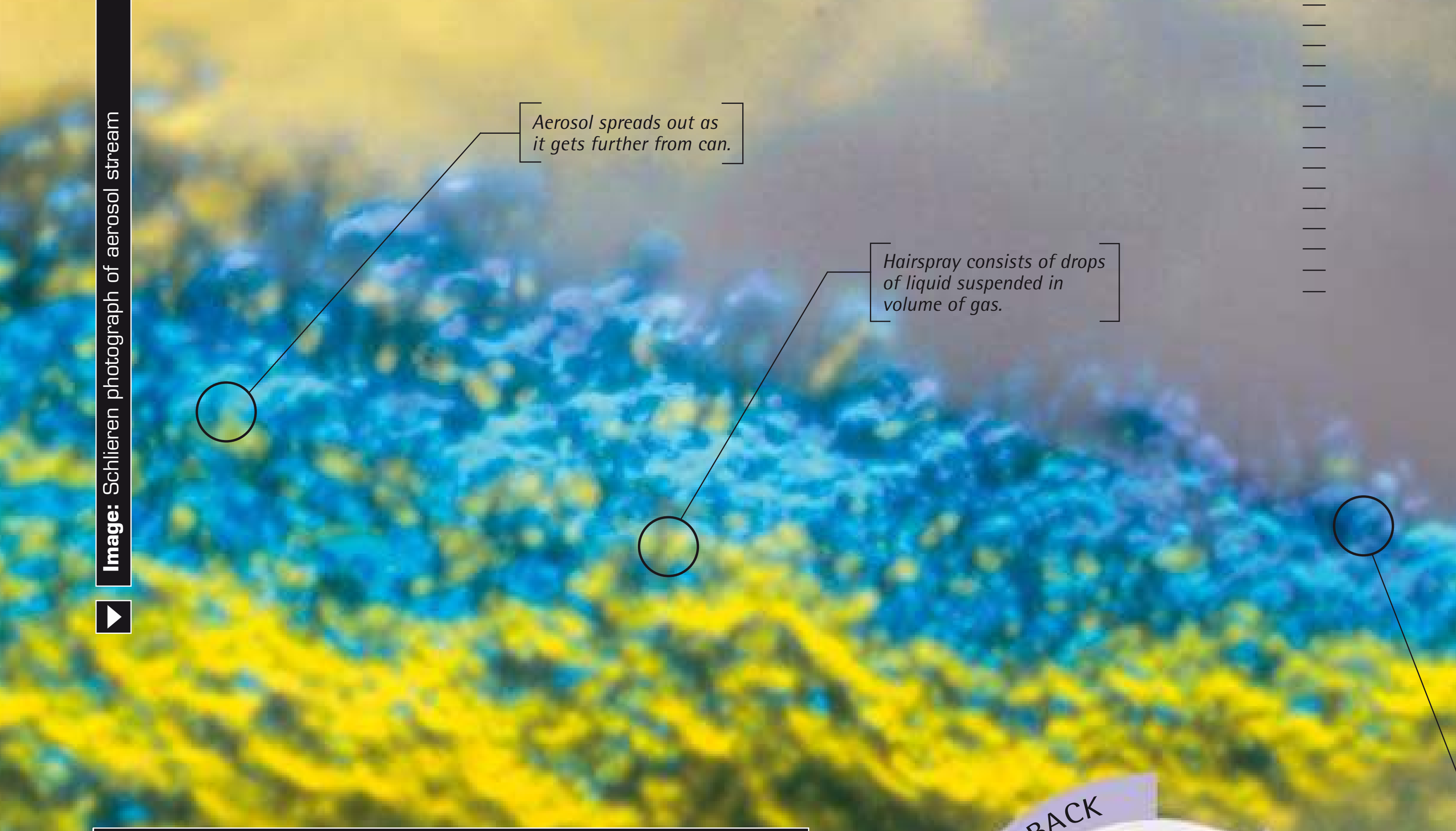
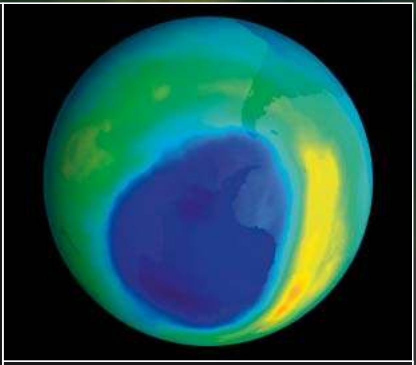


Image: Schlieren photograph of aerosol stream

How aerosols depleted the ozone layer

A layer of ozone gas in Earth's upper atmosphere (the stratosphere) acts like a natural sunblock, screening out harmful ultraviolet radiation. From the 1930s to the 1980s, chemical propellants used in aerosol cans reacted with ozone gas and caused some of it to disappear. This left an enormous hole in the ozone layer over Antarctica. Those chemicals are now banned, but the hole will not be filled for many decades.



Ozone hole over Antarctica (in blue)

BACK

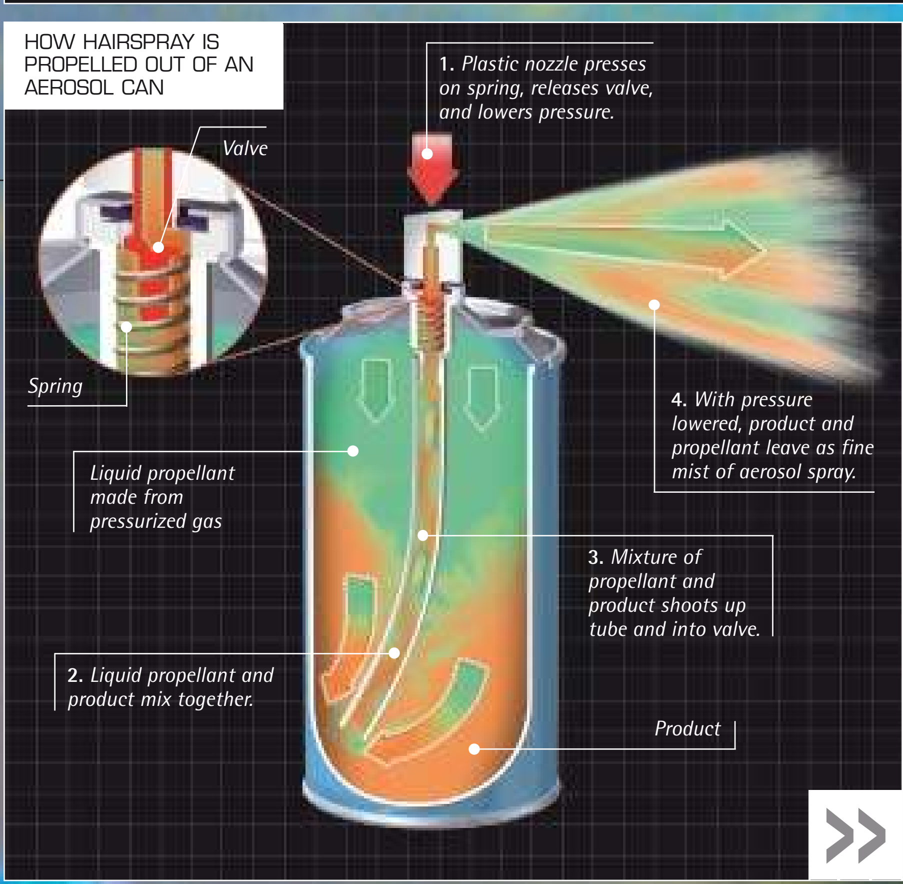
The potential of aerosol cans was not fully realized until World War II, when the US military introduced a device for dispensing insecticide.

Aerosol cans containing medicines will have an electronic counter, so that patients know they've used the correct dose, and when to re-order their prescription.

FORWARD

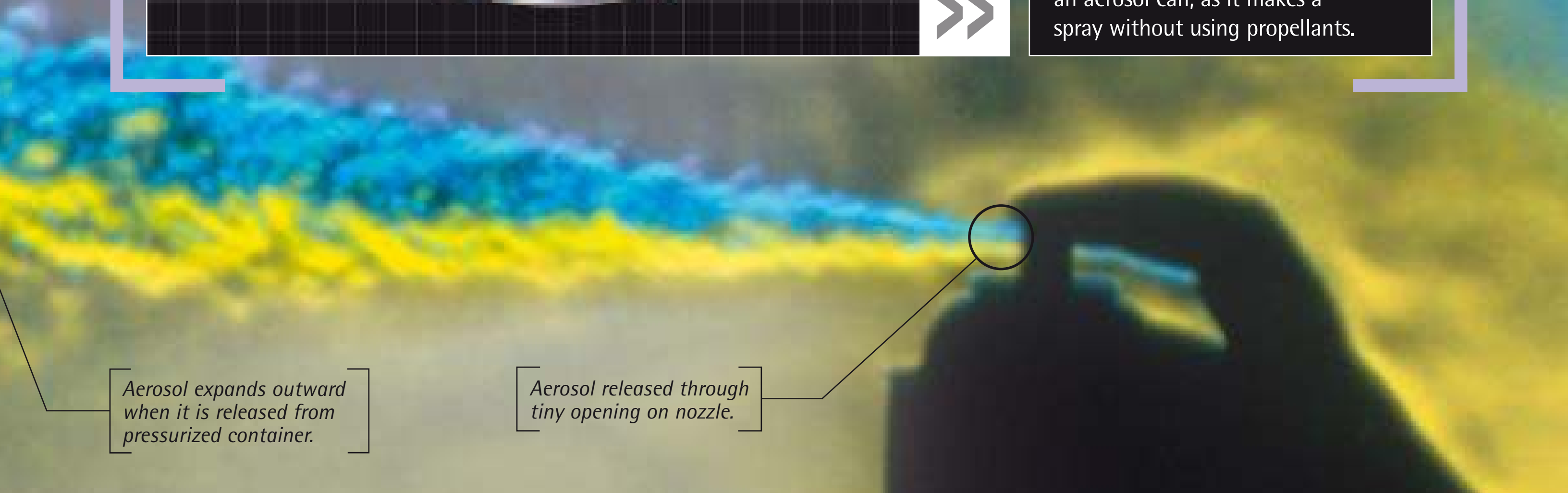
See also: Gas p244, Fridge p102, Neon p34, Pressure p249

HOW AN AEROSOL CAN WORKS



An aerosol can contains two different elements: a propellant which is normally a gas, such as butane or propane, and a liquid product, such as hairspray. The propellant is pumped into a can under pressure, becomes a liquid, and mixes with the product. When the nozzle of the can is pressed and the valve opens, the propellant shoots out, turning back into a gas, which expands in the air. It takes with it droplets or particles of the product. This cloud of gas and product is an aerosol.

Some aerosols are made another way, using a trigger-handle you squeeze repeatedly. As you pump the handle, the air above the liquid is pressurized, which forces the liquid up a small tube and out through a nozzle to form a spray. This type of product is safer and more environmentally friendly than an aerosol can, as it makes a spray without using propellants.

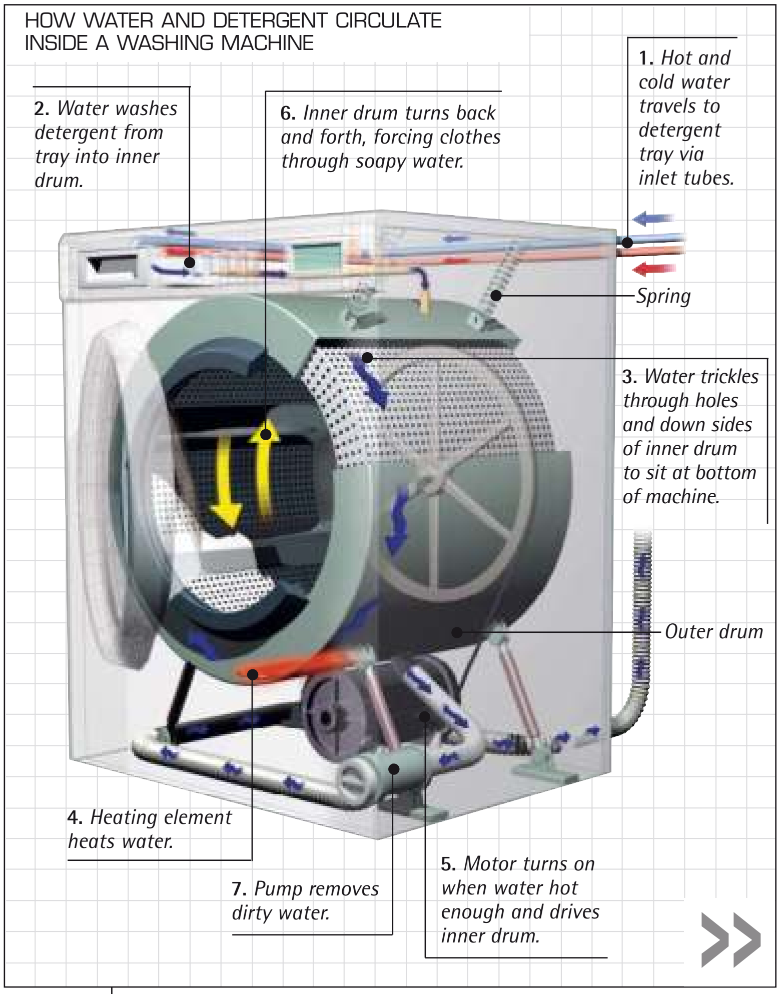


▲ **This expanding cloud** of hairspray is an aerosol: a collection of liquid droplets that are finely spread out within a gas. To create an aerosol, both the gas and liquid are squeezed into a contained area – in this case a can – and released under pressure through a tiny opening in the can's nozzle. The particles of the liquid are dispersed through the air with the released gas. Aerosols are not just manufactured, but can be found in the natural world, for example clouds, fog, and smog are all aerosols.

WASHING MACHINE

Pile in your laundry, add detergent, choose a program, and the washing machine does the dirty work. In its final spin, the inner drum races around at up to 130 km/h (80 mph).

HOW A WASHING MACHINE WORKS



The very latest washing machines are designed to be environmentally friendly, using as little water and energy as possible. Before beginning a wash, the machine weighs the load, and calculates how much water is needed. Using less water means less electricity is required to heat it. It also means the drum is lighter so less energy is needed to turn it. Some machines are designed to use less detergent, too. As the drum turns, paddles built into the sides scoop up the water and detergent and sprinkle it over the clothes to increase its cleaning power.

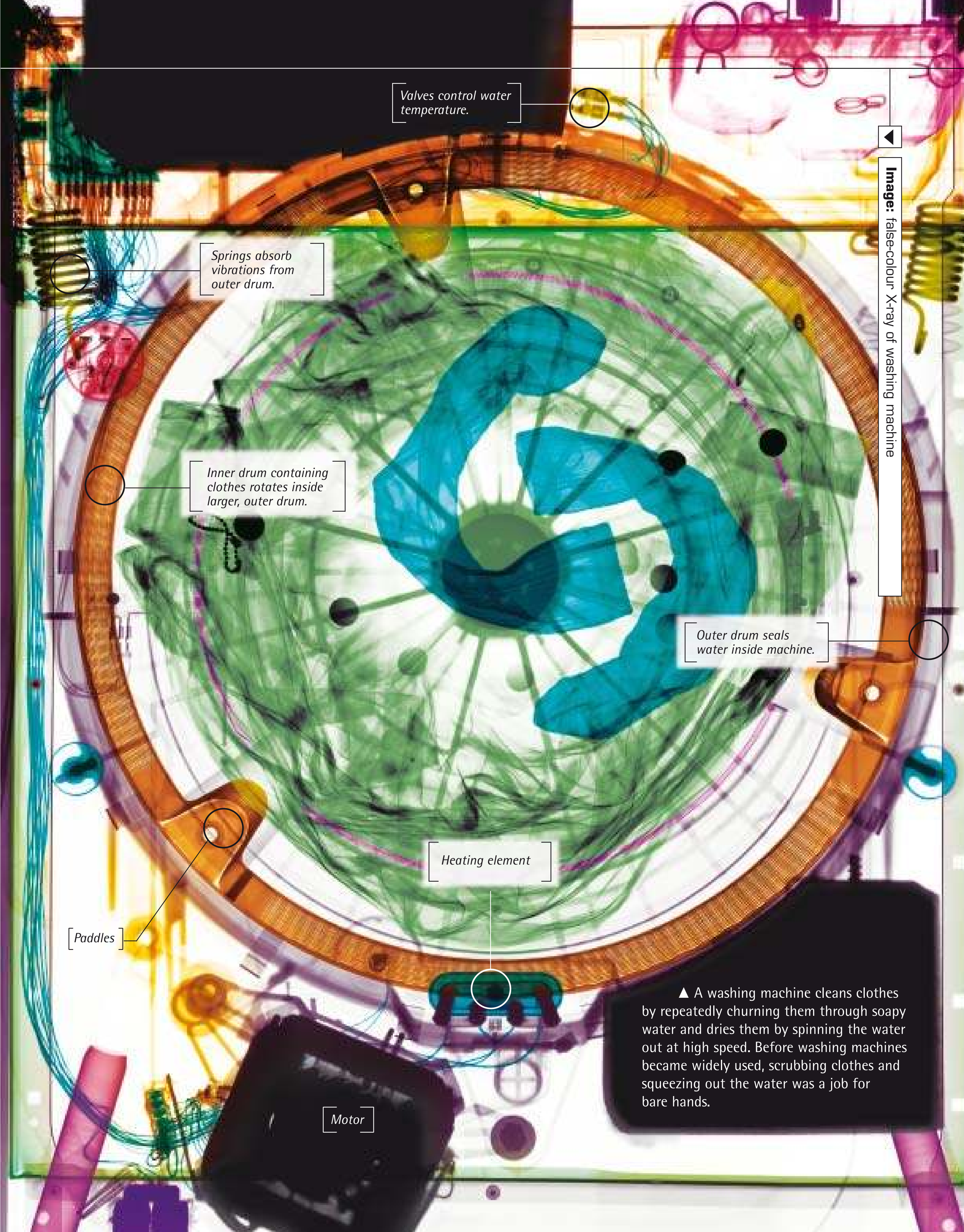
After the load has been rinsed, the drum spins up to 1,400 times per minute (23 times per second) to drain it. The drum has hundreds of tiny holes around its rim. As it spins, the water flies out through the holes. Some machines can remove two thirds of the water during spinning, so less energy is needed to dry the load.

Top loaders

Top loading washing machines have an upright tub rather than a horizontal drum. Clothes and detergent are loaded at the top, and the clothes stirred in the water by a paddle called an agitator. Front loading machines are more energy efficient than top loaders because they spin at faster speeds and use less energy for drying. Front loaders are also better for the environment, using around 5 per cent less water.

Top loaders on production line

See also: Detergent p242, Robot helper p118, Vacuum p116



▲ A washing machine cleans clothes by repeatedly churning them through soapy water and dries them by spinning the water out at high speed. Before washing machines became widely used, scrubbing clothes and squeezing out the water was a job for bare hands.

VACUUM

More than 5,000 prototypes were tested before this device was perfected: a cyclonic vacuum cleaner that never loses suction.

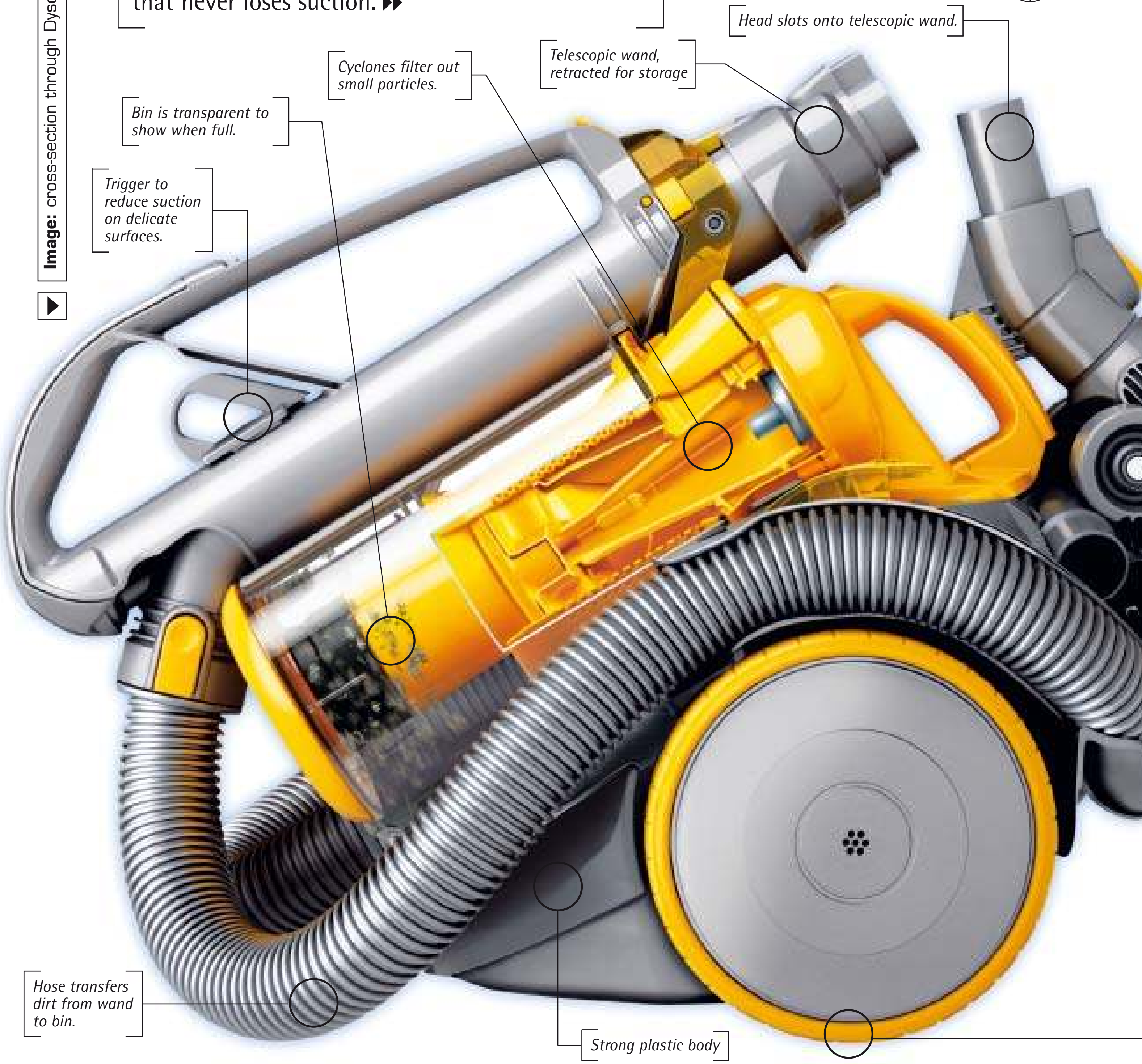
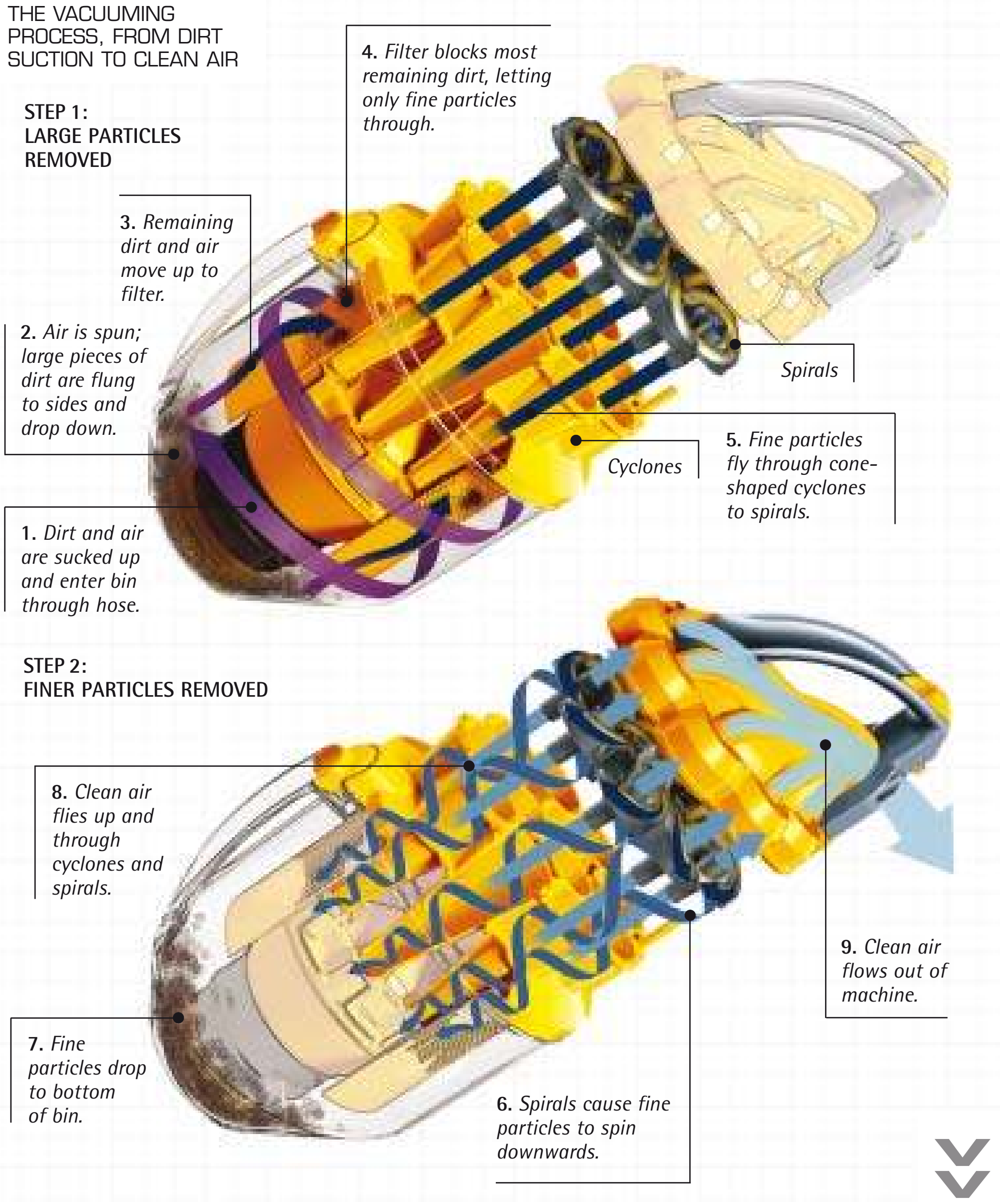


Image: cross-section through Dyson vacuum

▲ **This bagless vacuum cleaner** sucks up a mixture of air and dirt. Using spinning cyclones, it separates out the dirt, stores it in a bin, and passes the filtered air out again. This model has a telescopic wand that wraps around the body of the cleaner during storage, and is pulled out to its full length during use.

>> HOW THE CYCLONES WORK

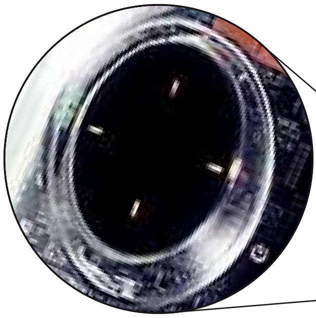


In a traditional vacuum cleaner, a pump sucks air and dirt through a bag that acts as a filter. The dirt catches in the bag, but the air whistles straight through, maintaining suction. As the bag fills up, however, the air struggles to pass through the clogged dirt. As a result, the pump loses suction, becoming increasingly less efficient until the bag is changed.
A cyclonic vacuum cleaner solves this by using centrifugal force to separate air and dirt. Centrifugal force – a force that makes things fly outwards when they go around in a circle – pushes the heavier particles further out than the lighter particles so that they separate and fall under their own weight into the bin. The finer particles rush up cone-shaped cyclones where the process is repeated to filter the air further. Because the dirt does not block the air flow, there is no loss of suction no matter how full the machine gets.

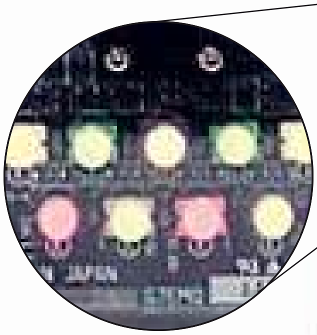
▶▶ See also: Centrifugal force p241, Robot helper p118, Washing machine p114

ROBOT HELPER

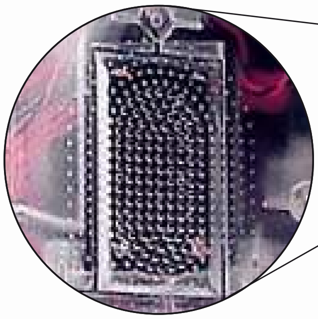
Cute on the outside, clever on the inside, friendly robots could be the home helpers of the future. Built-in microchips enable them to recognize and talk to you, and help with the housework.



Instead of eyes, the robot has twin digital cameras. These are programmed to look for faces. When PaPeRo finds a face, it looks for any familiar features. If it recognizes someone, the lights around the cameras turn orange.

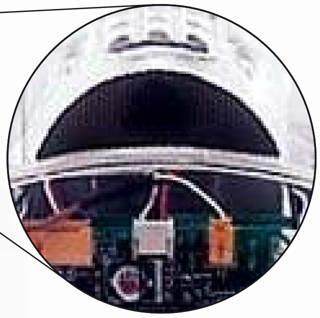


PaPeRo speaks with a friendly voice and small, coloured lights shine to show it is happy. The robot can recognize 650 phrases and 3,000 words. It is programmed to answer questions made up of these words and phrases.



The robot hears where noises are coming from because it has powerful microphones that locate them clearly. Microphones turn words into pulses of electricity, a microchip reads the electricity as digital information, and a voice recognition system deciphers the meaning of the words.

Image: PaPeRo robots in action



▲ **If the robot is touched,** sensors on top of its head detect the pressure. These sensors can even tell the difference between a pat and a stroke. Other sensors in the body detect when the robot is picked up.

◀◀ BACK

The word robot means forced labour in Czech. It first appeared in a play by Czech writer Karel Capek in 1921. Today, 90 per cent of the world's robots work in factories.

Robot helpers may soon be used to care for sick, disabled, or elderly people. They could make basic health checks and call doctors in an emergency.

FORWARD ▶▶

◀ **PaPeRo can sense obstacles.** Ultrasonic sensors detect when something is in the robot's way. By sending out high-pitched squeaks beyond the range of human hearing, PaPeRo can listen for echoes to tell whether objects lie ahead. Inside the robot is a heavy spinning wheel called a gyroscope. This helps it to balance.

Wheels can turn opposite ways to make robot swivel on the spot.

▲ **These battery-operated PaPeRo robots** are easy to use because they mimic the human senses. Designed to help out around the home, they can control household devices remotely. They can connect to the Internet to send your emails and read aloud incoming ones. Standing 38 cm (15 in) tall, they are about the same size as small dogs. Their backpacks make them seem more childlike and friendly.

Robot toys

▶ Some people find the idea of artificial beings strange or threatening. Scientists are trying to overcome this by designing user-friendly robots that balance the sophisticated technology of machines with the appeal of animals. Robot dogs and cats have powerful microchips which are programmed to mimic animal emotions such as happiness or fear. They move, play, and sleep like real pets, but they can also sing and dance.

Japanese robot dog

▶▶ See also: Robot surgery p208, Robot worker p186, Voice recognition p28

Within the next few years, we are likely to be wearing clothes with computers, communications devices, and heating systems built into them. New kinds of synthetic fibres, as well as ways of combining traditional fabrics with hi-tech materials such as aerogel, are making clothes lighter, more in tune with our bodies, and easier to clean.

The development of new materials will also have a big impact on our homes. Walls and windows could be insulated with aerogel, a lightweight but incredibly efficient insulating material. Less power will be needed to keep us warm, cutting down fossil fuel usage. Millions of houses might be able to source their energy from solar panels. These will be made from an infra-red sensitive film, capable of being sprayed on to any surface. Even on cloudy days, they will convert the Sun's energy into electricity, making them much more efficient than current solar cell technology.

“A new science called biomimicry is looking to nature's own ingenious design solutions to solve human problems.”

A new science called biomimicry is looking to nature to solve human problems. After 3.8 billion years of evolution, nature has worked out some ingenious and effective design solutions. Architects, designers, and engineers are becoming inspired by biomimicry, and new technologies could be developed as a result. For example, outside walls that copy the surface of lotus leaves will be cleaned by rainwater, rather than made more dirty by it. Colours of objects, such as cars, clothing, or the walls in your home, could alter according to how much natural light bounces off them, just as a peacock's feathers change colour by reacting to light. And sticky tape could mimic the way the hairs on a gecko's foot produce static electricity, allowing it to climb up walls.

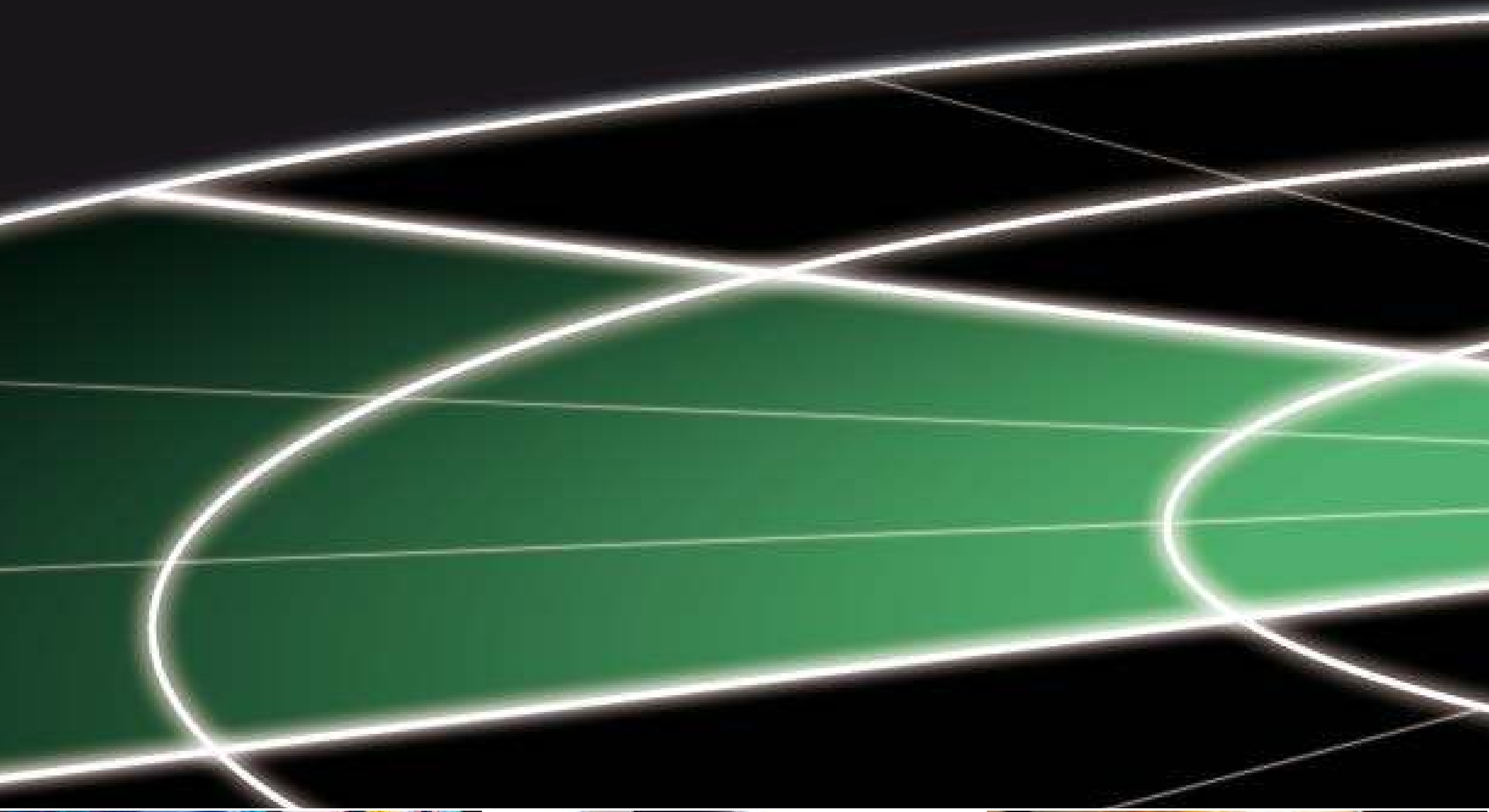
Our homes will become responsive to our needs. Almost any household object or appliance can be made smarter with sensors and microchips. These tiny devices will be found in every room, working away invisibly. This is called "ubiquitous computing". Washing machines will know when their parts are faulty or need replacing and contact a service engineer with a specific status report. Bathroom cabinets could alert you when medicines are close to their use-by dates. When you are about to run out of milk, fridges could automatically order another carton from the supermarket. Smart homes could also help the elderly and ill. Sensors in the floor, for example, could detect if you have fallen and alert a helper or the emergency services.

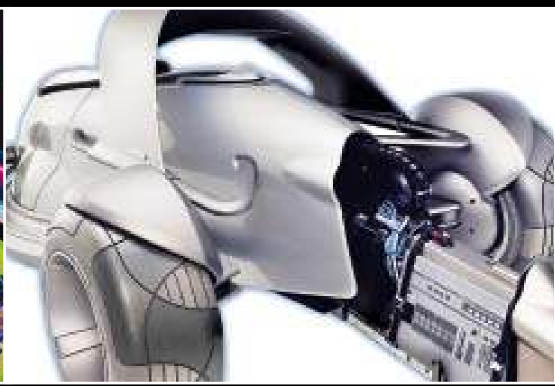
By the end of the century, many of the everyday items we use may be produced not in big industrial plants, but in our own homes. Replicating machines, already in development, will "print out" parts made of resin, using a set of instructions stored on a computer. The parts could then be assembled into various objects such as pieces of furniture, kitchen utensils, plates and cups, or even other replicating machines. These machines will become cheap enough for most of us to own or access, in much the same way that computers have become commonplace today.

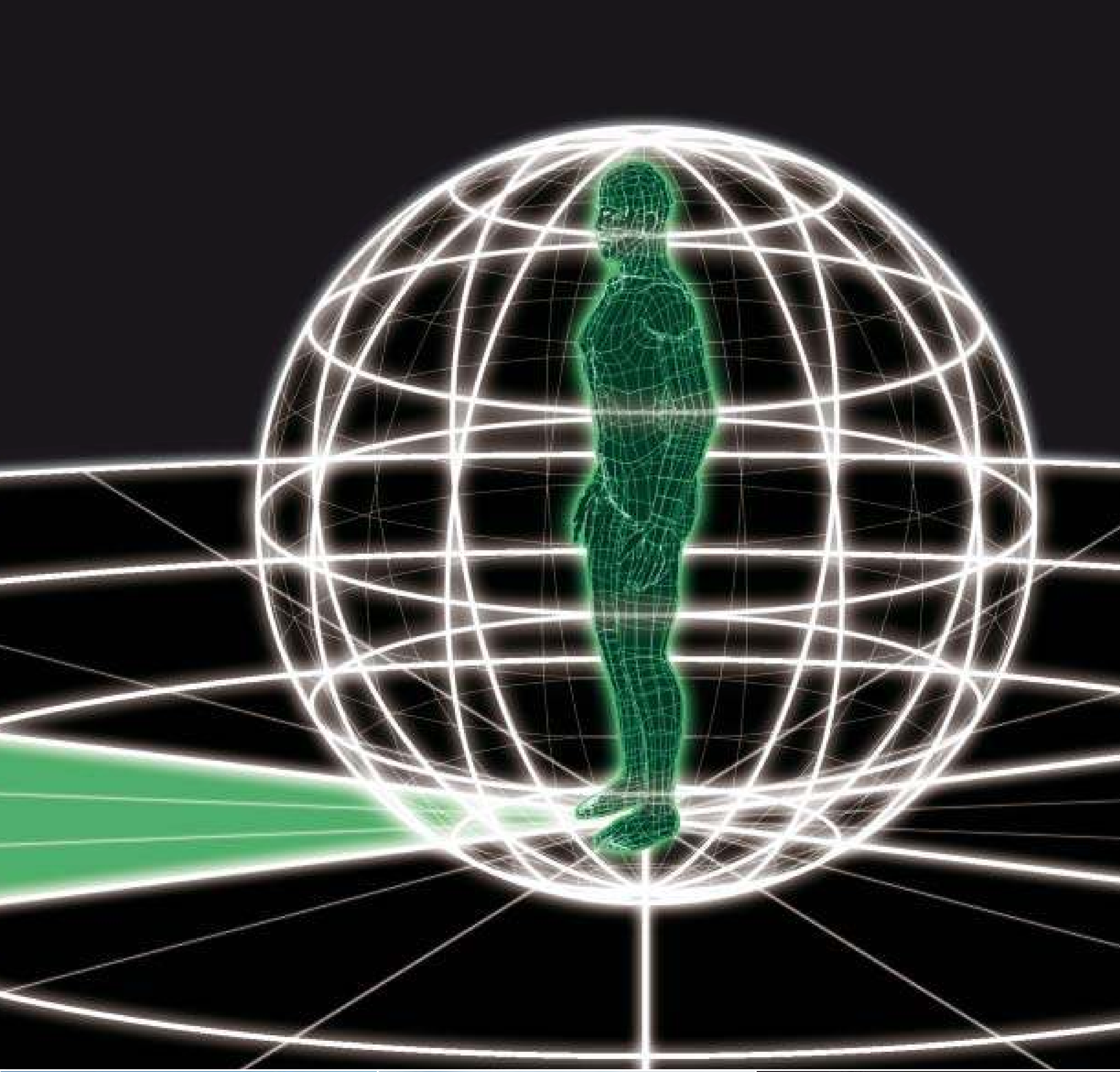
AEROGEL

>>MOVE

Motorbike >> Fuel-cell car >> Car engine >> Crash test >> Car tower >> Wheelchair >> Lift >> Submersible >> Osprey >> Jet engine >> Wind tunnel >> Black box >> Navigation >> Space Shuttle >> Space probe








SPEEDOMETER

In 1900, the two most important forms of transport that we use today were in their infancy. The Wright brothers, among others, had begun testing gliders. In 1903, they completed the first powered flight, which lasted just 12 seconds and covered 36.5 m (120 ft). Worldwide, fewer than one in 10,000 people owned a car. Fast-forward a century and the world has been transformed by our devotion to these twin technologies. In 2004, one and a half billion journeys were made by aeroplane – the equivalent of one flight for every fourth person on the planet. And there are more than 500 million cars on the planet, or one car for every 13 people.

Long before the arrival of the automobile and aircraft, steam engine technology had created its own transport revolution. Until rail networks were developed in the nineteenth century, most people rarely ventured outside their city, town, or even the village where they lived. The fastest it was possible to travel was on horseback. When the first steam train was invented in the eighteenth century, people thought it would be dangerous to travel at a speed greater than 40 km/h (25 mph). By 1916, people were using steam trains to cross continents in speed and comfort. Today, some trains regularly reach speeds of 430 km/h (268 mph).

The invention of the internal combustion engine, which ran on oil, led directly to the development of the car. This vehicle, more than any other, captured the public imagination with its promise of excitement, speed, and the freedom to travel wherever you chose. By the 1950s, reliable engines could power large planes economically. The Jet Age had arrived and mass travel abroad became a reality. Today, transport for people and goods increases every year, putting more and more pressure on transport networks. Congestion and safety are becoming serious challenges for the future.

> "In 1900, fewer than one in 10,000 people owned a car. Today, there is one car for every thirteen people on the planet."

Cutting-edge technology has found its way into all forms of transport. New developments in engineering, manufacturing, electronics, and computing have had a huge impact on the way we get around. Engines can power vehicles more efficiently, materials are getting stronger and lighter, and essential components have got smaller and smarter. Many new cars are fitted with sensors that can identify your precise location using the system of satellites called the Global Positioning System. Other computers control everything from the smooth running of lifts and escalators to rail network signalling.

A majority of vehicles are powered by petrol, which comes from oil. They produce waste gases that scientists believe are changing the world's climate. Also, world supplies of oil and other fossil fuels will decline as demand keeps growing, so the race is on to find other sources of power. One of the most exciting alternatives is the fuel cell, which uses hydrogen gas and oxygen to make electricity. Fuel-cell cars produce a harmless waste product: water. It is vital we succeed in the quest for alternative energy if we are to create sustainable transport and a cleaner future.

MOTORBIKE

The fastest motorbikes on the road today can reach speeds of 312 km/h (194 mph) and can accelerate from 0 to 100 km/h (60 mph) in under 3 seconds.

This Ducati sports motorbike has a compact engine suspended in a strong, lightweight frame. The engine is more powerful than many car engines, but the motorbike weighs a fraction of a car's weight. This combination of power and light weight allows bikes such as the Ducati to travel extremely fast.

Image: X-ray of a Ducati motorbike

▶▶ See also: Bike p58, Car engine p130, Gyroscope p245, Wheelchair p138

LCD computer screen displays performance and engine data.

How do motorbikes balance?

▶ When at rest, a motorbike needs a stand to stop it falling over, but when moving, it easily balances on its two wheels. This is because its wheels behave like gyroscopes. A gyroscope is a spinning disc that is very difficult to tilt. When riders go around a corner, they lean into the curve so their weight overcomes the centrifugal (outward-pushing) force that might otherwise tip the bike over. Leaning also enables them to corner at high speeds.

Superbike racer leaning into a bend

◀ **The handgrip** on the handlebars controls the power of the motorbike's engine. By twisting the handgrip, more fuel is let into the engine. Burning more fuel makes the engine work faster and produce more power to turn the back wheel. Twisting the handgrip can unleash more than 190 horsepower, equal to the power needed to light about 1,500 100-watt light bulbs.

◀ **Shock absorbers** connect the bike's wheels to its frame. When a wheel hits a bump, a coiled spring around the shock absorber squashes, cushioning the rider from the jolt. The shock absorber then stops the bike bouncing up and down by slowly pushing its internal piston through a cylinder full of oil.

▲ **Motorbike tyres** are made from layers of tough material set in rubber. Additives mixed with the rubber can improve performance. For example, adding silica gives better grip in wet conditions. A tyre's tread (grooved surface) also improves traction on wet roads by channelling water out from between the tyre and the road.

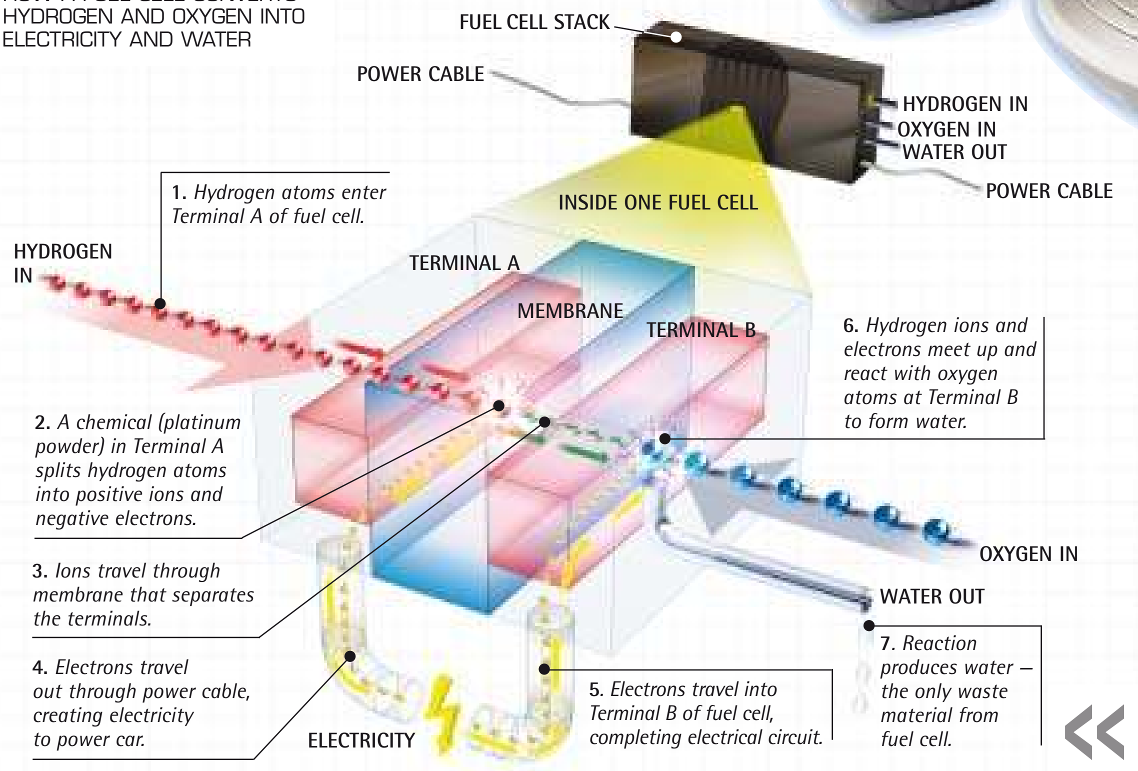
FUEL-CELL CAR

Electric fuel-cell cars are quiet and pollution-free. Originally designed for spacecraft, fuel cells could be the power source of the future as Earth's oil supplies run dry. All they need are supplies of two gases: hydrogen and oxygen.

HOW A FUEL CELL WORKS

A fuel cell is a bit like a battery that makes electric power through chemical reactions. Unlike a battery, a fuel cell never becomes flat and needs no recharging because the chemical ingredients it contains do not run out. The cell takes in a constant supply of pure hydrogen gas (from a cylinder carried in the car) and oxygen (from the air outside). These react together to make electricity for power and water as a waste product. The electricity is used to drive one or more electric motors, which have far fewer parts and are much quieter than a traditional engine. Fuel cells produce no harmful emissions.

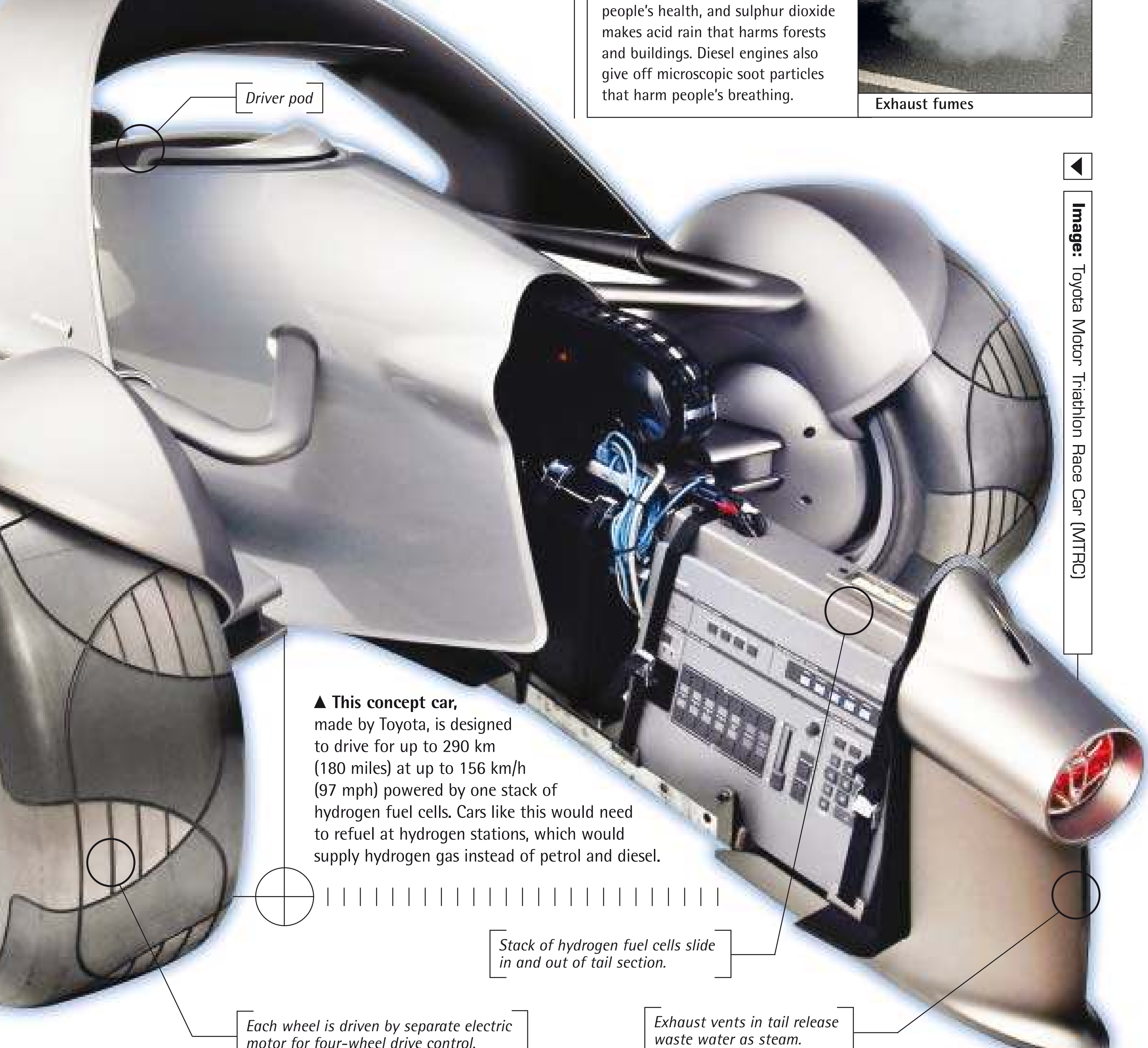
HOW A FUEL CELL CONVERTS HYDROGEN AND OXYGEN INTO ELECTRICITY AND WATER



Air pollution

▶When cars burn petroleum fuels, they produce waste gases known as exhaust fumes. Of these gases, carbon dioxide adds to global warming, carbon monoxide harms people's health, and sulphur dioxide makes acid rain that harms forests and buildings. Diesel engines also give off microscopic soot particles that harm people's breathing.

Exhaust fumes



▲ **This concept car,** made by Toyota, is designed to drive for up to 290 km (180 miles) at up to 156 km/h (97 mph) powered by one stack of hydrogen fuel cells. Cars like this would need to refuel at hydrogen stations, which would supply hydrogen gas instead of petrol and diesel.

Image: Toyota Motor Triathlon Race Car (MTRC)

▶▶ See also: Battery p94, Car engine p130, Car tower p136, Crash test p134, Electric motor p243

CAR ENGINE

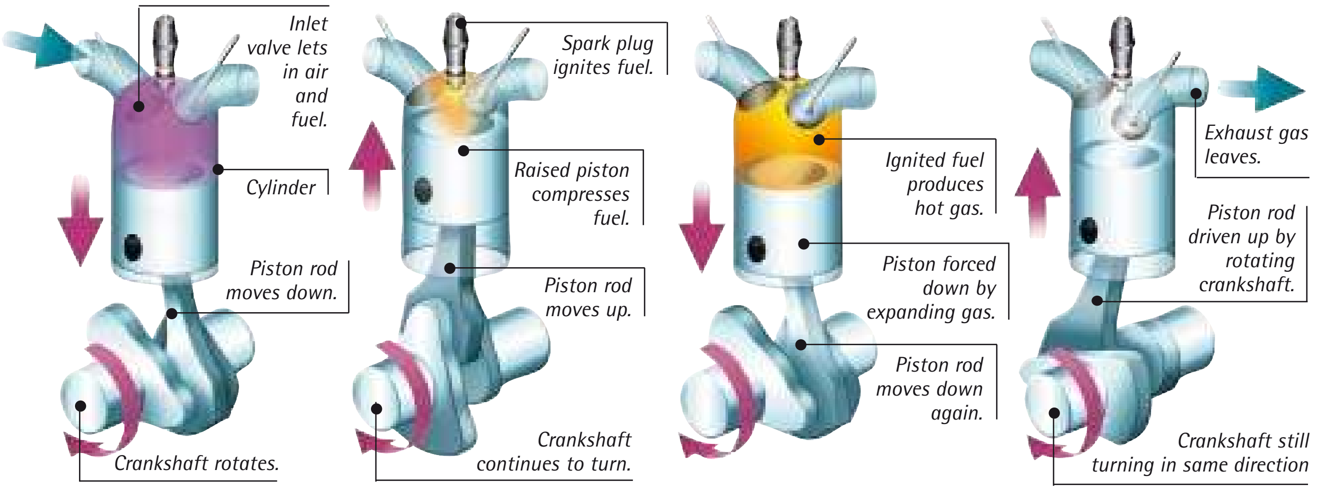
▶▶ About 50,000 tiny explosions occur inside a car engine every single minute, turning the chemical energy locked inside fuel into motion that can power the car. ▶▶

Image: cutaway of the internal workings of a Jaguar car

▼ **This rear-wheel drive** car transfers power from the cylinders in the engine to the back wheels, using a series of shafts and gears. Changing gears connects gear wheels of different sizes, so that the engine can work faster or slower as the car changes speed.

▶▶ See also: Fuel-cell car p128, Internal combustion engine p245, Jet engine p146

>> HOW A FOUR-STROKE ENGINE WORKS



Step 1: Intake The car's power is generated in four, continuously repeated steps. First the piston moves down and draws fuel and air into the cylinder through the inlet valve. The lowering of the piston rod turns the crankshaft.

Step 2: Compression The inlet valve closes. A close-fitting, heavy metal piston slides up inside the cylinder and squashes the fuel-air mixture. This makes it highly explosive. A high electrical voltage makes a tiny, brief spark in the spark plug at the top of the cylinder. The fuel-air mixture explodes and burns, giving off hot gases.

Step 3: Power The gases expand and push the piston down the cylinder. When the piston rod moves down and back up again, it rotates the heavy metal crankshaft that carries power to the car's gearbox. In this way, the heat created by burning the fuel is converted into mechanical power.

Step 4: Exhaust The exhaust valve opens. The steady turning of the crankshaft keeps the piston moving. As it drives back upwards, it pushes the waste gases out through the exhaust valve, emptying the cylinder. Then the cycle is repeated. A number of cylinders work together to keep the crankshaft turning.

◀◀BACK

The four-stroke petrol engine was invented in 1876 by German engineer Nikolaus Otto. It was called the Otto cycle in his honour.

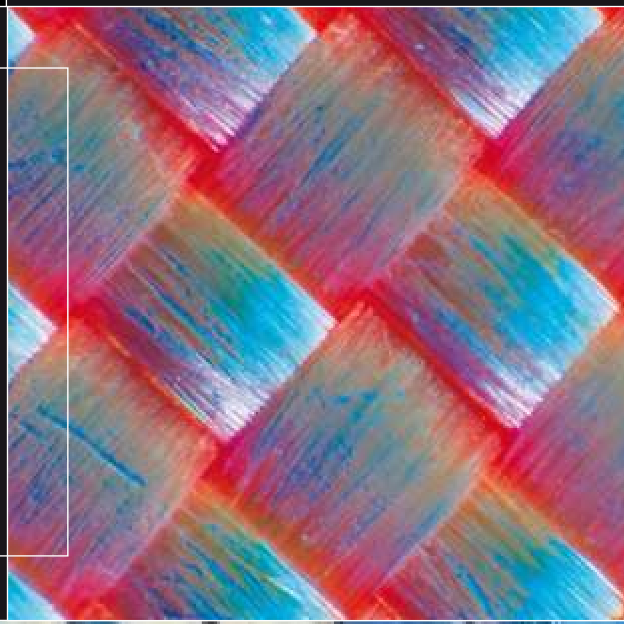
Solar cars may replace fuel-powered ones. Solar panels on the car's bonnet, boot, and roof convert sunlight into electricity and store it in batteries to power the car.

FORWARD▶▶

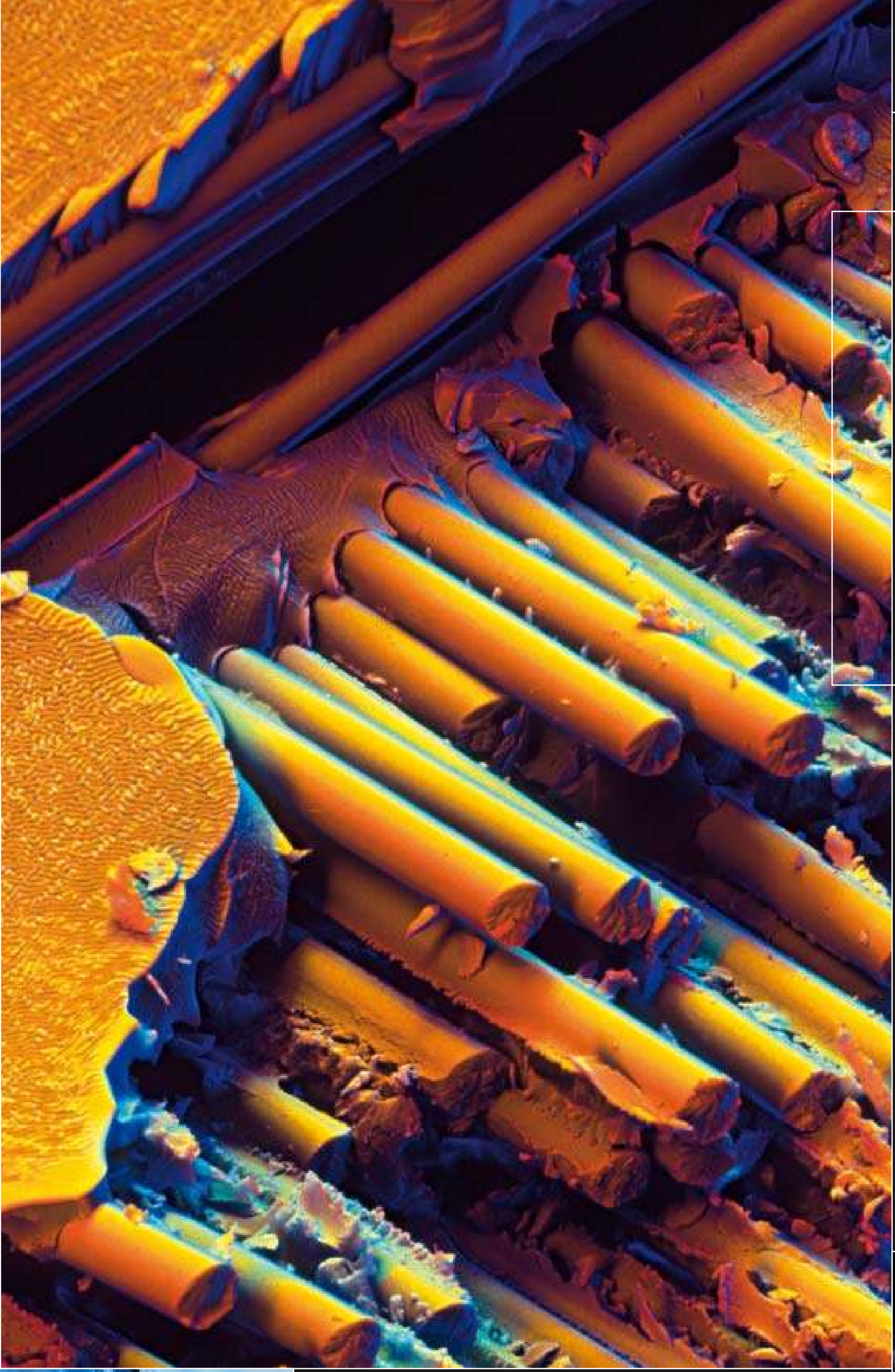
PARTS

Vehicles are now travelling faster and further than ever before, so their components need to be made stronger, lighter, and more durable. Scientists are constantly developing new materials for this task.

Carbon-carbon
This aircraft wing part is made from a carbon-carbon composite (combination of materials). To create this composite, carbon compounds are combined in layers and heat-treated to make them extremely tough. Unlike metals, this material becomes stronger when heated to high temperatures, making it useful for racing-car brakes, aircraft, and spacecraft.



Kevlar®
Like Lycra® and nylon, Kevlar® is a synthetic (man-made) fibre. Its tightly woven fibres make it five times stronger than steel, which makes it the ideal material for bulletproof vests. It is also used to make bicycle tyres, car brake pads, and windsurfing sails, which all rely on strength, long life, and light weight.



Fibreglass

Developed in the 1940s, fibreglass is the world's best-known composite. This magnified image, taken with a scanning electron microscope, reveals the tiny rod-shaped glass fibres within the material. These fibres provide the material's strength and are held together with a type of plastic called polyester. Fibreglass is heat-resistant, lightweight, and tough, as well as being flexible and durable. It is ideal for making boat hulls, car bodies, and aircraft parts.

Titanium

These huge jet engine fan blades are made from titanium, a metal found in Earth's crust and also in meteorites. It is as strong as steel, but almost half as light, does not corrode easily, and can tolerate extreme temperatures. It can be combined with other metals, such as aluminium or tin, to make strong alloys. Titanium and its alloys are used to make missiles, spacecraft, boats, and bike frames, which all need to be strong and light.

Testing materials in space

This picture shows a space experiment carried out by NASA. In 1984, a huge cylinder was covered in different materials and taken into space by a NASA Space Shuttle. The materials were exposed to the harshness of space for almost six years. When the cylinder returned to Earth, scientists used its data to see which materials could withstand such extreme conditions, to help NASA to build future spacecraft.

See also: Bike p58, Carbon p241, Fabric p60, Fire suit p190, Jet engine p146

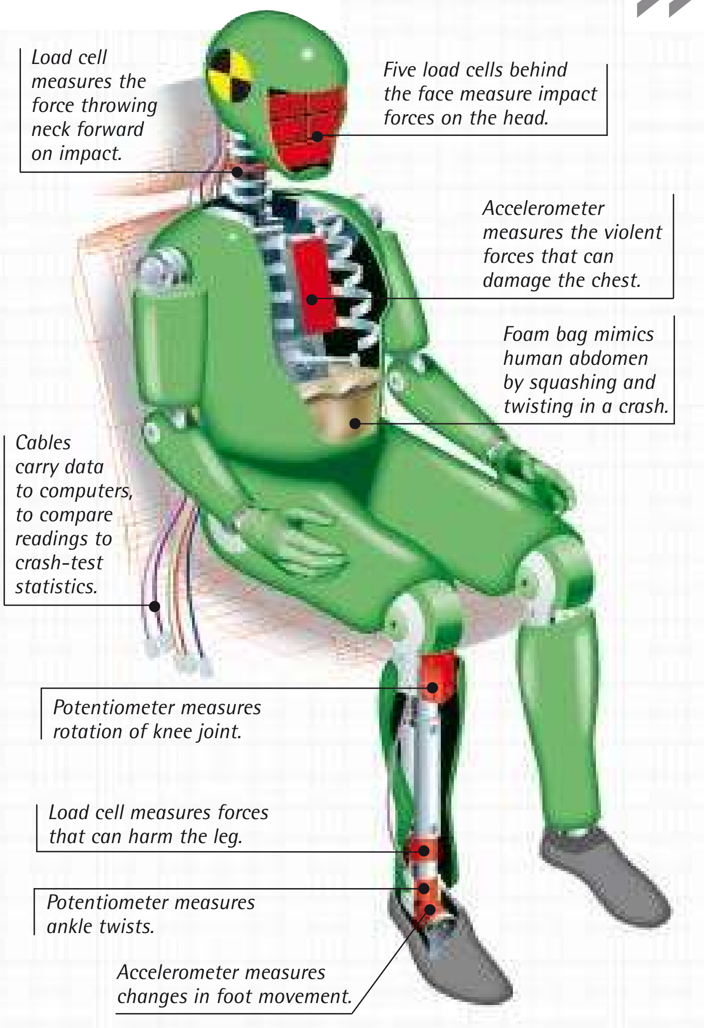
CRASH TEST

A crash-test dummy is a whole scientific laboratory packed into a plastic body. During a crash test, the dummy records measurements from more than 130 tiny sensors positioned inside it.

This crash-test dummy feeds hundreds of measurements to computers as an inflating airbag brings it safely to rest. For over 50 years, dummies have been used to refine seatbelt, airbag, and vehicle design to improve driver and passenger safety.

HOW A CRASH-TEST DUMMY WORKS

THE MAIN SENSORS IN A CRASH-TEST DUMMY



In a car crash, injuries to the head, chest, and legs are the most likely, so dummies need plenty of sensors in these areas. There are three types of sensor: load cells, accelerometers, and potentiometers. Load cells measure forces using tiny piezoelectric crystals that generate electricity as they stretch or squeeze. Accelerometers contain tiny magnets that slide past each other if the sensor moves, generating bursts of electricity that indicate changes in speed. Potentiometers generate a small voltage that measures how much they twist or turn. Different dummies are made for side-impacts and front-impacts, with sensors concentrated in specific areas.

This designer holds the neck of a child-sized dummy as he refines the design on screen. Computer-aided design helps to build dummies of different sizes, ages, and sexes.

Image: blurred motion photograph of crash-test dummy

The science of impacts

Aerial view of a car during a crash test

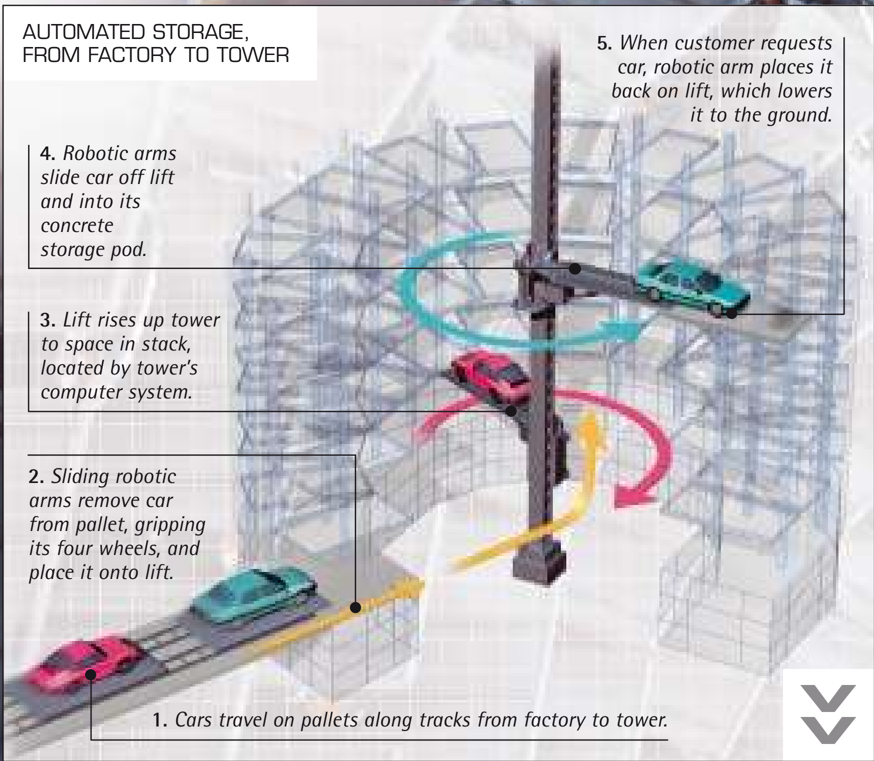
▲The bigger a car and the faster it moves, the more energy it has. When a car crashes, its sudden stop creates huge forces that can injure the people inside. Cars are specially designed to crumple to release the energy of an impact more slowly. This, combined with airbags and seatbelts, reduces the forces on the occupants and improves their chances of survival.

See also: Black box p150, Car engine p130, Car tower p136, Piezoelectricity p248

CAR TOWER

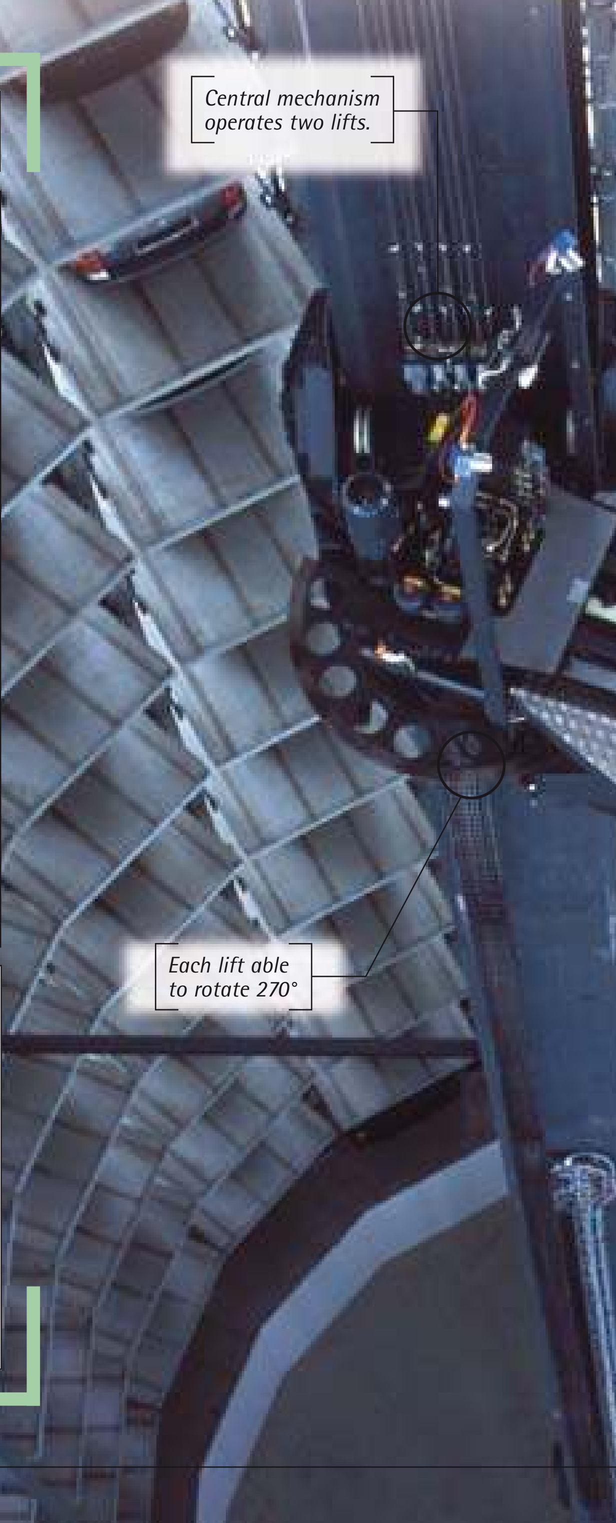
In the heart of industrial Germany is the world's largest car factory, producing 3,000 cars a day. Many of them are stored vertically, in a kind of giant vending machine called a car tower.

HOW A CAR TOWER WORKS




One of Autostadt's car towers

With around 550 million cars in the world and 40 million new vehicles made each year, finding a place to park can be difficult. The problem is particularly bad at car factories and showrooms, where hundreds of new vehicles need to be stored quickly and safely until customers are ready to collect them. Volkswagen's car tower solves those problems by rolling three classic inventions – the lift, the multistorey car park, and the forklift truck – into one. As cities become ever more congested, towers like this could soon start replacing urban car parks.



See also: Car engine p130, Fuel-cell car p128

▼ **The two cylindrical car towers** at Autostadt (car town) in Wolfsburg, Germany, have 20 storeys, are 47 m (154 ft) high, and can hold 400 vehicles each. The fully automated system delivers direct to a showroom where over 550 new cars are sold each day.

Lift can haul 2.5 tonnes at 7 km/h (4½ mph)

20 storage pods per storey

Image: inside one of Autostadt's car towers

Hi-rise stacking in nature

Inside a termite mound

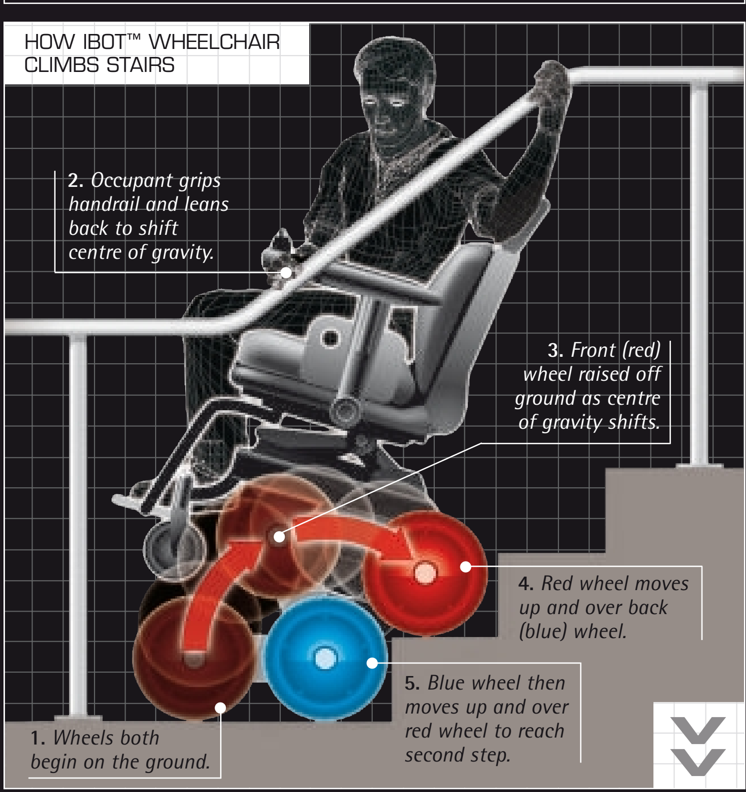
▲Termite nests, built from mud and chewed wood, are around 6 m (20 ft) high and house a million or more termites – an incredibly efficient use of space. An office block would need to be around 10 km (6 miles) high to hold as many people. This African termite nest has a spiral staircase, allowing the insects easy access to the different levels.

WHEELCHAIR

The acrobatic iBOT™ wheelchair can raise its occupant up to standing height and even climb stairs. Using its powerful four-wheel drive, it can plough through mud and sand and whizz along tarmac at up to 10 km/h (6 mph).

This iBOT™ wheelchair is in its raised position. From here, the occupant is at standing height and high enough to reach shelves. The chair's special balance mechanism detects when the occupant's centre of gravity moves, then shifts the clusters (pairs) of large wheels to compensate and balance the chair safely. When all wheels are on the ground, a joystick steers two smaller front wheels to move the chair.

HOW IBOT™ WORKS

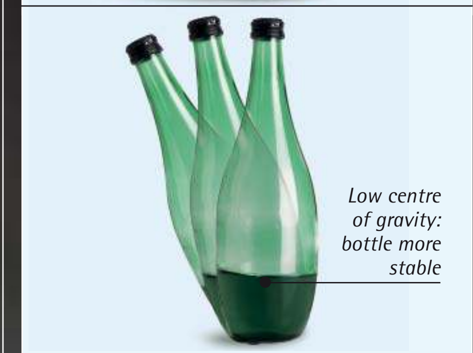


It is hard to pull a conventional wheelchair up stairs, because it has to be heaved vertically up each step. A ramp laid up the stairs can make the task easier, because the chair travels up the slope gradually instead of being pulled upwards against the force of gravity.
The iBOT™ wheelchair climbs stairs another way, using even less effort. Its secret lies in two pairs of large wheels called clusters. As the clusters move up and over one another, the chair rises up the stairs in a series of long, shallow curves. The extra distance each wheel travels helps to reduce the effort needed to climb stairs.

See also: Centre of gravity p241, Robot helper p118

Image: INDEPENDENCE® iBOT™ 3000 Mobility System in raised position

Centre of gravity



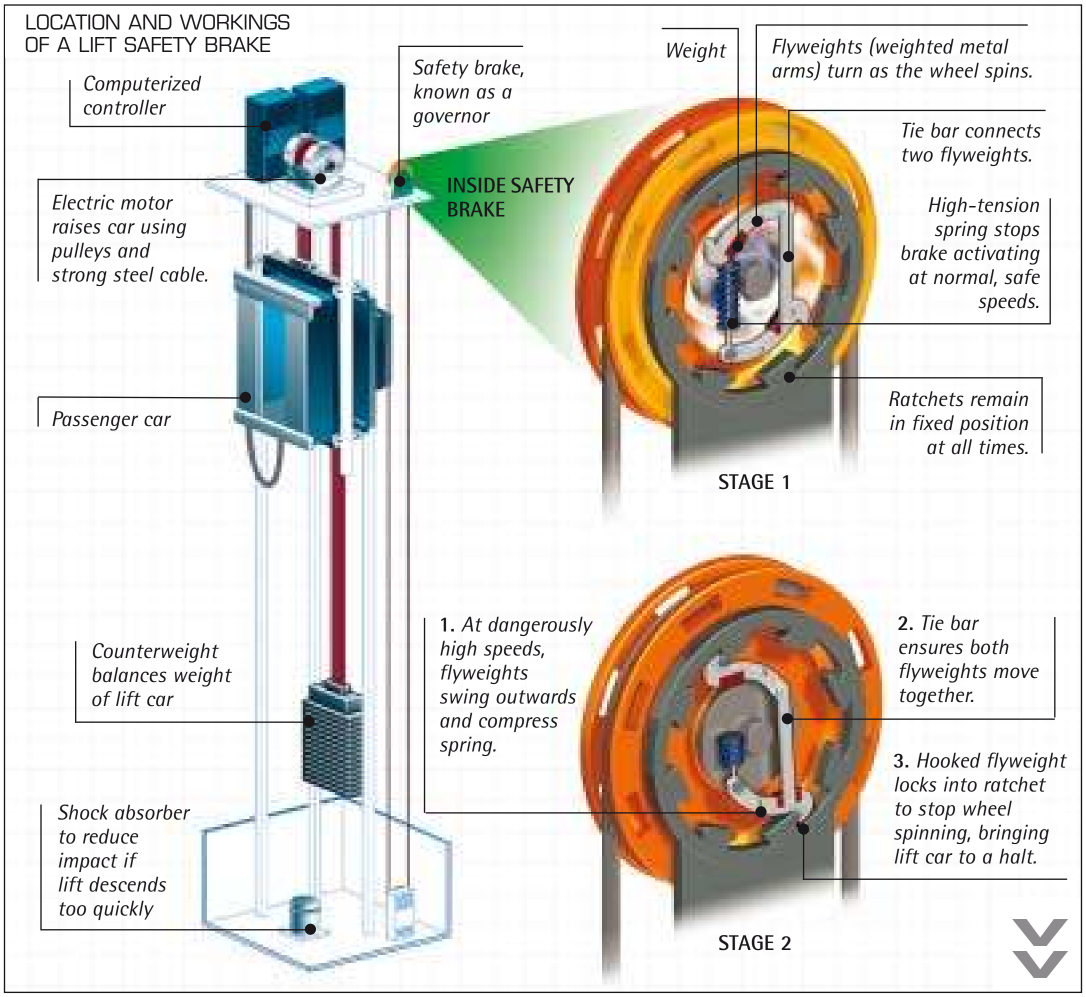
High and low centres of gravity

▲The centre of gravity is a point inside an object through which its whole weight acts. When an object's centre of gravity is directly above its base, it stays upright. If the centre of gravity tips too far to one side, the object falls over. An iBOT™ wheelchair has a balancing mechanism that senses changes in the occupant's position. It makes constant adjustments so the centre of gravity is always safely positioned above the large wheels.

LIFT

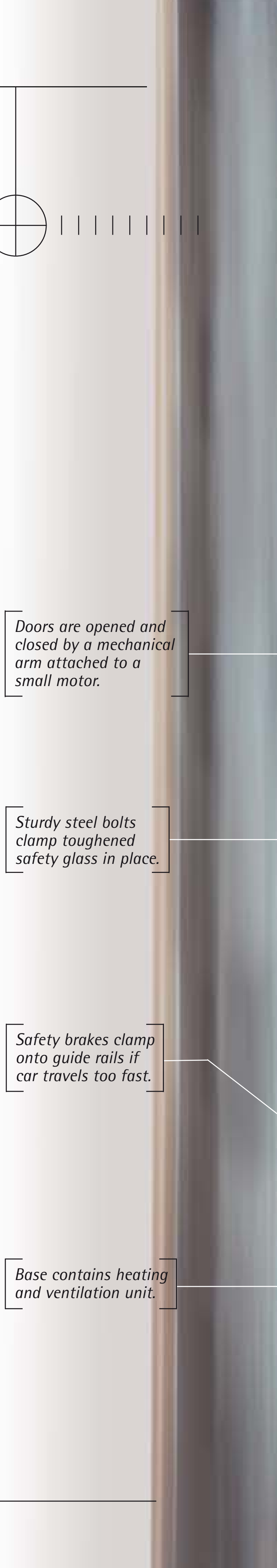
Lifts have helped our tallest city buildings to become skyscrapers. The highest lifts in the world service the Taipei 101 Tower in Taiwan, which is 509 m (1,670 ft) high.

HOW A LIFT WORKS

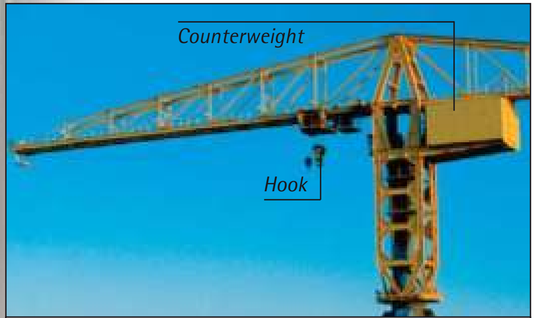


Lifts are designed to move efficiently and safely. A lift's passenger car is hauled along metal guide rails by a cable made from many steel ropes wound together. A secondary cable attaches the car to a safety brake called a governor. This sturdy wheel has two weighted arms inside it that turn as the wheel spins. If the main lift cable snaps, causing the car to plummet, the secondary cable turns the governor very quickly.

As the governor speeds up, the arms are thrown outwards, locking into the wheel. This pulls on the secondary cable, activating brakes that clamp the car safely to its guide rails. Many lifts use computerized controllers, which respond to different patterns of movement throughout the day. They ensure that lifts stop more often at busier floors and that, in the evening rush hour, they stop more frequently on downward journeys.



Counterweights



Counterweight of construction crane

▲ A lift car and its counterweight are connected by cables so that when one goes up, the other goes down. The falling counterweight helps to pull the lift car upwards, so that the lift's electric motor uses much less energy. Counterweights are also used on construction cranes. A huge block of concrete acts as a balance to the heavy load carried by the crane's hook. This prevents the crane from toppling over.

◀ **Compact electric lifts,** such as this one in the Lloyds Building, London, can be fixed to the outside of a building. They are easier to access for maintenance than indoor lifts. They also free up space inside the building and give passengers an interesting view. A typical lift climbs at speeds of up to 110 m (350 ft) per minute.

◀ **Image:** blurred motion photograph of glass lift

◀◀ BACK

American Elisha Graves Otis invented the safety brake in 1853. The first one was installed in a New York department store four years later.

Scientists plan to use nanotechnology to make a space elevator that will haul materials 100,000 km (62,000 miles) up towards the stars.

FORWARD ▶▶

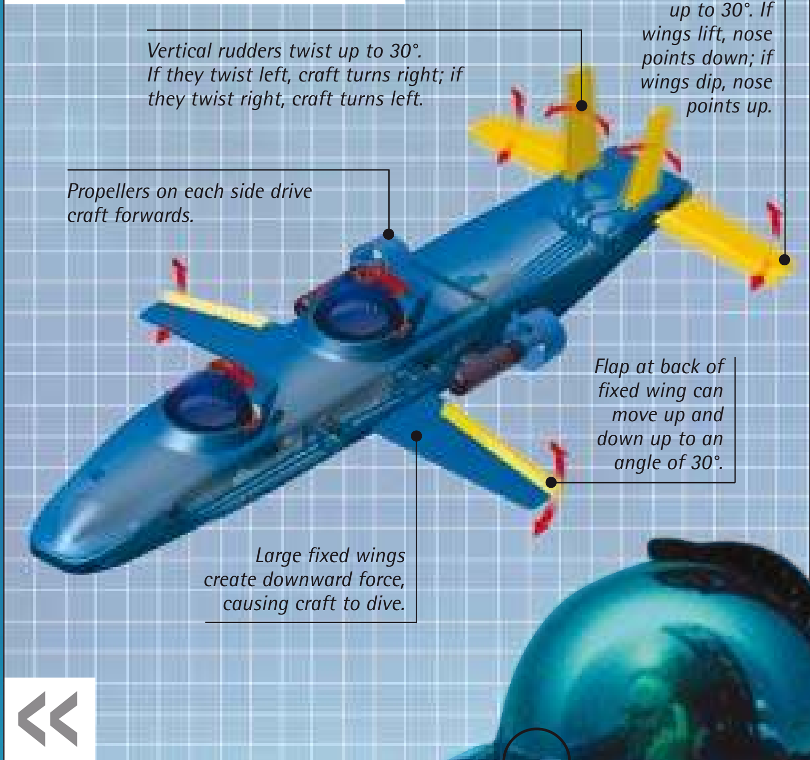
▶▶ See also: Car tower p136

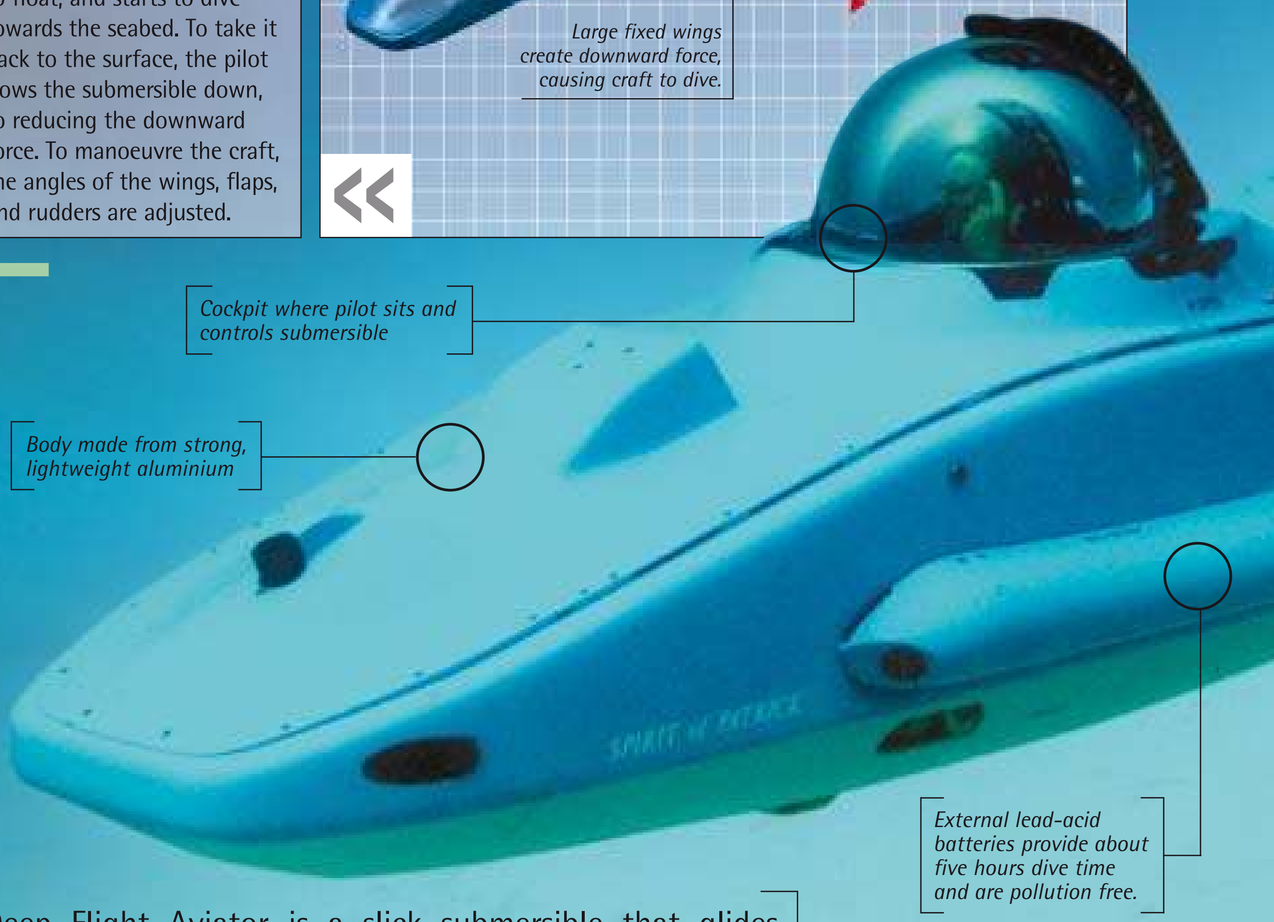
SUBMERSIBLE

HOW DEEP FLIGHT AVIATOR WORKS

Deep Flight Aviator is a submersible (mini-submarine) that literally flies through the water. It is made from very light materials that allow it to float naturally. The craft is powered by batteries, which drive its two propellers to move it through the water. As the submersible travels, water flows over the top and bottom of its large, curved wings at different speeds. The more speed the craft builds up, the more downward force is created by the wings. The craft then begins to overcome its natural tendency to float, and starts to dive towards the seabed. To take it back to the surface, the pilot slows the submersible down, so reducing the downward force. To manoeuvre the craft, the angles of the wings, flaps, and rudders are adjusted.

DEEP FLIGHT AVIATOR'S MANOEUVRABILITY UNDERWATER





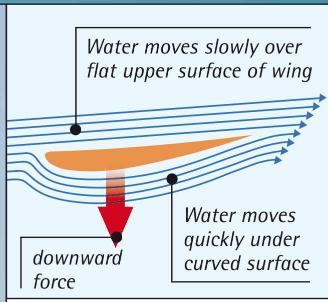
Deep Flight Aviator is a slick submersible that glides through the water. Swift and amazingly agile, it is used to explore the ocean depths and study marine animals.

Moving and diving

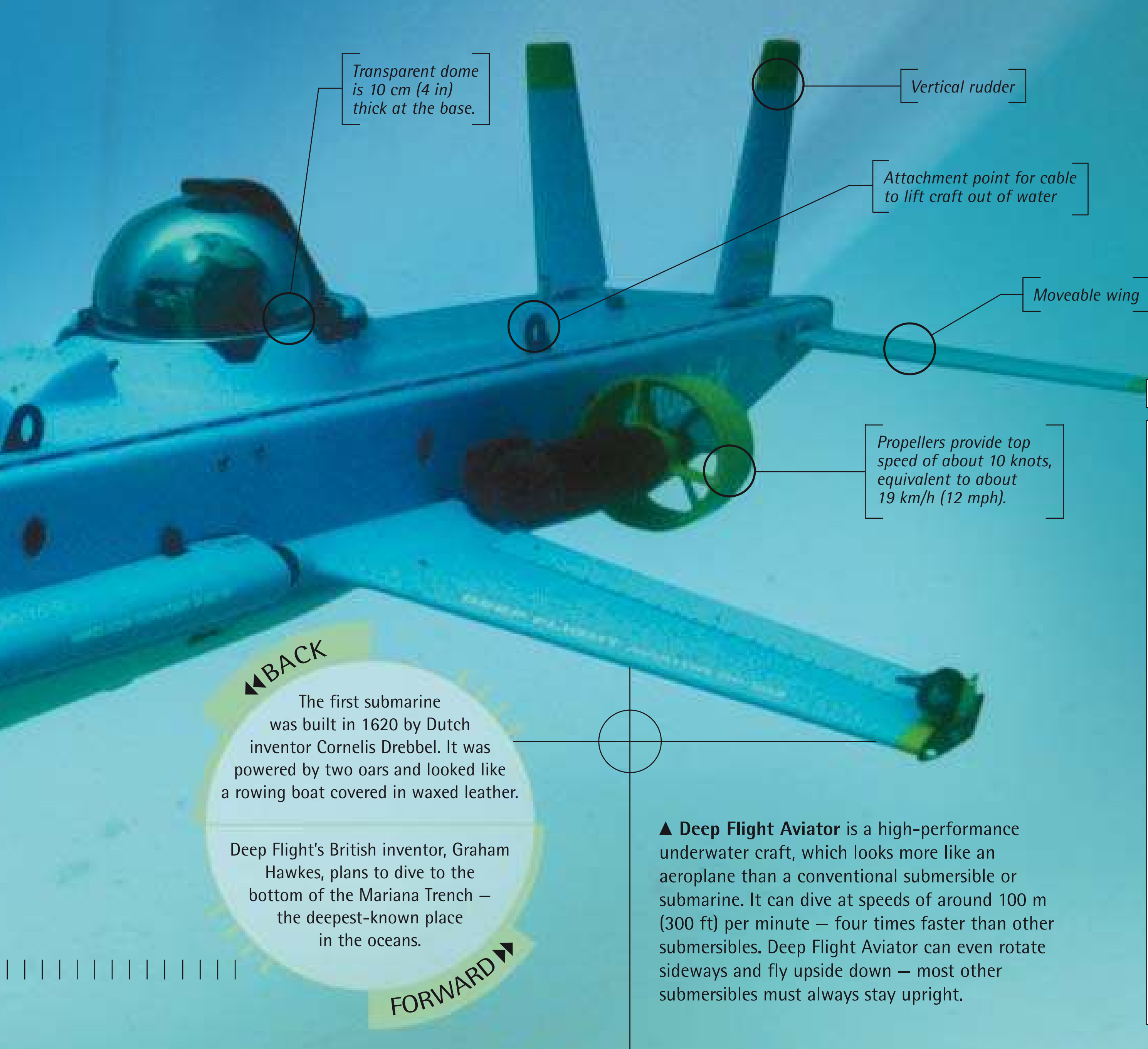
▶ Sharks move through the water in a similar way to Deep Flight Aviator, using their horizontal and vertical fins to manoeuvre. Other fish control their depth with an organ called a swim bladder. These are filled or emptied with gas if the fish needs to move down or up – conventional submarines also work in this way, filling their tanks with water to dive.

Shark moving through water

▶ Deep Flight Aviator's wings are just like an aeroplane's – only upside down. As the submersible speeds up, water moves more quickly beneath the curved bottom surface of the wings than over the flat upper surface. This lowers the pressure under the wings, producing a downward force that causes the craft to dive through the water.



How Deep Flight Aviator dives



◀◀ BACK

The first submarine was built in 1620 by Dutch inventor Cornelis Drebbel. It was powered by two oars and looked like a rowing boat covered in waxed leather.

Deep Flight's British inventor, Graham Hawkes, plans to dive to the bottom of the Mariana Trench – the deepest-known place in the oceans.

FORWARD ▶▶

▲ **Deep Flight Aviator** is a high-performance underwater craft, which looks more like an aeroplane than a conventional submersible or submarine. It can dive at speeds of around 100 m (300 ft) per minute – four times faster than other submersibles. Deep Flight Aviator can even rotate sideways and fly upside down – most other submersibles must always stay upright.

◀ **Image:** underwater photograph of Deep Flight Aviator submersible

▶▶ See also: Aerofoil p240, Jet engine p146, Osprey p144, Wind tunnel p148

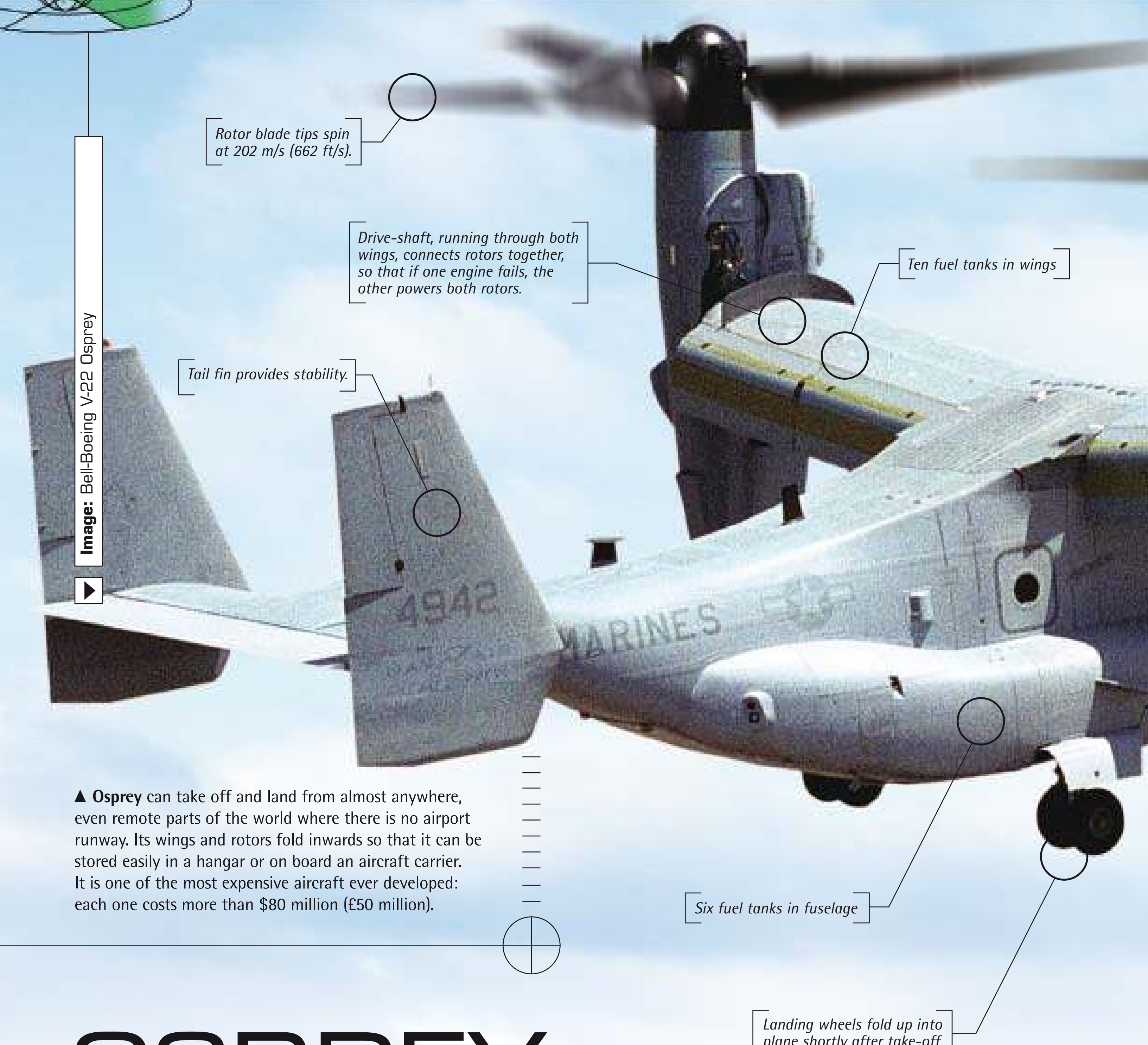
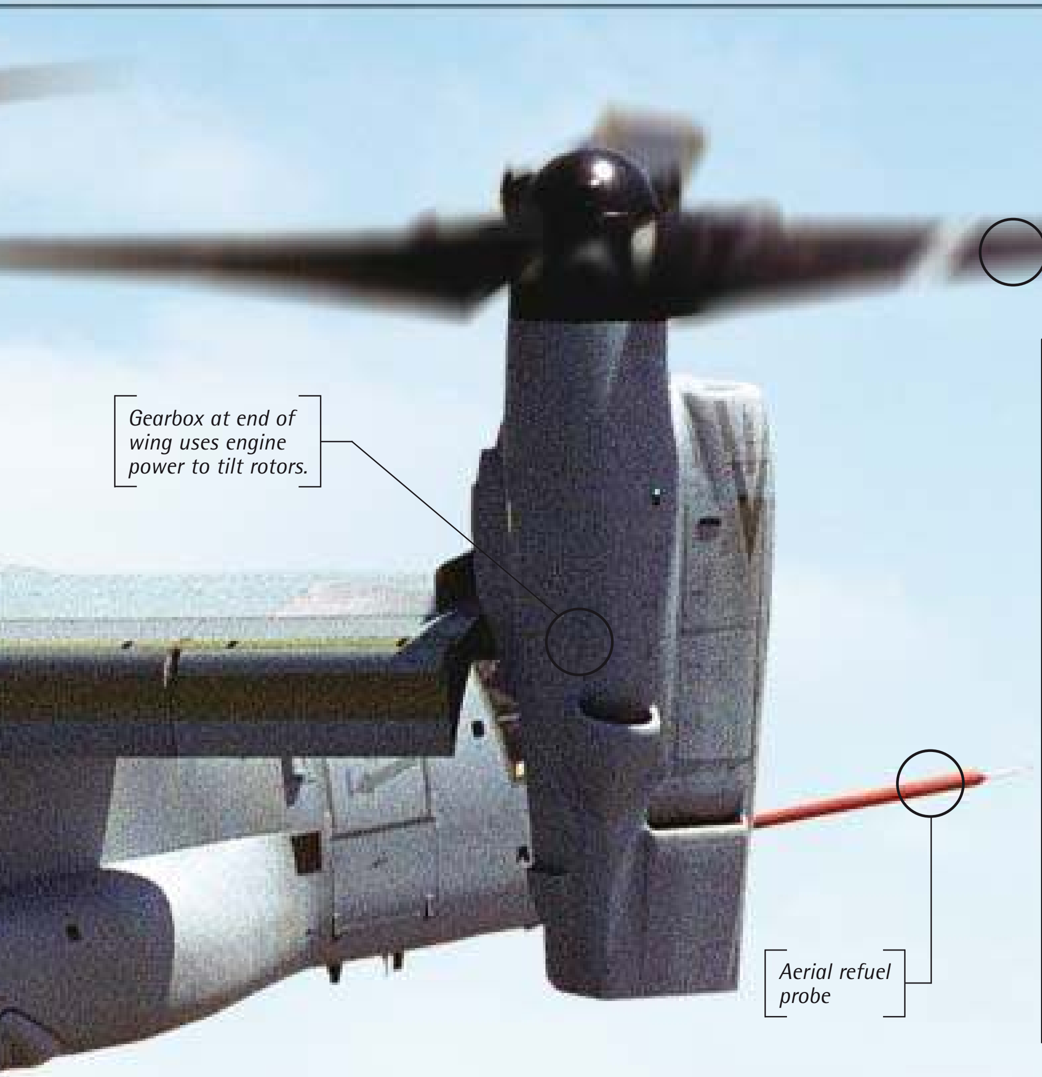


Image: Bell-Boeing V-22 Osprey

▲ **Osprey** can take off and land from almost anywhere, even remote parts of the world where there is no airport runway. Its wings and rotors fold inwards so that it can be stored easily in a hangar or on board an aircraft carrier. It is one of the most expensive aircraft ever developed: each one costs more than $80 million (£50 million).

OSPREY

Is it a helicopter? Is it a plane? The world's most versatile aircraft, the Osprey can switch from a plane to a helicopter in just 12 seconds. Built for the military, it is also used for rescue missions.



The osprey bird

Osprey hovering

▲Like the aircraft, this osprey can use its wings to soar through the air or hover on the spot. But the Osprey aircraft is a more efficient flying machine. The bird's wingspan is 1.5 m (5 ft) and the aircraft's just 20 times wider – but thanks to its powerful rotors, the aircraft can carry 10,000 times more weight.

HOW THE OSPREY WORKS

In helicopter mode, the two rotors spin above the aircraft, allowing it to take off vertically and hover. The rotors have three blades, each one the length of an average family car, made from a mixture of graphite and fibreglass.

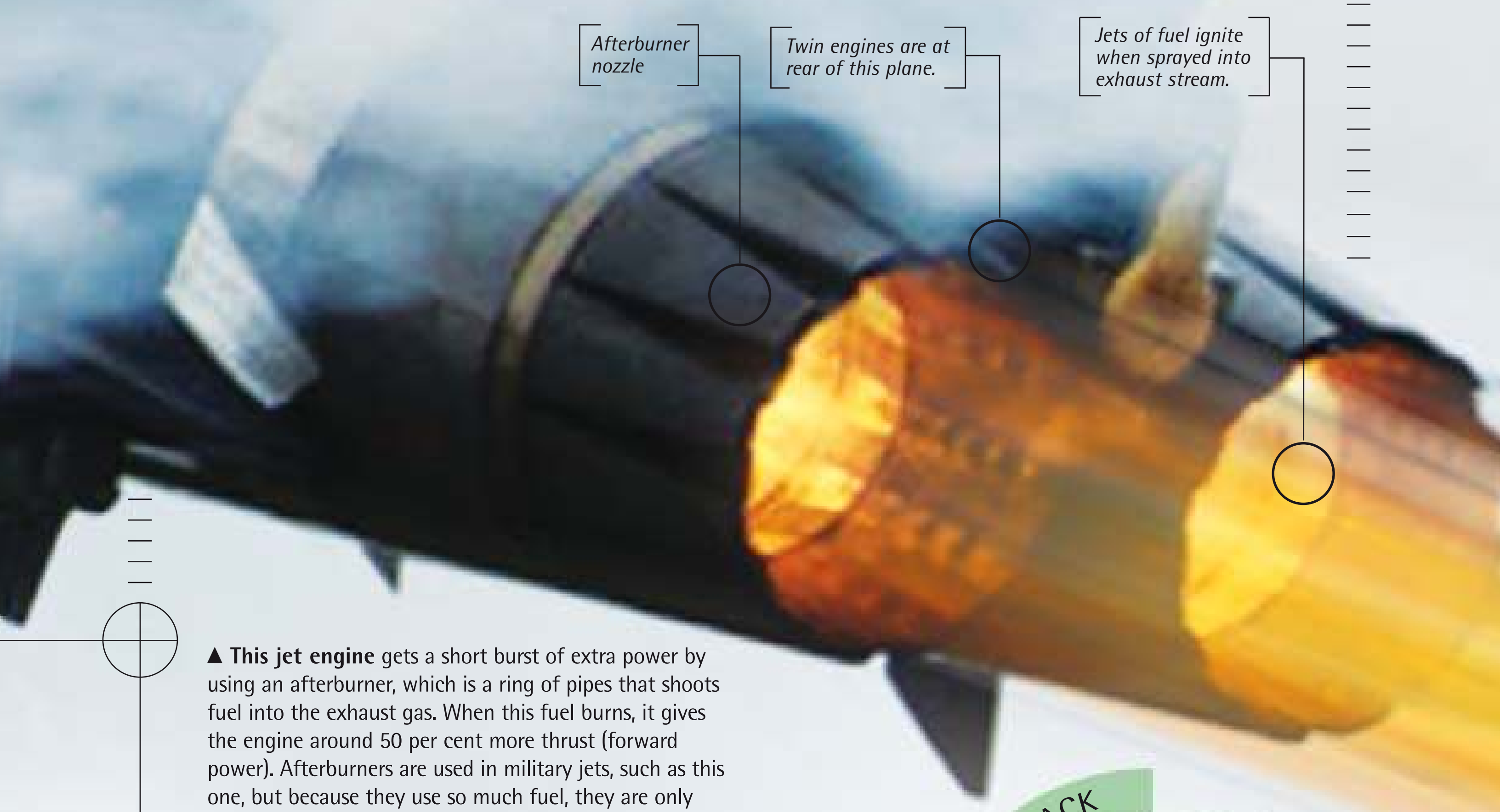
In mid-air, the engines and rotors tilt forwards, converting the Osprey from helicopter to plane. Each wing contains a 6,000 hp engine (about 30 times more powerful than a family car) and a gearbox that powers the rotor and the tilting mechanism.

In aeroplane mode, Osprey's twin engines power it forwards for up to 933 km (580 miles) without refuelling. The Osprey can fly twice as fast as a helicopter, at speeds up to 507 km/h (315 mph), carrying 4,536 kg (10,000 lb) of cargo or 24 passengers.

See also: Aerofoil p240, Black box p150, Jet engine p146

JET ENGINE

Powerful jet engines speed aeroplanes forwards by blasting a fiery jet of fast-moving gas backwards. A large engine can generate as much power as 3,000 cars racing along at top speed.



▲ **This jet engine** gets a short burst of extra power by using an afterburner, which is a ring of pipes that shoots fuel into the exhaust gas. When this fuel burns, it gives the engine around 50 per cent more thrust (forward power). Afterburners are used in military jets, such as this one, but because they use so much fuel, they are only switched on for take-off or to reach supersonic speeds.

Underwater jet propulsion

This octopus moves itself through the ocean by squirting jets of water from its body. This process uses the same physics as a jet engine and is known as action and reaction. As the water squirts one way (action), it propels the octopus in the opposite direction (reaction). This also occurs if you blow up a balloon and then let go of it. Air rushes out, shooting the balloon in the opposite direction.

Octopus propels itself through the water

BACK

British engineer Frank Whittle invented the first jet engine in 1930, but in 1939 the first jet flight used an engine made by his German rival, Hans Pabst von Ohain.

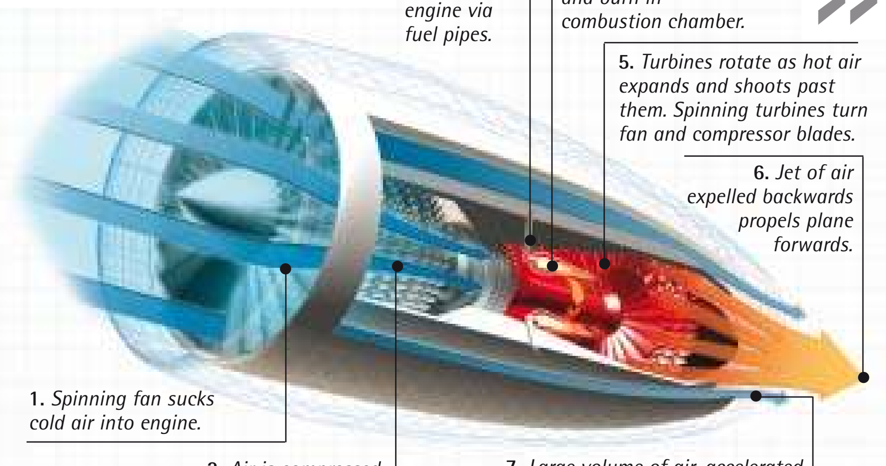
Japanese engineers are developing the SuperSonic Transport (SST) plane. It will carry three times more passengers, travel twice as far, yet be no noisier than a normal jet.

FORWARD

See also: Black box p150, Car engine p130, Laws of motion p248, Wind tunnel p148

HOW A JET ENGINE WORKS

HOW AIR PASSES THROUGH A TURBOFAN JET ENGINE



A jet engine works by compressing, heating, and speeding up the air moving through it. Like a car engine, it uses internal combustion: fuel burns with air in the combustion chamber to produce energy continually.
No spark is needed to ignite the fuel: the fuel-air mixture is compressed so much that it burns spontaneously. The energy produced heats and accelerates the air, which shoots out of the back to power the engine and propel the plane forwards. The most common jet engine is a turbofan.
A spinning fan at the front accelerates five times more air through the engine's outer casing than through its hot core, to produce extra thrust.

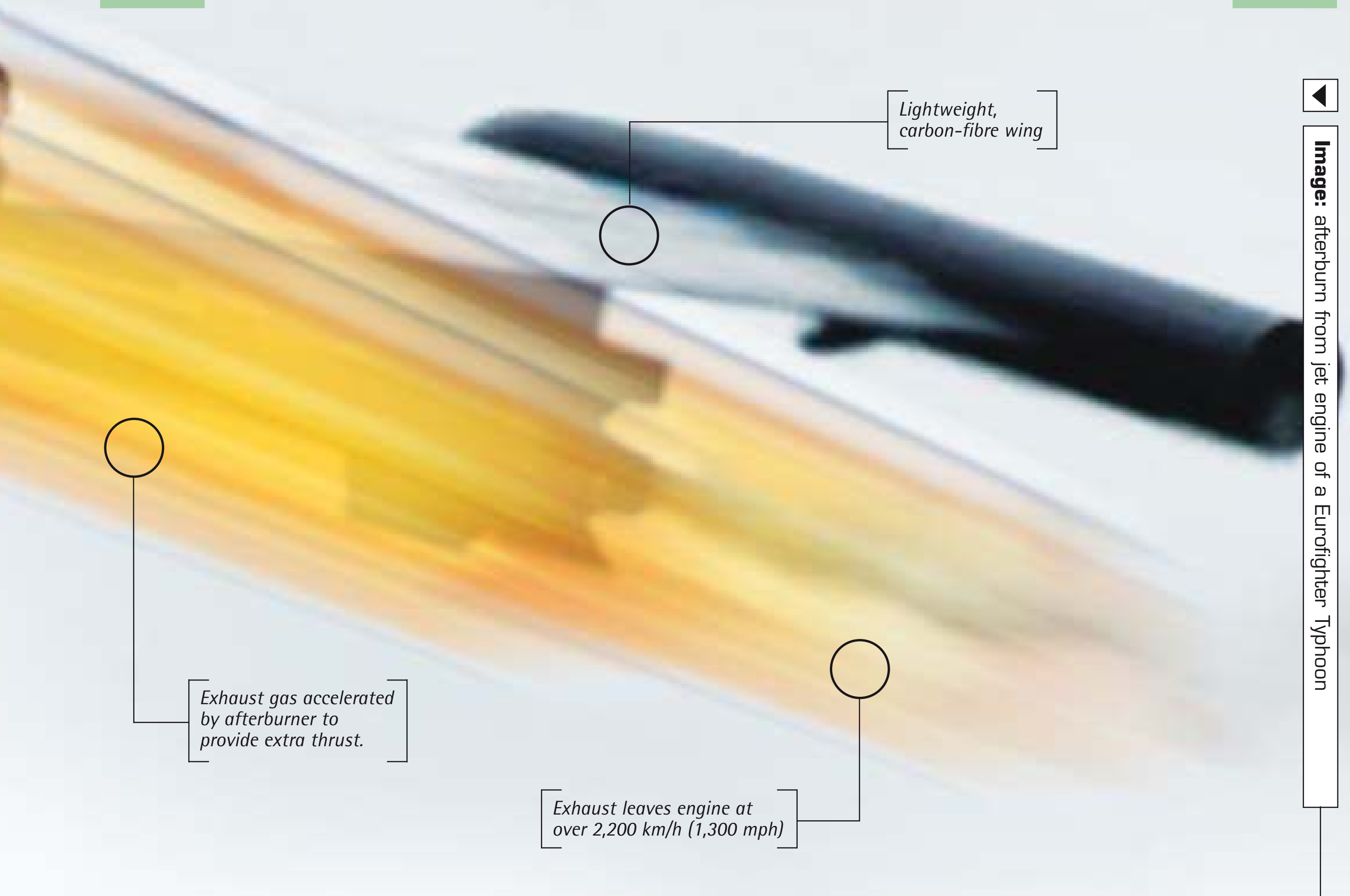


Image: afterburn from jet engine of a Eurofighter Typhoon

WIND TUNNEL

A wind tunnel is a sealed chamber in which aeroplanes are tested with high-speed air. The wind speed in the tunnel can be ten times faster than the speed of sound.

▼ This image shows details of the airflow around a model plane being tested in a wind tunnel. Scientists study how planes react to wind speeds to make sure their structure is robust. As the model plane "flies" at supersonic speeds – faster than the speed of sound – it overtakes the noise made by its own engine and trails shock waves behind it.

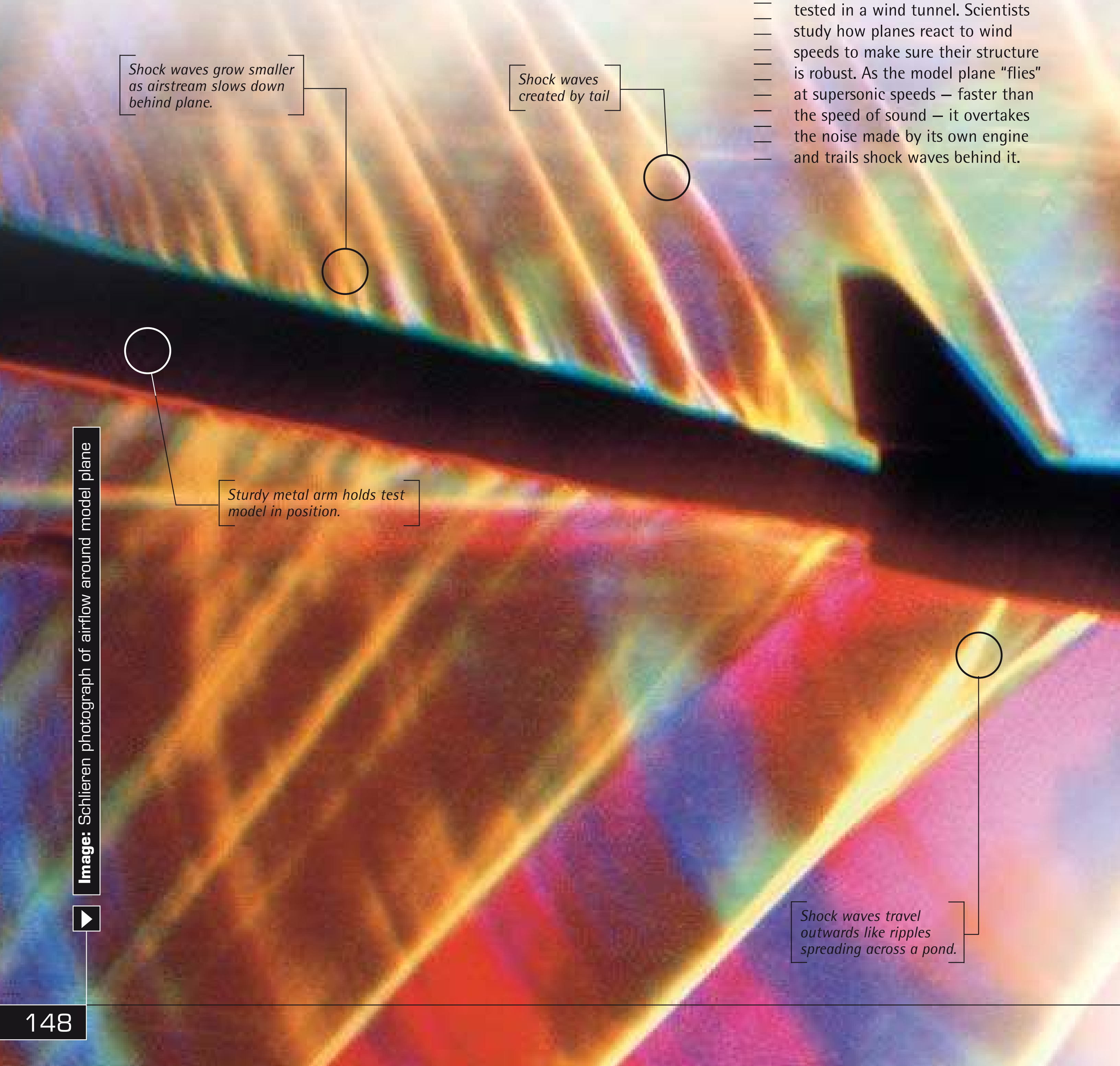
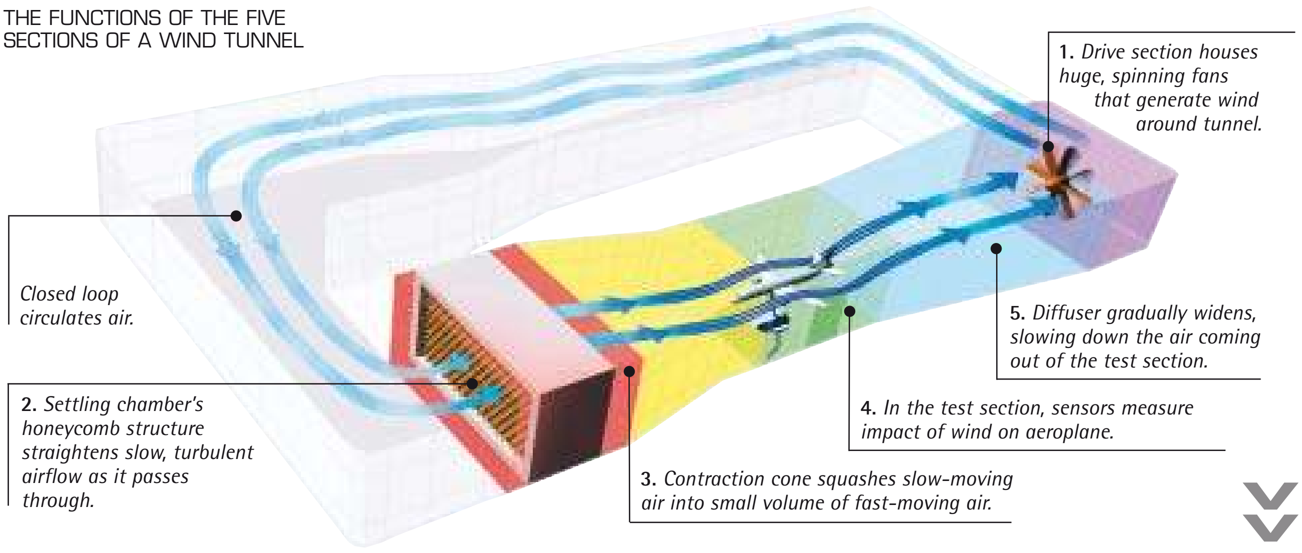


Image: Schlieren photograph of airflow around model plane

▶▶ See also: Aerodynamics p246, Jet engine p146, Space Shuttle p156

HOW A WIND TUNNEL WORKS

THE FUNCTIONS OF THE FIVE SECTIONS OF A WIND TUNNEL



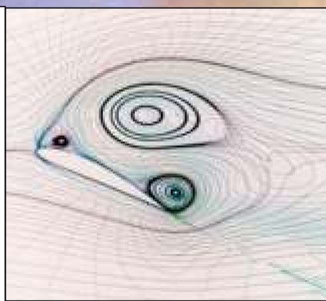
Wind tunnels are used to test how a plane's shape affects its ability to fly. Changes to a plane's design might be made following these tests. Aeroplanes are streamlined to maximize lift – an upward force that overcomes the plane's weight – and minimize drag – air resistance. The more lift and less drag a plane has, the more efficiently it flies, so that it uses less fuel. Wind tunnel tests are expensive, difficult, and can be dangerous. Even a small wind tunnel needs a huge building to generate the airstream. For supersonic tests, air must travel faster than the speed of sound. In a hypersonic test, when the speed is up to ten times faster still, the air can cool so much that it turns into liquid.

Computer modelling air turbulence

▶ Wind tunnel tests are so difficult to carry out that they are gradually being replaced by a technique called computational fluid dynamics (CFD). This involves using a computer model, based on thousands of complex mathematical equations, that can predict every aspect of an aeroplane's behaviour under different flying conditions.

Computer model of plane test

▶ Computer models can explain why an aeroplane suddenly stalls if the wings tilt too far back. At this stall angle, a wing creates two eye-shaped pockets of turbulence behind it. These disrupt the airflow so the wing no longer creates enough lift to keep the plane airborne – and the plane plummets to the ground.

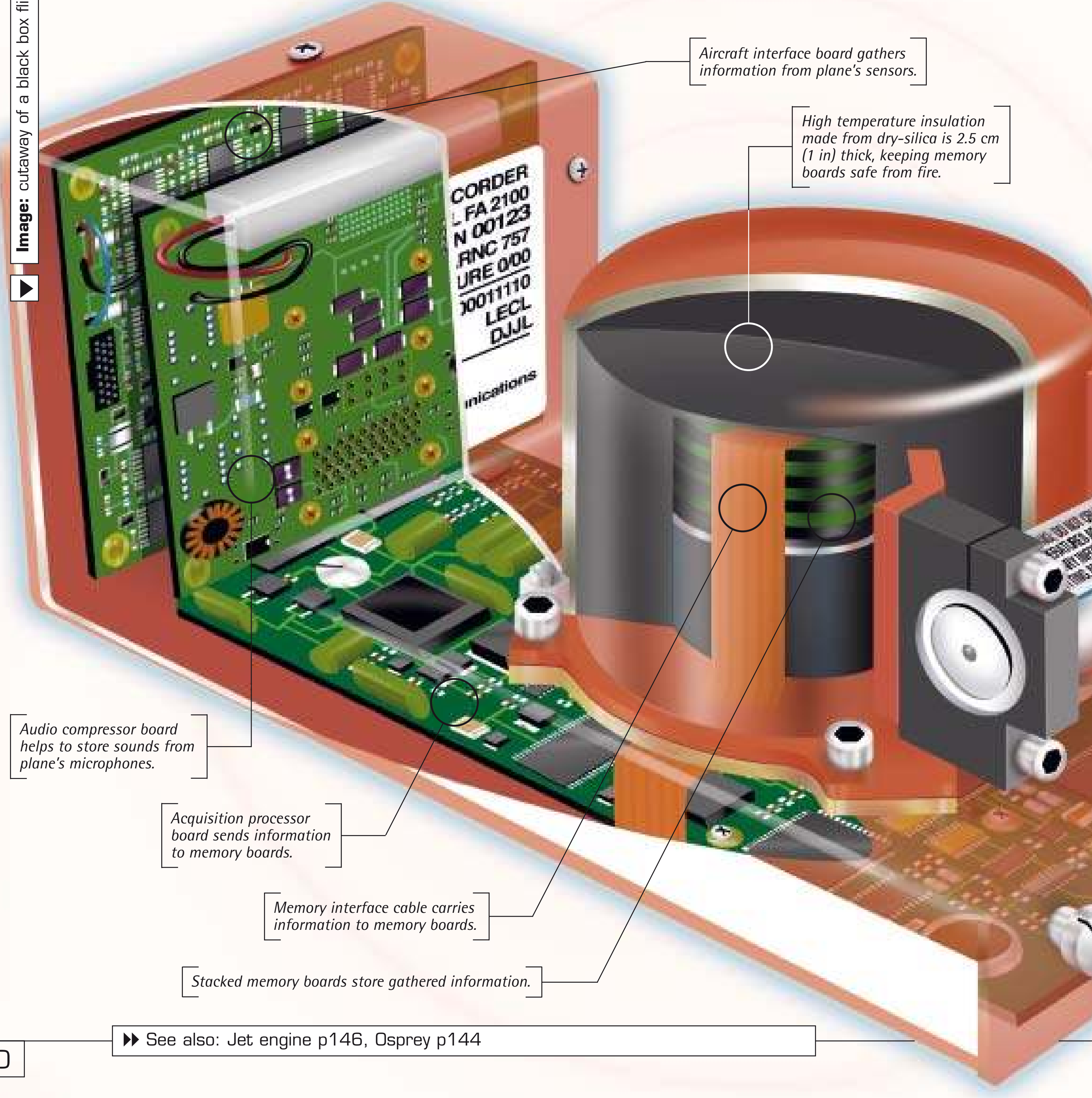


Airflow over wing

BLACK BOX

A black box, or flight data recorder, contains an almost indestructible record of a plane's journey. If a plane crashes, the information stored in the black box can reveal what went wrong.

Image: cutaway of a black box flight recorder

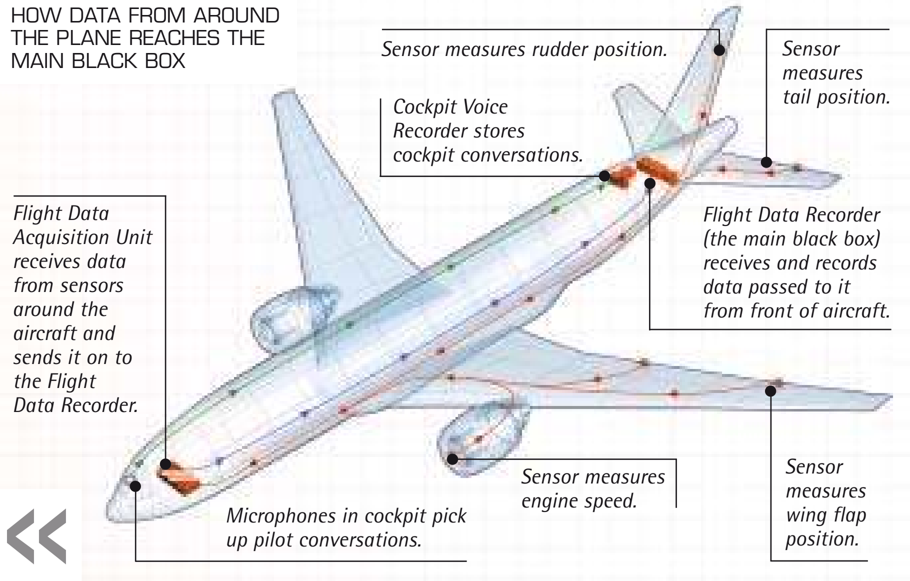


See also: Jet engine p146, Osprey p144

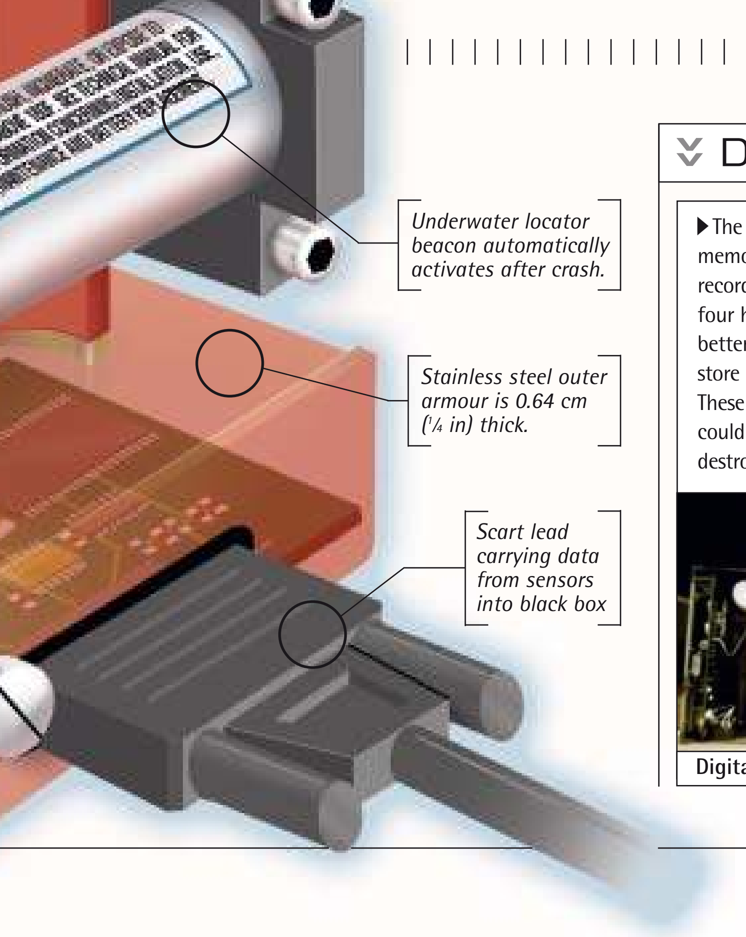
HOW A BLACK BOX WORKS

When an aeroplane crashes at great speed and from a great height, there may be few clues to reveal what went wrong. The black box contains data from instruments, measurements from sensors around the plane, and conversations recorded by microphones in the cockpit. Typically only the tail section of a plane survives the tremendous impact of a crash, so this is where the black box is stored. The box can withstand a 5-tonne weight without crushing and its automatic underwater beacon will send out a beeping signal for at least six years.

HOW DATA FROM AROUND THE PLANE REACHES THE MAIN BLACK BOX



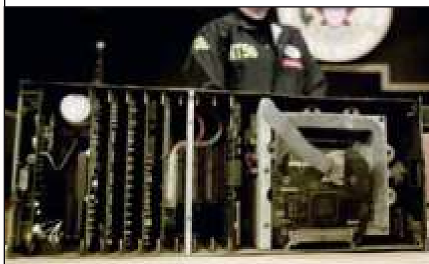
◀ **A black box** is housed in a sturdy metal box designed to withstand a plane crash and the fire that often follows. In spite of its name, it is usually coloured red to make it easier to find among the wreckage. It also has a signal transmitter so it can be located underwater.



Data recovery

▶ The first black boxes, called flight memories, were little more than tape recorders that continuously stored up to four hours of flight data. During the 1970s, better black boxes were designed that could store more data on wider magnetic tape. These boxes still had moving parts that could go wrong and the tape was sometimes destroyed in the inferno following a crash.


Early black box after crash


Digital flight data recorder

◀ The latest black boxes are made from electronic circuitry and have no magnetic tape or moving parts at all. Around 300 different measurements are stored in digital form on memory boards, much like those in a computer. They can hold two hours of audio data and 25 hours of flight data, storing over seven times more than the old magnetic tape recorders.

ROUTES

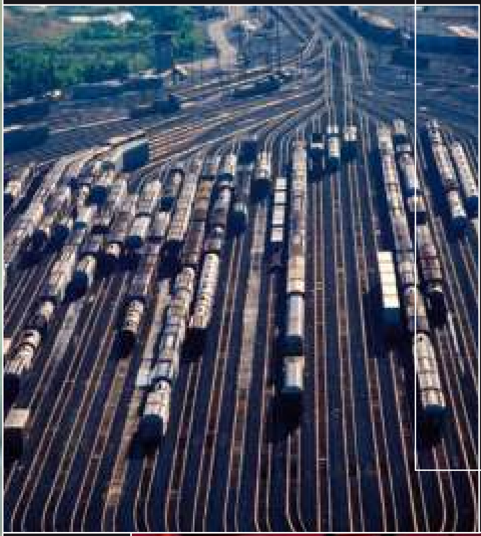
Pedestrians

Escalators can transport huge numbers of people underground, up and down steep hills, and within tall buildings. This escalator is in the 12-storey Lloyds building in London. The world's longest is the Central–Mid-Levels Escalator and Walkway System in Hong Kong. Used by 50,000 people daily, its 20 reversible escalators stretch 0.8 km (0.5 miles).

Road networks

To handle increased traffic and cope with limited land space, engineers have designed flyovers. These raised roads are made up of many loops of tarmac, criss-crossing each other on different levels. Each raised section needs to withstand the strain of thousands of vehicles every day, often for many decades.

Transport methods have become more sophisticated as travel becomes easier, cheaper, safer, and more extensive. To move cargo and people, complicated networks have grown rapidly on land, sea, and in air.



Rail

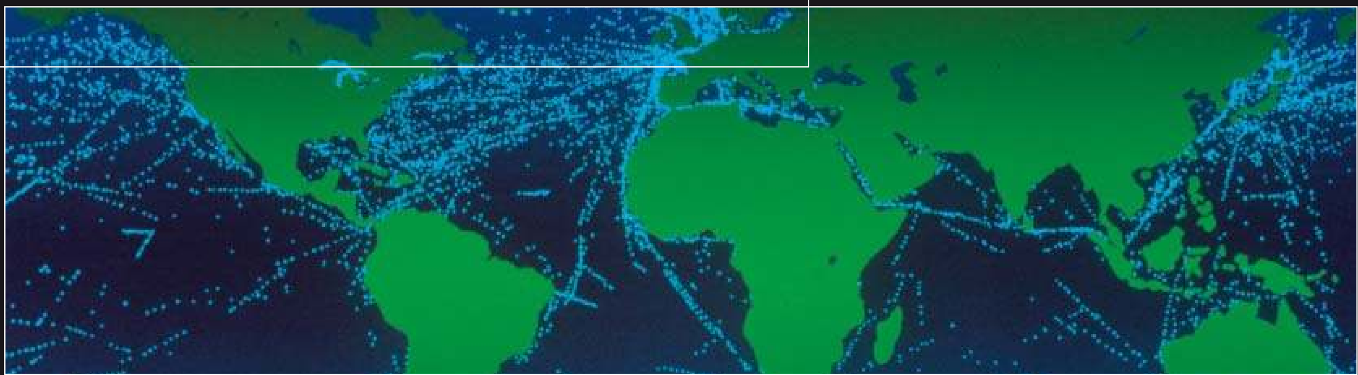
There are more than 1,100,000 km (700,000 miles) of railway lines in the world today. A complicated system of signals controls which tracks trains travel along, and also provides information about each route to prevent accidents and delays. The world's fastest passenger trains, in China, reach speeds of 431 km/h (268 mph).

Air networks

To avoid plane delays and mid-air collisions, airports use sophisticated equipment to control the landing and take-off of air traffic. Computers and radar systems also monitor sky traffic by tracking the flight paths that aircraft follow.

Water

Large commercial ships cannot travel freely throughout the oceans. They must follow designated shipping routes, seen as pale blue lines in this satellite image. Shipping lanes guide vessels along safe routes in deep water, keeping them away from coasts, reefs, and other hazards.



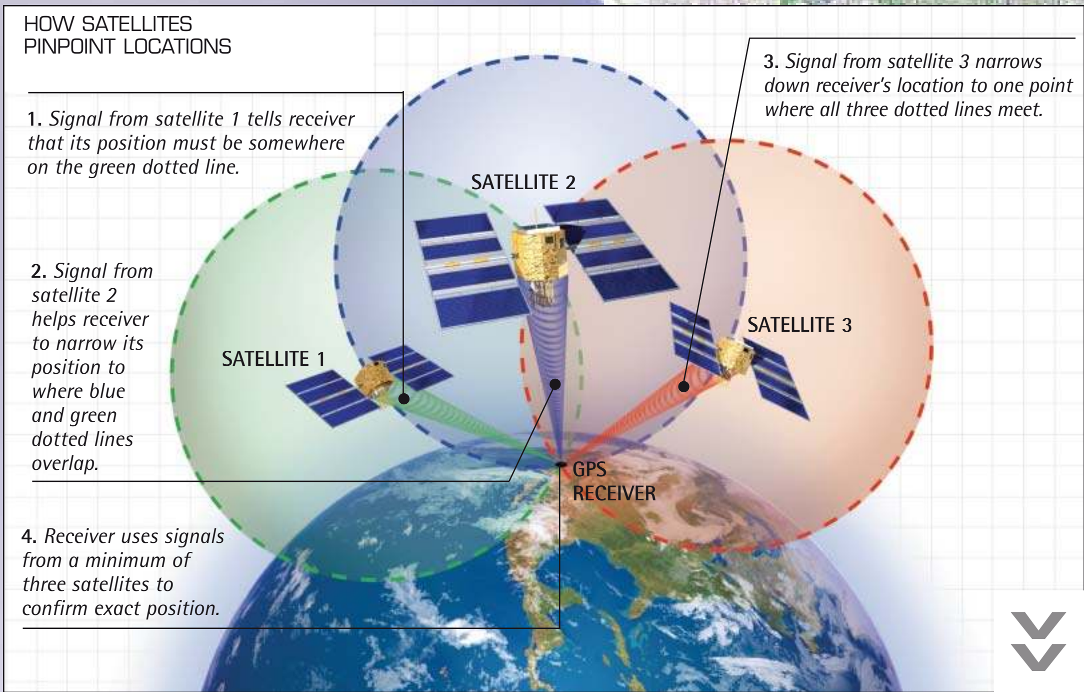
See also: Black box p150, Doppler radar p194

NAVIGATION

Satellites, orbiting the world thousands of kilometres away, can help people pinpoint their exact position on Earth, whether they are scaling mountains, crossing vast oceans, or trekking through jungles.

1. Satellite navigation uses signals from space to locate objects and places on Earth exactly. The best-known type of satellite navigation, Global Positioning System (GPS), uses a network of 24 satellites orbiting Earth, which feed signals to a control centre in the USA to identify precise locations anywhere in the world.

HOW SATELLITE NAVIGATION WORKS



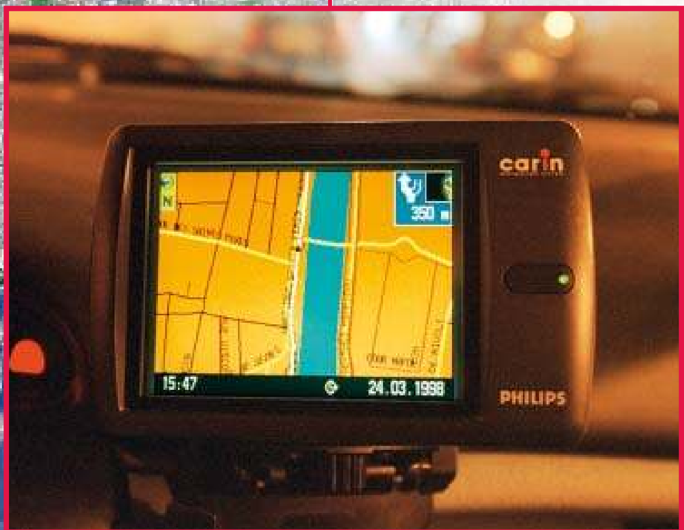
Navigation involves measuring your distance from landmarks, but satellite navigation (Sat-Nav) uses space satellites instead. Wherever you are on Earth, if you have a Sat-Nav receiver it will pick up signals from orbiting navigation satellites. Although the satellites move, their exact positions are known. Each satellite beams this information out in all directions. Using signals from three different satellites, a receiver can pinpoint its own position. With a fourth signal, it can also work out its altitude (height) above Earth's surface.

Satellite navigation can be used in many different ways. For example, a talking headset that uses satellite navigation has been developed to help blind people find their way around unfamiliar places. Parents can keep a watchful eye on their children with a special wristwatch that has a built-in satellite receiver. Some farmers use satellite navigation in their tractors to help calculate the exact areas of land that need fertilizers or pesticides, so they can reduce the amount of spray used.

See also: GPS p245, Mobile phone p18, Satellite p42, Toys p26

Image: satellite photograph of Los Angeles, USA

2. Most satellite navigation systems are accurate to within a few streets – or about 12 m (40 ft). This image zooms in on a detailed area of a city. The US military uses a satellite navigation system that is accurate to within 5 cm (2 in). It was originally developed so that they could guide their ships, planes, and missiles with pinpoint precision.



3. This screen is in a car and it displays a map, which helps the driver follow a route. It shows roads, geographical features, and also has a digital compass. The information relayed to a satellite receiver can be presented in different ways, depending on what is most helpful at the time. At sea, a receiver displays co-ordinates of latitude and longitude to indicate the position of a boat or ship.

SPACE SHUTTLE

The reusable Space Shuttle roars into space using rocket power, but flies back to Earth as gently as a glider. Since the first Space Shuttle *Columbia* took off in 1981, five Space Shuttles have completed more than 100 successful missions.

The Space Shuttle is designed to carry cargo and to be reused at least 100 times. Behind the cockpit is a huge payload bay for carrying equipment, such as satellites, into space. On this 1995 mission, STS-71, the shuttle *Atlantis* used a specially constructed module to dock with the Russian space station, *Mir*. It also carried spare parts that *Mir* needed for vital repairs.

BACK

Before the Space Shuttle was built, most astronauts used to return to Earth in a capsule that splash-landed into the sea.

Space Shuttles of the future will have much bigger engines. They will not need separate external booster rockets, so they will be less expensive.

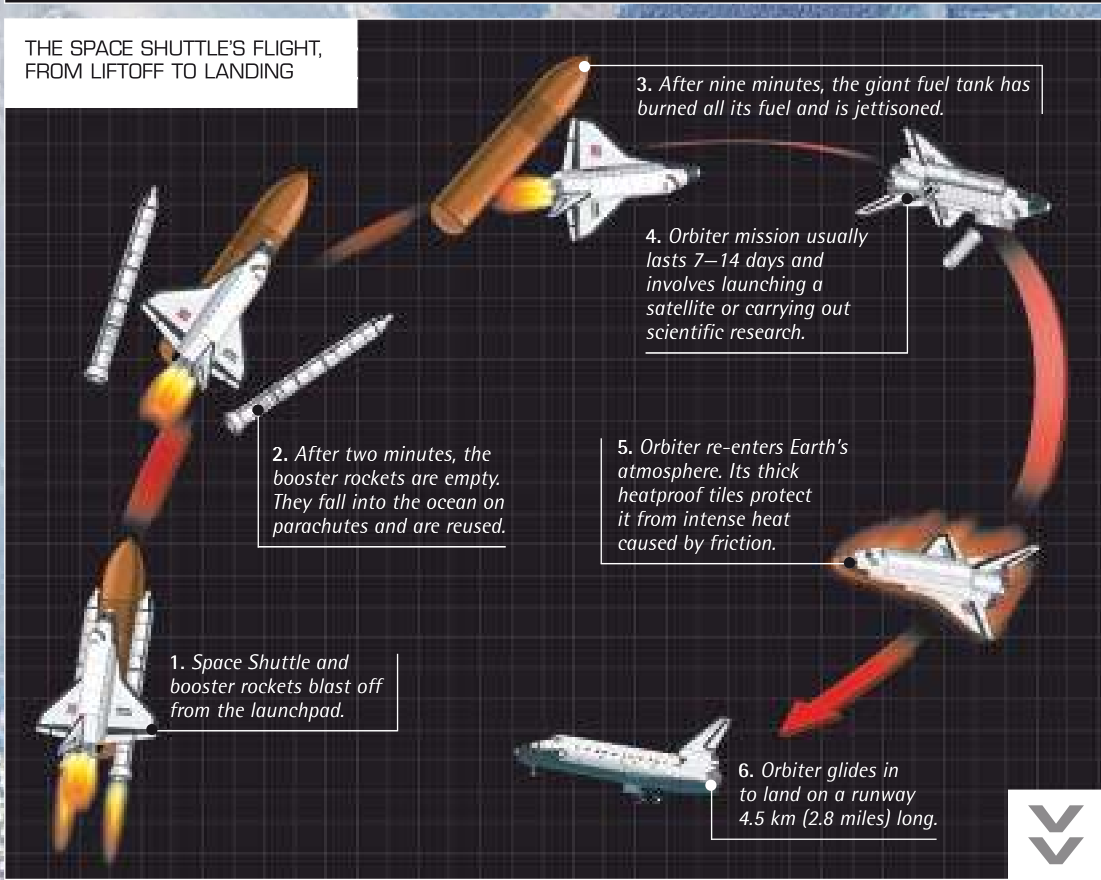
FORWARD

Image: aerial view of Space Shuttle *Atlantis* in space

See also: Parts p132, Satellite p42

HOW THE SPACE SHUTTLE WORKS

THE SPACE SHUTTLE'S FLIGHT, FROM LIFTOFF TO LANDING



The orbiter is the plane-like, main part of the Space Shuttle, which goes into space and returns again. It can carry a crew of up to seven people, including a pilot and mission specialists, such as scientists, who conduct experiments. At liftoff, three engines on the orbiter burn liquid fuel from the huge brown tank underneath. To reach its orbit, the shuttle uses two of its built-in engines – the orbital manoeuvring system engines (OMS). These also help to change the position and speed of orbit.

When returning to Earth, the orbiter slows down by turning around and firing the OMS engines in the opposite direction to the flight direction. Then, the craft turns over so that the nose and upper side, where the heatproof tiles are located, hit Earth's upper atmosphere first. Once in the air, the engines are no longer used and the shuttle glides back to Earth. It is travelling at 320 km/h (200 mph) as it comes in to land: a giant parachute brings it to rest on a long runway.

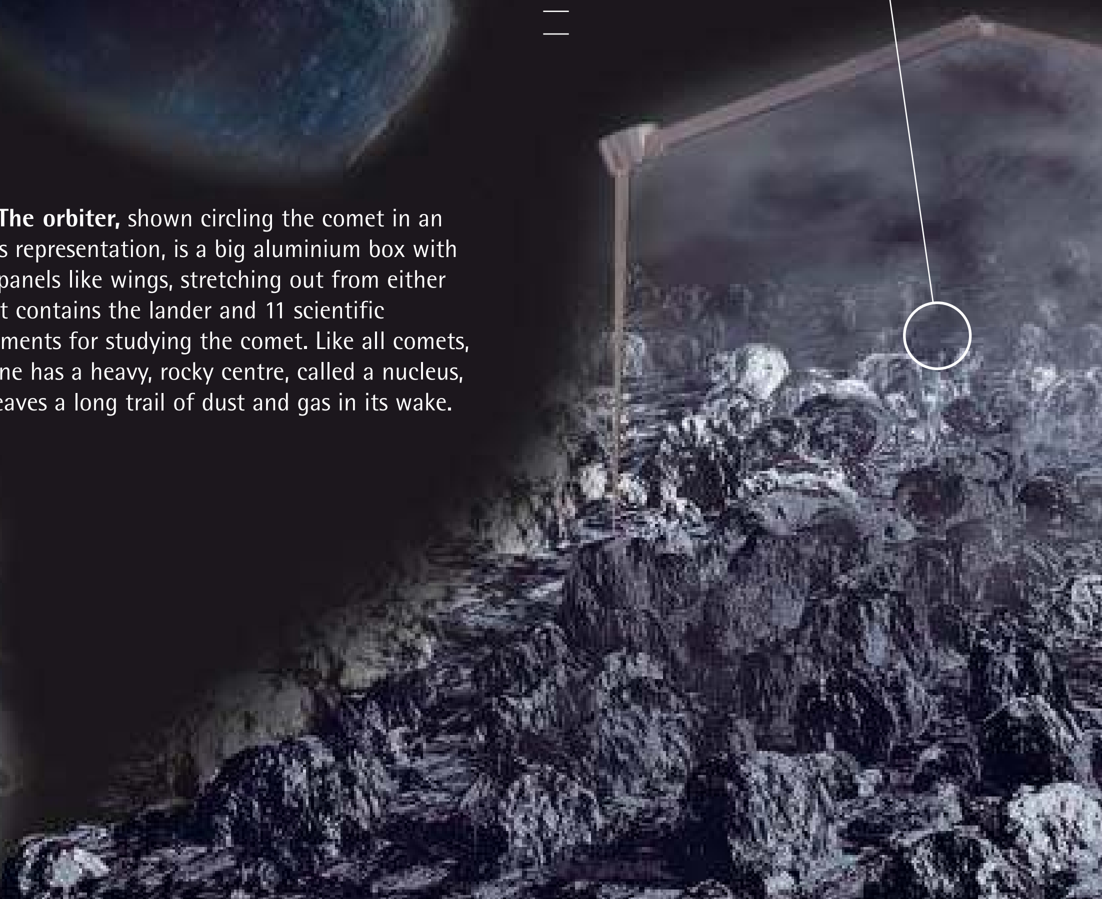
SPACE PROBE

In a ten-year cosmic adventure, the European space probe Rosetta will chase a comet through space at speeds up to 135,000 km/h (84,000 mph). Rosetta's lander will finally touch down on the comet's surface in 2014.

▼ **1. The Rosetta** orbiter blasted off from French Guiana on top of this European Ariane 5 rocket in February 2004. It will finally reach its target, Comet 67P/Churyumov-Gerasimenko, after a hazardous ten-year journey across the Solar System. The main Rosetta craft (the orbiter) will then send a smaller craft (the lander) down to the comet's surface.

▼ **3. Rosetta** will be the first spacecraft ever to study the nucleus (rocky centre) of a comet. The orbiter will send down its lander to the comet's surface in November 2014. The lander will carry out scientific experiments to reveal the comet's chemical and physical composition, as well as its magnetic and electrical properties.

Comet thought to be made from carbon, hydrogen, oxygen, and nitrogen.



▲ **2. The orbiter,** shown circling the comet in an artist's representation, is a big aluminium box with solar panels like wings, stretching out from either side. It contains the lander and 11 scientific instruments for studying the comet. Like all comets, this one has a heavy, rocky centre, called a nucleus, and leaves a long trail of dust and gas in its wake.

See also: Gravity p245, Satellite p42, Space Shuttle p156

HOW THE SPACE PROBE WORKS

Comet 67P/Churyumov-Gerasimenko orbits the Sun once every 6.6 years at up to 857 million km (532 million miles) away. No rocket has enough power to send Rosetta this far, so it gains the energy it needs by using the gravity of planets it passes on the way. It travels far enough from each planet not to be pulled into orbit around it. Instead, it is swept along by the planet's gravity and thrown onwards at a higher speed. Each planet gives Rosetta a boost that sends it into larger and larger orbits around the Sun until it reaches the path of the comet.

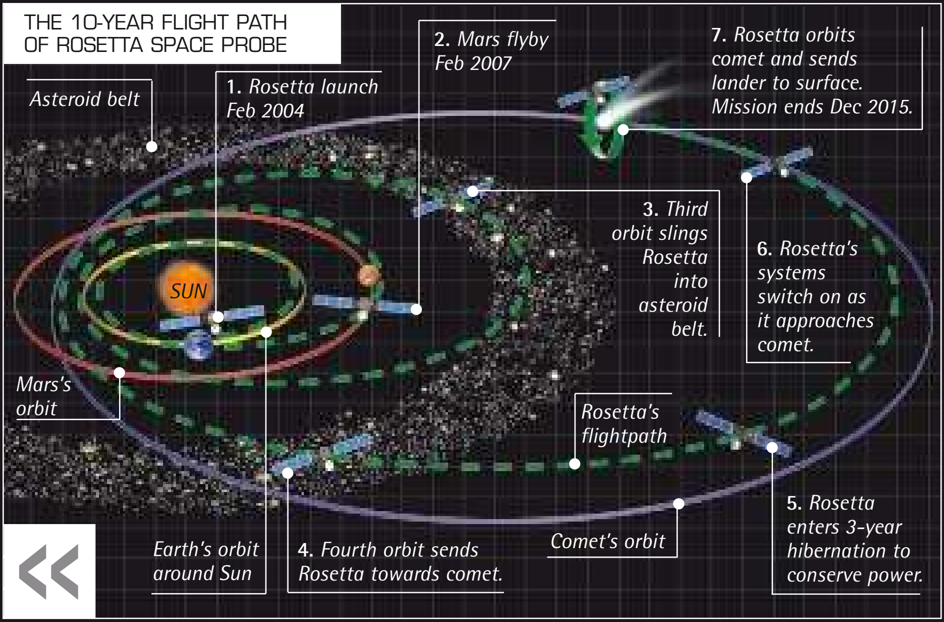


Image: artist's representation of Rosetta's lander on comet surface

Today, we travel further, faster, and more frequently than ever before. With so many people on the move, both on land and in the air, one of the big challenges for the 21st century is developing the technology to manage our overloaded transport systems.

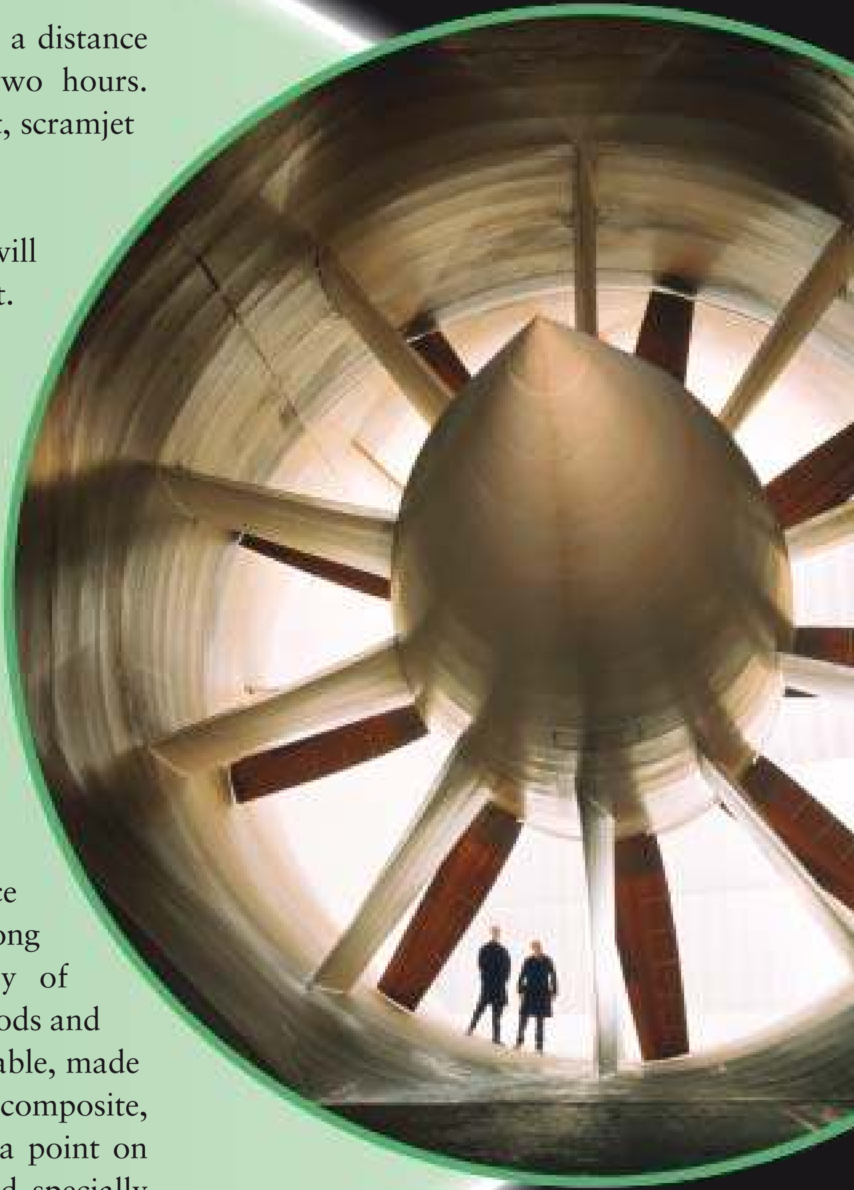
Traffic management systems are going to become more important. By 2010 most drivers will rely on in-car satellite systems to guide them around our cities, and direct them to routes where traffic is lowest. These guidances systems may become so intelligent that they will even be driving the cars themselves while we sit back and watch a movie, work, or talk on the phone. Trains will communicate continually with centralized railway computers that can co-ordinate whole networks, and air traffic control developments will use technology-enabling planes to talk directly to computers on the ground.

> “Undersea wonders, such as the wreck of the Titanic, deep sea vents, and even lost cities, will become tourist destinations.”

If current trends continue, by 2020 more than two billion journeys will be made by air annually. To meet this demand, new types of aircraft are being designed, simulated on computers, and tested in wind tunnels. Twin-deck super-jumbos, such as the Airbus A380, will be common within the next few years. These huge airliners will be able to carry more than 500 people. Further into the future, air taxis that can take off and land on tiny runways in city centres will ferry people to and from work, much as ordinary taxis do now. New propulsion technologies have already enabled development of the scramjet, or Supersonic Combustion Ramjet. The scramjet is as powerful as a rocket but flies inside the Earth’s atmosphere rather than in space. This technology may lead to the development of passenger aircraft that can travel from London to Sydney, a distance of 16,984 km (10,553 miles), in less than two hours. Researchers predict that with more development, scramjet speeds could reach 15 times the speed of sound.

The largely unchartered depths of the oceans will be seen as the last true wilderness on our planet. Undersea wonders such as the wreck of the Titanic, deep sea vents, and possibly even lost cities, will become tourist destinations. Paying passengers will fund ocean research and exploration, which will be carried out by a new generation of small, agile submersibles like Deep Flight Aviator.

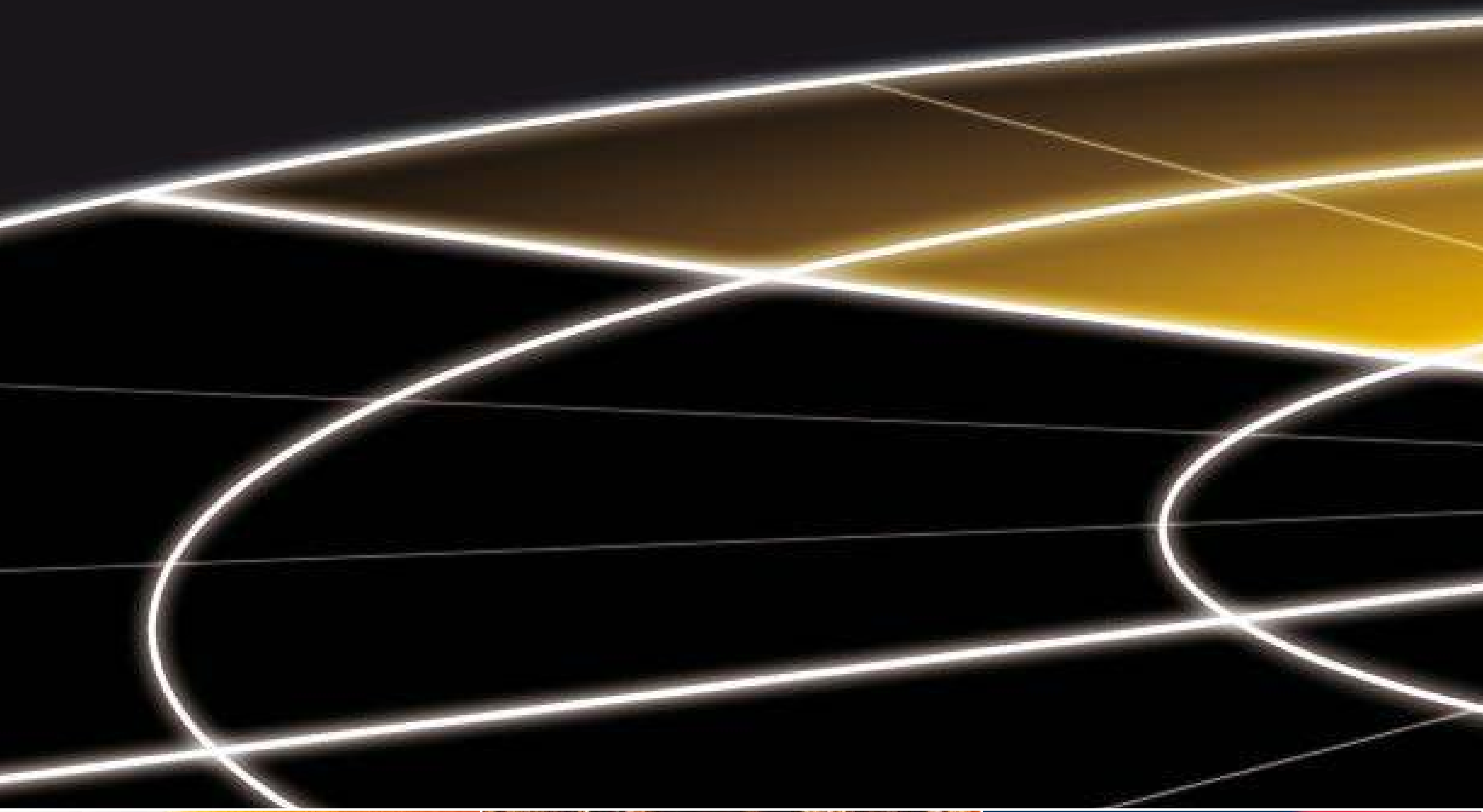
Space is set to become a travel destination too. The kind of experience previously available only to astronauts is already within reach of the very wealthy, and it will become cheaper. Tickets will be sold on passenger planes that can travel into space. But flights into space are very damaging to the atmosphere, so in the long run scientists are considering the possibility of constructing a space elevator in order to ferry goods and passengers in and out of orbit. A super-strong cable, made from a material called a carbon nano-tube composite, would connect the elevator from a satellite to a point on Earth near to the equator – probably an island specially constructed for the purpose.

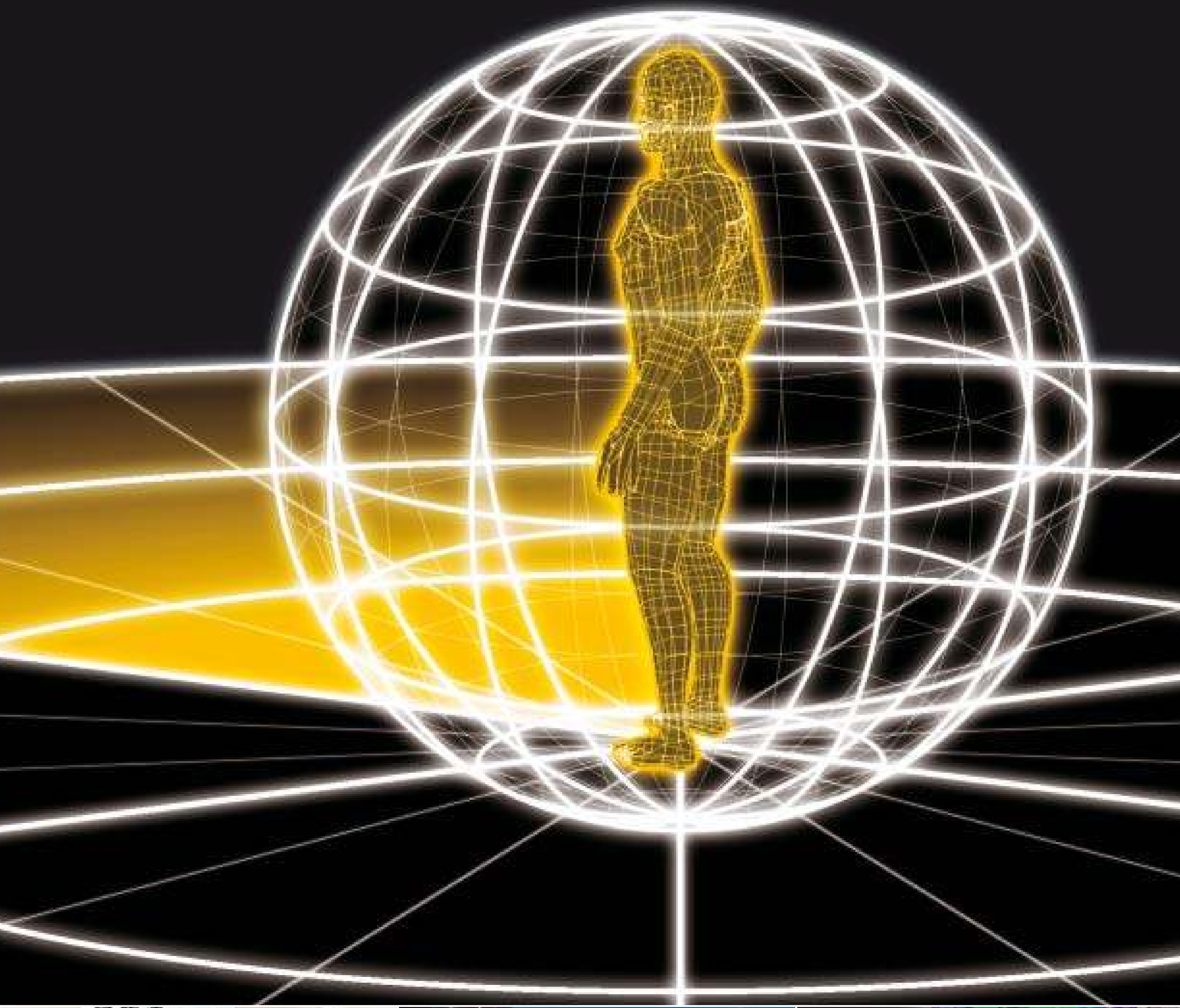


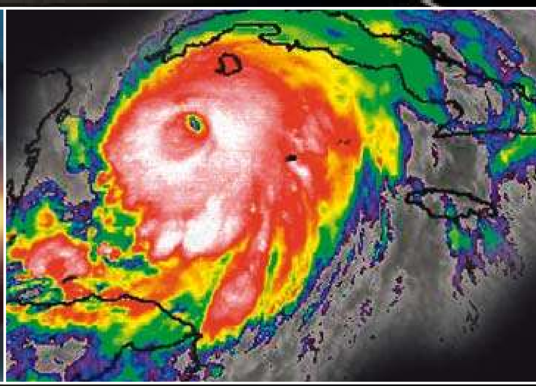
WIND TUNNEL

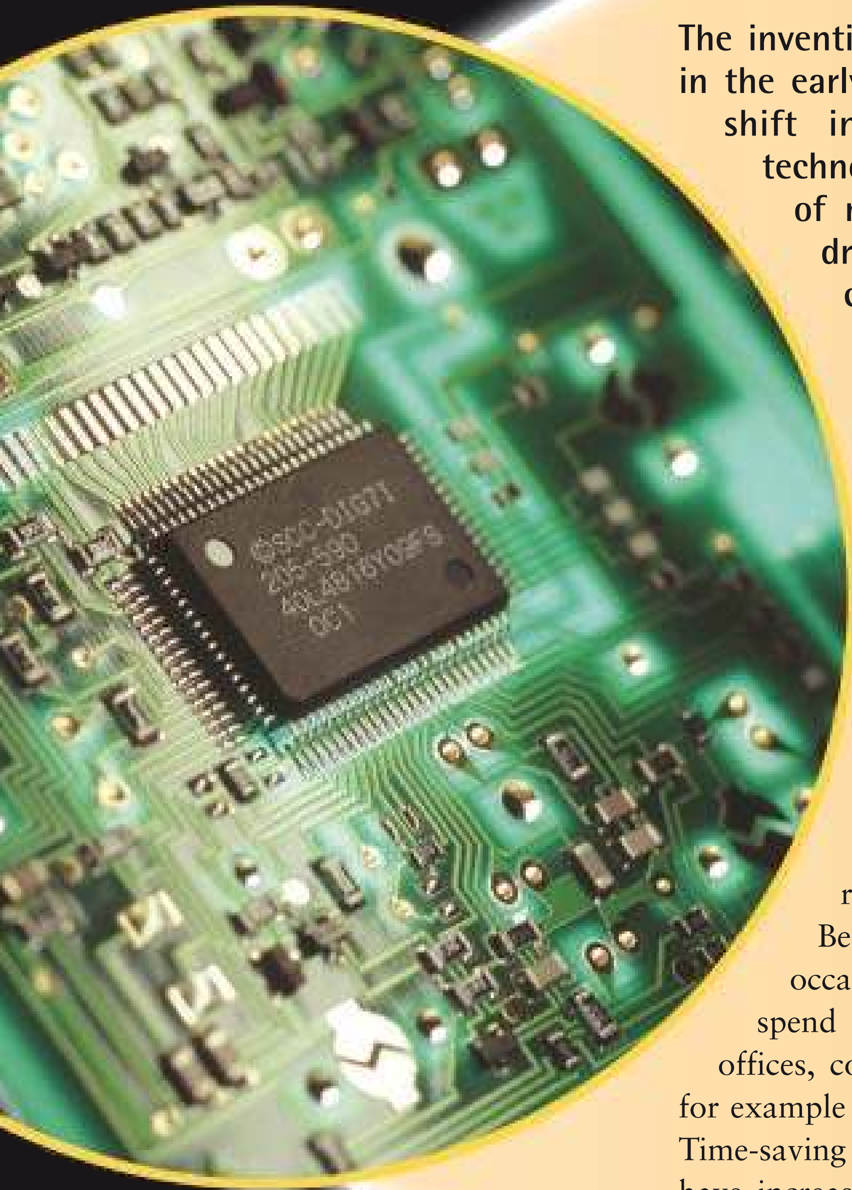
>>WORK

Digital pen >> Laptop >> Motherboard >> Flash stick >> Virtual keyboard >> Laser printer >> Scanner >> Smart card >> Radio ID tag >> Robot worker >> Wet welding >> Fire suit >> Doppler radar









COMPUTER CIRCUIT BOARD

The invention and development of the steam engine in the early 1700s marked the beginning of a huge shift in the way people worked. This new technology was used at first to pump water out of mines. By the end of the century it was driving factories full of looms producing cotton fabric – the first example of mechanical mass production. Huge numbers of people left their homes in the countryside and moved to cities to find work in factories and later in offices.

In the last few decades, computers have changed the way society is organized once again. Any job that can be made routine, or broken down into a series of simple steps, can be taken over by a computer or a robot designed for a specific task such as spray-painting a car. Robots can also perform the dangerous factory work that people would rather not do, such as handling hot metal plates. Because robots can do most of the repetitive and occasionally risky tasks in factories, factory workers spend less time on the production line. Similarly, in offices, computers process much of the repetitive work, for example calculating figures and printing out documents. Time-saving devices, including laser printers and scanners, have increased productivity. Thanks to the laptop and the mobile phone, office workers are less tied to their desks than they used to be. New technologies such as virtual keyboards, flash sticks, and digital pens have also led to more and more people working from home, working while travelling, or hot-desking – moving from one desk or office to another.

Some jobs can only be done by humans. The decisions that doctors have to make, for example, are too complex and subtle for a computer – diagnosis and treatment of a patient is usually carried out in person. Even so, technology plays a central role in most forms of work. Divers use wet-welding techniques to repair oil rigs and pipes standing deep beneath the ocean. Sailors use satellite navigation to help them pinpoint their exact location. Satellite technology and radar helps meteorologists predict the weather, which in turn helps farmers who need to know when the sun is going to shine and when it is going to rain. Modern materials such as Kevlar® help protect firemen inside burning buildings. Forensic scientists use fingerprint scanners to analyze samples taken from crime scenes, while shop assistants scan product barcodes to quickly process purchases. Businessmen and women use the number-crunching capabilities of microprocessors to keep track of orders and forecast future market conditions.

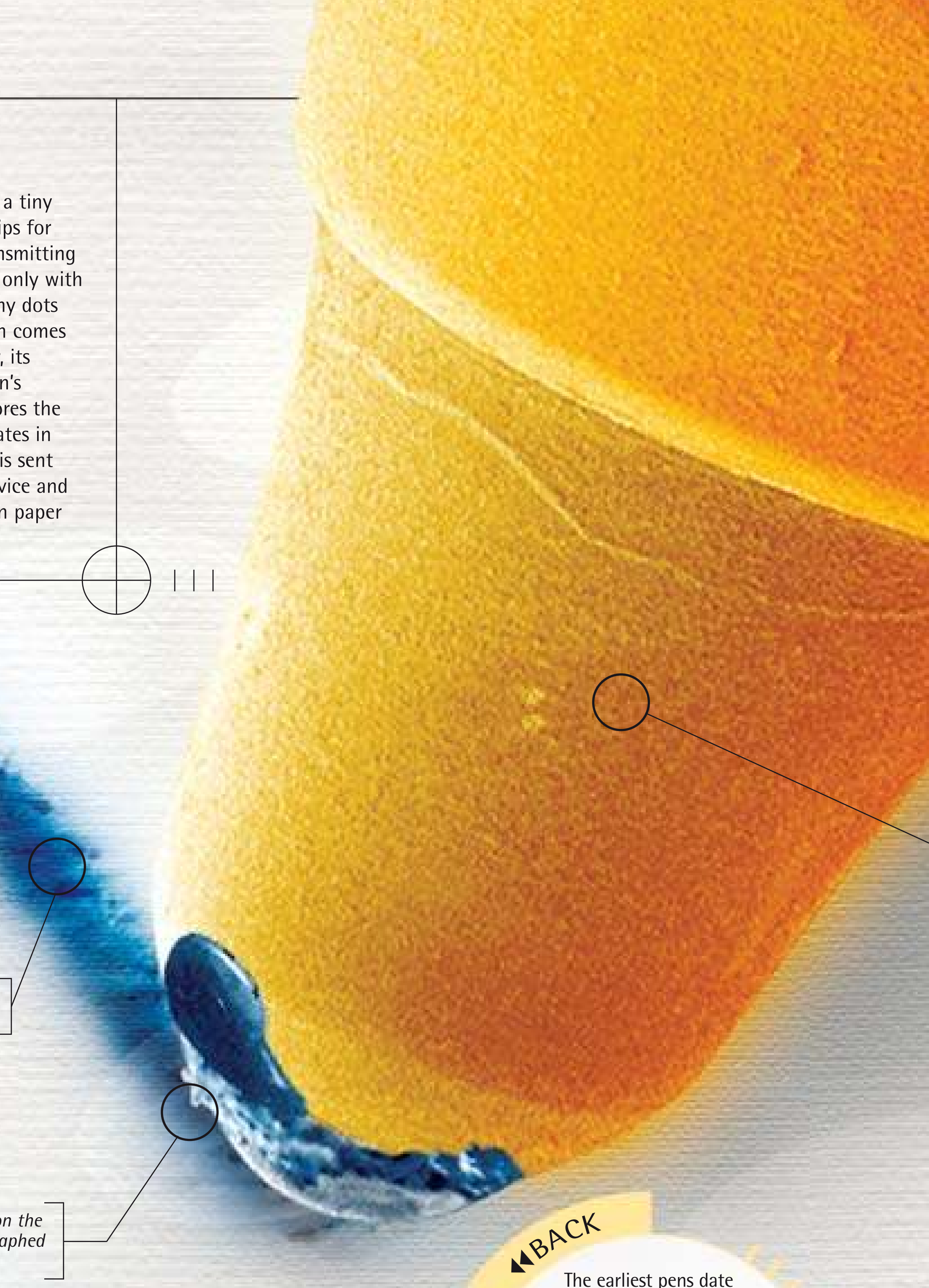
> “Today, one out of every ten workers on car assembly lines around the world is a robot – massively increasing productivity.”

One of the reasons people work, of course, is to earn money. Technology has changed the way we access our money too. The money is mostly invisible, existing as numbers in bank accounts, transferred there directly from the accounts of employers or customers. Sometimes we might go to a cashpoint and take out our earnings as banknotes, but most of the time we just use a smart card to make speedy, secure transactions.

DIGITAL PEN

▶ **Image:** macrophoto of a digital pen writing

▶ **The digital pen** contains a tiny digital camera and microchips for storing, processing, and transmitting information. It can be used only with paper on which a grid of tiny dots is printed. Wherever the pen comes into contact with the paper, its camera photographs the pen's position on the grid and stores the dots as a series of co-ordinates in the memory chip. The data is sent wirelessly to an external device and a replica of what appears on paper is created on screen.



Ink is the same as in an ordinary pen.

Position of pen on the paper is photographed by the camera.

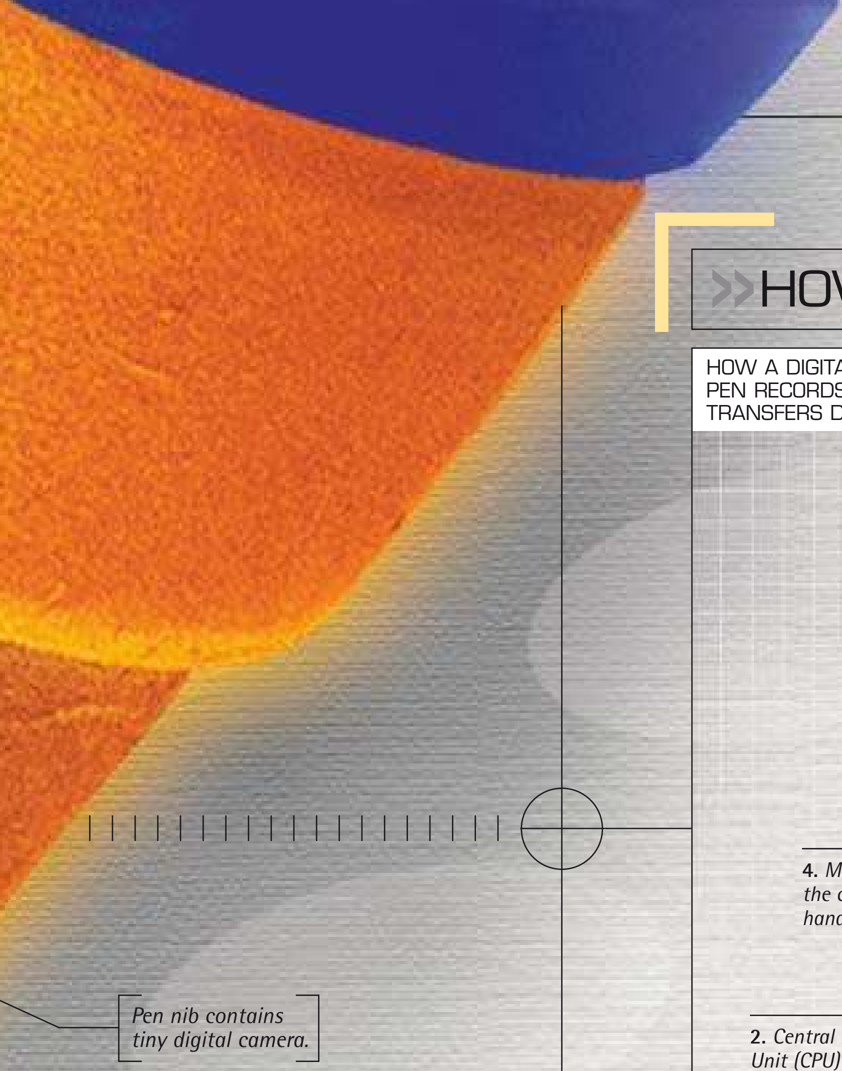
◀◀ BACK

The earliest pens date from about 3000 BC. They were just sharpened sticks, used by the ancient Sumerians to scratch their script on clay tablets.

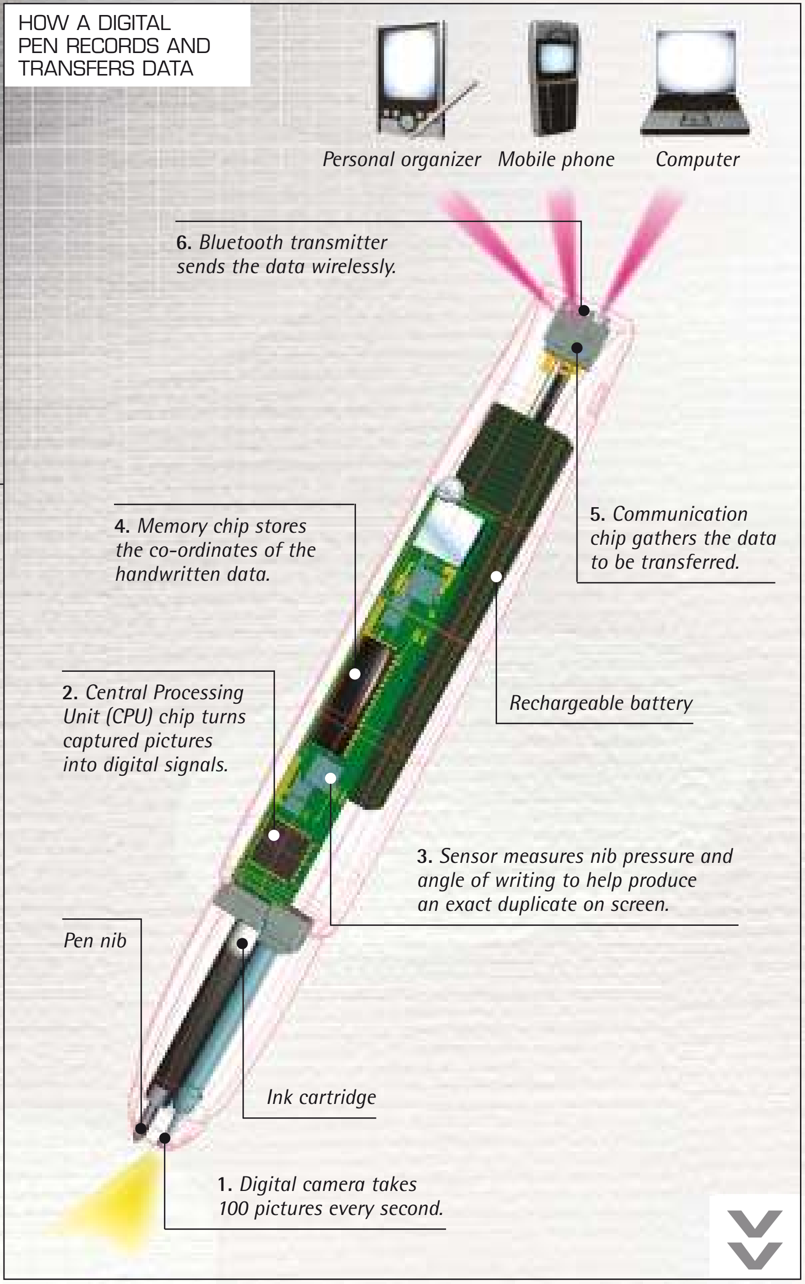
At wireless connection points in cafes and train stations, people will pay to download the latest edition of a newspaper onto paper or screens.

FORWARD ▶▶

▶▶ The digital pen remembers exactly what you write or draw. You can save ideas, memos, or sketches on the pen until you want to transfer them to a computer for safe-keeping or printing. ▶▶

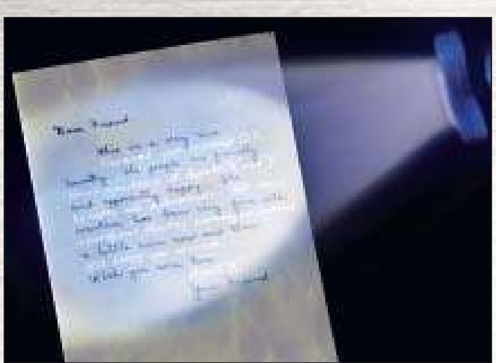


HOW A DIGITAL PEN WORKS



Digital pens look like ordinary ink pens and are just as easy to use. They work anywhere, and they do not need to be near a computer to function. As long as the dotted paper is used and the battery is fully charged, data is safely stored. Most pens can hold 40 A4-sized pages of information in their memory. When the memory is full, data must be downloaded to a personal organizer, mobile phone, or computer. The pen's sensor ensures that the screen version is identical to the paper version.

Invisible ink



Invisible ink revealed by ultraviolet light

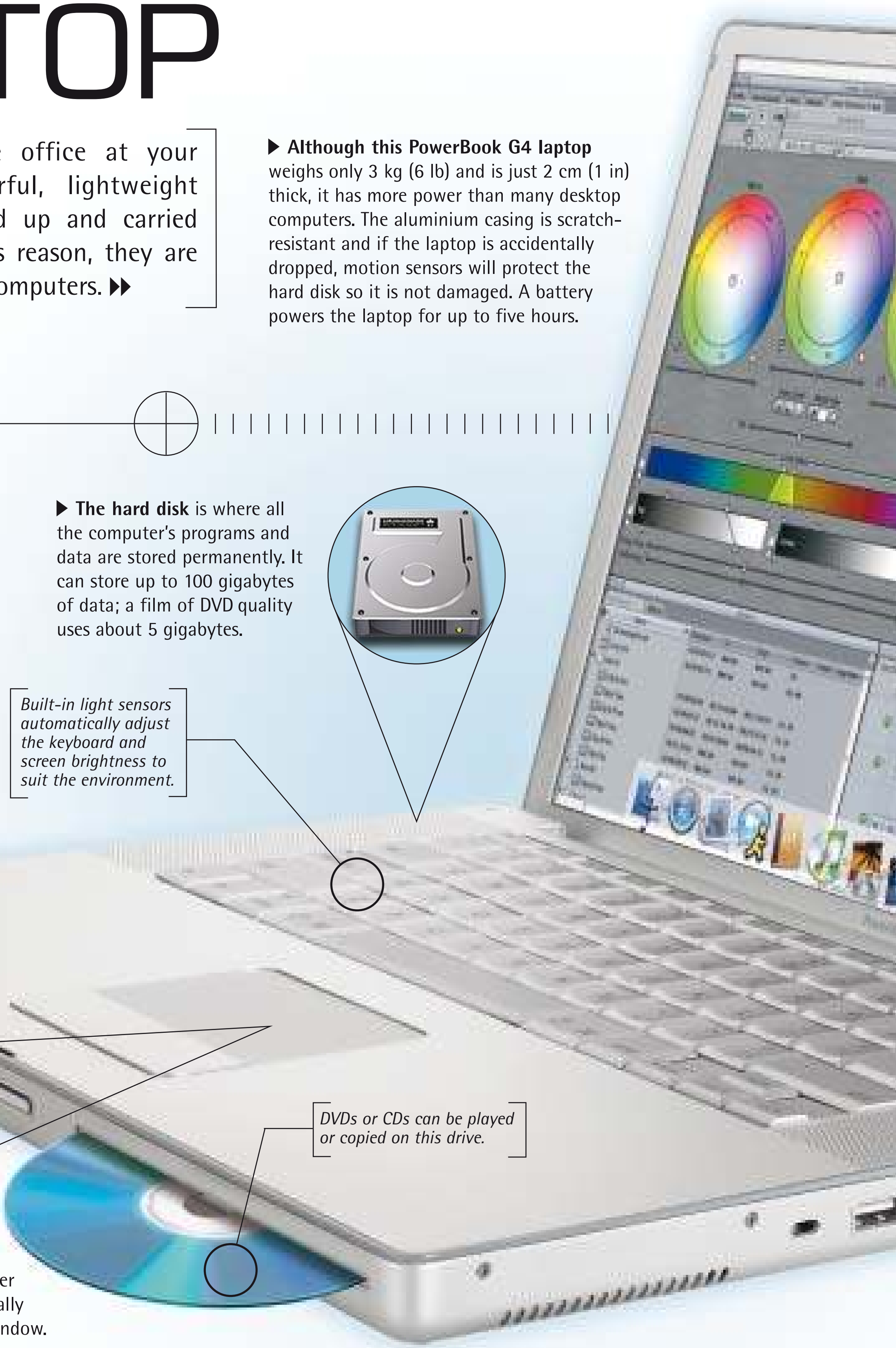
▲The digital pen uses visible ink, but its camera records its route across invisible dots. Similarly, invisible ink leaves a hidden trace on what seems like a normal letter. Invisible inks have been used by spies for centuries to write concealed messages. Some become visible when heated. Some, such as this one, show up under ultraviolet (UV) light.

See also: Bluetooth® p241, Flash stick p172, Laptop p168, Virtual keyboard p174

LAPTOP

▶▶ Laptops put a whole office at your fingertips. These powerful, lightweight computers can be folded up and carried almost anywhere. For this reason, they are also known as notebook computers. ▶▶

▶ **Although this PowerBook G4 laptop** weighs only 3 kg (6 lb) and is just 2 cm (1 in) thick, it has more power than many desktop computers. The aluminium casing is scratch-resistant and if the laptop is accidentally dropped, motion sensors will protect the hard disk so it is not damaged. A battery powers the laptop for up to five hours.

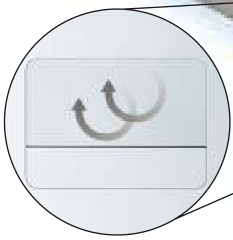


▼ **The processor,** or Central Processing Unit (CPU), is the brain of the laptop and the single most important chip. It performs calculations and instructions. This processor, called G4, is known for its speed.

▶ **The hard disk** is where all the computer's programs and data are stored permanently. It can store up to 100 gigabytes of data; a film of DVD quality uses about 5 gigabytes.

Built-in light sensors automatically adjust the keyboard and screen brightness to suit the environment.

DVDs or CDs can be played or copied on this drive.



▲ **The trackpad** controls the cursor on screen. By dragging two fingers over the trackpad, it is easy to scroll vertically and horizontally around any active window.

Graphic system supports millions of colours, which makes the screen ideal for watching films.

Image: a PowerBook G4 computer

▲ **A plug-in card** provides high-speed wireless Internet access using Wi-Fi technology. Many cafes, book shops, airport lounges, and hotels have Wi-Fi hotspots. Using these, the laptop can connect to the Internet without plugging a cable into a telephone socket.

▲ **This range of multi-ports** provides connections to external devices. Flash sticks, MP3 players, and printers can be plugged into the various ports.

Multi-purpose laptop

Telephone
The built-in microphone and speakers can work as a telephone when connected to the Internet.

Digital camera
You can connect a digital camera to a USB port and download pictures to save, adapt, or print.

Video camera
You can connect a video camera to a port and download home videos to watch, save, or edit.

Address book
Addresses entered in your mobile phone can be uploaded to your laptop for safe-keeping.

Photograph album
As well as storing photographs, the laptop lets you organize your pictures and create slide shows.

Diary
Your daily and weekly appointments can be stored on the laptop's calendar planner.

Pen and paper
The laptop has hundreds of different typefaces and page layouts to choose from.

BACK

The first laptop computer was sold by the Osborne Computer Corporation in 1981. It cost $1,795 (£900) and weighed a hefty 11 kg (24 lb).

Scientists in America are working on a laptop that will cost only $100 (£50), intended for school children in developing countries.

FORWARD

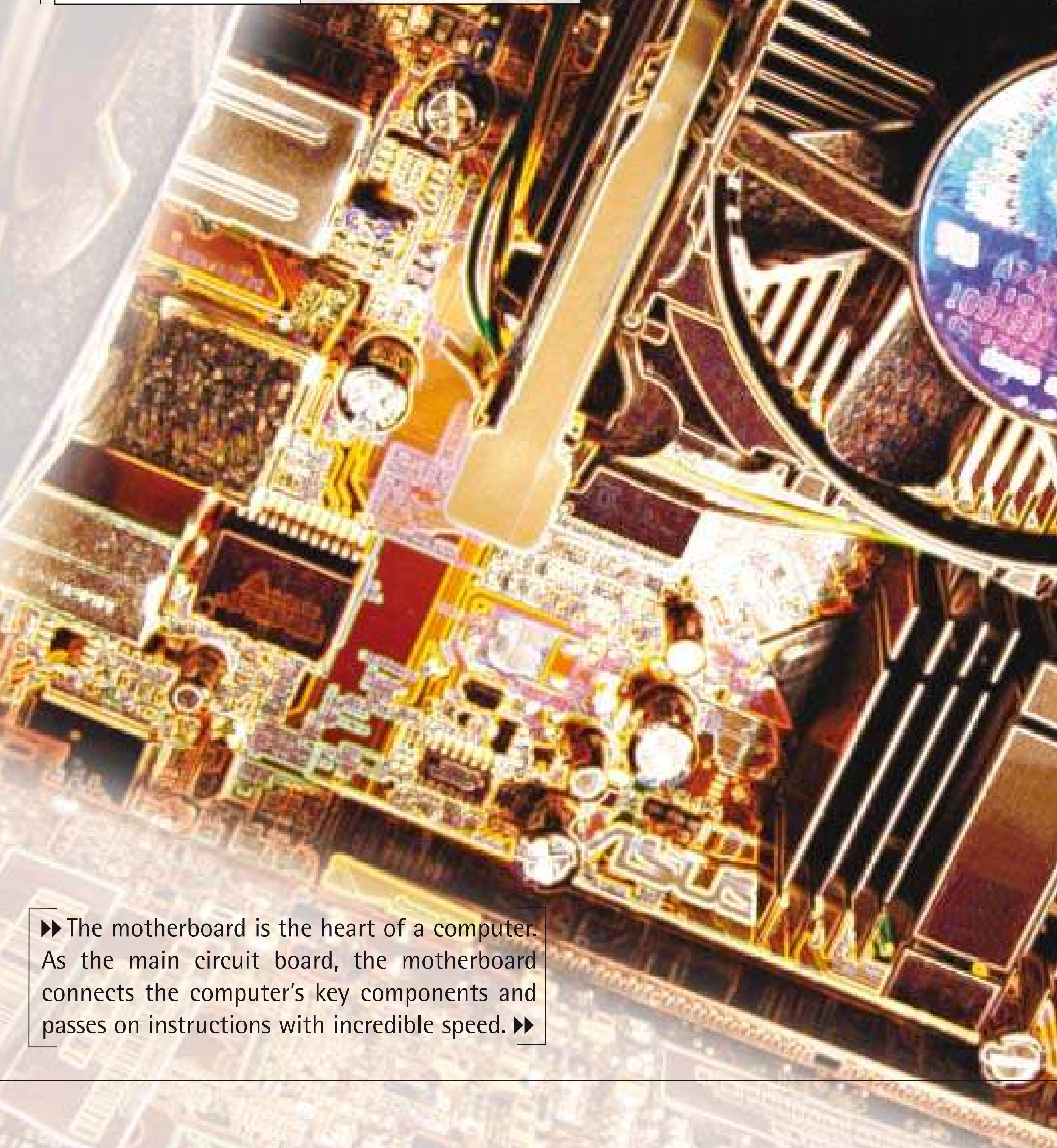
See also: Byte p241, Flash stick p172, Microchip p16, Motherboard p170

Wearable computer

Wearable screen

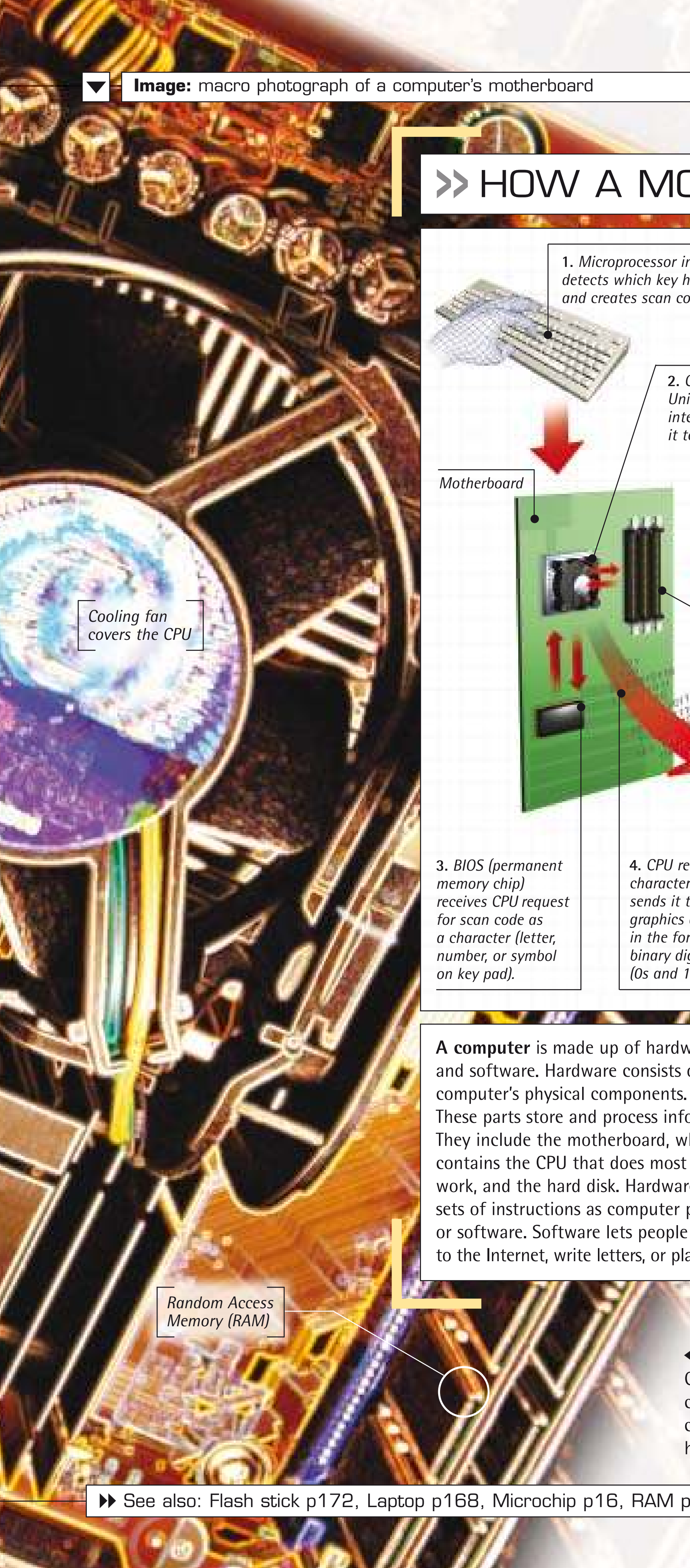
A wearable computer consists of a miniature screen and computer. The screen is worn like a pair of glasses and projects images generated by the computer straight to the wearer's eye. The computer is small enough to fit in a pocket or on a belt. These wearable computers enable technicians to consult manuals while they work on site.

MOTHERBOARD

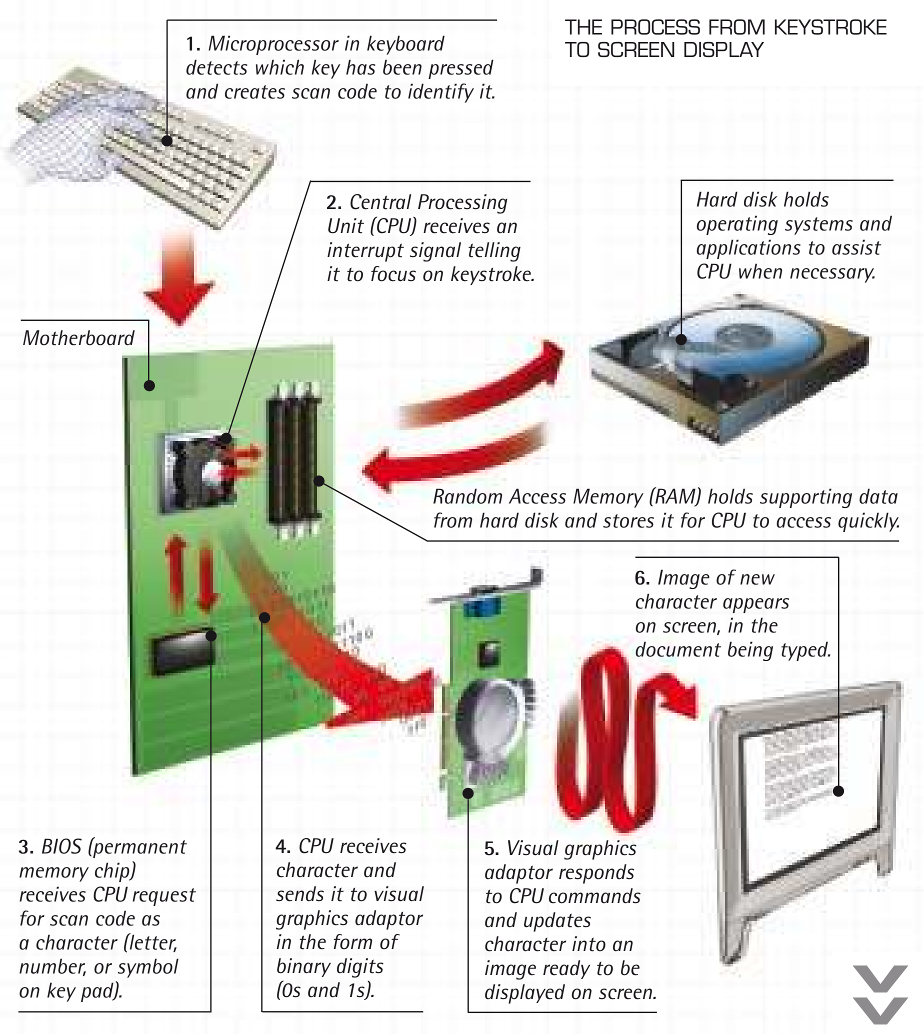


The motherboard is the heart of a computer. As the main circuit board, the motherboard connects the computer's key components and passes on instructions with incredible speed.

Image: macro photograph of a computer's motherboard



HOW A MOTHERBOARD WORKS



A computer is made up of hardware and software. Hardware consists of the computer's physical components. These parts store and process information. They include the motherboard, which contains the CPU that does most of the work, and the hard disk. Hardware stores sets of instructions as computer programs, or software. Software lets people connect to the Internet, write letters, or play games.

In 1946, the first digital computer was invented. Electronic Numerical Integrator and Computer (ENIAC) took three years to build and weighed 30 tonnes. It could do calculations and process 100,000 instructions per second. A modern computer is much smaller and faster, thanks to the invention of the microchip in the 1970s. One tiny chip could now hold many previously separate parts.

◀ At the centre of the motherboard is the CPU, or Central Processing Unit, which is a small microprocessor chip. The CPU performs hundreds of millions of calculations every second. This generates so much heat that the chip needs a fan to cool down.

See also: Flash stick p172, Laptop p168, Microchip p16, RAM p249

FLASH STICK

Packed with useful gadgets, the Swiss Army Knife's latest accessory is a flash stick. It can now carry around photographs, music, documents, or any other data that can be stored digitally.

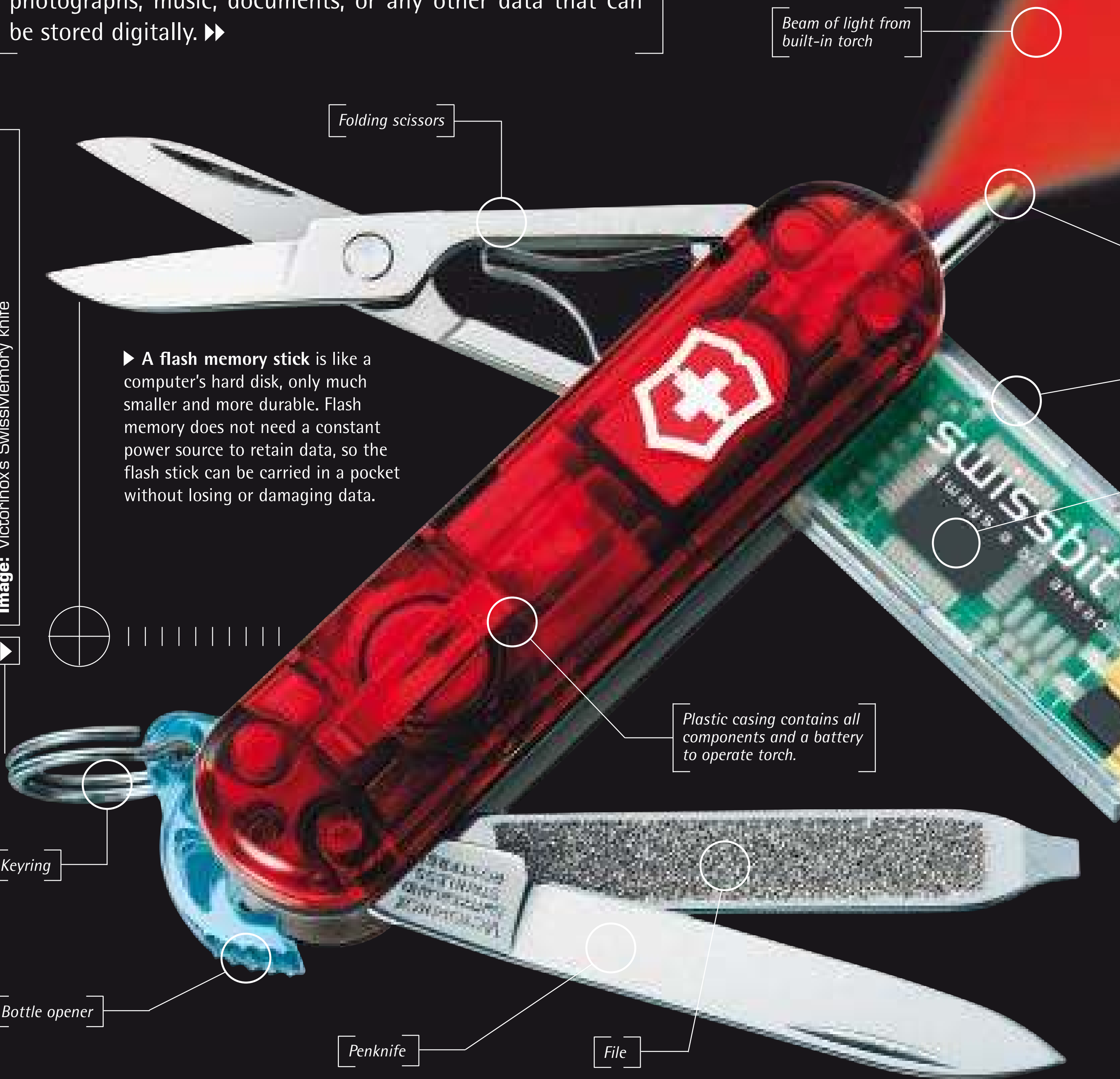


Image: Victorinox's SwissMemory knife

A flash memory stick is like a computer's hard disk, only much smaller and more durable. Flash memory does not need a constant power source to retain data, so the flash stick can be carried in a pocket without losing or damaging data.

◀◀BACK

In 1891, the Swiss Army Knife was invented for the military by Carl Elsener, a Swiss pocketknife manufacturer. He called it the "Officers and sports knife".

An 8-gigabit flash memory chip is being developed, which will be able to hold one hour of DVD material or 250 MP3 files.

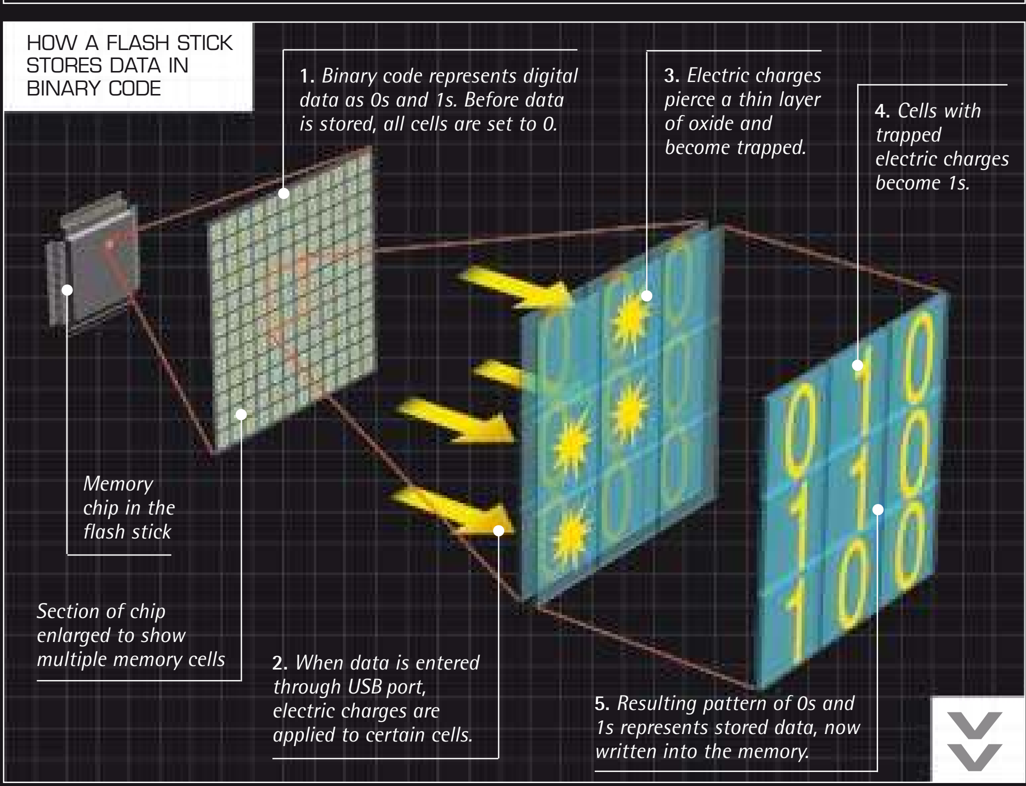
FORWARD▶▶

Stick storage

▶ In the past, business people had to carry their documents, notebooks, and photographs around in briefcases. The lightweight flash stick can carry all this and more. It is small enough to fit inside a pocket and can store 64 megabytes of data, the equivalent of about 9,400 sheets of printed A4 paper.

Contents of a briefcase

HOW A FLASH STICK WORKS



Flash memory stores data permanently so that it can be transported from one place to another. Many digital products, including mobile phones, personal organizers, cameras, video recorders, and MP3 players use flash memory as a storage device, making it easy to move information between different products. Flash sticks are simple to use and unlikely to fail and break.

The USB connector on the flash stick can be plugged into any USB port on a computer. Files can be uploaded, downloaded, and modified as required. Afterwards, the stick is removed from the USB port and the files remain on the stick until they are deleted. Flash memory gets its name because the entire contents of a stick can be deleted in a single, split-second flash.

▶▶ See also: Digital technology p243, Laptop p168, Motherboard p170

VIRTUAL KEYBOARD

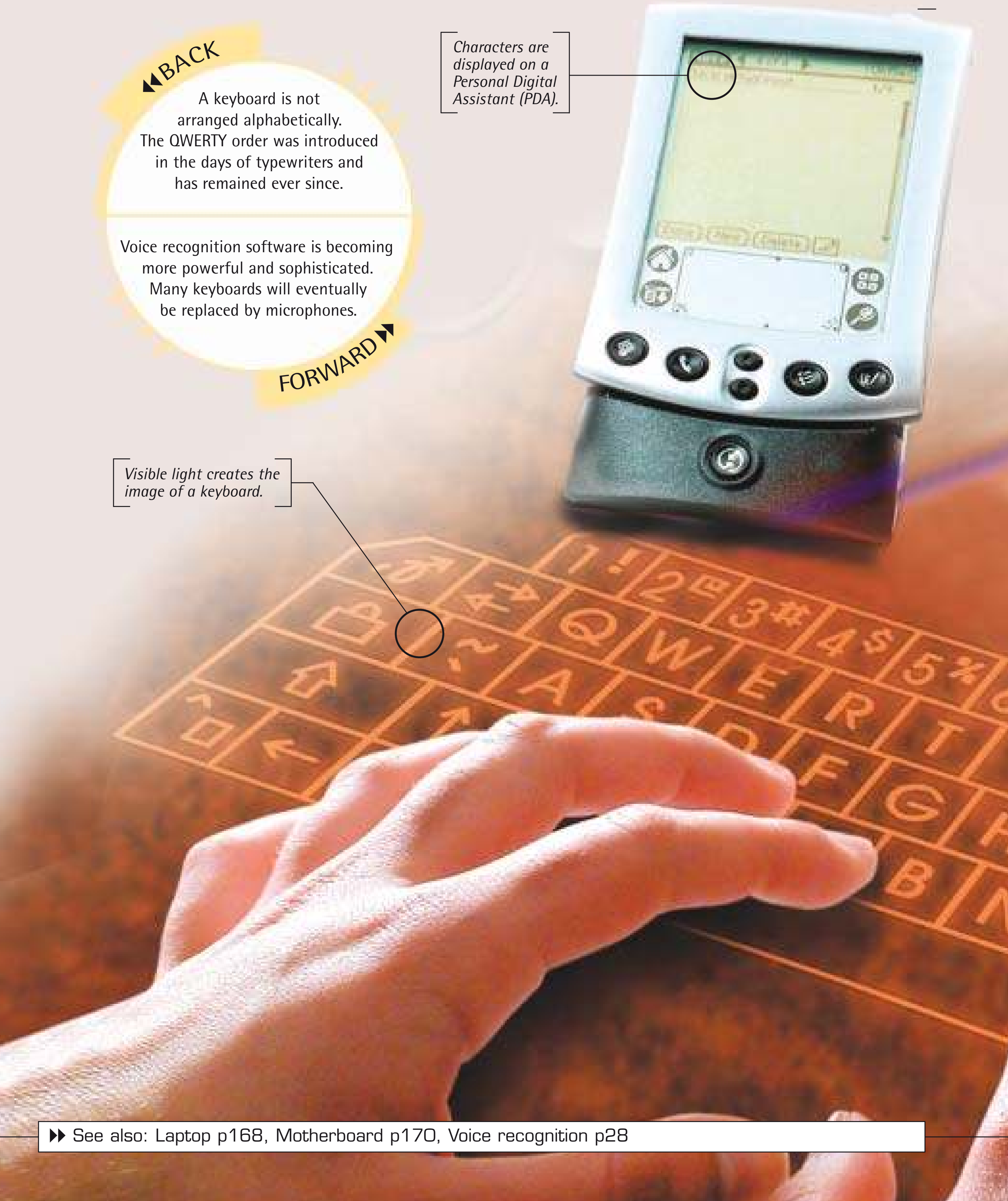
A virtual keyboard is made entirely of light. As a result, the keyboard can be projected onto any flat surface, making it the ideal space-saver. A separate infrared sensor tracks the keys as they are tapped.

BACK

A keyboard is not arranged alphabetically. The QWERTY order was introduced in the days of typewriters and has remained ever since.

Voice recognition software is becoming more powerful and sophisticated. Many keyboards will eventually be replaced by microphones.

FORWARD



Characters are displayed on a Personal Digital Assistant (PDA).

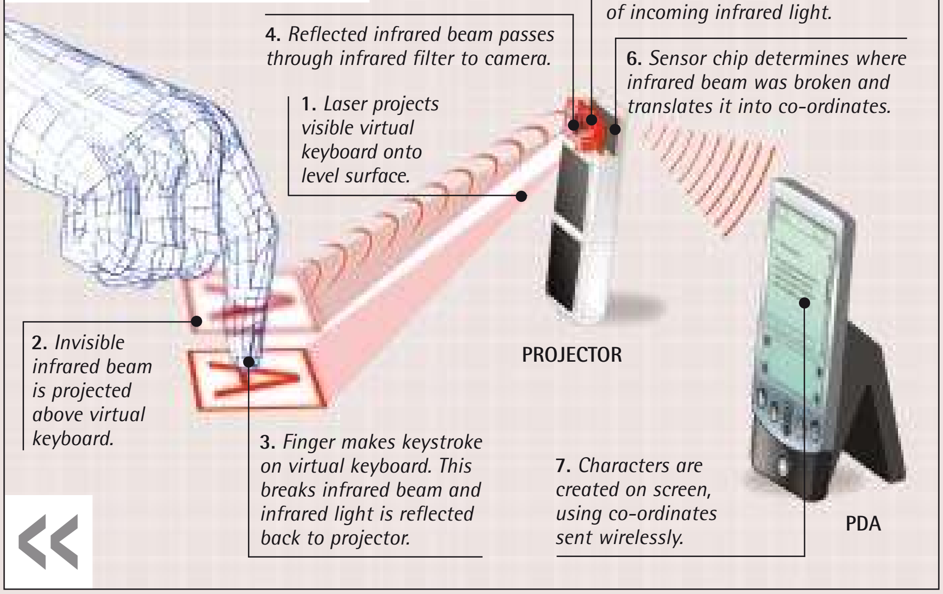
Visible light creates the image of a keyboard.

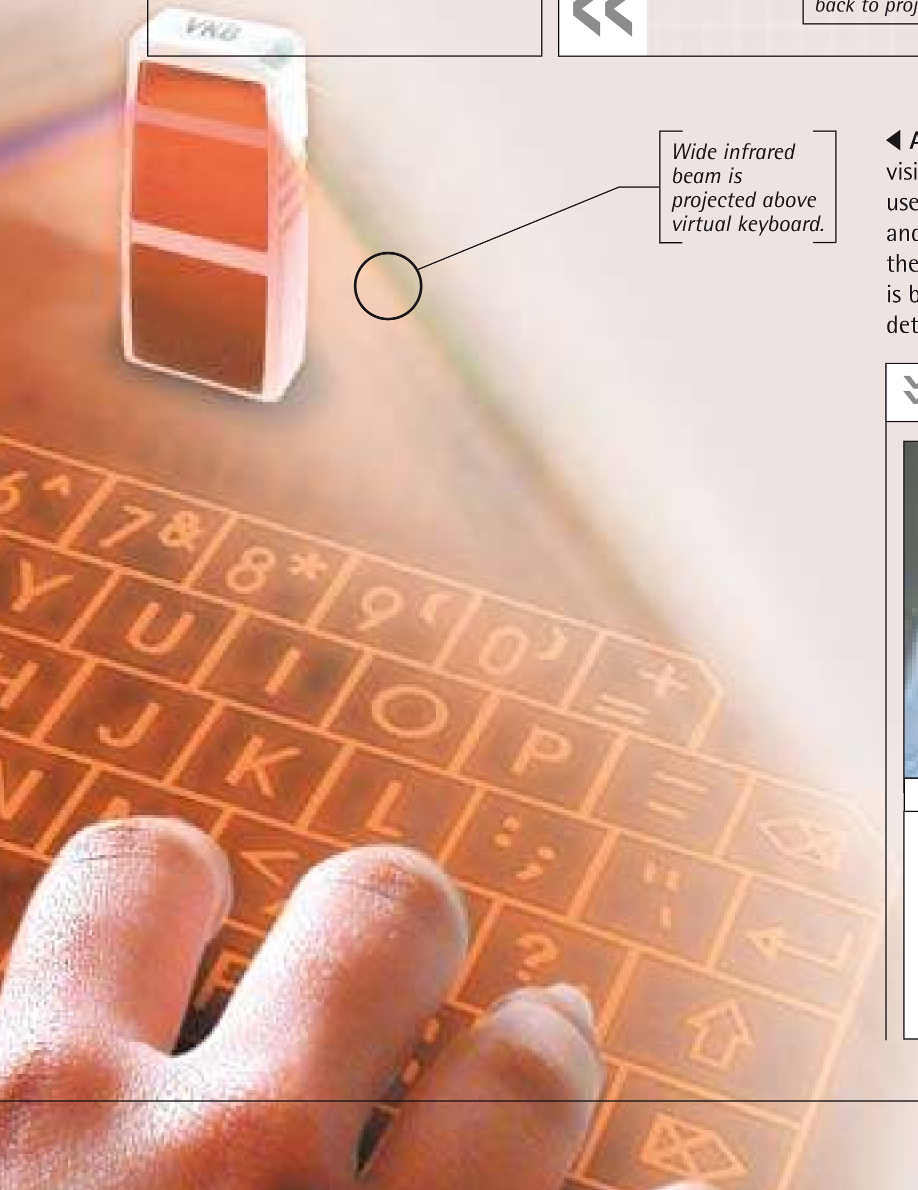
See also: Laptop p168, Motherboard p170, Voice recognition p28

HOW A VIRTUAL KEYBOARD WORKS

Handheld devices such as PDAs and mobile phones have tiny buttons that are often difficult to use. Although it is easy to key in a telephone number or send a text message, it is frustrating and time-consuming to type a long email or document. A virtual keyboard overcomes this problem. A small projector transmits an image of a keyboard layout on any level surface, for example, a briefcase lid. A sensor inside the projector captures keystrokes, converting them into on-screen characters. To create the illusion of a real keyboard, the projector makes a clicking sound when a keystroke is made.

HOW A KEYSTROKE ON A VIRTUAL KEYBOARD APPEARS ON SCREEN





◀ **A virtual keyboard** is created using both visible and invisible light. The visible light is used to project the keyboard onto a surface, and invisible infrared light is used to track the keystrokes. Every time the infrared beam is broken, a sensor inside the projector detects which key has been touched.

Image: virtual keyboard in use

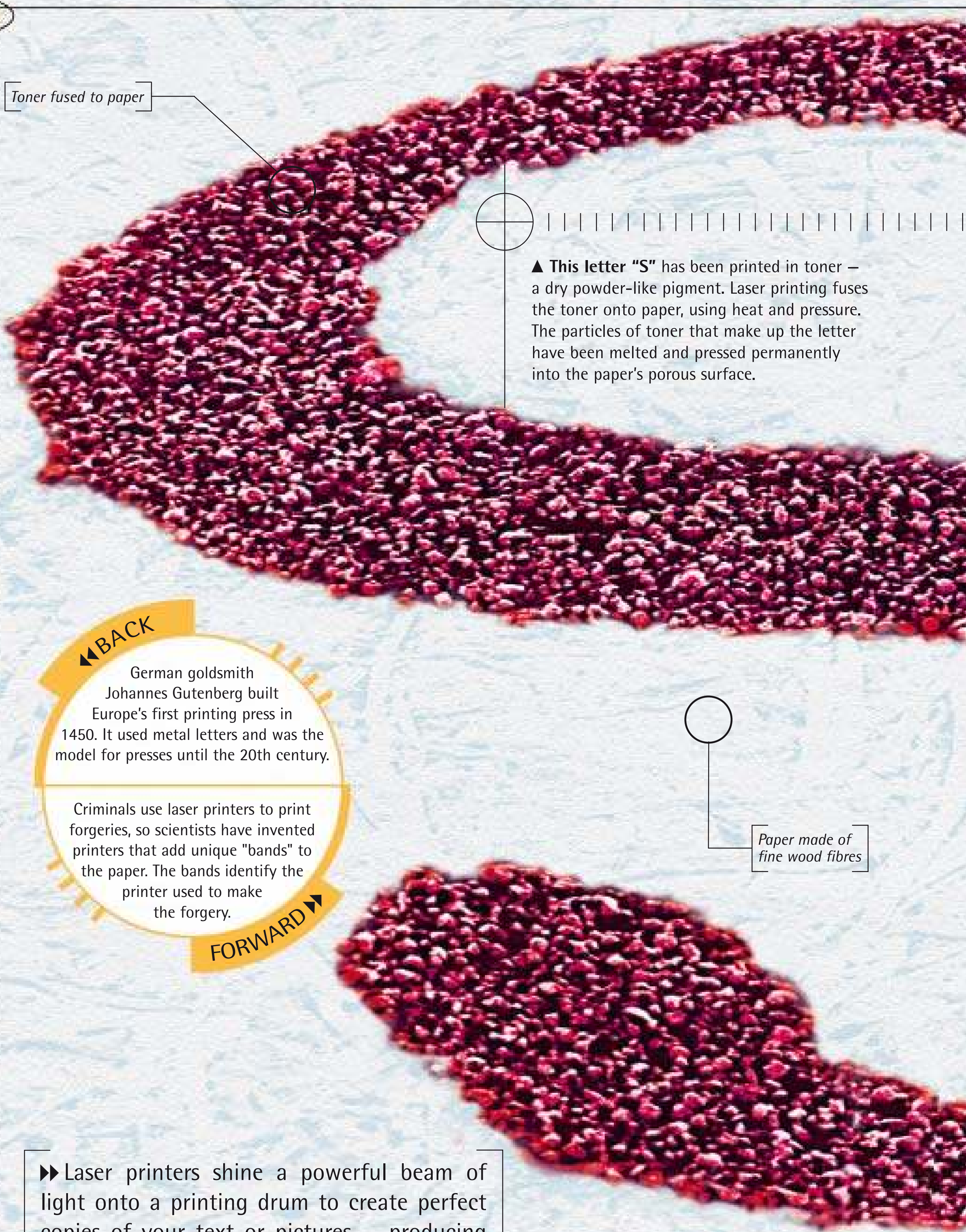
Thought games

Controlling a game by thought

▲Scientists at Germany's Fraunhofer Institute have created a brain-computer interface that allows people to control computer games, such as racing games and video tennis, using their thoughts. The player's intentions are picked up as brain waves through an electroencephalograph (EEG) headset, and advanced software converts them into on-screen movements.

LASER PRINTER

▶▶ Laser printers shine a powerful beam of light onto a printing drum to create perfect copies of your text or pictures – producing about 45 pages a minute. ▶▶



▲ **This letter "S"** has been printed in toner – a dry powder-like pigment. Laser printing fuses the toner onto paper, using heat and pressure. The particles of toner that make up the letter have been melted and pressed permanently into the paper's porous surface.

◀◀ BACK

German goldsmith Johannes Gutenberg built Europe's first printing press in 1450. It used metal letters and was the model for presses until the 20th century.

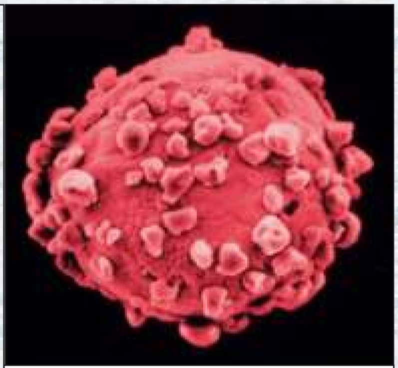
Criminals use laser printers to print forgeries, so scientists have invented printers that add unique "bands" to the paper. The bands identify the printer used to make the forgery.

FORWARD ▶▶

▲ **Image:** coloured SEM of a letter "S"

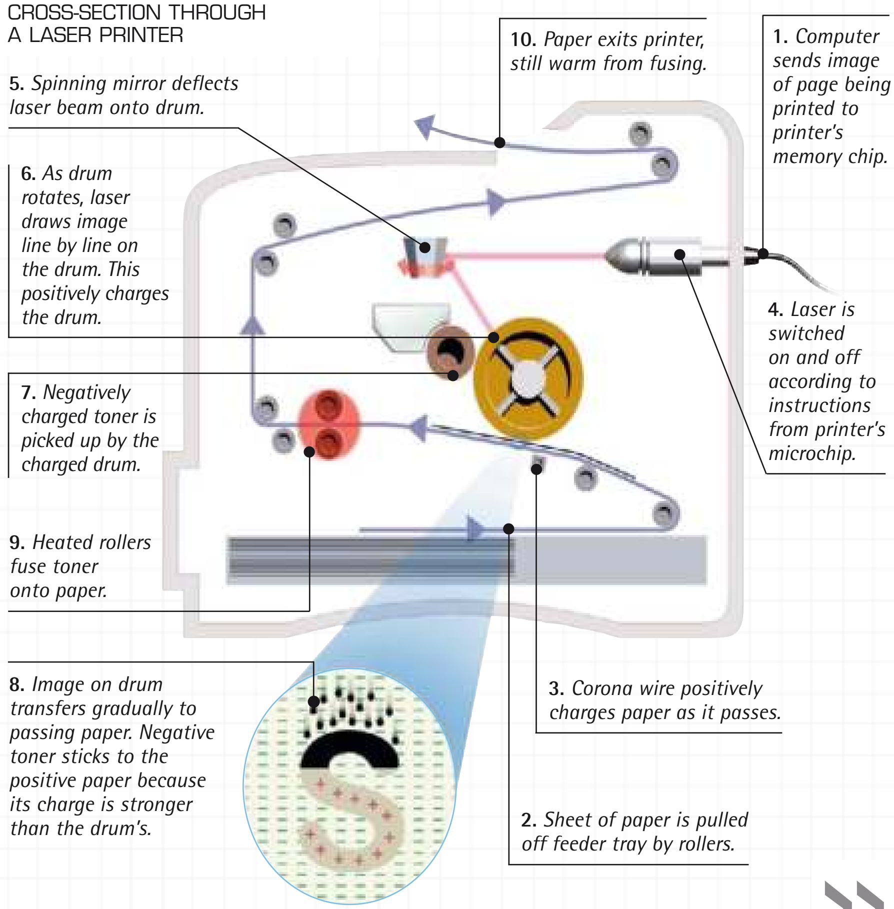
Toner beads

Toner is the dry pigment that laser printers use instead of wet ink. This fine powder consists of tiny plastic beads, each with particles of colour attached. Inside the laser printer, negatively charged toner is pulled off first by the positive charge of the drum, then by the stronger positive charge of the paper. When heated by rollers, the beads melt and fuse to the paper, trapping the toner in the wood fibres. Colour laser printers use four toners – black, cyan (light blue), magenta (purple-red), and yellow – to create full-colour images.



Toner particles attached to plastic bead

HOW A LASER PRINTER WORKS



The printer manufacturer Xerox developed the world's first laser printer. Although it was fast, it was also bulky and expensive. As personal computers became popular during the 1980s, the demand for smaller, cheaper printers increased. In 1984, the first LaserJet printer for personal computers was introduced. This was the first laser printer to have a replaceable toner cartridge.

The other main types of computer printer are called dot matrix, used mostly in the workplace, and inkjet, used more at home. Dot matrix printers, also called impact printers, use a series of pins to strike out an image over an ink-ribbon. They are much faster than laser printers and are typically used by companies to print large quantities of cheques and invoices. Inkjet printers were developed in the late 1980s. Although they are slower than laser printers, inkjet printers are more popular with home computer users because they produce excellent graphics at a more affordable price.

See also: Laser surgery p206, Microchip p16, Scanner p178

SCANNER

Any picture or text can be captured as an image by a scanner – from a painting or a family photograph to a legal document. Scanners convert images into digital files, which can be manipulated or printed using a computer.

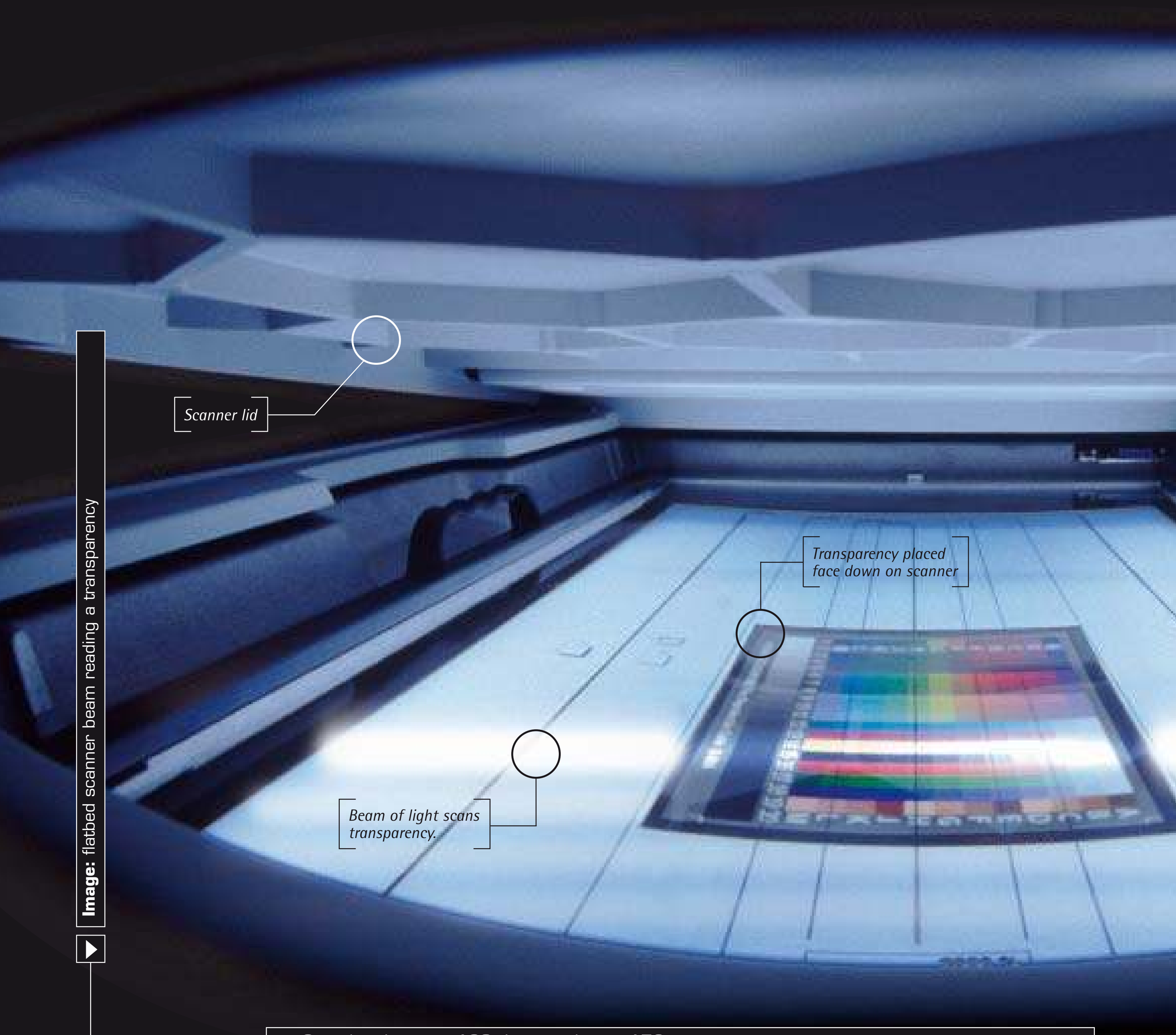


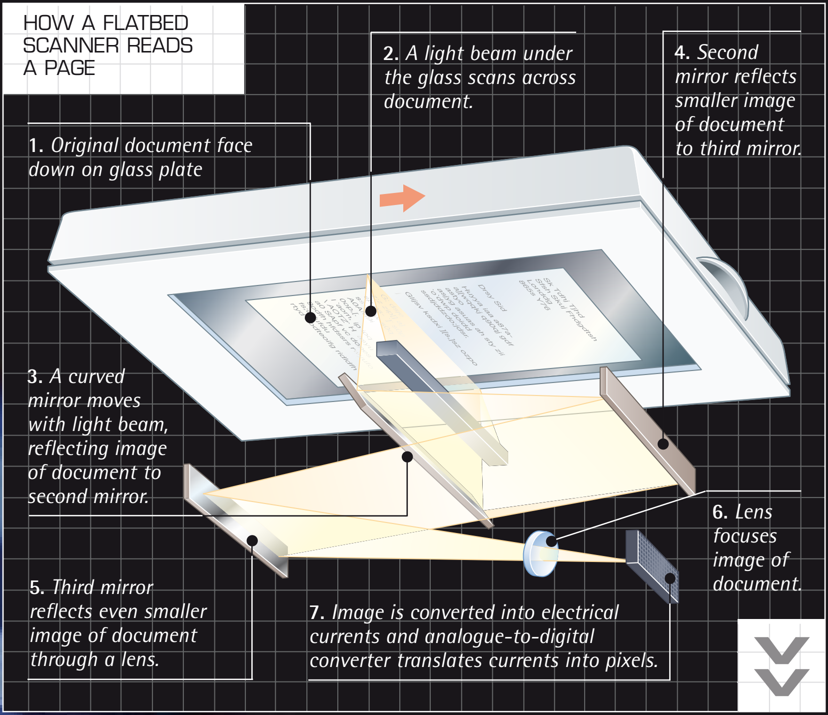
Image: flatbed scanner beam reading a transparency

See also: Laptop p168, Laser printer p176

▼ **A scanner** uses a beam of light to read the colours of an image or a piece of text. It then converts the information it has received into a digital file, which can be sent to a computer. A photocopier works in a similar way but it prints multiple copies of the image or text on to paper instead.

Glass plate under which light beam moves

HOW A SCANNER WORKS



The first scanners, called drum scanners, were developed in about 1957 by the publishing industry to create and print very detailed copies of images or text. These scanners are still used in situations where high quality and colour precision is critical, such as pictures of artefacts in museum catalogues. Today, flatbed scanners are used more frequently because, although less precise, they are cheaper and faster. A scanner can form an image of the page, which can be attached to an email and sent to many people at once. To save time typing, Optical Character Recognition (OCR) software can extract text from a scan of a page, so it can be edited on word processing programs.

Automatic mailing system

▶ Post offices use Optical Character Recognition (OCR) scanners to help the mail sorting process. The scanner takes an image of a postcode and compares it with a list of postcodes stored in a table. When the postcode is found, a pattern of codemarks are printed on the mail. Phosphor inks are used for these codemarks, as they glow in the dark under ultraviolet (UV) light and routing machines can easily read them, even if the mail is damaged.

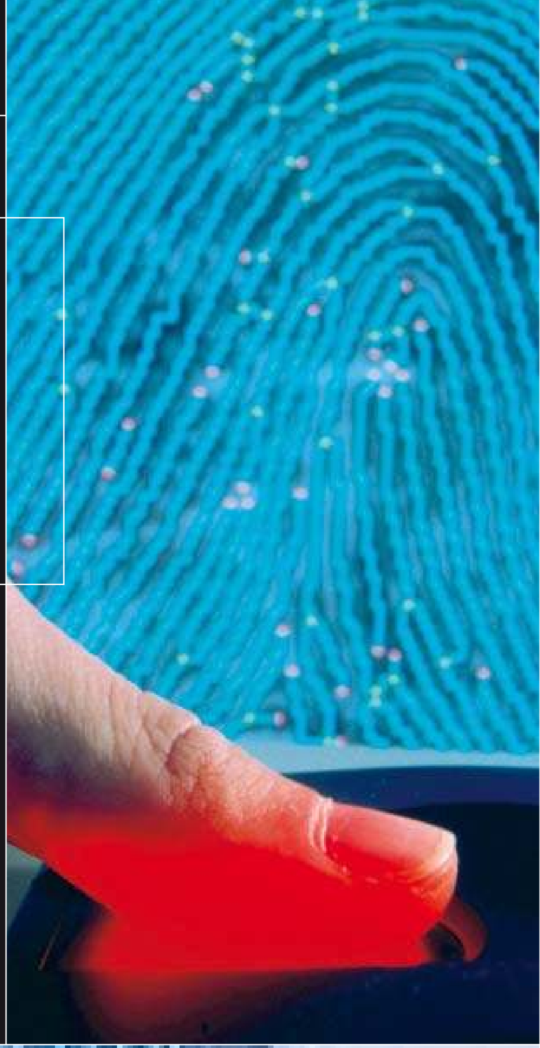
OCR scanner reading a postcode

ID

Identification (ID) technology proves a person is who they say they are and a product is not a forgery. For ID to work, it must be unique, such as a fingerprint, or difficult to copy, such as a hologram.

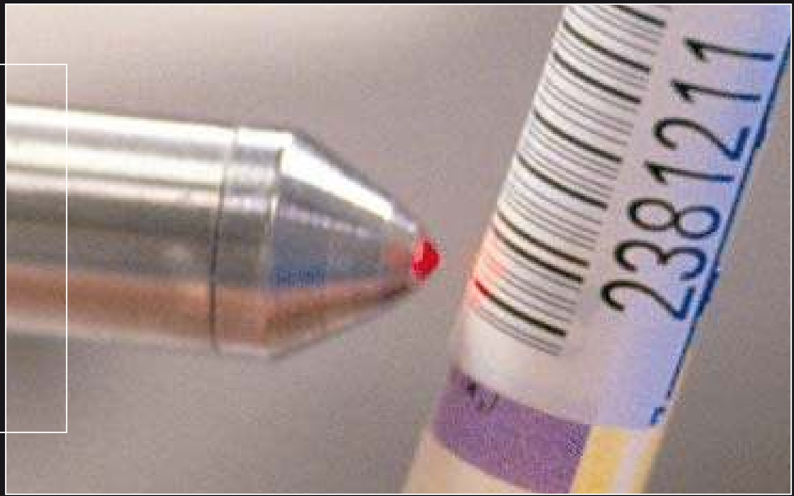
Fingerprint scanner

These scanners can be used to verify a person's identity. Reflected light from the fingertip is used to produce a digital image. This image is checked against the images of fingerprints held on a database to find a match. Forensic scientists also use databases to identify fingerprints from a crime scene.



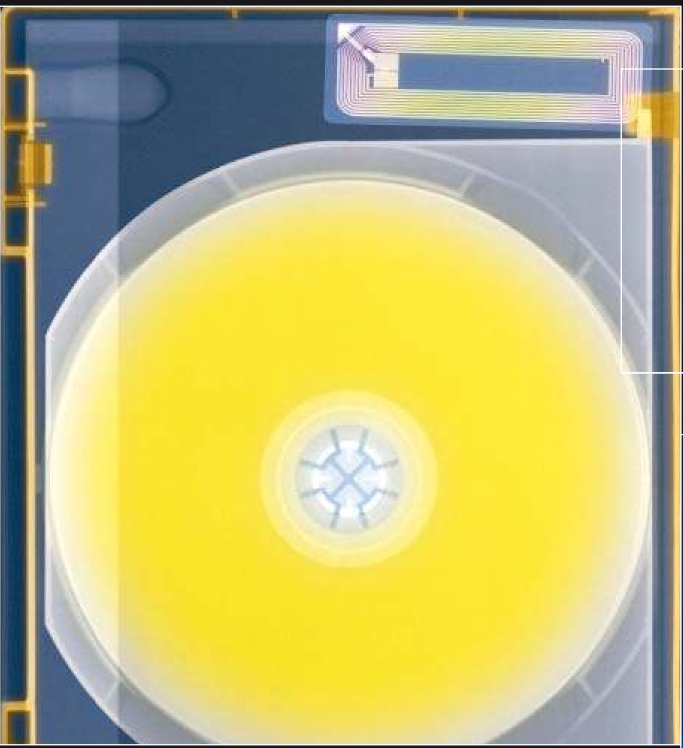
Security hologram

Holograms are two-dimensional pictures that appear three-dimensional to the human eye. They are created using lasers and are very hard to copy. Holograms are designed so anyone can identify a fake at a glance. Many bank notes and passports have them to deter criminals copying money or identities.



Barcode

A barcode consists of a series of vertical bars of different widths. They form a unique code that identifies a product. Barcode readers scan the code and convert the bars into numbers. These are then compared with a database of numbers to identify the product. Barcodes ensure data is entered rapidly and without any errors.



Security chip

This DVD has been packaged with a security chip, shown top right. The chip has an antenna that transmits and receives radio waves. If a person buys the DVD, the chip is deactivated by the salesperson at the till, but if someone tries to leave without paying, the chip reader at the door will set off the shop's alarm.

Fluorescent mark

This passport contains a complex fluorescent marking that glows under ultraviolet light, shown white. The mark proves that this passport is genuine. Many passports, travellers cheques, and bank notes contain fluorescent markings that are difficult for forgers to copy.

▶▶ See also: Fluorescence p244, Iris scan p32, Radio ID tag p184, Smart card p182

SMART CARD

A smart card is a plastic card with an embedded microchip. It can store 32 kilobytes of data, from bank details to medical records, in its memory. The data is encrypted – put into code – for extra security.

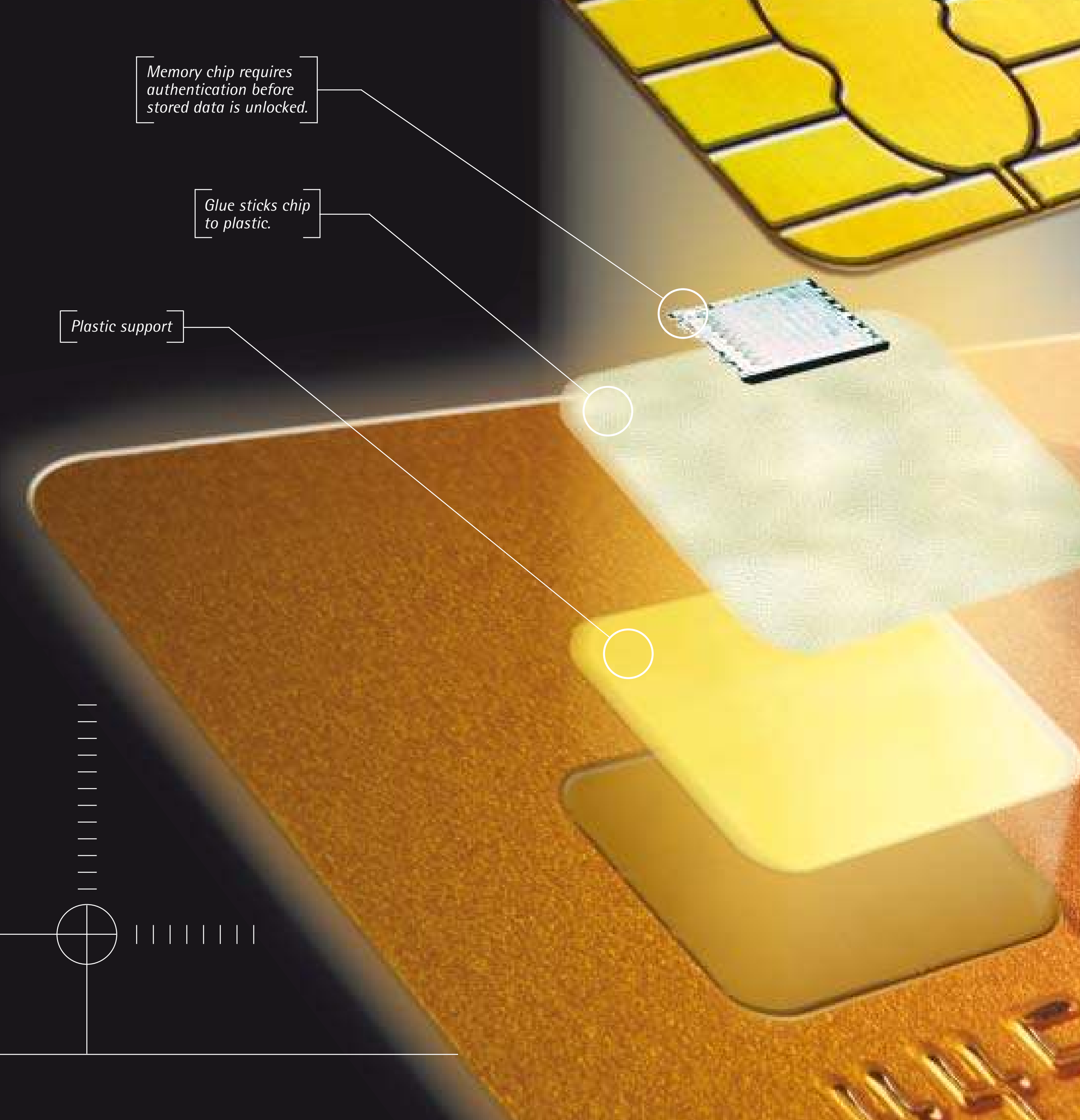


Image: exploded view of a smart card

▼ **A smart card** is more useful and secure than a magnetic-strip card. The card can hold up to 80 times more data and it is much harder to copy a chip than a magnetic strip. Data is protected because it is encrypted inside the chip. Although it is not impossible to steal data from the chip, the high cost and computing power required deters criminals.

BACK

The first smart cards were introduced in Europe during the 1990s. They were mainly used as payphone cards.

Biometric information, such as the cardholder's fingerprint or eye pattern, will be stored on smart cards to prevent criminals stealing and using identities.

FORWARD

Smart card uses

Money
People use smart cards to access their individual bank accounts and withdraw money or check their account information.

Telephone calls
Prepaid telephone cards are credited with a number of units to make calls.

Mobile phones
Smart cards in mobile phones contain subscriber information to identify the user to the network.

Computer security
To gain access to a personal computer, a smart card can authenticate the user.

Travel
Many metro systems use prepaid smart cards instead of tickets. Passengers swipe their cards to gain access.

Health
Smart cards provide an easy and safe way of storing and checking confidential medical information.

Chip and pin

Chip and pin makes card payments more secure. The chip in the card holds an encrypted copy of the user's four-digit personal identification number (PIN). By entering the number into a reading device, a user can prove they own the card. This has reduced instances of card fraud as, without the PIN, it is almost impossible for a criminal to steal and use another person's card.

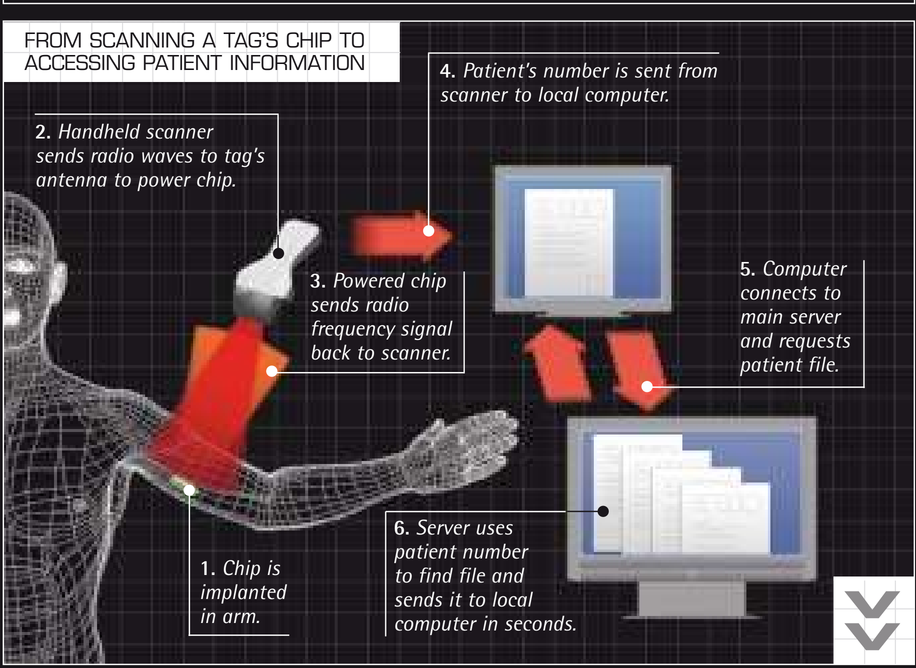

Using a chip and pin device

See also: Biochip p226, ID p180, Microchip p16

RADIO ID TAG

A radio frequency identification tag is a tiny tracking device with a microchip and antenna. Each tag has a unique code to identify the product, person, or animal wearing it. More than 50 million pets and 20 million livestock have already been tagged.

HOW A MEDICAL TAG WORKS



Radio frequency identification tags have been in use since the 1980s. Modern tags contain either an active or a passive chip. Active chips have their own power source and, as a result, a range of more than 90 m (295 ft). They are used for long-distance tracking, such as tagging cattle. Readers placed around the farm pick up the location of each tagged animal and relay it to the farmer's computer.

Passive chips are smaller, lighter, and cheaper to manufacture, so they are more commonly used than active ones. Unlike active chips, they do not have a power source, so a scanner must be used at close range to power them. Their range is limited to 5 m (16 ft), so they are used only for close-range purposes — such as identifying patients and blocking car theft.

VeriChip™ is a medical radio identification tag that can be implanted under the skin of a patient. The chip's memory holds the patient's identification number. This enables doctors to access quickly the vital medical records of unconscious patients in a hospital emergency room.

Uses of ID chips

Pets
With tags on their collars, stray cats and dogs can be returned to their owners.

Prisoners
Whether in jail or out on parole, wardens can track their movements.

Marathon runners
Runners can have their laces tagged so supporters can check locations and times.

Medical patients
In future, tags will store a patient's medical history as well as their patient number.

Car security
A chip in the car key holds the driver's number. If it matches the number in the car's memory, the car starts.

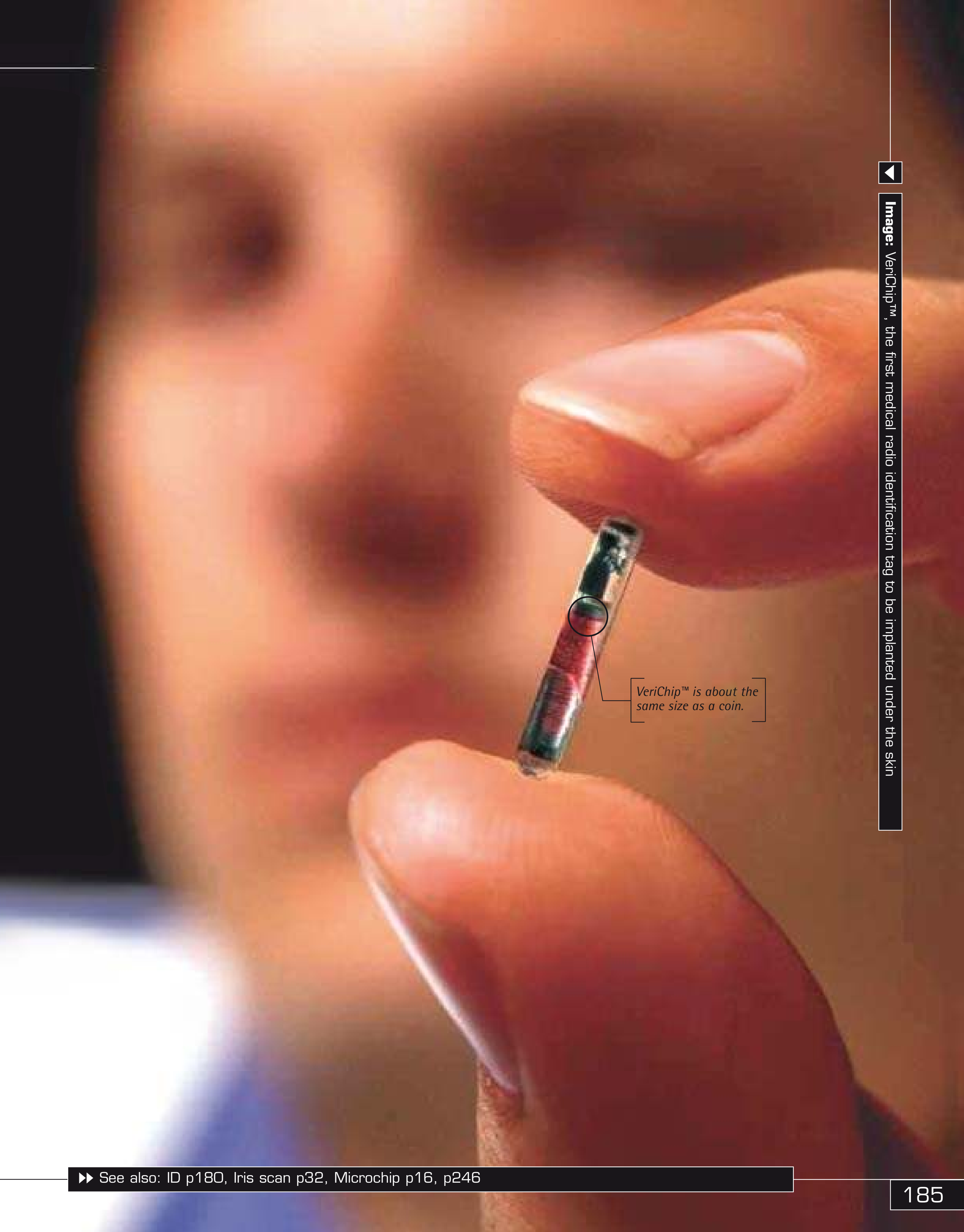


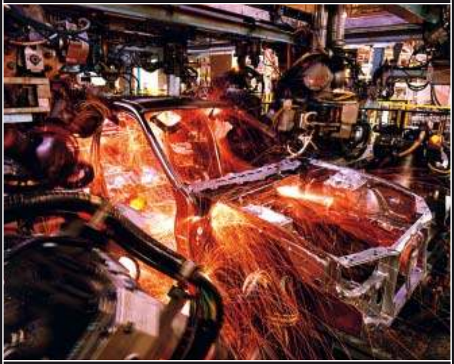
Image: VeriChip™, the first medical radio identification tag to be implanted under the skin

See also: ID p180, Iris scan p32, Microchip p16, p246

ROBOT WORKER

Industrial robots

Industrial robots have been used in factory assembly lines since 1961. The first industrial robot, called Unimate, stacked the sheets of hot metal used in car production. Today, there is one robot to every ten car production workers. Robots mainly work on car assembly lines, but they also work in many warehouses, hospitals, and laboratories.



Robot worker welding a car

Air tank powers dart gun with pressurized air.

Compass improves robot navigation.

Drive motors power the left and right wheels. When the robot needs to turn, one wheel rotates faster than the other. The wheels move easily allowing the robot to turn very quickly.

Robart III is a robotic security guard developed by the US navy. It can find intruders, chase them, photograph them, and fire a non-lethal dart. The main challenge facing this type of robot is how to determine the level of threat a trespasser really poses, and respond appropriately.

BACK

The US science fiction writer Isaac Asimov coined the word robotics. He correctly predicted the rise of the robot industry.

Nanorobots are a new generation of microscopic robots. These tiny robots could one day travel through the human arteries, looking for defects or obstructions.

FORWARD

Almost one million robots work in industry today. They perform many tasks that people find boring or dangerous, such as soldering computer parts or clearing landmines.

Image: front and back views of Robart III

▼ **Stereoscopic video cameras** help to judge depth. Like a cat's whiskers, they work out whether the robot will fit through a space.

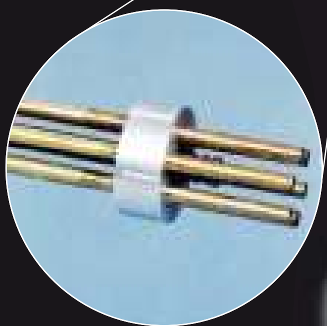
Microphone

▲ **The omnidirectional video camera** on top of the robot's head can pan, tilt, and zoom so it can focus on anything suspicious.

Alarm generates an extremely loud noise to deter intruders.

▲ **This optical range finder** checks doors in close proximity to Robart III are open, so it can safely pass through in an emergency situation.

One of the 16 sonars which protect the robot from collision



▲ **This pneumatic gun** can fire six rubber bullets or tranquillizer darts. It is controlled by the robot's arm, which has a rotating shoulder and wrist.

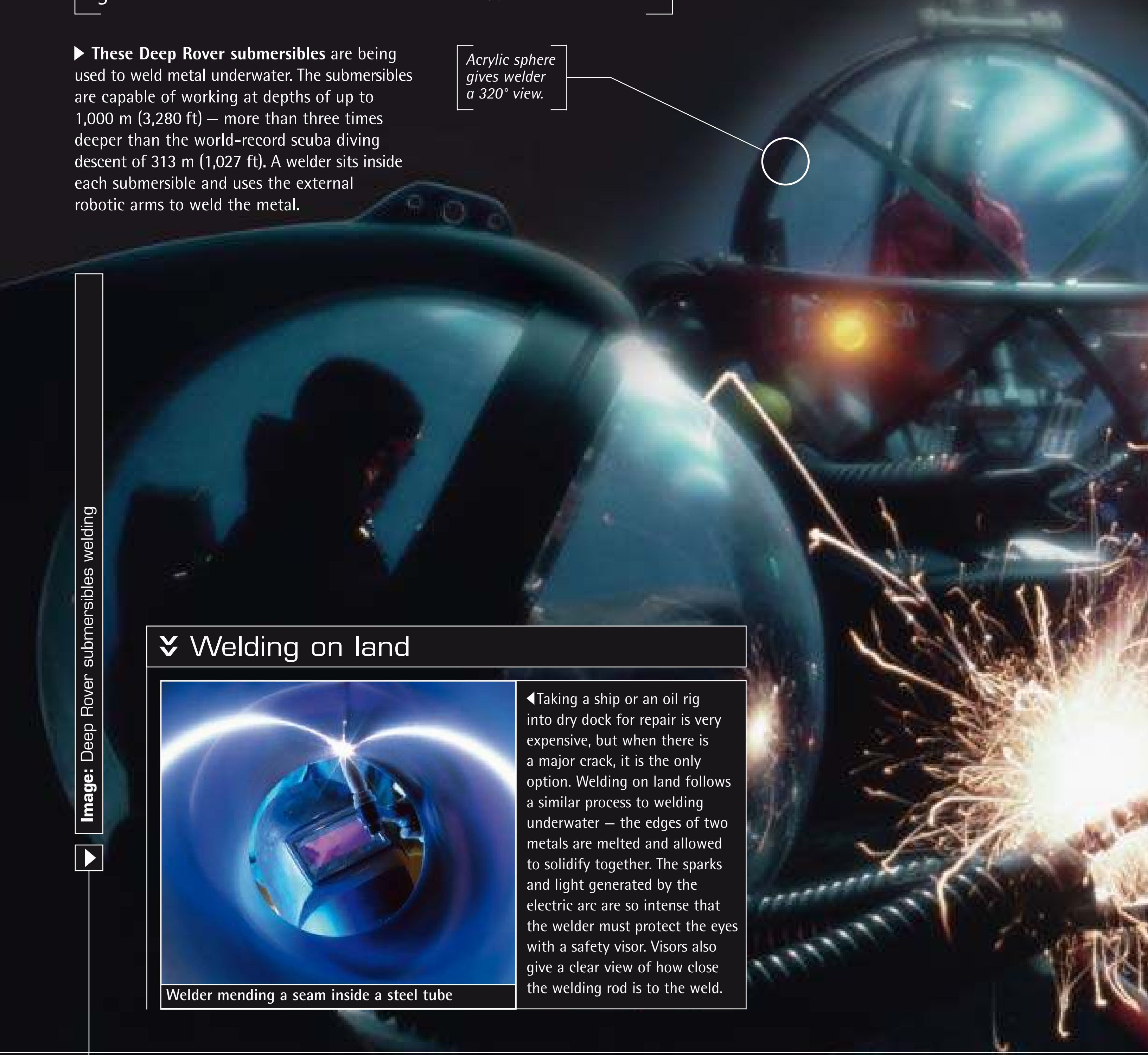
◀ **SLAM (Simultaneous Location and Mapping)**, shown blue, helps the robot keep track of its location. A laser gathers range and bearing information to determine the robot's position and prevent it from colliding into things.

▶▶ See also: Artificial intelligence p241, Robot helper p118

WET WELDING

Intense heat of up to 3,500°C (6,300°F) is used to melt and join metals. Wet welding uses a tiny electric arc to generate this extreme heat underwater.

These Deep Rover submersibles are being used to weld metal underwater. The submersibles are capable of working at depths of up to 1,000 m (3,280 ft) – more than three times deeper than the world-record scuba diving descent of 313 m (1,027 ft). A welder sits inside each submersible and uses the external robotic arms to weld the metal.



Acrylic sphere gives welder a 320° view.

Image: Deep Rover submersibles welding

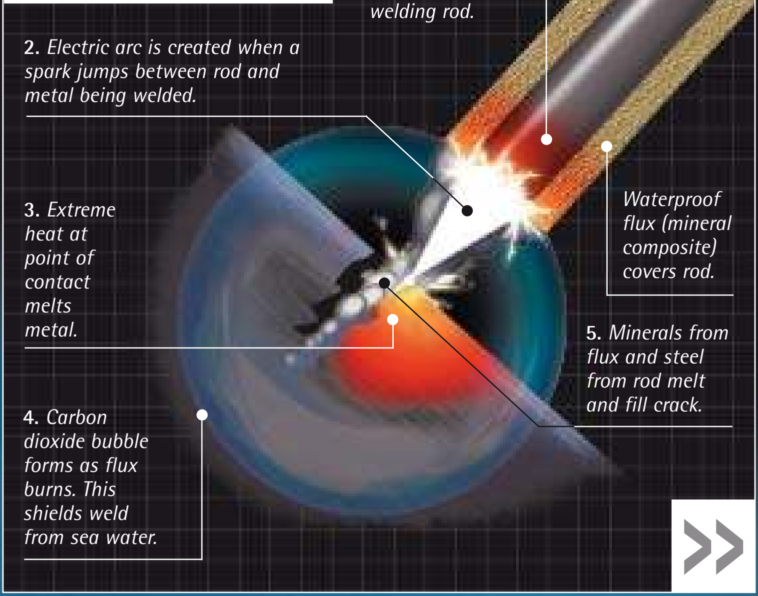
Welding on land

Welder mending a seam inside a steel tube

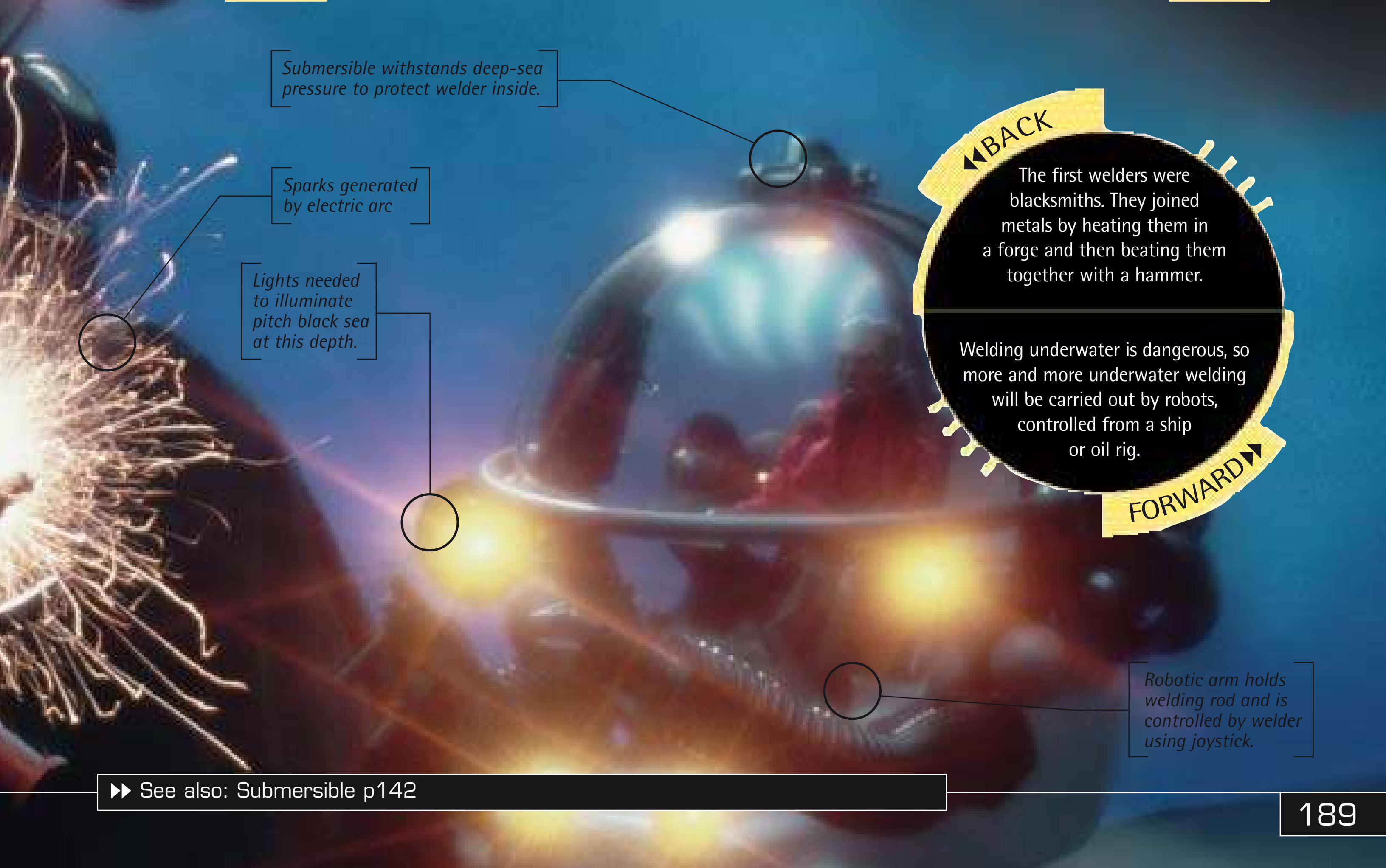
Taking a ship or an oil rig into dry dock for repair is very expensive, but when there is a major crack, it is the only option. Welding on land follows a similar process to welding underwater – the edges of two metals are melted and allowed to solidify together. The sparks and light generated by the electric arc are so intense that the welder must protect the eyes with a safety visor. Visors also give a clear view of how close the welding rod is to the weld.

» HOW WET WELDING WORKS

HOW METAL IS REPAIRED BY WELDING UNDERWATER



Underwater welding can repair vessels and rigs that have relatively small cracks in their metal structures. A generator on a ship or oil rig produces an electric current. This flows down a heavily insulated cable to the welding rod, and forms an arc of just a few millimetres to the metal being welded. The small carbon dioxide bubble that forms at the tip of the welding rod covers the crack that is being welded. The welder must keep the arc short. Otherwise the bubble would burst and the current would flow into the water and electrocute the welder. Fortunately, electric currents follow the shortest path, which lessens the risk to the welder.



◀◀ BACK

The first welders were blacksmiths. They joined metals by heating them in a forge and then beating them together with a hammer.

Welding underwater is dangerous, so more and more underwater welding will be carried out by robots, controlled from a ship or oil rig.

FORWARD ▶▶

▶▶ See also: Submersible p142

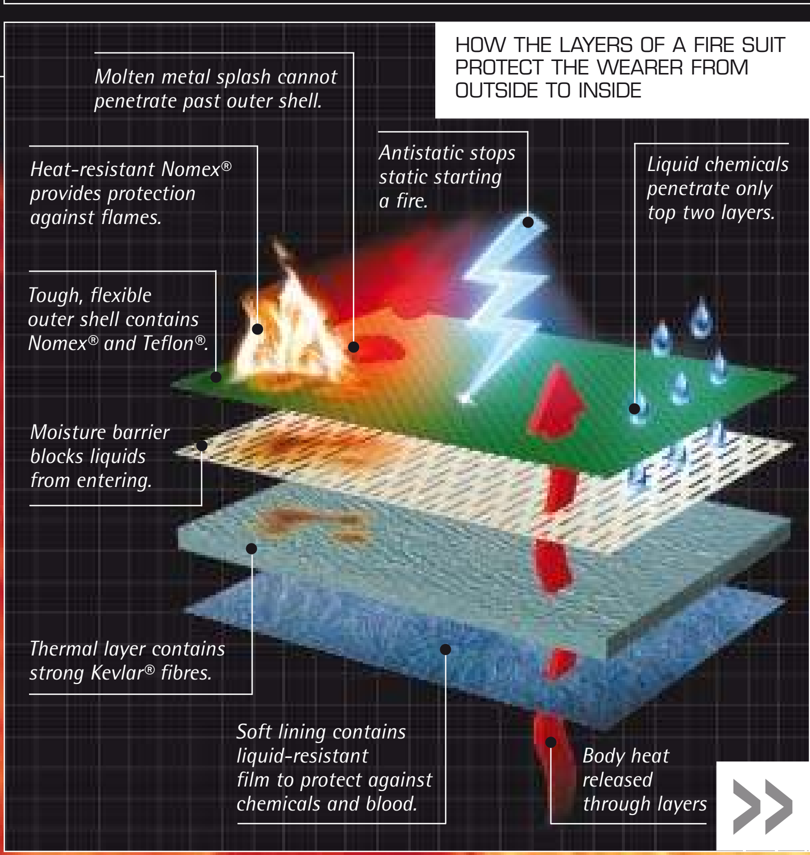
FIRE SUIT

▶▶ Firefighters depend on their fire suits for protection. They are made of multi-layered, synthetic fibres, capable of withstanding temperatures of up to 360°C (675°F). ▶▶

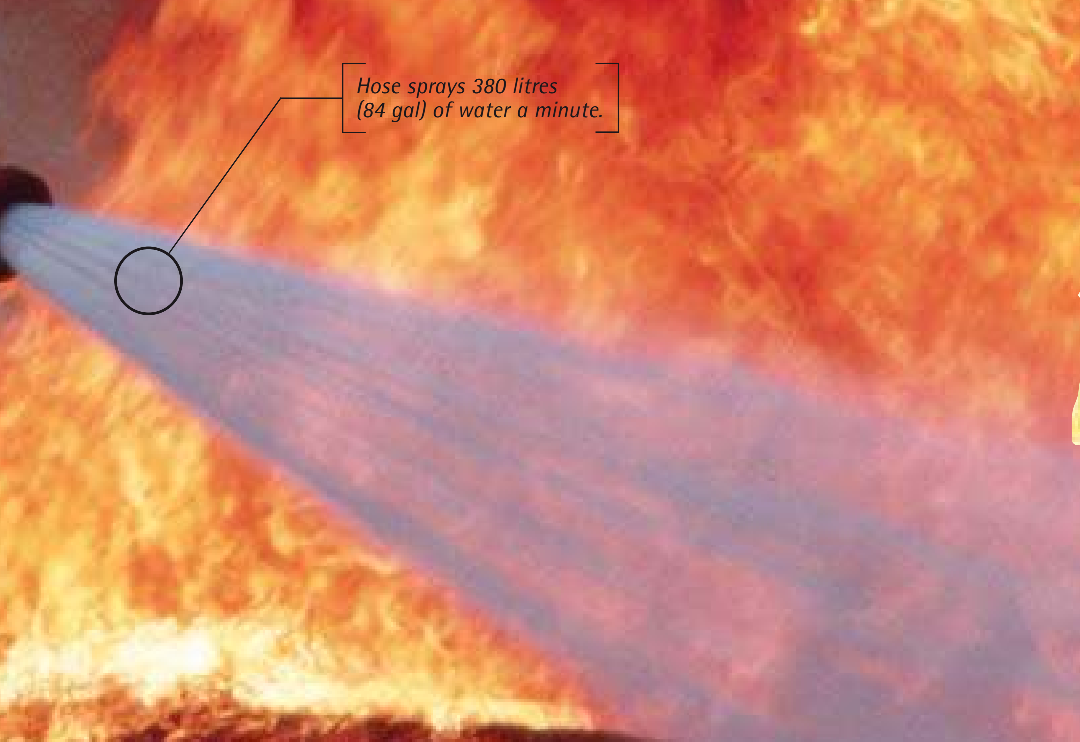
▼ **These two military firefighters** are involved in a practice session to put out fires at airports. Their protective clothing contains the heat-resistant material Nomex®, water-resistant Teflon®, and Kevlar®, which is stronger than steel and prevents the suits ripping or snagging.

Image: military firefighters putting out a blaze

HOW A FIRE SUIT WORKS



Burns can be life-threatening, so firefighters need to be fully protected when putting out a blaze. Fire suits, also called turnouts, contain protective fibres such as Nomex® and Teflon®. These fibres belong to a group of strong, heat-resistant, synthetic materials, known as aramids. They are also lightweight and flexible so the firefighter can move quickly and easily. The outer shell is water-resistant – to prevent steam building up inside the suit and causing serious injuries. The most important layer is the thermal layer, which provides about 73 per cent of the total heat protection of a turnout. Singes from flames cannot penetrate beyond this layer.



BACK

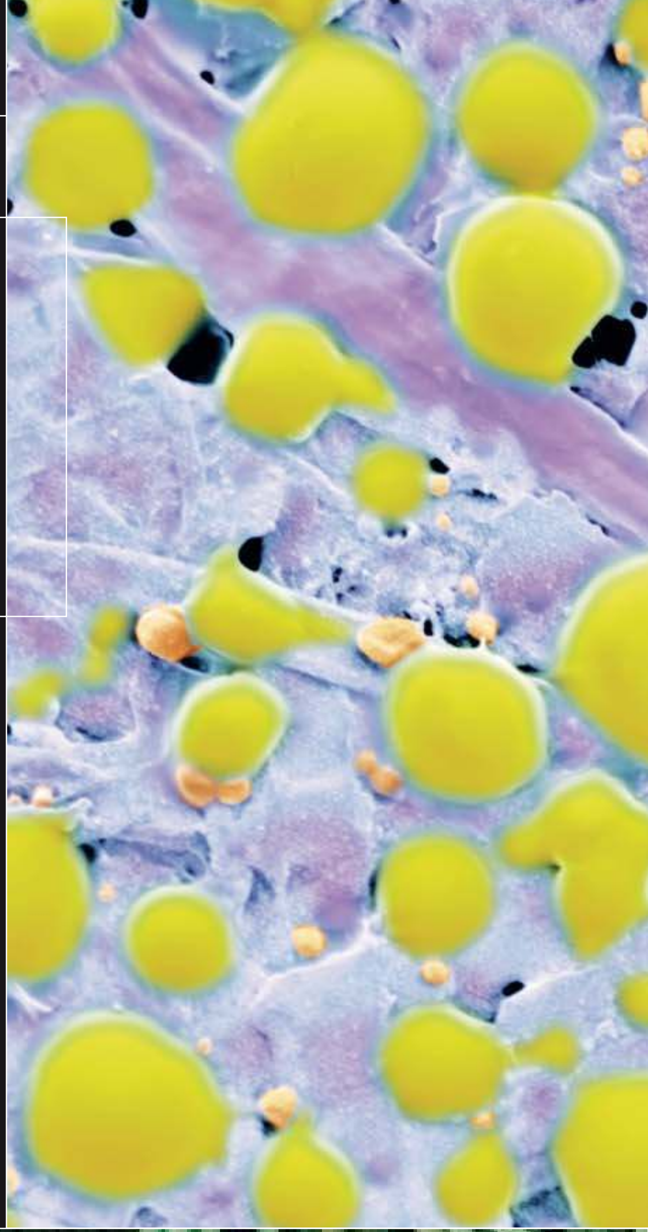
The first firefighters, known as *vigiles*, were introduced by the Roman emperor Augustus in 24 BC.

The next generation of fire suits will be resistant to toxic chemicals and biological warfare agents, such as anthrax.

FORWARD

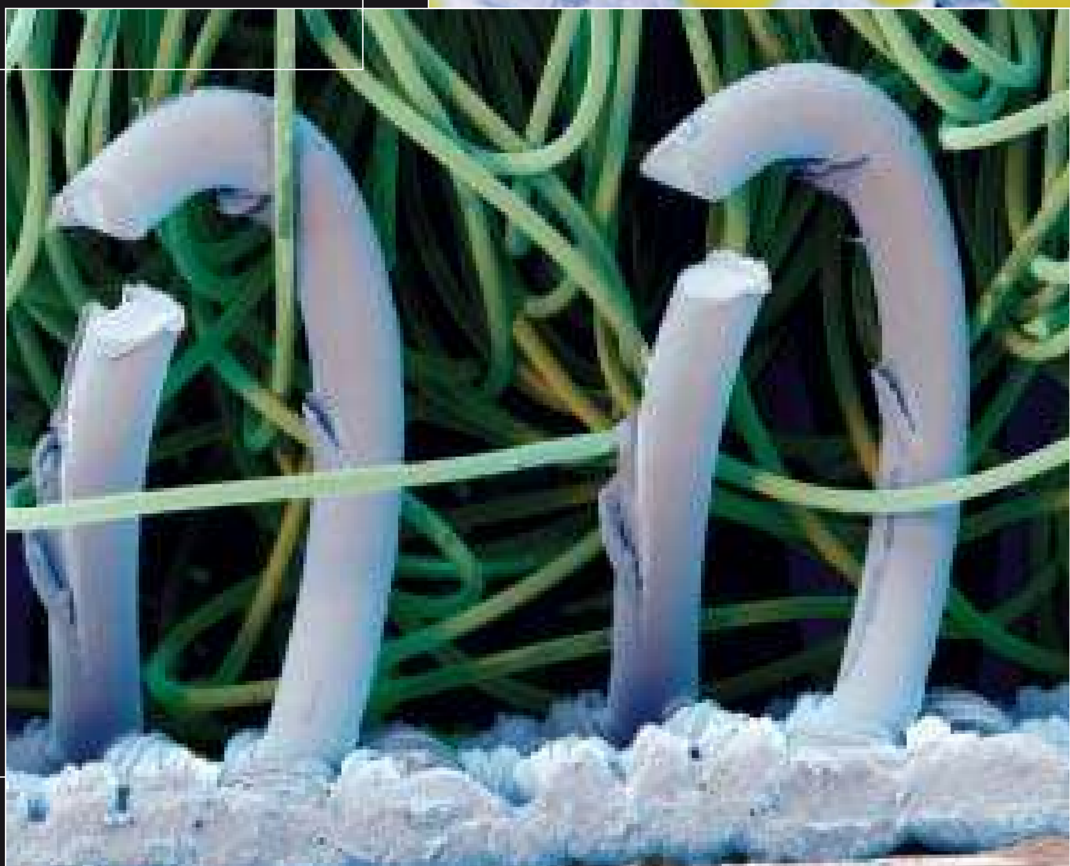
See also: Crash test p134, Heat p98

GLUES

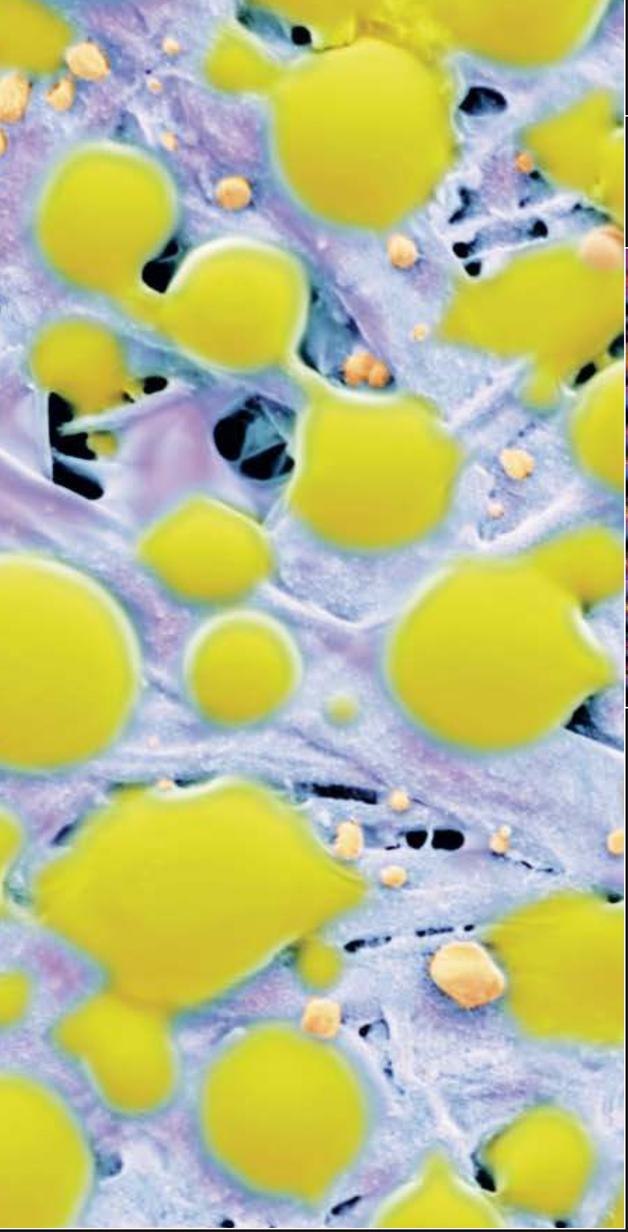


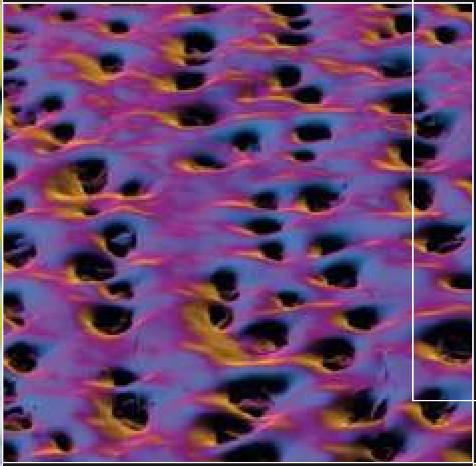
Post-it® Note
These yellow blobs are bubbles of glue on the adhesive strip of a Post-it® Note. When the note is pressed against a surface, some of the bubbles pop and the glue is released. There are so many bubbles on each strip that a Post-it® Note can be used several times.

Velcro®
Swiss inventor George de Mestral came up with the idea of Velcro® when he saw prickly seeds, called burrs, stuck to his trousers. Under a microscope, the tiny hooks of the burrs clung to the small loops of the fabric. Made of nylon, Velcro® has hooks on one side and loops on the other. When pressed together, the hooks fasten to the loops and form a bond.



For as long as humans have made objects, they have looked for ways to stick materials together. The earliest glues were tar and resin. Today, a wide range of different types of adhesives is in regular use.





Plaster

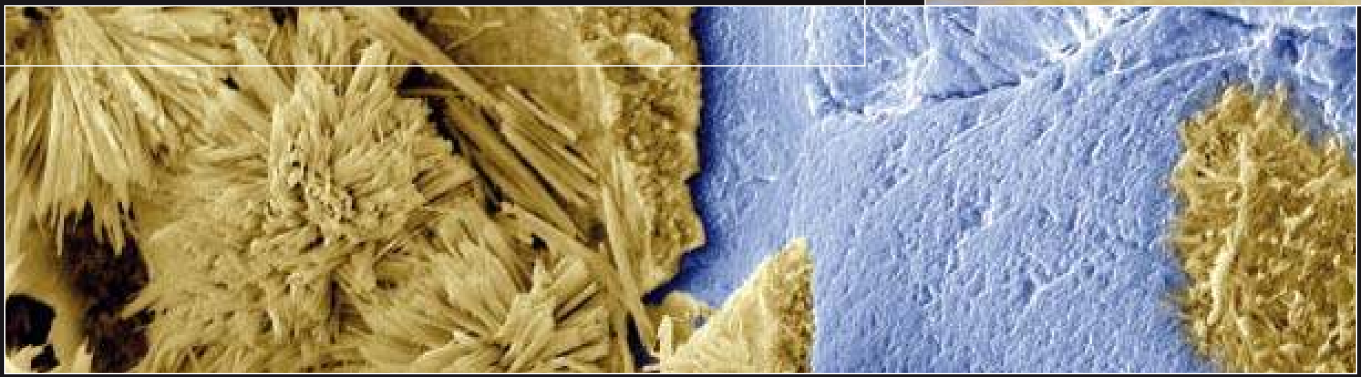
Adhesive plasters cover and protect most minor wounds and injection sites. Gaps in the glue, shown in black, let the skin breathe. Plasters are sterile and most are individually wrapped. They come in a range of materials, including waterproof and fabric adhesive dressings.

Glue

About 4,000 years ago, the Egyptians used animal hides to make glue to join wood together. Although hide glues are still used, synthetic glues are also available today, such as super glue. Made from a synthetic, acrylic resin, it is far stronger than hide glue.

Cement

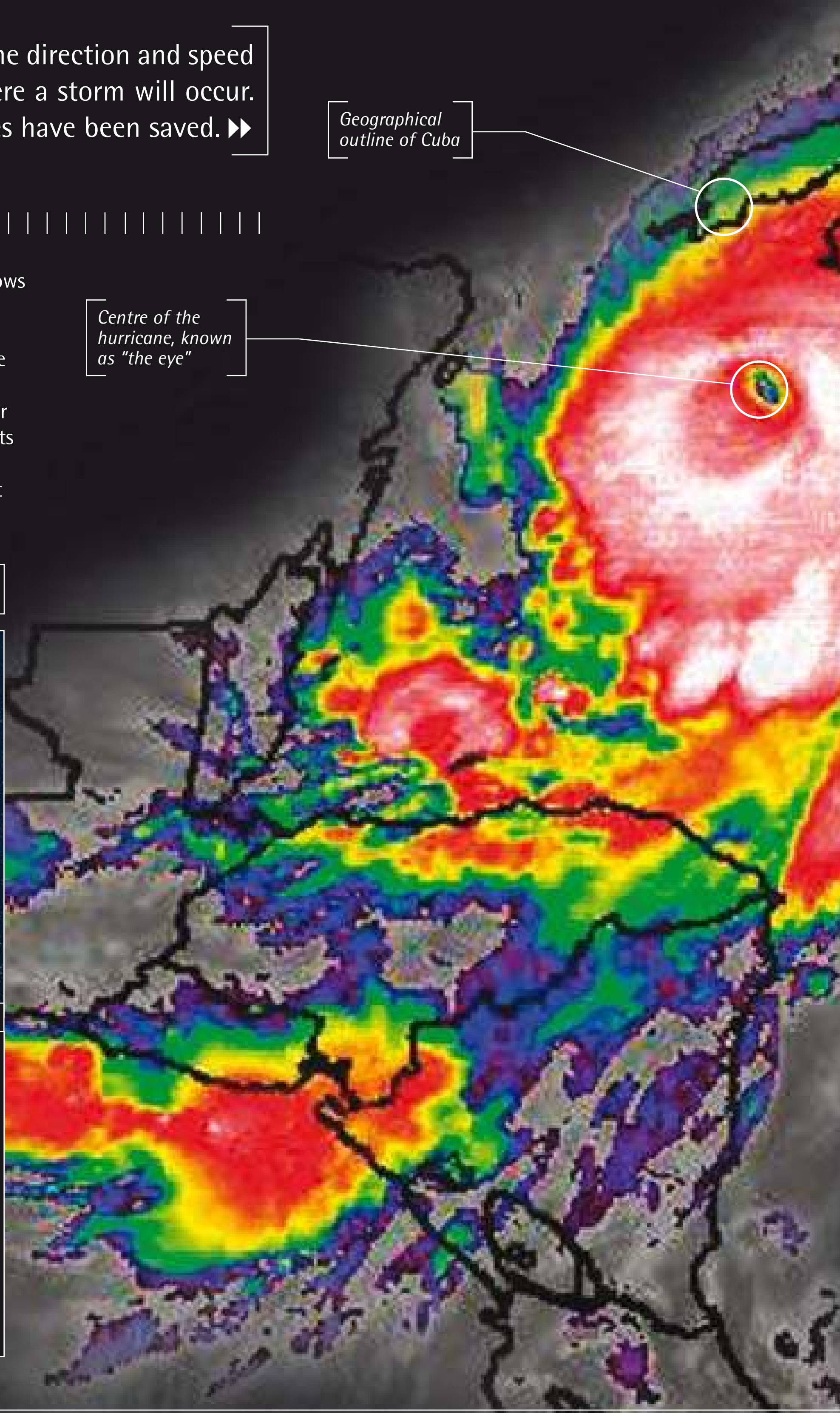
Each year, 1.2 billion tonnes of cement is produced. Cement is a dry powder that hardens when mixed with water. It is used to bond building materials and is the main ingredient of concrete, together with gravel, water, and sand. As concrete (blue) dries, it hardens to form crystals (brown).



See also: Fabric p60

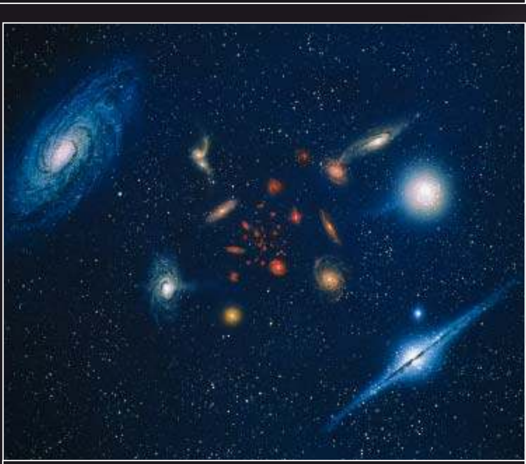
DOPPLER RADAR

Doppler radar is used to work out the direction and speed of moving objects. It can predict where a storm will occur. With this advance warning, many lives have been saved.



This Doppler radar image shows Hurricane Ivan heading towards Cuba in September 2004. Ivan reached 165 mph (270 km/h), the sixth strongest storm ever to hit the Atlantic Ocean. Doppler radar images are used by meteorologists to determine a storm's wind speed, direction, and the amount of rainfall to expect.

Red shift



Galaxies moving away from us appear redder

▲The difference in pitch between an object that is moving away from you and one that is moving towards you is due to the Doppler effect. When a police car comes towards you, the sound waves made by its siren are bunched up, making it sound higher-pitched. When it moves away, sound waves spread out and the noise is lower-pitched. The Doppler effect also applies to light waves. Astronomers use it to find out whether celestial objects are moving away or towards Earth. Light from objects moving away appears redder, called red shift, and light from those moving closer appears bluer, called blue shift.

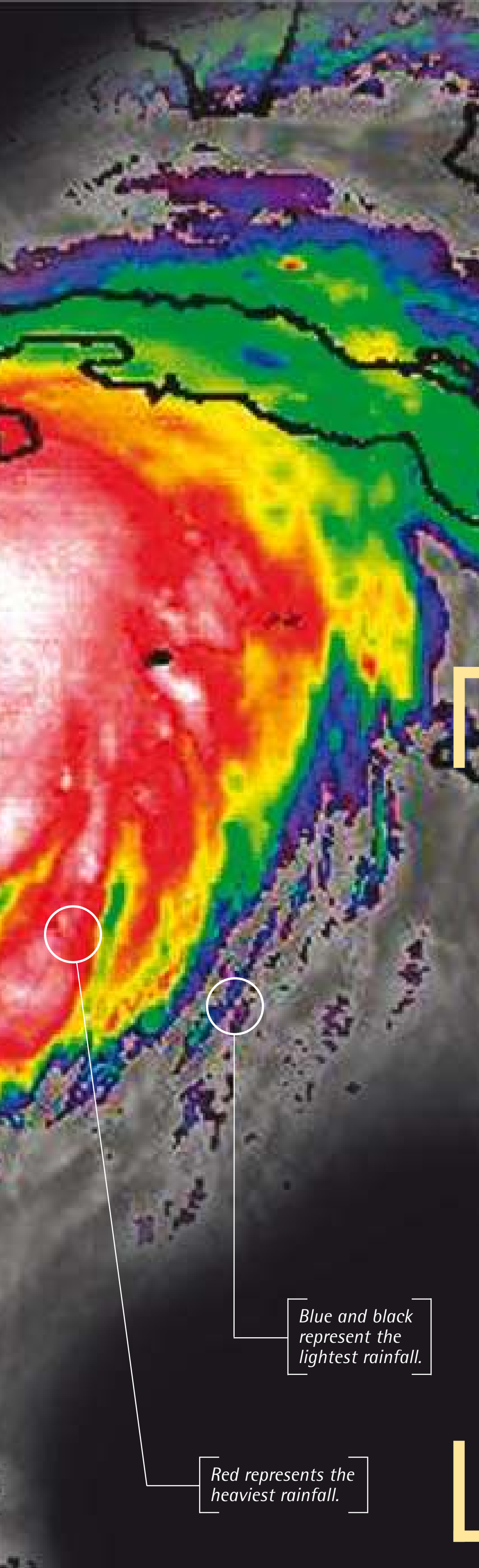


Image: radar image of Hurricane Ivan

BACK

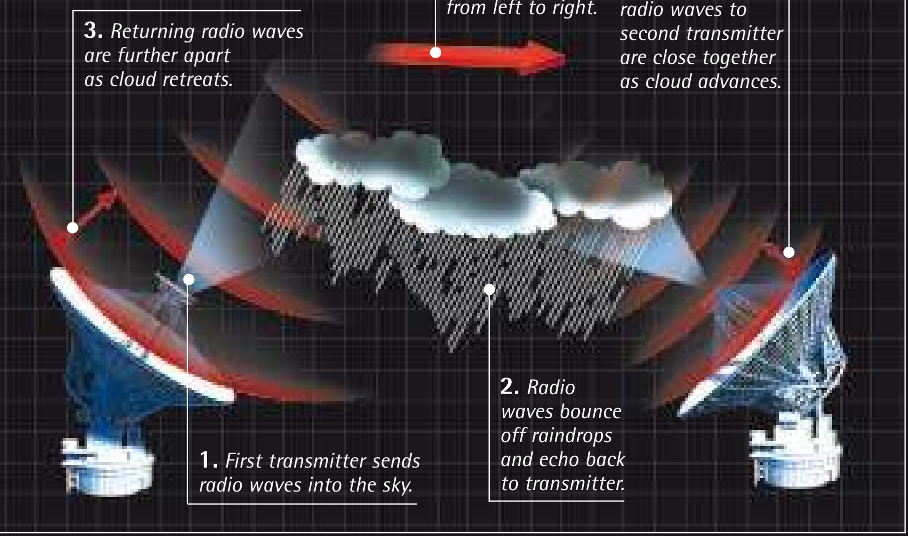
In 1842, Austrian physicist Christian Doppler devised the term Doppler effect to explain why the whistles of approaching and departing trains sound different.

The next generation of Doppler radar antennae are called phased-array. Phased-array antennae can track more sky and provide sharper images.

FORWARD

HOW DOPPLER RADAR WORKS

HOW RADIO WAVES ASSESS THE DIRECTION AND SPEED OF A STORM



Doppler radar is best known for its use in weather forecasting, but it started life as a military technology. The radar was used to detect and track enemy aircraft. Commercial airliners use Doppler radar to avoid a dangerous weather condition known as wind-shear – a sudden, dramatic change in wind direction. Doppler radar "guns" are carried by traffic police to record the speed of vehicles. These can also be used in sport to calculate speeds, such as the speed of a tennis ball.

See also: Digital radio p22, Mobile phone p18, Radio waves p249, Voice recognition p28

Although the invention of the internal combustion engine and the development of the car was the end of the horse and carriage industry, it created in its place a whole new industry. New kinds of jobs emerged, from production line workers to petrol station attendants. In a similar way, new industries and jobs, driven by the information technology revolution, are rapidly emerging. Already, the video games industry is bigger than the cinema box-office industry. And exciting fields such as nanotechnology, robotics, and new materials technology will rapidly expand as the century progresses.

> "As future robots become increasingly agile and intelligent, many more life-threatening jobs will be carried out remotely."

The ability to perform our jobs more efficiently will rely increasingly on special, so-called smart software. These complex computer programs will make decisions for us using artificial intelligence to learn about our preferences. Smart software will look after many of the day-to-day time-consuming tasks – such as prioritizing e-mail, putting through important phone calls while screening others, and automatically updating our schedule.

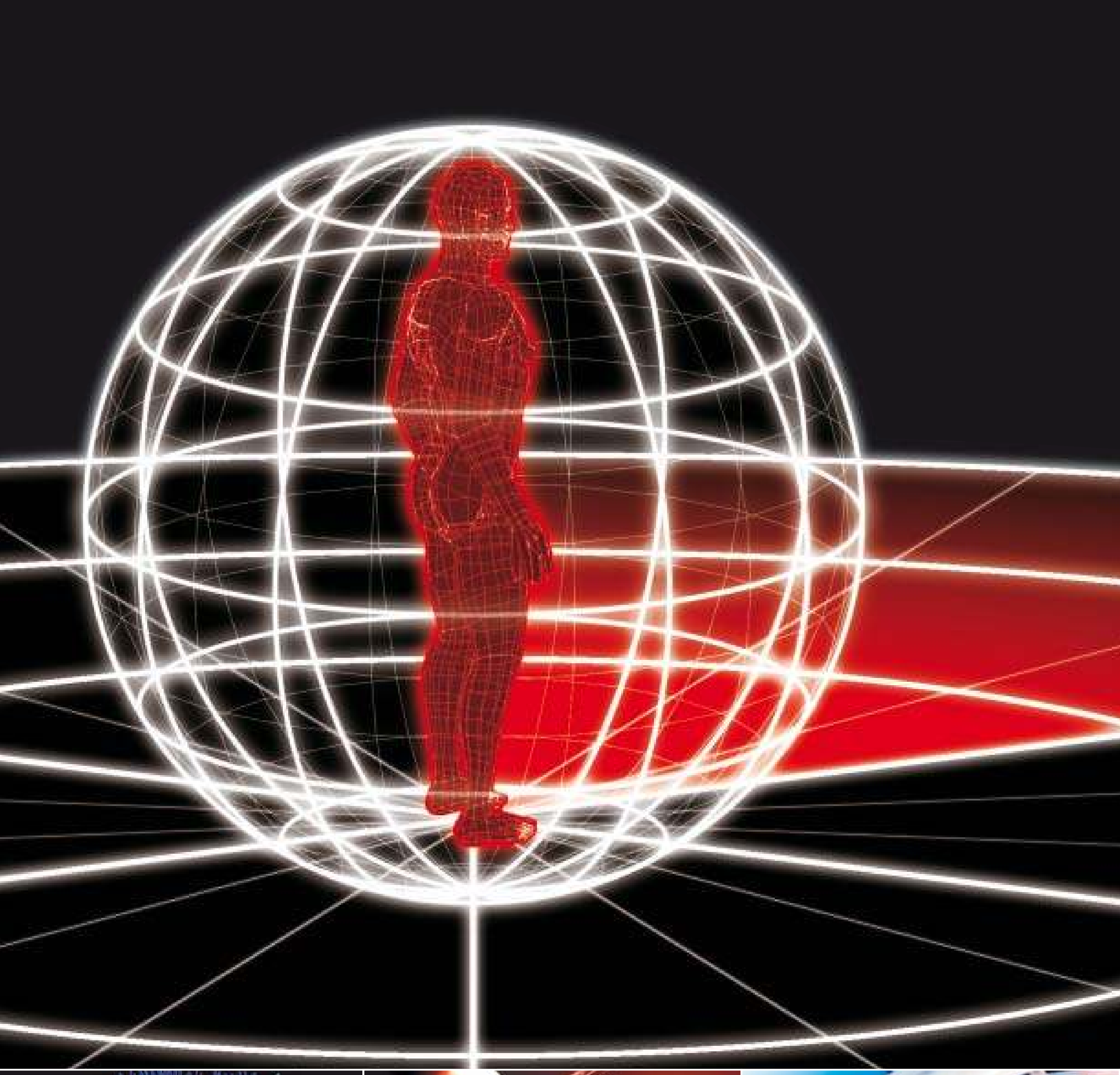
Artificial intelligence will also drive the development of expert systems. These will draw together all the knowledge of human experts in a particular field, automatically updating themselves with the latest information. Whether you are a doctor, an astronomer, or a journalist, expert systems will guide you through the most complex questions and issues. Voice recognition and digital talking heads on screen will give smart software and expert systems virtual personalities. This will make the way you communicate with the computer a much more user-friendly experience.

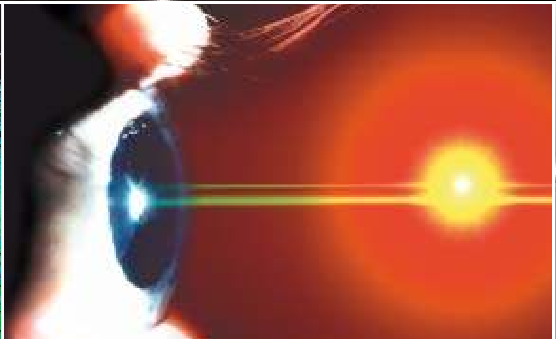
As future robots become increasingly agile and intelligent, many more life-threatening jobs will be carried out remotely. Already robots are used for bomb disposal and for carrying out tasks inside nuclear reactors where the high radiation levels would harm human beings. Over the next few decades, we will begin to see the use of robots that can be sent into fires to help save lives, and the introduction of robonauts – robots that can perform increasingly complex experiments and other tasks in the hostile environment of space.

This combination of robotics and communications can be used in all kinds of ways. Remote surgery is already a reality, with doctors carrying out operations using robots that may be thousands of miles away. Many other tasks will be done in this way. Instead of having to work in hazardous conditions, skilled operators will control machines for mining, construction, or even exploring other planets from the safety of their offices.

The technology revolution will continue until we can no longer replace human function with technological advancements. However, the drive towards advancing technologies means that employees need training to keep up with these developments in order to stay useful in the workplace.

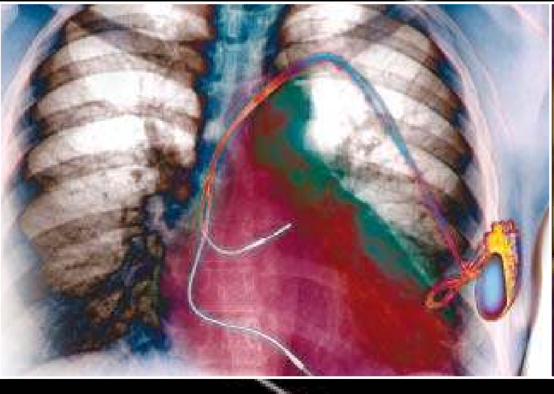
CONCEPT ARTWORK OF ARTIFICIAL INTELLIGENCE

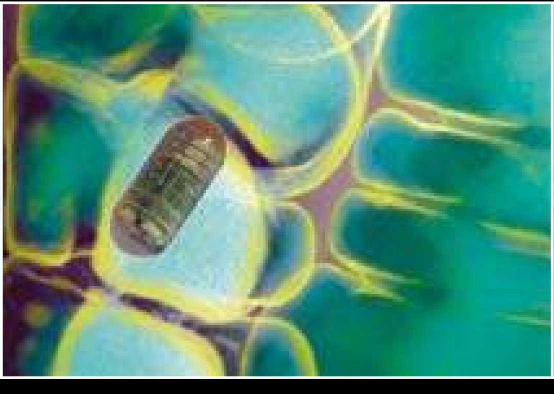


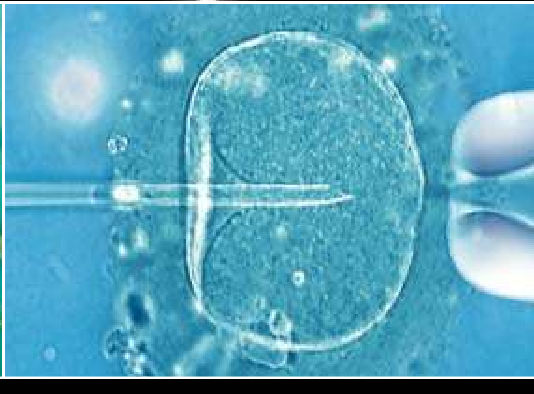



>>SURVIVE

MRI scan >> Laser surgery >> Robot surgery >> Pacemaker >> Camera capsule >> Bionic limbs >> Skin graft >> Vaccination >> Antibiotics >> IVF >> Biochip







Sometimes the simplest of technologies are the most important. One of these is soap, which has had a major impact on human health and civilization. Soap, in the form that we use today, was invented in the late 1700s. It is made of long molecules that stick to dirt at one end and water at the other, allowing us easily to remove dirt and harmful bacteria from our bodies. This has greatly reduced illness and disease.

A type of soap was used by the Ancient Romans. Along with the Ancient Greeks, the Romans provided the foundations for modern medicine, developing surgical instruments that are still used today and a more scientific approach to illness. In other ancient cultures, medicine was based on a combination of magic, herbal remedies, and primitive surgery. Illnesses were thought to be caused by evil spirits and treatment was usually carried out by a priest or a magician. In one headache cure, called trepanning, a hole was made in the patient's skull. Some remedies were effective in curing common ailments, but most were hit and miss.

ELECTRON MICROGRAPH OF COLD VIRUS

The development of the microscope in the 1600s revolutionized medical understanding. This tool, consisting of finely polished curved lenses, led to the discovery of bacteria and blood cells. People began to think of the body as a series of mechanical and chemical processes, no longer an object animated by mysterious spirits. The development of vaccinations in the late 1700s meant that for the first time doctors could combat infectious diseases such as smallpox. Other breakthroughs transformed medicine in the following century. Antiseptics, used to clean wounds and surgical instruments, dramatically reduced the number of deaths from infection. Anaesthetics, which made operations free from pain, allowed surgeons to take much more time and care during difficult procedures.

> “Major developments in medical imaging technology mean doctors can see inside the body in incredible detail.”

The discovery of X-rays at the end of the nineteenth century provided a way to see through human tissue without surgery and to examine, for example, broken bones. Today, modern scanning techniques such as ultrasound and magnetic resonance imaging (MRI) have given doctors an even greater understanding of the human body. Many other areas of medicine have also been transformed by technology. Robotic aids enable surgeons to carry out extremely complex operations while causing a minimum of damage to the patient. And using highly automated techniques in laboratories and powerful computers, scientist have mapped the 20-25,000 human genes that make up the blueprint for each and every one of us.

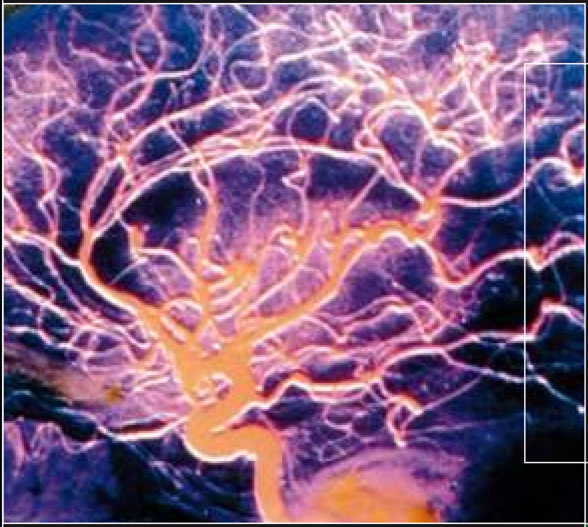
Despite the various advances in medicine over the last century, cures have not yet been found for many diseases, ranging from HIV/AIDS to the common cold. The brain also remains largely a mystery to us. Technology, however, is beginning to provide some answers. As scanning techniques become even more sophisticated, scientists are learning even more about the body and understanding how it works in greater detail.

SCANS

Medical imaging technology allows doctors to look inside the human body without making a single cut. Recent advances in image processing mean doctors can see many internal structures in detailed, three-dimensional (3D) form.

Full body MRI Unlike X-ray images, MRI (magnetic resonance imaging) scans reveal soft body tissues. As well as the skeleton (yellow), this scan shows the muscles (pink), brain tissue (green), lungs (red), and liver (below the lungs). The scanner detects electromagnetic signals emitted when hydrogen atoms in the body are knocked out of magnetic alignment. These signals are used to create an image on a computer.

Hand X-ray X-rays reveal hard structures inside the body, such as bones and teeth. This makes them ideal for diagnosing fractures, bone diseases, and tooth decay. They are produced by shining X-rays (a form of electromagnetic radiation) through the body and onto a photographic plate.

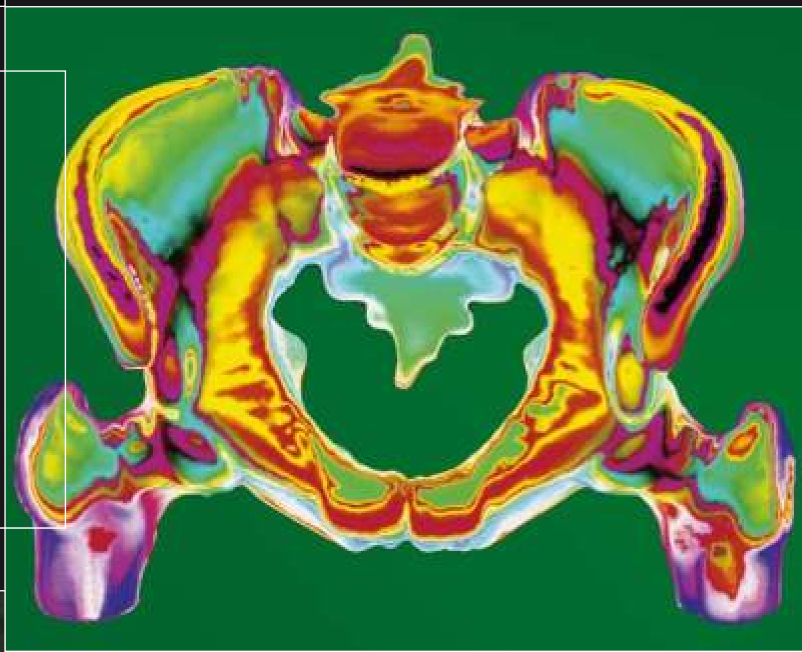


Cerebral angiogram

To search for abnormalities in blood vessels, doctors take a rapid series of X-rays after injecting a person with a dye that is radiopaque – opaque to X-rays. In the resulting images, called angiograms or arteriographs, blood vessels stand out brightly. This cerebral angiogram shows the network of blood vessels in a brain (cerebrum). Doctors use angiograms to look for aneurysms – dangerous swellings in blood vessels.

CAT scan of pelvis

A CAT (computed axial tomography) or CT scan is a 3D image compiled by computer from a series of X-rays taken by a machine that rotates around the body. This scan shows the bones of a normal adult pelvis. The pelvis is made of six separate bones that fuse together as you grow. It acts as a bridge between the spine and legs.



Ultrasound

Of all medical imaging technologies, ultrasound scanning poses the least risk to health. That is why it is used to produce images of unborn babies. Ultrasound scanners send high-frequency sound waves through the body. Returning echoes are recorded and used to create an image. Most ultrasound scanners produce a single-slice image, but the latest scanners take multiple slices to produce a 3D image. Unlike other scanners, ultrasound produces a live, moving image on screen.

▶▶ See also: Imaging techniques p10, MRI p204, X-Rays p251

MRI SCAN

A magnetic resonance imaging (MRI) scanner uses powerful magnets and radio waves to create images of soft tissues inside the body. The tube-shaped magnet produces a magnetic field up to 40,000 times more powerful than the Earth's.

This MRI scan highlights the major pathways that carry nerve signals through the brain. The coloured strands are the brain's main cables, each containing thousands of long, thin fibres. Each fibre is part of one brain cell, and together they form the brain's white matter. They carry billions of electrical signals between brain cells, and between brain and nerve cells.

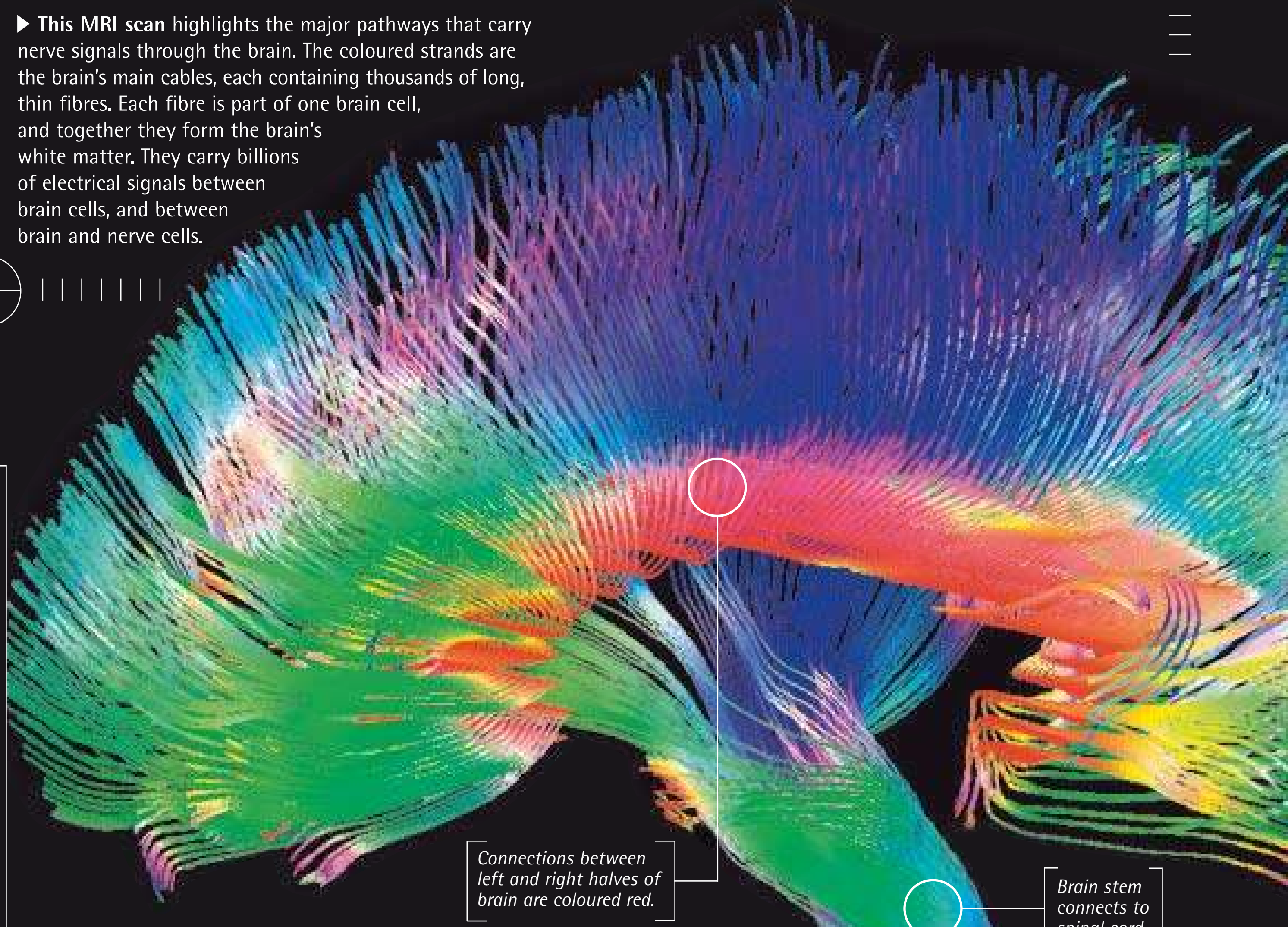
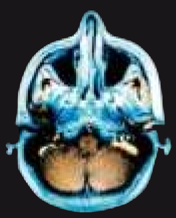


Image: false-colour MRI scan of the brain's nerve pathways

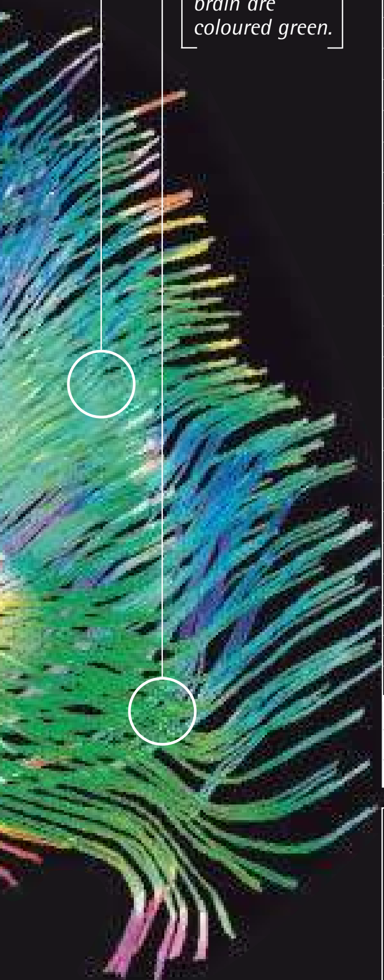


Bottom of brain

Middle of brain

Top of brain

MRI scanners can "slice" through the body, producing images at any depth. To do this, three additional magnets are used. These gradient magnets create variations in the magnetic field along precisely positioned planes through the body. The scanner reads signals from these planes, and a computer processes the signals to create an image.



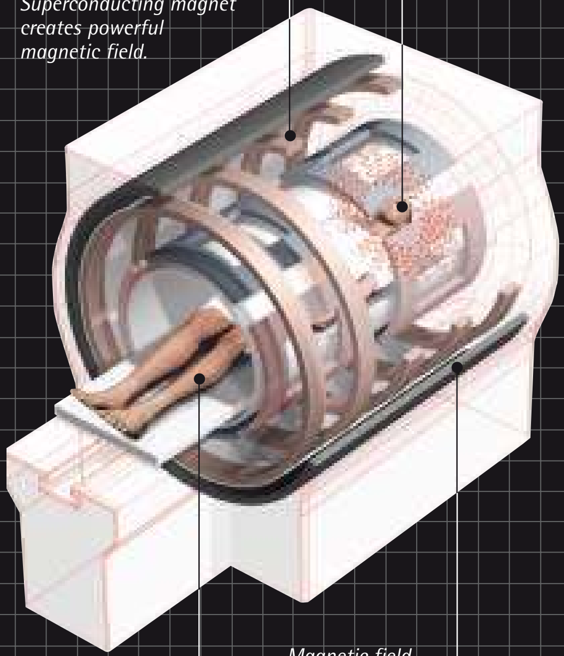
These pathways carry signals from eyes to visual centre at back of brain.

Connections between front and back of brain are coloured green.

Spinal cord transmits information between brain and rest of body.

HOW AN MRI SCANNER WORKS

HOW MRI SCANNERS USE MAGNETIC FIELDS AND RADIO WAVES TO BUILD IMAGES OF SOFT BODY TISSUES



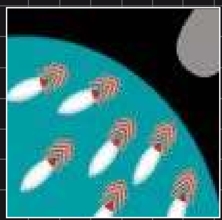
Superconducting magnet creates powerful magnetic field.

Patient lies in bore (hollow centre) of magnet.

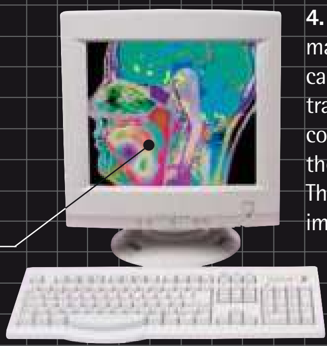
Magnetic field runs along length of scanner.

1. Hydrogen atoms in the body are usually randomly ordered, but the powerful magnetic field makes them line up like tiny magnets.

2. A pulse of radio waves produced by the scanner knocks the hydrogen atoms out of their new magnetic alignment.



3. As the radio waves cease, the atoms realign and emit faint radio signals that are detected by a sensor. The sensor sends signals as digital data to a computer.



Findings of MRI scan are processed on a computer.

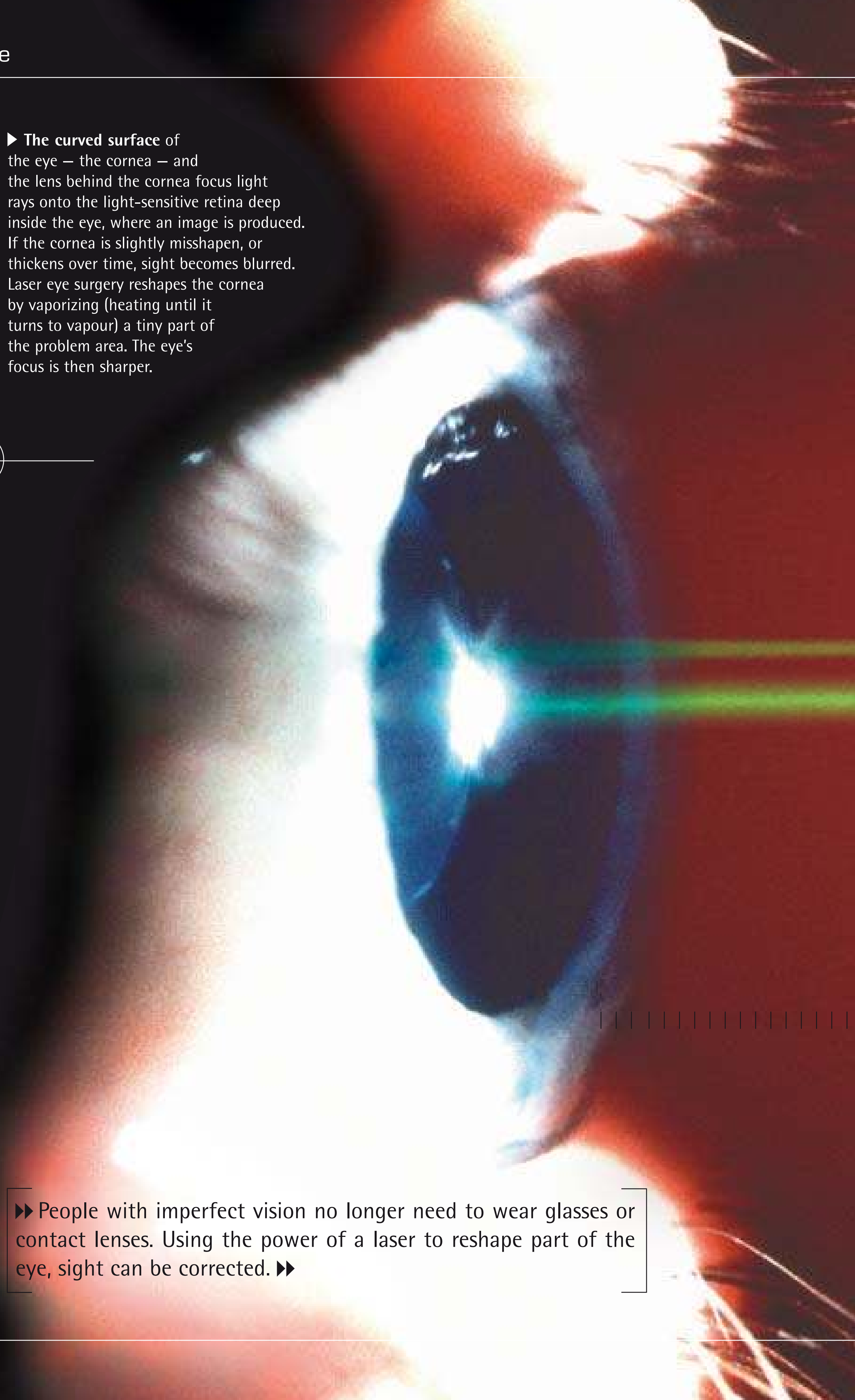
4. Using a complex mathematical process called a Fourier transformation, the computer converts the data into an image. The brightness of the image can be varied by alternating the magnetic field.

Unlike an X-ray, which reveals hard substances like bone and teeth, an MRI scan creates images of soft body tissues. This makes it ideal for detecting abnormal tissues such as tumours and haemorrhages. MRI is the most common technique for scanning brains, but it can be used to scan any soft tissues in the body. The image is built up from faint radio signals emitted by hydrogen atoms, which are found in all body tissues. Since the signals vary from one type of tissue to another, the image produced by the scanner can distinguish between different tissues, revealing details as small as 1 mm (0.03 in) wide. Although MRI scanners do not produce any harmful radiation, the powerful magnet is hazardous if loose metal objects are present – they are pulled with such force that they hurtle across the room like missiles. The world's first MRI scan took place on 3 July 1977, following seven years of preparation. The image took five hours to produce. Today, it takes seconds to compile an image.

See also: Imaging techniques p10, Magnets p246, Scans p202

LASER SURGERY

The curved surface of the eye – the cornea – and the lens behind the cornea focus light rays onto the light-sensitive retina deep inside the eye, where an image is produced. If the cornea is slightly misshapen, or thickens over time, sight becomes blurred. Laser eye surgery reshapes the cornea by vaporizing (heating until it turns to vapour) a tiny part of the problem area. The eye's focus is then sharper.



People with imperfect vision no longer need to wear glasses or contact lenses. Using the power of a laser to reshape part of the eye, sight can be corrected.

Lasers

Most light consists of a mixture of wavelengths. However, a laser is an intense, narrow beam of light that consists of a single wavelength, such as ultraviolet (UV) or infrared. Since lasers were first discovered in 1960, they have found many uses, including guiding missiles, removing tattoos, and reading the data on CDs.

Laser reflector on the Moon

A laser beam is aimed at the Moon

When astronauts from the *Apollo 14* mission landed on the Moon in 1971, they left a laser reflector. Scientists sent laser beams up to the reflector and measured the Moon's distance from Earth to within 3 cm (1 in). They worked out the distance by timing how long it took for the reflected beam to return to Earth.

BACK

Before laser eye surgery became widespread, surgeons could correct vision by making a series of spoke-like slits in the cornea with a scalpel.

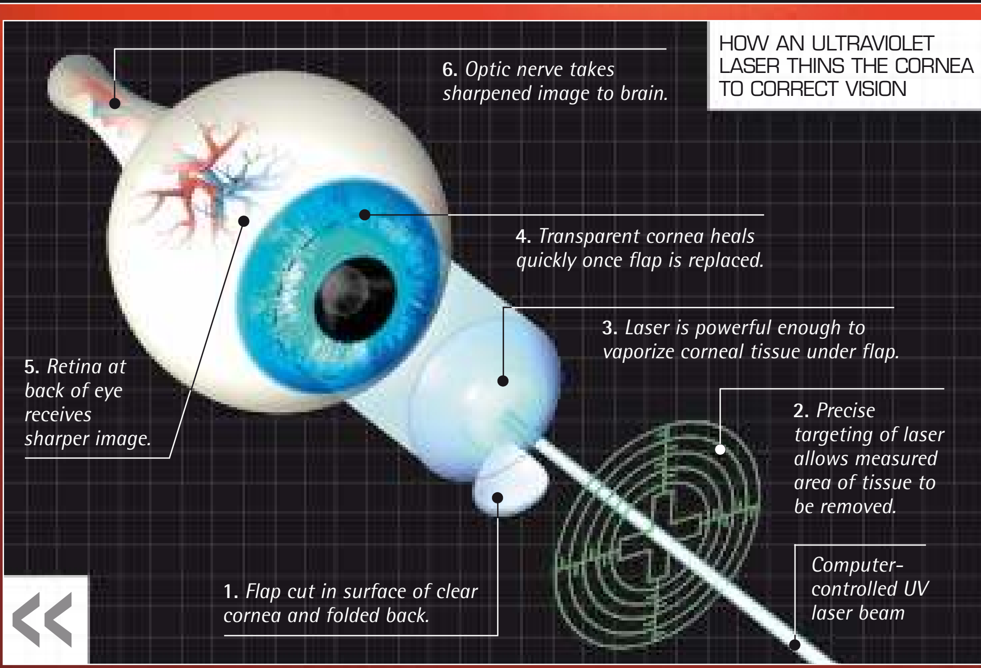
Surgeons may use a strong jet of fluid rather than a blade to cut the cornea flap prior to laser treatment.

FORWARD

Image: macrophoto of the human eye

HOW LASER EYE SURGERY WORKS

The cornea's shape is precisely mapped by a computer which calculates exactly how much tissue needs to be removed. The computer controls the ultraviolet laser to these specifications. A fine knife, a microkeratome, is used to cut a flap in the cornea's surface. The flap is folded aside, and the laser is aimed at the tissue behind. The laser does not penetrate the eye, but gently vaporizes the corneal tissue, making it thinner. The flap is folded back, which helps the eye to heal quickly without stitches. The patient can usually see straight away.



See also: Iris scan p32, Laser p246, Laser printer p176

ROBOT SURGERY

▶▶ Robotic arms enter the body through tiny incisions and perform delicate surgical procedures with complete precision. The robot is operated by a surgeon, using a remote-control system. ▶▶

▶ These robotic arms are performing a delicate procedure used in heart surgery on a model of the human chest. The arms pass between the ribs, with no need for a major incision. In 1999, this robot, called Zeus, was used to repair blood vessels on the surface of a beating heart.

◀◀ BACK

Surgical robots were invented in the 1980s. They combined robotic arms with surgical viewing devices called endoscopes.

The high-speed transmission of computer images and data makes it possible for doctors to carry out robot surgery on patients in hospitals thousands of miles away.

FORWARD ▶▶

Stitching ants

A biting ant sinks its jaws into a fingertip

▲ Although surgical procedures are increasingly sophisticated, wounds are still closed using the ancient technology of stitches. Rainforest people in Central America used the jaws of biting ants as tiny clamps to close wounds. Modern stitches are mostly made of synthetic fibres such as nylon or polyester.

HOW ROBOT SURGERY WORKS

A surgical robot has two main parts: a robotic arm unit, which is positioned over the patient, and a control console several feet away. During an operation the surgeon sits at the console, watching the procedure through a magnified viewfinder and guiding the robot arms with his hands. Assistants and an anaesthetist may also be present.

A camera attached to one of the robot's arms takes images inside the incision and relays them to the magnified viewfinder, which creates sharp, 3D images. The view is much clearer than is possible with the naked eye. The surgeon's hand movements are translated by sophisticated joysticks into far smaller, precise movements of the robotic arms. The system can eliminate any tremors in the surgeon's hands and improve accuracy.

The stainless steel robot arms enter the skin through three small incisions, each no wider than a pencil width. While the camera at the tip of one arm films the operation, other surgical instruments are used to cut, hold, and stitch. When not in use, the arms are rock steady. This reduces the level of trauma for the patient.

▶▶ See also: Camera capsule p212, Robot helper p118, Robot worker p186

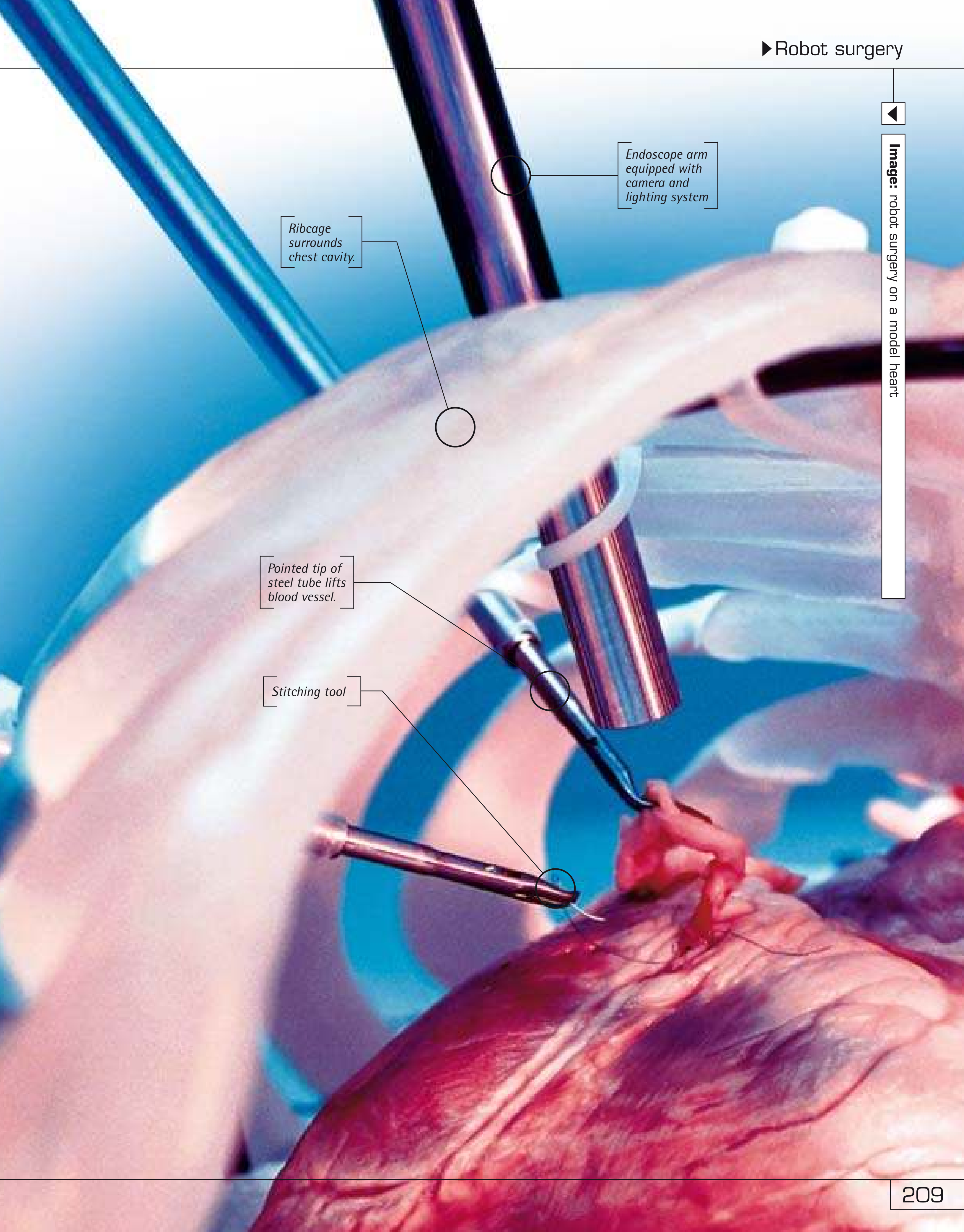
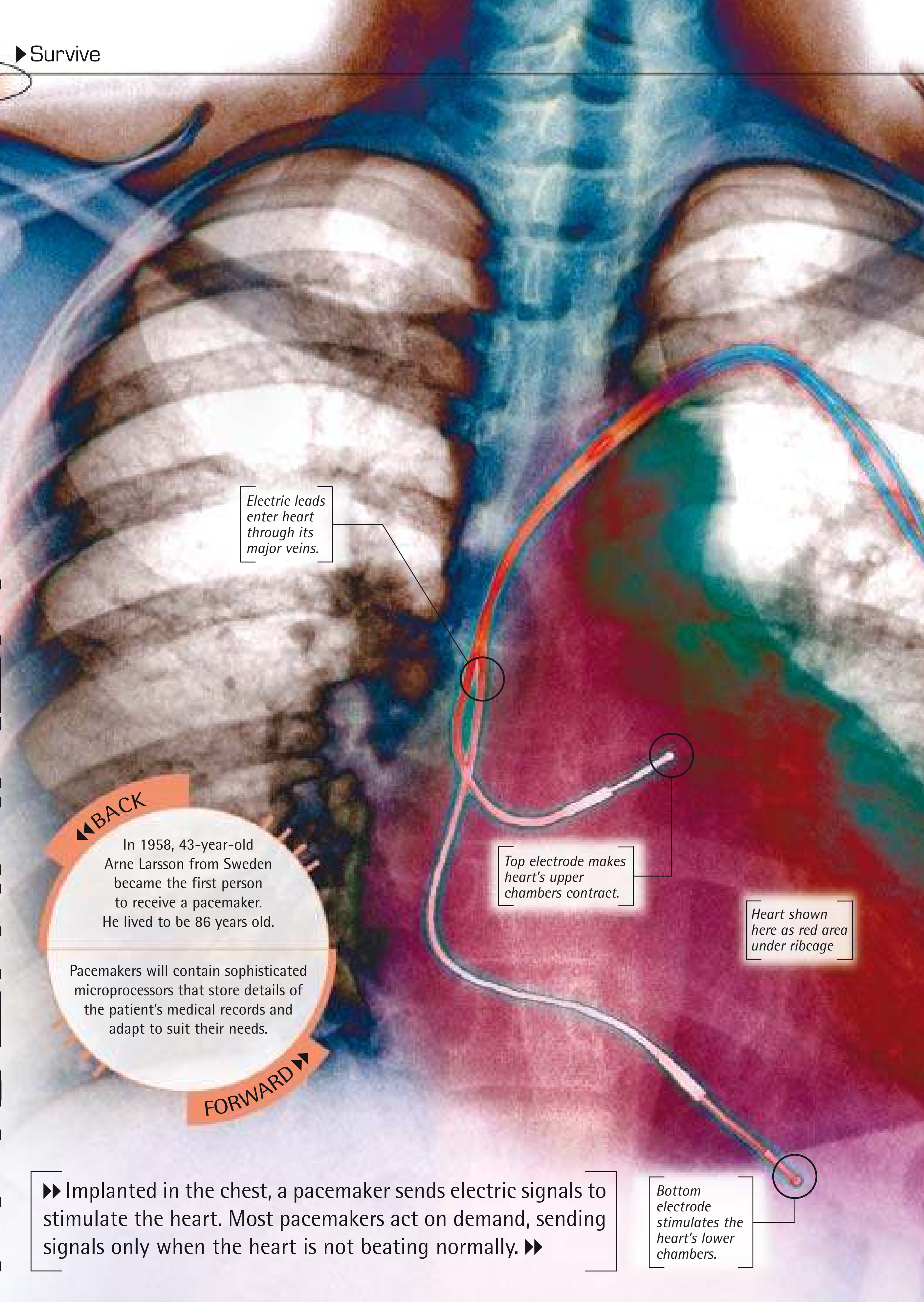


Image: robot surgery on a model heart

PACEMAKER

Image: false-colour X-ray of pacemaker in chest



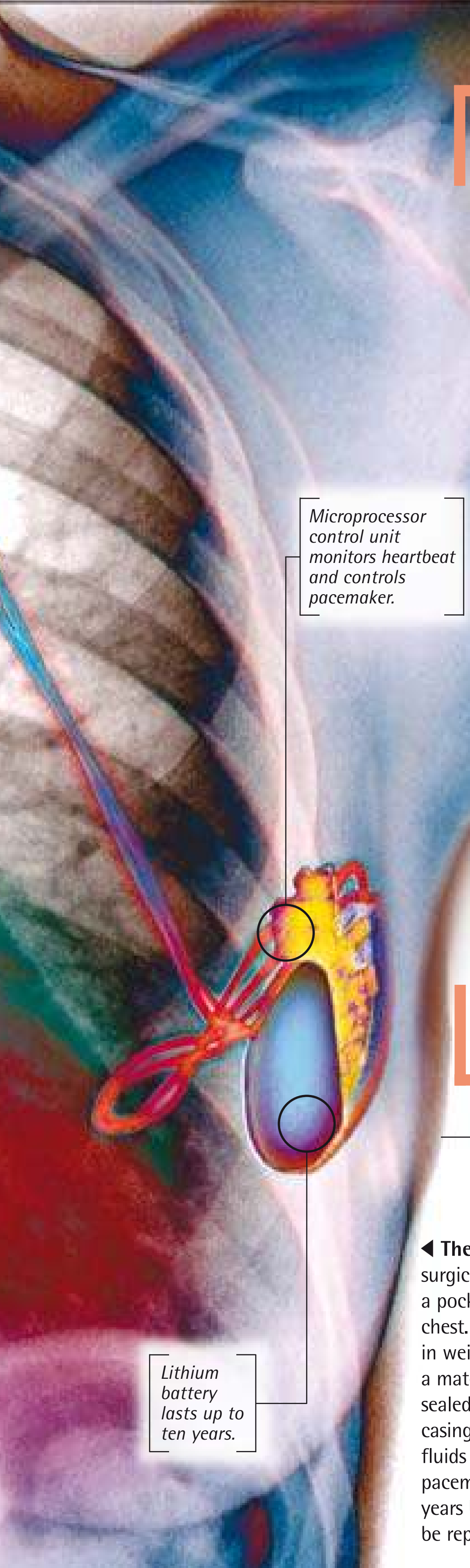
BACK

In 1958, 43-year-old Arne Larsson from Sweden became the first person to receive a pacemaker. He lived to be 86 years old.

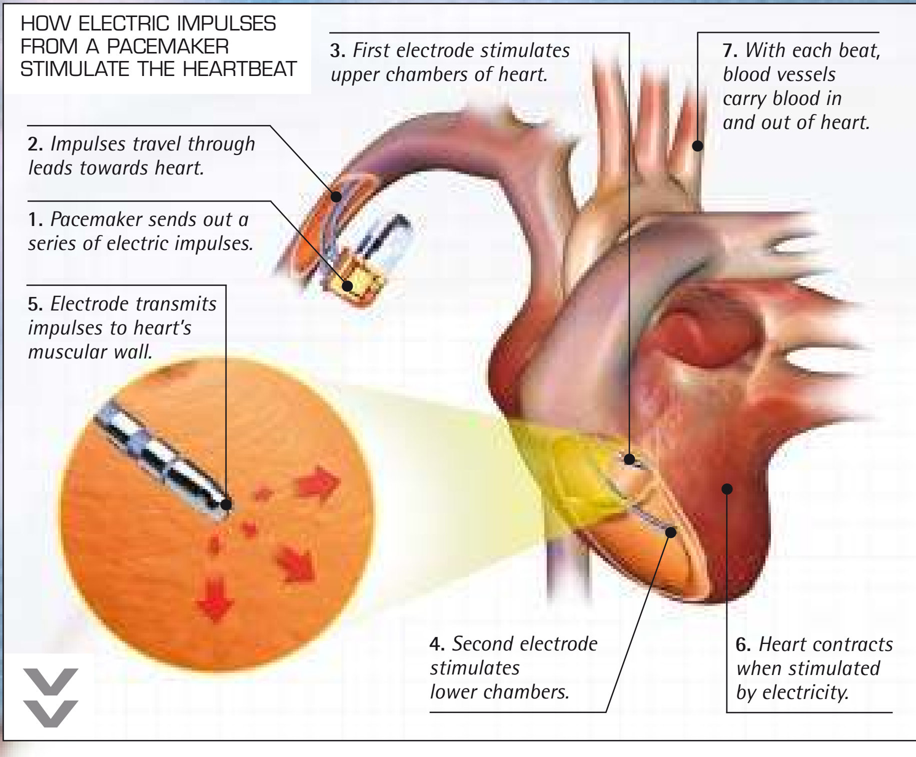
Pacemakers will contain sophisticated microprocessors that store details of the patient's medical records and adapt to suit their needs.

FORWARD

Implanted in the chest, a pacemaker sends electric signals to stimulate the heart. Most pacemakers act on demand, sending signals only when the heart is not beating normally.



HOW A PACEMAKER WORKS



A healthy human heart contains its own natural pacemaker: the sinus node. It sends waves through the heart's muscular walls, triggering the contractions that pump blood through the body with each heartbeat. If the sinus node fails to work properly, surgeons can implant an artificial pacemaker. This continually monitors the heart, and when it senses an abnormal heartbeat, it generates a series of electrical impulses that override the sinus node. Some pacemakers vary their output according to need; for example, they can increase the heart rate during exercise.

◀ **The pacemaker** is surgically implanted under a pocket of skin in the chest. Just 20–50 g (1–2 oz) in weight, it is smaller than a matchbox. It is completely sealed in a waterproof casing to prevent any body fluids leaking into it. Most pacemakers last about five years before they need to be replaced.

Artificial heart

▶ In 2001, US surgeons installed the world's first self-contained artificial heart in a patient with heart disease. Made of titanium and plastic, the AbioCor heart has a hydraulic motor to pump blood around the body. It is powered by an external battery, carried by the patient. It extends the life expectancy of patients with serious heart disease by a few months.


AbioCor artificial heart

▶▶ See also: Battery p94, Robot surgery p208

CAMERA CAPSULE

This coloured X-ray reveals the twists and turns of the human intestines. The camera capsule takes around 50,000 images during its seven-hour journey through the small intestine. Played back at high speed, the images produce a half-hour video of the camera's findings.

The camera capsule is a miniature video camera you can swallow like a pill. As it passes through the body, the capsule films the inside of the small intestine.

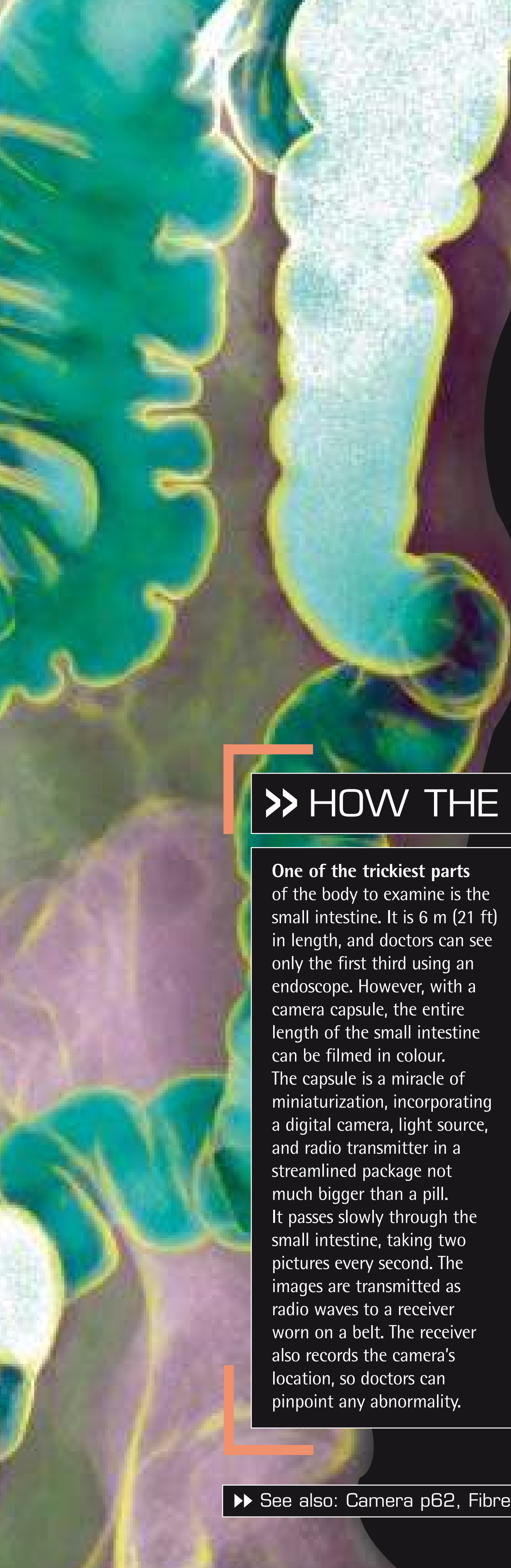


Image: X-ray of intestines with camera capsule

Endoscopy

The viewing device that surgeons normally use to look inside the body is called an endoscope. There are many different types, each suited to viewing a different part of the body. The simplest ones consist of a rigid tube with a lens at one end and a light at the other. The surgeon peers through the lens as though using a microscope.

Surgeon looks through an endoscope

Endoscope view of the stomach

More sophisticated endoscopes have a flexible tube and a video camera at the tip, so the surgeon can view images on a screen. Tiny forceps, scissors, or other attachments can be mounted on the tips of endoscopes. This makes it possible to carry out keyhole surgery – operations performed through a small incision in the body.

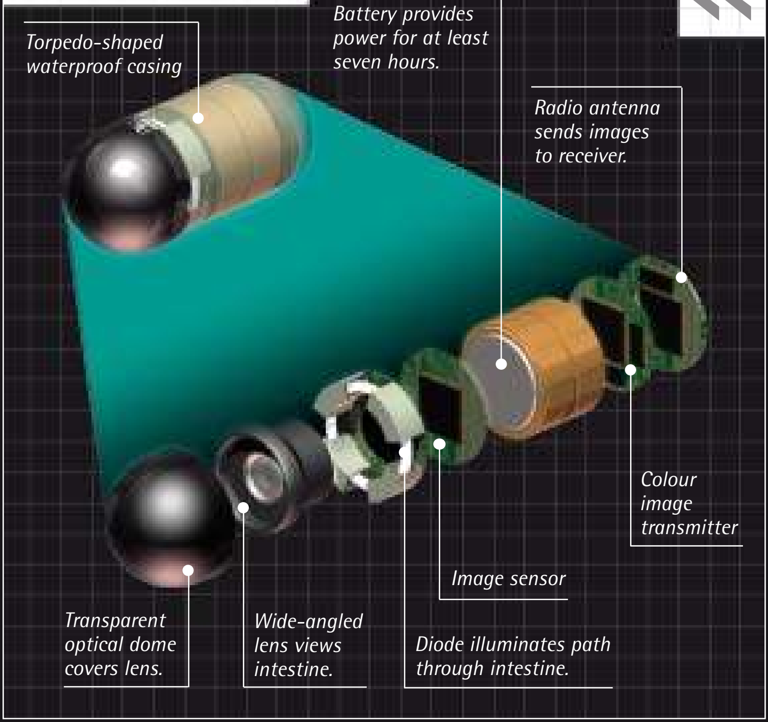
HOW THE CAMERA CAPSULE WORKS

One of the trickiest parts of the body to examine is the small intestine. It is 6 m (21 ft) in length, and doctors can see only the first third using an endoscope. However, with a camera capsule, the entire length of the small intestine can be filmed in colour.

The capsule is a miracle of miniaturization, incorporating a digital camera, light source, and radio transmitter in a streamlined package not much bigger than a pill.

It passes slowly through the small intestine, taking two pictures every second. The images are transmitted as radio waves to a receiver worn on a belt. The receiver also records the camera's location, so doctors can pinpoint any abnormality.

KEY COMPONENTS OF THE CAMERA CAPSULE

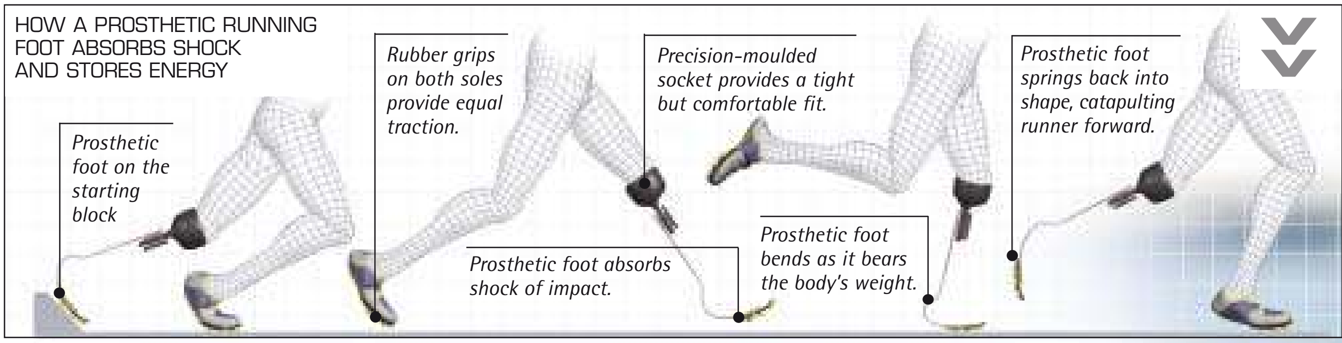


See also: Camera p62, Fibre optic p244, Radio waves p249, Robot surgery p208

BIONIC LIMBS

A prosthesis is an artificial replacement for a part of the body. Prosthetic feet allow Paralympic athletes to sprint almost as fast as able-bodied runners.

HOW A PROSTHETIC FOOT WORKS



Modern prosthetic feet are made from carbon-fibre composite – a combination of carbon-fibre filaments and plastic. This material is very strong and highly resistant to corrosion and stress, yet also lightweight and flexible. Varying the arrangement of carbon fibres in the mould allows designers to change the stiffness of the foot.

The carbon-fibre feet worn by athletes are designed to mimic the natural springiness of the human leg, storing energy as they are compressed and releasing it again as they spring back into shape. For everyday use, smaller, more life-like prosthetic feet are worn instead. Some designs have the appearance of skin.

Rubber grips on the prosthetic foot's sole

Bionic bodies

The dream of prosthetics research is to create mechanical (bionic) limbs that the brain can control directly, such as mechanical hands that can pick things up with the dexterity of a normal hand. Prosthetic limbs that respond to movements in a patient's muscles already exist, but connecting a machine to the body's nervous system has yet to be achieved.

Mechanical hand

BACK

Early prosthetic limbs were made of wood and metal. Major advances in design happened after World War I and II, when many soldiers lost limbs.

Some artificial body parts could become redundant in future as scientists develop new ways of growing replacement organs from a person's own cells.

FORWARD

See also: Carbon p241, Trainer p50, Skin graft p216

Image: athlete Oscar Pistorius running on prosthetic feet

▶ **Running on a pair of prosthetic feet,** 17-year-old Oscar Pistorius of South Africa won the gold medal in the 200-metre sprint at the 2004 Paralympics in Athens. He crossed the finish line at 21.97 seconds, smashing the world record for double amputees. His prosthetic feet, called Cheetahs, are custom-made for track and field sports.

▲ **US athlete** April Holmes won the bronze medal for the long jump at the 2004 Paralympics in Athens. She also set two new world records for her class – single below-knee amputees – in the 100-metre and 200-metre sprints.

SKIN GRAFT

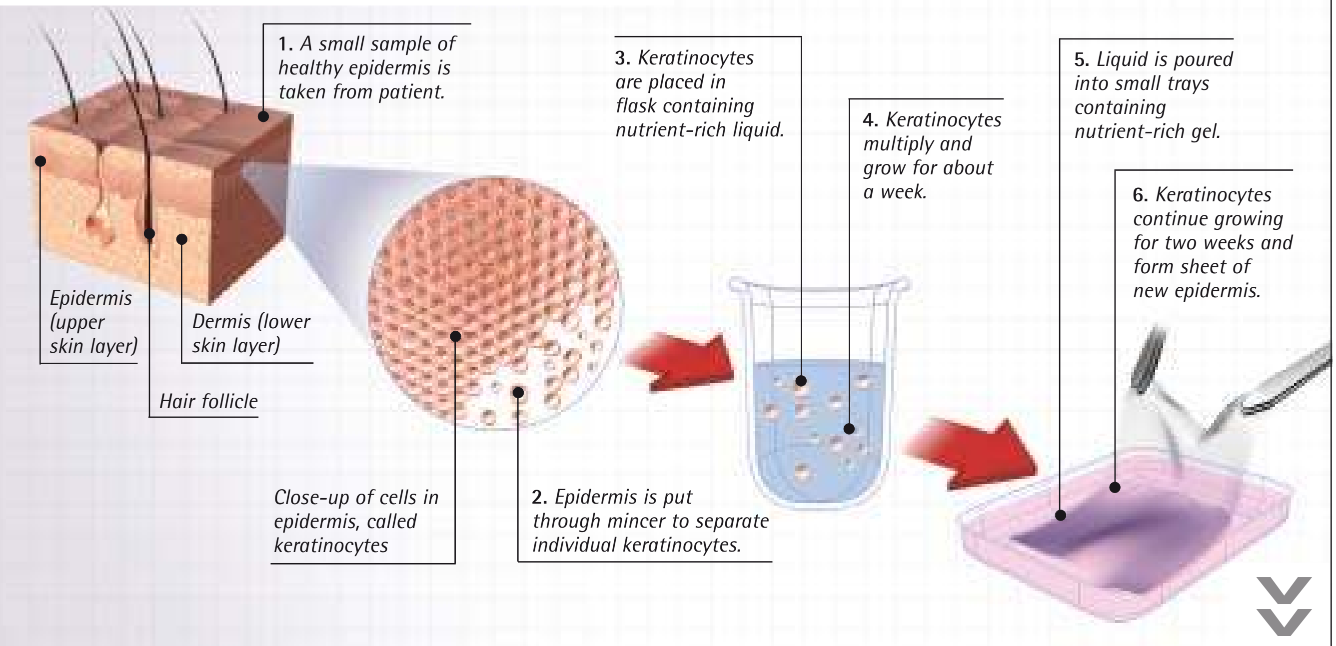
▶ **Image:** artificial skin grown in culture

▼ **A sheet of newly grown skin** is lifted from its dish. This skin has been grown in a laboratory and consists only of the epidermal cells that form the tough, outer layer of human skin. The sheet is laid on top of the damaged skin, where it sticks naturally.

▶▶ The latest skin grafts, called skin autografts, can save the lives of burns victims. A skin sample the size of a postage stamp is taken from a patient and enough skin to cover their body can be grown in just three weeks. ▶▶

HOW A SKIN AUTOGRAFT IS PREPARED

HOW A SKIN SAMPLE IS TREATED TO GROW A SHEET OF SKIN



Skin is the most resilient organ of the human body. Its outer layer, the epidermis, continually renews itself and can repair damage invisibly. Nevertheless, its regenerative powers are limited. If skin suffers severe burns, the regenerative layer at the bottom of the epidermis is lost. These burns can be treated with the most common type of skin graft, where healthy skin from another part of the body is moved to the damaged area. If the burns are so extensive that not enough skin is left to graft, a skin autograft can be performed. New skin is grown artificially by taking a small sample of the patient's skin. The skin is made from the patient's own cells, so the body's immune system will not reject it. If a patient receives skin from a skin bank, the skin is not their own, so the patient's immune system may reject the unfamiliar cells.

◀◀BACK

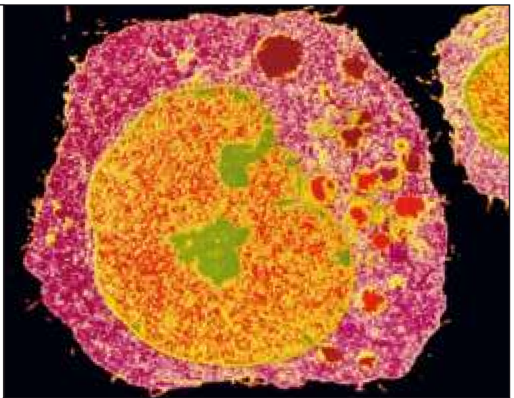
The first known skin grafts were performed in India more than 4,000 years ago. Sanskrit texts describe how skin from the buttocks can repair a damaged nose.

A recent development in skin grafting is a spray-on skin culture, which is much quicker to prepare than fragile skin sheets.

FORWARD▶▶

Tissue research

▶Scientists need to grow human tissue, such as skin, for research as well as for grafts. Normal cells are difficult to grow because they multiply a limited number of times before ageing and dying. So scientists use cancer cells because they divide endlessly, making them immortal. Most of the cancer cells they use come from a single sample of cancer tissue from an American woman, Henrietta Lacks, who died in 1951. They are called HeLa cells.



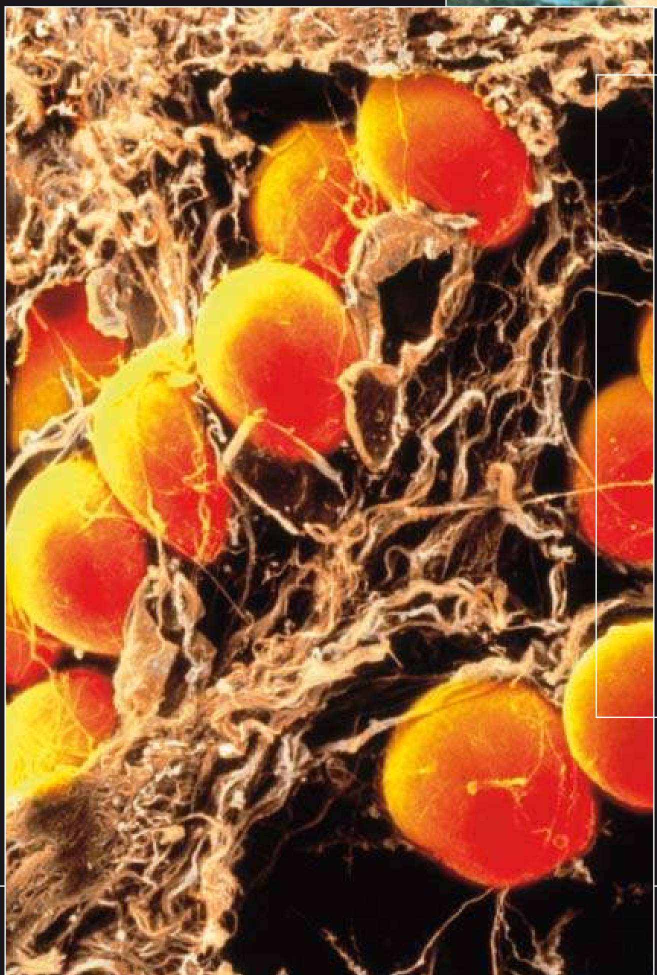
Magnified HeLa cell

▶▶ See also: Fire suit p190

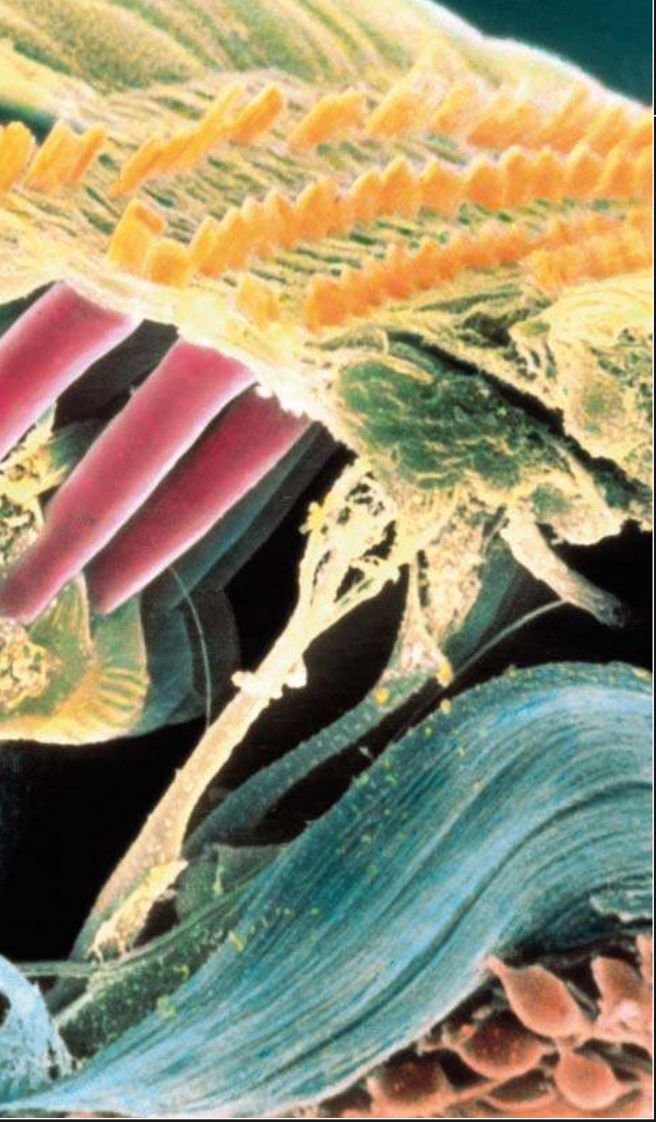
CELLS

The human body is made of 100 trillion cells, all of which are too small for the naked eye to see. Thanks to the microscope, we can view this miniature world with amazing clarity.

Inner ear This view through an electron microscope reveals the inner ear's hair cells, which help to give us the sense of sound. Magnified about 1,700 times, the image shows four rows of hair cells, the main bodies of which appear red. Tiny hairs, shown orange, project through a membrane at the top of the picture. When sound waves ripple through the fluid-filled inner ear, this membrane wobbles, tugging the hairs. The movement makes the hair cells generate nerve impulses, which travel to the brain.



Fat cells Seen through an electron microscope, these fat cells look like tiny bubbles, surrounded by fibres of connective tissue. Fat cells are among the largest cells in the human body. Each cell contains a single, large globule of fat. Any fat eaten but not used by the body gets stored as fat cells. As well as providing a store of energy, fat cells form an insulating layer below the skin, helping the body retain heat.

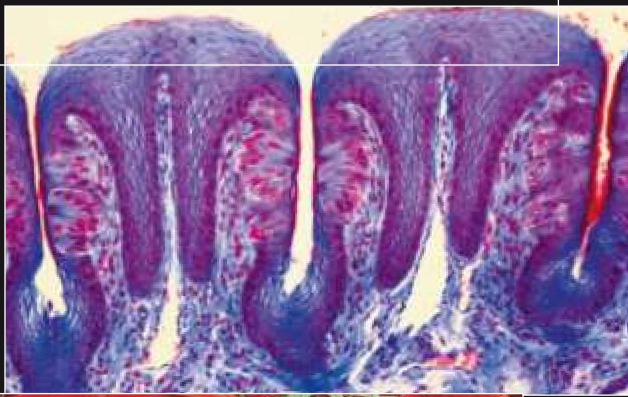


Follicle mites

The human face is the natural habitat for the wormlike creatures seen here, magnified 180 times under an electron microscope. These follicle mites live in the tiny shafts where hairs grow, especially eyelashes. Scientists believe most people have these harmless parasites.

Taste buds

This is a thin slice of the human tongue, magnified 120 times. The large folds are papillae – the tiny bumps on our tongues that feel velvety. In the crevices between them are taste buds. These sensory cells detect the five main tastes – sweet, salty, sour, savoury, and bitter.



Blood clot

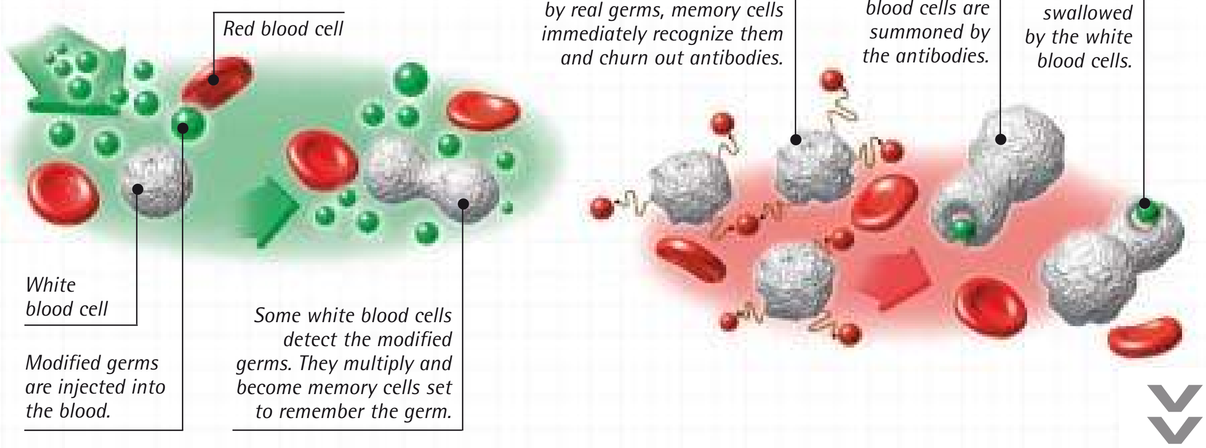
A drop of blood contains about five million red blood cells. These carry oxygen around the body. Here, red blood cells are tangled up in fibrin, an insoluble protein that forms when a blood vessel is damaged. Fibrin stops blood cells moving, so the blood solidifies and plugs the leak.

See also: DNA p243, Imaging techniques p10, Vaccination p220

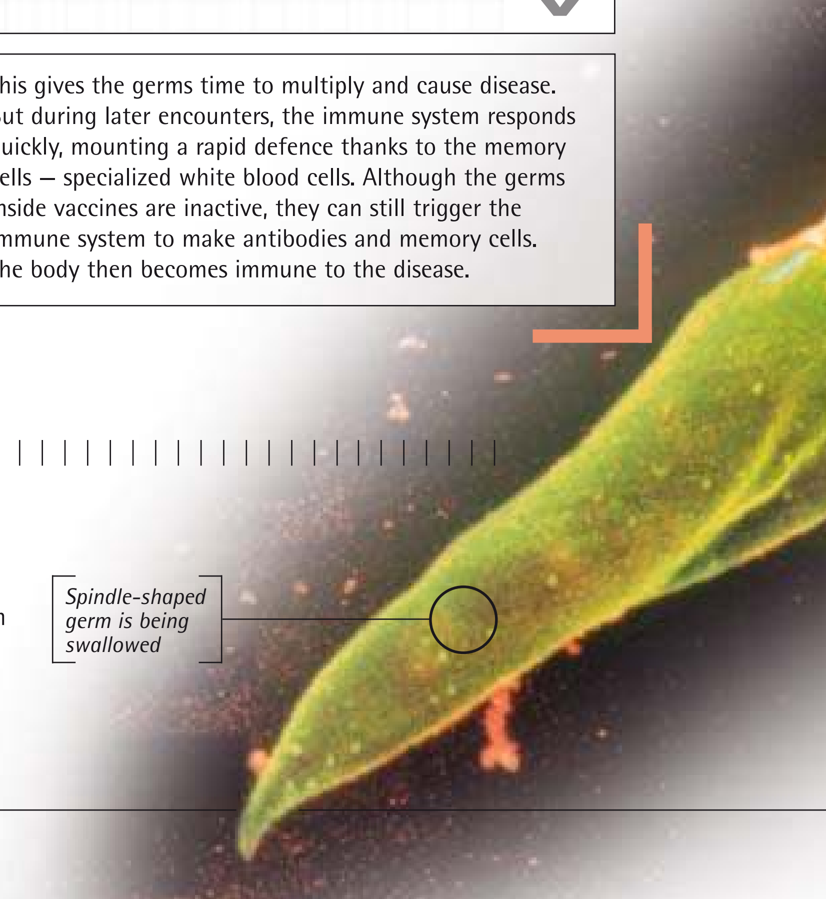
VACCINATION

Vaccines train the body's immune system to recognize and destroy germs – parasitic micro-organisms, such as bacteria and viruses – that cause disease. Most vaccines are made from the germs themselves, treated to make them harmless.

HOW VACCINATION WORKS



Vaccination relies on the body's ability to remember specific germs and attack them with much greater speed on subsequent encounters. When a new germ enters the body, white blood cells slowly learn to recognize and attack it. They produce chemicals called antibodies, tailored to attack a specific germ. The first time the germ enters the body, the antibody response is slow. This gives the germs time to multiply and cause disease. But during later encounters, the immune system responds quickly, mounting a rapid defence thanks to the memory cells – specialized white blood cells. Although the germs inside vaccines are inactive, they can still trigger the immune system to make antibodies and memory cells. The body then becomes immune to the disease.



Magnified more than 10,000 times by an electron microscope, this white blood cell is devouring the germ that causes the tropical disease leishmaniasis. White blood cells act like soldiers, patrolling the body in search of germs and attacking them in different ways. This white blood cell kills germs by swallowing them.

Image: white blood cell swallowing leishmaniasis germ

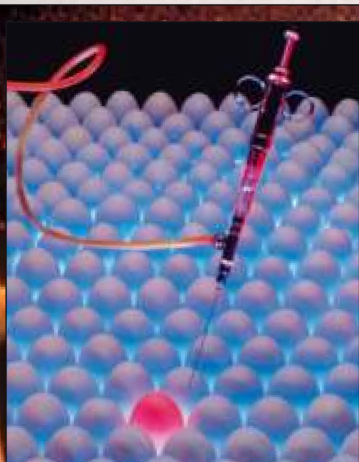
BACK

English doctor Edward Jenner invented the first vaccine in 1796. He made a boy immune to smallpox by infecting him with cowpox germs from cattle.

Future vaccines, made from the DNA of organisms that cause disease, could protect people against conditions such as AIDS, Alzheimer's disease, and cancer.

FORWARD

Making vaccines



Egg being injected with a virus

▲ Most vaccines are made from living germs. The influenza vaccine is made inside hens' eggs. The eggs are injected with the influenza virus and kept warm so that the virus multiplies. Days later, the eggs are opened and the virus is removed and chemically inactivated so it cannot cause disease.

See also: Antibiotics p222, Antibody p240, Bacteria p241, DNA p242

ANTIBIOTICS

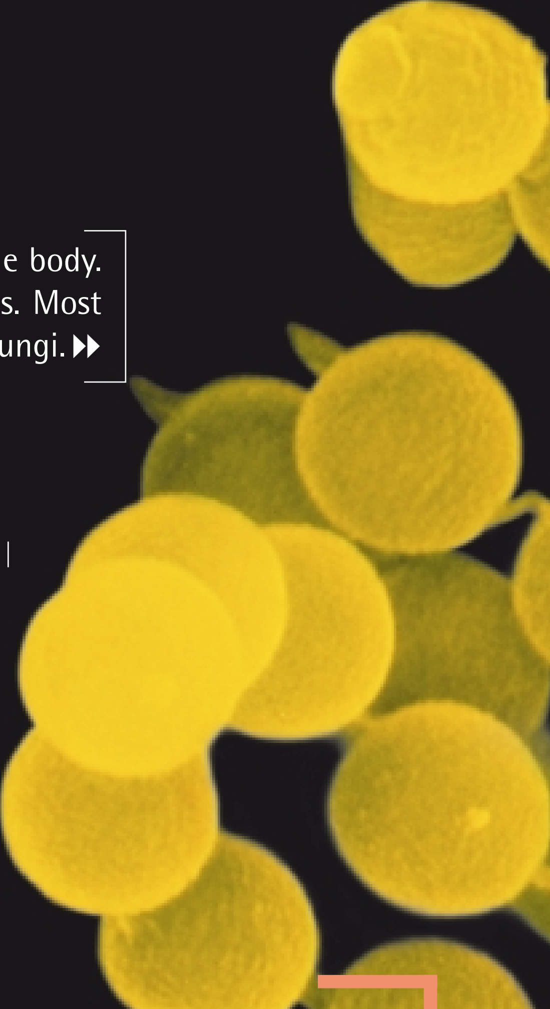
Antibiotics are drugs taken to fight bacteria that have invaded the body. Though poisonous to bacteria, antibiotics are usually harmless to us. Most antibiotics are natural substances made by micro-organisms such as fungi.

BACK

In 1928, Scottish scientist Alexander Fleming discovered antibiotics by accident, when he noted bacteria dying around *Penicillium* mould on a culture dish.

Although most modern antibiotics are still derived from bacteria and fungi, scientists hope to create new, synthetic antibiotics to fight superbugs.

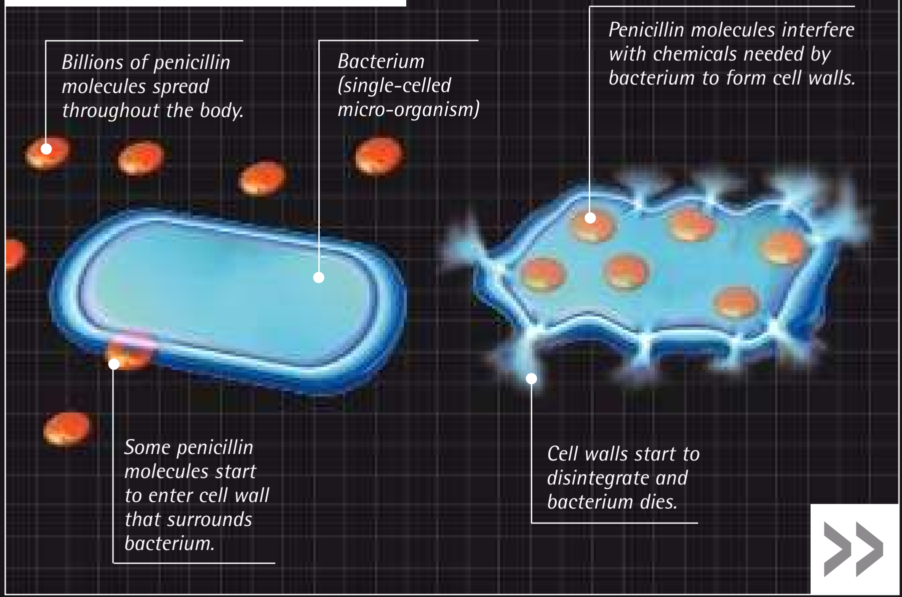
FORWARD



This is the fungus *Penicillium* magnified 6,000 times. *Penicillium* spreads by producing billions of microscopic spores. Each spore grows into a new patch of mould if it settles in a suitable place. *Penicillium* is the source of the first antibiotic to be discovered: penicillin. The fungus is probably most familiar to people as the dusty blue mould that grows on stale bread and rotting oranges.

HOW ANTIBIOTICS WORK

HOW PENICILLIN DESTROYS THE CELL WALLS OF BACTERIA



Antibiotics first became widely used in World War II, when penicillin prevented gangrene and blood poisoning affecting wounded soldiers. Since then, many more antibiotics have been discovered, leading to cures for hundreds of infectious ailments. Antibiotics attack bacteria in different ways. Penicillin bursts cell walls, but other antibiotics halt cell growth or stop bacteria multiplying. Some antibiotics, called broad-spectrum antibiotics, attack a range of bacteria. Others target specific types. Surgeons also use antibiotics to prevent open wounds becoming infected during operations. In the past, these operations carried a life-threatening risk of infection.

See also: Antibody p240, Bacteria p241, Vaccination p220

Superbugs

MRSA bacteria seen through a microscope

▲Bacteria can evolve to become immune to antibiotics. When a person takes an antibiotic, the drug kills most of the bacteria, but a few mutant bacteria may have genes that allow them to survive. These go on to reproduce and spread. Antibiotic-resistant bacteria are sometimes called "superbugs". One superbug is MRSA (methicillin-resistant *Staphylococcus aureus*), which causes infections in wounds. It first appeared in Britain in 1961 and has since spread across the world.

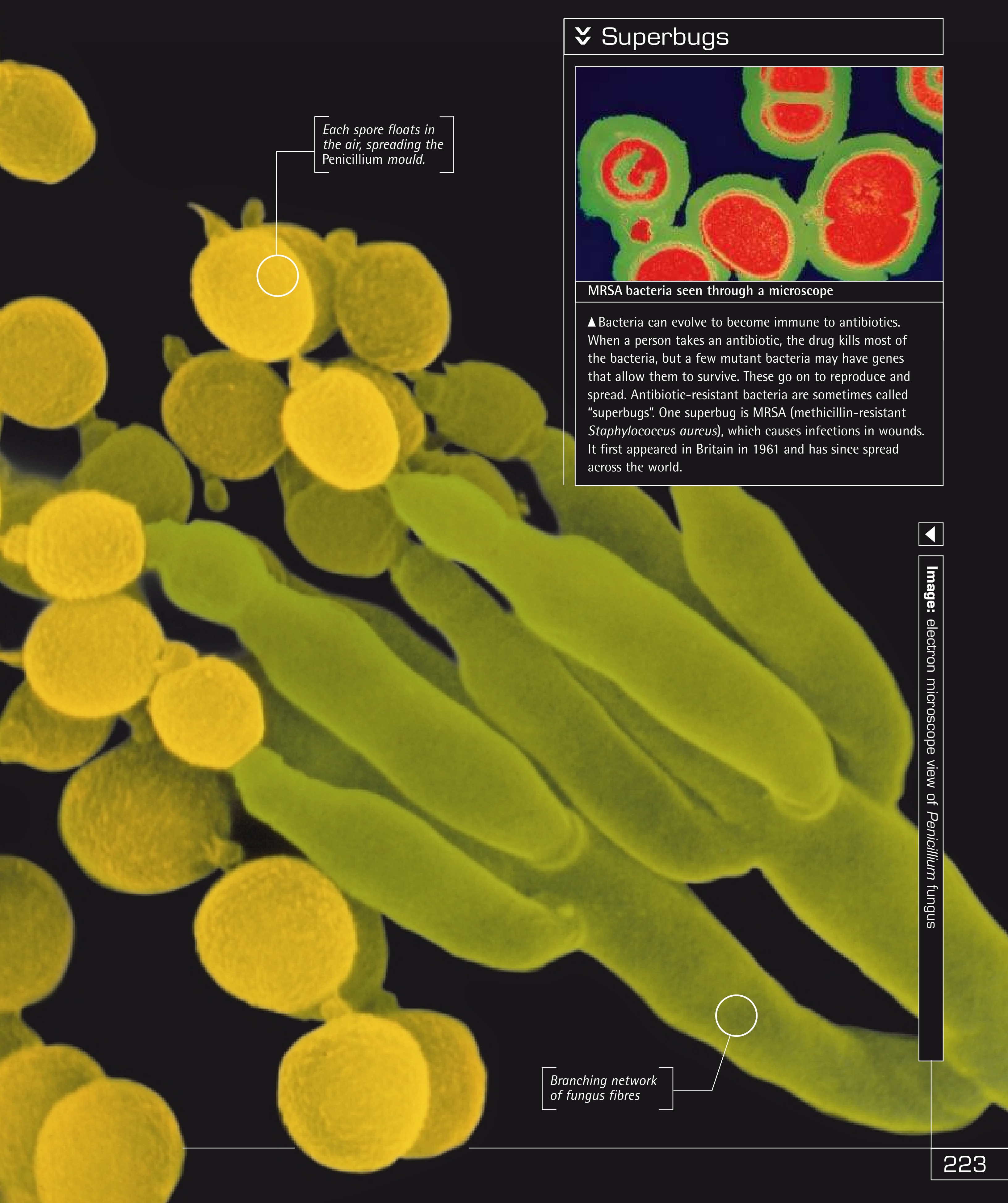


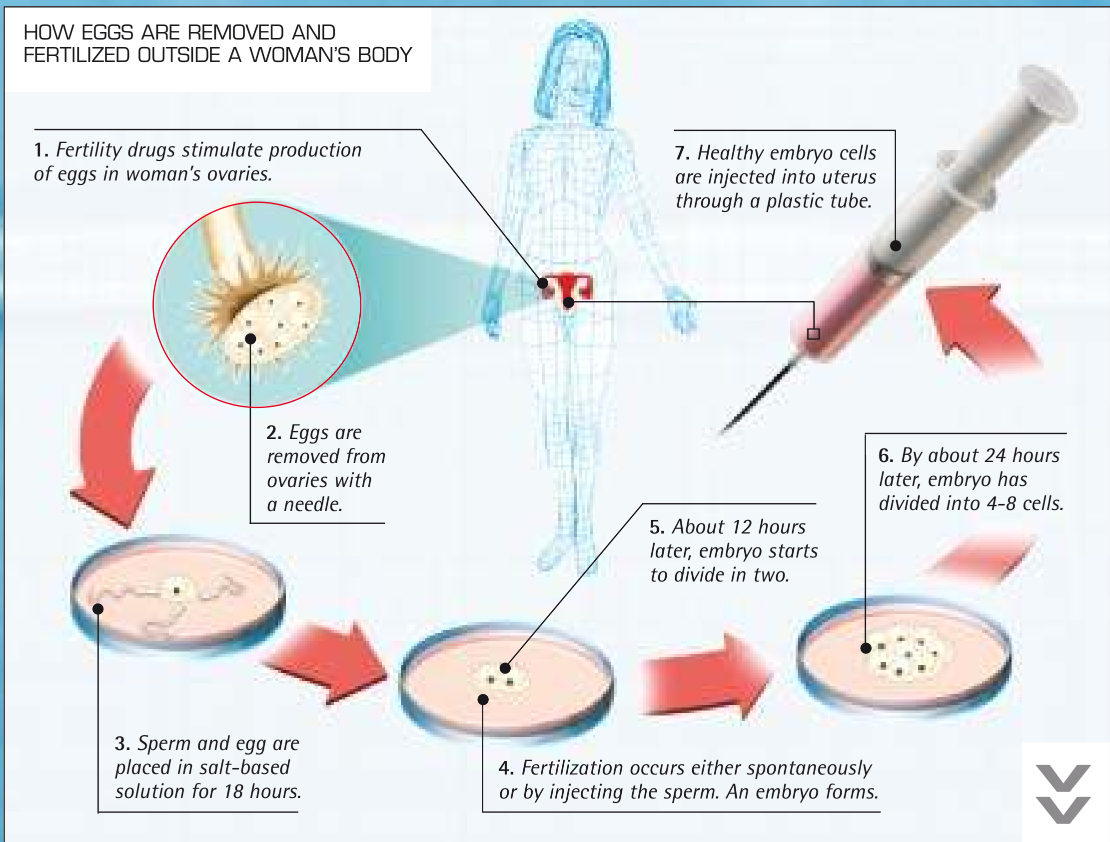
Image: electron microscope view of *Penicillium* fungus

IVF

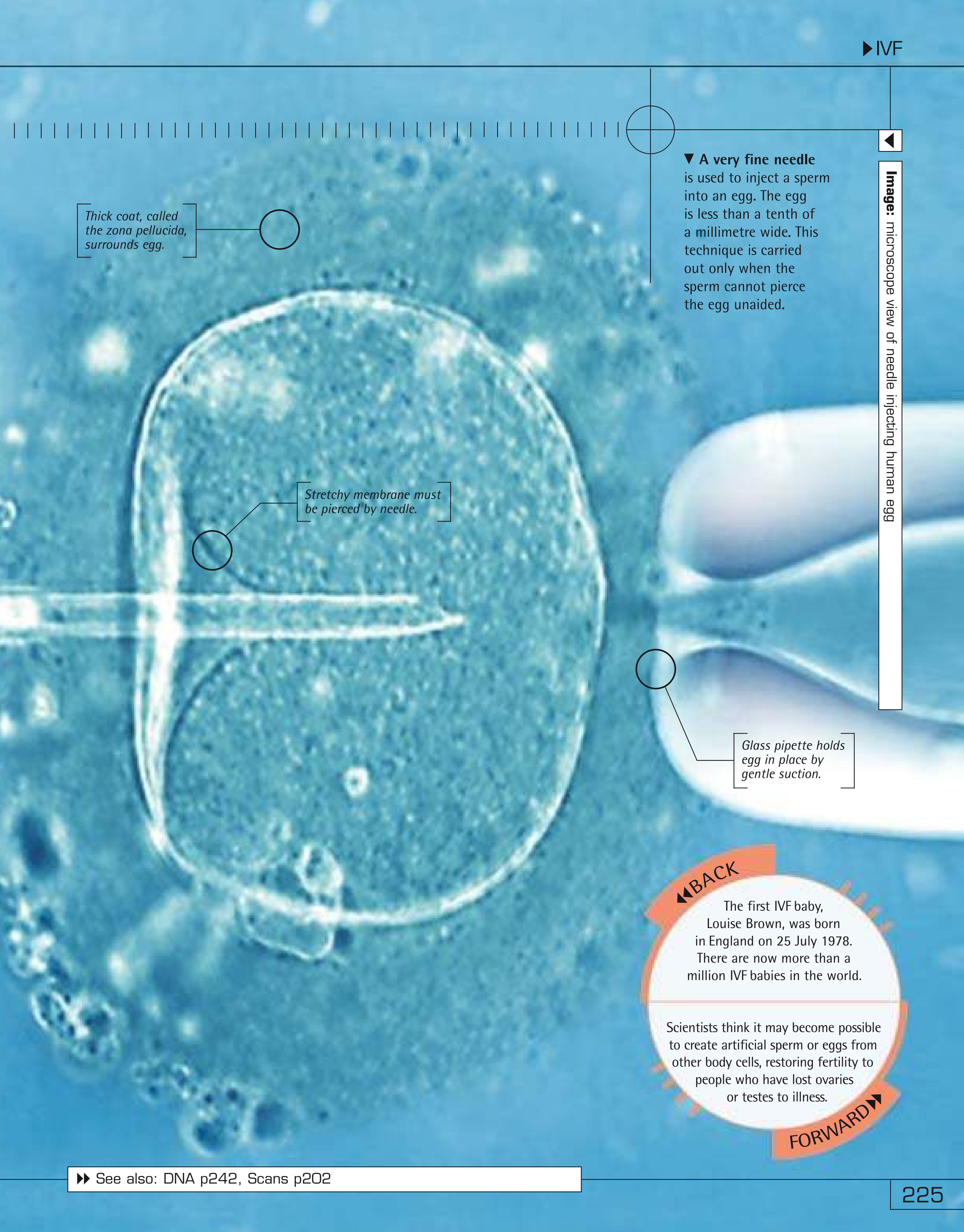
In Vitro Fertilization (IVF) can make it possible for infertile couples to have children. IVF is a technique in which a woman's eggs are fertilized by a man's sperm outside the body and then implanted into the woman's womb to develop normally.

Microscopic needle injects a sperm into the egg.

HOW IN VITRO FERTILIZATION WORKS



In vitro is Latin for "in glass" – when a couple is unable to conceive babies naturally, an artificial environment must be used, such as a glass test tube or petri dish. Common reasons for infertility include blockage of a woman's fallopian tubes (which carry eggs from the ovaries to the uterus) and a low sperm count in men. The technique has a 20 per cent success rate with each attempt, so to improve chances several embryos are often implanted, but this can lead to multiple pregnancies. IVF has become common in recent decades – one per cent of all US children are now born this way. The technique has caused controversy because it involves the creation of human embryos, not all of which survive.



A very fine needle is used to inject a sperm into an egg. The egg is less than a tenth of a millimetre wide. This technique is carried out only when the sperm cannot pierce the egg unaided.

Image: microscope view of needle injecting human egg

BACK

The first IVF baby, Louise Brown, was born in England on 25 July 1978. There are now more than a million IVF babies in the world.

Scientists think it may become possible to create artificial sperm or eggs from other body cells, restoring fertility to people who have lost ovaries or testes to illness.

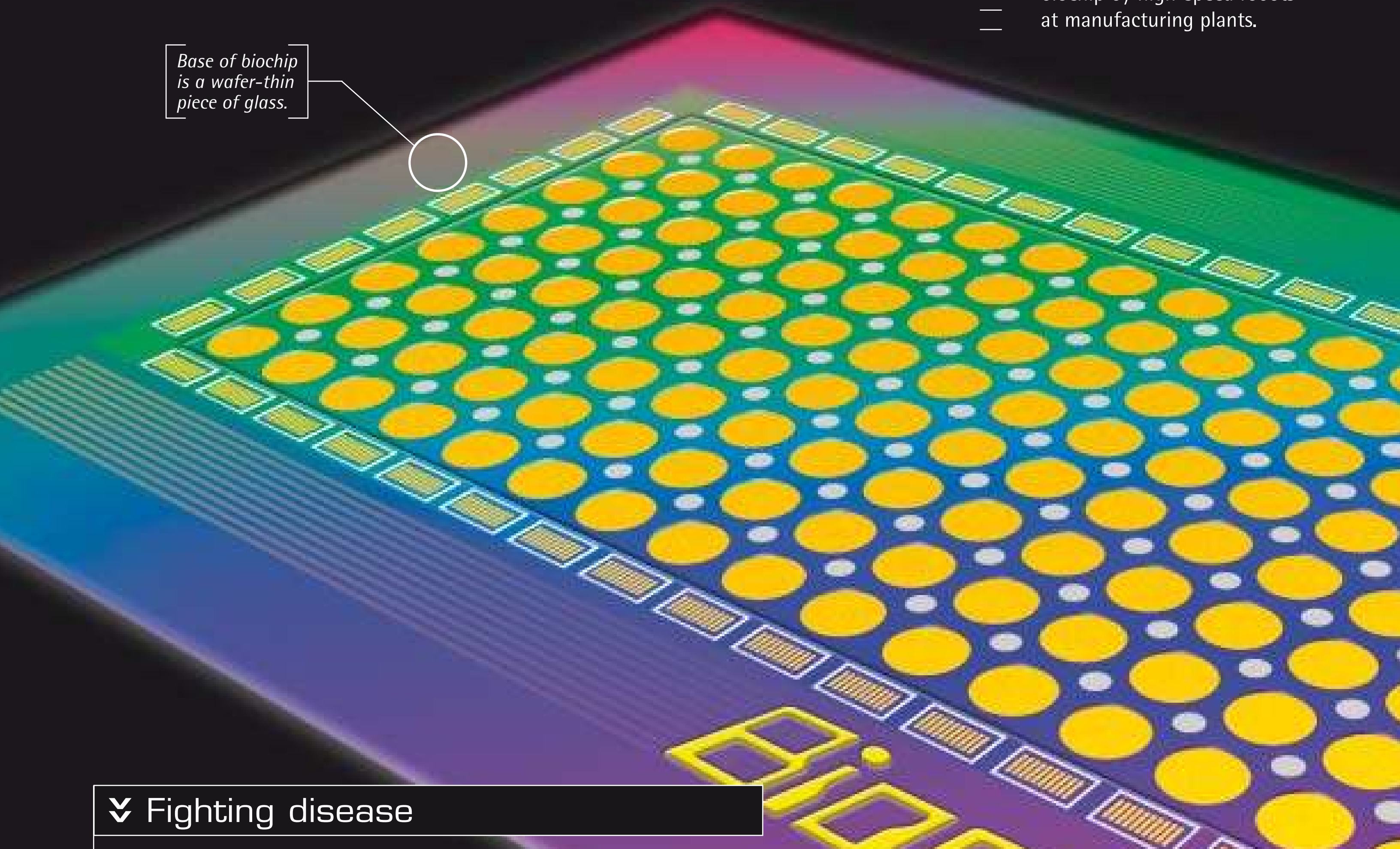
FORWARD

See also: DNA p242, Scans p202

BIOCHIP

Biochips make it possible to screen a biological sample for thousands of different biochemicals at once. Most biochips are used to test for genes – the inherited instructions, made of DNA, that control the way cells work. Scientists can use biochips to find out which genes are "switched on" inside living cells.

Biochips are barely larger than postage stamps, yet a single chip can test for thousands of different genes. The surface of the chip bears an array of microscopic dots, each containing DNA from a different gene. Most biochips contain human DNA, which is fixed to the dots of the biochip by high-speed robots at manufacturing plants.



Fighting disease

Biochips could help scientists find a cure for malaria. In 2002, scientists created a biochip with genes from the parasite that causes malaria. Using the chip helped them to identify which genes are active at crucial points in the parasite's life cycle. By creating chemicals to block the active genes, scientists hope to create drugs that kill the parasites.


Malaria-carrying mosquito

HOW A BIOCHIP WORKS

Biochips have all sorts of uses, but one of the most common is to search for genes that are "switched on", or active, in living human cells. In the human body, every cell contains the same set of 30,000 genes, but only a fraction of these are active in each type of cell. By identifying the active genes, scientists can research why brain cells work differently from fat cells, or why cancer cells are different from healthy cells. Scientists separate the two strands of active DNA in the cells and a dye is chemically attached to one strand. The dyed strand is then placed on a biochip where it will bind to any matching single strands of DNA already in the dots on the chip. When a match occurs, the two single strands join to form a double strand, or DNA helix. A match means the gene is active in the sample DNA.

◀◀ BACK

The world's first biochip was made in 1989, using a glass microscope slide. Before this, scientists could test samples for only a few genes at once.

Doctors may one day use biochips to diagnose diseases or check a person's genetic reaction to specific drugs.

FORWARD ▶▶

Image: computer artwork of a biochip

▶▶ See also: DNA p242, Genetics p244, Vaccination p220

The human body is the most complex machine on the planet. It has about ten thousand billion cells – more cells than there are stars in the visible universe. New technology will have a dramatic effect on our ability to monitor and repair this astonishing mechanism.

Using nanotechnology, the science and technology of manipulating individual atoms and molecules, we may be able to build devices called molecular machines. These miniscule machines, or nanobots (one nanometre is about a million times smaller than a full stop) may have the ability to reproduce themselves and perform tasks far beyond the scope of current medical technology. Nanobots could target and destroy cancerous cells one by one without damaging the surrounding healthy tissue, repair damaged cells, and reverse the ageing process, or remove harmful plaque from the inner walls of our arteries.

> "Nanorobots may one day travel through the body, armed with chemical weapons, on a mission to destroy bacteria and viruses."

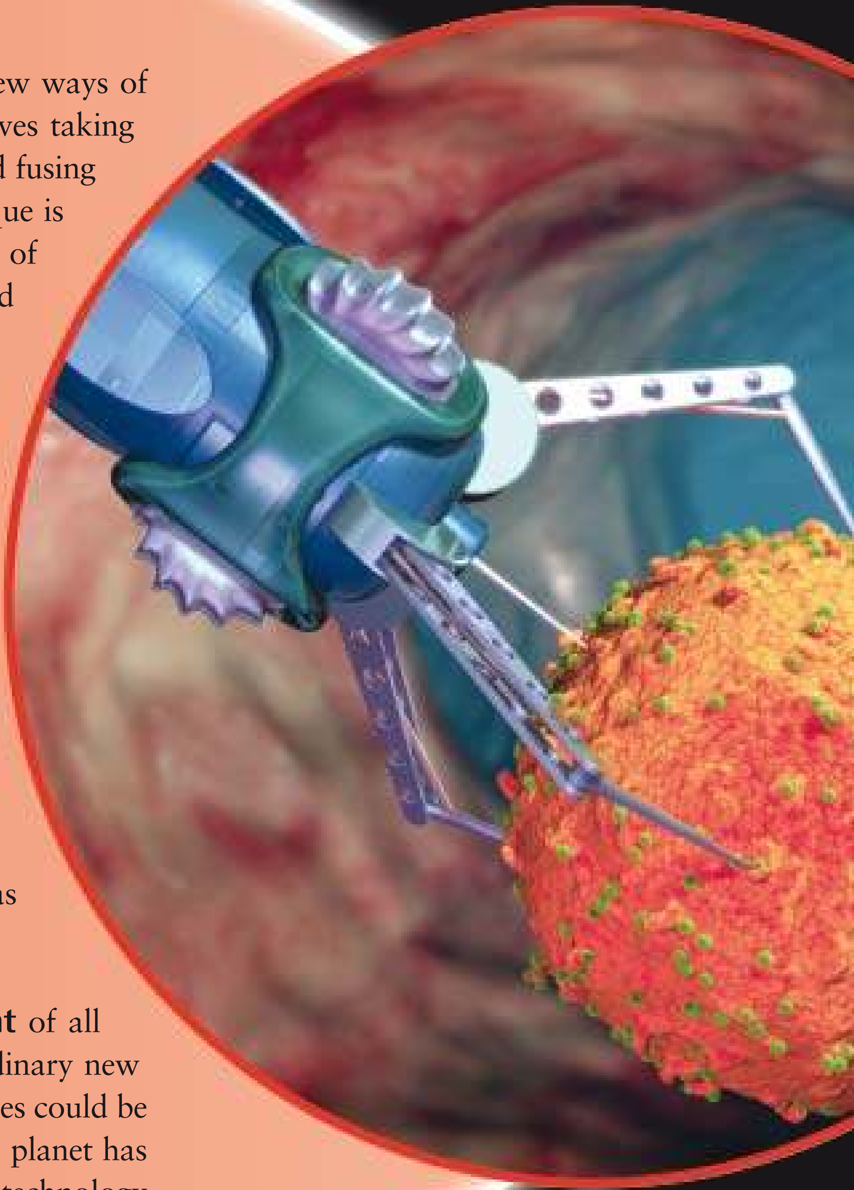
Micromachines called micro-electro-mechanical systems, or MEMS, may also have a major impact on medical treatment. These use tiny sensors and motors etched onto a wafer of silicon thinner than a human hair. Already found in car air bags to detect movement, they may be used to repair blood vessels by 2020.

Some animals such as lizards can re-grow a lost tail or leg. Humans, of course, do not have this ability. By taking cells, however, and seeding them on a special scaffolding, it may be possible to re-generate organs such as the liver or heart in the laboratory. By the end of the century, most parts of the body (apart from the brain) could be replaced if they become faulty.

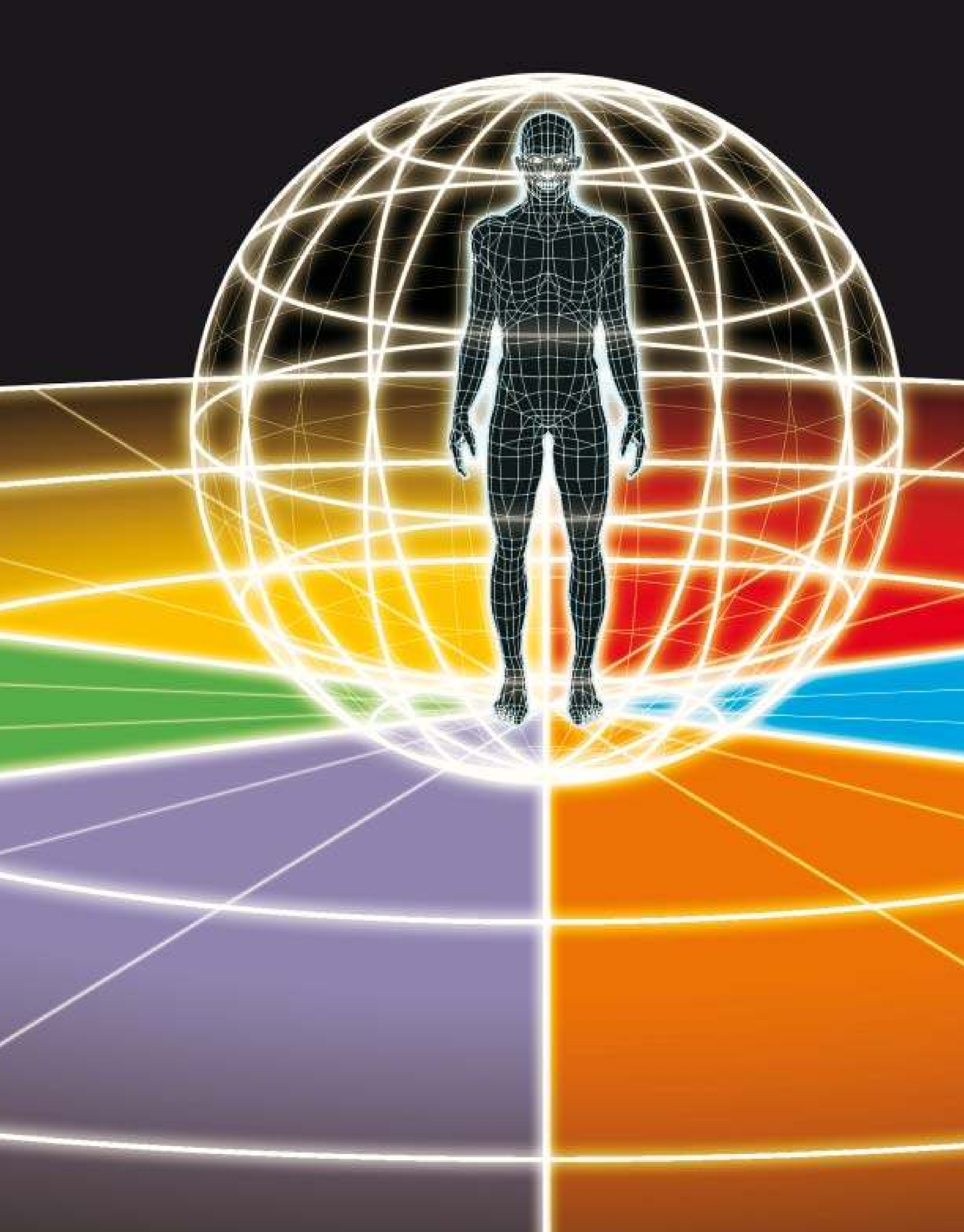
Cloning is another technology that offers us new ways of approaching health and medicine. Cloning involves taking genetic material from an adult or embryo cell and fusing it with an egg, which then develops. This technique is called therapeutic cloning. However, the use of human embryos for medical purposes is considered controversial by many. Despite this, cloning continues and whole organs could be produced from single cells or damaged cells could be replaced with healthy ones in future. Cloning could also be used to create genetically modified pigs which would develop organs suitable for human transplants – a technique known as xenotransplantation.

Gene therapy has already successfully treated certain conditions that are caused by our genetic make-up. This technology, which targets and repairs faulty genes, may be used in future to treat and prevent cancers and diseases such as Alzheimer's, arthritis, and heart disease.

Perhaps the most important new development of all will be something simpler than all these extraordinary new medical technologies – clean water. Millions of lives could be saved each year by ensuring that everyone on the planet has access to clean and safe drinking water. And the technology needed for this? Simple water purification systems.



ARTWORK OF NANOBOT INJECTING DRUG INTO HUMAN CELL



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Timeline >> Groundbreakers >> Techno terms >>
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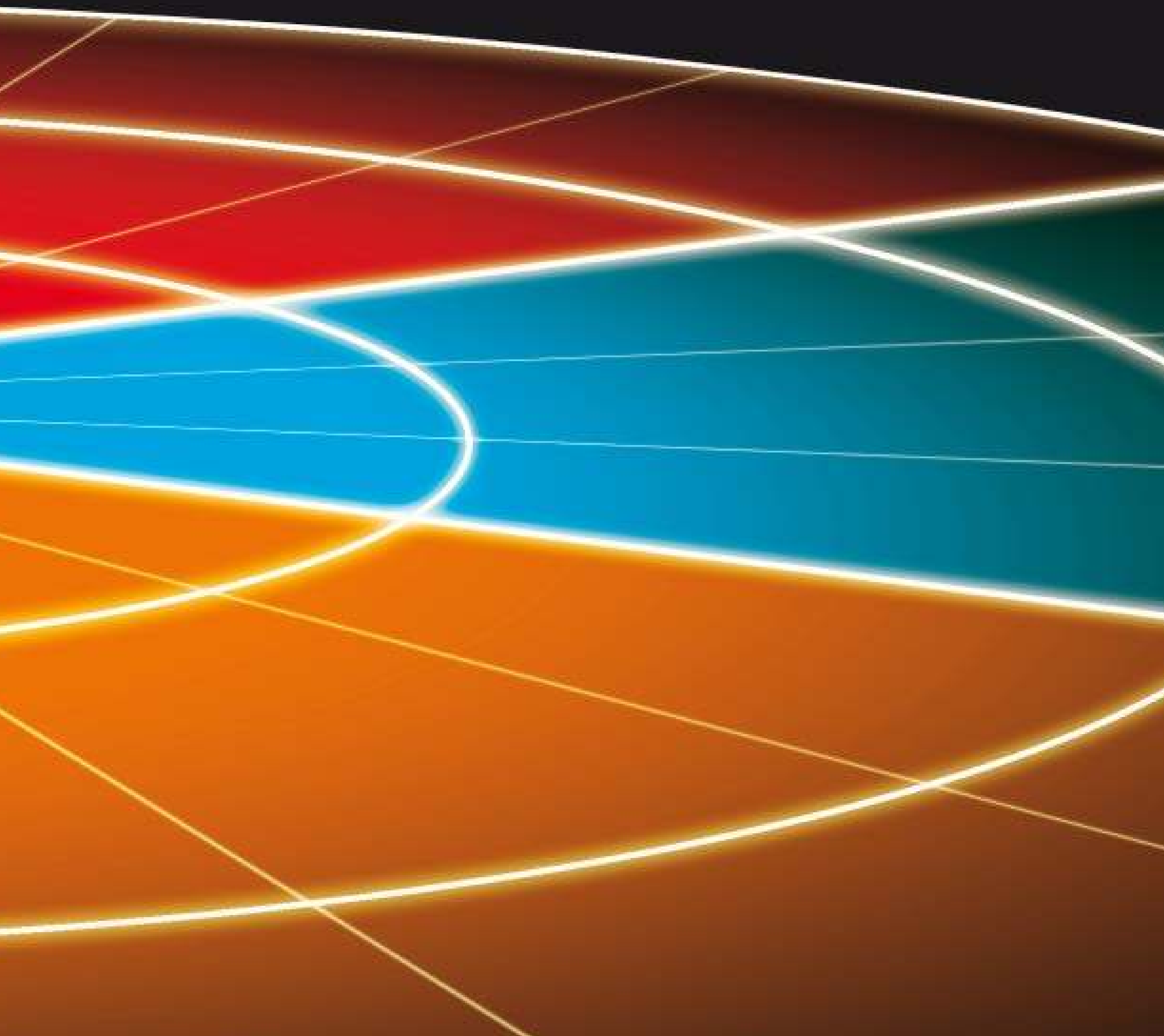


Timeline

c. 3200 BC

Wheels first used for transport. Ancient clay tablets show they were used on Mesopotamian chariots. A wheel with spokes first appeared in Egypt in about 2000 BC.

c. 1350 BC

Decimal numbers first used in China. Rather than inventing a new Chinese character for each number, a decimal system required just ten symbols.

1450

Printing press with moveable type invented by German Johannes Gutenberg. Books could now be produced more quickly, making literature accessible to a wider audience.

1642

Mechanical adding machine invented by 19-year-old French mathematician Blaise Pascal. He designed it to help his father calculate sums in his work as a clerk.

1752

Lightning rod invented by American Benjamin Franklin. It protects buildings during storms by transferring the electrical charge of a lightning strike safely to the ground.

1792

Scottish scientist William Murdoch invents gas lighting. After using gas made from coal to light his home, he began manufacturing gas lighting on a commercial scale.

1800

Infrared rays discovered by German astronomer William Herschel. He demonstrated there was a temperature increase just beyond the red end of the visible light spectrum.

1803

Modern atomic theory proposed by English chemist John Dalton. He explained the concept of atoms and described how elements form compounds.

1835

Mechanical computer designed by English mathematician Charles Babbage. It possessed all the essential logical features of the modern computer, such as running programs.

1852

Safety passenger lift invented by US inventor Elisha Graves Otis. It included a safety device to prevent the lift falling if a cable should snap.

1865

Austrian monk Gregor Mendel publishes his laws of genetic inheritance and the results of his experiments, which explored the inherited characteristics of pea plants.

1876

First practical telephone invented by Scottish-born scientist Alexander Graham Bell. The technology he developed paved the way for electronic sound recording.

1885

First practical car to be powered by an internal combustion engine built by German engineer Karl Benz. The vehicle had three wheels and an open carriage.

1887

First wearable contact lenses invented by German physiologist Adolf Eugen Fick. They were made from heavy brown glass and were first fitted on animals.

1895

Portable motion-picture camera, film processing unit, and projector called the Cinematographe invented by French brothers Auguste and Louis Lumière.

1895

X-rays discovered by German physicist Wilhelm Röntgen while experimenting with electron beams. A week after his discovery he took an X-ray photograph of his wife's hand.

1910

First synthetic drug produced by German bacteriologist Paul Ehrlich. He developed 605 different compounds before finding one that could kill a bacterium that caused disease.

1910

First neon light displayed to the public by French engineer Georges Claude. The device was made by applying an electrical discharge to a sealed tube of neon gas.

c. AD 1000

First paper money printed in China. It was known as flying money because it was so light it could blow out of a merchant's hand.

c. 1280

Mechanical clocks invented in Europe. They used a mechanism called an escapement, which ticks in a steady rhythm, causing gears to move in a series of equal jumps.

1686

Mathematical Principles of Natural Philosophy by English scientist Isaac Newton is published, containing the three laws of motion and his theory of universal gravitation.

1714

First mercury thermometer invented by German physicist Gabriel Fahrenheit. In 1724, he introduced the Fahrenheit temperature scale.

1796

The world's first vaccination created by English physician Edward Jenner. He developed a vaccination for smallpox, a deadly disease that was widespread in the 18th century.

1799

First battery invented by Italian physicist Alessandro Volta. Called the voltaic pile, it was made from thin sheets of copper and zinc separated by moist paper board.

1809

First electric light invented by English chemist Humphry Davy. He used wires to connect a battery to a charcoal strip, which glowed when charged with electricity.

1826

First photograph taken by French inventor Joseph Nicephore Niépce. The pewter plate he used was exposed to sunlight for eight hours to create the image.

1852

The gyroscope – a spinning wheel set in a moveable frame – invented by French physicist Jean Bernard Léon Foucault. Gyroscopes are used in navigational instruments.

1854

Boolean algebra developed by British mathematician George Boole. Microprocessors use the mathematics of Boolean algebra in their calculations.

1879

First four-stroke, piston-cycle, internal combustion engine built by German travelling salesman Nikolaus August Otto. This paved the way for the development of motor vehicles.

1879

First practical electric light bulb developed by US inventor Thomas Alva Edison. Using a carbon filament, this bulb could glow for over 1,500 hours.

1888

German physicist Heinrich Hertz conducts experiments that prove the existence of radio waves. His discoveries led to the development of the radio.

1893

Zip fastener patented by US inventor Whitcomb Judson. The invention was not an immediate success – it wasn't until the 1920s that the zip became popular.

1903

First working aeroplane invented by US brothers and self-taught engineers Orville and Wilbur Wright. The plane stayed in the air for 12 seconds.

1907

First helicopter to achieve free flight while carrying a passenger invented by French bicycle maker Paul Cornu. It flew for 20 seconds and rose 0.3 m (1 ft) above the ground.

1923

Method of flash-freezing food so that it stays fresh invented by Clarence Birdseye, a US businessman. The first frozen vegetables were sold to the public in 1930.

1928

The antibiotic penicillin discovered accidentally by Scottish research assistant Alexander Fleming after noticing a mould attacking bacteria in a set of culture dishes.

1930

Jet engine independently invented by English engineer Frank Whittle and German aeroplane designer Hans von Ohain. The first engine was not built until 1937.

1933

Frequency modulation (FM) radio invented by US engineer Edwin Howard Armstrong. FM radio receivers produced a clear sound that is free of static.

1946

Microwave oven invented by US scientist Percy Spencer after he noticed that his chocolate bar melted when he stood near a magnetron of a radar machine.

1947

Transistor invented by Americans John Bardeen, Walter Brattain, and William Shockley at Bell Laboratories, the research arm of telephone company AT&T.

1953

Black box flight recorder invented by Australian aviation scientist David Warren to record voices and instrument readings during flights to help investigate causes of crashes.

1956

Hovercraft – a vehicle that can travel across water supported by a pillow of air – invented by English scientist Christopher Cockerell.

1959

Internal heart pacemaker invented by US scientist Wilson Greatbatch. He also invented a corrosion-free lithium battery to power it.

1960

First working laser built by US physicist Theodore Maiman. Similar devices had been made earlier by other scientists, but none produced visible light.

1967

First successful human heart transplant carried out by South African surgeon Dr Christiaan Barnard. The 55-year-old recipient lived for 18 days after the operation.

1968

Computer mouse patented by American inventor Douglas Engelbert. He called his invention an "X-Y Position Indicator for a Display System".

1973

Post-it® Notes invented by Art Fry, a researcher at American company 3M. He became frustrated with paper bookmarks falling out of his church hymnbook.

1975

The first laser printer was developed at the Xerox Research Center in the United States, where an engineer developed a way to add laser light power to photocopier technology.

1981

First portable computer, Osborne 1, launched. Designed by the Osborne Computer Corporation, it had two floppy disk drives and a tiny 13 cm (5 in) screen.

1984

Apple Macintosh computer invented. It revolutionized the personal computer with its simple, graphic interface and mouse-pointing device.

1990

World Wide Web/Internet protocol (HTTP) and World Wide Web language (HTML) created by British scientist Tim Berners-Lee.

1995

Computer language Java invented by Canadian James Gosling. Java made it possible to connect different computer systems together.

2003

The Human Genome Project, which began in the 1990s, completed. It was an international research effort to sequence and map all human genes.

2003

Infrared Fever Screening System – invented by Singapore Technologies Electronics – used in public buildings to scan for people with a high temperature from a fever.

1938

Ballpoint pen invented by Hungarian Ladislao Biro. He came up with idea after observing how much faster newspaper ink dried compared to fountain pen ink.

1945

The world's first practical digital computer, ENIAC 1, was built. When a moth was discovered to have shorted a circuit, the computer bug was invented too.

1948

Velcro® developed by Swiss inventor George de Mestral. He came up with the idea when burrs caught on his clothes while he was walking his dog.

1953

Double-helix structure of DNA discovered by British and US scientists Francis Crick and James Watson. They were helped by the research of scientist Rosalind Francis.

1957

The first artificial Earth satellite, *Sputnik 1*, launched by the Soviet Union (now Russia). This marked the start of the space race between the Soviet Union and United States.

1958

Microchip separately invented by American scientists Jack Kilby and Robert Noyce. This invention revolutionized computer technology.

1962

First industrial robot invented by Unimation in the United States. The robot was installed at General Motors automobile factory in New Jersey.

1965

Moore's Law developed by US scientist Gordon Moore. The law stated that the number of transistors on a microchip would double every 18 months – and has proved true.

1969

ATM (automatic teller machine), or cashpoint, invented by American Don Wetzel. It took $5 million to develop, and the first machine was installed in a bank in New York City.

1971

Microprocessor chip invented by Frederico Faggin, Ted Hoff, and Stan Mazor at computer firm Intel. They put a computer's central processing unit onto a small microchip.

1979

Walkman® personal stereo invented by Japanese electronics company Sony. It was the first portable music player and came with lightweight headphones.

1981

The first reusable spacecraft, the Space Shuttle, launched by NASA in the United States. *Columbia* returned safely to Earth two days after take-off.

1985

Windows® operating system for personal computers developed by US company Microsoft. It did not go on sale until two years later.

1986

Disposable cameras introduced by Japanese company Fuji. The camera had film already inside it and was taken whole to the film-developing lab.

1995

Standard format for the DVD (Digital Versatile/Video Disc) agreed by all the major electronics firms involved in its invention. The first DVD players went on sale in 1996.

1998

First MP3 player invented. The AMP MP3 Playback Engine was developed by Croatian Tomislav Uzelac of Advanced Multimedia Products.

2004

SonoPrep, a device that can deliver medicine via sound waves rather than injection, invented by bioengineer Robert Langer of the Sontra Medical Corporation.

2004

Translucent concrete developed by Hungarian architect Aron Losonczi. Called LiTraCon, it was made by adding glass fibres to normal concrete mix.

Groundbreakers

THOMAS EDISON

CHARLES BABBAGE (1791–1871)
In 1823, British mathematician Charles Babbage designed a machine called a difference engine, which was able to calculate mathematical tables.
He went on to propose a device called an analytical engine, which would have the ability to make mathematical decisions as it was calculating.
This machine wasn't built, but its design contained many elements that are used in modern computers.

ALEXANDER GRAHAM BELL (1847–1922)
Scottish-born inventor Alexander Graham Bell is best known for his invention of the telephone. In 1876, using the technology of the telegraph, Bell and his assistant, Thomas A Watson, constructed instruments that could transmit recognizable voice-like sounds over a telegraph wire.

BELL LABORATORIES
Formed as the research and development section of the American Telephone and Telegraph company, (AT&T) Bell Laboratories has become one of the top research institutions in the United States. The transistor, the laser, the solar cell, and communications satellites are among the many technological advances developed at Bell.

TIM BERNERS-LEE (1955–)
British inventor of the World Wide Web, Berners-Lee joined together two technologies – hypertext (a way of displaying documents with automated cross-references) and the Internet.
On the World Wide Web, hypertext is viewed using a web browser program, which retrieves web pages from web servers and displays them on a computer. The first website was put online on 6 August 1991.

LADISLAO BIRO (1899–1985)
While working as a journalist, Hungarian-born Biro noticed that newspaper ink dried more quickly than that used in a fountain pen. He tried to use the same ink in a fountain pen, but found that it would not flow into the nib. Working with his brother, Georg, a chemist, he invented the ballpoint pen, in which a ball in a socket picks up ink from a cartridge and deposits it on the paper.

AUGUSTA ADA BYRON KING, COUNTESS OF LOVELACE (1815–1852)
Lovelace became interested in the work of mathematician Charles Babbage and worked with him to improve the design of his analytical engine. She also wrote a plan to program Babbage's machine to solve mathematical problems – making her the first computer programmer.

WALLACE CAROTHERS (1896–1937)
US chemist Wallace Carothers is considered the founder of the science of manufactured polymers. He led the research division of the DuPont chemical company, where his team invented neoprene, a synthetic rubber, and nylon, a synthetic fibre.

JACQUES ALEXANDRE CESAR CHARLES (1746–1823)
French physicist Charles formulated Charles' Law, which states that the volume of a gas at constant pressure is proportional to its temperature.
This law is fundamental to the operation of any internal combustion engine. For example, heating the air inside a jet engine causes it to expand and rush out of the engine as a fast jet.

GEORGES CLAUDE (1870–1960)
French inventor Georges Claude was the first to apply an electrical discharge to a sealed tube of neon gas to create a neon light.

FRANCIS CRICK (1916–2004) & JAMES WATSON (1928–)
In 1953, English physics graduate Francis Crick and US research fellow James Watson discovered the molecular structure of DNA.
They proposed that the DNA molecule consisted of two helical (spiral) chains – a double helix. They theorized that genetic information is passed on through DNA in the genes, which was later demonstrated through the work of other scientists. On the day of their discovery, Francis Crick walked into a local pub and announced: "We have found the secret of life."

WILLIAM CROOKES (1832–1919)
English scientist Crookes experimented with passing electric currents through glass tubes containing gases.
The ionized gas in the tube gives out a light – as in a neon sign.

DOROTHY CROWFOOT HODGKIN (1910–1994)
Egyptian-born chemist Dorothy Crowfoot Hodgkin used X-rays to discover the crystal structure of molecules, including penicillin, vitamin B-12, vitamin D, and insulin.
This contributed greatly to the development of synthetic versions of these substances, leading to the control of many diseases, for example diabetes.

GOTTLIEB DAIMLER (1834–1900)
German mechanical engineer Gottlieb Daimler was a key figure in the development of the car.
He developed the world's first motorbike in 1885 and the world's first four-wheeled car in 1886.

RUDOLF DIESEL (1858–1913)
French-German engineer Diesel invented an engine that worked using combustion in a cylinder. His pressure-ignited heat engine, the Diesel engine, was the first that proved that fuel could be ignited without a spark.

JAMES DYSON (1947–)
British-born engineer and inventor James Dyson developed a bagless vacuum cleaner – the Dyson Cyclone.
It has been manufactured since 1993.

THOMAS EDISON (1847–1931)
US inventor Thomas Edison patented hundreds of inventions in the late 19th and early 20th centuries.
He developed the first commercially

viable light bulb, invented the phonograph, and refined other inventions, such as motion pictures and typewriters. He famously said: "Genius is one per cent inspiration and 99 per cent perspiration."

ALBERT EINSTEIN (1879–1955)
German-born physicist Albert Einstein was one of the most influential scientists of the 20th century. He revolutionized our concepts of space and time and developed the theories used to build models of the Universe. As well as providing a mathematical description of the random movement of particles, Einstein described the photoelectric effect in which electrons are emitted when light falls on certain materials. In 1905 he proposed the special theory of relativity, which described the physics of objects moving at constant velocities.
The theory contained the equation $E=mc^2$, which explains the relationship between mass and energy.
Einstein went on to formulate the general theory of relativity, which explains how gravity works.

EUROPEAN SPACE AGENCY
The European Space Agency (ESA) pools the resources and expertise of many European countries to research space. ESA conducts projects and missions to find out more about Earth and the Solar System. It also develops satellite-based technologies. In February 2005, ESA launched the Rosetta space probe, which will land on a comet in 2014.

MICHAEL FARADAY (1791–1867)
English scientist Michael Faraday used electromagnetism to make the first electric motor. He also discovered electromagnetic induction, which is what makes transformers work and laid the foundations for James Clerk Maxwell's understanding of light and Heinrich Hertz's discovery of radio waves. Faraday's momentous discoveries were responsible for the electric generators and motors that power much of the modern world.

ALEXANDER FLEMING (1881–1955)
In 1928, while Scottish scientist Alexander Fleming was working as a research assistant, he discovered a mould growing on a set of culture dishes. The dishes were growing the *Staphylococcus* germ, which causes wounds to become septic.
Fleming noticed that germs had stopped developing where the mould was growing. The mould was named penicillin – Fleming had discovered the first antibiotic.

JEAN FOUCAULT (1819–1896)
French physicist Foucault made the first accurate measurement of the speed of light. He also demonstrated the Earth's rotation using a long pendulum and invented the gyroscope – a wheel mounted so that it can spin in any direction while its axis continues to point in just one direction.

ROSALIND FRANKLIN (1920–1958)
British scientist Franklin used X-ray crystallography (mapping atoms by looking at an image of a crystal under an X-ray beam) to analyse the DNA molecule. Her research was used by Crick and Watson in their description of the DNA structure. Sadly, her contribution to this discovery was not acknowledged during her lifetime.

YURI GAGARIN (1934–1968)
On 12 April 1963, Russian cosmonaut Gagarin became the first human to travel into space. His mission lasted one orbit of Earth.

BILL GATES (1955–)
Gates founded US computer software company Microsoft with schoolfriend Paul Allen in 1975. Today, it is the world's largest software company and its operating systems and programs are used on most computers.

DR IVAN GETTING (1912–2003)
American Ivan Getting was key in developing Global Positioning System (GPS), a satellite navigational system. It was originally designed for military purposes, but is now used in cars, boats, planes, computers, and phones.

DR JOHN GORRIE (1803–1855)
US physician John Gorrie was a pioneer in refrigeration, air conditioning, and the manufacture of ice. He built a refrigerator in 1844, which made ice to cool the air for patients suffering from yellow fever.

WILLIAM GROVE (1811–1896)
In 1839, Welsh lawyer and scientist William Grove invented an electrochemical cell, which he called a gas voltaic cell. It was the forerunner of modern fuel cells.

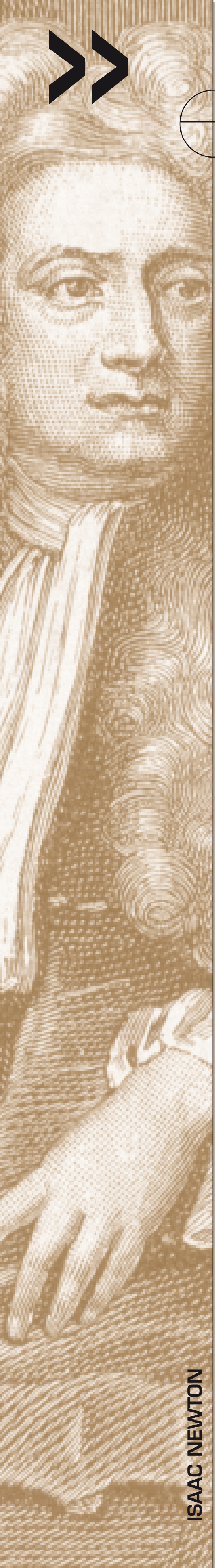
HEINRICH HERTZ (1847–1894)
German scientist Heinrich Hertz discovered radio waves in 1888, although James Clerk Maxwell had predicted their existence in 1864. Hertz conducted experiments to produce electromagnetic waves and measure their wavelength. The unit of frequency, the hertz, is named after him.

DR MARCIAN EDWARD "TED" HOFF JR (1937–)
Ted Hoff was an engineer at Intel Corporation in the United States.
In 1971, with his colleagues Frederico Faggin and Stan Mazor, he designed the Intel 4004, a computer-on-a-chip microprocessor. The technology placed a computer's central processing unit (CPU) and memory onto a silicon chip.

JOHN PHILIP HOLLAND (1841–1914)
Irish inventor Holland built the first practical submarine, the *Holland VI* in 1897, which was purchased by the US Navy and renamed the USS *Holland*.

STEVE JOBS (1955–) AND STEVE WOZNIAK (1950–)
Americans Jobs and Wozniak created the first successful personal computer, the Apple I. They built the early models in a garage. Apple, the company they founded, is one of the biggest computer manufacturers in the world.


ALBERT EINSTEIN


ISAAC NEWTON

JAMES PRESCOTT JOULE (1818–1889)

While experimenting with paddle wheels, the English physicist James Prescott Joule discovered the mechanical equivalent of heat – the amount of heat generated is precisely related to the amount of mechanical movement. He also demonstrated that different types of energy can be converted from one form to another, and that energy is neither created nor destroyed. The unit of energy, the joule, is named after him.

CHARLES KAO (1933–)

Chinese scientist Charles Kao suggested using glass optical fibres in telecommunications in the 1960s. Fibre-optic telephone lines appeared in 1970.

JACK KILBY (1923–2005) AND ROBERT NOYCE (1927–1990)

Two scientists, unaware of each other's activities, invented integrated circuits at almost the same time. The integrated circuit placed previously separated items, such as transistors, resistors, capacitors, and connecting wire, onto a single crystal, or microchip, made of semiconductor material. Kilby used germanium and Noyce used silicon for the semiconductor material. Jack Kilby also invented the portable calculator in 1967. Robert Noyce went on to found Intel, the company responsible for the invention of the microprocessor.

JOSEPH CARL ROBNETT LICKLIDER (1915–1990)

Licklider was a US psychologist with an interest in computer science. In 1965, he wrote a book called *Libraries of the Future*, in which he outlined his vision of a computer system that could connect the user to "everyday business, industrial, government, and professional information, and perhaps, also to news entertainment, and education". His ideas influenced the development of the Internet.

JOSEPH LISTER (1827–1915)

British physician Joseph Lister noticed that infections in wounds after operations were very common, despite efforts to keep hospitals clean. He began to spray carbolic acid on surgical instruments, wounds, and dressings. This first antiseptic dramatically reduced death rates.

GUGLIELMO MARCONI (1874–1937)

Italian scientist Marconi developed radio communication. In 1895, just seven years after the discovery of radio waves by Heinrich Hertz, Marconi succeeded in transmitting a radio message in Morse code.

JAMES CLERK MAXWELL (1831–1879)

Scottish physicist and mathematician James Clerk Maxwell identified light as part of the electromagnetic spectrum and developed mathematical equations to demonstrate this. His electromagnetic theory of light led directly to Heinrich Hertz's discovery of radio waves and to related advances in science and technology that have transformed the modern world.

GREGOR MENDEL (1822–1884)

Austrian botanist Gregor Mendel is considered the founder of genetics. He experimented with pea plants and noticed that the characteristics of offspring, such as height, exhibited recessive and dominant behaviour.

GEORGE DE MESTRAL (1907–1990)

Swiss inventor George de Mestral had the idea for Velcro® in 1948 when he became covered in burrs while walking his dog. He perfected his design, which uses hooks and loops to fasten two pieces of the fabric together, and patented it in 1955.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

The National Aeronautics and Space Administration (NASA) was formed in the United States in 1958 in reaction to the Soviet Union launching the first artificial satellite, *Sputnik 1*. NASA's first high-profile programme was Project Mercury, which investigated whether humans could survive in space. In 1969, NASA succeeded in putting the first humans on the Moon. In 1981, NASA launched the Space Shuttle programme, building the first reusable spacecraft. It is involved in the construction of the International Space Station and has launched a number of probes to other planets. NASA has played a huge role in the development of satellites, and its technological advances have influenced many areas of modern life.

JOHN VON NEUMANN (1903–1957)

The first electronic computers were not easy to reprogram with new tasks. Hungarian-born Neumann was the first to suggest that a computer's operating program should be stored in its memory. This would allow the rest of the computer to switch quickly from one task to another. All modern computers work in this way.

SIR ISAAC NEWTON (1642–1727)

English physicist and mathematician, Newton studied force and motion and wrote the three laws of motion. He also discovered the law of gravitation, which may have been inspired by seeing an apple fall from a tree. Newton made other important discoveries about light, and developed calculus in mathematics.

HANS OERSTED (1771–1851)

In 1820, Danish physicist Oersted placed a compass needle beside a wire carrying an electric current. The needle moved, showing that an electric current produces a magnetic field. Oersted had discovered electromagnetism, which is used in most modern electrical machines.

HANS JOACHIM PABST VON OHAIN (1911–1998)

In 1935, German scientist Hans-Joachim Pabst von Ohain patented a jet propulsion engine design similar in concept to that of Frank Whittle. In 1939, his design was used to build the first jet-powered aeroplane.

ELISHA GRAVES OTIS (1811–1861)
In 1852, US inventor Elisha Graves Otis conceived the safety elevator, which uses a ratcheted brake to stop the lift from falling if the main cable breaks. Otis demonstrated his invention by standing in a lift while the cable was cut with an axe.

NIKOLAUS AUGUST OTTO (1832–1891)
Otto was a German engineer who developed the four-stroke internal combustion engine as a power source. In 1876, Otto constructed the prototype of today's car engine.

JOHN R PIERCE (1910–2002)
John R Pierce was a research director at Bell Laboratories. He developed the first communications satellite in conjunction with NASA. Named *Telstar 1* it was launched in 1962.

ROY J PLUNKETT (1910–1994)
Roy Plunkett was a research chemist at the DuPont chemical company. While working on a refrigerant experiment, Plunkett accidentally discovered one of the best-known and most widely used polymers – Teflon®.

DR LAWRENCE ROBERTS (1937–)
US scientist Dr Lawrence Roberts led the team that designed and developed ARPANET – the forerunner to the Internet. While at the Massachusetts Institute of Technology (MIT) he created the first computer-to-computer network. Based on that success, he moved to ARPA, the research arm of the US Department of Defense, where he designed and managed the building of the ARPANET. The first four computers were connected in 1969 and by 1973, 23 computers were connected worldwide.

WILHELM RÖNTGEN (1845–1923)
German physicist Röntgen discovered X-rays in 1895. He found that a cathode-ray tube caused barium-coated paper positioned some distance away to glow with light. The tube gave out X-rays, which made the compound glow.

JAMES RUSSELL (1931–)
US scientist James Russell was a keen music fan frustrated by how quickly his vinyl records wore out. He thought a system that could record and replay sounds without physical contact between its parts would prevent the wear and tear, and that the best way to achieve such a system was to use light. From this idea he developed the digital compact disc (CD).

ERNEST RUTHERFORD (1871–1937)
New Zealand physicist Rutherford discovered that an atom is not a solid particle. He realized that an atom has a heavy centre, or nucleus, surrounded by electrons. He later discovered the proton, a positively charged particle within the nucleus.

JACOB SCHICK (1878–1937)
US soldier and inventor Jacob Schick developed the electric shaver in the 1920s. He came up with the idea when he had trouble shaving in the freezing conditions of an Alaskan winter.

PERCY SPENCER (1894–1970)
American self-taught engineer Percy Spencer invented a device to cook food using microwave radiation in 1945. While working on a radar research project, he noticed that a vacuum tube called a magnetron melted a chocolate bar in his pocket. He built a metal box into which he fed microwave energy and the microwave oven was invented.

COLONEL JOHN PAUL STAPP (1910–1999)
While carrying out crash research for the United States Air Force in the 1940s and 1950s, Colonel Stapp started applying the same research techniques to car crashes.
His pioneering work introduced the science of auto crash testing and the use of crash test dummies.

VALENTINA TERESHKOVA (1937–)
A former textile worker and amateur parachutist, Russian cosmonaut Tereshkova was the first woman in space. In June 1963, she made 48 orbits of Earth in the *Vostok 6* spacecraft, a flight lasting 71 hours.

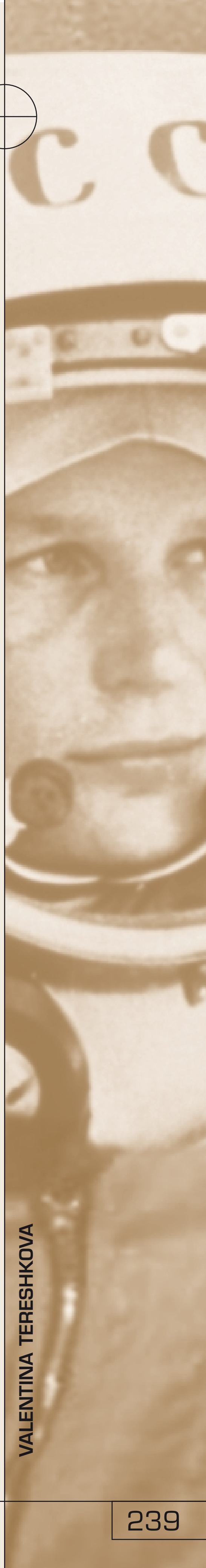
WILLIAM THOMSON (LORD KELVIN) (1824–1907)
British mathematician William Thomson researched thermodynamics and developed the concept of absolute zero. With James Prescott Joule he discovered that gases cool when allowed to expand - the Joule-Thomson effect.

ALAN TURING (1912–1954)
Considered the father of computer science, British mathematician Turing was involved in developing early electronic computers during World War II and wrote code for programming computers.

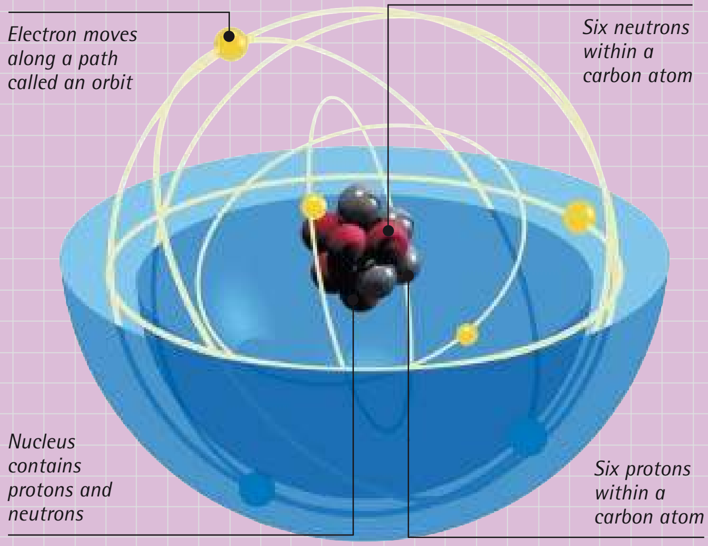
DR DAVID WARREN (1925–)
Warren worked at the Aeronautical Research Laboratories in Melbourne, Australia, where he invented the black box flight data recorder in 1953.

FRANK WHITTLE (1907–1996)
English engineer Frank Whittle conceived the idea of the jet engine in 1929, and set about building one. However, the first jet-powered aircraft flew in Germany in 1939. Whittle's own engine was used in an aircraft in 1941, and was the forerunner of the modern jet engine.

WILBUR WRIGHT (1867–1912) AND ORVILLE WRIGHT (1871–1948)
US brothers Wilbur and Orville Wright ran a bicycle shop in Ohio. They also had a great interest in the science of flying and read everything they could on the subject. The brothers built their own wind tunnel to test aerofoils and, on 17 December 1903, Wilbur and Orville Wright made the first sustained, controlled flight in a powered aircraft.


VALENTINA TERESHKOVA

STRUCTURE OF AN ATOM



Every single thing you can see, hear, feel, smell, and taste is made from microscopic particles called atoms. An atom is itself made up of even smaller particles called subatomic particles. The tightly packed nucleus in the centre of each atom contains protons and neutrons. These particles are made up of particles called quarks, which are held together by gluons. Particles called electrons whizz around the atom's nucleus. More than 200 other subatomic particles have been discovered in experiments in which particles are smashed into each other at high speed to create even tinier particles. The machines that are used to do this are called particle accelerators.

Techno terms

A

Absorption
Absorption occurs when one substance completely absorbs another, rather like a sponge soaking up water. Absorption also means the taking up of energy such as light. **Mirror p90**

Acceleration
When the velocity (speed) of an object increases, it is accelerating. Acceleration is a change in velocity over a certain amount of time. **Crash test p134, Jet engine p146 Motorbike p126**

Aerodynamics
Aerodynamics is the study of the motion of gases, particularly air, and the movement of objects in air, for example aircraft. **Bike p58, Football p52, Wind tunnel p148**

Aerofoil
A structure, such as a wing, which is shaped to give lift as air flows over it. An aerofoil is usually curved on top and flat underneath. Its shape causes air passing over a wing to travel faster than the air passing below it. The pressure of the air is reduced as it moves. The faster air moves, the lower its pressure. This is called Bernoulli's effect. It means that the air above the wing has a lower pressure than the air below it. The difference in pressure pushes up the wing and produces lift. The moving air also creates some drag. **Submersible p142, Osprey p144**

Air resistance
Friction, or drag, acting on something that moves through air. **Bike p58, Wind tunnel p148**

Alloy
A mixture of metals or a metal and non-metal. Mixing a metal with other metals, or sometimes with another element, for example carbon, results in a substance with more useful properties than the metal alone. Alloying a metal may increase its hardness, strength, and resistance to corrosion. Stainless steel is an example of an alloy. **Motorbike p126, Parts p132, Robot surgery p208, Vacuum p116, Watch p92**

Amplitude
The height of a peak or trough in a wave, such as an ocean wave or a sound wave. A greater amplitude means that a wave is transferring more energy. For example, a sound wave with a large amplitude is louder than a sound wave with a small amplitude. **DJ decks p76, Guitar p66, Voice recognition p28**

Analogue
Analogue technology was originally used to broadcast and record sound and images, and to make telephone calls. It transmits sound in the form of continuous electrical signals. **Compact disc p68, Digital radio p22, Motherboard p170, Toys p26**

Antibody
A blood protein that is produced by the body's immune system in response to infection. It recognizes and helps fight infectious agents, such as bacteria and viruses. **Antibiotics p222, Vaccination p220**

Artificial intelligence
The ability of a computer to think and work like a human being. A computer that has some degree of artificial intelligence can assess its own performance, and work out ways to improve it. A computer can be programmed to play a game of chess, for example, but an intelligent

computer can learn from each game it plays, so that it is able to play better the next time. **Robot helper p118, Robot worker p186**

Atom
All matter is made up of tiny particles called atoms. An atom is the smallest particle of an element that can exist on its own. There are just over 100 different types of atom, each of which contains even smaller subatomic particles. Every element has an atomic number, which is based on the number of protons that are contained in the nucleus of its atoms. **MRI scan p204, Neon p34**

B

Bacteria
Microscopic, single-celled organisms that live in and around us. Some are helpful, but others can cause diseases. **Antibiotics p222**

Bandwidth
The maximum amount of data that can travel along a communications path in a given time, usually measured in bits per second. **Satellite p42, Video link p40**

Binary
Digital technology converts any data that is not already in the form of numerals – such as letters, the parts of an image, and musical notes – into coded numbers. The letter A, for example, becomes 65. These code numbers are then converted into binary numbers, such as 01000001, which is the binary number for 65. The binary code consists of a signal made up of pulses of electricity that are on (1) or off (0). For example, the number 13 becomes the binary code on-on-off-on, because its binary number is 1101. Microchips in a computer process and store these binary signals. **Compact disc p68, Digital radio p22, Flash stick p172, Microchip p16, Mobile phone p18, Motherboard p170**

Bit
The word bit is short for the term "binary digit". It is the smallest possible unit of memory used by a computer. A computer uses electrical signals that are groups of on-off pulses. A group of pulses represents a binary number made up of the numerals 1 and 0. Each numeral in the binary number is called a bit, so 11010011 is an eight-bit number. **Flash stick p172, Microchip p16**

Bluetooth®
Chip technology that enables wireless voice and data connections between a wide range of devices through short-range, digital, two-way radio. **Digital pen p166, Virtual keyboard p174**

Buoyancy
The ability of an object to float in a fluid, such as a liquid or a gas. When a boat is placed in water, the liquid pushes on it with an upward force called upthrust. This occurs because the pressure of the water is greater underneath the boat than at the water's surface. A boat floats if the upthrust is equal to its weight. Solid objects are more buoyant if they have a low density. **Submersible p142**

Byte
When a computer stores data, it converts it into a long sequence of binary numbers. These numbers are changed into signals in binary code. Each number has eight bits and is called a byte. The capacity of a memory unit, such as Read-only-memory (RAM) or a disk, is measured by the total number of bytes that it can store. This is given in kilobytes (KB), which each contain 1,024 bytes; in megabytes (MB), which each contain 1,048,576 bytes; and in gigabytes (GB), which contain 1,073,741,824 bytes. **Laptop p168, Microchip p16, Smart card p182**

C

Carbon
A non-metallic element that occurs in several forms. For example, diamond is a form of carbon that is a hard crystal, and is used in jewellery and drills. Graphite is a soft, black solid that is used as a lubricant and in pencils. Carbon black is a fine powder used in making rubber. Coke is a form of carbon used to make steel. Carbon fibres are used to make strong materials, such as reinforced plastic. **Bike p58, Bionic limb p214, Match p86, Motorbike p126, Parts p132**

Centre of gravity
The point at which the whole weight of an object is balanced. For example, you can balance a tray of glasses on one hand if you support it directly beneath its centre of gravity. The force of gravity pulls equally on all parts of the tray around this point. **Wheelchair p138**

Centrifugal force
In a centrifuge, a container holding a mixture spins around at high speed. This exerts a strong force on the mixture, causing it to separate into its different components. The heavier articles of the mixture move outwards because of their greater inertia. There appears to be an outward force, often called centrifugal force, pulling upon the particles. **Lift p140, Vacuum p116**

Charge
Each atom has an equal number of negatively charged electrons and positively charged protons, which means that an atom is electrically neutral. If the atoms in an object lose electrons, the object gets a positive charge. The amount of charge depends on how many electrons are gained or lost. **Laser printer p176**

Chemical reaction
In a chemical reaction, the atoms of elements in substances rearrange to form new substances, which contain the same atoms, but in different combinations. For example, when you make toast, a chemical reaction takes place. Bread contains carbohydrate, a compound containing the elements carbon, hydrogen, and oxygen. Heating the bread changes the carbohydrate into black carbon, which forms on the surface of the bread. Water (made of hydrogen and oxygen) also forms and escapes into the air as vapour. **Battery p94, Fireworks p78, Fuel-cell car p128, Match p86**

Colour
Our eyes normally detect a range of colours – from red, orange, and yellow, through to green, blue, and violet. We see different colours because each colour has a different wavelength of light. Red has the longest wavelength and violet the shortest. Some objects, such as traffic lights, emit (give out) light of a particular colour. Other objects appear coloured because they absorb some wavelengths and reflect others. Green grass, for example, reflects only green light, and absorbs all other colours. **Fireworks p78, LCD TV p24, Neon p34**

Combustion
Combustion is a chemical reaction between a fuel and oxygen that produces heat and, usually, light. A material that can combust (catch fire or ignite) is said to be flammable. To combust it has to be heated to an ignition temperature. At this point, a chemical reaction starts between the substance and oxygen in the air. This process gives out heat, which keeps the fuel hot enough for combustion to continue until all the material has burned. **Car engine p130, Fireworks p78, Jet engine p146, Match p86**

Compound
A compound is a substance in which the atoms of two or more elements are combined. It contains fixed proportions of elements linked to form molecules, or a larger structure that combines many molecules. The chemical name of a compound shows the elements within it. For example, the chemical name for salt is sodium chloride, showing that it is a compound of sodium and chlorine. A compound's properties may be very different from those of the individual elements it contains. Sodium is a soft metal, and chlorine is a poisonous gas. It is not safe to eat either, yet salt is an important food. **Fuel-cell car p128**

Compression
The action of squashing a substance so that it takes up a smaller space. When a gas is compressed, its pressure increases. When a solid is compressed, forces in the solid react against the compression. These forces are responsible for the strength of a solid. **Car engine p130, Fridge p102, Trainer p50**

Conduction
The flow of heat through a solid. For example, if a metal bar is heated, the atoms within start to move more quickly. These particles strike others and speed them up, spreading heat energy through the object. A thermal conductor is a material that carries heat in this way. Its conductivity is a measure of the rate at which heat flows. Heat flows easily through materials with a high conductivity, for example metals. **Heat p98**

Conservation of energy
The law of conservation of energy states that the total amount of energy in a system is constant. A system is anything that contains or uses energy. For example, the light and heat produced by a torch's bulb are equal to the electrical energy produced by the battery. Energy can be neither created nor destroyed; it can only change from one form to another. This law does not apply to the production of nuclear energy, in which mass changes to energy. **Crash test p134, Light bulb p88, Watch p92**

Crystal
A crystal is a solid containing a regular, symmetrical arrangement of particles. Some elements, such as iodine, form crystals. Many compounds form crystals when they leave solutions. For example, if you leave salty water exposed to the air, it forms tiny white crystals of salt as the water evaporates. Most molten compounds also form crystals as they solidify. The process of forming crystals is called crystallization. As a crystal forms, atoms, ions, or molecules link together in a geometric network called a lattice. The crystal grows as more atoms, ions, or molecules join the lattice. The shape of the lattice gives the crystal its particular pattern. **Microchip p16, Mirror p90**

Current
The flow of electric charge through a substance. An electric charge can only flow through a substance that can conduct electricity, for example, a copper wire. A charge flows through a wire when an electromotive force, or voltage, drives electrons into the conductor. The electrons are negatively charged, which means that they repel electrons ahead, causing them to jump from one atom to the next. As electrons in the conductor move from atom to atom, the charge is carried along the wire in a flow called an electric current. **Battery p94, Fuel-cell car p128, Wet welding p188**

D

Data compression
Any technique used to encode data so that it takes up less storage space. **Iris scan p32, MP3 player p70**

Detergent
Washing liquids and powders contain detergents, which are made of chemicals obtained from petroleum. Detergent molecules surround particles of greasy dirt on the surface of soiled cloth. The molecules carry the particles away from the surface and into the water. **Washing machine p114**

Digital
In communications and computer technology, digital refers to a method of encoding data using a binary system made up of zeroes and ones. **Camera p62, Compact disc p68, Digital pen p166, Digital radio p22, Flash stick p172, Iris scan p32, Mobile phone p18, Pet translator p30, Scanner p178, Video link p40**

Digitization
The process of converting analogue information into digital format. For example, converting an image into a binary code. **Scanner p178**

DNA (deoxyribonucleic acid)
The chemical within the cells of living things that carries all the information needed to build it and keep it alive. DNA is passed from one generation to

the next when living things reproduce. **Biochip p226**

Drag
The natural resistance or friction of the air or water as an aircraft flies or a boat powers forwards. Drag increases the faster the craft moves. In order to overcome drag, a craft needs thrust from its engines. A streamlined shape reduces drag. **Bike p58, Fabric p60, Jet engine p146, Submersible p142, Wind tunnel p148**

E

Efficiency
The measure of how much energy a machine converts into useful work. For example, an efficient light bulb uses most of the electrical energy that it takes in to produce light, rather than heat. **Light bulb p88, Washing machine p114**

Electrical energy
The energy of moving electrons, as in an electrical current that flows through a wire connected to a battery. When we use electricity, electrical energy changes to another form of energy, for example, light in a light bulb or kinetic energy in an electric motor. **Light bulb p88, Neon p34**

Electric motor
A machine that uses electricity to produce movement. It contains a coil of wire, which is suspended in the magnetic field of a magnet or electromagnet. When an electric current flows through the coil, it produces its own magnetic field. The two fields push or pull on each other, causing the coil to rotate and drive the shaft of the motor. **Fuel-cell car p128, Lift p140, Washing machine p114**

Electrochemistry
The branch of chemistry that involves electricity. Electricity plays a part in all chemical reactions, because atoms contain electrically charged particles. For example, a battery uses a chemical reaction to generate an electric current. An electrical current can also be used to break up a compound into the individual elements it contains. **Battery p94, Fuel-cell car p128**

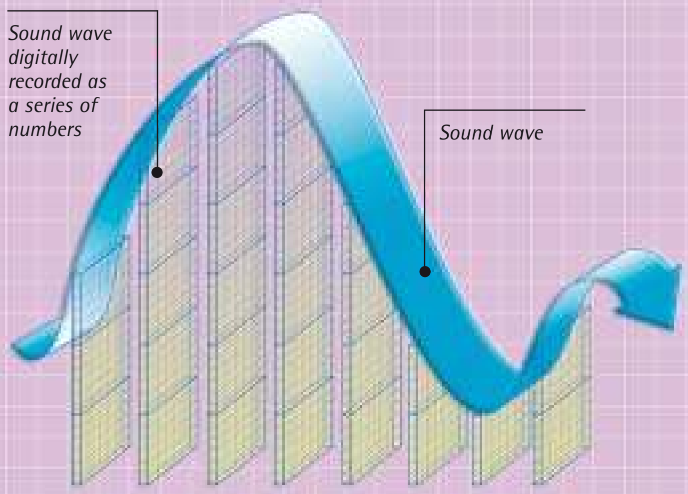
Electrode
Any terminal that conducts an electric current into or away from conducting substances in a circuit, such as the anode (positive terminal) or cathode (negative terminal) of a battery. **Battery p94, Fuel-cell car p128, Light bulb p88**

Electrolyte
A non-metallic substance that conducts an electric current in solution by moving ions (atoms or groups of atoms that carry an electric charge) rather than electrons. **Battery p94, Fuel-cell car p128**

Electromagnet
A form of magnet that works using electricity. It consists of a coil of wire wound round a piece of iron. When an electric current flows through the coil, the iron becomes a magnet. **Headphones p74, Lift p140**

Electron
A tiny particle that moves in a shell around the nucleus of an atom. Electrons have a negative electric charge. They balance an equal number of protons, which have a positive charge. This makes the whole atom electrically neutral. If an atom gains or loses an electron, the charges are unbalanced and it becomes a charged atom called an ion. **Battery p94, Fuel-cell car p128, Light bulb p88, Neon p34, Solar cell p96**

DIGITAL TECHNOLOGY



Digital technology can read, write, and store information that is represented in numerical form. For example, music can be digitally recorded. A microphone converts the music into an electric signal, which is measured by a computer thousands of times a second. These measurements are reproduced as a series of numbers in binary code. Each number is a measure of the height of the sound wave at a given point.

Digital technology allows us to electronically store and manipulate data. It can be encrypted for security, or compressed, so large amounts of information can be stored on a tiny digital device. Data can also be transferred between devices, so we can take photos with a mobile phone or watch movies on a laptop.

Energy
Energy is the ability to cause an action. There are several different kinds of energy. Whenever anything happens, one kind of energy is present and it changes to another kind. For example, in an electric motor, electrical energy becomes kinetic energy – the energy of movement. **Fireworks p78, Light bulb p88, Neon p34, Racket p54, Watch p92**

F

Fibre optic
Light rays are able to pass along a thin glass thread or fibre, called an optical fibre. An outer coating of a different kind of glass reflects the light into the centre of the fibre, so that it cannot escape. Fibre optics are used to carry laser light signals along telephone cables. An endoscope is a flexible tube of optical fibres that is inserted into the body. It is used in medicine to produce images of the interior of the body. It carries an image to an eyepiece at the other end. **Camera capsule p212, Fibre optics p20**

Filament
A light bulb contains a piece of thin, coiled tungsten wire called a filament. The filament is heated by an electric current until it gets so hot that it glows white and gives off light. The bulb is filled with an unreactive gas, such as nitrogen or argon, to prevent the filament from burning out, as it would in air. **Heat p98, Light bulb p88**

Fluorescence
The ability of certain molecules to absorb light at one wavelength and emit (give off) a light at a longer wavelength. Bright fluorescent paints take in light of various colours or invisible ultraviolet rays and emit light of just one colour. This light is usually much brighter than normal reflected light. **ID p180, Light bulb p88**

Force
A force can push, pull, twist, turn, stretch, or squeeze an object. A force can cause an object to speed up, slow down, or change direction. When the forces acting upon an object are balanced, the object is in equilibrium. **Crash test p134, Racket p54**

Frequency
The regularity with which something happens. It is most often applied to a wave or vibration. A wave's frequency is the number of times its complete cycle occurs each second. Frequency is measured in hertz (Hz). **Digital radio p22, Doppler radar p194, Guitar p66**

Friction
Friction occurs where moving objects or surfaces rub together. It acts against the direction of motion, causing objects to slow down or stop and creating heat. The amount of friction depends on the texture of the surfaces, and the force pressing them together. Rough surfaces create the most friction. **Match p86, Space Shuttle p156**

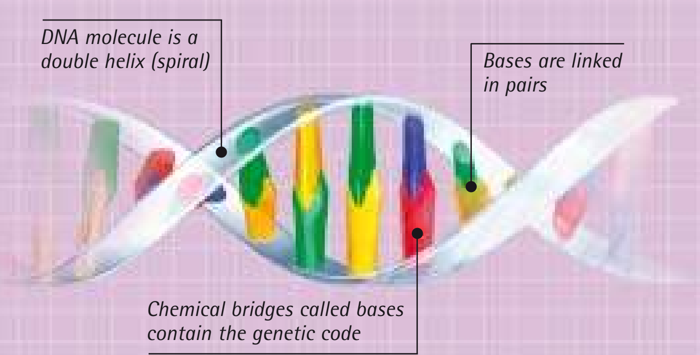
G

Gas
Gas is matter in a form that has no definite shape or volume. Gas particles are spaced far apart. The forces between them are not strong enough to hold them in place, so they move freely and rapidly in all directions. Because gas has no fixed shape or volume, it expands to fill any container it is put into. **Aerosol p112, Fridge p102, Jet engine 146, Neon p34**

Gear
A gear is a pair or series of toothed wheels that are connected so that one wheel turns another. Gears transmit force and motion. The wheels are usually of different sizes and mesh together, or are connected by a chain. A large wheel causes a small wheel to turn with less force, but greater speed. A small wheel makes a large wheel turn with more force, but less speed. Gears can also change the direction of the motion they transmit. **Bike p58, Lock p108, Watch p92**

Gel
A jelly-like material composed of a liquid evenly dispersed in a solid. **Aerogel p104, Trainer p50**

» GENETICS



Every form of life is put together by a chemical code. The code is contained in molecules of deoxyribonucleic acid (DNA), which are packed away inside the cells of all living things. The DNA molecule is in the shape of a double helix, linked by chemicals called bases. The chemical code is very complex. The code inside one human cell contains 50,000 to 100,000 separate instructions, called genes, and each one controls a different characteristic. In a cell's nucleus, there are several lengths of DNA. Each one is called a chromosome. DNA works by telling a cell how to make the many different proteins that your cells need to function.

Genetics
Genetics is the study of the way inherited characteristics are passed on in living things. **Biochip p226, IVF p224**

Geostationary satellite
A satellite that circles the Earth once every 24 hours, and appears to be fixed in the sky. **Satellite p42**

GPS (Global Positioning System)
GPS is a space-based navigation and positioning system. Receivers on Earth work in conjunction with fixed-orbit satellites to determine a precise location. **Navigation p154**

Gravity
A force of attraction between all objects with mass. All bodies of matter exert a force of gravity, but it is strong only when something has a large mass, such as a planet, moon, or star. Gravity becomes weaker as bodies of matter move further apart. **Space probe p158**

Gyroscope
A wheel mounted in a ring so that its axis is free to turn in any direction. When spun rapidly, a gyroscope will point in the same direction, no matter which way the ring is turned. Gyroscopes are used as stabilizers to help moving objects balance, and as navigational devices. **Robot helper p118, Satellite p42, Wheelchair p138**

H

Heat
Heat is a form of energy that makes things hot or cold. All objects, whether hot or cold, possess heat because the particles (atoms and molecules) within them are moving. An object gains heat and becomes hotter the faster its molecules move. When heat is applied to an object, the movement of its particles speeds up. If the molecules slow down, it loses heat and cools. Heat energy always passes from a hotter object to a cooler object. Heat can be produced in many ways, including by friction, combustion, and from electricity. **Aerogel p104, Car engine p130, Fridge p102, Homes p106, Laser printer p176, Match p86, Wet welding p188**

Hypertext
Any text on a web document that contains links to other documents. By clicking on words, phrases, or images in a document, another document is retrieved. **Internet p38**

I

Image sensor
A light-sensitive device used in scanners, digital cameras, and video cameras that records the brightness of the light that strikes it during an exposure. **Digital camera p62, Scanner p178**

Incandescence
The emission of light by a hot substance. When substances get hot, they become incandescent (glow with light). The colour of the light given out depends on how hot the substance is. An object glows red at first, and then yellow and white as it gets hotter. Most household light bulbs contain a thin tungsten filament. When an electric current passes through it, the filament becomes so hot that it gives off a bright white light. **Light bulb p88**

Inertia
Every object has inertia, which causes it to resist a change in its motion. Therefore, a moving object will try to keep moving in a straight line, and a stationary object will try to remain at rest. If you are travelling in a car that stops suddenly, your body's inertia will cause you to carry on moving. Wearing a seatbelt contains this movement. Inertia depends on mass – an object with a large mass has a lot of inertia. **Crash test p134**

Infrared ray
When warm and hot objects give off heat by radiation, they produce infrared rays. Remote controls use a weak infrared beam to send signals that operate controls. Thermography uses infrared rays to produce pictures that show the warm and cool parts of an object as different colours. **Imaging techniques p10, Virtual keyboard p174**

Insulator
An insulator is a material that does not conduct heat or electricity well. Insulators include wood, plastics, cork, and air. **Aerogel p104, Homes p106**

Internal combustion engine
A heat engine that burns fuel inside the engine to produce power. A gas is heated and expands. The pressure of the expanding gas moves parts inside the engine, changing the heat energy into kinetic energy (energy of motion). **Car engine p130, Jet engine p146**

Internet
A network of many computers connected via telecommunication networks. The computers communicate using a set of protocols called TCP/IP (Transmission Control Protocol/ Internet Protocol). The Internet provides access to a wide range of resources from all around the world. **Fridge p102, Internet p38, Laptop p168, Links p36, Robot helper p118, Toys p26**

Ion
An ion is an atom, or group of atoms, that carries an electric charge. When atoms gain electrons, they form ions with negative electric charge. These ions are called anions. When atoms lose electrons, they form ions with a positive charge, called cations. Many compounds contain ions joined together by ionic bonds. The electrical charges that attract the ions to each other are very strong, so most ionic bonds are very difficult to break. **Battery p94, Fuel-cell car p128, Neon p34**

Ionization
The formation of ions is called ionization. It occurs when compounds dissolve or melt. A chemical reaction may take place as the ions join up again in new combinations. **Battery p94, Fuel-cell car p128**

J

Jet engine
An engine that produces a high-speed jet of air. Most aircraft are powered by jet engines. As the engine burns fuel, a jet of hot air and other gases is forced from the exhaust of the engine, pushing it forwards. A turbofan is a jet engine with a large fan at the front. The fan blows air around the gas turbine to join the jet at the rear, increasing the engine's thrust. **Jet engine p146, Space Shuttle p156**

K

Kinetic energy
The energy that a particle or object possesses due to its movement or vibration. The faster an object travels, the more kinetic energy it has. It loses its kinetic energy as it slows down. **Crash test p134, Neon p34, Watch p92**

L

Laser
A device that produces a beam of high-energy light. Laser stands for "light amplification by stimulated emission of radiation". Inside a laser is a material called a lasing medium. Passing an electric current or light into the medium gives energy to, or excites, its atoms. The excited atoms suddenly release their extra energy and emit (give off) light. One atom emits a light ray, which strikes another atom and causes it to emit another ray, and so on in a cascade of emissions. The waves of light are very concentrated, which means that they move exactly in step. Mirrors reflect the rays, so that the cascade builds up. The light leaves through one of the mirrors, which is partly transparent. Lasers can also emit invisible infrared rays. **Compact disc p68, Fibre optics p20, ID p180, Laser surgery p206, Shaver p110**

LCD (liquid crystal display)
LCD screens use thousands of tiny red, green, and blue filters to create an image. Behind these filters is a layer of liquid crystals. When an electric current is passed through the crystals, they twist or untwist, acting like shutters to allow light to either pass through to a transparent screen and form an image. **LCD TV p24, Pet translator p30**

LED (light-emitting diode)
An LED is a diode (an electronic component that can either pass or block an electrical current) that gives out light or infrared rays. They are illuminated by the movement of electrons in a semiconductor material. LEDs are found in many devices. They are often used as warning or safety lights. Remote control units contain LEDs that convert electrical signals into invisible infrared control signals. **Fibre optics p20, Robot helper p118, Virtual keyboard 174**

Light
Light is a form of energy. It travels in waves that have the fastest-known speed of anything in the Universe. Life on Earth could not exist without light. Our most important source is the Sun, but we can also produce light using electricity. The light you can see is part of a range of electromagnetic radiation. It contains wavelengths that your eyes detect as colours, ranging through the spectrum from red to violet. Light can act either as a wave or as a tiny packet of energy called a photon. **Light bulb p88, Neon p34, Solar cell p96, Virtual keyboard p174**

Luminescence
Luminescence occurs when objects take in energy other than heat and change it into light energy. Luminescent animals, such as glow-worms and fireflies, glow because chemical energy in their bodies changes to light energy. Some television screens contain luminescent materials that light up when struck by a beam of electrons. **Neon p34**

M

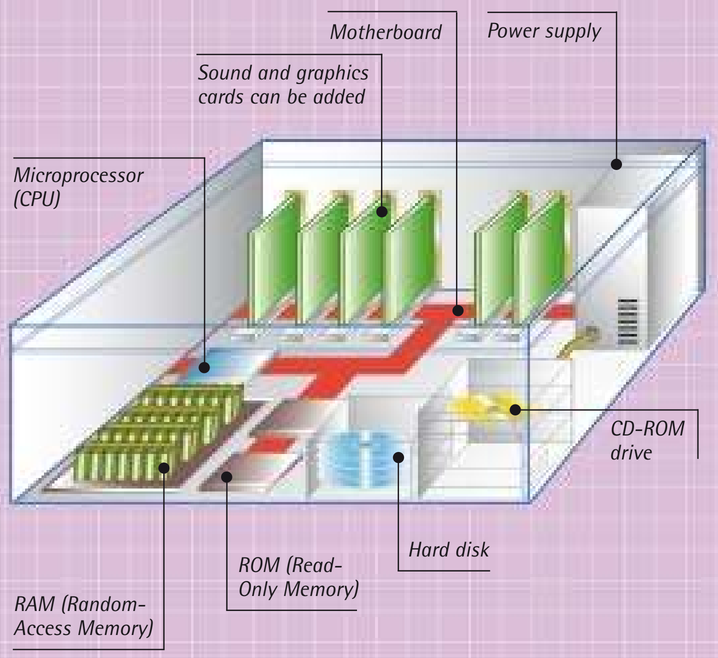
Magnet
A magnet creates an area around it called a magnetic field, which contains properties that either attract or repel other magnets . A magnet has two poles – a north pole and a south pole. The magnetic force is strongest at each pole. Only certain materials are magnetic. These include some metals, such as steel, iron, nickel, and cobalt; some alloys; and some ceramics. Lodestone is a magnetic mineral made of iron oxide. A permanent magnet is always magnetic, but a temporary magnet can gain and lose its magnetic force. **Guitar p66, Headphones p74, MRI scan p204**

Magnetic field
A magnet only attracts objects when they are within its magnetic field. Two magnets attract or repel each other if their magnetic fields come together. At each point in the field, the magnet exerts a force in a certain direction. These directions follow lines of force, or flux, which loop around the magnet from one pole to the other. A wire carrying an electric current is also surrounded by a magnetic field while the current is flowing. **Guitar p66, MRI scan p204, Trainer p50**

Microchip
A microchip is an integrated circuit – a complete set of electronic components in one unit. It consists of a single piece of semiconductor, usually silicon, which contains thousands of linked components, such as transistors and diodes. A microchip can carry out many complex actions – so many, in fact, that the circuit of a whole computer may be connected in one chip. **Digital pen p166, Microchip p16, Mobile phone p18, Motherboard p170, Racket p54, Radio ID tag p184, Smart card p182**

Microprocessor
A microprocessor is a complete computer on a single tiny chip of silicon. It is the most sophisticated type of microchip. All computers have a central processing unit, or CPU, containing one or more microprocessors. The CPU is the most important part of the computer and its job is to control the computer, perform tasks, and calculate results. By following the instructions of a program, the CPU processes data and displays the result on the screen. **Games p64, Laptop p168,**

INSIDE A COMPUTER



Everything a computer does is overseen by the central processing unit (CPU), which contains one or more microprocessors. Memory is the storage used to hold data. Random-access memory (RAM) is used to store the information that the computer is currently working with. Read-only memory (ROM) is a permanent memory storage for data that does not change. The hard disk provides permanent storage, and is used to hold information such as programs. The operating system is the software that allows the user to interface with the computer. A computer's motherboard, which usually houses the CPU and memory chip, is the main circuit board. The sound card plays audio, and the graphics card translates image data into a format that can be displayed by the monitor.

Motherboard p170, Smart card p182, Trainer p50

Microwave
Microwaves are electromagnetic waves with a short wavelength. They are used for telephone and television links. A microwave oven uses microwaves to cook and warm food quickly. A beam of microwaves penetrates the food. The water in the food absorbs the waves and heats up, cooking the food. **Links p36, Microwave p100, Satellite p42**

Molecule
Atoms that have bonded with other atoms are called molecules. These can be formed from atoms of just one element. For example, oxygen molecules are made from two oxygen atoms that have bonded together (O2). Molecules can also form when atoms of different elements bond. For example, a water molecule has two hydrogen atoms and one oxygen atom (H2O). Molecules can be very simple, containing just a few atoms, or can be incredibly complex, containing thousands of connected atoms of different elements. These particles are so tiny that a single drop of water contains more molecules than there are grains of sand on a large beach. **Antibiotics p222, Fabric p60, Microwave p100**

Momentum
The momentum of an object depends on its mass and velocity (speed). The heavier an object and the faster it moves, the greater its momentum, so it is harder for it to stop. This means that an object's momentum changes as it accelerates. Momentum can be transferred between objects. For example, when a moving ball collides with a stationary one the first ball transfers some of its momentum to the second ball. The total momentum of the two balls is the same as the first ball's momentum before the collision. This is the principle of conservation of momentum. **Crash test p134**

Multiplexing
Multiplexing is the combination of two or more signals from two or more channels to form a single output. For example, transmitting multiple digital television programmes through a single digital carrier. **Fibre optics p20**

N

Noble gases
The elements helium, neon, argon, krypton, xenon, and radon. Noble gases are unreactive, which means they form very few compounds with other elements. They are also called rare or inert gases. Noble gases make up about one per cent of the air and are often used in lighting. **Neon p34**

O

Optics
Optics is the study of light and the ways in which light rays form images. These images occur when light rays coming from an object are reflected by mirrors and bent, or refracted, as they pass through lenses. **Camera p62, Mirror p90**

Oscillation
Oscillation is a repeated back-and-forth movement around a fixed point. For example, a pendulum oscillates when it swings to and fro. Gravity starts the pendulum moving at the top of its swing, and slows it down again as it rises on the other side. Oscillation can also refer to a regular change between a maximum and minimum value, as in the voltage of an alternating current of electricity. A vibration is a rapid oscillation over a short distance. For example, a guitar string vibrates when you pluck it. **Guitar p66, Watch p92**

P

Packet
A unit of data formatted for transmission on a network such as the Internet. The TCP/IP protocol breaks large data files into smaller packets for transmission across the network. Each packet is separately numbered and includes the Internet address of the destination. The individual packets for a given file may travel along different routes across the Internet. When they have all arrived, they are reassembled into the original file. **Internet p38**

Phosphorescence
Phosphorescence occurs when a substance absorbs energy and later emits it as light. Luminous paints work in this way, storing the energy of daylight and then glowing in the dark. **Neon p34**

Photons
Electromagnetic radiation, for example visible light, often carries its energy in waves. But it can also carry its energy as a stream of separate particles called photons. Photons of light cause solar cells to produce electricity. **Neon p34, Solar cell p96**

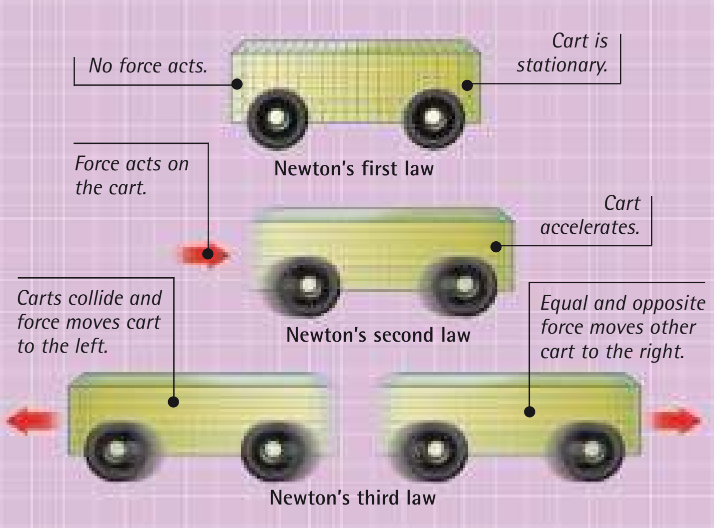
Photovoltaic cell
Also called a solar cell, this is an energy-conversion device that captures solar energy and directly converts it to electrical current. A photovoltaic cell contains two layers of silicon. Some atoms in the upper layer of silicon have an extra electron, while some in the lower layer are missing an electron. Electrons move from the upper to the lower layer – creating an electric charge in the atoms. If light strikes the cell, electrons in the lower layer are dislodged. These are then pulled into the upper layer by the electric charge, producing a current. **Homes p106, Satellite p42, Solar cell p96**

Piezoelectricity
Piezoelectricity is electricity produced from crystals. Certain crystals produce an electric current when they are squeezed or made to vibrate. For example, many watches contain a vibrating quartz crystal that gives out an accurate control signal to keep good time. **Racket p54**

Piston
A petrol engine contains several tubes that are closed at one end called cylinders. Within each cylinder is a piston, a device shaped like an inverted cup, which slides up and down. A valve at the top of each cylinder lets petrol and air into the space above the piston. This space contains a spark plug, to which a high voltage is applied to make a spark. The spark ignites the petrol, which explodes and forces the piston down the cylinder. **Car engine p130**

Pixel
An abbreviation of the term "picture element". A pixel is the

>> LAWS OF MOTION



In 1687, English scientist Sir Isaac Newton put forward three laws of motion. These laws explain how objects move. His first law states that if an object is not being pushed or pulled by a force, it will either stay still or move in a straight line at a constant speed. If you are in a car that stops suddenly, for example, you will keep moving forwards until stopped by the force of the seatbelt. Newton's second law states that when a force acts on an object, the object will start to move, speed up, slow down, or change direction. The third law states that if you push or pull an object, it will push or pull you to an equal extent. As Newton put it: "To every action there is an equal and opposite reaction."

smallest graphic unit that display software can use to create text and images. It is a single-coloured dot. Usually the dots are so small and so numerous that, when printed on paper or displayed on a computer monitor, they appear to merge into a smooth image. A single digital photograph is made up of thousands of pixels. **Camera p62, LCD TV p24, Mobile phone p18**

Pressure
Pressure is the amount of force exerted on a unit area of surface. You exert pressure when you apply a force to an object. The amount of pressure depends on the strength of the force, and the surface area to which you apply the force. Pressure is greater if the area is smaller. A fluid (a liquid or a gas) exerts pressure on its container and on objects immersed in it. For example, when you dive under water, pressure increases with depth as the weight of water pushing on you increases. **Aerosol p112, Football p52, Laser printer p176, Submersible p142, Wet welding p188**

Prism
A transparent block of glass that splits white light into a spectrum of visible colours (red, orange, yellow, green, blue, indigo, and violet), separating its different wavelengths. A prism refracts (bends) each wavelength at a different angle as it passes from glass to air, or air to glass. **Compact disc p68**

Protocol
A set of rules that governs how information is to be exchanged between computer systems. For example, the HTTP protocol defines the format for communication between web browsers and web servers. Protocols allow data to be taken apart for faster transmission, and then reassembled in the correct order. **Internet p38**

Pulley
A pulley is a grooved wheel, or set of wheels, around which a rope passes in order to move a load. In a pulley system, one end of the rope is attached to the load, and the free end is pulled to move the load. A pulley system reduces the effort needed to move the load by an amount that depends on the number of pulley wheels used. **Lift p140**

R

Radio waves
Electromagnetic waves that bring us radio and television. Feeding an electrical signal with a certain frequency to a radio transmitter causes it to produce a radio wave at a different frequency as the electrical signal. Radio broadcasts use the lower range of radio frequencies, while television broadcasts use the higher range of radio frequencies. **Camera capsule p212, Digital radio p22, Doppler radar p194, Links p36, Microwave p100, Mobile phone p18, MRI scan p204, Radio ID tag p184, Satellite p42**

RAM (Random-Access Memory)
RAM is the part of a computer's memory whose contents can be changed. It consists of integrated circuits, built onto microchips, in the computer. These chips store data and programs that are fed into the computer on a disk, or typed in using the keyboard. The data can be altered and new data and programs can be added at any time. This type of memory is called random access memory because data can be retrieved from any part of it, and in any order. **Motherboard p170**

Reaction
Forces act in pairs called the action and the reaction. When you walk, your feet push on the ground (the action). The ground pushes back on your feet with an equal and opposite force (the reaction). This moves you forwards. This is Newton's third law of motion. **Jet engine p146**

Reflection
Reflection is the way in which light rays bounce off surfaces. You see an object in front of you because light rays are reflected from it. Bright objects reflect more light than dark objects. When parallel light rays strike a smooth surface, such as a mirror, it reflects all the rays at the same angle. This produces a clear image called a reflection. If the surface is uneven, the rays bounce off, or diffuse, at different angles. Light rays passing through a dense substance, such as a glass block, may be reflected from its inner surface back into the substance. This is total internal reflection. **Compact disc p68, Fibre optics p20, Games p64, Mirror p90**

Refraction
Refraction is the way in which light rays bend as they enter and leave a transparent substance. It occurs when light rays change speed as they move from one substance to another. For example, rays slow down as they pass from air into glass, bending away from the boundary between the two substances. As they leave the glass, the rays speed up and bend towards the boundary. A lens can bend light rays to a focus at a single point, forming a clear image. **Camera p62**

Remote sensing
Acquiring information about an object without contacting it physically. Remote sensing methods include aerial photography, radar, and satellite imaging. **Doppler radar p194, Routes p152**

ROM (Read-Only Memory)
ROM is the part of a computer's memory whose contents cannot be changed. It is permanent memory, which retains information on microchips when the computer is switched off. Once data has been recorded onto a ROM chip, it cannot normally be altered or removed, and can only be read. The content of the ROM chip is usually fixed at the time the computer is made. In a personal computer, for example, the ROM may store important programs and essential data. ROM is being replaced by flash memory. **Motherboard p170**

S

Sampling
Sampling, or analogue-to-digital conversion, is the process of converting an analogue signal to a series of digital samples (numbers). **Digital radio p22, Mobile phone p18, Video link p40**

Semiconductors
A semiconductor is a material that varies in electrical conductivity. Most electronic components, such as diodes and transistors, are made of a semiconductor, such as silicon. The semiconductor can change its ability to conduct electricity. It may pass a large or small electric current, or it may block the current. This allows semiconductors to produce and process electrical signals. **Microchip p16**

Sensor
Sensors detect such things as heat, pressure, magnetic fields, movement, speed, vibration, and smoke. They may also measure these things. Most sensors send out an electric signal to operate a controlling or warning system. **Camera p62, Compact disc p68, Crash test p134, Laptop p168, MRI scan p204, Robot helper p118**

Server
A computer or device on a network that manages network resources. For example, a file server is a computer and storage device dedicated to storing files, and a print server is a computer that manages one or more printers. **Internet p38, Links p36, Radio ID tag p184**

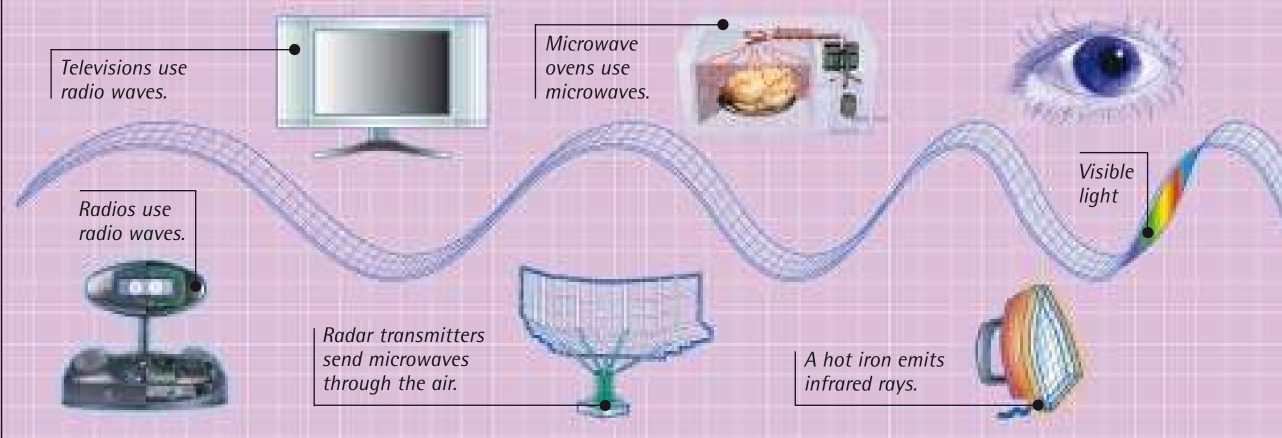
Sound wave
Sound waves are the vibrations that occur in a material as a sound passes through it. You can hear people talking or singing because sound waves travel through the air from their mouths to your ears. A source of sound vibrates to and fro, and sets the air around it vibrating. The vibrations spread through the air as a series of regular changes in pressure. They travel at a speed of about 340 metres per second (1,115 feet per second). A sound wave consists of compressions, which are regions of high pressure. Each compression is followed by a rarefaction, a region of low pressure. You hear sound when the pressure changes reach your ears. **Doppler radar p194, Guitar p66, Headphones p74, MP3 player p70, Pet translator p30**

Spectrum
A spectrum is the bands of colour formed when white light is split by a prism. When the white light strikes the prism, it is separated according to its different wavelengths: from red, which has the longest wavelength, through orange, yellow, green, and blue, to violet, which has the shortest wavelength. A prism creates a spectrum by bending (refracting) wavelengths at different angles. The separation of light into its component colours is called dispersion. A rainbow is a spectrum that occurs when sunlight is refracted by raindrops. **Compact disc p68, LCD TV p24**

Speed
Speed is the measurement of the distance travelled by an object in a certain unit of time. For example, the walking speed of an average person is about 5 kph (3 mph). A motor vehicle, such as a car or a truck, may travel at a speed of 60 kph (37 mph). **Bike p58, Crash test p134, Fuel-cell car p128, Jet engine p146, Navigation p154, Osprey p144, Snowboard p56, Space Shuttle p156**

Speed of light
The speed at which light (electromagnetic radiation) travels through space. Light speed equals 299,792,458 metres per second (186,000 miles per second). It is the speed of an electromagnetic wave in free space. Einstein's Special Theory of Relativity states that nothing can go faster than the speed of light. **Microwave p100, Satellite p42**

ELECTROMAGNETIC SPECTRUM



T

TCP/IP (Transmission Control Protocol/ Internet Protocol)
The protocols, or rules, that computers use to communicate over the Internet. **Internet p38**

Telemetry
The use of telecommunication devices, such as satellites, to automatically record measurements from a distance. **Navigation p154**

Thrust
A forward force acting on an aircraft. The jet engines or propellers of an aeroplane produce thrust to drive the aeroplane forwards. In a helicopter, the main rotor produces thrust. **Jet engine p146, Osprey p144, Space probe p158**

Transistor
A transistor is an electronic component that switches or amplifies an electric current. Transistors are important components in computers and amplifiers. A transistor contains three pieces of semiconductor. The central piece is called the base, and the outer pieces are the emitter and collector. A main current flows through the whole transistor, while a small control signal goes to the base. The control signal either sends electrons into the base, or attracts them away from it. This movement of electrons affects the passage of electric current through the whole transistor. **Microchip p16, Motherboard p170**

Transponder
Equipment on board a satellite that receives and retransmits a signal, including the antenna, receiver, and transmitter. **Satellite p42**

U

Ultraviolet rays
Electromagnetic radiation with a shorter wavelength than visible light. Sunlight is the greatest source of UV light, but it is also produced artificially. It is used in industry and in medicine for a wide variety of purposes, including creating fluorescent effects and killing bacteria. **Digital pen p166, Laser surgery p206, Solar cell p96**

URL (Uniform Resource Locator)
The World Wide Web address of a site on the Internet. **Internet p38**

V

Vaccine
A substance that contains antigens from an infectious organism. By stimulating an immune response (but not disease), it protects against subsequent infection by that organism. **Vaccination p220**

Vibration
A vibration is a rapid oscillation over a short distance. For example, a guitar string vibrates when you pluck it. Sound is a travelling vibration – it vibrates the molecules it travels through. **Guitar p66, Headphones p74, Voice recognition p28, Watch p92**

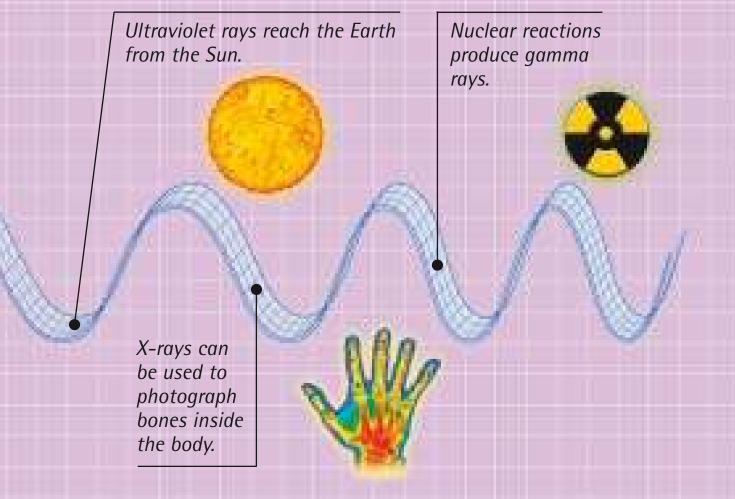
Voltage
The force that makes electrons move in an electric current. It is produced by a source of electrical energy, for example a battery. **Battery p94**

W

World Wide Web
A system of Internet servers that support documents formatted in a language called HTML (HyperText Markup Language). **Internet p38**

X

X-ray
X-rays are electromagnetic radiation with a very short wavelength. They can be made in an X-ray tube. An electron beam strikes a metal target, causing it to emit X-rays. Bones show up on X-ray photographs because they block the path of the rays. **Imaging techniques p10**



Electromagnetic waves of energy – including visible light, radio waves, microwaves, X-rays, infrared rays, gamma rays, and ultraviolet waves – travel through space and matter. Each type of energy has a different wavelength and carries a different amount of energy. The complete range of electromagnetic waves is called the electromagnetic spectrum. The colours of the rainbow – visible light – form the only part of this spectrum that we can see. All the other waves are invisible. Infrared, microwave, and radio waves have a longer wavelength and carry less energy than visible light. Ultraviolet, X-rays, and gamma rays have a shorter wavelength and carry more energy. Although some are harmful, all of the rays can be useful to us.

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