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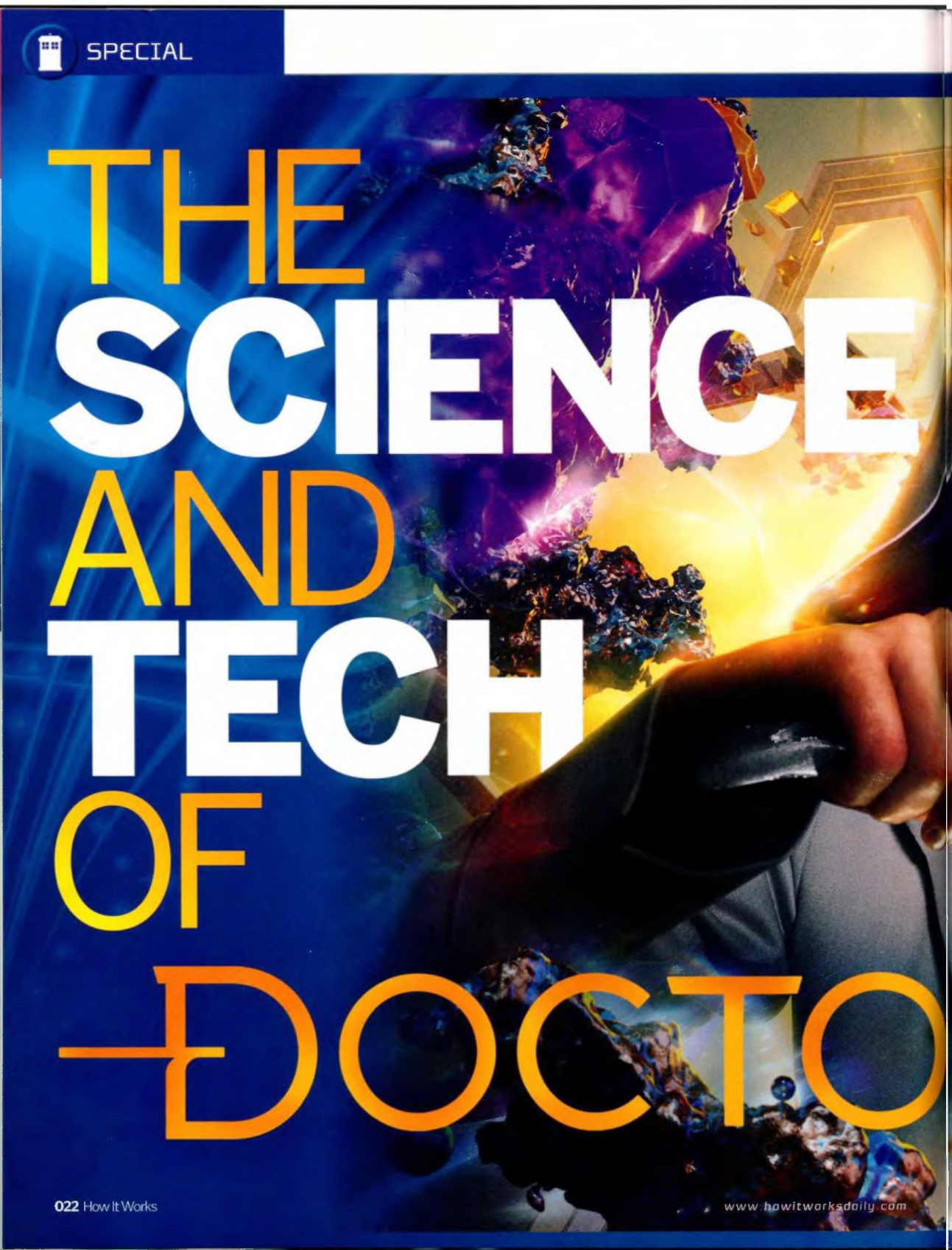
THE SCIENCE AND TECH OF DOCTOR WHO



BBC

From the Daleks to Dyson spheres, discover the science and tech behind the Time Lord

Words by **Scott Dutfield**

The Doctor has always stretched the boundaries of space and time, literally. Since it first hit the TV screens in 1963, *Doctor Who* has continued to stretch our imaginations, journeying to alien worlds in far-off galaxies and delving into the complexities of time travel. Science and science fiction are carefully intertwined to create an entertaining combination of fantasy and reality, supported by somewhat accurate depictions of various scientific principles. From venturing through wormholes to battling the Cybermen, *Doctor Who* is filled with hidden science that seems completely impossible.

As a Time Lord, the Doctor is attuned to the fine stitches in the fabric of space-time and how best to navigate through them. The show tackles both the limitations and endless possibilities of space and time travel according to Einstein's theories of special and general relativity. Even creating violent villains based on quantum mechanics (the Weeping Angels) and advanced bionics (the Cybermen) or harvesting energy from the stars (like the Tardis) are just some of the ways *Doctor Who* is keeping science at the forefront of science fiction.

THE SCIENCE OF SPACE-TIME

We often think about space and time as two different entities. Space is perceived in three dimensions, but we view time in a singular dimension, always flowing 'forward' into the future. However, the truth is that space and time are integrated together as the four-dimensional space-time, or as the Doctor puts it, "a big ball of wibbly-wobbly timey-wimey...stuff".

Space-time can be thought of as a stretchy sheet, and masses – such as planets – sitting in space-time distort it in the same way a bowling ball would create a dip on the surface of a trampoline. If a bowling ball's mass were great enough, the dip would continue to travel downwards and potentially connect with another sheet. This would theoretically connect the two sheets of space-time by a tunnel called a wormhole, or an Einstein-Rosen bridge. In theory, these connected folds of space-time could be used to create an interstellar shortcut between different regions of the universe.

"Mass distorts space-time like a bowling ball would create a dip on the surface of a trampoline"

General relativity

Presented in 1915, this theory explains space-time

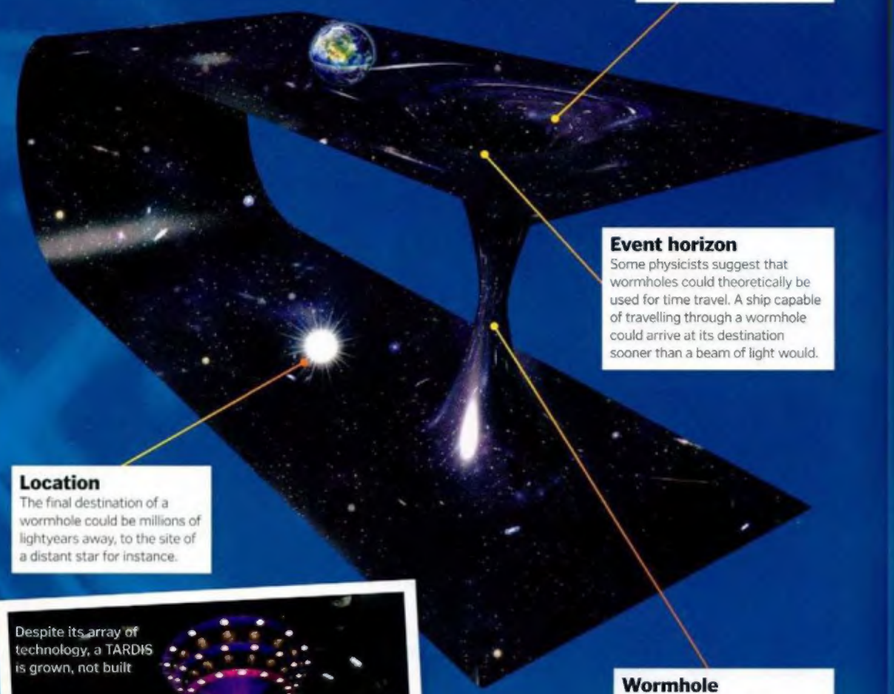
Free-fall and floating
Einstein explained in his theory of general relativity that free-falling is the same as floating in space, therefore Newton's theory of gravity alone couldn't be correct.

Gravity and acceleration
Accelerating in a vehicle feels the same as the effects of gravity. Einstein postulated that both are caused by curved paths through space-time.

Bending of light
While accelerating in your vessel, the path of light from a source would appear to bend due to the curvature of space-time.

Crossing space-time

If Einstein's theory of general relativity is correct, what would a wormhole look like?



Curved space-time
Space-time is distorted by concentrated mass – the greater the mass, the more space-time will curve.

Event horizon
Some physicists suggest that wormholes could theoretically be used for time travel. A ship capable of travelling through a wormhole could arrive at its destination sooner than a beam of light would.

Location
The final destination of a wormhole could be millions of lightyears away, to the site of a distant star for instance.

Wormhole
This gravitational well connects two singularities – such as black holes – creating a cylindrical tunnel through space-time.

Despite its array of technology, a TARDIS is grown, not built

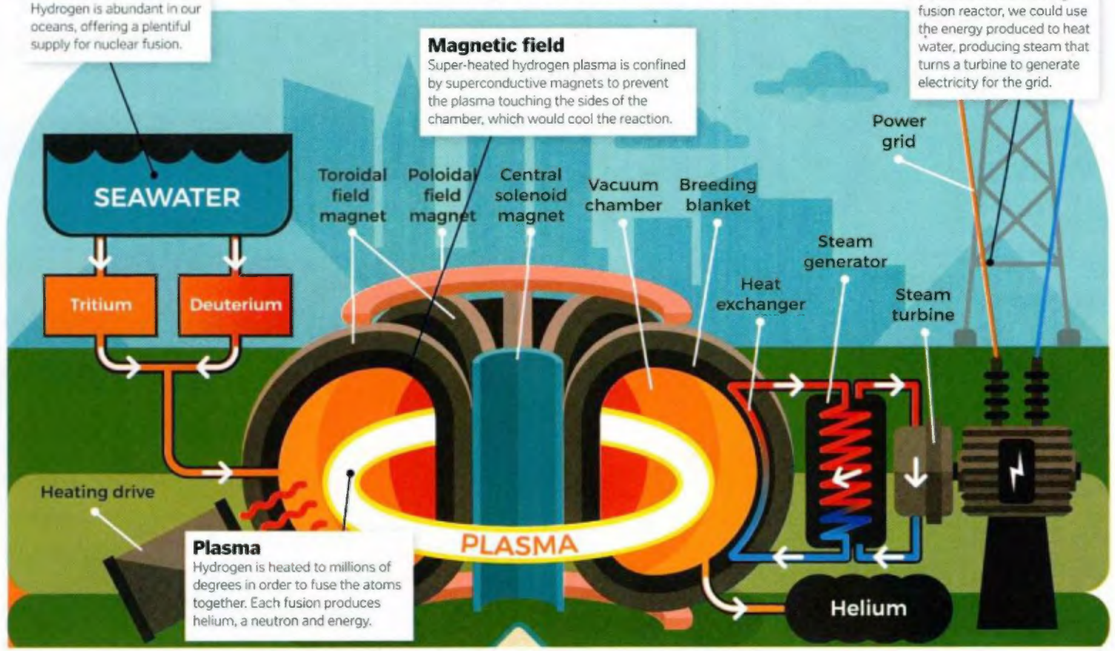
The ultimate solar power

The Doctor uses the energy of a star to power the TARDIS (more about this on page 30), but can humans truly tap into such solar energy potentials? If we wanted to harness the full energy of a star, we would need to create what is known as a Dyson sphere. In 1960, scientist Freeman Dyson first described the concept of a network of solar panels to completely envelop a star and tap into its immense energy output. The solar mega structure of a Dyson sphere, or shell, would theoretically comprise of millions of individual solar panel satellites capable of capturing, storing and transmitting the energy back to Earth for use. However, in order to construct such an array around a Sun-like star, we would require more material than currently exists in our entire Solar System!

Could we harness the power of a star and create a new civilisation around it?

Recreating the Sun

Could we harness the energy of the Sun in a similar way to the TARDIS?



BOTTLING A STAR

If Earth's engineering can't reach the Sun to create a Dyson sphere, then why not recreate a star on Earth? The Sun's nuclear fusion is made possible due to its immense mass and gravity heating its core to 15 million degrees Celsius. Within its internal incinerator, hydrogen atoms can fuse together to form helium. It's this reaction that releases energy, and it's a process that we could try to replicate.

Currently, we have mastered the process of splitting the atom to release energy, known as nuclear fission. However, if we could take inspiration from the Sun and succeed in engineering a viable fusion reactor to stick atoms together, our power-producing potential could be out of this world.

There are two main approaches to achieve nuclear fusion: magnetic or inertial confinement. Inertial confinement uses laser beams to focus energy and heat up hydrogen isotopes, forcing the atoms to come together to form helium. Magnetic confinement, however, uses magnetic fields to confine and compress hydrogen plasma at high temperatures until fusion occurs, generating helium and energy.

In both cases the energy released from fusion can be used to heat water, creating steam that in turn spins a turbine that can power a generator, ultimately producing electricity. With our current fusion reactor technology, however, the energy required to power the process of fusion is greater than the energy output of the reactors.

HUMAN UPGRADE

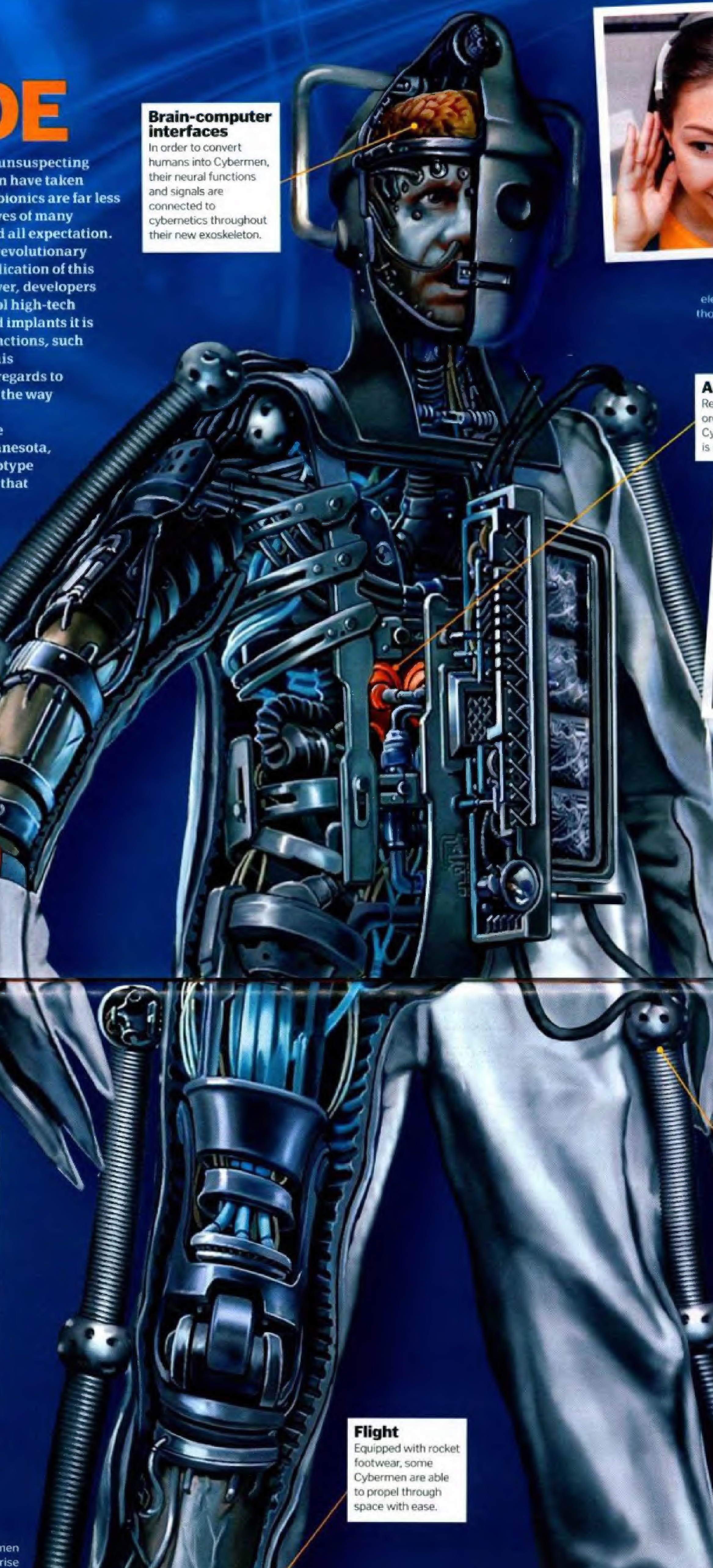
As an evil race of robots hell-bent on converting unsuspecting humans into technological terrors, the Cybermen have taken bionics to the dark side. Thankfully, real-world bionics are far less sinister and are used to enhance, not end, the lives of many people. The advancements to date have exceeded all expectation.

Brain-computer interfaces pose a potentially revolutionary advancement in bionic technology. The first application of this type of technology is hearing restoration. However, developers are also working to use our brainpower to control high-tech prosthetic limbs. Through the use of sensors and implants it is possible to interpret brain activity as specific functions, such as to lift an arm or stretch an exoskeleton leg. This technology is still very much in its infancy with regards to commercial use, but has the potential to change the way many people interact with the world.

Engineers are also making waves in bionic eye technology. Researchers at the University of Minnesota, US, have developed a 3D-printed bionic eye prototype using semiconducting polymers to print devices that convert light into electrical signals.

Inside a Cyberman

What makes up a Cyberman and how do we use similar technologies today?



Brain-computer interfaces
In order to convert humans into Cybermen, their neural functions and signals are connected to cybernetics throughout their new exoskeleton.

Artificial organs
Replacing a human's internal organs with circuit boards, the Cybermen's internal regulation is machine-reliant.

Cybernetic limbs
As a race of super soldiers, the Cybermen are equipped with cybernetic limbs to enhance their strength and add weaponry.

Suspended animation
Waiting dormant, the Cybermen are held in suspended animation before being awakened for battle.

Hydraulics
A network of hydraulic pipes control the wires and cables that dictate the movements of the emotionless Cybermen.

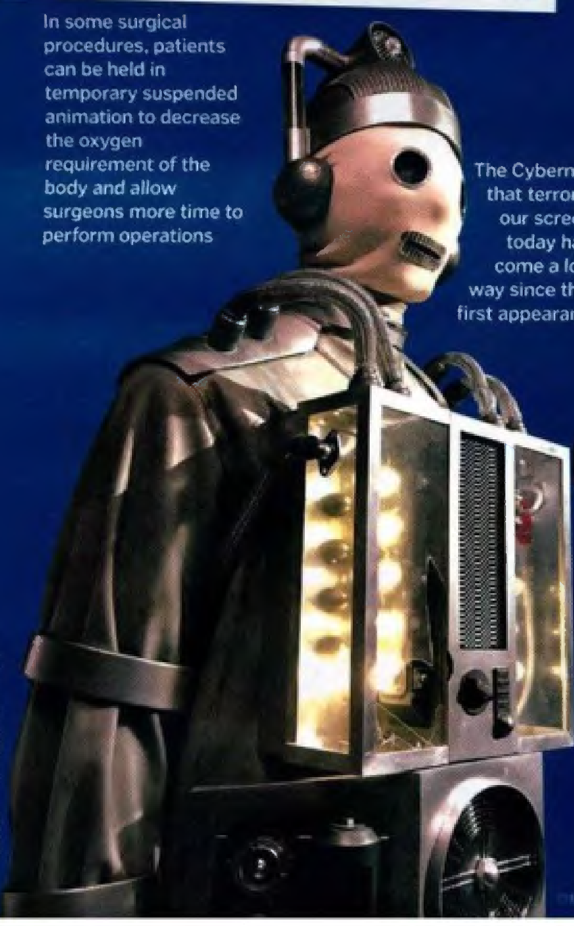
Flight
Equipped with rocket footwear, some Cybermen are able to propel through space with ease.

Internal or external sensors monitor brain function and electrical activity and interpret those signals to operate bionics

Devices such as artificial pancreases have demonstrated the potential of artificial organs

Bionic prosthetics can now use several methods to recreate the function and form of limbs

In some surgical procedures, patients can be held in temporary suspended animation to decrease the oxygen requirement of the body and allow surgeons more time to perform operations



The Cybermen that terrorise our screens today have come a long way since their first appearance

A personal flight suit by developer Richard Browning uses miniature jet engines to propel him through the skies

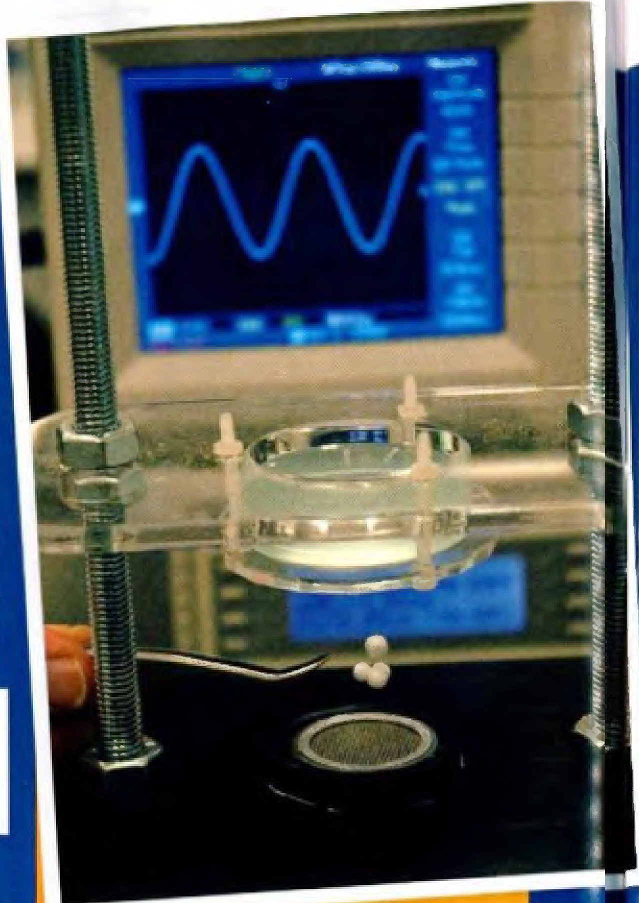
DID YOU KNOW? *The Cybermen were created by Dr Kit Pedler, a medical scientist, and Gerry Davis, script editor, in 1966*

LITTLE BLUE BOX

'Time And Relative Dimension In Space' sounds more like a physics paper than a spaceship. Nevertheless, the TARDIS – in the guise of a blue police phone box – is capable of travelling anywhere and anywhen.

It does so by ripping through the fabric of space-time to journey into a connecting wormhole. In order to travel through space and time, the TARDIS needs an exceptional amount of power and energy, and what more bountiful source of both can there be than that generated by a star?

The TARDIS is powered by a dying star in the process of decaying into a black hole, known as the Eye of Harmony. Using Time Lord knowledge, this cataclysmic event is suspended in time while the TARDIS utilises this energy as a power source.



Reverberating sound waves are able to hold objects in a state of levitation due to sound pressure

It's bigger on the inside

What makes the TARDIS tick?

Time rotor
The time rotor column stores the energy for the TARDIS' engines, preventing its escape.
Directional unit
The directional unit once helped in navigating to specific locations.
Fluid links
These links require mercury to function and are one of the components that helps provide power to the TARDIS.
Chameleon circuit
This manifests the outside of the spaceship to fit in with its surroundings. However, this technology is broken, hence the permanent police box exterior.
Artron mainframe
The mainframe connects all the computer networks and systems aboard the TARDIS and acts as its interface for the Doctor.

The energy produced through the death of a star is held in time beneath the TARDIS console and used for power

Sonic science

A screwdriver, pen, lipstick and gun – sonic technology has always been in the firm grip of the Doctor, her friends and enemies. At the press of a button, the Doctor can disarm a Silurian solider, sever a suspended rope and crack any lock… as long as it's not made of wood.

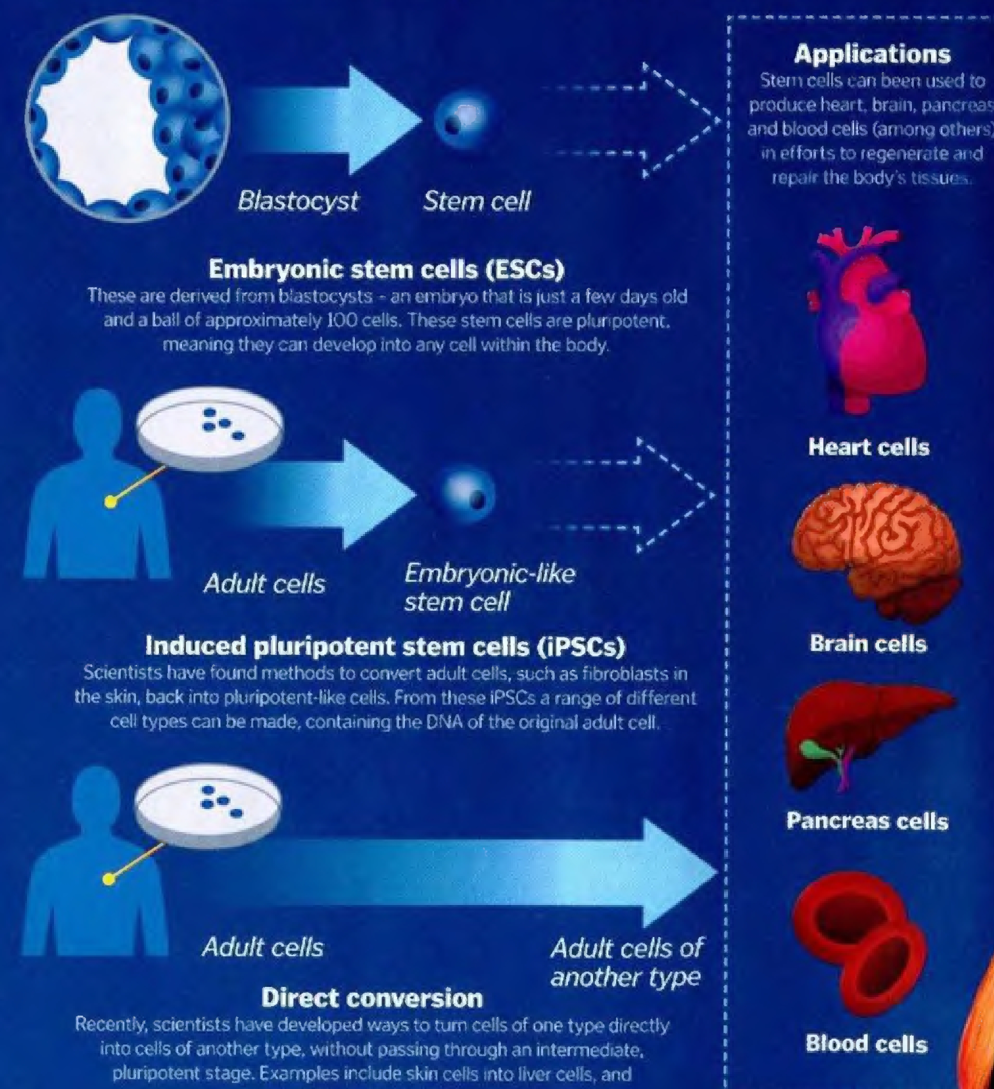
The power of the sonic screwdriver is not merely the product of mechanical make-believe but follows the logic of high-kinetic sonic waves. The physical abilities of sonic technology can be demonstrated in acoustic levitation. Using a sound-emitting transducer, sound waves are sent upwards to an overhanging reflector, which reflects the waves back down. At a specific wavelength this sound pressure can hold an object in its grasp and appear to make it levitate. However, these sound waves can do much more than hold a ball in mid-air. Sound waves, such as ultrasound, can be used to see inside the body, used at high frequencies to vibrate the dirt away when cleaning tanks, while infrasound can even be weaponised to affect hearing, balance and induce headaches.

REAL-LIFE REGENERATION

The Doctor has experienced 14 regenerations, whereby her physical form is renewed to heal injuries. Every cell in her body changes during this process, and with each regeneration her cells become new.

In order to achieve this total transformation, the Doctor uses latent regeneration energy. The human body has no such energy, but does have some regeneratative capacity. Stem cells are unique in their ability to perform no specialised function in the human body. These cells cannot carry oxygen like red blood cells, nor can they absorb the nutrients in the intestines like microvillus cells.

However, through a process known as differentiation, they can transform into different cell types to complete any cellular function. These cells act as the understudy in the human body, waiting for their time to play a variety of roles. They are found in specific tissues, such as the bone marrow and skin, but scientists have developed several ways of producing these valuable cells.



Blastocyst
Stem cell
Embryonic stem cells (ESCs)
These are derived from blastocysts – an embryo that is just a few days old and a ball of approximately 100 cells. These stem cells are pluripotent, meaning they can develop into any cell within the body.
Adult cells
Embryonic-like stem cell
Induced pluripotent stem cells (iPSCs)
Scientists have found methods to convert adult cells, such as fibroblasts in the skin, back into pluripotent-like cells. From these iPSCs a range of different cell types can be made, containing the DNA of the original adult cell.
Adult cells
Adult cells of another type
Direct conversion
Recently, scientists have developed ways to turn cells of one type directly into cells of another type, without passing through an intermediate, pluripotent stage. Examples include skin cells into liver cells, and astrocytes into neurons.
Applications
Stem cells can been used to produce heart, brain, pancreas and blood cells (among others) in efforts to regenerate and repair the body's tissues.
Heart cells
Brain cells
Pancreas cells
Blood cells

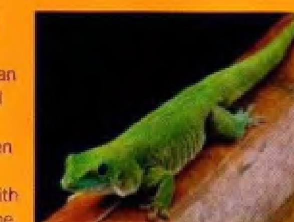
"The power of the sonic screwdriver is not merely the product of mechanical make-believe but follows the logic of high-kinetic sonic waves"

Regeneration in the wild

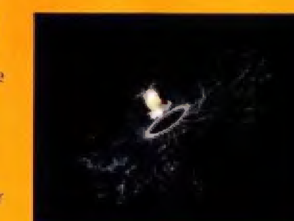
A lost limb is of little concern to these remarkable creatures

Starfish
The Indo-Pacific starfish genus Linckia can regenerate a lost arm or even its entire body from a single separated arm.

Giant day gecko
These lizards can detach their tail as a defence mechanism then regenerate a replacement with a rod of cartilage.

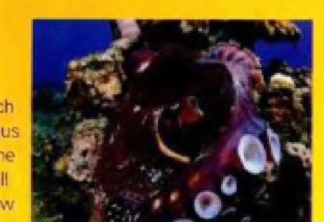


Immortal jellyfish
These jellies are arguably the real-life Time Lords, able to revert to their younger cellular polyp form.



Salamander
Similarly to the giant day gecko, the salamander is able to lose limbs such as arms in a bid to escape and then regenerate them over time.

Cephalopods
When mating, males will detach their hectocotylus and leave it in the female. They will regenerate a new one later.



NEW SERIES!
Catch the new season of Doctor Who this October on BBC1 or BBC America