

THE INCREDIBLE SCIENCE OF DOCTOR WHO

50TH
ANNIVERSARY
SPECIAL



As the Time Lord celebrates 50 years of travelling in time and space, **Brian Clegg** investigates the science behind the TARDIS, Daleks and sonic screwdrivers

ON 23 NOVEMBER 1963 a new television series amazed the viewing public with its dark and mysterious storyline. Although a family show, *Doctor Who* made no concessions to its younger viewers. Before long, the ability to travel anywhere in time and space (subject to the Doctor's limited control of his craft) proved a winning formula, bringing in many scientific themes. Over the last 50 years, the longest-running science fiction show has featured all kinds of real and hypothetical technology. To celebrate its golden jubilee, we explore the ultimate in Whovian science over the next few pages.

ILLUSTRATOR: MAGICTORCH





WILLIAM HARTNELL

1963-1966
TIME TRAVEL

THE FIRST DOCTOR arrived in a junkyard with his battered police box and it soon became obvious that he was not human – and the police box was far more than it seemed. At the heart of the story is time travel. However, real time travel is very different from a journey in the TARDIS.

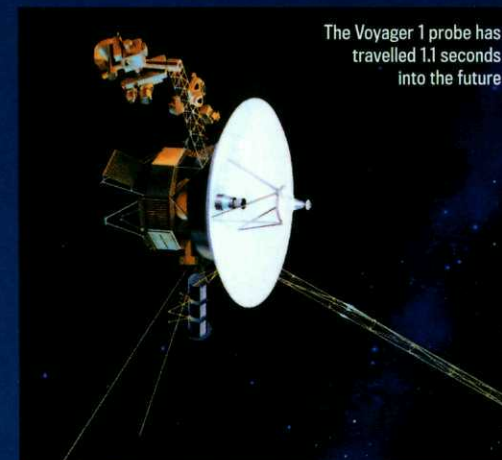
Travelling forwards in time is simple – all that's necessary is to move. The faster you go, the slower your time flows compared to home, so when you return, you will find yourself in the Earth's future – this is Einstein's Special

Relativity. Our best time machine is the Voyager 1 probe, which as it leaves the Solar System has moved 1.1 seconds into the future.

To obtain a sizeable effect means travelling at a good percentage of the speed of light. Voyager, at 17,000 metres per second, only manages 0.06 per cent of light speed. But forward travel is much simpler than getting into the past. To do this, General Relativity, the theory that explains gravity as a warp in space-time, is used. Gravity slows time down, but to make use of this requires

extreme engineering to open a wormhole in space, for instance.

But we're already masters of time because relativity influences sat-nav. GPS satellites are accurate clocks, broadcasting the time. They are corrected to allow for the impact of special relativity, slowing the clocks, but they also experience less gravity than something on Earth, so run fast. From their viewpoint, travelling to Earth would be a tiny shift to the past. If the clocks weren't corrected, the GPS accuracy would drift about 3km (2 miles) a day.



TARDIS

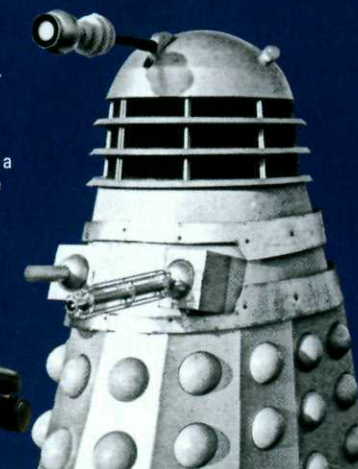
Fictional time machines date back to HG Wells, but the only serious scientific attempt to date is by American physicist Ron Mallett, who has dedicated his life to the concept. Ten-year-old Mallett wanted to go back to speak to his dead father. Professor Mallett now knows this isn't possible, as General Relativity time machines can't travel back beyond the point they were created. However, he still hopes to construct a machine producing a tiny displacement into the past.



THE DALEKS

These mutants inhabit robotic bodies and are efficient fighting machines. In the real world we are designing exoskeletons, metal and carbon fibre suits that amplify the wearer's movements to enable faster movement and heightened strength. DARPA in the US has an 'Exoskeletons for Human Performance Augmentation' programme. And unlike Daleks, they can climb stairs.

'Exterminatel'. When we don exoskeletons hopefully we won't develop a desire to wipe out all life in the Universe



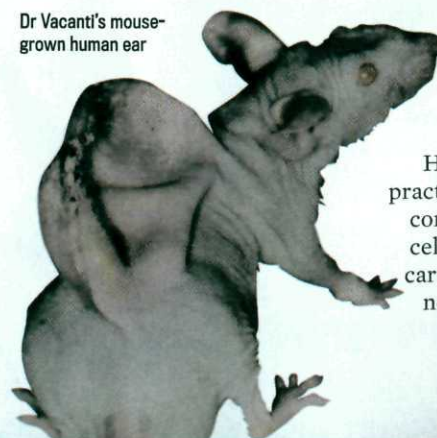
PATRICK TROUGHTON

1966-1969
REGENERATIVE MEDICINE

WHEN WILLIAM HARTNELL was replaced by Patrick Troughton, the change needed to be explained. The Doctor, we were told, could regenerate, coming back in a new – and in this case altogether more whimsical – form. We can't regenerate humans, but regenerative medicine may enable us to

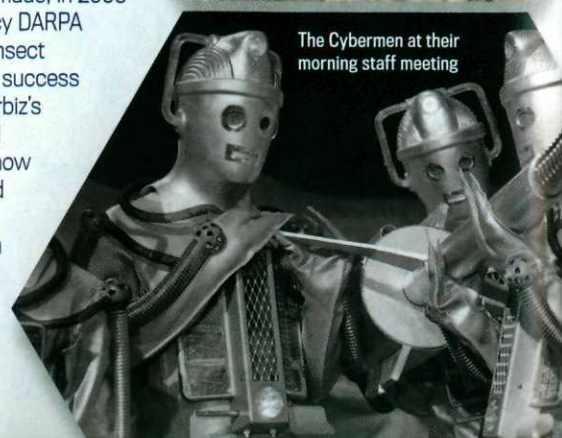
grow replacement organs from a patient's own cells, overcoming transplant rejection and the donor waiting list. This is a long way from being practical. Though in 1997 Dr Jay Vacanti of the Massachusetts General Hospital grew a human ear on the back of a mouse, it is much harder to construct a complex organ than a simple structure of cartilage. It also may be possible to use stem cells to reproduce the natural ability of the salamander to regrow limbs after damage.

However, the earliest practical examples may come from blood stem cell repairs to the cardiovascular and nervous systems.



THE CYBERMEN

The Cybermen, first faced by Hartnell's Doctor, became more convincing in Troughton's time. Although such fearsome human/machine crossovers are unlikely to be made, in 2006 US defence agency DARPA put out a call for insect cyborgs. The first success was Michel Maharbiz's remote-controlled flying beetle, but now start-up Backyard Brains has a DIY cyborg cockroach controlled from a smartphone.



JON PERTWEE

1970-1974
PIEZOELECTRIC EFFECT

THE THIRD DOCTOR, a dandy and action man, presented his companion Jo Grant with a Metabelis crystal as a wedding present. Though we have no equivalent of this crystal's ability to concentrate thoughts, real world crystals can generate electricity from pressure and move when a current is passed through them.

Demonstrated by Pierre Curie in 1880, piezoelectric devices soon moved into the home in the cartridges used to convert the wiggles of a record groove into electrical signals. They also turned up at the production end of the music business, providing pickups for guitars, and are used in a whole range of movement

“Electrical signals make crystals flex and vibrate in everything from loudspeakers to inkjet printers”

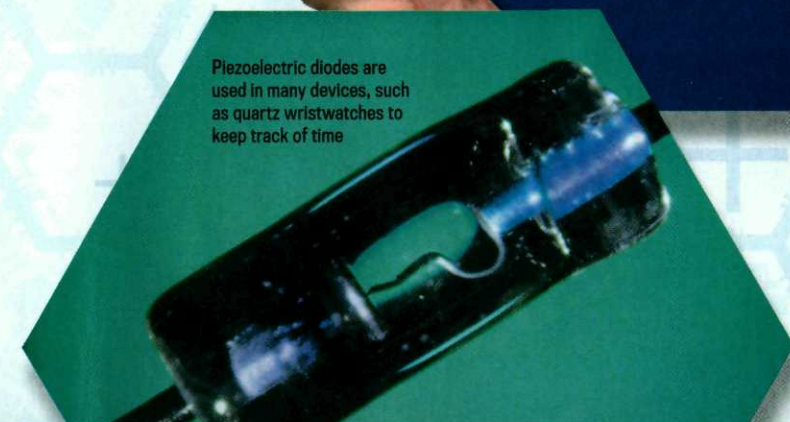
sensors. Most impressively, the sparks used to ignite cigarette lighters and gas stoves are generated from a high-voltage piezoelectric crystal. Working the other way round, electrical signals make crystals flex and vibrate in everything from loudspeakers and inkjet printers to the quartz clocks in computers.



SONIC SCREWDRIVER

The Doctor's sonic screwdriver was first used by Patrick Troughton, but the third doctor took it from a literal screwdriver to a sonic tool. For years efforts have been underway to develop a sound equivalent of a laser, a 'saser'. This would enable far higher frequencies to be generated, transforming the detail available from ultrasound medical imaging.

Piezoelectric diodes are used in many devices, such as quartz wristwatches to keep track of time





TOM BAKER

1974-1981

COMPUTER NETWORKS

WITH HIS TRADEMARK scarf, Tom Baker transformed the role. During the fourth Doctor's time, viewers discovered more about his home planet, Gallifrey. Here, in a 1976 story, came a surprising discovery. The Time Lords had a computer system called the Matrix, a knowledge store 'virtual world' people could enter mentally, where battles could take place, and where the participants could be killed, resulting in the death of their real bodies. This might seem like a rip-off of the movie *The Matrix* if it hadn't been broadcast 23 years before.

This Matrix predates the term cyberspace, and though ARPANET, the predecessor to the internet, existed in 1976, it was just a linkage of large computers in universities. The

internet proper was arguably not implemented until 1982, while Tim Berners-Lee started the World Wide Web in 1990.

The Doctor's battles in the Matrix also had a touch of the computer game about them – and this too was apt timing. In 1976, the same year the Matrix appeared in *The Deadly Assassin*, a computer engineer working on ARPANET, Will Crowther, had a bold idea.

Crowther wanted to keep his children amused, so he put together a text-based game that involved exploring a sequence of caves containing items like treasure and monsters. He

called it *Adventure*. There were already computer games, notably *Pong*, but Crowther's was the first that could be played across a network, starting a trend that has become huge in the computer gaming market.

K-9

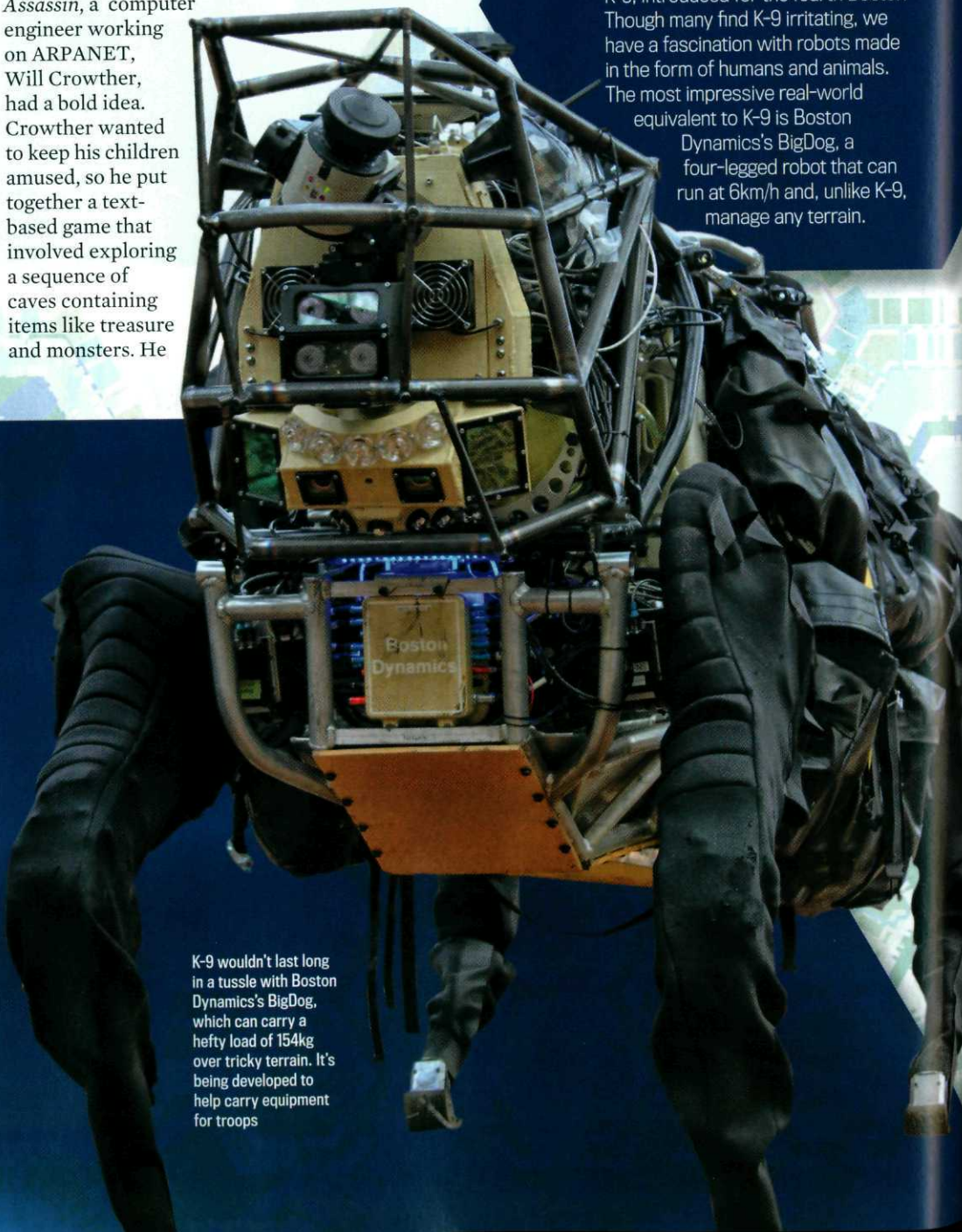
If there's one piece of *Doctor Who* kit that splits opinion it is his robot dog, K-9, introduced for the fourth Doctor. Though many find K-9 irritating, we have a fascination with robots made in the form of humans and animals. The most impressive real-world equivalent to K-9 is Boston Dynamics's BigDog, a four-legged robot that can run at 6km/h and, unlike K-9, manage any terrain.



DAVROS

It wasn't until 1975 that we met the Dalek's creator Davros. Apart from his Dalek wheelchair, the most striking aspect of Davros was his artificial eye. The first real equivalent came soon after in 1978, when maverick scientist William Dobelle gave a man limited sight by linking cameras on his glasses to electrodes embedded in the visual cortex of his brain.

K-9 wouldn't last long in a tussle with Boston Dynamics's BigDog, which can carry a hefty load of 154kg over tricky terrain. It's being developed to help carry equipment for troops



PETER DAVISON

1981-1984

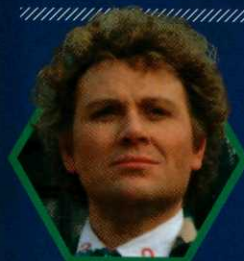
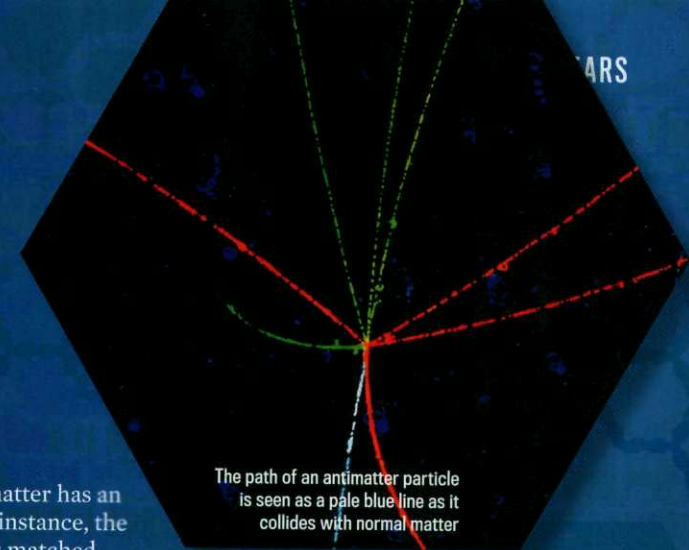
ANTIMATTER

PETER DAVISON'S FIFTH Doctor was a likeable, cricket-loving chap. He continued the revelations of Time Lord history, meeting the founder of this mysterious race, Omega. The fifth Doctor comes across Omega when the ancient Time Lord is released from exile in an antimatter universe. Although it sounds pure science fiction, antimatter is real.

Every particle making up matter has an antimatter equivalent, so, for instance, the negatively charged electron is matched with the positively charged positron. When matter and antimatter come together, they annihilate to produce vast amounts of pure energy. At the moment we can only make tiny amounts of antimatter. It remains a mystery why the

The path of an antimatter particle is seen as a pale blue line as it collides with normal matter

Universe seems to be almost all matter. One possibility is that there is a separate antimatter universe like Omega's, though it is more likely that there was more matter than antimatter created after the Big Bang.

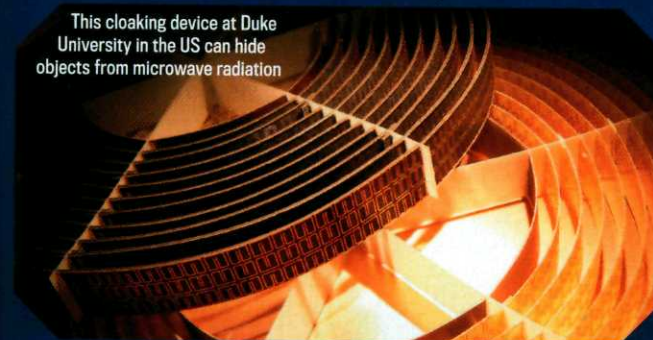


COLIN BAKER

1984-1986

METAMATERIALS

This cloaking device at Duke University in the US can hide objects from microwave radiation



THE BOMBASTIC SIXTH doctor, played by Colin Baker, faced a new villain: the Rani, a renegade Time Lord with her own TARDIS. Unlike the Doctor's, the Rani's TARDIS had a working chameleon circuit, which made it blend into its surroundings. The closest we have to such a device are metamaterials. Normal materials bend light inwards as it goes from a less dense material into something denser. In metamaterials the light bends the opposite way. This means it's possible to produce the chameleon-like effect of an invisibility cloak, where light is bent around an object to hide it. It'll be a long time before a metamaterial can conceal a police box, but it may eventually be possible.

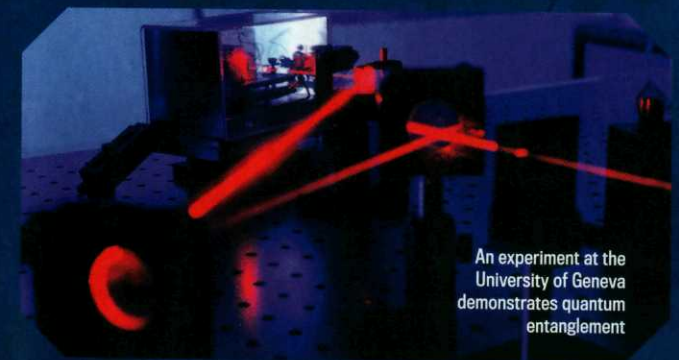


SYLVESTER MCCOY

1987-1989

TELEPORTATION

SYLVESTER MCCOY TOOK the reins as the quirky seventh Doctor and starred in the show's 25th anniversary season. This saw the return of an early Dr Who technology: the transmat. Such a matter transmitter is possible in reality on a tiny scale using quantum teleportation. Teleportation uses a quantum effect called entanglement to transfer the state of a particle to another one at a different location. Quantum teleportation may only be small scale, but it has been performed across considerable distances, including a demonstration of teleported particles across the river Danube in 2004.



An experiment at the University of Geneva demonstrates quantum entanglement



PAUL MCGANN

1996
INTERSTELLAR TRAVEL

IT'S EASY TO miss Paul McGann, as the eighth Doctor only appeared in a single feature-length episode between the original series and its modern incarnation. At the heart of the story was a piece of Time Lord technology, the Eye of Harmony. The Eye is an artificial black hole that provides power for the Time Lords, used in this story as the driving force behind the TARDIS. We have never directly seen a black hole, and certainly don't know how to make one, but there is a hypothetical spaceship drive using a similar concept, called a Schwarzschild Kugelblitz drive.

Karl Schwarzschild was a German physicist who used Einstein's General Relativity to predict that massive stars could collapse to produce such

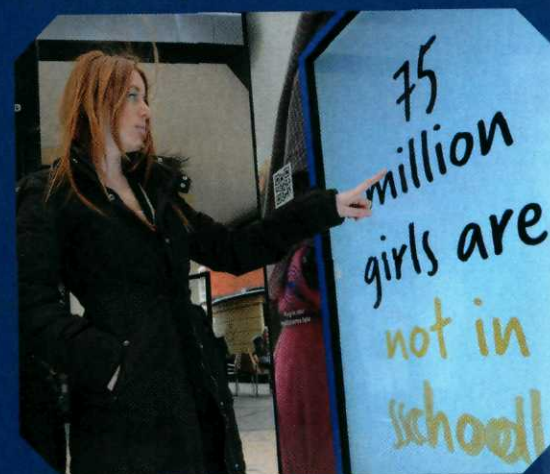
a concentrated mass that even light could not escape them. They were named black holes in the 1960s, but remarkably Schwarzschild dreamed them up in his spare time in the trenches in the First World War. The 'Kugelblitz' part is German for ball lightning. A Kugelblitz is a black hole made not of matter, but of light. Einstein showed that mass and energy are equivalent. If sufficient light energy is pumped into a small space it should create a micro-black hole. This could then be used to power a spaceship, because black holes give off a stream of radiation known as Hawking radiation. A Kugelblitz has never been made, but potentially an Eye of Harmony-type device could be created by zapping space with very powerful gamma-ray lasers.

Could we harness the power of a black hole to power a spaceship like the TARDIS?

"Eating will become separated from providing our energy needs, using nanotechnology to remove unwanted material"

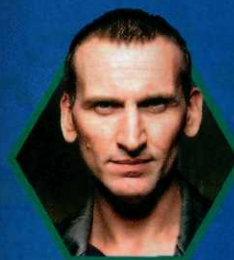


It's not 'psychic paper', but a digital advert by Plan UK used facial recognition technology to determine whether a man or woman was standing in front of it and displayed different content



PSYCHIC PAPER

The Doctor's blank ID card, which says whatever the reader expects it to say, is still science fiction for now, but advertisements that appear differently to different people are on the way. Various companies make digital billboards with built-in cameras and facial recognition. So far, these are used to track which demographic pays most attention to a particular ad, but they could easily be used to send targeted ads. In fact, the charity Plan UK did just that last year, with an advert on bus shelters about gender discrimination that could only be seen in full by female viewers.



CHRISTOPHER ECCLESTON

2005
NANOTECHNOLOGY

WHEN DOCTOR WHO returned in 2005, Christopher Eccleston gave the part a new grittiness. The series also introduced more complex companions, notably Billie Piper as Rose Tyler, and John Barrowman's Captain Jack Harkness. Harkness is a con man from the 51st Century. He owns a Chula spaceship, a wartime ambulance that carries a technology known as nanogenes, a swarm of near-invisible devices that

can enter a body and undertake medical repairs.

Nanotechnology – the use of materials and devices a few nanometres (billionths of a metre) in size – has been around a while, notably in sunscreens, which use nanoscale particles that prevent ultraviolet light getting through but are invisible to the eye. The ultimate dream though, just like nanogenes, is to have tiny robotic devices that enter a

body and interact directly with organs or remove cancers, cell by cell.

Future-gazing technology millionaire Ray Kurzweil envisages a time when, for instance, self-propelled nanobots replace red blood cells as carriers of oxygen and carbon dioxide, meaning that the heart will no longer be necessary for survival. He has also suggested that eating will become separated from providing our energy needs, using nanotechnology to remove unwanted material, so we could eat whatever we liked and still have perfect nutrition.

As yet these miniature robots are science fiction, and the challenges are immense. It's not just a matter of making a conventional robot smaller – different forces become important at this scale. However, there is already research going on to realise the dream of medical nanotechnology. For instance, it would be desirable to use bacteria to release chemicals in the body, but the immune system attacks them. By enclosing the bacteria in a tiny capsule of carbon nanofibres, the bacteria are kept away from the body's defences but the chemicals can pass through the nanoscale gaps in the capsules unhindered.

An unfortunate illness – still, you'd be able to survive a noxious chemical leak. Every cloud...

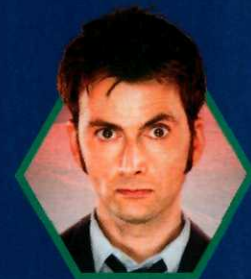


THE EMPTY CHILD

The 'empty child', a boy in a gas mask asking 'Are you my mummy?', crossed paths with the ninth Doctor. The child begins a plague where gas masks grow on patients' faces. This contagion is caused by an alien technology replicating a dead child in a gas mask to 'repair' injured humans. Scientists use a similar technique, molecular cloning, to produce large quantities of DNA. Enzymes snip out a desired DNA sequence, which is then introduced to bacteria. As the bacteria reproduce they make multiple copies of the DNA sequence, which can then be harvested for use in experimental studies.

Futurist Ray Kurzweil foresees a time when nano-scale robots pervade our bodies, operating like the ninth Doctor's nanogenes

A strange illness for the ninth Doctor to investigate, with symptoms including slight breathing difficulties



DAVID TENNANT

2005-2010

THE ZENO EFFECT

THE TENTH DOCTOR proved more laid-back than his predecessor, though David Tennant faced the scariest of the modern monsters: 'Weeping Angels' (pictured on p56). These statues remain motionless but move when not observed, closing in on you in the blink of an eye to reveal a monstrous set of teeth. Weeping Angels cover their eyes to avoid seeing each other, the deadly statues being inspired by the childhood game Grandmother's Footsteps. What's more, they have a surprising reflection in reality with the quantum Zeno effect.

Zeno was an ancient Greek philosopher who believed

change and motion were illusions. He pointed out that an arrow in flight didn't appear to be moving if you looked at it in any particular moment of time. Zeno's name was picked up by George Sudarshan and Baidyanath Misra, physicists working at the University of Texas, to describe a weird quantum phenomenon.

At the heart of quantum theory, the science governing very small particles like atoms and photons of light, is probability. What happens to quantum particles isn't definite, but down to chance. This was why Einstein hated the theory and made his famous remarks about God not

playing dice. A good example of this is that when a particle undergoes radioactive decay, you can't say when it will decay, just the probability of the decay happening.

However, the duo noticed something very strange. If you make a measurement of the particle, it won't decay at that point in time. And if you keep looking regularly enough, you can prevent it from decaying for as long as you like – this is the quantum Zeno effect. Like a watched pot never boiling, or a Weeping Angel never moving while being looked at, unstable quantum systems like a decaying atom really do wait to act until you look away.



THE MASTER

The tenth Doctor faced a new incarnation of the Master, his nemesis since 1971. The Master is elected Prime Minister using subliminal control. Such messages are not noticed consciously, but affect the brain. Flashing up a logo can encourage a thirsty person to desire a particular drink, for instance, but it isn't possible to fool someone into thinking they are thirsty – or to like something they didn't already.

SUPERPHONE

Since the series reboot, companions have had a 'superphone' – a mobile, modified to work across time and space. The tenth Doctor dubbed this 'universal roaming'. As yet we don't have the same problem, but we do experience time lags when communicating with probes in space, due to the finite speed of light. The Curiosity rover on Mars takes around 20 minutes to respond to a command, while the signal from Voyager 1 as it leaves the Solar System takes around 17 hours to reach us.

It takes 20 minutes for a signal to reach NASA's Curiosity rover on Mars. If only we had 'universal roaming' technology to speed things up

"String theory replaces the zoo of particles used to explain matter and forces with a single fundamental element"



THE SONTARANS

The pudding-headed Sontarans have been regular villains since Jon Pertwee's time. With the eleventh Doctor a Sontaran, Strax, became one of the Doctor's allies. Sontarans are cloned, explaining their near-identical looks. A clone is produced from the genetic material of a single 'parent', which it was originally assumed would make it identical. But in reality, environment plays a large role in the development of an organism. This is why the first cloned cat 'Cc' was a tabby, despite her 'parent' being a calico.

Cc, which is short for 'Carbon Copy', is the world's first cloned pet



MATT SMITH

2010-2013

STRING THEORY

THE TARDIS HAS always been bigger inside than out. It's a feature that the sometimes clown-like eleventh Doctor, played by Matt Smith, often refers to, turning 'It's bigger on the inside' into a running gag. That is until thrown by new companion Clara commenting 'It's smaller on the outside.' The usual explanation is that the TARDIS is 'dimensionally transcendental.' A transcendental number (like pi) is one that can't be represented exactly by a finite equation. Here it implies that the spatial dimensions inside are different to those outside.

Something similar crops up in string theory, and its big brother M-theory. These are attempts in physics to combine the forces of nature, bringing together the otherwise incompatible quantum theory and General Relativity. String theory replaces the zoo of particles used to explain matter

and forces with a single fundamental element: the string. This chameleon-like, one-dimensional object produces all the familiar particles through its different vibrations, either as a closed or open loop.

This simplifies things wonderfully, but comes at a price. String theory only works with nine spatial dimensions plus one of time. There are several variants of string theory that are combined to make M-theory, but to do this requires adding yet another space dimension. An obvious problem is that we don't see nine or 10 space dimensions, we see just three: length, height and width. The argument goes that the 'extra' dimensions are curled up so small that we can't detect them.

It would be rather neat if the 'transcendental' dimensions used by the TARDIS turned out to be some of string theory's spares.

GRAVITY GLOBE

Floating gravity globes containing an 'antigravity' substance are key to an eleventh Doctor episode. No known substance blocks gravity – if one existed, it could be used to make a perpetual motion machine, turning a water wheel that has gravity blockers on one side of each paddle. However, some theories suggest that antimatter could be repelled by the gravitational force. Because we've never made enough antimatter to be able to test it, we don't yet know how it responds to gravity. Turn to p56 for the latest experiment to investigate antigravity.

BRIAN CLEGG is a science writer and the author of *Build Your Own Time Machine: The Real Science Of Time Travel* (Duckworth, £8.99)

Find out more

BBC TWO

Prof Brian Cox presents *The Science Of Doctor Who* on BBC Two on 14 November.

BBC ONE

The *Doctor Who* 50th anniversary episode 'The Day Of The Doctor' airs on 23 November on BBC One.