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.
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. Travelling forwards in time is simple – all that’s necessary is to move. The faster you go, the slower your time flows. However, real time travel is more than it seemed. At the obvious that he was not human. The TARDIS, at 67,000 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 space because our activities influence sat-nav. GPS satellites are accurate clocks, broadcasting the time. They are corrected to allow for the effect 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.

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 67,000 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 space because our activities influence sat-nav. GPS satellites are accurate clocks, broadcasting the time. They are corrected to allow for the effect 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.

DOCTOR WHO: 50 YEARS

PATRICK TRAUGHTON
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 embryonic to regenerate limbs after damage. However, the earliest practical examples may come from blood stem cell repairs to the cardiovascular and nervous systems.

THE CYBERMEN

The Cyberman, first faced by Hartnell’s Doctor, became more convincing in Troughton’s time. Although such fearsome human/cyborg crossovers are unlikely to be made, in 2006 US defence agency DARPA put out a call for insect cyborgs. The first success was represented by a remote-controlled flying beetle, but now start-up Backyard Brains has a DIY cybercockroach that can crawl, 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 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 to inkjet printers.

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

THE THIRD DOCTOR, a dandy and action man, presented his companion Jo Grant with a Metaball 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 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 to inkjet printers.

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, or a ‘saser’. This would enable for higher precision to be generated, transforming the detail available from ultrasound medical imaging.

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 USA has an Exoskeletons for Human Performance Augmentation programme. And unlike Daleks, they can climb stairs.

DOCTOR WHO: 50 YEARS

WILLIAM HARTNELL
1963-1966
TIME TRAVEL

RELATIVITY.
DOCTOR WHO: 50 YEARS

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 it was just a linkage of large computers in universities. The internet proper was arguably not implemented until 1982, while Tim Berners-Lee started ARPANET, the predecessor to 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.

DAVROS
It wasn’t until 1975 that we met the Daleks’ creator Davros. Apart from his Dalek wheezer, the most striking aspect of Davros was his artificial eye. The first real equivalent came soon after in ARPANET, where it’s inventor William Dobbie gave a man limited sight by linking cameras on his glasses to electrodes embedded in the visual cortex of his brain.

K-9
If there’s one piece of Doctor Who kit that quite captivates 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.

THE BOMBSATIC 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 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.

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 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 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.

SYLVESTER MCCOY TOOK the reins as the quirky seventh Doctor and stared 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.

COlIN BAKER
1984-1986
METAMATERIALS

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DOCTOR WHO: 50 YEARS

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 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 of 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.

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

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 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 (billions 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 as nanogenes, is to have tiny robotic devices that can be introduced 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 nanotubes, the bacteria are kept away from the body’s defences but the chemicals can pass through the nanoscale gaps in the capsule unhindered.

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 strip 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.

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CHRISTOPHER ECCLESTON

NANOTECHNOLOGY

2005

An unfortunate illness – still, you’ll be able to survive a mechanical chemical leak. Every cloud...
**THE TENTH DOCTOR**

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.

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**THE ZENO EFFECT**

The tenth Doctor faced a new incarnation of the Master. His nemesis since 1971. The Master is elected Prime Minister using subnormal control. Each message is not noticed consciously, but effect 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.

**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 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.

**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. But in reality, environment plays a large role in the development of an organism. This is why the 'first cloned cat' wasn't a tabby, despite her 'parent' being a calico.

**STRING THEORY**

String theory replaces the zoo of particles used to explain matter and forces with a single fundamental element. This chameleon-like, one-dimensional object produces all the familiar particles through its different vibrations, much as a closed or open loop. It would be rather neat if the 'extra' dimensions used by the TARDIS turned out to be some of string theory's spaces.