



MEASURING IT

How science splits time into units



ATTOSECOND: A billionth of a billionth of a second, this is the shortest interval of time with a name. Motions inside the atom take attoseconds and researchers at Vienna Technical University have been the first to observe them using a pulse of red laser light.



PICOSECOND: One thousandth of a billionth of a second. In liquid water the individual hydrogen bonds are constantly breaking and reforming, a process that takes a few picoseconds each time.



MICROSECOND: One millionth of a second. Explosions happen in microseconds. Once the fuse has expired on a stick of dynamite, it takes 24 microseconds to explode. In nature, bats can perceive echoes arriving just two microseconds apart.

Albert Einstein proved that time was stranger than anyone thought, and intimately connected to space

What is time?

Time, according to one anonymous wit, is just one damn thing after another. The joke betrays the slippery nature of trying to define time. Everybody knows what time is because we feel it passing; it is probably the most basic aspect of human experience. But as St Augustine of Hippo remarked, if we try to explain what time is, we are lost for words.

Psychological time is not the same as objective, physical time. Einstein once said that an hour spent with a pretty girl passes much faster than an hour in the dentist's chair. Clocks are the scientist's way of taking the subjective factor out of duration.

Until a hundred years ago people assumed that time, like space, was simply there – God-given and absolute. It came as a shock when Einstein overthrew this cosy image by showing that time is relative. This means that your time and my time will not be the same if we move differently. Take a plane from London to Cape Town and back and you will get out of step by a few nanoseconds (billionths of a second) relative to those who stayed put. More precisely, the duration of the trip will differ slightly as measured by you in the plane compared to the clock at Heathrow. So the interval of time between two particular events is not a fixed duration, but depends on who is measuring it.



A laboratory engineer compares time measured by his atomic clock with the time shown on clocks that have just flown around the world

Time warping by movement is called the 'time dilation effect', and it can easily be demonstrated using atomic clocks. In a famous experiment in 1971, two American physicists flew atomic clocks round the world, and found they got out of kilter relative to ground-based clocks by 59 nanoseconds – exactly as Einstein's formula predicted.

To get a really big time warp it is necessary to approach the speed of light (300,000km/s). This is well beyond foreseeable technology for human beings. To accelerate a payload of one tonne to 99 per cent of the speed of light would require

the entire energy output of the planet for 2,000 years.

If we could achieve such a speed, the consequences would be very weird. You could take a two-year rocket trip to a nearby star and come back to Earth again only to find the date was 14 years after your departure. This is called the twins effect, because if one member of a pair of twins were to take the trip, the twins would no longer be the same age afterwards, even though they were born on the same day.

Though dramatic time dilation effects for people are still science fiction, propelling subatomic


Who's who in time

Galileo Galilei



Galileo Galilei (1564-1642), Italian physicist, mathematician and astronomer, was the first scientist to state clearly that time is the key parameter in describing the laws of motion. Legend has it that he timed a swinging lantern during a boring church service and thus discovered the principle of the pendulum clock in June 1637.

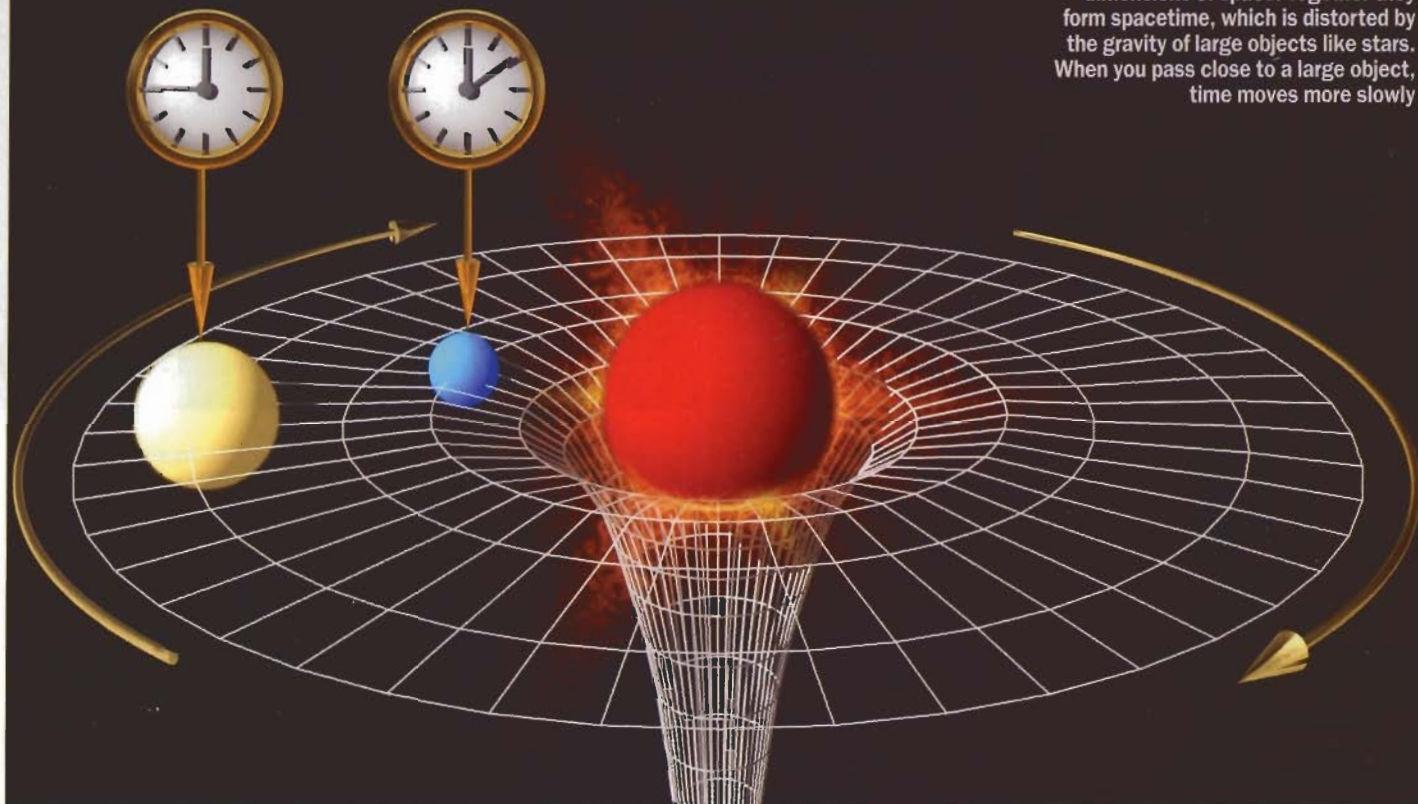
Isaac Newton



Isaac Newton (1642-1727), English physicist and mathematician, made time the basis of his theory of motion in 1686. He envisaged the entire universe as a gigantic piece of clockwork, its parts moving with mathematical precision according to fixed laws. Newton's time was absolute and universal – the same for everyone everywhere, no matter how they moved.

Relatively speaking

Einstein's breakthrough was to think of time not as a separate entity but inextricably linked to the three dimensions of space. Together they form spacetime, which is distorted by the gravity of large objects like stars. When you pass close to a large object, time moves more slowly



OLIVER BURTON

What is spacetime?

Einstein predicted that time is stretched by motion. He also suggested that space shrinks, by the same factor. This link between space and time was new, and suggested that it was better to think of a unified 'spacetime' with four dimensions – three of space and one of time. For this reason it is sometimes said that time is the fourth dimension.

Physically, however, intervals of time are obviously not the same as distances across space, but they can be combined into one set of mathematical formulae.

It's hard to think in four dimensions, but mathematically it's easy to work out the geometry. Einstein suggested that gravity warps spacetime. For example, the sun's gravity curves

space in its vicinity, changing its geometry. A flat triangle drawn around the sun would have angles that add up to a little more than the 180 degrees we learn in school geometry. Subsequent observations showed he was right. Proponents of time travel seized on spacetime, arguing that if you could warp it enough you could visit your own past.

Albert Einstein

In 1905 Albert Einstein (1879-1955) re-wrote Newton's ideas. He showed that time is not absolute and universal, but relative. Your time and my time can get out of step if we move differently. This led directly to the slowing of time by motion – the so-called time dilation effect predicted by relativity. "The past, present and future are only illusions," he wrote.



Hermann Minkowski

Hermann Minkowski (1864-1909) showed that Einstein's theory of relativity implied a link between time and space, so that it is not possible to separate them in a way that all observers agree on. "Henceforth time by itself and space by itself are doomed to fade away into mere shadows," he said.



Time terms

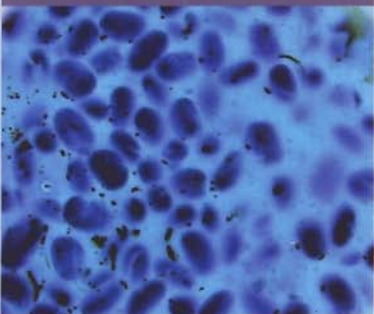
- **TIME DILATION EFFECT:** A prediction of the theory of relativity that says time is dramatically slowed as the speed of light is approached.
- **SPACEWARP:** A distortion of the geometry of space caused by gravity.
- **WORMHOLE:** A spacewarp that links two widely-separated points in space to make a shortcut, or stargate.
- **BLACK HOLE:** An empty region of space and time with a gravitational field so intense that even light is trapped.
- **QUANTUM PHYSICS:** The weird set of rules that govern the realm of atoms and molecules, characterised by uncertainty and unpredictability.
- **SPACETIME FOAM:** On an ultra-microscopic scale space may consist of a labyrinth of three-dimensional wormholes and bridges.
- **TACHYON:** A hypothetical particle that travels faster than light itself.

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SECOND: A human heartbeat lasts for about one second. The exact rate varies with the person but is normally between 50 and 100 beats every minute. It takes light from the moon 1.3 seconds to reach the Earth.



HOUR: In one hour the average person expends about 350,000 Joules of energy, which is roughly equivalent to the energy given off by a 100W light bulb. In biology, rapidly reproducing cells take about one hour to divide.



DAY: The time it takes the Earth to rotate once on its axis is roughly one day. Precisely speaking, a day is 23 hours 56 minutes and four seconds long because the Earth completes slightly more than one turn every 24 hours.

Right: Time is relative when you travel around the world. When you fly, time actually slows down. The difference is just a few billionths of a second and it's nothing at all to do with the world's timezones

▶ particles to near the speed of light is now routine, using giant accelerator machines like those at CERN near Geneva. Experiments reveal a slow-motion world in which unstable atomic fragments defy death, immensely extending their lifetimes relative to time in the lab.

TIME'S AMBIGUITY

The other way to warp time is to use gravity, because time runs faster in weaker gravity. These effects can be measured by putting clocks in rockets or comparing the frequencies of nuclear vibrations at the top and bottom of buildings. On Earth the effects are miniscule but near a neutron star time is slowed by 30 per cent compared to Earth time. The ultimate timewarp is the black hole. At its surface time literally stands still relative to us. Fall into a black hole and, in the split second it takes you to cross the point of no return, all of eternity will have passed in the outside universe. The interior of the hole is beyond the end of time, as far as external observers are concerned.

Because time is different for different observers, there can be no meaningful notion of a universal now, or present moment. In daily life we divide time into past, present and future, but these labels have no general significance.

This ambiguity about what is past and what is future leads inevitably to the physicist's notion of 'block time,' or the timescape. Instead of regard-



ing only the present moment as real, it is more accurate to think of all past and future events as 'out there' too. Which leaves a mystery about why we experience time on a moment-by-moment basis. What is it that causes the 'now' of our awareness to march forward, turning future events into present events, and then consigning them to the past? Physicists and philosophers have long argued about whether the passage or flow of time is a real physical effect, or merely an illusion. Certainly there is nothing in physics that corresponds to a flux or motion of time, as opposed to the motion of a body through space in time.

Although the concept of 'the past' and 'the future' has no universal meaning, there is certainly a real lopsidedness in time between past and future directions. This is often referred to as the arrow of time. We are surrounded by processes that have a direction in time: people

grow old, clocks run down, water flows downhill, stars burn out... The best-studied of these irreversible processes involves heat. It is a fundamental law of nature that heat flows from hot bodies into cold bodies, and not the other way around. When you put an ice cube in a glass of tepid water, you would not expect the ice to accumulate and the water to boil.

The universe as a whole seems to be on a one-way slide toward a state of thermal degeneration, in which sources of heat such as stars burn up their fuel and die. Indeed, the cosmos seems to be slowly dying, degenerating bit by bit as irreversible physical processes use up the remaining available energy. The origin of time's arrow can be traced to the rather special way that the universe began in a Big Bang, 14 billion years ago. In another 14 billion years it will be well on the way to its final 'heat death.'

Who's who in time

Alexander Friedman

In the 1920s, Russian mathematician Alexander Friedman (1888-1925) showed that an expanding universe can have a beginning in time, just as St Augustine of Hippo had suggested back in the fifth century. His mathematical model of an expanding universe was the first to include a Big Bang origin.



John Archibald Wheeler

Black holes didn't even have a name until the American theoretical physicist John Archibald Wheeler (1911-) coined the term back in 1968. He introduced the notion of black holes as infinite time warps - portals to eternity. "Time is nature's way of preventing everything from happening at once," he quipped.



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Cosmologists think the Big Bang could have been the absolute beginning of time: there may have been no 'before.' The idea that time has not always existed, that it does not stretch back forever and ever, is a consequence of Einstein's theory of relativity. However, the idea is not new. In the fifth century, Augustine declared that "the world was made with time, and not in time". History has shown he was probably right.

Could there be an end of time too? Possibly. If the expansion of the universe one day slows to a halt, then the entire cosmos will collapse to a 'big crunch' like the Big Bang in reverse. In which case space and time might well be obliterated totally, leaving absolutely nothing. This cataclysm could happen before the universe has succumbed to the heat death – its alternative fate if the expansion goes on forever.

Question time

Professor Paul Davies of Sydney's Macquarie University tackles the big questions

Q. Can time have a beginning? Surely something must have happened before it?

A. Asking what came before the beginning of time is like asking what lies north of the north pole, Stephen Hawking once remarked. The north pole marks the farthest geographical limit, but the Earth does not actually end there. In the same way, time may have a past extremity – the Big Bang. This is the case in the standard Big Bang theory of cosmology. But in recent, more elaborate, theories there are many Big Bangs embedded in an eternally expanding space, so time does not have a beginning.

Q. Can time run backwards?

A. Many scientists have suggested that the arrow of time might flip one day, perhaps if the universe expanded to a maximum size and then started to contract. This would mean water flowing uphill, people getting younger and stars sucking up heat and light. However, beings living in the time-reversed phase would have their mental states flipped too, so for them the world would appear normal. It would be our world that would seem reversed. Attempts to provide a detailed physical model of a time-reversing universe always run into trouble, however.

Q. Can I go back in time by travelling faster than light?

A. If you could break the light barrier, you would be able to visit the past. But the theory of relativity says that if you try accelerating a body towards the speed of light, it



British-born Paul Davies is no stranger to matters temporal, being the author of the books *How to Build a Time Machine* and *About Time*

gets heavier and heavier. More and more energy goes into making mass, less and less into increasing speed. You need an infinite amount of energy to reach light speed, which is impossible.

Q. Can anything at all travel faster than light?

A. The theory of relativity doesn't strictly forbid faster-than-light travel, so long as the light barrier isn't crossed. Physicists have conjectured about particles called tachyons that could never be slowed to less than light speed. If they exist, tachyons could be used to signal the past. From time to time, claims are made that tachyons have been observed, but most physicists are sceptical.

Q. Is time dilation a recipe for eternal youth?

A. Sadly, no. Time always appears

normal in the observer's frame of reference. Time dilation is experienced only by comparing one observer's experiences with someone else's. Remember that the Earth is whizzing through space at a staggering speed relative to other galaxies, yet Earth time remains unaffected for terrestrial observers.

Q. Does time really exist?

A. Space and time form part of the physicist's basic description of nature. Almost all physical theories are cast in the language of space and time. Yet a final unified theory of physics would need to explain them; in other words, space and time should come out of the theory, not be put in. In which case, time may turn out to be a secondary or derivative property of the world, not a primary property. Space and time might be 'made up of' some deeper structure. Just what, nobody knows.

Forward v backward time travel

Forwards

In a sense we are all travelling forwards in time – by one second per second! But Einstein's theory of relativity permits us to reach the future faster, by moving at near light speed. You could fast forward to Earth in the year 3000 in just one year but you'd have to travel at 99.999999 per cent of the speed of light. Difficult, but possible in principle thanks to time dilation.

Backwards

Visiting the past is altogether different and much harder than jumping into the future. You can't just throw the great cosmic movie into reverse. Going back in time means journeying on a closed loop in space, and coming back before you left. To do it you would have to exploit a bizarre gravitational warp in the fabric of spacetime. Creating such a warp is possible in theory.



"You're not thinking fourth dimensionally, Marty"

It isn't easy but physicists have shown that you could, in theory, travel through time

How to build a time machine

Time travel is an old dream beloved of science fiction writers. But can it really be done? Well, maybe. Einstein's theory of relativity does not actually forbid it, but finding a way isn't easy.

The most feasible idea surfaced in the 1980s and involved a 'wormhole'. This is a region of intense gravity bearing some resemblance to a black hole. Whereas a black hole is a one-way journey to nowhere, a wormhole would have an exit as well as an entrance: it has two 'mouths.' In sci-fi parlance, a wormhole is a stargate, a shortcut between two distant points in space. Objects passing through one can be projected into either the past or future, depending on which direction they go. Large wormholes might have been made in the Big Bang. But the best place to get one now is in the quantum microworld. The engineering challenges involved in making a wormhole time machine are formidable but, once constructed, cost would cease to be a problem. The first time traveller could come back from the future with a list of stock prices and make the necessary investments to pay for the trip! Here is how to build a wormhole time machine in four easy steps. (Warning. Don't try this at home!)



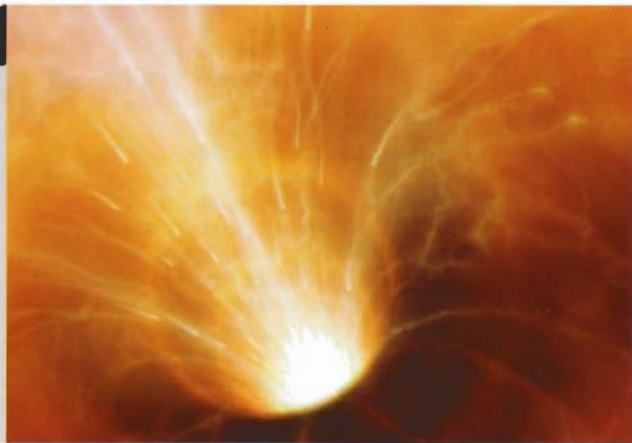
What could go wrong?

If wormholes are created spontaneously in nature, perhaps amid spacetime foam, they can also be destroyed spontaneously. To make use of one, you have to procure and stabilise it before it vanishes again. This may require impossibly swift action. The average spacetime foam wormhole is estimated to live for only about a 10-million-trillion-trillion-trillionth of a second.

Even if a microscopic wormhole is brought under control, inflating it to human size may require stupendous quantities of exotic antigravitating

matter that would not only be impractical to deploy, it may zap any astronaut attempting to traverse the wormhole. There's also the risk of tearing the astronaut to shreds, owing to the wormhole's intense gravity.

The wormhole might also be unstable. Once a wormhole permits time loops, tiny fluctuations in energy might circle round and round and become amplified to explosive proportions. Or the antigravity may overwhelm normal gravity, causing the wormhole to inflate uncontrollably.





STEP 1 The Collider

The first step necessary to build a wormhole starts not out in space but in a particle accelerator, which is also called a collider. The reason for this is to have some control over the process. Creating a wormhole from scratch, away from the Earth, means making a cut in space. This would play havoc with nature, unleashing incredibly violent energies. A better idea is to exploit the nature of matter at the smallest possible scale. To do this entails splitting matter into its building blocks. That's where the collider comes in. Colliders, like those at CERN in Geneva, recreate the conditions that existed a few microseconds after the Big Bang, when the temperature was 10 trillion degrees. The collider smashes two uranium nuclei together at enormous speed. The shock of impact 'melts' the nuclei, creating an amorphous blob of its basic constituents – quarks and gluons.

STEP 2 The Imploder

Shrink the quark-gluon blob by a factor of 100 billion billion. This could be done explosively by simultaneously detonating several thermonuclear bombs enveloping a magnetic field. This compresses the field, enormously boosting its intensity, and in turn the field squeezes the blob. Theory suggests that on an incredibly small scale (some 20 powers of 10 smaller than an atomic nucleus) space should be a seething ferment of activity. This is sometimes called spacetime foam. Here, temporary wormholes will be continually forming by quantum effects and rapidly collapsing again. To capture one it would be necessary to inject a pulse of energy equivalent to 10 billion joules. If the Imploder works, the shrunken blob will deliver a punch of this magnitude to a fleeting wormhole, stabilising it long enough for the next step...

STEP 3 The Inflator

To send an astronaut through a wormhole it needs to be at least many metres across, so the microscopic wormhole must be inflated. This requires deploying antigravity, which would cause the wormhole to balloon out of the spacetime foam. One way of generating antigravity is to inject negative energy into the wormhole, but producing this kind of energy isn't easy. A high-energy laser might be made to pulse in short bursts, but this would produce both positive and negative energy. One way round this is to reflect the only negative energy pulses using rotating mirrors, to direct them into the mouth of the tiny wormhole. Once inflation is triggered by this antigravity effect, the wormhole's own spacewarp should generate the much greater antigravity required to sustain the process.

STEP 4 The Differentiator

The final step is to turn the wormhole into a time machine. This entails manipulating one mouth of the wormhole while leaving the other fixed. The easiest way is to stop the inflation while the wormhole is still of subatomic size and inject an electric charge, enabling the mouths to be moved with electric and magnetic fields. Then one mouth can be whirled round a ring-shaped tube in a specially adapted particle accelerator. The time dilation effect would imprint a permanent time difference between the two mouths. This step might take years, but when it is complete, the wormhole could be returned to the Inflator and boosted to the size of an astronaut. Both mouths could be brought close together and conveniently parked in the solar system so that the time travellers would not have to travel far across space.

OLIVER BURTON

Other ways of making a time machine

Other than wormholes, only two time machine designs have been extensively studied. In 1937 a mathematician named van Stockum proved that a massive cylinder spinning on its axis twists spacetime into a vortex, enabling a spaceship circumnavigating the cylinder to loop back into its own past. The other method involves so-called cosmic strings. These slender threads of trapped energy may have been left behind as exotic relics of the Big Bang. They would have enormous mass and produce powerful gravitational effects. American mathematician J Richard Gott III

calculated that a pair of straight cosmic strings moving past each other at very high speed on parallel paths would permit closed time loops. An astronaut circling the strings on a carefully chosen trajectory would go back in time.

Gott's calculation is an idealised one: it assumes the strings are infinitely long and perfectly straight. It is not clear whether more realistic scenarios involving stringy time machines are possible, or whether the fields involved would be stable everywhere. Nor is it obvious how to set up the string configuration in the first place.



EVERYDAY TIME MACHINES

Why everyone on Earth is a time traveller



SUBMARINES

In a submarine cruising at a speed of 20 knots, time is stretched by a paltry one second every half a million years, relative to the clock back at base.



AEROPLANES

Airline travel produces readily measurable time dilation. Flying at 600km/h, time is slowed by one part in 150 billion, or one second every 5,000 years.



THE EARTH

Humans are all space travellers, because we whiz around the sun at 300km/s. This produces a whopping time dilation of one part in two million, or one second every 23 days.

Scientists disagree on whether time travel is possible, but new theories could provide the answer

Time for some answers

Although nothing in Einstein's theory forbids travel into the past, many scientists reject the idea as either too weird or outright paradoxical. What happens to the time traveller who goes back and murders his mother as a child? Surely he would never have been born, so he could not commit the murder. When cause and effect, past and future get muddled up, consistent reality can be a casualty.

To get around this problem, Stephen Hawking has proposed a "chronology protection conjecture" that forbids travel back in time. This would prevent a wormhole or other device from being turned into a time machine. One possibility, based on Heisenberg's uncertainty principle, comes from quantum physics and applies to the subatomic realm. It states that energy fluctuates unpredictably even in empty space. In effect, energy is 'borrowed' for free, surging out of nowhere. Nature permits this loan as long as the energy is 'paid back' promptly; nothing can stop these random energy fluctuations. According to the

Right: CERN's Large Hadron Collider will bring protons and ions into head-on collisions at higher energies than ever achieved before. It might send subatomic particles into the past or future

uncertainty principle, the greater the energy, the shorter the loan. If a time machine existed, borrowed energy could be conveyed around a time loop and paid back at the same instant. In this case there would be no limit to the magnitude of the loan. Calculations suggest that such runaway surges in quantum energy would generate massive gravitational fields and turn the wormhole into mush.

Research by Kip Thorne at the California Institute of Technology leaves open the question of whether quantum fluctuations would wreck time machines. The trouble is, quantum physics and gravity don't marry up too well, and clear answers will have to await a future unified theory of quantum gravity. Popular theories currently include M theory,

which seeks to unify all the forces and particles of nature into one mathematical scheme; and superstring theory, in which the universe is built out of little loops of string in 10 dimensions. So far, these theories have little to say about time travel.

QUANTUM PHYSICS

Not all physicists are fazed by the paradoxes of time travel. David Deutsch of Oxford University believes that quantum physics comes to the rescue. The uncertainty implied in Heisenberg's principle means that, on a microscale, we cannot know precisely what will happen from one moment to the next. One way to envisage quantum uncertainty is to imagine an array of contending realities, each representing one permissible atomic future. In



A brief history of time travel



HG Wells started a trend in 1895

1895 HG Wells's book *The Time Machine* is published. This novel is the trailblazer for modern science fiction.

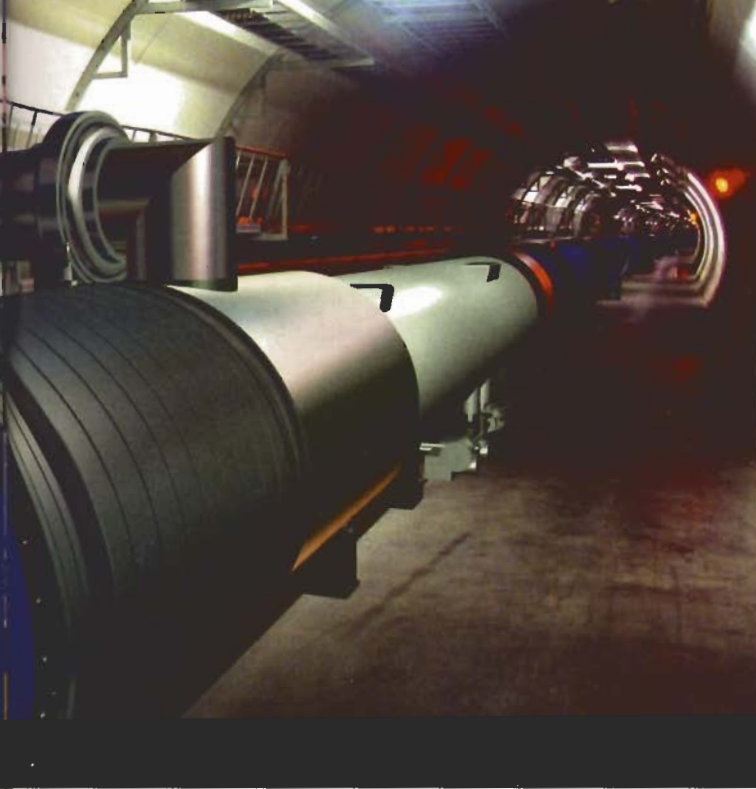
1905 Albert Einstein publishes the first of his papers on the theory of relativity. He argues mathematically that time can be stretched and shrunk by motion. His ideas trigger a scientific revolution.

1915 Einstein completes his theory of relativity, showing that gravity can warp time too. This work paves the way for the ideas of black holes and wormholes.

1937 An obscure physicist named

The galaxy Circinus is thought to contain massive black holes





Stephen Hawking is one physicist who believes it will never be possible to travel back in time. His theory shows that a time machine's wormhole would be turned into mush by massive gravitational fields

one world an atom moves to the left, in another it moves to the right. Deutsch envisages two parallel universes, one with a left-moving atom, the other with a right-moving atom. Both these universes are equally real. In practice, there will be an infinite number of side-by-side quantum realities, encompassing all possible atomic gymnastics.

If time travel is allowed, atomic uncertainty could be amplified to everyday dimensions, so that a time traveller will be presented with not just a single past, but a multiplicity. He could kill his mother in the history of one world, leaving his mother alive in the universe he departed from. This neatly avoids the paradoxical causality loops that make time travel so problematic for science fiction writers.

So why do we never see time tourists coming back from the future? It turns out that a wormhole can't be used to go back to a time before it was adapted to make a time machine. That's because it will take at least a hundred years to create a one-hundred-year time difference between the ends of the wormhole. So we couldn't manufacture a time machine and go back to see the dinosaurs, for example.

Assuming time machines are not outlawed by some obscure physical process, when might we realistically expect to make one? Current ideas of wormhole manufacture are so technically challenging it is hard to imagine it being the product of anything less than a truly cosmic civilization. But few scientists believe Einstein's theory of relativ-

ity is the last word on the nature of time and gravity. Some alternative theories of gravitation currently doing the rounds predict that significant departures from relativity may show up in the next generation of particle accelerators. The so-called Large Hadron Collider being built at CERN, near Geneva, will hurl protons and antiprotons together at unprecedented energies. There is speculation that the resulting high-speed collisions may create microscopic black holes and wormholes. Though it would not be feasible to inflate those wormholes, even a subatomic-sized wormhole might serve to send a particle very slightly into the past or future. It is not impossible that this limited two-way time travel might be demonstrated before 2010.

Fast facts



- The highest energy cosmic rays move so close to the speed of light, they could cross the galaxy in a few minutes in their frame of reference.
- If you were sealed in a totally impenetrable box you would be dead within minutes. But the random agitation of your molecules imply that you would be resurrected to the same state after a duration in years equal to one followed by a trillion trillion zeros.
- In 1972 the American physicist Bruce Partridge attempted to detect radio waves from the future using an antenna at the top of a mountain pointing towards intergalactic space. He didn't find anything.
- The universe was probably born in a quantum flash that lasted just 10-million-trillion-trillion-trillion-trillionths of a second.
- According to the standard 'inflationary' model of the Big Bang, the universe jumped in size by a factor of a billion trillion trillion trillion trillion trillion in a mere 10 trillion-trillion-trillionths of a second.

van Stockum uses Einstein's theory of relativity to argue that the gravitational field of a massive rotating cylinder might serve as a time machine.

1949 Einstein's colleague Kurt Godel proves that if the entire universe were rotating, travel into the past would be permitted. Einstein is very upset, because he is disturbed by the prospect of backward time travel.

1957 John Archibald Wheeler conjectures the existence of wormholes. Few scientists take him seriously.



Sagan's 1986 novel *Contact* was made into a Hollywood film in 1997

1986 Carl Sagan's novel *Contact* is published. The story involves using a

wormhole as a stargate. At this stage the concept is pure fiction. *Contact* is later turned into a film starring Jodie Foster.

1988 Kip Thorne and his colleagues check out Sagan's wormhole idea and discover it might just work. They soon discover that the wormhole can be turned into a general-purpose time machine, allowing both forward and backward travel in time.

1990 Stephen Hawking comes out against unrestricted time travel, publishing his so-called chronology protection conjecture and "making the world safe for historians."