# Time travel

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*This article details time travel itself. For other uses, see Time Traveler.*

Unsolved problems in physics: *Is **time travel** theoretically and practically possible? If so, how can paradoxes such as the grandfather paradox be avoided?*

**Time travel** is the concept of moving backwards and/or forwards to different points in time, in a manner analogous to moving through space. Additionally, some interpretations of time travel suggest the possibility of travel between parallel realities or universes.[1] Although time travel has been a common plot device in fiction since the 19th century, and one-way travel into the future is arguably possible given the phenomenon of time dilation in the theory of relativity, it is currently unknown whether the laws of physics would allow backwards time travel. Any technological device, whether fictional or hypothetical, that is used to achieve two-way time travel is known as a **time machine**.

## Contents

# Origins of the concept

There is no widespread agreement as to which written work should be recognized as the earliest example of a time travel story, since a number of early works feature elements ambiguously suggestive of time travel. For example, *Memoirs of the Twentieth Century* (1733) by Samuel Madden is mainly a series of letters from English ambassadors in various countries to the British "Lord High Treasurer", along with a few replies from the British Foreign Office, all purportedly written in 1997 and 1998 and describing the conditions of that era.[2] However, the framing story is that these letters were actual documents given to the narrator by his guardian angel one night in 1728; for this reason, Paul Alkon suggests in his book *Origins of Futuristic Fiction* that "the first time-traveler in English literature is a guardian angel who returns with state documents from 1998 to the year 1728",[3] although the book does not explicitly show how the angel obtained these documents. Alkon later qualifies this by writing "It would be stretching our generosity to praise Madden for being the first to show a traveler arriving *from* the future", but also says that Madden "deserves recognition as the first to toy with the rich idea of time-travel in the form of an artifact sent backwards from the future to be discovered in the present."[2]

Louis-Sébastien Mercier's *L'An 2440, rêve s'il en fut jamais* ("The Year 2440: A Dream If Ever There Was One") is a utopian novel set in the year 2440. An extremely popular work (it went through twenty-five editions after its first appearance in 1771), the work describes the adventures of an unnamed man, who, after engaging in a heated discussion with a philosopher friend about the injustices of Paris, falls asleep and finds himself in a Paris of the future. Robert Darnton writes that "despite its self-proclaimed character of fantasy...L'An 2440 demanded to be read as a serious guidebook to the future." [Robert *Darnton, The Forbidden Best-Sellers of Pre-Revolutionary France* (New York: W.W. Norton, 1996), 120.]

In the science fiction anthology *Far Boundaries* (1951), the editor August Derleth identifies the short story *"Missing One's Coach: An Anachronism"*, written for the *Dublin Literary Magazine* by an anonymous author in 1838, as a very early time travel story.[4] In this story, the narrator is waiting under a tree to be picked up by a coach which will take him out of Newcastle, when he suddenly finds himself transported back over a thousand years, where he encounters the Venerable Bede in a monastery, and gives him somewhat ironic explanations of the developments of the coming centuries. It is never entirely clear whether these events actually occurred or were merely a dream — the narrator says that when he initially found a comfortable-looking spot in the roots of the tree, he sat down, "and as my sceptical reader will tell me, nodded and slept", but then says that he is "resolved not to admit" this explanation. A number of dreamlike elements of the story may suggest otherwise to the reader, such as the fact that none of the members of the monastery seem to be able to see him at first, and the abrupt ending where Bede has been delayed talking to the narrator and so the other monks burst in thinking that some harm has come to him, and suddenly the narrator finds himself back under the tree in the present (August of 1837), with his coach having just passed his spot on the road, leaving him stranded in Newcastle for another night.[5]

Charles Dickens' 1843 book *A Christmas Carol* is considered by some[6] to be one of the first depictions of time travel, as the main character, Ebenezer Scrooge, is transported to Christmases past, present and yet to come. These might be considered mere visions rather than actual time travel, though, since Scrooge only viewed each time period passively, unable to interact with them.

A clearer example of time travel is found in the popular 1861 book *Paris avant les hommes (Paris before Men)*, published posthumously by the French botanist and geologist Pierre Boitard. In this story the main character is transported into the prehistoric past by the magic of a "lame demon" (a French pun on Boitard's name), where he encounters such extinct animals as a Plesiosaur, as well as Boitard's imagined version of an apelike human ancestor, and is able to actively interact with some of them.[7] Another clear early example of time travel in fiction is the short story *The Clock That Went Backward (http://www.horrormasters.com/Text/a2221.pdf) PDF (35.7 KiB)* by Edward Page Mitchell, which appeared in the *New York Sun* in 1881. Mark Twain's *A Connecticut Yankee in King Arthur's Court* (1889), in which the protagonist finds himself in the time of King Arthur after a fight in which he is hit with a sledge hammer, was another early time travel story which helped bring the concept to a wide audience, and was also one of the first stories to show history being changed by the time traveler's actions.

The first time travel story to feature time travel by means of a time *machine* was Enrique Gaspar y Rimbau's 1887 book *El Anacronópete*.[8] This idea gained popularity with the H. G. Wells story *The Time Machine*, published in 1895 (preceded by a less influential story of time travel Wells wrote in 1888, titled *The Chronic Argonauts*), which also featured a time machine and which is often seen as an inspiration for all later science fiction stories featuring time travel.

Since that time, both science and fiction (see Time travel in fiction) have expanded on the concept of time travel, but whether it could be possible in reality is still an open question.

# Time travel in theory

Some theories, most notably special and general relativity, suggest that suitable geometries of spacetime, or specific types of motion in space, might allow time travel into the past and future if these geometries or motions are possible.[9] In technical papers physicists generally avoid the commonplace language of "moving" or "traveling" through time ('movement' normally refers only to a change in spatial position as the time coordinate is varied), and instead discuss the possibility of closed timelike curves, which are worldlines that form closed loops in spacetime, allowing objects to return to their own past. There are known to be solutions to the equations of general relativity that describe spacetimes which contain closed timelike curves, but the physical plausibility of these solutions is uncertain.

Physicists take for granted that if one were to move away from the Earth at relativistic velocities and return, more time would have passed on Earth than for the traveler, so in this sense it is accepted that relativity allows "travel into the future" (although according to relativity there is no single objective answer to how much time has 'really' passed between the departure and the return). On the other hand, many in the scientific community believe that backwards time travel is highly unlikely. Any theory which would allow time travel would require that issues of causality be resolved. For example, what if one were to go back in time and kill one's own grandfather before one's father was conceived? (see grandfather paradox)

## Tourism in time

Stephen Hawking once suggested that the absence of tourists from the future constitutes an argument against the existence of time travel—a variant of the Fermi paradox. Of course this would not prove that time travel is physically impossible, since it might be that time travel is physically possible but that it is never in fact developed (or was cautiously never used); and even if it is developed, Hawking notes elsewhere that time travel might only be possible in a region of spacetime that is warped in the right way, and that if we cannot create such a region until the future, then time travelers would not be able to travel back before that date, so "This picture would explain why we haven't been over run by tourists from the future."[10]

### General relativity

However, the theory of general relativity does suggest scientific grounds for thinking backwards time travel could be possible in certain unusual scenarios, although arguments from semiclassical gravity suggest that when quantum effects are incorporated into general relativity, these loopholes may be closed. These semiclassical arguments led Hawking to formulate the chronology protection conjecture, suggesting that the fundamental laws of nature prevent time travel, but physicists cannot come to a definite judgment on the issue without a theory of quantum gravity to join quantum mechanics and general relativity into a completely unified theory.

## The "presentist" view

*Presentism* holds that neither the **future** nor the **past** exist—that the only things that exist are present things, and there are no non-present objects. Some have taken presentism to indicate that time travel is impossible for there is no future or past to travel to; however, recently some presentists have argued that although past and future objects do not exist, there can still be definite truths about past and future events, and that it is possible that a future truth about the time traveler deciding to return to the present date could explain the time traveler's actual presence in the present.[11] This view is contested by another contemporary advocate of presentism, Craig Bourne, in his recent book 'A Future for Presentism', although for substantially different (and more complex) reasons. In any case, the relativity of simultaneity in modern physics is generally understood to cast serious doubt on presentism and to favor the view known as four dimensionalism (closely related to the idea of block time) in which past, present and future events all coexist in a single spacetime.

## Time travel to the past in physics

Time travel to the past is theoretically allowed using the following methods:[12]

- Traveling faster than the speed of light
- The use of cosmic strings and black holes
- Wormholes and Alcubierre 'warp' drive

### The equivalence of time travel and faster-than-light travel

If one were able to move information or matter from one point to another faster than light, then according to special relativity, there would be some inertial frame of reference in which the signal or object was moving backwards in time. This is a consequence of the relativity of simultaneity in special relativity, which says that in some cases different reference frames will disagree on whether two events at different locations happened "at the same time" or not, and they can also disagree on the order of the two events (technically, these disagreements occur when spacetime interval between the events is 'space-like', meaning that neither event lies in the future light cone of the other).[13] If one of the two events represents the sending of a signal from one location and the second event represents the reception of the same signal at another location, then as long as the signal is moving at the speed of light or slower, the mathematics of simultaneity ensures that all reference frames agree that the transmission-event happened before the reception-event.[13] However, in the case of a hypothetical signal moving faster than light, there would always be some frames in which the signal was received before it was sent, so that the signal could be said to have moved backwards in time. And since one of the two fundamental postulates of special relativity says that the laws of physics should work the same way in every inertial frame, then if it is possible for signals to move backwards in time in any one frame, it must be possible in all frames. This means that if observer A sends a signal to observer B which moves FTL (faster than light) in A's frame but backwards in time in B's frame, and then B sends a reply which moves FTL in B's frame but backwards in time in A's frame, it could work out that A receives the reply before sending the original signal, a clear violation of causality in *every* frame. An illustration of such a scenario using spacetime diagrams can be found here (http://www.theculture.org/rich/sharpblue/archives/000089.html) .

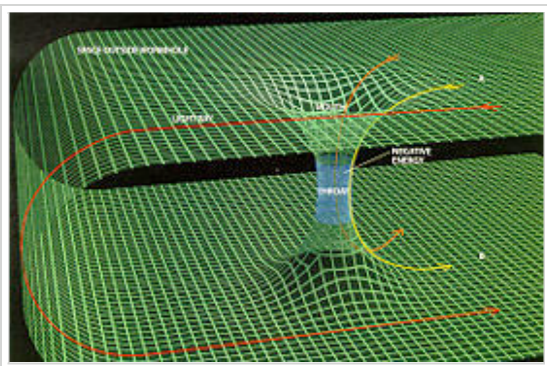
It should be noted that according to relativity it would take an infinite amount of energy to accelerate a slower-than-light object to faster-than-light speeds, and although relativity does not forbid the theoretical possibility of tachyons which move faster than light at all times, when analyzed using quantum field theory it seems that it would not actually be possible to use them to transmit information faster than light,[14] and there is no evidence for their existence.

## Special spacetime geometries

The general theory of relativity extends the special theory to cover gravity, illustrating it in terms of curvature in spacetime caused by mass-energy and the flow of momentum. General relativity describes the universe under a system of field equations, and there exist solutions to these equations that permit what are called "closed time-like curves," and hence time travel into the past.[9]The first of these was proposed by Kurt Gödel, a solution known as the Gödel metric, but his (and many others') example requires the universe to have physical characteristics that it does not appear to have.[9] Whether general relativity forbids closed time-like curves for all realistic conditions is unknown .

## Using wormholes

*Wormholes* are a type of hypothetical warped spacetime which are also permitted by the Einstein field equations of general relativity, although it would be impossible to travel through a wormhole unless it was what is known as a traversable wormhole.



A wormhole

A proposed time-travel machine using a traversable wormhole would (hypothetically) work in the following way: One end of the wormhole is accelerated to some significant fraction of the speed of light, perhaps with some advanced propulsion system, and then brought back to the point of origin. Alternatively, another way is to take one entrance of the wormhole and move it to within the gravitational field of an object that has higher gravity than the other entrance, and then return it to a position near the other entrance. For both of these methods, time dilation causes the end of the wormhole that has been moved to have aged less than the stationary end, as seen by an external observer; however, time connects differently *through* the wormhole than *outside* it, so that synchronized clocks at either end of the wormhole will always remain synchronized as seen by an observer passing through the wormhole, no matter how the two ends move around. This means that an observer entering the accelerated end would exit the stationary end when the stationary end was the same age that the accelerated end had been at the moment before entry; for example, if prior to entering the wormhole the observer noted that a clock at the accelerated end read a date of 2007 while a clock at the stationary end read 2012, then the observer would exit the stationary end when its clock also read 2007, a trip backwards in time as seen by other observers outside. One significant limitation of such a time machine is that it is only possible to go as far back in time as the initial creation of the machine;[15] in essence, it is more of a path through time than it is a device that itself moves through time, and it would not allow the technology itself to be moved backwards in time. This could provide an alternative explanation for Hawking's observation: a time machine will be built someday, but has not yet been built, so the tourists from the future cannot reach this far back in time.

According to current theories on the nature of wormholes, construction of a traversable wormhole would require the existence of a substance known as "exotic matter" with negative energy. Many physicists believe that negative energy may actually be possible due to the Casimir effect in quantum physics.[16] Although early calculations suggested a very large amount of negative energy would be required, later calculations showed that the amount of negative energy can be made arbitrarily small.[17]

In 1993, Matt Visser argued that the two mouths of a wormhole with such an induced clock difference could not be brought together without inducing quantum field and gravitational effects that would either make the wormhole collapse or the two mouths repel each other.[18] Because of this, the two mouths could not be brought close enough for causality violation to take place. However, in a 1997 paper, Visser hypothesized that a complex "Roman ring" (named after Tom Roman) configuration of an N number of wormholes arranged in a symmetric polygon could still act as a time machine, although he concludes that this is more likely a flaw in classical quantum gravity theory rather than proof that causality violation is possible.[19]

## Other approaches based on general relativity

Another approach involves a dense spinning cylinder usually referred to as a Tipler cylinder, a GR solution discovered by Willem Jacob van Stockum[20] in 1936 and Kornel Lanczos[21] in 1924, but not recognized as allowing closed timelike curves[22] until an analysis by Frank Tipler[23] in 1974. If a cylinder is long, and dense, and spins fast enough about its long axis, then a spaceship flying around the cylinder on a spiral path could travel back in time (or forward, depending on the direction of its spiral). However, the density and speed required is so great that ordinary matter is not strong enough to construct it. A similar device might be built from a cosmic string, but none are known to exist, and it does not seem to be possible to create a new cosmic string.

Physicist Robert Forward noted that a naïve application of general relativity to quantum mechanics suggests another way to build a time machine. A heavy atomic nucleus in a strong magnetic field would elongate into a cylinder, whose density and "spin" are enough to build a time machine. Gamma rays projected at it might allow information (not matter) to be sent back in time; however, he pointed out that until we have a single theory combining relativity and quantum mechanics, we will have no idea whether such speculations are nonsense.

A more fundamental objection to time travel schemes based on rotating cylinders or cosmic strings has been put forward up by Stephen Hawking, who proved a theorem showing that according to general relativity it is impossible to build a time machine in any finite region that satisfies the weak energy condition, meaning that the region contains no exotic matter with negative energy. Solutions such as Tipler's assume cylinders of infinite length, which are easier to analyze mathematically, and although Tipler suggested that a finite cylinder might produce closed timelike curves if the rotation rate were fast enough,[24] he did not prove this. But Hawking points out that because of his theorem, "it can't be done with positive energy density everywhere! I can prove that to build a finite time machine, you need negative energy."[25] This result comes from Hawking's 1992 paper on the chronology protection conjecture, where he examines "the case that the causality violations appear in a finite region of spacetime without curvature singularities" and proves that "[t]here will be a Cauchy horizon that is compactly generated and that in general contains one or more closed null geodesics which will be incomplete. One can define geometrical quantities that measure the Lorentz boost and area increase on going round these closed null geodesics. If the causality violation developed from a noncompact initial surface, the averaged weak energy condition must be violated on the Cauchy horizon."[26] However, this theorem does not rule out the possibility of time travel in regions which contain exotic matter with negative energy (which would be necessary for traversable wormholes or the Alcubierre drive), and because the theorem is based on general relativity, it is also conceivable a future theory of quantum gravity which replaced general relativity would allow time travel even without exotic matter (though it is also possible such a theory would place even more restrictions on time travel, or rule it out completely).

## Time travel and the anthropic principle

It has been suggested by physicists such as Max Tegmark that the absence of time travel and the existence of causality might be due to the anthropic principle. The argument is that a universe which allows for time travel and closed time-like loops is one in which intelligence could not evolve because it would be impossible for a being to sort events into a past and future or to make predictions or comprehend the world around them (at least, not if the time travel occurs in such a way that it disrupts that evolutionary process).

## Experiments carried out

Certain experiments carried out during the last ten years give the impression of reversed causality but are interpreted in a different way by the scientific community. For example, in the delayed choice quantum eraser experiment performed by Marlan Scully, pairs of entangled photons are divided into "signal photons" and "idler photons", with the signal photons emerging from one of two locations and their position later measured as in the double slit experiment, and depending on how the idler photon is measured, the experimenter can either learn which of the two locations the signal photon emerged from or "erase" that information. Even though the signal photons can be measured before the choice has been made about the idler photons, the choice seems to retroactively determine whether or not an interference pattern is observed when one correlates measurements of idler photons to the corresponding signal photons. However, since interference can only be observed after the idler photons are measured and they are correlated with the signal photons, there is no way for experimenters to tell what choice will be made in advance just by looking at the signal photons, and under most interpretations of quantum mechanics the results can be explained in a way that does not violate causality.

The experiment of Lijun Wang might also give the appearance of causality violation since it made it possible to send packages of waves through a bulb of cesium gas in such a way that the package appeared to exit the bulb 62 nanoseconds before its entry. But a wave package is not a single well-defined object but rather a sum of multiple waves of different frequencies (*see* Fourier analysis), and the package can appear to move faster than light or even backwards in time even if none of the pure waves in the sum do so. This effect cannot be used to send any matter, energy, or information backwards in time, so this experiment is understood not to violate causality either.

The physicists Günter Nimtz and Alfons Stahlhofen, of the University of Koblenz, claim to have violated

Einstein's theory of relativity by transmitting photons faster than the speed of light. They say they have conducted an experiment in which microwave photons - energetic packets of light - traveled "instantaneously" between a pair of prisms that had been moved up to 3ft apart, using a phenomenon known as quantum tunneling. Nimtz told New Scientist magazine: "For the time being, this is the only violation of special relativity that I know of." However, other physicists say that this phenomenon does not allow information to be transmitted faster than light. Aephraim Steinberg, a quantum optics expert at the University of Toronto, Canada, uses the analogy of a train traveling from Chicago to New York, but dropping off train cars at each station along the way, so that the center of the train moves forward at each stop; in this way, the center of the train exceeds the speed of any of the individual cars.[27]

Some physicists have attempted to perform experiments which would show genuine causality violations, but so far without success. The Space-time Twisting by Light (STL) experiment run by physicist Ronald Mallett is attempting to observe a violation of causality when a neutron is passed through a circle made up of a laser whose path has been twisted by passing it through a photonic crystal. Mallett has some physical arguments which suggest that closed timelike curves would become possible through the center of a laser which has been twisted into a loop. However, other physicists dispute his arguments (*see* objections).

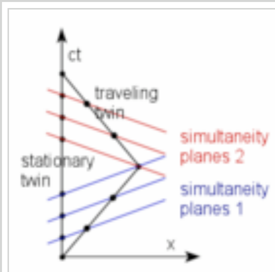
### Non-physics based experiments

Several experiments have been carried out to try to entice future humans, who might invent time travel technology, to come back and demonstrate it to people of the present time. Events such as Perth's Destination Day or MIT's Time Traveler Convention heavily publicized permanent "advertisements" of a meeting time and place for future time travelers to meet. These experiments only stood the possibility of generating a positive result demonstrating the existence of time travel, but have failed so far--no time travelers are known to have attended either event. Although it is theoretically possible that future humans have traveled back in time, but have traveled back to the meeting time and place in a parallel universe.[28] Another factor is that not all time travel devices under current physics (such as those that operate using wormholes) permit their users to travel back to before the time machine was actually made[29], rendering such tests useless.

A website with a similar plan called FindTimeTravel.com was also created in 2005 with no results as yet. [30].

## Time travel to the future in physics

There are various ways in which a person could "travel into the future" in a limited sense: the person could set things up so that in a small amount of their own subjective time, a large amount of subjective time has passed for other people on Earth. For example, an observer might take a trip away from the Earth and back at relativistic velocities, with the trip only lasting a few years according to the observer's own clocks, and return to find that thousands of years had passed on Earth. It should be noted, though, that according to relativity there is no objective answer to the question of how much time "really" passed during the trip; it would be equally valid to say that the trip had lasted only a few years or that the trip had lasted thousands of years, depending on your choice of reference frame.



Twin paradox diagram

This form of "travel into the future" is theoretically allowed using the following methods:[12]

- Using time dilation under the Theory of Special Relativity, for instance:
  - Traveling at almost the speed of light to a distant star, then slowing down, turning around, and

traveling at almost the speed of light back to Earth[31] (see the Twin paradox)
    - Orbiting Earth for long periods of time (practical, but insignificant);
- Using time dilation under the Theory of General Relativity, for instance:
    - Residing inside of a hollow, high-mass object;
    - Residing just outside of the event horizon of a black hole

Additionally, it might be possible to see the distant future of the Earth using methods which do not involve relativity at all, although it is even more debatable whether these should be deemed a form of "time travel":

- Hibernation
- Suspended animation

## Time dilation


Transversal Time dilation

*Time dilation* is permitted by Albert Einstein's special and general theories of relativity. These theories state that, relative to a given observer, time passes more slowly for bodies moving quickly relative to that observer, or bodies that are deeper within a gravity well.[32] For example, a clock which is moving relative to the observer will be measured to run slow in that observer's rest frame; as a clock approaches the speed of light it will almost slow to a stop, although it can never quite reach light speed so it will never completely stop. For two clocks moving inertially (not accelerating) relative to one another, this effect is reciprocal, with each clock measuring the other to be ticking slower. However, the symmetry is broken if one clock accelerates, as in the twin paradox where one twin stays on Earth while the other travels into space, turns around (which involves acceleration), and returns—in this case both agree the traveling twin has aged less. General relativity states that time dilation effects also occur if one clock is deeper in a gravity well than the other, with the clock deeper in the well ticking more slowly; this effect must be taken into account when calibrating the clocks on the satellites of the Global Positioning System, and it could lead to significant differences in rates of aging for observers at different distances from a black hole.

It has been calculated that, under general relativity, a person could travel forward in time at a rate four times that of distant observers by residing at the bottom of a 5 meter tall funnel with the mass of Jupiter.[12] For such a person, every one second of their "personal" time would correspond to four seconds for distant observers. Of course, squeezing the mass of a large planet into a non-spherical object five meters in length is not expected to be within our technological capabilities in the near future.

## Time perception

Time perception can be apparently sped up for living organisms through hibernation, where the body temperature and metabolic rate of the creature is reduced. A more extreme version of this is suspended animation, where the rates of chemical processes in the subject would be severely reduced.

Time dilation and suspended animation only allow "travel" to the future, never the past, so they do not violate causality, and arguably should not be considered time travel.

# Other ideas about time travel from mainstream physics

### The possibility of paradoxes

The Novikov self-consistency principle and recent calculations by Kip S. Thorne indicate that simple masses passing through time travel wormholes could never engender paradoxes—there are *no* initial conditions that lead to paradox once time travel is introduced. If his results can be generalised, they would suggest, curiously, that none of the supposed paradoxes formulated in time travel stories can actually be formulated at a precise physical level: that is, that *any* situation you can set up in a time travel story turns out to permit *many* consistent solutions. The circumstances might, however, turn out to be almost unbelievably strange.

Parallel universes might provide a way out of paradoxes. Everett's many-worlds interpretation of quantum mechanics suggests that all possible quantum events can occur in mutually exclusive histories.[33] These alternate, or parallel, histories would form a branching tree symbolizing all possible outcomes of any interaction. If all possibilities exist, any paradoxes could be explained by having the paradoxical events happening in a different universe. This concept is most often used in science-fiction, but some physicists such as David Deutsch have suggested that if time travel is possible and the many-worlds interpretation is correct, then a time traveler should indeed end up in a different history than the one he started from.[1] On the other hand, Stephen Hawking has argued that even if the many-worlds interpretation is correct, we should expect each time traveler to experience a single self-consistent timeline, so that time travelers remain within their own world rather than traveling to a different one.[10]

Daniel Greenberger and Karl Svozil proposed that quantum theory gives a model for time travel without paradoxes.[34] In quantum theory observation causes possible states to 'collapse' into one measured state; hence, the past observed from the present is deterministic (it has only one possible state), but the present observed from the past has many possible states until our actions cause it to collapse into one state. Our actions will then be seen to have been inevitable.

### Using quantum entanglement

Quantum-mechanical phenomena such as quantum teleportation, the EPR paradox, or quantum entanglement might appear to create a mechanism that allows for faster-than-light (FTL) communication or time travel, and in fact some interpretations of quantum mechanics such as the Bohm interpretation presume that some information is being exchanged between particles instantaneously in order to maintain correlations between particles.[35] This effect was referred to as "spooky action at a distance" by Einstein.

Nevertheless, the fact that causality is preserved in quantum mechanics is a rigorous result in modern quantum field theories, and therefore modern theories do not allow for time travel or FTL communication. In any specific instance where FTL has been claimed, more detailed analysis has proven that to get a signal, some form of classical communication must also be used. The no-communication theorem also gives a general proof that quantum entanglement cannot be used to transmit information faster than classical signals. The fact that these quantum phenomena apparently do *not* allow FTL/time travel is often overlooked in popular press coverage of quantum teleportation experiments. How the rules of quantum mechanics work to preserve causality is an active area of research.

## Ideas from fiction

### Types of time travel

Time travel themes in science fiction and the media can generally be grouped into two main types and a third, less common type (based on effect—methods are extremely varied and numerous), each of which is further subdivided. These classifications do not address the issue of time travel itself, i.e. how to travel through time, but instead call to attention differing rules of the time line.

1. The time line is consistent and can never be changed.

    1.1 One does not have full control of the time travel. One example of this is *The Morphail Effect*. This concept of time can be referred to as circular causation. For examples of circular causation, see Robert A. Heinlein's story *By His Bootstraps*.
    1.2 The Novikov self-consistency principle applies (named after Dr. Igor Dmitrievich Novikov, Professor of Astrophysics at Copenhagen University). The principle states that if you travel in time, you cannot act in such a way so as to create a paradox.
    1.3 Any event that appears to have changed a time line has instead created a new one. It has been suggested that travel to the past would create an entire new parallel universe where the traveler would be free from paradoxes since he/she is not from that universe[36].

        1.3.1 Such an *event* can be the life line existence of a human (or other intelligence) such that manipulation of history ends up with there being more than one of the same individual, sometimes called *time clones*.
        1.3.2 The new time line might be a copy of the old one with changes caused by the time traveler. For example there is the *Accumulative Audience Paradox* where multitudes of time traveler tourists wish to attend some event in the life of Jesus or some other historical figure, where history tells us there were no such multitudes. Each tourist arrives in a reality that is a copy of *the original* with the added people, and no way for the tourist to travel back to *the original* time line.

2. The time line is flexible and is subject to change.

    2.1 The time line is extremely change resistant and requires great effort to change it. Small changes will only alter the immediate future and events will conspire to maintain constant events in the far future; only large changes will alter events in the distant future. (Example: The Saga of Darren Shan, where Major events in the past cannot be changed, but minor events can be affected. This is explained as if you went back in time and killed Hitler, another Nazi would take his place and do all his evil deeds.)
    2.2 The time line is easily changed (example: Doctor Who, where the time line is fluid and changes often naturally; even changes to the traveler's own timeline are possible, though it is suggested such an act would destroy most of the Universe).

3. The time line is consistent, but only insofar as its consistency can be verified.

    3.1 The Novikov self-consistency principle applies, but if and only if it is verified to apply. Attempts to travel into the past to change events are possible, but provided that:

        -They do not interfere with the occurrence of such an attempt in the present (as would be the case in the Grandfather Paradox), and
        -The change is never ultimately verified to occur by the traveler (e.g. there is no possibility of returning to the present to witness the change).

There are also numerous science fiction stories allegedly about time travel that are not internally consistent, where the traveler makes all kinds of changes to some historical time, but we do not get to see any consequences of this in our present day.

### Immutable timelines

Time travel in a type 1 universe does not allow any paradoxes, although in 1.3, events can *appear* to be paradoxical.

In 1.1, time travel is constrained to prevent paradox. If one attempts to make a paradox, one undergoes involuntary or uncontrolled time travel. Michael Moorcock uses a form of this principle and calls it *The Morphail Effect*. In the time-travel stories of Connie Willis, time travelers encounter "slippage" which prevents them from either reaching the intended time or translates them a sufficient distance from their destination at the intended time, as to prevent any paradox from occurring.

> Example: A man who travels into the past with intentions to kill Hitler finds himself on a Montana farm in late April 1945.

In 1.2, the Novikov self-consistency principle asserts that the existence of a method of time travel constrains events to remain self-consistent (i.e. no paradoxes). This will cause any attempt to violate such consistency to fail, even if extremely improbable events are required.

> Example: You have a device that can send a single bit of information back to itself at a precise moment in time. You receive a bit at 10:00:00 p.m., then no bits for thirty seconds after that. If you send a bit back to 10:00:00 p.m., everything works fine. However, if you try to send a bit to 10:00:15 p.m. (a time at which no bit was received), your transmitter will mysteriously fail. Or your dog will distract you for fifteen seconds. Or your transmitter will appear to work, but as it turns out your receiver failed at exactly 10:00:15 p.m., etc. Two examples of this kind of universe is found in *Timemaster*, a novel by Dr. Robert Forward, and the 1980 Jeannot Szwarc film *Somewhere In Time* (based on Richard Matheson's novel *Bid Time Return*).
>
> An example which could conceivably fall into either 1.1 or 1.2 can be seen in book and film versions of *Harry Potter and the Prisoner of Azkaban*. Harry went back in time with Hermione to change history. As they do so it becomes apparent that they are simply performing actions that were previously seen in the story, although neither the characters nor the reader were aware of the causes of those actions at the time. This is another example of the predestination paradox. It is arguable, however, that the mechanics of time travel actually prevented any paradoxes, firstly, by preventing them from realizing *a priori* that time travel was occurring and secondly, by enabling them to recall the precise action to take at the precise time and keep history consistent.

In 1.3, any event that appears to have caused a paradox has instead created a new time line. The old time line remains unchanged, with the time traveler or information sent simply having vanished, never to return. A difficulty with this explanation, however, is that conservation of mass-energy would be violated for the origin timeline and the destination timeline. A possible solution to this is to have the mechanics of time travel require that mass-energy be exchanged in precise balance between past and future at the moment of travel, or to simply expand the scope of the conservation law to encompass all timelines. Some examples of this kind of time travel can be found in David Gerrold's book *The Man Who Folded Himself* and The Time Ships by Stephen Baxter.

### Mutable timelines

Time travel in a Type 2 universe is much more complex. The biggest problem is how to explain changes in the past. One method of explanation is that once the past changes, so too do the memories of all observers. This would mean that no observer would ever observe the changing of the past (because they will not remember changing the past). This would make it hard to tell whether you are in a Type 1 universe or a Type 2 universe. You could, however, infer such information by knowing if a) communication with the past were possible or b) it appeared that the time line had *never* been changed as a result of an action someone remembers taking, although evidence exists that other people are changing their time lines fairly often. An example of this kind of universe is presented in *Thrice Upon a Time*, a novel by James P. Hogan. The Back to the Future trilogy films also seem to feature a single mutable timeline (see the Back to the Future FAQ (http://www.bttf.com/film_faq.htm) for details on how the writers imagined time travel worked in the movies' world). By contrast, the short story *Brooklyn Project* by William Tenn provides a sketch of life in a Type 2 world where no one even notices as the timeline changes repeatedly.

In type 2.1, attempts are being made at changing the timeline, however, all that is accomplished in the first tries is that the *way* of how decisive events happen is changed; final conclusions in the bigger scheme cannot be brought to a different outcome. Example: A paper note is being sent to the past with vital information to prevent the main plot incident. All that happens, though, is that an ATF agent gets killed, with the final disaster still not being prevented; also, the very same agent died in the previous version of the timeline as well, albeit under different circumstances. Finally though, the timeline is changed (Claire Kuchever is being saved from murder) by sending a human back into the past in order to prevent the murder of Claire and the main incident (a terrorist attack), which is arguably a "stronger" measure than simply sending back a paper note.

> Similar to the Back to the Future movie trilogy, there seems to be a ripple effect (changes from the past 'propagate' into the present, and people in the present have altered memory of events occurred after the changes made to the timeline)
> The type of timetravel in Deja Vu fits the 2.1 Type very well: Sending the paper note seems to be too "weak" a measure to cause any permanent effect, but agent Carlin going back into the past has a final decisive impact.

The science fiction writer Larry Niven suggests in his essay *The Theory and Practice of Time Travel* that in a type 2.1 universe, the most efficient way for the universe to "correct" a change is for time travel to never be discovered, and that in a type 2.2 universe, the very large (or infinite) number of time travelers from the endless future will cause the timeline to change wildly until it reaches a history in which time travel is never discovered. However, many other "stable" situations might also exist in which time travel occurs but no paradoxes are created; if the changeable-timeline universe finds itself in such a state no further changes will occur, and to the inhabitants of the universe it will appear identical to the type 1.2 scenario. This is sometimes referred to as the "Time Dilution Effect."

Few if any physicists or philosophers have taken seriously the possibility of "changing" the past except in the case of multiple universes, and in fact many have argued that this idea is logically incoherent,[37] so the mutable timeline idea is rarely considered outside of science fiction.

Also, deciding whether a given universe is of Type 2.1 or 2.2 can not be done objectively, as the categorization of timeline-invasive measures as "strong" or "weak" is arbitrary, and up to interpretation: An observer can disagree about a measure being "weak", and might, in the lack of context, argue instead that simply a mishap occurred which then led to no effective change.

An example would be the papernote sent back to the past in the film Deja Vu, as described above: Was it a too "weak" change, or was it after all just (time-local; that is, in the past) bad circumstance which made it have no effect, but it might have worked if the paper note would have been sent back 1 hour earlier, or 1 hour later into the past? As the universe in Deja Vu seems to be not entirely self-preserving from paradoxes (some, arguably minute, paradoxes, do occur), both versions seem to be equally probable, to which the film gives no further clarification.

## Gradual and instantaneous

In literature, there are two methods of time travel:

1. The most commonly used method of time travel in science fiction is the instantaneous movement from one point in time to another, like using the controls on a CD player to skip to a previous or next song, though in most cases, there is a machine of some sort, and some energy expended in order to make this happen (Like the time-traveling De Lorean in *Back to the Future* or the phonebooth which traveled through the 'circuits of history' in *Bill and Ted's Excellent Adventure*). In some cases, there is not even the beginning of a scientific explanation for this kind of time travel; it's popular probably because it is more spectacular and makes time travel easier. The "Universal Remote" used by Adam Sandler in the movie *Click* works in the same manner, although only in one direction. While his character Michael Newman can travel back to a previous point in his life, Michael appears as a separate person, and is unable to change any action.

2. In *The Time Machine*, H.G. Wells explains that we are moving through time with a constant speed. Time travel then is, in Wells' words, "stopping or accelerating one's drift along the time-dimension, or even turning about and traveling the other way." To expand on the audio playback analogy used above, this would be like rewinding or fast forwarding an analogue audio cassette and playing the tape at a chosen point. This method of gradual time travel fits best in quantum physics, but is not as popular in modern science fiction. Perhaps the oldest example of this method of time travel is in Lewis Carroll's *Through the Looking-Glass* (1871): the White Queen is living backwards, hence her memory is working both ways. Her kind of time travel is uncontrolled: she moves through time with a constant speed of -1 and she cannot change it. T.H. White, in the first part of his Arthurian novel *The Once and Future King*, *The Sword in the Stone* (1938) used the same idea: the wizard Merlyn lives back in time, because he was born "at the wrong end of time" and has to live backwards from in front. "Some people call it having second sight", he says.

## Time travel, or space-time travel?

An objection that is sometimes raised against the concept of time machines in science fiction is that they ignore the motion of the Earth between the date the time machine departs and the date it returns. The idea that a traveler can go into a machine that sends him or her to 1865 and step out into the exact same spot on Earth might be said to ignore the issue that Earth is moving through space around the Sun, which is moving in the galaxy, and so on, so that advocates of this argument imagine that "realistically" the time machine should actually reappear in space far away from the Earth's position at that date. However, according to the theory of special relativity, this argument is based on a false premise. Special relativity rejects the idea of absolute time and space; there can be no universal truth about the spatial distance between events which occurred at different times (such as an event on Earth today and an event on Earth in 1865), and thus no objective truth about which point in space at one time is at the "same position" that the Earth was at another time, because the distance depends on the observer's frame of reference.[38]

Nevertheless, the idea that the Earth moves away from the time traveler when he takes a trip through time has been used in a few science fiction stories, such as the 2000 AD comic *Strontium Dog*, in which Johnny Alpha uses "Time Bombs" to propel an enemy several seconds into the future, during which time the movement of the Earth causes the unfortunate victim to re-materialize in space. Other science fiction stories try to anticipate this objection and offer a rationale for the fact that the traveler remains on Earth, such as the 1957 Robert Heinlein novel *The Door into Summer* where Heinlein essentially handwaved the issue with a single sentence: "You stay on the world line you were on." In his 1980 novel *The Number of the Beast* a "continua device" allows the protagonists to dial in the six (not four!) co-ordinates of space and time and it instantly moves them there—without explaining how such a device might work. The television series *Seven Days* also dealt with this problem; when the chrononaut would be 'rewinding', he would also be propelling himself backwards around the earth's orbit, with the intention of landing at some chosen spatial location, though seldom hitting the mark precisely. In Piers Anthony's *Bearing an Hourglass*, the potent Hourglass of the Incarnation of Time naturally moves the Incarnation in space according to the numerous movements of the globe through the solar system, the solar system through the galaxy, etc.; but by carefully negating some of the movements he can also travel in space within the limits of the planet.

# See also

## Speculations

- Grandfather paradox
- Predestination paradox
- Temporal paradox
- Tipler Cylinder
- Ronald Mallett
- Temporal Counterfeiting

## Claims of time travel

- Philadelphia Experiment
- Chronovisor
- Darren Daulton
- John Titor
- Montauk Project
- Time slip

## Fiction, humor

- Andrew Carlssin
- Time travel in fiction
- Thiotimoline
- Time loop

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15. ^ Black Holes and Time Warps by Kip S. Thorne p.504
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# External links

- Black holes, Wormholes and Time Travel (http://www.vega.org.uk/video/programme/61) Freeview Lecture. A Royal Society Lecture by Paul Davies provided by the Vega Science Trust
- The logic of time travel: Part 1 (http://www.zen118085.zen.co.uk/logicoftimetravel.htm) , by Dr Paul Shackley
- The logic of time travel: Part 2 (http://www.zen118085.zen.co.uk/logicoftimetravel2.htm) , by Dr Paul Shackley
- Time Travel and Poul Anderson (http://www.zen118085.zen.co.uk/timetravelandpoulanderson.htm) , by Dr Paul Shackley
- SF Chronophysics (http://www.xibalba.demon.co.uk/jbr/chrono.html) , a discussion of Time Travel as it relates to science fiction
- On the Net: Time Travel (http://www.asimovs.com/_issue_0407/onthenet2.shtml) by James Patrick Kelly in *Asimov's Science Fiction*
- Howstuffworks' article on "How Time Travel Will Work" (http://science.howstuffworks.com/time-travel.htm)
- Time Travel in Flatland? (http://www.theory.caltech.edu/people/patricia/lctoc.html)
- NOVA Online: Time Travel (http://www.pbs.org/wgbh/nova/time)
- Professor Predicts Human Time Travel This Century (http://www.physorg.com/news63371210.html) Ronald Mallett, Professor at the University of Connecticut, has used Einstein's equations to design an experiment to observe a time traveling neutron in a circulating light beam. He published his research in *Physics Letters*.
- Through The Looking Glass: Time-Travel in Brane Theory (http://www.americanantigravity.com/articles/552/1/) An interview with a University of Hawaii research team seeking reverse-time communications using sterile neutrinos
- Time Traveler Convention (http://web.mit.edu/adorai/timetraveler) , at MIT - "Technically, you would only need one..."
- Time Machines in Physics (http://www.math.siu.edu/Kocik/tm/tm-all-ch.htm) - almost 200 citations from 1937 through 2001
- Stanford Encyclopedia of Philosophy:
  - Time Machines (http://plato.stanford.edu/entries/time-machine/)
  - Time Travel and Modern Physics (http://plato.stanford.edu/entries/time-travel-phys/)
- Internet Encyclopedia of Philosophy:
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  - Time Travel (http://www.iep.utm.edu/t/timetrav.htm)
- Aparta Krystian. Conventional Models of Time and Their Extensions in Science Fiction

(http://www.timetravel.110mb.com) A master's thesis exploring conceptual blending in time travel.

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- This page was last modified 20:10, 5 February 2008.