

Stephen Hawking's final book suggests time travel may one day be possible – here's what to make of it

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"If one made a research grant application to work on time travel it would be dismissed immediately," writes the physicist Stephen Hawking in his posthumous book [Brief Answers to the Big Questions](#). He was right. But he was also right that asking whether time travel is possible is a "very

serious question" that can still be approached scientifically.

Arguing that our current understanding cannot rule it out, Hawking, it seems, was cautiously optimistic. So where does this leave us? We cannot build a [time](#) machine today, but could we in the future?

Let's start with our everyday experience. We take for granted the ability to call our friends and family wherever they are in the world to find out what they are up to *right now*. But this is something we can never actually know. The signals carrying their voices and images travel incomprehensibly fast, but it still takes a finite time for those signals to reach us.

Our inability to access the "now" of someone far away is at the heart of Albert Einstein's theories of space and time.

Light speed

Einstein told us that space and time are parts of one thing – spacetime – and that we should be as willing to think about distances in time as we are distances in space. As odd as this might sound, we happily answer "about two and half hours", when someone asks how far Birmingham is from London. What we mean is that the journey takes that long at an average [speed](#) of 50 miles per hour.

Mathematically, our statement is equivalent to saying that Birmingham is about 125 miles from London. As physicists [Brian Cox](#) and [Jeff Forshaw](#) write in their book [Why does \$E=mc^2\$?](#), time and distance "can be interchanged using something that has the currency of a speed". Einstein's intellectual leap was to suppose that the exchange rate from a time to a distance in spacetime is universal – and it is the speed of light.

The speed of light is the fastest any signal can travel, putting a

fundamental limit on how soon we can know what is going on elsewhere in the universe. This gives us "causality" – the law that effects must always come *after* their causes. It is a serious theoretical thorn in the side of time-travelling protagonists. For me to travel back in time and set in motion events that prevent my birth is to put the effect (me) before the cause (my birth).

Now, if the speed of light is universal, we must measure it to be the same – 299,792,458 metres per second in vacuum – however fast we ourselves are moving. Einstein realised that the consequence of the speed of light being absolute is that space and time itself cannot be. And it turns out that moving clocks must tick slower than stationary ones.

The faster you move, the slower your clock ticks relative to ones you are moving past. The word "relative" is key: time will seem to pass normally to you. To everyone standing still, however, you will be in slow motion. If you were to move at the speed of light, you would appear frozen in time – as far as you were concerned, everyone else would be in fast forward.

So what if we were to travel *faster* than light, would time run backwards as [science fiction](#) has taught us?

Unfortunately, it takes infinite energy to accelerate a human being to the speed of light, let alone beyond it. But even if we could, time wouldn't simply run backwards. Instead, it would no longer make sense to talk about forward and backward at all. The law of causality would be violated and the concept of cause and effect would lose its meaning.

Wormholes

Einstein also told us that the force of gravity is a consequence of the way mass warps space and time. The more mass we squeeze into a region of

space, the more spacetime is warped and the slower nearby clocks tick. If we squeeze in enough mass, spacetime becomes so warped that even [light](#) cannot escape its gravitational pull and a black hole is formed. And if you were to approach the edge of the black hole – its event horizon – your clock would tick infinitely slowly relative to those far away from it.

So could we warp spacetime in just the right way to close it back on itself and travel back in time?

The answer is maybe, and the warping we need is a [traversable wormhole](#). But we also need to produce regions of negative energy density to stabilise it, and the classical physics of the 19th century prevents this. The modern theory of [quantum mechanics](#), however, might not.

According to quantum mechanics, empty space is not empty. Instead, it is filled with pairs of particles that pop in and out of existence. If we can make a region where fewer pairs are allowed to pop in and out than everywhere else, then this region will have negative energy density.

However, finding a consistent theory that combines quantum mechanics with Einstein's theory of gravity remains one of the biggest challenges in theoretical physics. One candidate, string theory (more precisely M-theory) may offer up another possibility.

M-theory requires spacetime to have 11 dimensions: the one of time and three of space that we move in and seven more, curled up invisibly small. Could we use these extra spatial dimensions to shortcut [space](#) and time? Hawking, at least, was hopeful.

Saving history

So is [time travel](#) really a possibility? Our current understanding can't rule

it out, but the answer is probably no.

Einstein's theories fail to describe the structure of spacetime at incredibly small scales. And while the laws of nature can often be completely at odds with our everyday experience, they are *always* self-consistent – leaving little room for the paradoxes that abound when we mess with cause and effect in science fiction's take on time travel.

Despite his playful optimism, Hawking recognised that the undiscovered laws of physics that will one day supersede Einstein's may conspire to prevent large objects like you and I from hopping casually (not causally) back and forth through time. We call this legacy his "[chronology protection conjecture](#)".

Whether or not the future has time machines in store, we can comfort ourselves with the knowledge that when we climb a mountain or speed along in our cars, we change how time ticks.

So, this "[pretend to be a time traveller day](#)" (December 8), remember that you already are, just not in the way you might hope.

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