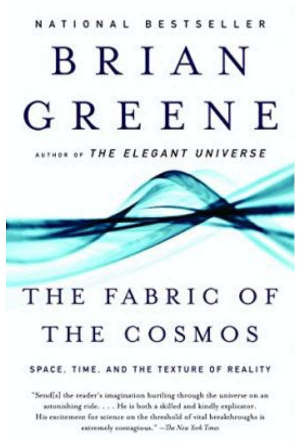


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# The Fabric of the Cosmos

Space, Time, and the Texture of Reality

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**Science** / Physics

## Take-Aways

- What we perceive is not real.
- Space is not absolute and neither is time. Both are contingent and relative.
- The past is not gone and the future is not still to come. Both are as real as the present. The past, present and future all exist permanently in spacetime.
- Space and time are relative, but spacetime is absolute.
- The faster one moves through space, the slower one moves through time.
- There may be as many as 10 space dimensions. We only perceive three of them.
- The speed of light is constant no matter how fast one is moving; yet the speed of everything else is relative to the speed of the observer.
- Gravity consists of bends and wrinkles in spacetime.
- All particles may be vibrating strings whose frequencies of vibration determine whether the string will appear to be an electron, a quark or some other particle.
- Concerned about quantum theory's strange consequences, Einstein attempted to overturn it - but could not.

## Recommendation

*getAbstract.com* highly recommends this excellent introduction to theoretical physics, which is accessible to any determined reader, even those with no mathematical and little scientific background. Pulitzer Prize-winning author Brian Greene is scrupulous about clarity, and has a gift for metaphor that makes it possible for him to discuss even the most abstruse, esoteric physics with skill, clarity and wit. Readers will discover baffling wonders that flatly contradict ordinary quotidian experience, and will come to realize that what they perceive as real is anything but real. Moreover, they will learn that physicists seem to have a great deal more success at demonstrating what is not real than at discovering what is. The most commonplace things - the difference between yesterday and tomorrow, between here and there - continue to baffle the greatest minds in science. Now you can begin to understand why.

## Summary

### Appearances Are Deceiving

Reality is not what we perceive it to be. That is the fundamental lesson of the past six centuries of scientific inquiry. The second lesson seems to be that we are far from knowing what reality is. Contemporary physics challenges almost all of our ordinary assumptions and intuitions about the nature of existence. For example, consider the idea that time moves forward - that the past is behind us and the future awaits. In fact, nothing in physics supports the notion that time moves at all. Equipped with the equations of physics, you would be hard-pressed to explain why whole eggs fall from kitchen counters and break, but shattered eggs do not reconstitute themselves on the floor and fall up to the counter.

> *"The universe's luminous constituents - stars - were revealed as but floating beacons in a giant ocean of dark matter."*

The search for a unified theory occupied Albert Einstein for the last three decades of his life. Now that superstring theory may point the way toward such a discovery, our notions of reality may get another severe shaking. String theory suggests that the universe has many more dimensions than the four of which we are aware (three-dimensional spatial reality plus time). Superstring theory needs 11 dimensions: 10 dimensions of space and one dimension of time.

### Where and When

Take space and time. You check your watch, walk across a room, go through the door, drive to the airport, take a plane and set your watch to a new time zone. You have moved through space and time. Or have you?

> *"Maybe...the universe has already drawn out the microscopic fibers of the fabric of the cosmos and unfurled them clear across the sky, and all we need to do is learn how to recognize the pattern."*

In his Principia Mathematica, Isaac Newton described space as an absolute that exists, "without reference to anything external." Thus, no matter who measures the space between two things, provided that the measuring rod is accurate, the measurements will always be the same. Newton thought of time in much the same way. He wrote, "Time exists in and of itself and flows equably without reference to anything external." This implies that two people measuring time, given accurate instruments, would get precisely the same answer about the time it took for something to happen, no matter where they might be.

> *"Nothing in the equations of fundamental physics shows any sign of treating one direction in time differently from the other, and that is totally at odds with everything we experience."*

Philosopher Gottfried Wilhelm von Leibniz disagreed with Newton. For example, Leibniz thought that space was a sort of fiction of language, merely a way of talking about the position of one thing relative to the position of another. To think of space without objects would make no more sense than to think of the alphabet without letters.

> *"And since, according to the big bang theory, the bang is what is supposed to have happened at the beginning, the big bang leaves out the bang."*

In 1689, Newton gained the upper hand in this debate with an experiment. It was quite simple. Fill a bucket with water, hang the bucket on a rope, twist the rope as far as you can and let go. The bucket begins to spin. At first, the water stays flat even though the bucket is spinning. But as the bucket spins faster and faster, the water also starts to spin, changing its shape so that it is high at the edge and low in the center. Commonplace though it may be, this experiment implies something profound about space. The water should only change its shape if it is moving. But the water is still in the bucket, and the bucket is still hanging from the rope, yet the water changed its shape. If space were not real, Newton reasoned, then the water could not have changed its shape, because it had not moved in relation to anything. Yet, the fact that the water had changed its shape indicates that it was accelerating with respect or in relation to something. What could that something be? Leibniz had to concede a point and did so, saying, "I grant that there is a difference between absolute true motion of a body and a mere relative change of its situation with respect to another body."

> *"Quantum mechanics shows that the best we can ever do is predict the probability that an experiment will turn out this way or that."*

For more than 200 years, the matter seemed settled. Newton had shown that the water was spinning in relationship to absolute space. Space itself was real. Objects moved in relation to this absolute reality, or they did not move at all.

Yet there were problems. For example, consider an ice skater spinning on the ice. Or consider an arena spinning around an ice skater who is standing still on the ice. From the viewpoint of a spectator, the ice skater is spinning. From the viewpoint of the ice skater, the arena is spinning. Who can say that either the spectator or the ice skater is wrong?

> *"This quantum uncertainty ensures that the microworld is a turbulent and jittery realm."*

In the middle of the nineteenth century, Austrian physicist Ernst Mach offered a new argument reminiscent of Leibniz's contention. It might have been premature of Newton to conclude that the water was spinning with respect to absolute space. Why not say that it was spinning with respect to the room in which it hung, or in relation to the trees and ground if the experiment occurred outside, or in relation to stars and planets if the experiment should occur in deep space? Mach supposed that without other things, there would be no way to know if something were spinning or not. Mach challenged the foundation of Newton's argument by suggesting that the water's behavior in the lab could well be different in empty space. He suggested that motion only occurs relative to other matter in the universe.

> *"Scientists have now established that, through the wonders of quantum mechanics, individual particles can be - and have been - teleported."*

Mach's thinking had a great influence on Einstein, who propounded the special theory of relativity in 1905. Einstein knocked the pins out from under Newton's notion of space and time. He found that neither space nor time were absolute. Only the speed of light was absolute. The speed of light is constant in that no matter how fast or slow you happen to be moving, no matter where you are, the speed of light will be the same. However, space and time are both relative. The speed with which an object moves through time and the speed with which it moves through space must equal the speed of light. This means time would slow down for someone moving very rapidly through space, and motion through space would slow down for someone moving very rapidly through time. In 1971, researchers tested this proposition and found that, indeed, when atomic clocks flew around the world on commercial jets, they registered less time elapsed than did clocks stationery on the ground. The difference was only measurable in billionths of a second - but there was a difference.

> *"Two things can be separated by an enormous amount of space and yet not have a fully independent existence."*

Einstein replaced Newton's idea of absolute space and absolute time with a new entity: absolute spacetime. He saw space and time as part of this flexible, dynamic reality. Interestingly, Einstein preferred to emphasize not the relative but the absolute part of his theory. He preferred the name "invariance theory" for what we usually refer to as the "relativity theory" The name "invariance theory" made it clear that the real discovery of the theory was not relativity, but the absolute reality of spacetime. To recapitulate briefly:

- Newton declares that space exists absolutely and that acceleration is relative to space.
- Leibniz denies that space exists absolutely and holds that all motion is relative.
- Newton's experiment with the spinning bucket carries the day - only to fall later.
- Mach denies that space exists and says all motion is relative to the average distribution of mass in the universe.
- Einstein shows that spacetime is absolute, but both space and time are relative.

## A Sense of Gravity

Now, consider gravity. You might think that if you were to fall out of a moving airplane, you would accelerate toward the ground. But Einstein recognized that gravity is equivalent to acceleration. Someone who is falling feels no acceleration, because he or she is moving in perfect sync with gravity. The falling person does not experience falling. By contrast, to the falling person, the earth and everything on it seem to be moving up.

This point of view might very well be correct. Only those who feel gravity’s force are accelerating - think of someone pressed to the side of a car as it takes a sharp turn. Those who do not feel the force of gravity are not accelerating. If you put a scale under the feet of a parachutist in free-fall, the scale will not register any weight.

> *“Thus, through this indirect but carefully considered reasoning, the experiments lead us to conclude that an object over there does care about what you do to another object over here.”*

Einstein theorized that in an empty universe, without matter or energy, absolute spacetime would be flat. But the presence of matter and energy causes warps and curves in spacetime. When something moves through space, it moves along the warps and curves of spacetime. That is how gravity works. Einstein developed equations to track the course of celestial objects through the curves of spacetime. Observation confirms the accuracy of his equations. They are consistently more accurate than Newton’s equations. However, Einstein was not the last word in physics, far from it. Even he shied away from some implications of his theory, such as quantum mechanics.

## Quantum Weirdness

As surprising as it may seem to think that the parachutist is not accelerating through space, but rather that the ground is, indeed, moving to meet him, physics has even more striking paradoxes and challenges. Quantum mechanics offers contradictions so difficult to accept that Einstein himself worked hard to disprove them. Yet he could not.

> *“Observers moving relative to each other have different conceptions of what exists at a given moment, and hence they have different conceptions of reality.”*

Although, at first glance, Einstein’s theory may seem to have overturned Newton, both Einstein and Newton had certain fundamental ideas in common. Einstein’s preference for the term "invariance theory" underscores the fact that both believed in something absolute. Both held that if it were possible to know the location and speed of motion of every particle in the universe precisely, one could predict the state of the universe in the future, or accurately calculate its condition in the past. Quantum mechanics drops this notion. Quantum theory says that the best scientists can hope to calculate about many phenomena is merely the probability, the odds, of a certain outcome. This is not because science can’t get the data. To a large extent, getting the data in and of itself has an effect on the outcome scientists observe. Quantum mechanics experiments leave little doubt that it is impossible to know the location and the speed of every particle in the universe. In fact, it is impossible to know the location and the speed of even one particle.

> *“Our entire existence - everything we do, think and experience - takes place in some region of space during some interval of time. Yet science is still struggling to understand what space and time actually are.”*

It seems that particles may not have certain characteristics until people observe them. It is as though they are in a state of suspension until they are observed. Moreover, experiments confirm that observation of the behavior of a particular particle in front of the viewer may affect the behavior of a particle many kilometers away. Consider your sunglasses. Any individual photon may have a 50-50 probability of making its way through your polarized lenses. However, quantum mechanics also shows that any individual photon might have an "entangled" photon miles away that, if it encounters a pair of polarized sunglasses, will behave exactly as your photon just did. This is a staggering idea: although separated widely by space, some particles confronting the same random probability will do the same thing, not randomly, but because they are somehow linked despite distance.

> *"Absolute space does not exist. Absolute time does not exist. But according to special relativity, absolute spacetime does exist."*

The strangeness of quantum mechanics is difficult to exaggerate. Fire a beam of particles at a receiver and they will form a wave pattern, even if you fire them one by one and wait a long time between shots. But track precisely where each particle is going, and they will form a different pattern. This happens even if the tracking method does not touch or disturb them. Untracked, the particles form a probability wave. Tracking, even with no contact, seems to cause the probability wave to collapse, so the particles form an entirely different pattern. It gets stranger. If you track a particle and then put in place a kind of "eraser" so that there is no record of the original tracking, the particles go back to forming the probability wave pattern. So it is impossible to measure both the position and the speed of a particle. The best we can do is calculate the odds. Thus, Einstein and Newton were both wrong (even though quantum theory traces its origins to Einstein's own work).

### Superstring Theory and Beyond

Until recently there was not one single string theory, but several. Then, in 1995, physicist Edward Witten found a unifying thread among them. The ensuing M-theory suggests that the universe has 11 dimensions of spacetime. Filaments of energy called strings vibrating in different frequencies may constitute the whole of reality. Some researchers, by contrast, suggest that the whole universe may be a hologram, and our three dimensional reality might be a projection of things taking place in only two dimensions.

Science has come a long way in understanding what reality is not. But what is reality? What really happens when you walk across the room, check your watch, get on an airplane, and fly through space and time? So far, no one really knows.

## About the Author

**Brian Greene** is a professor of physics and mathematics at Columbia University and author of the Pulitzer Prize-winning *The Elegant Universe*.