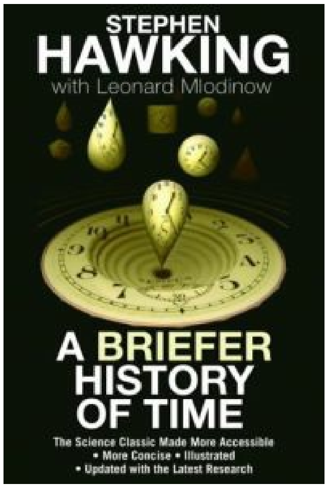


# Book A Briefer History of Time

Stephen Hawking and Leonard Mlodinow
Bantam, 2008
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## Recommendation

Stephen Hawking's first edition of this book came out in 1988. It sold more than 10 million copies, but you might hesitate to try reading it, given the book's universal ambition. Now, you can pick up this abbreviated, accessible revision with pleasure and anticipation. Hawking and Leonard Mlodinow smoothly explain the most profound questions about the physical world. They illustrate their points with brief stories, analogies and a cluster of images. The result is a compressed introduction to science, physics and cosmology, with sketches of key historical points. Even with clear explanations, the conceptual density can be challenging. Still, it's the best explanation out there. *BooksInShort* recommends this highly readable tour through the universe's most compelling mysteries.

## Take-Aways

- A scientific approach is the best way to understand the physical universe.
- Scientific theories are models that enable people to make predictions.
- Humanity's view of the world developed from a flat world at the center of everything to a rotating sphere circling one of billions of stars in one of many galaxies.
- Galileo shaped modern science by arguing that people can understand the natural world through observation.
- Newton explained gravity and the fundamental laws of motion.
- Einstein's theory of relativity removed the idea of absolute time, and showed the relationship between space and time.
- Quantum physics introduced an element of randomness to the human understanding of the universe.
- The Earth exists in an expanding universe in which time began with the Big Bang.
- The universe has four major forces: gravity, electromagnetism, the strong nuclear force and the weak nuclear force.
- Matter is made up of atoms.

## Summary

### Look Up in Wonder

Looking at the distant, mysterious stars raises the same questions that your ancient ancestors asked: "Where did the universe come from? Where is it going?" Is there a beginning and will there be an end? What is space and what is time?

As recently as 500 years ago, you could "find people who thought the earth was flat." Citizens of ancient Greece observed how ships appeared over the horizon a bit at a time. They concluded this fit a round world better than a flat one, on which the entire ship would be visible but very small. The Greeks noted that some lights in the sky moved differently than others. Most followed regular paths; a few doubled back. The Greeks called them "wanderers." They were the planets.

> "The eventual goal of science is to provide a single theory that describes the whole universe."

The ancients constructed models to explain celestial movements. Aristotle argued for a stationary Earth around which the stars and other objects "moved in circular orbits." Ptolemy posited a model of the universe as nested, moving spheres. The stars were stationary on these spheres, but the planets moved, thus explaining their wandering. This flawed model was "fairly accurate" at predicting celestial motion. In 1514, Nicolaus Copernicus argued that the planets moved around the sun, not the Earth. Most people rejected this truer model for another 100 years, until Johannes Kepler's and Galileo Galilei's observations gave it weight. In 1687, Isaac Newton explained why the planets moved around the sun in his *Principia*, "the most important single work ever published in the physical sciences." Newton articulated the laws of motion, identified and named gravity, and explained the math that governed it.

## Scientific Theory and Fact

To discuss the great questions of the universe, you need to understand "what a scientific theory is." Scientific theories provide models of the universe. They come with "a set of rules" about how aspects of the model relate to what you see in the physical world. Good theories "accurately describe" many observations and let you make "definite predictions" about what you will observe. Empedocles theorized that the world was made up of "four elements: earth, air, fire and water." However, his notions did not let Aristotle make any predictions and so they do not qualify as scientific theory. "Newton's theory of gravity" was even simpler. It argued that all physical objects attract one another, based on a specific force determined by their mass and the distance between them. This single theory enables highly accurate predictions about celestial movement.

> "We live in a strange and wonderful universe. Its age, size, violence and beauty require extraordinary imagination to appreciate."

All scientific theories are "provisional." No one can prove them out, no matter how many experiments show confirming results. A single contradicting observation can disprove a theory. The more times a theory has been confirmed, the more people trust it. New theories often extend and modify existing theories, but don't disprove them. Consider Albert Einstein's and Newton's theories. Newton's theories predicted the planet Mercury would move one way; Einstein's theories predicted a slightly different motion, which observations confirmed. Despite this confirmation, Newton's theories continue to have wide acceptance because they describe most of the situations people encounter, and are easier concepts to grasp and utilize.

## Galileo and Newton

Galileo played a larger role than any other person in creating "modern science." He was one of the first thinkers to argue that humans could "understand how the world works" by observing nature. He suffered the Catholic Church's Inquisition and arrest for his ideas. He helped provide an alternative to the dominant Aristotelian model of the physical world, which argued that objects had natural states of being "at rest," and that things moved only if something else forced them to. In this model, heavier objects should fall faster than lighter ones. Galileo demonstrated this was incorrect by rolling "balls of different weight down a smooth slope." The balls increased their speed by the same rate, regardless of their size.

> "Our present ideas about the motion of bodies date back to Galileo and Newton."

Newton built on these observations for his "laws of motion." Newton's first law argued that any object that does not experience some outside force would keep going "in a straight line at the same speed." His second law said if an outside force does interact with objects, the objects would change their speed at a rate "proportional to that force." Newton articulated a theory of gravity that identified a specific equation: Objects attract one another "with a force proportional to the mass" of each. Newton showed that gravity grows weaker as two objects grow farther apart.

> "Galileo, perhaps more than any other single person, was responsible for the birth of modern science."

A key distinction between the Aristotelian and the Galilean/Newtonian model is that "Aristotle believed in a preferred state of rest." Thus, the Earth is "at rest" or stationary. Newton's laws demonstrate that no such state exists. This distinction matters, because it leads to the conclusion that the universe has no "absolute standard of rest." This holds tremendous implications for physics, because it negates the idea of "absolute position." Observers can see things differently in the physical world and never resolve their differences. Aristotle and Newton agreed on a single "absolute time" that scientists could measure; this belief lasted until the 20th century.

## Living in Einstein's Universe

Understanding light is central to understanding Einstein's theories of relativity. As early as 1676, astronomical observations of Jupiter's moons led to the recognition that light has a "finite but very high speed." In 1865, physicist James Clerk Maxwell articulated "Maxwell's theory" of "the propagation of light." His equations unified the "partial theories" that previously explained magnetism and electricity. He showed that "wavelike disruptions" move through electromagnetic fields, and he calculated that they traveled at the speed of light. This speed was fixed – that appeared to contradict Newton's position that "there is no absolute standard of rest." To reconcile these theories, scientists introduced the idea of the "ether," a hypothetical substance that filled apparently empty space as light waves moved through it. In 1877, the "Michelson-Morley experiment" disproved the existence of the ether by observing light moving at uniform speeds independent of the Earth's position. Science needed a new answer.

> "Einstein's theory of general relativity is based on the revolutionary suggestion that gravity is not a force like other forces but a consequence of the fact that space-time is not flat, as had been previously assumed."

In 1905, Einstein demonstrated that you didn't need the idea of the ether if you were willing to give up "the idea of absolute time." His "theory of relativity" indicated that scientific law governs everything, including Maxwell's theory. "According to the theory of relativity, nothing can travel faster than the speed of light." This seems straightforward, but carries profound implications. Space and time are no longer separate, but instead are part of a single unified concept of "space-time." Rather than occurring at a specific and absolute time, events in time are similar to those in space. As you can describe the position of any object in space with three coordinates, so you identify the position of an event in space-time with four coordinates.

> "In order to talk about the nature of the universe and to discuss such questions as whether it has a beginning or an end, you have to be clear about what a scientific theory is."

Relativity also established an equivalency between "mass and energy," as summed up in Einstein's famous equation "$E=mc^2$." In this equation, "*E* is energy, *m* is mass and *c* is the speed of light." However, this theory of "special relativity" contradicts Newton's assumptions on gravity. Einstein did not address this point until 1913.

> "It is possible to travel to the future. That is, relativity shows that it is possible to create a time machine that will jump you forward in time."

Einstein's theory shifted the scientific understanding of gravity. It postulated that instead of being a force like magnetism, gravity was a product of the fact that space-time is curved: The energy and mass distributed within it warps it. This general theory of "relativity predicts that gravitational fields should bend light," as a United Kingdom expedition in Africa observed in 1919. General relativity also predicts that time runs at different rates depending on the proximity to mass: If you are closer to the Earth's surface, time runs more slowly than if you are far above it. These theoretical shifts fundamentally changed humanity's understanding of the physical universe.

> "According to the theory of relativity, nothing can travel faster than the speed of light."

Before Einstein, you could regard the universe as unchanging. Things happened in it, but events did not fundamentally affect the objective universe of space or time. Now, both time and space are perceived as "dynamic qualities." When an object moves, it changes how space and time curve, and this curvature changes how things move and act. Because Einstein's theories eliminate the idea of absolute time or space, they open the door to intriguing possibilities, such as building time machines and using "wormholes" – shortcuts in space – to reduce drastically the immense distances space travel requires.

## An "Expanding Universe" of Wonders

The Earth's sun is part of a rotating spiral galaxy, the Milky Way. In 1924, astronomer Edwin Hubble demonstrated that the Milky Way is one of many galaxies and that tremendous tracts of "empty space" separate the galaxies.

> "With the advent of quantum mechanics, we have come to recognize that events cannot be predicted with complete accuracy: there is always a degree of uncertainty."

Hubble calculated the distance to these galaxies indirectly. He found similar stars in distant galaxies and estimated their distance based on their luminosity. When something glows, it emits a specific spectrum of light according to how hot it is. Starting in the 1920s, astronomers studying stellar spectra noticed that some colors they expected to see were missing. The light had "shifted toward the red end of the spectrum" because the stars move away from Earth. The farther away a galaxy, the more red-shifted its light appears from Earth. That means that the more distant a galaxy, the faster it is moving away. The entire "universe is expanding."

> "Because theories are always being changed to account for new observations, they are never properly digested or simplified so that ordinary people can understand them."

Will the universe continue to expand? Will it stop and collapse back on itself? Or will expansion slow to a near stop? If you run the expansion backward, you get a highly compressed universe and a point where time as we know it began – the Big Bang. By one second after the Big Bang, the universe's temperature dropped "to about 10 billion degrees Celsius." The particles in the universe had "so much energy" that collisions between them produced many pairs of particles and antiparticles. One hundred seconds after the Big Bang, the temperature dropped to about one billion degrees, cool enough for atomic nuclei to form. These atoms are comprised of smaller "elementary particles": "electrons, protons and neutrons," which are in turn made up of "smaller particles called quarks."

> "Any physical theory is always provisional...it is only a hypothesis: you can never prove it."

Scientific understanding advanced so markedly and was so successful in explaining the universe that some 19th-century thinkers said "the universe was completely deterministic." The Marquis de LaPlace held that if you knew the "complete state of the universe at any one time," understanding natural laws would let you predict everything else that would happen. This model was popular in the scientific world until the start of the 20th century, when analyses of how it would explain stellar radiation led to the conclusion that a star would have to radiate infinite energy.

> "It turns out to be very difficult to devise a theory to describe the universe all in one go."

Max Planck proposed an alternative model of light, saying that radiating bodies could emit energy only "in certain discrete packets," or "quanta." One quantum of light is a "photon." Quantum physics works in terms of probabilities, not Newtonian certainties, thus introducing a constant element of randomness. "With the advent of quantum mechanics, we have come to recognize that events cannot be predicted with complete accuracy: there is always a degree of uncertainty."

## Fundamental Forces

Contemporary physics seeks a "complete unified theory of the universe." Any successful unified theory must integrate the fundamental forces governing interactions between particles. Science has identified four of these forces:

- **"Gravity"** – Gravity is a "universal" force: All particles feel it by "mass or energy." Although "gravity acts over great distances," it is by far the weakest of the four forces.
- **Electromagnetism** – "Electromagnetic force" affects only charged particles, like quarks or electrons: It does not affect "uncharged particles" like neutrinos. Electromagnetic force, which is $10^{42}$ times stronger than gravity, exists in two forms: positive and negative charges. Two positives repulse one another, as do two negatives. In large objects, the positive and negative charges are roughly balanced.
- **"Weak nuclear force"** – You encounter gravity and electromagnetism daily, but not this third force. Weak nuclear force is responsible for "the decay of atomic nuclei."
- **"Strong nuclear force"** – This strongest force operates invisibly in daily life. It holds quarks together within neutrons and protons. Without it, the repulsion between positively charged protons within nuclei would blow apart every atom above the size of the hydrogen atom – which has only one proton.

# About the Authors

Physicist **Stephen Hawking**, author of A Brief History of Time, was generally considered to be the most brilliant theoretical physicist since Albert Einstein. Hawking passed away on March 14, 2018. Physicist **Leonard Mlodinow** wrote *Feynman's Rainbow* and *The Drunkard's Walk,* among other books.