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Introduction
Modern Ideas in Science

Since the dawn of mankind, humanity has discovered an astounding amount about itself and the world. In just 10,000 years, *Homo sapiens* have gone from living in caves to transforming the planet. Humanity's journey from using primitive tools to launching spacecraft into orbit and beyond is a testament to human ingenuity and capacity for creating powerful explanatory frameworks.

This process of development is not simply a gradual accumulation of data. Science has progressed through the emergence of new insights, often revolutionary in their time, though eventually absorbed into the body of common knowledge. Here are just a few examples:

- *The shape of the world*: The notion that the world is round was first conjectured by Aristotle in the fourth century BCE based on the circular shape of lunar eclipses. Soon after, Eratosthenes accurately calculated the

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circumference of the Earth using the angles of shadows. This insight was radical because it required accepting an abstract model of the world that contradicted everyday perception. Today, this truth is easily confirmed by boarding a plane.

- *The planets orbit the Sun*: In the sixteenth century, Copernicus developed the simpler heliocentric model to explain planetary orbits, and his model was later bolstered by Galileo and Kepler. His insight challenged both intuition and religious dogma and fundamentally changed humanity's understanding of its place in the universe. While this is harder to confirm personally, the Earth's tilted axis, together with its revolution around the Sun, forms a simple and compelling explanation for the seasons, rooted in Earth's orbit and tilt.
- *Evolution by natural selection*: In the mid-nineteenth century, Darwin and Wallace gave a compelling theory of biological evolution that offered a powerful mechanism to explain the diversity of life, without appealing to divine purpose or design. Natural selection gives a beautiful and parsimonious explanation of many phenomena surrounding the variety of life on Earth.

Though even these basic insights still have their doubters (flat-Earthers, contemporary geocentrists, and creationists, respectively), they are broadly accepted and representative of ideas that have long entered common knowledge. Other widely understood theories include Newton's laws of motion, the germ theory of disease, and the periodic table's explanation of element properties. Some more complex concepts – such as thermodynamics and electromagnetism – have widespread awareness, even if most people are hazy on their details.

All of these theories, however, are well over a century old. When it comes to the great ideas of the twentieth century, people are less informed. They may have heard of the "Big Bang," $E = mc^2$, and the "butterfly effect," but this knowledge is usually superficial. Other topics, like quantum mechanics or computational complexity, are

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often seen as too hard to explain. Even worse, in popular accounts they are often bungled, leaving readers confused or misinformed.

The mathematics involved in quantum mechanics, relativistic electrodynamics, or computational complexity is indeed more difficult than the equations governing Newton's laws of motion,* but the underlying ideas of these fields are not only possible to grasp but also form a bigger picture that is elegant and accessible. These modern theories, despite their mathematical complexity, ultimately reveal a deeper, more unified understanding of the physical world.

The twentieth century witnessed an explosion of new ideas wholly unlike those seen in the science of previous centuries. Einstein's theory of relativity reexamined the nature of time, quantum mechanics overturned classical notions of physical reality, and Gödel's theory of incompleteness exposed inherent limits on mathematical reasoning. These developments revealed that uncertainty and incompleteness are not merely epistemic limitations but fundamental aspects of nature itself. A striking unifying pattern across these fields showed that seemingly simple rules and principles can generate extraordinary complexity, while computation emerged as a fundamental and ubiquitous process underlying physical reality, biological systems, and human thought. This computational perspective has culminated in recent advances in artificial intelligence and machine learning, prompting society to reconsider broader questions surrounding what it means to be human.

These modern scientific insights have yielded profound practical applications that shape contemporary life. Quantum mechanics underpins technologies from lasers to magnetic resonance imaging (MRI), relativity provides time corrections essential for the global positioning system (GPS), molecular genetics advances medicine

* It is worth noting that to apply these laws, Newton had to develop calculus, but even calculus is taught in secondary school.

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through gene therapies and personalized treatments, and information theory drives the internet protocols used by billions daily. In addition to their abstract beauty, these ideas provide an invisible scaffolding to twenty-first-century life, enabling capabilities that previous generations would have considered miraculous.

This book aims to demystify the ideas behind these and other modern intellectual triumphs. Each chapter focuses on a different idea or set of related ideas.* All of these are scientific ideas in the comprehensive sense of the term. A broad view of science appreciates that reasoning and explanation play as much of a role in scientific understanding and progress as the discovery of physical laws. In this encompassing sense, areas of computation, game theory, and mathematics present key scientific insights, some of which are represented within these chapters. Appreciating the topics herein requires some thoughtful reflection and an open mind, but the intellectual rewards are well worth the effort.

* Though some of the chapters involve connected ideas, they are presented in a way that they can be read independently. It is, however, recommended to read them in order.

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