SAMPLE

The Four Forces

Gravity, Electromagnetism, and the Nuclear Forces

Aira Astralis

Free sample: Introduction & Chapter 1

putrabooks.github.io

Buy the full book:

Carousell carousell.sg/p/the-four-forces-ebook-pdf-1467819259

ElevenReader

Ko-fi

Payhip

Contents

Introduction

Chapter 1: The Discovery of The Four Forces

Chapter 2: Understanding The Four Forces

Chapter 3: Key Characteristics of The Four Forces

Chapter 4: The Science Behind The Four Forces

Chapter 5: Observation and Measurement of The Four Forces

Chapter 6: Important Features of The Four Forces

Chapter 7: The Four Forces in Context

Chapter 8: Modern Understanding of The Four Forces

Chapter 9: Research and Exploration of The Four Forces

Chapter 10: Significant Discoveries About The Four Forces

Chapter 11: Challenges and Mysteries of The Four Forces

Chapter 12: Future Directions in The Four Forces Research

Chapter 13: Fun Facts and Trivia on the Four Forces

Chapter 14: Conclusion: On the Significance of the Four Forces

Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

In physics, the fundamental interactions or fundamental forces are interactions in nature that appear not to be reducible to more basic interactions. There are four fundamental interactions known to exist: gravity, electromagnetism, weak interaction, and strong interaction. The gravitational and electromagnetic interactions produce long-range forces whose effects can be seen directly in everyday life. The strong and weak interactions produce forces at subatomic scales and govern nuclear interactions inside atoms.

Some scientists hypothesize that a fifth force might exist, but these hypotheses remain speculative.

Each of the known fundamental interactions can be described mathematically as a field. The gravitational interaction is attributed to the curvature of spacetime, described by Einstein's general theory of relativity. The other three are discrete quantum fields, and their interactions are mediated by elementary particles described by the Standard Model of particle physics.

Within the Standard Model, the strong interaction is carried by a particle called the gluon and is responsible for quarks binding together to form hadrons, such as protons and neutrons.

As a residual effect, it creates the nuclear force that binds the latter particles to form atomic nuclei. The weak interaction is carried by particles called W and Z bosons, and also acts on the nucleus of atoms, mediating radioactive decay.

The electromagnetic force, carried by the photon, creates electric and magnetic fields, which are responsible for the attraction between the negatively charged orbital electrons and the positively charged atomic nuclei which holds atoms together, as well as chemical bonding and electromagnetic waves, including visible light, and forms the basis for electrical technology. The electromagnetic force is far stronger than gravity, but unlike gravity, the electromagnetic force has opposing negative and positive charges.

Large objects tend to have about the same number of negative charges as positive charges making them effectively uncharged with no resulting electromagnetic forces between them. Over (astronomical) distances, gravity is the dominant force, responsible for holding together the large scale structure in the universe, such as planets, stars, and galaxies.

The exchange of bosons always carries energy and momentum between the fermions, thereby changing their speed and direction.

Chapter 1: The Discovery of The Four Forces

The historical success of models that show relationships between fundamental interactions have led to efforts to go beyond the Standard Model (which does not describe gravity) and combine all four forces into a theory of everything. In his 1687 theory, Isaac Newton postulated space as an infinite and unalterable physical structure existing before, within, and around all objects while their states and relations unfold at a constant pace everywhere, thus absolute space and time.

Inferring that all objects bearing mass approach at a constant rate, but collide by impact proportional to their masses, Newton inferred that matter exhibits an attractive force. His law of universal gravitation implied there to be instant interaction among all objects. As conventionally interpreted, Newton's theory of motion modelled a central force without a communicating medium. Thus Newton's theory violated the tradition, going back to Descartes, that there should be no action at a distance.

Conversely, during the 1820s, when explaining magnetism, Michael Faraday inferred a field filling space and transmitting that force. Faraday conjectured that ultimately, all forces unified into one. In 1873, James Clerk Maxwell unified electricity and magnetism as effects of an electromagnetic field whose third consequence was light, travelling at constant speed in vacuum. If his electromagnetic field theory held true in all inertial frames of reference, this would contradict Newton's theory of motion, which relied on Galilean relativity.

If, instead, his field theory only applied to reference frames at rest relative to a mechanical luminiferous aether—presumed to fill all space whether within matter or in vacuum and to manifest the electromagnetic field—then it could be reconciled with Galilean relativity and Newton's laws.

In the Standard Model, the electromagnetic, strong, and weak interactions associate with elementary particles, whose behaviours are modelled in quantum mechanics (QM). For predictive success with QM's probabilistic outcomes, particle physics conventionally models QM events across a field set to special relativity, altogether relativistic quantum field theory (QFT). Force particles, called gauge bosons—force carriers or messenger particles of underlying fields—interact with matter particles, called fermions.

Everyday matter is atoms, composed of three fermion types: up-quarks and down-quarks constituting, as well as electrons orbiting, the atom's nucleus. Atoms interact, form molecules, and manifest further properties through electromagnetic interactions among their electrons absorbing and emitting photons, the electromagnetic field's force carrier, which if unimpeded traverse

potentially infinite distance. Electromagnetism's QFT is quantum electrodynamics (QED). The force carriers of the weak interaction are the massive W and Z bosons. Electroweak theory (EWT) covers both electromagnetism and the weak interaction.

At the high temperatures shortly after the Big Bang, the weak interaction, the electromagnetic interaction, and the Higgs boson were originally mixed components of a different set of ancient pre-symmetry-breaking fields. As the early universe cooled, these fields split into the long-range electromagnetic interaction, the short-range weak interaction, and the Higgs boson. In the Higgs mechanism, the Higgs field manifests Higgs bosons that interact with some quantum particles in a way that endows those particles with mass.

The strong interaction, whose force carrier is the gluon, traversing minuscule distance among quarks, is modeled in quantum chromodynamics (QCD). EWT, QCD, and the Higgs mechanism comprise particle physics' Standard Model (SM). Predictions are usually made using calculational approximation methods, although such perturbation theory is inadequate to model some experimental observations (for instance bound states and solitons). Still, physicists widely accept the Standard Model as science's most experimentally confirmed theory.

In the conceptual model of fundamental interactions, matter consists of fermions, which carry properties called charges and spin ±1⁄2 (intrinsic angular momentum ±ħ⁄2, where ħ is the reduced Planck constant). They attract or repel each other by exchanging those bosons.

The exchange may also transport a charge between the fermions, changing the charges of the fermions in the process (e.g., turn them from one type of fermion to another). Since bosons carry one unit of angular momentum, the fermion's spin direction will flip from +1⁄2 to −1⁄2 (or vice versa) during such an exchange (in units of the reduced Planck constant). Since such interactions result in a change in momentum, they can give rise to classical Newtonian forces.

In quantum mechanics, physicists often use the terms "force" and "interaction" interchangeably; for example, the weak interaction is sometimes referred to as the "weak force". According to the present understanding, there are four fundamental interactions or forces: gravitation, electromagnetism, the weak interaction, and the strong interaction. Their magnitude and behaviour vary greatly, as described in the table below. Modern physics attempts to explain every observed physical phenomenon by these fundamental interactions.

The fundamental interactions can be compared using dimensionless coupling constants that characterize the intensity or "strength" of the interactions. The

modern (perturbative) quantum mechanical view of the fundamental forces other than gravity is that particles of matter (fermions) do not directly interact with each other, but rather carry a charge, and exchange virtual particles (gauge bosons), which are the interaction carriers or force mediators.

Electrical and magnetic phenomena have been observed since ancient times, but it was only in the 19th century James Clerk Maxwell discovered that electricity and magnetism are two aspects of the same fundamental interaction.

The discovery of asymptotic freedom led most physicists to accept QCD since it became clear that even the long-distance properties of the strong interactions could be consistent with experiment if the quarks are permanently confined: the strong force increases indefinitely with distance, trapping quarks inside the hadrons.

The discovery narrative also has a human arc worth noticing: each of the four was found by someone looking at something else. Newton was closing an argument about orbits, not seeking a universal pull; Maxwell was reconciling electric and magnetic laws, not inventing light's speed; the weak interaction emerged from a puzzle about beta-ray energy that looked like an accounting error; the strong force began as an embarrassment in Rutherford's nucleus. Fundamental physics has rarely been found by going out to look for it; it has been tripped over by people carrying other questions.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.