SAMPLE

Symmetry and Symmetry Breaking

How Symmetry Shapes Physics

Aira Astralis

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

Introduction

This book is about the quietest idea in physics and the loudest thing it does. The idea is symmetry: the fact that some things do not change when you change them. A face in a mirror, a snowflake turned by a sixth of a turn, a circle seen from any angle at all. The loud thing it does is breaking. The laws of nature are almost embarrassingly symmetric, and yet the world they produce is lopsided: matter exists and antimatter mostly does not, magnets point somewhere in particular, crystals take sides, the vacuum itself picked a direction when the universe was young. The whole subject lives in that tension, and the subject's whole lesson is that the tension is productive.

Nothing in modern physics, from superconductors to the Higgs boson, from the boiling of water to the existence of galaxies, makes sense without the pair of words in this book's title.

The approach here is the series' standing one: plain words, no equations, honest grades on every claim. Symmetry is unusually kind to this approach. It can be drawn, held, turned, and watched, more so than almost any other subject in physics. The mirror in a bathroom, the hexagon of a honeycomb, the two poles of a refrigerator magnet, and the ice in a glass are all honest exhibits, and Where the subject gets deep, the depth is carried by images and stories: a ball rolling off a bump in a bowl, a magnet cooling through its critical temperature, a wave of ripples costing nothing, a field that fills the universe and was found in 2012.

The walk has eighteen stops. It begins with the idea itself and the people who forged it, from the Greek fascination with the regular solids through Pierre Curie's principle, Emmy Noether's theorem, and the twentieth century's discovery that symmetry breaks. It climbs through the grammar of the subject, the celebrated connection between symmetry and conservation, the everyday evidence in butterflies and crystals, and the central distinction between spontaneous and explicit breaking. It then follows the idea where it does its most famous work: phase transitions, Goldstone's waves and the Higgs mechanism, the broken mirror of parity violation, superconductors and superfluids, the early universe's frozen accidents, and the open questions that keep the subject alive.

The closing chapters are the series' standard pair: a graded shelf of trivia, a farewell that gathers the estate, and a final image for the reader to keep. Every claim in the walk is settled, graded, or marked as open as the evidence allows, and the reader is never asked to take a fact on faith when a date or a demonstration exists.

Chapter 1: The Idea of Symmetry

The word entered English through the Greeks, who built it from two pieces: together, and measure. To the Greeks, symmetry meant proportion, the right relation of parts to each other and to the whole. A temple was symmetric when no part demanded more attention than the design allowed. A face was symmetric when the halves agreed. The word has since narrowed and deepened, and physics keeps both meanings alive at once: proportion in the classical sense, and changelessness in the modern one. The modern sense is the one this book follows, and it deserves a careful first statement, because everything later grows from it.

The modern definition is short enough to carry anywhere: a symmetry is an alteration that leaves its object itself. Not all change, and not unchanged in every respect, but a specific change, applied to a specific thing, with a specific survivor. A circle survives any turn about its center, so every one of those turns is a symmetry of the circle. A square survives only four of them: the identity turn that does nothing, then the three next turns, each a further quarter of the way round. Turn a square by an eighth of a revolution and the corners land where edges used to be; the square has visibly moved, so the eighth turn is not one of its symmetries.

The face in the mirror is the same test with reflection instead of rotation: the mirror changes left for right, the face survives, and the change is a symmetry. The definition's quiet power is that it makes symmetry countable. A circle has infinitely many rotational symmetries; a square has four; a rectangle has two that matter; a scalene triangle has only the identity, the change that changes nothing. Symmetry admits of more and less, which means it can be compared, graded, and even ordered, and a physics that can be ordered can be reasoned about with unusual discipline.

The definition has two different targets. A thing can be symmetric: the circle, the snowflake, the honeycomb. A law can also be symmetric: the rule that generates the thing, the statement that survives a change with its meaning intact. The law of gravity does not care whether the two masses are in Shanghai or in Stockholm, today or in 1859, aligned with the room's walls or tilted against them. Move the whole experiment, and the law says the same thing. The law is symmetric under translations in space, translations in time, and rotations, and this trio of symmetries is so basic that most people never notice it as a fact at all.

But it is a fact, it is a fact with consequences, and one of this book's later chapters will show that the conservation laws taught in every first physics

course, the conservation of momentum, energy, and angular momentum, are not separate discoveries bolted onto the laws of motion. They are the laws' symmetries, worn as a different face. The connection is called Noether's theorem, and it is the single most important sentence in this neighborhood of physics. It is stated plainly, in words, in its own chapter.

Between the symmetric thing and the symmetric law lies the subject's whole drama. The laws of physics, as far as anyone has ever measured, are far more symmetric than the world they produce. The laws of electricity and magnetism are perfectly happy with a universe of nothing but radiation, light in equilibrium with light, a featureless blaze with no matter in it at all. The actual universe is not like that. The laws treat left and right, on paper, with perfect even-handedness, and the actual world has spiral galaxies turning one way, amino acids all of one handedness, and a matter surplus over antimatter that has no business existing if the laws are as even-handed as they read.

The laws know nothing of north, and every compass needle on Earth points, with eerie agreement, along the planet's field. The gap between the law's symmetry and the world's lopsidedness is not a scandal. It is, as the twentieth century learned, the engine of almost everything interesting. The mechanism that fills the gap is called symmetry breaking, and its study is the reason this book exists.

The distinction deserves its own careful sentence, because the two halves of the subject are often confused in casual talk. A symmetric law can produce a symmetric state, and then nothing much happens: the uniform blaze, the faceless equilibrium, the circle. Or a symmetric law can produce, from a symmetric starting point, a state that is not symmetric at all, one candidate among several equally legal ones, chosen by accident and then stuck to. That second outcome is symmetry breaking, and the word spontaneous is reserved for the case where nothing external made the choice: no hand tilted the bowl, no field favored the direction. The universe simply had to pick something, picked at random, and the pick became history. Spontaneity is the difference between a pushed thing and a settled thing, and the whole subject's most important examples, the magnet, the crystal, the vacuum, are settled things. Their laws are symmetric; their states are not; and the settling is the story.

The chapter's closing image is the smallest honest exhibit of the whole idea: a plain round dinner roll on a plain dinner table, with a knife laid beside it. The roll can be cut from any angle; the result is the same roll, and the uncut roll's symmetry is complete. But once the knife goes in from one side, that one cut is a broken symmetry in miniature: any angle was legal, one was chosen, and the choice is now visible to everyone at the table. Nobody supposes the roll's

law, so to speak, preferred that side. The knife simply had to enter somewhere. The subject of this book is the physics of that necessity, from dinner rolls to the first second of the universe, and the reader who holds the image holds the subject's whole architecture in miniature.

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.