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Aperiodic Penrose tiling at Oxford University.

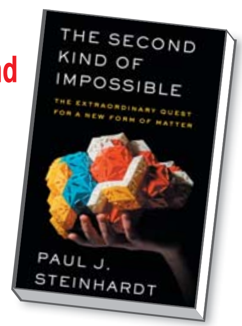
The hunt for natural quasicrystals

Scientific discovery is the successful extension of human knowledge into the unknown. Particularly satisfying are those discoveries that appear impossible at first glance but upon closer inspection reveal a long-overlooked loophole in our most basic assumptions. *The Second Kind of Impossible: The Extraordinary Quest for a New Form of Matter* by Paul Steinhardt is the story of several such gaps in the fields of crystallography and mineralogy. It is a thrilling mix of scientific memoir and true detective story. Most importantly, it is a tale of the excitement that drove the author to extraordinary insights far outside his original area of expertise.

Quasicrystals, the main subject of the book, are complex ordered phases of matter first found in metallic alloys. Their study has a rich history filled with unique protagonists and unexpected developments. Thus they are a perfect topic for a scientifically themed book aimed at a general audience.

The first part of *The Second Kind of Impossible* introduces the foundations of quasicrystal research. It covers the origins of crystallography in the 18th century through the end of the 20th century, when quasicrystals became established as a real and fascinating form of matter. In the 1970s mathematician and physicist Roger Penrose introduced Penrose tilings, intricate and aesthetically beautiful patterns with long-range order but without periodicity. The tilings were thought to be a mathematical gimmick until two independent advancements brought them to the attention of a wider community. At Princeton University in the early 1980s, Steinhardt and his graduate student Dov Levine envisioned an icosahedral generalization of Penrose tilings. They dubbed that hypothetical new form of matter quasicrystals. Unbeknownst to Steinhardt, materials scientist Daniel Shechtman, using electron microscopy, had already identified an aluminum-manganese alloy with icosahedral diffraction symmetry.

The Second Kind of Impossible
The Extraordinary Quest for a New Form of Matter
Paul J. Steinhardt
Simon & Schuster, 2019. $27.00



Steinhardt describes both the mathematics that went into his theory and his construction of geometric models from styrofoam balls, pipe cleaners, and paper. The astonishingly fruitful interplay between theory and model building soon explained all aspects of Shechtman's discovery and subsequent developments. After that success, Steinhardt needed a new challenge to continue his research. As of 1999 all known quasicrystals were synthetic in origin, so Steinhardt began wondering if perfect quasicrystals might develop without human intervention.

The book next dives into Steinhardt's 20-year hunt to answer that question. He reasoned that if a natural quasicrystal existed, it could be found in some known but incompletely characterized mineral sample. But as a theoretical physicist and cosmologist, he had no formal training in mineralogy. He contacted experts in materials characterization around the world to ask for their assistance and collaboration.

The reader follows Steinhardt as he recounts scouting crystal diffraction databases and exploring the intricacies of microscopic crystalline grains. Convincing colleagues of his unexpected findings was not always easy. Against the odds and after many drawbacks, including dealing with smugglers and deciphering clues in secret diaries, Steinhardt and his closest collaborator, Italian geologist Luca Bindi, traced the origins of a natural quasicrystal candidate to one of the most remote places on Earth: the Koryak Mountains in Siberia.

In the final part of the book, Steinhardt and a team of 12 scientists, prospectors, and support personnel make an adventurous field expedition to the Koryak Mountains. There they hope to find needles in a haystack—tiny rocks only millimeters in size, surrounded by thick clay in the banks of a pristine river bed. The samples they eventually uncover are of extraterrestrial origin and date back to the beginning of the solar system. I refrain from recounting the many astonishing turns of events the team encountered. But suffice to say that a fiction writer could hardly have thought of better plot twists. This section was the highlight of *The Second Kind of Impossible*. The hunt captured and held my attention; I could not put the book down.

One of the book's strengths is its accessibility. Despite the specialized topic, Steinhardt conveys with engaging passion his motivation and how it changed over the course of his quest. He describes his struggles with unreliable sources, competitors, and skeptics. His approach—assembling a “red team” of critics and a “blue team” of advocates that engaged in friendly competition until the scientific truth was revealed—is a formidable demonstration of how to avoid confirmation bias. Finally, and this I find a particularly important moral, Steinhardt uses his personal perspective to demonstrate that scientific discovery is often not a solitary effort. Instead, true progress comes from openness to the world and the acceptance of potential failure. The events described in the book are an extraordinary display of tenacity and serendipity, and the writing is captivating, entertaining, and full of fascinating scientific content. I strongly recommend *The Second Kind of Impossible* to experts and lay audiences alike.

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A pocket watch made for the Japanese market circa 1715.

Telling time in Tokugawa Japan

Making Time
Astronomical Time Measurement in Tokugawa Japan
Yulia Frumer
U. Chicago Press, 2018. $45.00

Yulia Frumer’s *Making Time: Astronomical Time Measurement in Tokugawa Japan* will fascinate readers with its study of the evolution of different systems of time measurement in Japan. The book begins with the arrival of the first Western mechanical clocks during the Tokugawa (or Edo) period from 1603 to 1868, when the ruling shogunate restricted contact with foreigners and strengthened the country’s traditional temporal system. The author then traces timekeeping technologies and systems through to the calendar reform of 1873, when the Japanese people wholeheartedly embraced Western methods of timekeeping.

In 17th-century Japan, Western clocks seemed nonsensical to consumers because they measured time in 24 equal hours and were dissociated from natural events like dawn and dusk. By contrast, the Japanese people divided their day into 12 unequal hours, following an ancient Chinese system introduced in Japan in the 7th century. Daylight and darkness were each split into six equal parts, no matter what the season. The daylight hours grew longer in the summer and shorter in the winter, with the reverse occurring for the nighttime hours. The hours of the day and night were equal in length only on the equinoxes. Each hour was named for 1 of 12 animal signs and was also given a number that could be used to announce the hour by strikes of a bell. Midday, for example, was Horse (9). A vestige of this system is still found in the modern Japanese expression that refers to morning as “before Horse” and afternoon as “after Horse.”

Although sundials could find the time directly from the Sun overhead, water and fire clocks were commonly used to keep time. Incense clocks, a type of fire clock widely used in the Tokugawa period, had moveable hour markers placed in the sand alongside a trail of burning incense and required a standardized system for shifting the hour markers as the year progressed. The lengths of day and night hours were adjusted 24 times a year according to seasonal weather changes such as with the “beginning of spring,” “rain water,” “major heat,” “cold dew,” “frost descending,” and “major snow.”

Japanese users noticed that those seasonal weather markers were not in tune with Japan but with northern China, where the calendar had originated. Moreover, scholars saw the need to regulate the lunar calendar against the solar year so that the seasons would not drift. To that end, the central government established an astronomical bureau to manage and reform the calendar as needed.

Frumer notes that by the late 17th century, Japan had in place a standardized calendar and a single time zone for the entire country. She also shows how Japanese clockmakers reengineered Western mechanical clocks to keep variable hours and shape them to suit Japanese life. Weights on the ends of the foliot in early mechanical clocks were shifted as often as twice daily to speed up or slow down the passage of day or night hours. Later mechanical clocks had moveable digits, index arms with adjustable lengths, and faces marked with hour lines like sundials.

Frumer argues that Tokugawa astronomers became comfortable with Western clocks and the system of 24 equal hours during the 18th century, as they measured the motion of heavenly bodies along celestial arcs and timed star