MATERIALS SCIENCE

The hunt for quasicrystals

Sharon Glotzer enjoys a riveting tale of derring-do in materials science.

Picture this. In Russia's far east, a motley crew of conspirators races against time to solve a mystery hidden for billions of years. The enigma could link a speck of rock found in the dusty basement of an Italian museum to the evolution of the Solar System. To solve it, a brilliant theoretical physicist must overcome impossible odds, Kremlin agents, a vanished package, secret diaries and a trek across a volcanic peninsula.

This is no Hollywood blockbuster: it is real-world scientific derring-do. In *The Second Kind of Impossible*, theoretical physicist Paul Steinhardt relates his bold quest to find a natural quasicrystal, a form of matter with an unusual arrangement of atoms thought impossible for a crystal. The result is a mix of sober, lab-bound scientific memoir and rollercoaster adventure, packed with discovery, disappointment, exhilaration and persistence.

In crystals, atoms are arranged in a repeating pattern. In quasicrystals, they are still ordered but the pattern is not periodic: it doesn't repeat. This oddity results in unexpected rotational symmetries (different from, say, that of a square lattice, which repeats itself four times in a full rotation). Quasicrystals were first discovered in the

The Second Kind of Impossible: The Extraordinary Quest for a New Form of Matter
PAUL J. STEINHARDT
Simon & Schuster (2018)

1980s, but the interpretations proffered for them were not accepted by many in the scientific community, bar physicists, for some time. After all, they upset nearly two centuries of scientific understanding about the structure of matter. French priest René-Just Haüy's 1801 *Treatise of Mineralogy* established that solids contain microscopic building blocks and that all elements and mixtures thereof can, at least in principle, be found in crystal form, from sucrose to sapphire. Despite thousands of possible atomic arrangements, the rules to describe crystals were simple: the materials could have only two-, three-, four- or six-fold symmetry. Until quasicrystals' discovery violated them.

> *"Steel hardened by small quasicrystal particles is used in needles for acupuncture and surgery, dental instruments and razor blades."*

Steinhardt's story begins in Pasadena, California, in 1985. Then on the faculty at the University of Pennsylvania in Philadelphia, Steinhardt had given a talk at his undergraduate alma mater, the California Institute of Technology, where he explained to physicist Richard Feynman, his former professor, a theory that he had devised with doctoral student Dov Levine. This predicted the possibility of quasicrystals, with symmetries technically possible but extremely unlikely: the "second kind of impossible".

FORBIDDEN STRUCTURE

Since the late 1970s, Steinhardt had imagined that 'forbidden' crystals with five-fold symmetry might be possible if, on cooling, atoms were arranged into a space-spanning network of icosahedra. He and Levine experimented first with styrofoam balls and pipe cleaners, and later with paper models. They looked to Penrose tilings, in which two shapes combine to create a non-repeating pattern, not unlike those seen in classical Islamic tiling. They realized that by drawing parallel lines on a Penrose tiling, they could prove that the tiles are arranged quasiperiodically, producing five-fold symmetry. This was the breakthrough they needed. The leap

ALISON FORNER/*THE SECOND KIND OF IMPOSSIBLE*, SIMON AND SCHUSTER

A model of a quasicrystal structure.

to three dimensions produced Steinhardt's long-imagined icosahedral quasicrystal.

Unknown to them, a couple of hundred kilometres away, a materials scientist had obtained a diffraction pattern unlike any he had seen before — for a rapidly cooled alloy of aluminium and manganese. The researcher was Dan Shechtman, and he was working at the National Bureau of Standards (now the National Institute of Standards and Technology) in Gaithersburg, Maryland. The diffraction pattern had ten-fold rotational symmetry. Astonished, Shechtman drew its concentric rings of ten dots in his lab book, writing "10-fold???" next to it. He didn't know it yet, but he had just discovered the first quasicrystal. In 2011, he won the Nobel Prize in Chemistry for it.

Steinhardt and Levine, recognizing the collective implications, published a paper on their theory in *Physical Review Letters*, laying the foundations of the field of quasicrystal research (D. Levine and P. J. Steinhardt *Phys. Rev. Lett.* **53**, 2477; 1984).

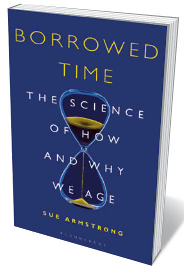
Hundreds of quasicrystals with different symmetries have now been made in the lab. Non-stick frying pans were among the first applications of quasicrystals, owing to the alloys' low friction, high hardness and low surface reactivity. Steel hardened by small quasicrystal particles is used in needles for acupuncture and surgery, dental instruments and razor blades. Quasicrystals have been discovered in materials other than metals, including polymers and mixtures of nanoparticles. Computer simulations suggest that quasicrystals should be even more ubiquitous.

All these quasicrystals were human-made, but Steinhardt became curious about naturally occurring ones. In 1999, now on the faculty at Princeton University in New Jersey, he set out on a quest that few theoretical physicists could imagine — to find one. This is the true heart of his book.

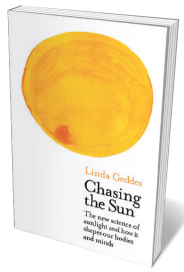
GLOBAL HUNT

Steinhardt started by looking to the past — in museums, which have huge collections of mineral samples from around the world. Perhaps, he surmised, one of these was a misidentified quasicrystal. He assembled a crack team of fellow hopefuls — including a geoscientist, an electron microscopist and an undergraduate — and the hunt began. Years of combing through dusty archives turned up nothing, until a box from the Museum of Natural History in Florence, Italy, arrived at Princeton containing a nearly invisible speck of a rare mineral, khatyrkite. On 2 January 2009, the researchers became certain that they had discovered a natural quasicrystal (later named icosahedrite). But where did it come from? ▶

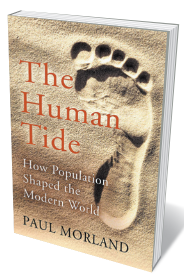
Books in brief



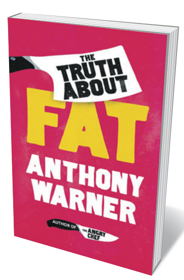
Borrowed Time
Sue Armstrong BLOOMSBURY *(2019)*
Is death genetically programmed? Is ageing a disease? Engrossing questions throng science writer Sue Armstrong's round-up of research on the biology of ageing. She brings us up to speed on the illuminating (if partial) answers through work by the likes of biologist Tom Kirkwood on the 'disposable soma' theory of limited resources; Nobel laureates Elizabeth Blackburn, Carol Greider and Jack Szostak on telomeres, the end caps of chromosomes; evolutionary biologist Steven Austad on the long-lived clam *Arctica islandica*; and various Alzheimer's disease specialists. A rich, timely study for the era of 'global ageing'.



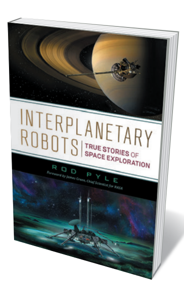
Chasing the Sun
Linda Geddes PROFILE *(2019)*
Light pollution, indoor lifestyles and glowing screens can play havoc with our health. So shows science writer Linda Geddes in her deft study of chronobiology, the science of organismic cycles in relation to solar rhythms. Geddes marshals an array of findings on everything from the suprachiasmatic nucleus — the cluster of cells in the brain that acts as the body's master clock — to US Amish communities living dawn to dusk and off grid, and submarine crews who rarely see the Sun. She even turns guinea pig to test measurable benefits from candlelight and outdoor exercise.



The Human Tide
Paul Morland JOHN MURRAY *(2019)*
The Industrial Revolution sparked a triple boom: in technology, population and emigration. In this sweeping treatise spanning the past 200 years, demographer Paul Morland traces the surge of humans in numbers and on the move, and the transformations wrought by this accelerating "demographic whirlwind" on individuals, nations and empires. It's an extraordinary ebb and flow, from the 4 million Italians who poured into the United States in the 35 years before the First World War to today's tide of African children making harrowing journeys across the Mediterranean.



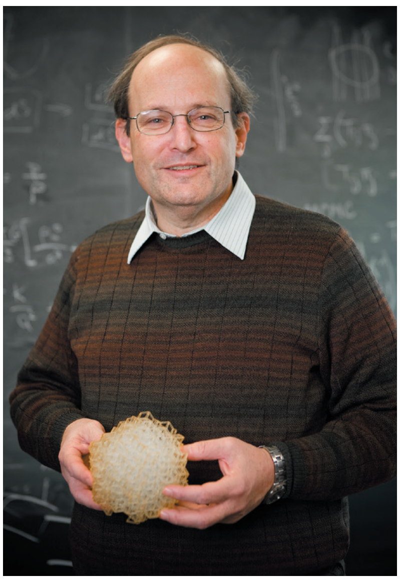
The Truth About Fat
Anthony Warner ONEWORLD *(2019)*
In this trenchant manifesto-cum-study, Anthony Warner (aka the Angry Chef) takes a honed knife to flabby theorizing about what makes us fat. He examines proven and putative drivers, including hormones such as leptin, calories, genetic factors, the human microbiome, inactivity, dietary fats and carbohydrates, environment and poverty. Given the complexities of the findings, Warner argues for a system-level solution involving public-health officials and communities. He also calls for an end to the moral panic surrounding fat. A nuanced approach to this global issue.



Interplanetary Robots
Rod Pyle PROMETHEUS *(2019)*
On 15 July 1965, NASA's Mariner 4 probe sent back grainy images of Mars, revealing a forbidding surface that destroyed florid Victorian speculation in a trice. Over the next 50 years, robotic missions researched the rest of Earth's planetary neighbours. Space writer Rod Pyle tours craft from the Soviet Luna 3, which snapped the Moon's far side in 1959, to NASA's New Horizons and its 2015 fly-by of Pluto. Sandwiched between these are tales of the Voyagers, Galileo, Cassini and more. Geeky escapism at its best. **Barbara Kiser**

The sample, they deduced after many unexpected twists and turns, had probably been found on Russia's remote, volcanic Kamchatka Peninsula. Steinhardt led an expedition there in 2011 — a wild scavenger hunt searching for the stream that the team thought contained the original source. The group ultimately worked out that the speck came from a meteorite that also contained a second natural quasicrystal, dubbed decagonite.

This book is a front-row seat to history as it is made. For quasicrystal aficionados like me, it is riveting. For anyone who has dreamt of finding a scientific needle in a haystack, it is exhilarating. Steinhardt strikes a balance between mathematical detail and accessibility. He captivates with vivid details about his wonder, frustrations and even a few moments of unleashed ego. We learn about the deep relationships and bold ideas that kept his journey on course.


TRUSTEES OF PRINCETON UNIV.

Paul Steinhardt with a quasicrystal model.

This nail-biting narrative reminds us that the thrill of scientific discovery is not found in a single eureka moment. It is instead marked by determination, team work, optimism and, importantly, luck. Contemplating Julia 89, an asteroid orbiting the Sun between Mars and Jupiter that could be the source of the fateful meteorite, *The Second Kind of Impossible* ends as it begins — with the possibility of impossibility. ■

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PHYSICS

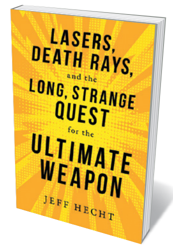
Dreaming of death rays

Lasers have long held allure for physics, the military and science fiction, finds **Luke Fleet**.

Lasers first emerged nearly 60 years ago, but the idea of using powerful beams of heat or light is hardly new. In the third century BC, for instance, Greek scientist Archimedes allegedly used mirrors reflecting the Sun's rays to attack Roman ships off Sicily. Millennia later, 'death rays' — concentrated light or electricity — became a science-fiction trope, from H. G. Wells's 1898 *The War of the Worlds* to the Star Wars franchise.

As often happens, futurist fiction sparked the real thing. And that's the story told in *Lasers, Death Rays, and the Long, Strange Quest for the Ultimate Weapon*.

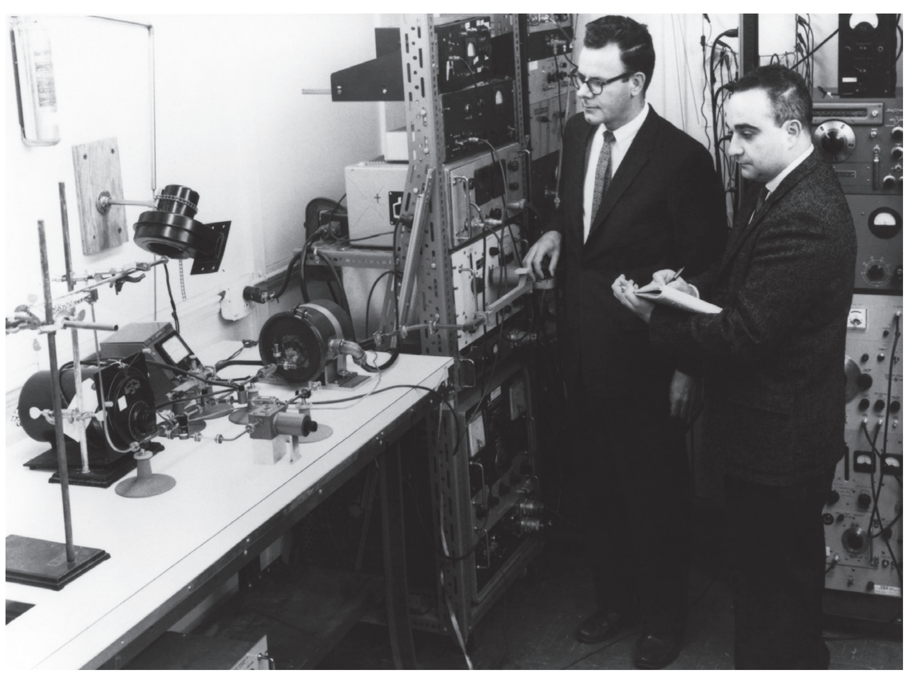
As the title indicates, Jeff Hecht's book is not about the mundane, ubiquitous lasers of supermarket checkouts and CD players. Hecht, a science writer who has covered lasers since the 1970s, instead records efforts to adapt the technology for military use. In 1934, for instance, inventor Nikola Tesla — instrumental in developing the alternating-current electricity system — announced that he had attempted to design a device that would send a 'death beam' of concentrated particles to detect and destroy submarines. As Hecht relates, US government agents looked into the proposal after Tesla's death, but reviewer John G. Trump, an electrical engineer (and uncle of the current US president), declared it too speculative.



Lasers, Death Rays, and the Long, Strange Quest for the Ultimate Weapon
JEFF HECHT
Prometheus (2019)

The United States was hardly alone in its fervour for a death ray. Before the Second World War, the British air ministry offered a bounty of £1,000 (more than £60,000 (US$76,000) today) to anyone who could craft and demonstrate a 'ray weapon' that could kill a sheep at 100 metres. (This was ambitious: by the end of the Second World War, the Japanese military could still only kill rabbits at 30 metres using microwave tubes.) By the 1950s, a new invention was about to focus minds.

The laser, as Hecht makes clear, was a technology intertwined with politics. The star figure is physicist Gordon Gould. In the late 1950s, Gould explored using light to optically 'pump' a maser — a device emitting microwaves at a specific frequency, invented by physicist Charles Townes in 1953. This was, in essence, the first conceptualization of a laser, which


ESVA/AIP/SPL

Gordon Gould (left, with Ben Senitsky) experimented with microwave lasers in the 1950s.