Universe — but there is nothing we can say about the Universe except in terms of what we see and think. I'm not suggesting that we make it all up arbitrarily. We're constrained by something, but it is extremely difficult to say what it is.

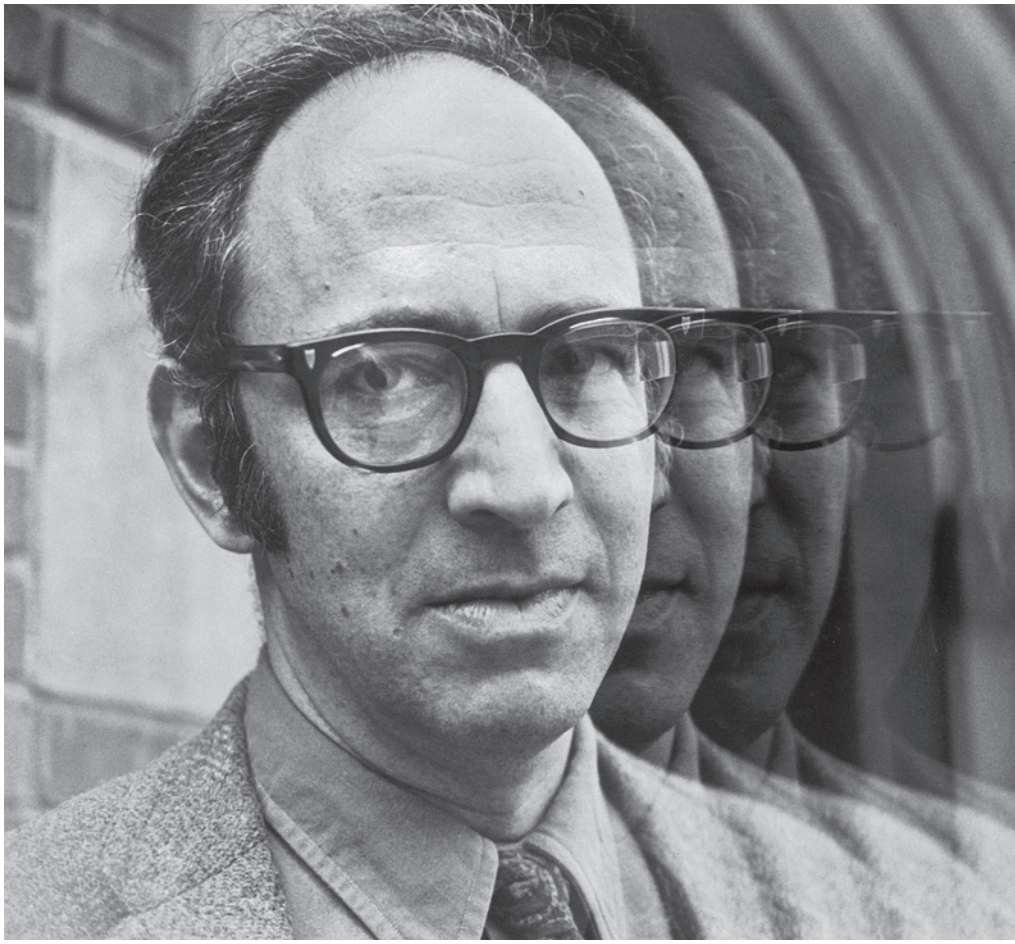
Some scientists would argue with that.
I can see how resistant scientists are to that side of the paradox. I was invited to CERN near Geneva, Switzerland, to talk about *The Human Touch*, and it was really daunting. They had appointed a jury that asked detailed questions. One of the jury members said beforehand: "We're going to haul you over the coals." It seemed to me — although they were all very charming and friendly about it — that they were unreconstructed Platonists. They believed that numbers and the laws of science are objective entities, whereas I think that they are constructs that we place on the world to understand it.

As a non-scientist, are you confident in writing about science?
Fortunately, professional science writers and scientists have made enormous efforts to get through to lay audiences. But people like the physicist Richard Feynman insist that if you haven't got mathematics you're never really going to understand physics — it is like trying to explain music to the tone-deaf. I made a lot of mistakes writing *Copenhagen*, in spite of getting the text read. I got letters from scientists pointing out basic errors. But I was struck by their generous tone.

How do you approach writing?
As a writer, you can't think, "I'd like to write a play about stem-cell research and there will be these characters." It doesn't work like that: ideas just seem to fall into your head out of nowhere, and develop of their own accord. So there is resonance with the case of Peierls and Frisch, or the chemist August Kekulé dreaming about the structure of the benzene ring. There is an unconscious leap, a synthesis, that goes on, even though much science is about trying to find a specific answer to a specific problem.

So playwrights run experiments too?
Plays are called plays for a good reason. As a playwright, you are saying, what if we had enough uranium-235, or what if somebody discovered that their brother was their father, and you take over from these fictitious situations. It is messing around, but messing around often has serious results. ■

INTERVIEW BY RICHARD VAN NOORDEN



Thomas Kuhn recognized the importance of revolutionary changes, or 'paradigm shifts', in science.

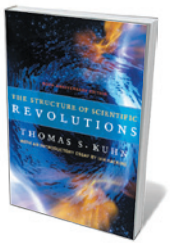
IN RETROSPECT

The Structure of Scientific Revolutions

David Kaiser marks the 50th anniversary of an exemplary account of the cycles of scientific progress.

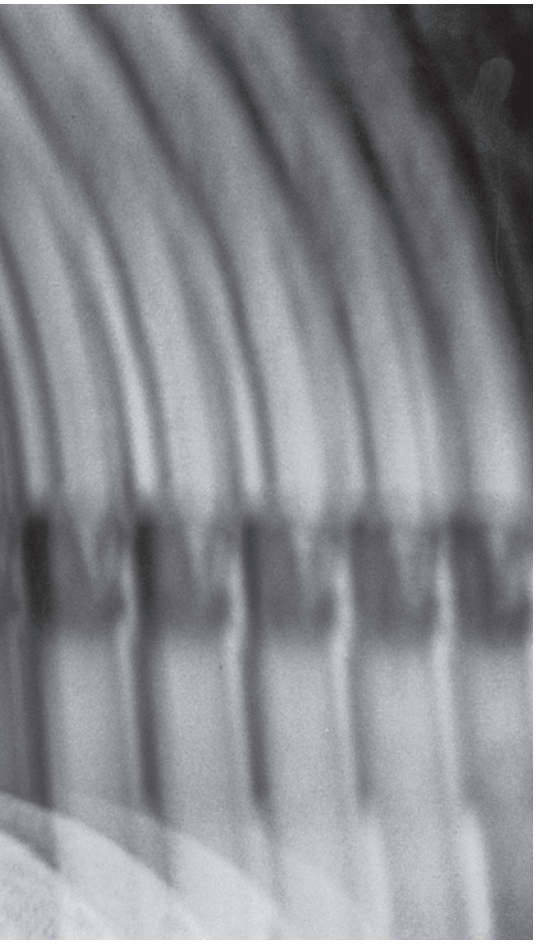
Fifty years ago, a short book appeared under the intriguing title *The Structure of Scientific Revolutions*. Its author, Thomas Kuhn (1922–1996), had begun his academic life as a physicist but had migrated to the history and philosophy of science. His main argument in the book — his second work, following a study of the Copernican revolution in astronomy — was that scientific activity unfolds according to a repeating pattern, which we can discern by studying its history.

Kuhn was not at all confident about how *Structure* would be received. He had been denied tenure at Harvard University in Cambridge, Massachusetts, a few years before, and he wrote to several correspondents after the book was published that he felt he had stuck his neck "very far out". Within months,



The Structure of Scientific Revolutions: 50th Anniversary Edition
THOMAS S. KUHN (WITH AN INTRODUCTION BY IAN HACKING)
Univ. Chicago Press: 2012. 264 pp. $45, £29

B. PIERCE/TIME LIFE/GETTY

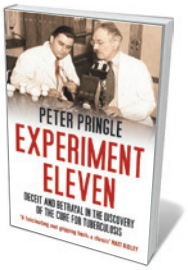


however, some people were proclaiming a new era in the understanding of science. One biologist joked that all commentary could now be dated with precision: his own efforts had appeared "in the year 2 B.K.", before Kuhn. A decade later, Kuhn was so inundated with correspondence about the book that he despaired of ever again getting any work done.

By the mid-1980s, *Structure* had achieved blockbuster status. Nearly a million copies had been sold and more than a dozen foreign-language editions published. The book became the most-cited academic work in all of the humanities and social sciences between 1976 and 83 — cited more often than classic works by Sigmund Freud, Ludwig Wittgenstein, Noam Chomsky, Michel Foucault or Jacques Derrida. The book was required reading for undergraduates in classes across the curriculum, from history and philosophy to sociology, economics, political science and the natural sciences. Before long, Kuhn's phrase "paradigm shift" was showing up everywhere from business manuals to cartoons in *The New Yorker*.

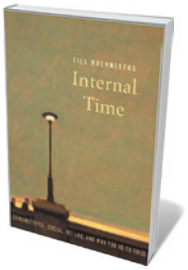
Kuhn began thinking about his project 15 years before it was published, while he was working on his doctorate in theoretical physics at Harvard. He became interested in ▶

Books in brief

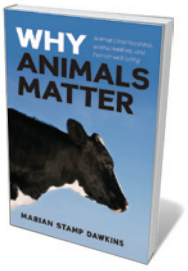


Experiment Eleven: Deceit and Betrayal in the Discovery of the Cure for Tuberculosis
Peter Pringle BLOOMSBURY *288 pp. £18.99 (2012)*
The 1943 discovery of a drug treatment for tuberculosis did much to kick-start big pharma. But this is a knotted tale, deftly unpicked by investigative journalist Peter Pringle. We learn that Albert Schatz, a US graduate student, found streptomycin in the eponymous 11th experiment on a farmyard bacterium — but that his research director, Selman Waksman, took the credit, along with patent royalties and a Nobel prize. A chance rediscovery brought Schatz the reputation he deserves.

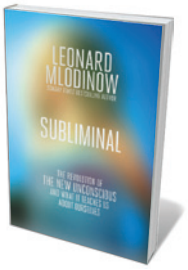
The Forever Fix: Gene Therapy and the Boy Who Saved It
Ricki Lewis ST MARTIN'S *336 pp. $25.99 (2012)*
This popularized examination of gene therapy hinges on a breakthrough case: Corey Haas's recovery from Leber's congenital amaurosis type 2, which had made him virtually blind at the age of eight. Medical writer Ricki Lewis interweaves science, the history of medical trial and error, and human stories. The contrast can be intense, running from the death in 1999 of teenager Jesse Gelsinger, from a reaction to gene therapy intended to combat his liver disease, to radical successes in some children with adenosine deaminase deficiency.



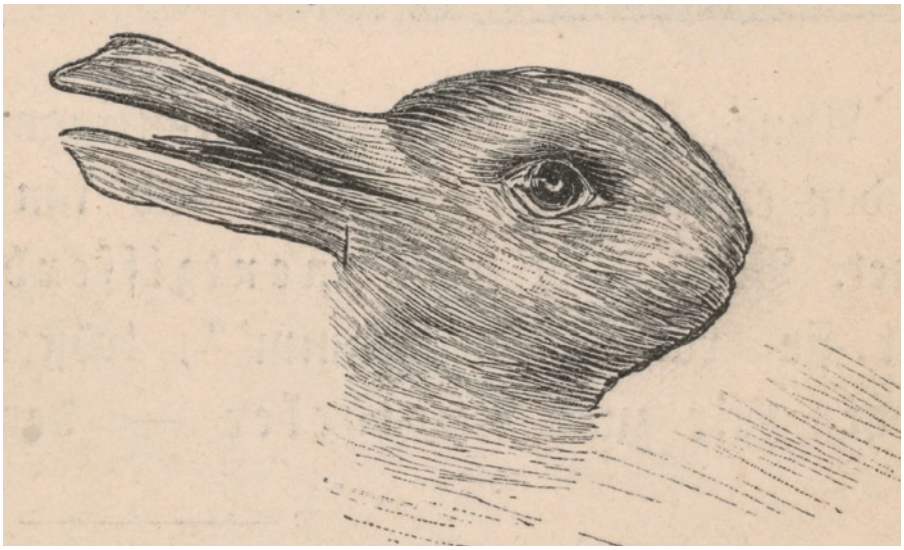
Internal Time: Chronotypes, Social Jet Lag, and Why You're So Tired
Till Roenneberg HARVARD UNIVERSITY PRESS *288 pp. $26.95 (2012)*
Time really is of the essence, says medical psychologist Till Roenneberg. By neglecting our body clocks — which rarely run in synchrony with the crazily cranked-up pace of modern life — we can develop "social jetlag", endangering our health and careers. Roenneberg has built his book on decades of research in everything from fungi and single-celled organisms to humans. In brilliantly minimalist terms, he explains the temporal mismatches behind teen exhaustion, early birds and night owls, and sleep phobia.



Why Animals Matter: Animal consciousness, animal welfare, and human well-being
Marian Stamp Dawkins OXFORD UNIVERSITY PRESS *224 pp. £16.99 (2012)*
Too little science and too much anthropomorphism have made our approaches to animal welfare a shambles, says ethologist Marian Stamp Dawkins. Her radical rethink involves linking their welfare with our own to harness a powerful driver of change: human self-interest. Dawkins advises sidestepping the question of animal consciousness to focus on animal health and hard-wired 'wants' such as foraging, to benefit both groups. Also key is never letting up on research into our intertwined existences, she says.



Subliminal: The Revolution of the New Unconscious and What it Teaches Us About Ourselves
Leonard Mlodinow PANTHEON *272 pp. $25.95 (2012)*
Perception "below the threshold of consciousness", as Carl Jung put it, is here pushed into the limelight. Physicist Leonard Mlodinow shows how humans have "parallel tiers" of a conscious brain superimposed on an unconscious mind. Drawing on research and anecdotes, Mlodinow explores the pattern-matching, gap-filling role of the unconscious in perception, memory, sociality, emotions and self-estimation. An illuminating journey through a hidden world.



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The duck–rabbit figure shows how two pictures can be derived from the same evidence.

developmental psychology, avidly reading works by Swiss psychologist Jean Piaget about the stages of cognitive development in children.

Kuhn saw similar developmental stages in entire sciences. First, he said, a field of study matures by forming a paradigm — a set of guiding concepts, theories and methods on which most members of the relevant community agree. There follows a period of "normal science", during which researchers further articulate what the paradigm might imply for specific situations.

In the course of that work, anomalies necessarily arise — findings that differ from expectations. Kuhn had in mind episodes such as the accidental discoveries of X-rays in the late nineteenth century and nuclear fission in the early twentieth. Often, Kuhn argued, the anomalies are brushed aside or left as problems for future research. But once enough anomalies have accumulated, and all efforts to assimilate them to the paradigm have met with frustration, the field enters a state of crisis. Resolution comes only with a revolution, and the inauguration of a new paradigm that can address the anomalies. Then the whole process repeats with a new phase of normal science. Kuhn was especially struck by the cyclic nature of the process, which ran counter to then-conventional ideas about scientific progress.

At the heart of Kuhn's account stood the tricky notion of the paradigm. British philosopher Margaret Masterman famously isolated 21 distinct ways in which Kuhn used the slippery term throughout his slim volume. Even Kuhn himself came to realize that he had saddled the word with too much baggage: in later essays, he separated his intended meanings into two clusters. One sense referred to a scientific community's reigning theories and methods. The second meaning, which Kuhn argued was both more original and more important, referred to exemplars or model problems, the worked examples on which students and young scientists cut their teeth. As Kuhn appreciated from his own physics training, scientists learned by immersive apprenticeship; they had to hone what Hungarian chemist and philosopher of science Michael Polanyi had called "tacit knowledge" by working through large collections of exemplars rather than by memorizing explicit rules or theorems. More than most scholars of his era, Kuhn taught historians and philosophers to view science as practice rather than syllogism.

> ***"Scientists have no way to compare concepts on either side of a scientific revolution."***

Most controversial was Kuhn's claim that scientists have no way to compare concepts on either side of a scientific revolution. For example, the idea of 'mass' in the Newtonian paradigm is not the same as in the Einsteinian one, Kuhn argued; each concept draws meaning from separate webs of ideas, practices and results. If scientific concepts are bound up in specific ways of viewing the world, like a person who sees only one aspect of a Gestalt psychologist's duck–rabbit figure, then how is it possible to compare one concept to another? To Kuhn, the concepts were incommensurable: no common measure could be found with which to relate them, because scientists, he argued, always interrogate nature through a given paradigm.

Perhaps the most radical thrust of Kuhn's analysis, then, was that science might not be progressing toward a truer representation of the world, but might simply be moving away from previous representations. Knowledge need not be cumulative: when paradigms change, whole sets of questions and answers get dropped as irrelevant, rather than incorporated into the new era of normal science. In the closing pages of his original edition, Kuhn adopted the metaphor of Darwinian natural selection: scientific knowledge surely changes over time, but does not necessarily march towards an ultimate goal.

And so, 50 years later, we are left with our own anomaly. How did an academic book on the history and philosophy of science become a cultural icon? *Structure* was composed as an extended essay rather than a formal monograph: it was written as an entry on the history of science for the soon-to-be-defunct *International Encyclopedia of Unified Science*. Kuhn never intended it to be definitive. He often described the book (even in its original preface) as a first pass at material that he intended to address in more detail later.

To me, the book has the feel of a physicist's toy model: an intentionally stripped-down and simplified schematic — an exemplar — intended to capture important phenomena. The thought-provoking thesis is argued with earnestness and clarity, not weighed down with jargon or lumbering footnotes. The more controversial claims are often advanced in a suggestive rather than declarative mode. Perhaps most important, the book is short: it can be read comfortably in a single sitting.

For the 50th-anniversary edition, the University of Chicago Press has included an introductory essay by renowned Canadian philosopher Ian Hacking. Like Kuhn, Hacking has a gift for clear exposition. His introduction provides a helpful guide to some of the thornier philosophical issues, and gives hints as to how historians and philosophers of science have parted with Kuhn.

The field of science studies has changed markedly since 1962. Few philosophers still subscribe to radical incommensurability; many historians focus on sociological or cultural features that received no play in Kuhn's work; and topics in the life sciences now dominate, whereas Kuhn focused closely on physics. Nevertheless, we may still admire Kuhn's dexterity in broaching challenging ideas with a fascinating mix of examples from psychology, history, philosophy and beyond. We need hardly agree with each of Kuhn's propositions to enjoy — and benefit from — this classic book. ■

David Kaiser *is Germeshausen Professor of the History of Science at the Massachusetts Institute of Technology in Cambridge. His latest book is* How the Hippies Saved Physics *(Norton, 2011).*
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