netic analyses, because characters regarded as unique to a living group may well have had a much wider distribution, as possibly shown by the 'calcichordates'.

The book reads extremely well, as would be expected from an author who is an assistant editor of *Nature* and a popular science writer. Each chapter is followed by a series of notes explaining technical terms in the main text and discussing certain points in more depth.

Before the Backbone is warmly recommended to professional biologists and palaeontologists, historians of science, lecturers, students, and even amateur zoologists and palaeontologists. It provides not only an up-to-date account of the debates on vertebrate origins, but also a critical assessment of the methods and aims of biologists and palaeontologists. □

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Measuring science revolutions

Mark Buchanan

Conversations with the Sphinx: Paradoxes in Physics. By Etienne Klein. *Souvenir: 1996. Pp. 211. £18.99, $22.95.*

ALBERT Camus was probably right when he said that "All great deeds and all great thoughts have ridiculous beginnings". Had he been a scientist, he might have added that all great theories have paradoxical beginnings.

Such is the conclusion of Etienne Klein in his new book, which offers a philosophically light-hearted look at the significance of paradox in science. Paradox sometimes involves self-contradiction, as in "this sentence is false", a statement that ties itself in a self-referential knot. But Klein focuses on paradox of a different sort.

To a scientist, a paradox is a seemingly impossible conclusion that follows inescapably from a combination of unquestionable beliefs. And the emergence of paradox spells trouble. At the end of last century, for example, Lord Rayleigh showed that Maxwell's electrodynamics, coupled with classical statistical mechanics, requires all objects to glow with infinite brightness, an obvious absurdity.

Klein entertainingly describes a handful of examples, ranging from the paradoxical null result of the Michelson–Morley experiment, to the still problematic role of measurement in quantum mechanics. In each case, he shows that although paradox does indeed spell trouble, it is precisely the discomfort that it engenders that directs the intellect towards deeper truth. As Klein puts it: "Paradox is truth standing on its head to get attention". The ultraviolet catastrophe forced Max Planck to question the notion that objects emit and absorb energy continuously. By formulating the idea of quantized energy exchange, he sidestepped the paradoxical infinity and ushered in the quantum era.

A paradox such as the "ultraviolet catastrophe" represents a kind of defect in the tightly woven network of interdependent ideas and beliefs that is science. Klein's thesis is that paradox focuses and amplifies intellectual stress in this network, and so sets the stage for upheaval, discovery and sometimes scientific revolution.

All this may seem rather obvious: science learns by making mistakes. In this sense, the book contributes no truly novel ideas, and sometimes reads like a condensed, although more animated, version of Thomas Kuhn's *The Structure of Scientific Revolutions*. Normal science, crises, scientific revolutions — they're all here, although sometimes in disguise.

Still, before reading this book, I thought of paradox as a sort of scientific equivalent of the pothole — an annoying but perhaps inevitable feature of the landscape. Klein establishes paradox in a more positive sense, as an essential mechanism by which science develops. This philosophical perspective is offered in the first half of the book, which is a well-written, carefully conceived essay. Klein clearly has an appetite for philosophy, and the text is littered with incisive quotations from Nietzsche, Kierkegaard, Bachelard and a score of others.

Unfortunately, the second half of the book, a hectic tour through the backyard of modern physics, is not so good. The sights are largely familiar: quantum nonlocality, Schrödinger's cat, parity violation and so on — seven paradoxes treated in an all-too-brief 100 pages. Those who haven't already met these ideas will not understand much, and readers familiar with them will find nothing new.

That said, the ideas in this book may suggest a way to generalize and develop the Kuhnian perspective on science. For Kuhn, 'scientific revolutions' punctuate the normally slow and continuous process of scientific development. What is not clear, however, is how to identify a 'revolution' out of a background of normality. Can there be small revolutions? And could normal periods of science result not from the absence of revolution but from a barrage of small revolutions that together give the appearance of continuous development?

The latter dynamic strongly resembles processes that take place in other settings. For example, stress in the Earth's crust is released through earthquakes. Remarkably, the amount of energy released varies enormously — over many orders of magnitude — from one earthquake to another. The evolution of mechanical stress in the Earth is influenced not only by rare large earthquakes, but also by the much more frequent smaller ones. Might the evolution of science be similar?

Klein's notion of paradox can broadly be taken to refer not only to truly outstanding intellectual puzzles but also to many scientific problems of lesser significance. Some problems threaten to shake the foundations of all science, but most are less imposing, and their resolution affects beliefs and practices in a more limited way.

Seismological observations show that earthquakes that release an amount of energy E occur with a relative frequency proportional to $E^{-2/3}$. This is the Gutenberg–Richter law, and it implies, through its power-law form, that earthquakes have no typical size and that there is similarity in the mechanisms driving quakes of all sizes. If one could measure the size of a scientific revolution (perhaps through studies of citations?), and so estimate the magnitude of the rearrangement it entails, then one might similarly quantify the dynamics of scientific understanding. A study of the distribution of the sizes of episodes of scientific change would then reveal whether the Kuhnian dichotomy of normal and revolutionary is really true, or if science instead develops by way of revolutions of all sizes. Might there be an 'intellectual Gutenberg–Richter law'? □

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The dangers of Green dogma

Julian Morris

Green Backlash: Global Subversion of the Environment Movement. By Andrew Rowell. *Routledge: 1996. Pp. 504. £45, $65 (hbk), £12.99, $18.95 (pbk).*

DURING the late 1980s, the media, spurred by groups such as Greenpeace and Friends of the Earth, fed us a diet rich in polyunsaturated environmental scare stories. We were warned that greenhouse gas emissions would result in runaway global warming, causing sea levels to rise so much that London and New York would cease to be habitable. Chlorofluorocarbons would destroy the stratospheric ozone layer, resulting in a catastrophic rise in skin cancers. Persistent organic pollutants would cause genetic mutations, making fish and humans alike infertile.

The exaggerated nature of these claims