BOOKS & ARTS

Pulling the strings

Mathematics holds the key to a unified theory of the Universe.

Hiding in the Mirror: The Mysterious Allure of Extra Dimensions, from Plato to String Theory and Beyond

by Lawrence M. Krauss
 Viking: 2005. 288 pp. \$24.95

Michael Atiyah

The search for the fundamental physical laws that govern the Universe has fascinated and driven humans for centuries. Its modern form was essentially launched by Isaac Newton, building on the pioneering work of his predecessors, notably Johannes Kepler and Galileo. From the publication of Newton's *Principia* onwards, it has been a remarkable story, which has delved into every realm of the physical world from the subatomic scale to that of the cosmos and the Big Bang. The theoretical framework that supported this great enterprise has, following the path firmly established by Newton, been based on mathematics. At every major step, physics has required, and frequently stimulated, the introduction of new mathematical tools and concepts. Our present understanding of the laws of physics, with their extreme precision and universality, is only possible in mathematical terms.

This mathematical take-over of physics has its dangers, as it could tempt us into realms of thought which embody mathematical perfection but might be far removed, or even alien to, physical reality. Even at these dizzying heights we must ponder the same deep philosophical questions that troubled both Plato and Immanuel Kant. What is reality? Does it lie in our mind, expressed in mathematical formulae, or is it 'out there'. The recent developments in modern physics that go by the deceptively simple name of 'string theory' bring these age-old questions back to the fore, and are the focus of *Hiding in the Mirror*, a new book by Lawrence Krauss.

Most popular-science books are written by enthusiastic protagonists who seek to convey their excitement to the general public. This book is refreshingly different. On the big questions, Krauss remains a sceptic, a hard-nosed physicist questioning the mountain of mathematical theory that has yet to produce any experimental evidence. But this is no debunking exercise; Krauss makes a serious attempt to bring the reader to the very frontier of modern physics. He describes the intricate theoretical constructs that have been erected

IMAGE
UNAVAILABLE
FOR COPYRIGHT
REASONS

Out for the count: is physics being taken over by mathematics?

and he acknowledges that, at present, there is no alternative on the table: "it's the only game in town".

One of the book's main themes is indicated by its subtitle, which refers to "the mysterious allure of extra dimensions". This guides the reader through the ever-increasing complexity of physical theory. As Krauss points out, the mystery of extra dimensions exercised the imagination long before it entered serious physics. We are enchanted by the account of Edwin Abbott's *Flatland*, a nineteenth-century classic that combines a scientific and philosophical aim with social satire worthy of Jonathan Swift. The erudite but volatile British mathematician James Joseph Sylvester tried to refer to extra dimensions as 'inconceivable' (by analogy with 'imaginary' numbers). Fortunately for Einstein and subsequent physicists, the term never caught on.

Krauss gives pride of place to Einstein's revolutionary ideas that showed, first in his special theory of relativity and even more convincingly in his subsequent general theory, that space and time form an indissoluble four-dimensional continuum. This was undoubtedly

a landmark in the history of human thought and fully justifies Einstein's iconic status. As Krauss explains, Einstein's general theory, which supplanted Newton's theory of gravitation, was reached by a process of pure thought — not by the pressure of unexplained experimental data. Einstein was motivated by aesthetic considerations, an impressive example of the power of beauty to act as a guiding light. On this point, Krauss quotes the mathematician Hermann Weyl: "My work always tried to unite the true with the beautiful, but when I had to choose one or the other, I usually chose the beautiful."

Krauss comments that mathematicians, poets, writers and artists can all choose beauty over truth, but scientists do not have this luxury.

This is the final word in the book, but Krauss had already mentioned an episode involving Weyl in which beauty eventually triumphed. After Einstein had explained gravity in terms of the curvature of four-dimensional space-time, Weyl attempted to explain electromagnetism in similar terms. Einstein pointed out a fatal flaw in Weyl's explanation (not in the mathematics, but in its physics). Remarkably, Weyl did not withdraw the paper, and the paper was published together with Einstein's objection as an appendix. Clearly the beauty of the mathematics exercised its own appeal.

A few years later, after the appearance of quantum mechanics, a new physical interpretation of Weyl's mathematics was possible; this was the beginning of modern 'gauge theory', the basis of elementary particle physics. To a mathematician this seems a remarkable case of beauty winning through in the end, justifying Weyl's preference. After all, beauty is subjective, it is in the eye of the beholder, and we can be certain about ourselves. Truth is much

more elusive and can change as new facts or ideas emerge.

Krauss's book is well written for a general audience and puts the scientific advances into a historical and philosophical context while keeping the technicalities under control. After a rapid overview of the past it focuses on the current aim of combining the two fundamental theories of twentieth-century physics: Einstein's general theory of relativity, and quantum mechanics, which between them deal with the very large and the very small. The need to unify these two theories is entirely aesthetic; there seems to be little need from the point of view of the experimentalist.

Over the past few decades, string theory has emerged as a serious contender to be such a unified theory. It involves extra dimensions galore: not just Einstein's four, or the five that also incorporates electromagnetism, but a total of 10 or 11. The extra dimensions are viewed as very small and curled up, so that, for most purposes, we are not aware of them. They only manifest themselves at very high

energies, of the kind encountered in particle accelerators. Moreover, these extra dimensions are constrained by very precise symmetry requirements. The upshot of this is that string theorists can exhibit plausible models of a unified Universe, but unfortunately they cannot explain why we inhabit a particular one.

The mathematics involved in string theory is quite remarkable by any standards. In subtlety and sophistication it vastly exceeds previous uses of mathematics in physical theories. Almost every part of contemporary mathematics is involved somewhere in the story. Even more remarkable is that string theory has led to a whole host of amazing results in mathematics in areas that seem far removed from physics. To many this indicates that string theory must be on the right track. But Krauss is not a mathematician, so perhaps he is unaware of all this mathematical success, or maybe he discounts it as irrelevant. Time will tell. ■

Michael Atiyah is president of the Royal Society of Edinburgh, 22-26 George Street, Edinburgh EH2 2PG, UK.

The greatest challenge for Lightman is to give substance to his claim that "the first reports of the great discoveries of science are works of art", an assertion often made but rarely demonstrated. He makes it especially difficult for himself, as instead of giving an overview of the works' literary qualities, he introduces each paper (or sometimes a pair of papers) separately. The result is that the book is a series of 22 essays, each followed by the paper or papers that he has discussed. He reproduces some of them in full, but sensibly cuts the rest of them — a few by as much as two-thirds, others by only a fifth. The research papers are all in English, Lightman having found lucid translations of the seven papers in his selection that were originally written in German.

The physics-related chapters are, predictably, the most accomplished. Best of all is his essay on Hubble's law, which led to the realization that the Universe is expanding. It opens like a novel, on a chilly evening in the late 1920s, the sky "a deep purple gash flecked with stars". Lightman then paints a vivid picture of Edwin Hubble and explains why the discovery made such an impact. The problem is that he does much the same for all the other topics too, so the book is somewhat formulaic and repetitive. As one would expect of this author, the writing is unfailingly clear, but it disappointingly lacks his usual grace and style. Most of his explanations are surprisingly lacking in flair, and are little better than those conventionally served up elsewhere. Nor is the style especially pleasing: I would never have expected this most elegant of science writers, for example, to introduce Max Planck's ideas on quantization to a lay audience by referring to "elemental vibrating resonators".

I had hoped Lightman would persuade me that the finest scientific papers are often great art. Alas, it was not to be. I found myself guiltily flicking through the papers that are outside

Bitesize breakthroughs

The Discoveries: Great Breakthroughs in 20th Century Science Including the Original Papers

by Alan Lightman

Pantheon: 2005. 576 pp. \$32.50

Graham Farmelo

Tapas are one of the greatest pleasures of Spain. These delicious snacks and appetizers are one of the foundations of the country's cuisine. Tapas-style books are becoming common too, as the average attention span of modern readers falls by the year. Here we have a promising science book in the genre, *The Discoveries*, a collection of short pieces on 25 of the best research papers of twentieth-century science.

It is an appealing idea, all the more attractive in this case for being prepared by the much-admired writer Alan Lightman, a physicist and adjunct professor of humanities at Massachusetts Institute of Technology. The author of three well-crafted novels, several popular-science books and many elegantly written essays, he is well qualified to achieve his ambitious aim of providing an insightful overview of modern science.

In his introduction, Lightman says that he sought to find the patterns of discovery, and to compare their discoverers and the different styles of working and thinking among leading scientists. He spent six months consulting widely before he made his final selection of discoveries. In his description at the end of the process, he is winningly open about his passion for science: "I held the stack of twenty-five papers in my arms, a century of scientific thought. My eyes filled with the tears."

Any selection of science's 'greatest hits' is bound to be controversial. But it seems to me that Lightman's choice is reasonable, if rather biased towards physics. He includes papers on quantum theory, Einstein's special (but not general) theory of relativity, nuclear physics, cosmology, Linus Pauling's pioneering paper on the chemical bond, Alexander Fleming's discovery of penicillin, Barbara McClintock's jumping genes, the structures of DNA and haemoglobin, and the first demonstration of genetic engineering. The most striking omission is a paper on plate tectonics, one of the few authentic revolutions of modern science.

IMAGE
UNAVAILABLE
FOR COPYRIGHT
REASONS

Steven Weinberg (right) won the 1979 physics Nobel with Sheldon Glashow (left) and Abdus Salam.