BOOKS: PHYSICS

The Seductive Melody of the Strings

Sidney Perkowitz

Scientific literacy seems to be in short supply among the American public. Too many graduates of our best universities do not know the ABC's of science, such as basic facts about the solar system. Mathematics and physics may be the biggest problems; in fact, physicists learn to suppress a sigh when a new acquaintance says, almost inevitably, "physics was my worst subject in college." Yet people love hearing about exotic physical ideas, from quantum computing to black holes. That explains why books like Brian Greene's *The Elegant Universe* get written; the difficulty of conveying cutting-edge physics explains why such books are hard to write well.

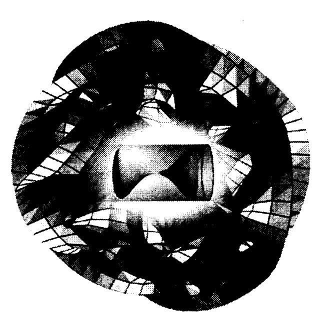
Greene, a physicist at Columbia University, works in the area called string theory and does his best to present its abstract ideas to the general reader. The heart of the theory is this: physicists have long thought that the minuscule electrons, quarks, and so on that constitute matter at the smallest scale behave like mathematical points. String theory says no, there is a deeper structure: Each elementary particle is a particular mode of vibration of a minute oscillating string. To use a classical image, this change of perspective is like replacing Euclid's perfect geometric points with the harmoniously thrumming strings that Pythagoras related to the music of the spheres. That isn't all, for these elementary-particle strings vibrate in ten dimensions of space-time. We see only four, because six of the dimensions are "rolled up" or "compacted" into a tiny format.

The Elegant Universe
Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory
by Brian Greene

Norton, New York, 1999. 464 pp. $27.95. ISBN 0-393-04688-5.

If you are unused to the dizzying heights of theoretical physics, if you trust visceral reactions more than equations, all this talk of strings is extremely strange. But we have learned to live with weirdness. After nearly a century, both quantum mechanics and the theory of relativity remain full of puzzling outcomes remote from ordinary human experience. Yet both theories work—they give predictions that can be verified by experiment.

So Greene makes a valid point when he urges his readers not to dismiss string theory just because it seems odd. Still, why would we want to substitute intricate vibrating systems for the purity of dimensionless points? This seems to violate an axiom stated by the English philosopher William of Occam in the 14th century, and still beloved by scientists: "What can be done with fewer assumptions is done in vain with more." Moreover, there is the embarrassing fact that this refined mathematical edifice has yet to produce clear predictions that can be experimentally confirmed. This shortcoming has engendered considerable controversy over the value of the approach, which has been criticized by the likes of the Nobel laureate Sheldon Glashow, whose research has deeply probed elementary particles and their interactions. (Glashow proposed the existence of the "charm" quark, which was later found; and, with Steven Weinberg and Abdus Salam, he showed that electromagnetism and the weak nuclear force—two of the four fundamental interactions that make the universe work—are aspects of a single "electroweak" interaction.)



String shield. By encircling a tear in the fabric of space, a string can prevent the catastrophic effects that would otherwise be encountered.

But as Greene explains it, the apparent complication is actually a great simplification, worth pursuing because the prize is so tempting. String theory seems to unite quantum physics, which describes the smallest scales, with general relativity, Einstein's theory of gravity that describes the biggest structures in the universe. Such unity has long been the brass ring that physicists strain to reach. Our best effort so far, the Standard Model, correctly describes the elementary particles and goes beyond electroweak theory to include the strong nuclear force. But it does not explain gravity, the fourth force. Now strings offer the possibility of including that as well to give, finally, a "theory of everything."

Greene's style in explaining string theory follows many of the prescriptions about science writing I give my students: a look at the history of the subject (it all began in 1968, with an insight made by a young theorist named Gabriele Veneziano); plentiful application of metaphor and analogy; and—often overlooked—the use of pictures when words fail, expressed here with especially handsome drawings. But to provide sufficient background to appreciate the potential power of the theory, Greene must cover quantum physics and general relativity as well as strings themselves. This is a lot of deep material, and its presentation is not helped by the dense writing and level of detail in much of this 450-page book. For the non-expert, less would have been a great deal more.

Nevertheless, Greene's belief in strings comes through as he writes about what it means to have a theory that awaits experimental verification, and his stake in that. Greene is correct in saying that opinion among even Nobel laureate physicists is turning toward giving strings a chance, if only because no better theory is available; still, he puts the rosiest possible spin on the prospects for confirmation. This is perfectly understandable, for Greene is one of the string theorists who, he writes, "know that they are taking a risk; that a lifetime of effort might result in an inconclusive outcome."

The risk seems enormous when we consider that the most direct test of string theory would require a particle accelerator at least the size of our galaxy. For the ultimate benefit of physics, and to save a great deal of theorizing from going to waste, let us hope that a more attainable test will show whether reality truly does dance to the music of these particular strings.

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BOOKS: CHEMISTRY

Toward Benign Ends

Walter Leitner

The "green" vogue has hit chemistry! "Green chemistry" is now an established part of the Gordon Conference series, and the Royal Society of Chemistry has just launched a new periodical with the same title. "Green chemistry," "sustainable chemistry," "clean chemistry," "environmentally benign synthesis," and other synonyms for the same approach find increasing attention and application in industry. The topic is currently entering many research programs in chemistry and related disciplines (including the European Community's Framework V). Academic activities in green chemistry are emerging all over the world, as researchers realize their investigations can potentially contribute to the development of a more benign synthetic chemistry. Increasing numbers of universities and graduate schools now offer courses or curricula on these topics. Two recent books that give an introduction to green chemistry and highlight examples of current activities in the field are therefore timely and very welcome.

Green Chemistry
Theory and Practice
by Paul T. Anastas and John C. Warner

Oxford University Press, Oxford, 1998. 147 pp. $85, £45. ISBN 0-19-850234-6.

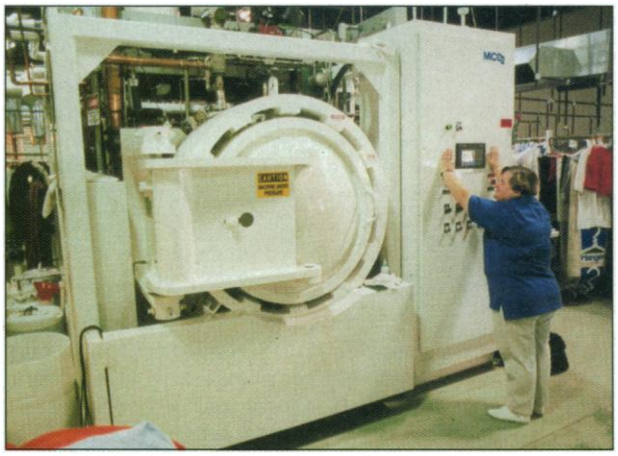
Green Chemistry
Frontiers in Benign Chemical Syntheses and Processes
Paul T. Anastas and Tracy C. Williamson, Eds.

Oxford University Press, Oxford, 1998. 382 pp. $115, £65. ISBN 0-19-850170-6.

What is green chemistry? In *Green Chemistry: Theory and Practice*, Paul T. Anastas and John C. Warner provide a concise and comprehensive answer: "Green chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products." Anastas has played a major role in promoting the idea of a fundamental scientific approach to environmentally benign synthesis and is said to have coined the expression "green chemistry." Measure by measure, he and Warner fill this abstract and fairly broad definition with life. Their short book provides a framework for the pursuit of environmentally compatible chemistry. This introductory text is intended to provide a basis for teaching and includes a collection of exercises for the topics of each chapter.

In a very interesting retrospective, the first chapter recalls some of the most stupendous detrimental effects of earlier chemical manufacturing, effects that have contributed much to the anxiety and resentment towards chemistry in today's society. An increasing knowledge of the impact that chemicals can have on human health and the environment has, arguably, led to remarkable improvements through what the authors call the "command and control" approach. They discuss the limitations of this end-of-the-pipe methodology and convincingly demonstrate that the principles of green chemistry open a promising and exciting new strategy. Interestingly, they include a very strong argument that is often forgotten in other discussions on "green" issues: economy. If pursued properly, green chemistry may be attractive for monetary as well as environmental reasons; it can offer dramatic savings on downstream costs. Anastas and Warner present a detailed outline of the principles of clean chemistry and some guidelines for using them to evaluate chemical syntheses. After providing very brief summaries of examples of green starting materials, reactions, reagents, solvents, reaction conditions, and products, the authors conclude with some general remarks on future trends.

Green chemistry is a very broad field, and its principles may find countless applications. Thus it is natural that some of the authors' statements must remain fairly general, or even vague, at this stage. It is also clear that some of their views will lead to debate among their fellow chemists instead of consensus, but this should be taken as grounds for merit rather than criticism. A few inaccuracies have found their ways into the fairly short parts of the book focused on chemistry, so thorough additional work is necessary before using these parts for teaching. These shortcomings cannot, however, distract from Anastas and Warner's excellent overall effort and should not diminish the positive impact that this book will have.



Green cleaning machine. This drycleaning equipment uses environmentally benign liquid carbon dioxide and specially designed detergents instead of the chlorinated organic solvent perchloroethylene.

CREDIT: JEFFREY S. OTTO/COURTESY OF J. M. DESIMONE, UNIVERSITY OF NORTH CAROLINA, CHAPEL HILL AND MICELL TECHNOLOGIES

The volume edited by Paul Anastas and Tracy Williamson is a collection of review articles that provide an overview of recent research activities incorporating or based on the principles of green chemistry. Although the book is restricted almost entirely to developments in the United States, it gives a flavor of the wide variety of possible applications of environmentally benign strategies, and it may serve as a stimulating incentive for other projects.

As one might expect, the editors' introduction has some overlap with the book Anastas wrote with Warner, but it contains useful additional information and illustrates some aspects from a slightly different angle. The project-oriented reviews are interesting to read and very informative. They provide helpful background information and highlight recent achievements of the individual groups. The quality of the more general contributions, however, varies considerably and is sometimes less satisfactory. For example, "alternative solvents" are a fascinating aspect and an important area of green chemistry. Recent advances in using supercritical carbon dioxide as a reaction medium, from research at the Los Alamos National Laboratories and the University of North Carolina at Chapel Hill, are described in two excellent accounts by Bill Tumas and Joe DeSimone and their co-workers. In contrast, the general summary on alternative solvents, attempted in chapter 12, gives only a very narrow view of the state of the art. Less than half a page is dedicated to the application of aqueous solutions in transition metal catalysis; this includes the rather surprising statement that the use of sulfonated phosphines was "pioneered" by work published in 1993. (In fact, the field was opened by research in the early 1970s, and the Ruhrchemie–Rhône-Poulenc process for the hydroformylation of 1-propene has utilized this benign technology on a commercial scale since 1984.) A discussion of truly recent developments like the use of ionic liquids or perfluorinated solvents is sorely missed.

In summary, the two books provide an excellent introduction into the fast growing field and the fascinating science of green chemistry. The collection edited by Anastas and Williamson provides interesting insight into a variety of the current U.S. research activities in this area. The shorter yet more general account by Anastas and Warner should be consulted by anyone who wants to know about environmentally benign chemistry and, especially, by scientists who contemplate adopting its principles in their own research or teaching efforts.

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