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Relativity for the Questioning Mind [book review]

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Daniel F. Styer and Stephen Boughn

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An Indispensable Truth: How Fusion Power Can Save the Planet. Francis F. Chen. 433 pp. Springer, New York, 2011. Price: $29.95 (hardcover) ISBN 978-1441978196. (Gary J. Weisel, Reviewer.)

In 1974, Frank Chen published the first edition of his *Introduction to Plasma Physics* and for four decades it reigned as the standard textbook of general plasma physics for upper-level undergraduate and first-year graduate students. The early 1970s had brought fusion energy research to the attention of the public and the federal government after a number of developments. One was the energy crisis, in which the U.S. faced weakening domestic oil production and difficulty in maintaining its supply from the Middle East. Another was the arrival of "new" fusion machine concepts, like the tokamak (which had been invented by Soviet physicists in the 1950s but went largely unnoticed until 1969) and inertial-confinement laser fusion (which, before 1972, had been classified due to its military applications). Excitement in the fusion and plasma physics community was high in the late 1970s. In 1984, the first volume of the second edition of Chen's textbook was published. But the fickleness of Federal support provided a hard lesson. As concerns about the energy crisis faded and as it became apparent that the milestones promised by the fusion scientists would not come on schedule, Congressional support weakened. By the early 1980s, the federal budget for fusion energy research lost its race with inflation, leading soon thereafter to a precipitous decline that lasted over a decade. The projected second volume of Chen's textbook, which was to survey the different types of fusion energy machines, was never published.

Chen's new book fulfills some of the promise of the long-lost second volume and has the added benefit of being addressed to a much wider audience. As Chen stresses, even though the public, Congress and the general scientific community seem to have lost interest in fusion, the fusion community has continued to make impressive gains. In the first pages, he asserts that "controlled fusion energy is not a pipedream." This defensive remark indicates just how difficult it has been for fusion during the last three decades. In our increasingly cantankerous political climate, scientists probably must expect to be targets of unfair and misguided attacks. One of these is Charles Seife's recent popular book *Sun in a Bottle*. Despite strengths—it is well–written and occasionally insightful—Seife's book has the drawbacks of being unfair (by depicting fusion community as chasing rainbows at every turn) and misleading about scientific developments (by concatenating everything from magnetic fusion, to inertial confinement fusion, to cold fusion, to bubble fusion, within the theme of the scientist's "wishful thinking.")

An Indispensable Truth provides a necessary corrective, by focusing on the progress made in scientific problems (especially plasma instabilities) and technical difficulties (such as plasma heating and materials development) in language that is understandable to the educated layman. Much of the book surveys the past development, current status, and future plans of the now front-running class of fusion machine, the tokamak. Another substantial chapter reviews a number of other approaches to fusion, including varieties of stellarators, mirror machines, pinches, and inertial confinement fusion. Although his writing is sometimes choppy and repetitive, Chen has a unique gift for explaining complicated ideas in straightforward language, and for spicing up the text with amusing asides and jokes. In addition, his words are well supported by 254 colorful figures.

As promised by the book's title, Chen stresses that the economic and environmental reasons for pursuing fusion research have only increased since the 1970s. He devotes three introductory chapters (about third of the book) to showing how fusion energy is uniquely positioned to provide long-term, safe, and affordable "backbone power" for our increasingly energy-hungry society. One of these chapters summarizes evidence that the world supply of fossil fuels will become more and more depleted and expensive (reaching a crisis within 40 yr for oil). Another reviews evidence, provided by the climate science community, that oil, gas, and coal, whatever their supply and cost, should be avoided so as to minimize anthropogenic global warming. A third chapter argues that it is highly doubtful that alternative and renewable energy sources (such as wind and solar) will ever have the capacity to replace fossil fuels as backbone power. Although he is not an expert in energy resources or climate science, Chen's descriptions of topics such as Hubbert's Peak, climate forcings, and photovoltaics are clear and accessible.

In his loose historical review of the tokamak, Chen does a better job than anyone before him at describing the complicated behavior of magnetically-confined plasmas. After giving an excellent explanation for the tokamak's use of a helical field, he describes the Rayleigh-Taylor instability and its stabilization with sheared magnetic fields (a solution to which Chen himself made fundamental contributions). Equally cogent discussions follow of other instabilities. Chen does a remarkable job at describing the "insidious, cunning way[s] that plasma finds to escape from its magnetic trap," without the use of mathematics.

Such clarity is maintained, even as Chen moves forward to the present day, and his discussion necessarily becomes a bit more condensed and difficult. Discussions of magnetic islands and wells are followed by an explanation of the tokamak's D-shape. The special benefits of the tokamak, including self-healing magnetic topology, the bootstrap current, and the all-important high mode (which Chen calls one of "Mother Nature's gifts"), are balanced with some of the negatives, including edge-localized modes, disruptions, and the Greenwald limit. Important subsections note that plasma physics has progressed interactively with computer modeling and chaos theory.

Along with the successes of Chen's book, veteran observers of fusion will sense familiar problems. One is that even the best efforts at describing fusion plasmas become dizzying after a while. In the process of impressing the reader with the advances that have been made in high-temperature plasmas, Chen often points out yawning gaps in understanding (including experimental results without theoretical models and mathematical models without direct experimental confirmation). This sort of half empty-half full logic becomes more noticeable upon reaching the chapter on the engineering challenges posed by deuterium-tritium (D-T) machines such as ITER (originally named the International Thermonuclear Experimental Reactor, which is slated to have first plasma by 2020) and DEMO (the Demonstration Power Plant, which should be completed in 2050). On the one hand, Chen's description of the difficulties of building and operating these machines reassures us that the scientists are working hard and making progress. On the other hand, the sheer magnitude of the remaining challenges might lead us to question the entire enterprise anew. These challenges include finding an appropriate material for the "first wall" (beryllium will likely be used for ITER but has too low a melting point for DEMO), finding a way for the complex "blankets" (of which there are many competing designs) to produce sufficient tritium, avoiding damage from plasma disruptions (only one of which can severely damage a large machine), finding higher-temperature and cheaper superconducting materials, and finding a way for fusion machines to be serviced by robots after they are neutron activated and contaminated with tritium.

Another problem concerns Chen's focus on the tokamak. As Chen notes, the fusion community's allegiance to the tokamak arose from "the lucky break" that the machine stole the spotlight in 1969 (on solid technical grounds). Because the community has the most experience (and has spent the most money) on the tokamak, it is compelled to build on this foundation. At the same time, however, Chen claims that other machines (often burning other fuels than D-T) hold out great promise. For example, in recent years, the stellarator has overcome some of its weaknesses vis-a-vis the tokamak. In addition to the fact that modern tokamaks no longer rely on the self-healing mechanism that made them so attractive in 1969, the stellarator is not nearly as prone to plasma disruptions. Chen's remark that stellarators "are probably better suited for reactors than tokamaks" (p. 373) may seem worrisome given all the time and money that is planned for ITER and DEMO.

Such technical decisions are no doubt best left to the fusion community itself. Still, many of us will have questions when viewing Chen's argument from its broadest perspective. His plea for fusion is based not only on scientific progress but also on the imperative that, now more than ever, human society must set and maintain sensible priorities. In the book's closing pages, Chen observes that the cost of ITER is not much more than the cost of one month of the war in Iraq and asserts that a crash program for U.S. fusion would almost certainly bear fruit. "A high-priority Apollo-like program to put fusion on a fast track will cost less than Apollo did and will solve the CO_2 problem, the fossil-fuel shortage problem, and the oil dependence problem all at once" (p. 421). Many of us will have the creeping sensation that we have heard such things before and will object that fusion already had a crash program in the late 1970s. Chen would no doubt respond that the progress of the last three decades has allowed the fusion community to be more specific about the funds and time needed the reach its goal, and that a decisive jump is called for in view of the environmental and energy dilemmas facing humanity.

Others of us might wish to expend public resources on other energy options. Instead of fusion, we might just as easily imagine a federal program that seeks aggressive progress on a number of different energy options at once, rather than a single backbone power source. In speeches given in the months following his 2007 Nobel Peace Prize, Al Gore (whose film and book *An Inconvenient Truth* are mirrored in Chen's title) suggested an Apollo-like federal program relying on many of the elements that Chen rejects individually, including higher efficiency photocells and wind turbines, a smart energy grid able to interface with renewable energy sources, and a systematic program of conservation.[1]

But, in the end, none of us can be certain of what we see in the crystal ball. Perhaps the best we can say is that it is prudent to cover as many promising options as possible. Chen's book makes a convincing case for the continued strength and relevance of fusion energy research. This intervention—by one of our great plasma physicists and physics teachers—will hopefully shift the conversation about fusion energy to something more reasonable than what we have experienced over the last three decades.

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[1]Al Gore, A Generational Challenge to Repower America July 17, 2008. <http://blog.algore.com/2008/07/a_generational_challenge_to_re.html>

Relativity for the Questioning Mind. Daniel F. Styer. 197 pp. The Johns Hopkins U. P., Baltimore, Maryland, 2011. Price: $30.00 (paper) ISBN 978-0-8018-9760-3. (Stephen Boughn, Reviewer).

According to Daniel Styer, the Library of Congress has nearly 900 books about relativity and I suspect that even more have been published. He then asks whether his "slim volume" can hope to add anything to the subject. His answer is that the present book is neither simply a description nor a technical (mathematical) but rather a "rigorous but non-technical" treatment of special relativity "intended for the general audience, that is, for both scientists and non-scientists." The result, *Relativity for the Questioning Mind*, admirably hits this mark. Like Styer, I dove into relativity as a teenager. For me it was Lillian Lieber's *The Einstein Theory of Relativity*. That book, perhaps more than anything else, influenced my future career as a physicist. Even though I've forgotten the details of Lieber's text, I suspect that Styer's book would have reinforced this impression and, perhaps, hastened my foray into physics.

Styer pledges early on not to ask readers to accept facts on the basis of authority, but wants them to actively participate in acquiring an understanding of relativity. He is largely true to this pledge save a few instances for which he gives ample warning. The result is that the motivated reader can achieve a fundamental, although necessarily limited, understanding of Einstein's theory using only arithmetic and simple algebra. On the other hand, Styer's text is not a quick read. He also requests, or rather demands, that readers puzzle through many problems on their own. These challenges, for the most part, are tendered in problems at the end of every chapter. While the author gives a list of hints and "skeleton" answers in the back of the book he discourages his audience from turning to them, at least not before struggling with the problems. In the author's words, "You will certainly get lost, but will learn through getting lost" and then find your way back by exploring on your own. I wholeheartedly agree with this pedagogical philosophy and often express it to my students, not so elegantly, by telling them how important it is for them to spend time banging their heads against the wall. If readers avoid these struggles, it is unlikely that they will learn any more special relativity than those who consume one of the many descriptive accounts. An example of this modus operandi is a problem at the end of Chapter 10 concerning the restrictions on the speed of a red dot made by a laser pointer on a distant wall. While hints are given, the author refrains from a full explanation of this superluminal phenomenon.

Most of the discussions revolve around length contraction, time dilation, and clock synchronization, and how these three are logically consistent. I very much concur with this approach. Of course, all three follow from the constancy of the speed of light; however, for me, the relativity of clock synchronization is the most difficult to grasp. Therefore, I often elevate the relativity of simultaneity to a position of supreme importance and demonstrate how the other two follow as consequences. This approach requires a bit more mathematical sophistication and is, therefore, probably not appropriate for a general audience. That these three aspects of relativity are visited again and again undoubtedly will result in the committed reader acquiring hard to come by relativistic intuition.

Most people who have studied relativity for any length of time come to a special, personal understanding as to the best way to think about the subject; therefore, it's not surprising that there are some viewpoints expressed in Styer's book with which I disagree. (I'm sure if I had written such a book, he would say the same thing.) I winced when he referred to Einstein's General Theory of Relativity as a theory regarding accelerated frames and later claims that the insightful resolution of the twin paradox "lies in gravitational time dilation." The formalism of special relativity is quite capable of handling accelerations and, in fact, it is more appropriate to use these results, together with the equivalence principle, to provide insight into the effects of gravity (as the author does elsewhere in the text) rather than vice versa. In fact, it's my experience that one of the most confusing aspects of the twin paradox is the persistent notion of students that it is the acceleration of one of the twins that "causes" the differential aging. I was disappointed that Styer didn't address this.

There are a couple of disconcerting passages in the chapter entitled "Speed Limits" where the author is forced to venture into one of the few areas wherein the reader is asked "to accept facts on the basis of authority." In one Styer "explains" why constantly whacking a tennis ball (by a long line of tennis players who deliver one whack to the tennis ball every second) does not increase its speed without limit. He argues that, in the ball's frame, the whacks occur less frequently as the speed increases and, therefore, it picks up less speed than it would had it been whacked once a second. This argument seems dubious to me in several respects and the claim that the whacks occur less than once a second is simply wrong. Owing to the lack of synchronization of the tennis players' clocks in the ball's frame, the whacks are actually delivered more frequently than once a second. Another passage uses (by authority) the expression $E = Mc^2$ to claim that "relativity is responsible for the generation of sunlight and all star light." Of course, this is true in a sense, but then it is also true that relativity is "responsible" for the generation of heat by wood stoves and of the energy that enables a human to walk. Saying that relativity is responsible for these actions doesn't in the least enlighten us about the physical processes involved.

Finally, in an extended conversation about pole vaulters and barns, Styer insists that relativity is a theory of space and time and not of the behavior of clocks and measuring rods, "which are just scaffolding to propel the argument". Maybe it's the experimentalist in me, but I prefer to view relativity as precisely a theory of the behavior of clocks and rods (and matter and energy), with space and time as scaffolding used to elucidate these behaviors. However, as Styer and I both maintain, Einstein's theory can be an endless source of both enjoyment and puzzlement for even seasoned scientists and "would hate to ever feel that [we] had mastered relativity."

The author admits that, although he started learning relativity over 30 yr ago, he continues to "find something new and unexpected and puzzling." After nearly 50 yr, the same is true for me. I recommend this book to all, but especially to those just beginning their exploration of this foreign land.

Stephen Boughn is John Farnum Professor of Astronomy at Haverford College, and currently Visiting Professor of Physics at Princeton University. His research interests include gravitation, cosmology, extragalactic astronomy, and the foundations of physics.

BOOKS RECEIVED

About Time: Cosmology and Culture at the Twilight of the Big Bang. Adam Frank. 428 pp. Simon and Schuster–Free Press, New York, 2011. Price: $26.00 (hardcover) ISBN 978-1-4391-6959-9.

Constructing Reality: Quantum Theory and Particle Physics. John Marburger. 295 pp. Cambridge U.P., New York, 2011. Price: $29.00 (hardcover) ISBN 978-1-107-00483-2.

Dynamical Heterogeneities in Glasses, Colloids, and Granular Materials. L. Berthier, G. Biroli J.-P. Bouchaud, L. Cipelletti, and W. van Saarloos (eds.) 463 pp. Oxford U.P., New York, 2011. Price: $ 135.00 (hardcover) ISBN 978-0-19-969147-0.

Einstein on the Road. Josef Eisinger. 250 pp. Prometheus Books, Amherst, NY, 2011. Price: $25.00 (hardcover) ISBN 978-1-61614-460-9.

Elegance and Enigma: The Quantum Interviews. Maximilian Schlosshauer (ed.) 311 pp. Springer, Secaucus, NY, 2011. Price: $69.95 (hardcover) ISBN 978-3-642-208879-9.

The Feynman Lectures on Physics: The New Millennium Edition. Richard. P. Feynman, Robert B. Leighton, and Matthew Sands. Perseus–Basic Books, New York, 2011. **Volume I: Mainly Mechanics, Radiation, and Heat**. 560 pp. Price: $40.00 (paper) ISBN 978-0-465-02493-3. **Volume II: Mainly Electromagnetism and Matter**. 592 pp. Price: $40.00 (paper) ISBN 978-0465-2494-0. **Volume III: Quantum Mechanics**. 400 pp. Price: $36.00 (paper) ISBN 978-0-465-02501-5.

Galileo's Muse: Renaissance Mathematics and the Arts. Mark A. Peterson. 352 pp. Harvard U.P., Boston, MA, 2011. Price: $28.95 (hardcover) ISBN 978-0-674-05972-6.

The House of Wisdom: How Arabic Science Saved Ancient Knowledge and Gave us the Renaissance. Jim al-Khalili. 331 pp. The Penguin Press, New York, 2011. Price $29.95 (hardcover) ISBN 978-159420-279-7.

How We See the Sky: A Naked-Eye Tour of Day and Night. Thomas Hockey. 249 pp. The University of Chicago Press, Chicago, 2011. Price: $ 20.00 (paper) ISBN 978-0-226-34577-2.

Learning and Teaching Mathematics Using Simulations: Plus 2000 Examples From Physics. Dieter Rößß (Roess). 255 pp. Walter De GruyterInc., Boston, MA, 2011. Price: $49.00 (paper) ISBN 978-3-11-025005-3.

The Manga Guide to the Universe. Kenji Ishikawa, Kiyoshi Kawabat, and the Verte Corp. 263 pp. No Starch Press, San Francisco, CA, 2011. Price: $19.95 (paper) ISBN 978-1-59327-267-8.

The Physicist's World: The Story of Motion and the Limits to Knowledge. Thomas Grissom. 323 pp. Johns Hopkins U.P., Baltimore, MD, 2011. Price: $30.00 (paper) ISBN 978-1-4214-0084-6.

A Student's Guide to Data and Error Analysis. Herman J. Berendson. 237 pp. Cambridge U.P., New York, 2011. Price: $29.99 (paper) ISBN 978-0-521-13492-7.

INDEX TO ADVERTISERS