John Heilbron's *The Sun in the Church* (Harvard, 1999) makes clear. Tycho's geo-heliocentric compromise, well supported by the Jesuits, was a dead end from the standpoint of physics, as both Kepler and Galileo perceived. The kind of progress in physics leading to Newton was thoroughly heliocentric and hence was seriously compromised if not killed in the geo-heliocentrically oriented Catholic countries.

Randles does a thorough job on the topic of his title, the unmaking of the medieval Christian cosmos, tracing the Catholic Church's final coming to terms with the new astronomy by dropping any claims to a specific sacred geography/cosmology. But this must not be confused with a discussion of the European adoption of the Copernican system. His account is much too narrow and blinkered for that. Galileo's rhetorical role and his search for Copernican arguments quite outside the nature of the spheres isn't considered here. There was a great deal more to the new physics than simply defining the nature of the space above us or finding a place for Heaven.

As a sourcebook on "from solid heavens to boundless aether," as the subtitle puts it, Randles's book is excellent, filled with extensive quotations and citations of relatively obscure 16th- and 17th-century authors. It offers a rich, new perspective on parts of the transition to the heliocentric cosmology. But as a comprehensive, synthetic account of that revolution, too much is lacking. It's great as vitamins, but where's the protein?

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Classical Electrodynamics

Julian Schwinger, Lester L. DeRaad, Jr, Kimball A. Milton and Wu-yang Tsai
Perseus Books, Reading, Mass., 1998. 569 pp. $60.00 hc
ISBN 0-7382-0056-5

As most physicists know, Julian Schwinger was a brilliant lecturer. His death in 1994, at the age of 76, raised the urgent question: How might his lectures be preserved and made available to a much wider audience? *Classical Electrodynamics* provides the answer, at least for his lectures on that subject. We must all be grateful to the authors Lester L. DeRaad, Kimball A. Milton, and Wu-yang Tsai.

Classical Electrodynamics is based on Schwinger's 1976 lectures at UCLA, which DeRaad, Milton, and Tsai attended as graduate students and postdoctoral fellows. By 1979, they had produced a manuscript of these lectures, aided by detailed notes supplied by Schwinger. Following later extensive revisions by Schwinger, the manuscript lay dormant for years. After Schwinger's death, the three junior authors revived their manuscript but excluded later material provided by Schwinger which, they claim, might have made the book less accessible to students.

The authors succeeded very well in preserving Schwinger's uniquely elegant style as well as his original and inimitable approach to the subject matter, both of which I well recall from my own attendance of Schwinger's electrodynamics lectures soon after my arrival as a new graduate student at Harvard in 1946. (Schwinger was on the Harvard faculty from 1945 until his departure for UCLA in 1966).

It is natural to compare this text to the very well-known and highly regarded graduate text, also called *Classical Electrodynamics*, by J. David Jackson (Wiley), whose third edition also appeared 1998. Jackson follows the conventional approach of starting with a thorough discussion of electrostatics; he presents Maxwell's equations and macroscopic electromagnetism almost one-third into the book. Schwinger's lectures start with Maxwell's equations, derived in the first chapter in a heuristic way. The treatment of electrostatics begins later, almost one-quarter into the book and after an introduction to special relativity. For Schwinger, the action principle plays a dominant role; it is introduced fairly early, and two chapters are devoted to it. Jackson mentions it only in passing.

Both books do a fine job on special functions, introducing them as they are needed, although Schwinger's lectures give a little more of their properties. This is consistent with his mathematically somewhat more sophisticated approach. Synchrotron radiation and wave guides are two topics to which Schwinger contributed a great deal, as is also reflected in the book.

The omission of Schwinger's later work is unfortunate in at least one respect: It prevents inclusion of Schwinger's 1983 paper solving the old 4/3 problem of electromagnetic energy–momentum in a very general way; this work is covered in Jackson's third edition.

In view of the large number of (short) chapters, DeRaad, Milton, and Tsai provide a guide to those chapters that they consider inessential and those (18 out of 52) that they suggest skipping on first study. There are plenty of exercises at the end of the chapters, chosen to supplement the material presented in the text. The units are Gaussian throughout, following Schwinger's usage.

Just one little gripe: A problem that has caused a great deal of confusion in the past, radiation from uniformly accelerated charges, is discussed and is given a fine and correct treatment. But that chapter confuses the reader by introducing the subject with an unphysical problem setting (nonrelativistic motion with constant acceleration over an infinite time interval), which, not surprisingly, has a physically nonsensical answer (no radiation emission at any frequency). The authors would have done better to omit that introduction.

This is an excellent textbook, full of interestingly presented material. One can learn a great deal from it, but it does require a little more sophistication than do other texts, both in the subject matter and in the powerful use of mathematics.

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General Relativity: A Geometric Approach

Malcolm Ludvigsen
Cambridge U. P., New York, 1999. 217 pp. $74.95 hc ($27.95 pb)
ISBN 0-521-63019-3 hc (0-521-63976-X pb)

Many physics and engineering students are genuinely curious about general relativity but are frightened away by its mathematical complexity. Malcolm Ludvigsen's *General Relativity* may help many students to overcome this problem, at least on the conceptual level. His textbook is written for final-year undergraduate mathematics or physics students; it may work for engineering students as well, if they are sufficiently motivated.

The main purpose of the book, as the author states it, "is to describe, in as simple a way as possible, our present assumptions about the nature of space, time, and spacetime." He reaches the goal almost perfectly. This short, elegant book describes the major ideas of special and general relativity with unprecedented clarity and mathematical depth (for its level). Reading it reminded me of the feelings I had reading I. M. Gel'fand's beautiful textbook on linear algebra, *Lectures on Linear Algebra* (Interscience, 1961), many years ago.

Geometry, the cornerstone of general relativity, is the soul of Ludvigsen's book. All the calculations presented are short and elegant, but many require detailed consideration of the basic geometric concepts lying behind them. Geometry produces both the elegance and major difficulty in understanding the equations. For instance, the derivation of the Friedmann equations in relativistic cosmology is done almost without any calculations.

The book does not contain concrete astrophysical or cosmological applications of general relativity, but it explains very well basic systems and concepts—the Schwarzschild and Kerr singularities, black-hole thermodynamics, and relativistic cosmological models with and without the cosmological term, for example. The author provides the proofs of some important theorems; others are only formulated. As I suspect many physicists do, I close 90% of the books I pick up as soon as I see the word theorem three times. This book, however, is one of a few that did not frighten me off, because the author provides a clear physical explanation for every rigorous mathematical result.

(I noticed only one minor physical inaccuracy: From reading Sec. 16.5, one might conclude that cosmological recombination occurs when the majority of photons have energies sufficient to ionize hydrogen atoms. It was not explained clearly enough that only a tiny fraction of photons has such energies at 3000 K, since the energy of the ionization of hydrogen (13.6 eV) corresponds to the temperature $T = 13.6\ \mathrm{eV}/k_B = 158{,}000$ K. Cosmological recombination happens at much lower temperatures, because the number of photons is about 10^9 times the number of hydrogen atoms. Thus, a tiny fraction of energetic photons in the tail of the thermal distribution is able to ionize hydrogen in the universe. This little drawback by no means modified my very high opinion of this captivating book.)

The textbook is nicely structured. It consists of 16 fairly short chapters, each supplemented by several problems. There are more than ninety problems in all, with solutions provided for about two thirds of them. The bibliography contains references to about forty books on general relativity and cosmology.

Overall, Ludvigsen's book is a very

good addition to the library of anyone who is interested in general relativity, black holes, and cosmology. Many who learned or studied general relativity from other sources would gain from the depth and beauty of the geometrical approach so beautifully described here. Reading Ludvigsen's book will be a particular pleasure for those who prefer deep thinking to performing tedious calculations.

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