Quantum Computing: A Short Course from Theory to Experiment.

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BOOK REVIEWS

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Post-Use Review. Spacetime and Geometry: An Introduction to General Relativity. Sean M. Carroll. 527 pp. Addison Wesley, San Francisco, 2004. Price: $85.60 ISBN 0-8053-8732-3. (Daniel Finley, Reviewer.)

During the last few years there have been several new books that attempt to make general relativity more accessible to students who do not plan to specialize in (the theoretical aspects of) that area. There are, of course, many good reasons for wanting to do this. The theory has a reputation for being highly mathematical, replete with nonlinear equations that are difficult to solve and difficult to visualize. On the other hand, that same reputation says that it is the "very model" of the way that a classical field theory should behave, even providing the equations for the behavior of test particles without any need to append them to the theory. The first line of this book's preface says that "General relativity is the most beautiful physical theory ever invented … leading to unambiguous predictions that have received spectacular experimental confirmation." How, indeed, could any true student of advanced physics not want to learn such a theory? Still more seductive to some students is the appeal of cosmology, a subject that has attracted scientists for thousands of years. Modern, experimental cosmology can provide a different line of research, one that uses a reasonable understanding of general relativity to help pick out answers from the heavens.

The new books on general relativity have varied from simple expositions of the predicted behavior of objects near black holes, written to be accessible to freshmen or sophomores, up to the present text, which attempts to provide a good background for serious graduate students in physics or astrophysics. Carroll's text is more advanced and mathematical than *Gravity*, by James B. Hartle, but is aimed at a broader audience than a traditional older text such as *General Relativity*, by Robert M. Wald.

The author comes from a training as a particle physicist, rather than a specialist in the geometrical and mathematical depths of general relativity. This background is probably an advantage for many readers, who will better understand the more familiar viewpoint toward the mathematics. The preface states that the book takes "a point of view that helps one to appreciate the connections among GR, particle physics, and string theory." Carroll's approach to the mathematics is perhaps ideal for the intended audience, and is presented with great clarity. On the other hand, I would describe this book's presentation of tensors as old-fashioned. These days, most research work in relativity uses a more coordinate-free approach, with less index notation and more use of differential forms.

The book's early chapters review special relativity and use it as a vehicle to introduce the basic machinery of tensors, albeit with many indices. After that, the more abstract, but quite important, notion of a tangent space is introduced in a very natural way. Then, there are explicit examples of manifolds, which are quite good, although there are not many. These are accompanied by rather successful descriptions of affine connections and their curvature, along with the important physical interpretation of curvature as tidal gravitational force. As the mathematical descriptions continue, there is very good interplay between the mathematics and the physics that it is intended to interpret. Well-phrased descriptions of the behavior of tangent vectors under coordinate transformations lead the author to also consider objects that transform in an inverse mode, such as the differentials of the coordinates. On the other hand, while these differentials do lead into an introduction of cotangent spaces, or spaces of 1-forms, their importance is downplayed. The discussions of the curvature tensor, the connections, the Bianchi identities, and the equations of geodesic deviation would really be improved by more use of differential forms.

This omission is partly addressed in the very last appendix in the text. However, this is clearly an "add on," which I would hope to see incorporated into the main body of the book in a subsequent edition. Also introduced only in this appendix is the use of non-holonomic basis 1-forms—again quite seriously downplayed in the main body of the text, even though this is the most common approach for research papers in this area. Non-holonomic basis sets begin with coordinate constructions, but they are then weighted by functions of those coordinates in such a way as to provide a good generalization of the orthonormal sets of basis vectors usually used in undergraduate mechanics and electromagnetic theory. Just as in those courses, the use of non-holonomic basis sets makes it easier to quickly acquire the correct physical intuition for the vector components. This approach to basis sets was forcefully introduced to the astrophysical community, now quite some time ago, by J. M. Bardeen and his collaborators in their important 1972 paper concerning the intuitively unexpected things that can occur in the neighborhood of a rotating black hole.

Carroll does provide good descriptions of several other important mathematical constructions that are not always done well, at any intuitive level, in other books. These include Lie derivatives, essential for a true understanding of the role that symmetries play in field theories, and also conformal, or Penrose, diagrams, which are an important tool for understanding "points at infinity." This approach also allows Carroll to give clear, brief discussions of the nature of causality in general relativity—definitely an important topic.

Additional strengths of this book include its detailed, up-to-date physical descriptions of many interesting astrophysical objects. Prominent among those objects are the various sorts of black holes, including those that are charged or rotating. The physical descriptions are well supplemented by discussions of event horizons, Killing horizons, naked singularities, trapped surfaces, and maximal extensions of the manifolds that pertain to black holes. This material provides an excellent foundation for future work in black-hole physics, including numerical simulations of accretion disks and black-hole collisions.

The discussion of gravitational radiation is heavily weighted toward the hopefully upcoming experimental results from Laser Interferometer Gravitational-Wave Observatory (LIGO) and other gravitational-wave telescopes. The discussion of cosmology is very current, with much discussion of where experimental cosmology is headed, along with quick, clear analyses of why cosmologists believe they should be headed that way. There could have been more discussion of current work along other directions than that which the cosmologists seem to be heading, for instance recent work of G.F.R. Ellis. The final chapter attempts to introduce students to some very interesting quantum effects that are of considerable interest in astrophysical relativity, such as the Unruh effect and the Hawking effect; there is even a mention of the holographic principle. This is a good try; however, the overquick introduction to quantum field theory was insufficient for most of the students in my class. Here they needed to have more of Carroll's background in particle physics than they actually did have.

Various topics have been omitted, both theoretical and experimental. This is clearly necessary to maintain a reasonable size for the book. However, I would have liked to see some mention of the spinor descriptions of the underlying mathematics, and also the Petrov classification of the curvature tensor, including some discussion of all the work required to determine whether two apparently different solutions of the Einstein field equations actually correspond to the same manifold. There is also no real discussion of all the current work on exact solutions and the intense effort to determine which ones may have physical consequences; a mention of the newly published second edition of *Exact Solutions to Einstein's Field Equations*, by Hans Stephani *et al.*, would be appropriate in this regard.

As a summary, I will simply say that I will use this book again in my graduate-level introduction to general relativity. I will also note that there is a useful Web site that advertises the book and its contents, and keeps an ongoing list of known (mostly minor) errata: http://spacetimeandgeometry.net or http://pancake.uchicago.edu/~carroll/grbook.

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Quantum Computing: A Short Course from Theory to Experiment. Joachim Stolze and Dieter Suter. 244 pp. Wiley, Hoboken, NJ, 2004. Price: $59.95 (paper). ISBN 3-527-40438-4. (David P. DiVincenzo, Reviewer.)

Quantum computing is a new idea for how information processing can be done in a setting where quantum superpositions are routine. This concept first attracted noticeable attention less than 15 years ago: the serious literature before 1994 is significant, but minute. In the short time since, quantum computing has grown to a gigantic enterprise with thousands of researchers and a voluminous and ramified research literature. *Ad hoc* courses that try to make some sense of this subject for students at various levels and with varying backgrounds have sprung up abundantly in recent years, and this new book of Stolze and Suter comes from their lecture notes for one such course.

One would think that 15 years is too short a time for a settled pedagogy to have been established for such a new endeavor, but in fact there seems already to be a fixed canon that is followed by the majority of courses that lecturers are putting together on this subject. First, there must be a review from the ground up of quantum theory, since the student may be from computer science and have no prior knowledge whatever of physics. This review emphasizes the mathematical structure of quantum mechanics and touches lightly, if at all, on the phenomenology of the quantum world: von Neumann, not Landau. Second, there has to be a review of theoretical computer science from the ground up, since the student may be from physics, etc. Here one learns about Turing machines, Boolean logic, and complexity theory, but not nasty practical things like compilers and the Internet. Then follows the synthesis: quantum hypotheses applied to bits give qubits, quantum gates, and quantum circuits. The amazing quantum algorithms are next, usually those of Deutsch, Jozsa, Grover, and especially (and in considerable technical detail) Shor. Another chapter is needed for error correction in a quantum setting (Shor again).

This much seems to be mandatory; what follows depends a bit on taste. The theory of quantum communication can be done more thoroughly. Various areas of phenomenology can be delved into, since a quantum computer needs to be made out of something someday. This may take the course into spectroscopy, optics, solid state devices, superconductivity, ion traps, or nuclear magnetic resonance—the possibilities at this point are many.

This assembly of topics is more than enough for a full course, and for a full volume of lecture notes. Stoltze and Suter dutifully, and, in fact, rather enthusiastically, do the mandatory subjects, followed by a short but well-done excursion into the electives, most notably in nuclear magnetic resonance methods of implementing quantum computing. I think that they, and their students, had some good fun with this material, and the book shows it.

However, the potential buyer, or lecturer, or student, needs to be aware that there are a lot of other options out there for following the canonical pedagogy. Of the many that the Google-savvy Internet surfer will locate after a couple of seconds, I want to commend two especially to the reader of this column, plus a few more.

First there is Nielsen and Chuang, *Quantum Computation and Quantum Information* (reviewed in AJP **70**, 558–559, 2002). Published in 2000, this has rapidly become *the* canonical book for the canonical course—indeed, this book had not a little to do with defining the canon as I described it above. Nielsen and Chuang are both leading researchers in the field, and the writing here shows it: it is in depth, well informed, and comprehensive. There is only a little in Stolze and Suter that is not in Nielsen and Chuang. On the other hand, Nielsen and Chuang has been not-so-charitably described as "encyclopedic"; its 676 pages can be hard going for the newly initiated, so Stolze and Suter's paring down to 244 pages may well be a valuable service for some users.

But for those who want a *really* pared-down go at quantum computing, David Mermin's lecture notes (only a Web resource at the moment: http://people.ccmr.cornell.edu/~mermin/qcomp/CS483.html) are unique in filling the gaps that are present in every other treatment if one is to do a good job of teaching the subject to undergraduates. For example, he patiently takes the student through the trivial but perilous notational chores needed to properly write a state vector of a multiqubit wave function. Mermin manages to get through the standard canon too, if only barely.

Finally, there are several other sources that must be mentioned as essential complements to all the foregoing, for students who want to go further—the faint of heart should not venture into this territory. The outstanding example in this genre is John Preskill's lecture notes (also Web only at present, http://www.theory.caltech.edu/~preskill/ph219/index.html), which will take readers from the standard canon into the stratosphere of quantum dynamics of topological excitations in many-body systems. Finally, for those who want to dive deep into the computer science side of the subject, the honest-to-God book by Kitaev, Shen, and Vyalyi, *Classical and Quantum Computation* (American Mathematical Society, Providence, 2002), and the lecture notes of Vazirani (http://www.cs.berkeley.edu/~vazirani/quantum.html), are the places to go.

So, Stolze and Suter enter a crowded field, but perhaps have a narrow place in it. Their little volume is significantly marred, in my opinion, by the inclusion of no exercises; many can be found in the materials mentioned above. But these lively lectures can, I think, be a help to the poor student who embarks on this difficult study.

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BOOKS RECEIVED

Adventures in Order and Chaos: A Scientific Autobiography. George Contopoulos. 191 pp. Kluwer, Norwell, MA, 2004. Price: $129.00 ISBN 1-4020-3039-8.

American Prometheus: The Triumph and Tragedy of J. Robert Oppenheimer. Kai Bird and Martin J. Sherwin. 722 pp. Knopf, New York, 2005. Price: $35.00 ISBN 0-375-41202-6.

Applied Mathematical Methods in Theoretical Physics. Michio Masujima. 377 pp. Wiley, Hoboken, NJ, 2005. Price: $180.00 ISBN 3-527-40534-8.

Challenges to the Second Law of Thermodynamics: Theory and Experiment. Vladislav Čápek and Daniel P. Sheehan. 347 pp. Springer, New York, 2005. Price: $159.00 ISBN 1-4020-3015-0.

Chance: A Guide to Gambling, Love, the Stock Market, and Everything Else. Amir D Aczel. 160 pp. Thunder's Mouth Press, New York, 2004. Price: $21.00 ISBN 1-56858-316-8.

Dual Superconductor Models of Color Confinement. Georges Ripka. 145 pp. Springer, New York, 2004. Price: $59.95 ISBN 3-540-20718-X.

Einstein and Culture. Gerhard Sonnert. 427 pp. Humanity Books, Amherst, NY, 2005. Price: $28.00 ISBN 1-59102-316-5.

Einstein's Miraculous Year: Five Papers that Changed the Face of Physics (reprint). Edited by John Stachel. 248 pp. Princeton U. P., Princeton, NJ, 2005. Price: $16.95 (paper) ISBN 0-691-12228-8.

Electromagnetic Field Theory Fundamentals (second edition). Bhag Guru and Hüseyin Hiziroğlu. 681 pp. Cambridge U. P., New York, 2005. Price: $85.00 ISBN 0-521-83016-8.

A First Course in Computational Physics and Object-Oriented Programming with C++. David Yevick. 403 pp. (plus CD-ROM). Cambridge U. P., New York, 2004. Price: $70.00 ISBN 0-521-82778-7.

A First Course in Scientific Computing: Symbolic, Graphic, and Numeric Modeling Using Maple, Java, Mathematica, and Fortran90. Rubin H. Landau. 481 pp. (plus CD-ROM). Princeton U. P., Princeton, NJ, 2005. Price: $49.50 ISBN 0-691-12183-4.

The Geometry of Time. Dierck-Ekkehard Liebscher. 241 pp. Wiley, Hoboken, NJ, 2005. Price: $85.00 (paper) ISBN 3-527-40567-4.

Introduction to Optics. Germain Chartier. 595 pp. Springer, New York, 2005. Price: $89.95 ISBN 0-387-40346-9.

Laser Resonators and Beam Propagation: Fundamentals, Advanced Concepts and Applications (second edition). Norman Hodgson and Horst Weber. 793 pp. Springer, New York, 2005. Price: $149.00 ISBN 0-387-40078-8.

Lunar Orbiter Photographic Atlas of the Near Side of the Moon. Charles J. Byrne 329 pp. (plus CD-ROM). Springer, New York, 2005. Price: $79.95 ISBN 1-85233-886-5.

Measurement Uncertainties in Science and Technology. Michael Grabe. 269 pp. Springer, New York, 2005. Price: $89.95 ISBN 3-540-20944-1.

Nematic and Cholesteric Liquid Crystals: Concepts and Physical Properties Illustrated by Experiments (translation). Patrick Oswald and Pawel Pieranski. 618 pp. Taylor & Francis, Boca Raton, FL, 2005. Price: $129.95 ISBN 0-415-32140-9.

Quantum Theory of the Electron Liquid. Gabriele F. Giuliani and Giovanni Vignale. 777 pp. Cambridge U. P., New York, 2005. Price: $90.00 ISBN 0-521-82112-6.

Special Relativity: A First Encounter. Domenico Giulini. 168 pp. Oxford U. P., New York, 2005. Price: $14.99 ISBN 0-19-856746-4.

Study Skills: A Student Survival Guide. Edited by Kathryn L. Allen. 122 pp. Wiley, Hoboken, NJ, 2005. Price: $30.00 (paper) ISBN 0-470-09485-0.

The Sun, Solar Analogs and the Climate. J. D. Haigh, M. Lockwood, and M. S. Giampapa. 425 pp. Springer, New York, 2005. Price: $89.95 ISBN 3-540-23856-5.

Topological Quantum Field Theory and Four Manifolds. Jose Labastida and Marcos Marino. 222 pp. Springer, New York, 2005. Price: $79.95 ISBN 1-4020-3058-4.

Victory and Vexation in Science: Eintein, Bohr, Heisenberg, and Others. Gerald Holton. 229 pp. Harvard U. P., Cambridge, MA, 2005. Price: $35.00 ISBN 0-674-01519-3.

The Violent Universe: Joyrides through the X-ray Cosmos. Kimberly Weaver. 224 pp. Johns Hopkins U. P., Baltimore, 2005. Price: $30.00 ISBN 0-8018-8115-3.