American Journal of Physics

BOOK REVIEWS | JANUARY 01 2021

Quantum Legacies: Dispatches from an Uncertain World FREE

Quantum Legacies: Dispatches from an Uncertain World.. David Kaiser 360 pp. University of Chicago Press, Chicago, IL, 2020. Price: $26 (hardcover). ISBN 978-0-22-669805-2.

Cameron Reed

Am. J. Phys. 89, 123–124 (2021)
https://doi.org/10.1119/10.0002262

BOOK REVIEWS

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Exploring Black Holes. 2nd ed. Edwin F. Taylor. John Archibald Wheeler, Edmund Bertschinger. Electronic version only; freely downloadable at http://www.exploringblackholes.org. (David Derbes, Reviewer.)

More than half a century ago, Edwin F. Taylor and John Archibald Wheeler wrote the indispensable *Spacetime Physics,* an unconventional, brilliant, and unique—what else would you expect from John Wheeler?—introduction to special relativity. It has been in print ever since, and now, through Taylor's generosity, the second edition is available for free.[1] But before getting to the sequel, reviewed here, some background seems in order, for a famous book and its legendary authors.

In 1962, Taylor was a young physics professor at Wesleyan University, starting a sabbatical at Princeton, and somewhat prophetically taking up residence in the office of Eric M. Rogers,[2] on leave. He was about to complete his first book,[3] when, a few days into his visit, he fell into conversation with Wheeler. The conversation changed his life, and, if you have studied physics in the past 50 years, probably yours as well; it certainly changed mine. Wheeler was about to engage in one of those wildly audacious enterprises he was famous for: beginning his honors first year class with *relativity*. (Feynman is quoted in the *New York Times*' obituary of his old teacher: "Some people think Wheeler's gotten crazy in his later years, but he's always been crazy."[4]) Would Taylor be willing to attend Wheeler's lectures, transcribe them, and then with him turn these notes into a book? He accepted, and the rest is history.

Taylor described his collaboration in Wheeler's 60th birthday festschrift.[5] Most of the papers therein, including contributions by Wheeler's two (so far!) Nobel-winning students Feynman and Kip S. Thorne, describe new results by friends and colleagues. The last contribution, by Taylor, stands apart. The narrative details the work Taylor did with Wheeler and its consequence. As important as Niels Bohr was to John Wheeler, so was John Wheeler to Edwin Taylor. Apprentice grew into collaborator, and a younger man was set alight by the inner fire of the older master, and finally in Taylor's own words, "graduated from him to himself." The experience redirected the trajectory of his life, away from pure physics research to "a path less traveled by," the art and science of teaching physics. And for nearly 60 years that is what Edwin Taylor has done, with uncommon skill and dedication.

After the sabbatical, he left Wesleyan to join the Science Teaching Center (now the Educational Research Center) at MIT. There he collaborated with Anthony French in writing the last of a series of four undergraduate texts (available in paperback, to keep their price low).[6] Forty years ago he became one of the first to introduce computers into physics instruction, particularly in relativity and quantum mechanics, where these machines could provide a virtual workshop for phenomena not easily accessible otherwise. In addition to his books and articles, he's served as the editor of this Journal, and was recognized "for notable contributions to the teaching of physics" by the Oersted Medal, in 1998.

So much of Taylor's work has been directed towards making physics, and particularly the physics that takes your breath away, *accessible*—this is the *leitmotif* of his professional career. For decades, he has tried to encourage and validate women in physics (in his request for applications to edit this Journal, he pointedly remarked that there had been no appearance of gendered personal pronouns;[7] in his later books, he made sure that both male and female individuals appeared in examples and exercises). Aware that not everyone can afford them, he has made available for download software, articles, previous books, and now, this most recent publication. Mirroring Wheeler's audacious introduction of relativity to beginning students, in later years, Taylor has championed the early application of the principle of least action as a skeleton key for opening wide the secret chambers of classical mechanics, quantum mechanics, and general relativity,[8] in courses often taught well in advance of the usual sequence. In this work, he has had the assistance of several colleagues. The calculus of variations may not be appropriate for beginners, but *applying* it cleverly requires at most ordinary derivatives, well within the reach of neophytes. To get this powerful tool into their hands, you have to be inventive. Taylor and Wheeler have been masterly in showing the rest of us how to do it.[9]

I had the good fortune to serve as Taylor's teaching assistant for a couple of weeks in July of 1988, when I was one of 50 high school physics teachers at a Woodrow Wilson institute held at Princeton. A couple of days in, the director asked for help from someone who was comfortable with relativity and computers. I volunteered, was given Taylor's email address, and got in touch with him. He sent me (via the standard delivery system of 1988, the US Postal Service) software he and his MIT students had developed to show some of the peculiar aspects of relativity: "Spacetime," for length contraction, time dilation, and the failure of simultaneity (allowing the user to frame various simulations, including the twin paradox); "Collision" for calculating final velocities in relativistic collisions, and "Visual," representing the appearance (in color) of geometrical solids as seen out the windshield of a spaceship traveling past them at a user-adjustable relativistic speed.[10] He was to give a handful of hourly lectures at the summer institute, and introduce us in a laboratory setting to the use of the software (which he then encouraged us to give away to our students). It was my job to get the computer lab ready. I met him at Princeton's "Dinky" shuttle station (he was wearing a jaunty seersucker suit, and tieless; perfect for the hot, sticky summer days in New Jersey[11]), and drove him to the Nassau Inn. We talked now and again during the week he was there. He reminded me a little of Wheeler (whose sophomore class I'd taken in 1971–1972); expansive, warm, considerate, and enormously enthusiastic. He was a hell of a lot of fun to talk with. Since then I have had only sporadic communication with him. One of these conversations led to an early sighting of the sequel to *Spacetime Physics,* then called *Scouting Black Holes,* circa 1990, which I think he invited me to obtain electronically (ftp) from MIT.

What I recall about *Scouting Black Holes* (my copy is not to be found; perhaps loaned to a student) is that it began as a *continuation* of *Spacetime Physics;* the first chapter was numbered 4. While *Spacetime Physics* had needed only algebra, *Exploring Black Holes* assumed a knowledge of derivatives and elementary integrals (nothing beyond the first semester of calculus). Unlike the earlier work, the new book was largely project-driven; a series of explorations were laid out to be gone through more or less sequentially. It was at least as revolutionary as its predecessor. Sometime in the next four years, *Scouting Black Holes* became *Exploring Black Holes,* and no longer presupposed a good knowledge of the earlier book (the chapters more conventionally began at 1, and there was some introductory material largely borrowed from *Spacetime Physics*). The projects were demoted in importance, and the book, now far more expository, was much closer in form to *Spacetime Physics.* The first edition was published in 2000,[12] and very regrettably is out of print (I've held on to mine). Copies may be found at online secondhand bookstores, but they command at least twice the original list price. Perhaps discouraged by the fate of the first edition, Taylor followed the advice offered by Ruth Chabay to forget about publishing the second edition in hard copy. Although what is online is labeled a draft, it represents a quarter century of writing and thinking about the material. Apart from a very small number of images that need tweaking, and perhaps a section or two to be filled in, it's ready for the printer.

The main idea of the book is explained in the third chapter, "Curving" (Box 4, pp. 3–10). In comparison to the rest of the universe, the black hole is not so forbidding: "its relatively small size allows us to call the black hole our 'little jugged apocalypse,' a phrase the writer John Updike uses to describe the view into the portal of a front-loading clothes washing machine." Its manageable (and mostly simple) size and character "make[s] the black hole a useful example to teach large swaths—but not all—of general relativity." Not all, but quite a lot! The key to the (non-spinning) black hole is the Schwarzschild metric. Much can be learned from the geodesic trajectories which follow from it by the action principle. In the second edition, unlike in the first, geodesics themselves are not introduced by that name. Instead, they are described by "The Principle of Maximal Aging": proper time (here called "wristwatch time") is to be maximized (as it is along a geodesic[13]), and a connection is made between worldlines and Euclid's theorem about the minimum distance being a straight line. In both editions, the Schwarzschild metric is *not* derived, nor is most of the machinery of general relativity introduced: no Riemann tensor, no Christoffel symbols, certainly no Einstein field equations. Nevertheless, most of the classic tests of general relativity *are* here: The bending of light and the 1919 eclipse results (Chapter 13), the perihelion shift of Mercury (and other planets) in Chapter 10, and the gravitational red shift (in the treatment of GPS, Chapter 3). A regrettable loss from the first edition is a careful study of the fourth classic test of general relativity, Irwin Shapiro's wonderful experiments of timing radar echoes off Mercury, Venus, and Mars to establish directly the effect of gravitation on the speed of light (Project E).

The most noticeable changes in the second edition are the absence of projects (though they are nearly all laid out as guided examples) and the far greater content of the second edition, reflected in the nearly double number of pages (p. 660 vs. p. 340). There are five chapters and seven projects in the first edition, and twenty-one chapters in the second. A new addition is the considerable time and detail devoted to orbital mechanics around both stationary and spinning black holes, the latter requiring the Kerr metric (in both Boyer–Lindquist and Doran forms).[14] In the first edition, spinning black holes are relegated to a project (F); in the second, they are given the last five chapters. Results which had not been known in 2000 are discussed, in particular LIGO and the discovery of dark energy. (In the first edition, Wheeler states (p. G-11) that he doesn't believe the then recent results found by Saul Perlmutter, Adam Riess, and Brian Schmidt, implying the existence of dark energy. These were soon confirmed and won their discoverers the 2011 Nobel Prize.) Topics covered in the first edition are often given improved and deeper coverage in the second. For example, the familiar "rubber sheet" funnel-shaped diagram of the spacetime near a spherical mass was merely described in the first edition; in the second, the shape of the surface is derived. In the description of the bending of light (Chapter 13, "Gravitational Mirages"), new features include a historical timeline (starting with J. Soldner, and giving the (incorrect) Newtonian calculation as a guided exercise), and much more about gravitational lensing. (Did you know you can visualize an Einstein ring formed by a star using a candle and the stem of a wine glass?) In both editions, the vast majority of calculations are very gently worked out for the benefit of readers who are not so confident in their mathematics.

Because the book is in a form allowing small changes, I suggest a few things that might make it even more attractive: the return of the Shapiro experiment discussion, inclusion of the recent work of Sheperd Doeleman and his team in capturing the first image of a black hole,[15] in particular the result of the photosphere at $r = 3GM/c^2$ (a result which is derived in Chapter 11, Exercise 4), and (to steal an innovation from Misner, Thorne, and Wheeler's epochal *Gravitation*[16]) the introduction of the MTW "Track 1" and "Track 2" notations to help readers distinguish the main thread from more intricate results. There was no need for this in the first edition, but perhaps there is in the second. The first edition might serve broadly as the "Track 1" material, and the fine details about orbital mechanics, and nearly all of the content concerning spinning black holes and the Kerr metric, could be "Track 2."

The second edition of *Exploring Black Holes* is a remarkable achievement, a lovely capstone to a great and luminous career. As was true of its predecessor, there is really nothing else like it. Professors and students who would like a first look, or perhaps a different look, at the wonders of general relativity would do well to spend time with this wonderful gift.

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[1]*Spacetime Physics*, 2nd ed., released under Creative Commons license, available at the Internet Archive, or at <http://www.spacetimephysics.org>.

[2]Eric M. Rogers, a Cambridge-trained physicist and Oersted Medal winner (1969) helped develop the PSSC program. Rogers believed fervently in the democracy of physics: It should be made available and accessible to everyone who wants it. He was one of the pioneers of "Physics for Poets" courses, and his *Physics for the Inquiring Mind* (Princeton U. P., Princeton, 1960) was an early textbook for these. Rogers' wonderful PSSC film *Coulomb's Law* (1959) has been made available for free at the Internet Archive courtesy of the director, Richard Leacock; <https://archive.org/details/coulombs_law>.

[3]Edwin F. Taylor, *Introductory Mechanics* (John Wiley & Sons, New Jersey, 1963).

[4]*New York Times,* April 14, 2008.

[5]Edwin F. Taylor, "The anatomy of a collaboration," in *Magic without Magic: John Archibald Wheeler*, edited by John R. Klauder (W.H. Freeman and Co., New York, 1972); Available at <http://www.eftaylor.com/pub/anatomy.html>.

[6]A. P. French and E. F. Taylor, *An Introduction to Quantum Physics*, The M.I.T. Introductory Physics Series (W. W. Norton & Co., New York, 1978).

[7]Edwin F. Taylor, "Why not be an editor?," Am. J. Phys. **45**, 323 (1977).

[8]Edwin F. Taylor, "A call to action," Am. J. Phys. **71**, 423–425 (2003); "The boundaries of nature: Special and general relativity and quantum mechanics, a second course in physics, the Oersted Award acceptance lecture," **66**(5), 369–376 (1998).

[9]A comparable *tour de force* may be found in Richard P. Feynman, *QED: The Strange Theory of Light and Matter* (Princeton U. P., Princeton, 1988).

[10]The "Spacetime" software has been ported to Java by Slavomir Tuleja, and may be downloaded at github: <https://github.com/nathaniel/spacetime>.

[11]In an address to the physics teachers that summer, David Wilkinson told us, "Summer in Princeton is an IQ test: The smart ones leave."

[12]Edwin F. Taylor and John Archibald Wheeler, *Exploring Black Holes* (Addison-Wesley Longman, Massachusetts, 2000).

[13]Feynman used this principle as the basis of a riddle posed to an assistant of Einstein's: Richard P. Feynman, "Who stole the door?," in *Surely You're Joking, Mr. Feynman* (W. W. Norton & Co., New York, 1985), p. 37.

[14]Many graphs in the second edition were produced by the GROrbits program of Slavomir Tuleja, based on earlier software written by Adam Riess for his senior thesis at MIT, under the guidance of Taylor. This software may be downloaded from <https://stuleja.org/grorbits/>.

[15]M. Wielgus *et al.*, "Monitoring the morphology of M87* in 2009-20117 with the event horizon telescope," Astrophys. J. **901**, 67–95 (2020). <https://eventhorizontelescope.org>.

[16]Charles Misner, kip S. Thorne, and John Archibald Wheeler, *Gravitation* (Princeton U. P., Princeton, 2017). This is a reissue of the 1973 edition, with new introductions.

Quantum Legacies: Dispatches from an Uncertain World. David Kaiser. 360 pp. University of Chicago Press, Chicago, IL, 2020. Price: $26 (hardcover). ISBN 978-0-22-669805-2. (Cameron Reed, Reviewer.)

Quantum mechanics, relativity, and their progenies of particle physics and modern cosmology continue to intrigue and baffle students, working physicists, and laypersons alike. In the century since modern physics began, progress has been astonishing, and some current ideas seem as outlandish as the probabilities that so disturbed Einstein in the 1920s. What were once idealized textbook examples or hotly debated theories (quantum wells, entanglement, and gravitational waves) are now the subject of precise and sometimes incredibly expensive experiments, have garnered Nobel Prizes, and even become mass-market technologies. In this collection of essays, Massachusetts Institute of Technology particle physicist/cosmologist and historian of science David Kaiser takes readers on an engaging and informative tour through the quests of twentieth-century physicists to understand space, time, and matter at its most fundamental levels. Kaiser does not try to teach his readers physics; rather, the emphasis is on the connections between scientific exploration and the human condition as viewed through the lives of individual scientists and how they were influenced by the times and places in which they worked, political externalities, collaborators, and evolving institutional priorities. Scientists too are embedded in their cultures.

Kaiser divides his 19 essays into four sections plus an Introduction; there is also a charming Foreword by Alan Lightman, who remarks that the human drive to find patterns may be what holds off insanity. For readers who wish to dig into more background, over 40 pages of notes list a wealth of source material. Most of the essays appeared in other books and articles (notably the *London Review of Books*), but having them gathered into one place will bring them to the attention of a much broader audience.

In his Introduction, Kaiser explains that by "quantum legacies," he has in mind the development of shared understanding that emerges between individuals and across generations. Some of these legacies are explored by examining the efforts of individuals and small groups of collaborators, while others involve the influences of machines such as enormous accelerators and programmable computers, and yet others are entangled with institutions and government agencies. The essays could be read at random, but are best taken together in their respective sections.

Kaiser's sections are Quanta, Calculating, Matter, and Cosmos. In brief, Quanta focuses on discrete moments in the transformation of understanding of the microscopic world from the 1920s onward; here we encounter, among others, Dirac, Einstein, Schrödinger, Pontecorvo, Pauli, Fermi, Bell, and Zeilinger. Calculating is not about computing *per se*, but about how and why the young people of new generations became physicists within the United States during and after WW II, influenced by the Manhattan Project and generous government funding, even while they "learned to calculate" as new technologies emerged. Matter brings the story back to efforts to understand the subatomic realm, with external influencers being the machines of big science; here Peter Higgs is the main personality. Cosmos examines steps in the development of modern cosmology as it grew from being regarded as a slightly disreputable area into a precision science, where cyclic multi-dimensional universes and SETI are topics of serious analysis. The landscape runs from the subatomic to the cosmological, but with human beings always in the foreground.

Kaiser touches on seemingly everything from the sophistication of modern creationist movements to Hawking radiation. Rather than dissect each essay, I will focus on a few items which particularly caught my attention. I especially enjoyed those in "Calculating," which describes the post-war training of physicists in the United States. In effect, this was the educational analog of a classic economic bubble. Overhyped and careless misinterpretations of studies of Soviet training of scientists and engineers led to fear of a manpower gap, which universities were happy to exploit to rake in funding. Ironically, US graduation rates for scientists and engineers were actually ahead of those of the Soviet Union, as well as programs being far ahead in quality. As with any bubble, the bottom inevitably fell out; the crash began about 1970 with funding cutbacks and growing opposition to the Vietnam war. A second bubble emerged in the 1980s when the National Science Foundation warned of another looming manpower shortage, coupled with increased defense funding during the Reagan administration. The breakup of the Soviet Union prompted another crash, which took the supercollider with it. Supply side boosterism disconnected from reality is not limited to just the latest marketing gimmick or questionable investment.

Tied to enrollment booms and busts is an interesting survey of the evolution of the teaching of quantum mechanics in the United States as reflected through generations of textbooks. In the early (pre-war) days, there was considerable emphasis on interpretive and philosophical issues, but with the postwar boom in enrollments and emphasis on applying physics to national defense issues, attention focused much more on practical calculation-grinding training of quantum mechanists, illustrated by the contrasting approaches of texts by Schiff and Bohm. The 1970s downturn and emergence of the new-age generation saw the pendulum begin to swing back, as exemplified by the publication of Capra's *The Tao of Physics*. Contemporary texts go for more of a superposition of the two approaches; as Kaiser concludes, there is no best way to teach quantum mechanics.

This book is full of striking statistics, commentary, and lovely analogies and metaphors. Some of the latter are Kaiser's own while others are attributed; even if a reader is familiar with the physics, they will help crystallize concepts otherwise known only known through formalities and equations. A sampling: The quarter-century after World War II saw more physicists trained than had been, cumulatively, in human history. Wavefunction collapse is likened to having no definite weight until you step on your bathroom scale. Gluons are elves who skitter around, enforcing symmetry. Entanglement is illustrated by correlated or anti-correlated dessert choices of far-separated twins. Richard Feynman's remark that particle-collision experiments are like hurling two pocket watches at each other and examining the remains to divine the intricate mechanisms that were within cannot help but inspire a vivid image, as does the comment that "As far as a photon is concerned, time simply does not flow." (Reviewer comment: Does a photon see the entire universe as Lorentz-contracted to a point?) The Higgs field is molasses through which particles attempt to slog. Cosmology is a poor man's accelerator, and has been a succession of seemingly absurd proposals from Copernicus on up. Chandrasekhar's remark that Misner, Thorne, and Wheeler's *Gravitation* was "… written with the zeal of a missionary preaching to cannibals" has an elegance that most reviewers can only hope to emulate. LIGO is the largest project funded by the NSF, having spawned some 600 dissertations in the US alone since 1992. Every essay illuminates the reader about something.

My only quibbles with this book are that it can be MIT-centric in places, and Kaiser's tendency to dabble in amateur psychologizing. After chiding Dirac biographer Graham Farmelo for speculating that Dirac's personality traits, which would now probably now be regarded as lying on the autism spectrum, were crucial to his success as a physicist, Kaiser goes on in his very next essay to speculate that in the face of a looming world war and genocide, Erwin Schrödinger's thoughts turned to poison, death, and destruction, with the result being his eponymous cat. Later, Alexander Friedmann's cosmologies which emphasized potentially violent change over time are linked to the political tumult of post-World War I Russia.

Overall, however, these are engaging, though-provoking, fun-to-read essays that are compact enough that one can get through several in an evening. They will make you consider familiar physical concepts in new ways. All readers will come away richer in their knowledge of the people and circumstances behind how physics arrived at where it is. You will enjoy this book.

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BOOKS RECEIVED

Bedeviled: A Shadow History of Demons in Science. Jimena Canales. 408 pp. Princeton U. P., Princeton, New Jersey, 2020. Price: $29.95 (hardcover) ISBN 978-0-691-17532-4.

Fly by Night Physics: How Physicists use the Backs of Envelopes. A. Zee. 454 pp. Princeton U. P., Princeton, New Jersey, 2020. Price: $45 (hardcover) ISBN 978-0-691-18254-4.