readers can be assured that he wraps up his mysteries with sober resolutions, but intriguing lessons remain.

Other popular accounts have already covered much of what *Now* discusses, but the book stands apart because Muller, a professor at the University of California, Berkeley, is a leading experimental cosmologist. Although Muller's lucid discussions of the behind-the-scenes difficulties of cosmological experiments make up only a small fraction of the text, they present important new insights to a general audience. It would not hurt if the Antaeus parable, which warns of the perils of losing touch with the ground, were declared required reading for any theoretical physicist.

The first parts of the book aim to introduce the basic physics of spacetime. Some crucial passages, however, may be hard to follow for a novice, as the treatment of relativity relies perhaps too much on difficult discussions of frames. For instance, someone not already familiar with local inertial frames is not likely to get much out of the statement, "If you are accelerating, handle the equations by imagining that your acceleration is essentially a continuous jumping of your proper frame from one reference frame to another one that is moving slightly faster." It is also unfortunate that the book eschews spacetime diagrams on the grounds that they could undermine Muller's new view of time by giving the impression of a spacetime without a dynamical flow.

Muller advises readers to be clear about frames of reference, but he does not always follow that important counsel. When he asks, "How far is it from the outside to the surface of the black hole?" he replies, "The answer is infinite." He seems to be integrating the line element at fixed time, varying only the radial Schwarzschild coordinate, but that trajectory is not the worldline followed by the "falling surface" alluded to in his statement.

The main purpose of these introductory discussions is to set the stage for a new theory of time. In an attempt to avoid spoilers, I'll let the brief quote "the explosion of the universe continually creates not only new space but also new time" suffice to indicate the main idea. Muller is open about the proposal's weaknesses, such as the possibility of violations of general covariance. As the quote suggests, his proposal incorporates an incremental progress of time, which has been envisioned in some discrete theories of quantum gravity. Proponents of such theories are still struggling with the immense difficulties of making their proposals consistent with covariance.

Muller's proposal is original and intriguing, and it has implications beyond physics. He dares to think in broad categories, connecting a physical theory about the universe with climate change and such unwieldy topics as free will. Potential observational tests of Muller's new theory, however, receive rather short treatment. Some statements might be held against the theory if taken as specific predictions; for example, in chapter 22, Muller draws connections between entropy, empathy, and the electorate, and asserts that "the US voter does not want to elect a sociopath." In addition, it sometimes seems that Muller is too quick to push aside competing theories. For instance, he argues that the immense entropy contained in black holes cannot matter for Arthur Eddington's explanation regarding the arrow of time, because black holes are so far away from us. There may be much to criticize about Eddington's proposal, but such quick dismissal is not entirely persuasive.

Nevertheless, Richard Muller's new theory deserves a serious look, and his book presents important lessons in physics and beyond. Most readers will find intriguing new insights in *Now: The Physics of Time*. The book might even be useful to the future presidents in the title of Muller's previous opus.

Martin Bojowald
Pennsylvania State University
University Park

Cavity Optomechanics

Nano- and Micromechanical Resonators Interacting with Light

Edited by Markus Aspelmeyer, Tobias J. Kippenberg, and Florian Marquardt

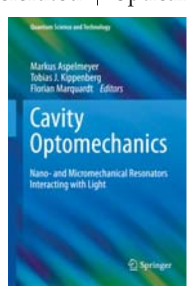
Springer, 2014. $179.00 (357 pp.). ISBN 978-3-642-55311-0

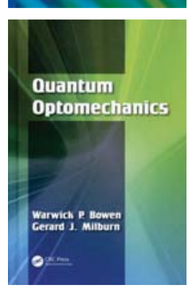
Quantum Optomechanics

Warwick P. Bowen and Gerard J. Milburn

CRC Press, 2016. $99.95 (358 pp.). ISBN 978-1-4822-5915-5

Optomechanics, the study of the mechanical effects of light on massive objects, has a long and distinguished history. It took off nearly 50 years ago, when Arthur Ashkin demonstrated that small dielectric balls can be accelerated and trapped using the radiation-pressure forces associated with focused laser beams. That led to the development of optical tweezers, a tool with wide-ranging applications in biological science.





A parallel development, investigations into the strong enhancement of mechanical effects created by resonant light scattering, led to the laser cooling of ions and neutral atoms. That was followed by the realization of atomic Bose–Einstein condensates in 1995 and the subsequent explosion in the study of quantum degenerate atomic systems. Critical breakthroughs can also be traced back to work on optical gravitational-wave antennas that started in the 1970s and 1980s. It is in that context that researchers understood the role of fundamental quantum optical effects in mechanical position measurements and the resulting standard quantum limit and advanced the idea of back-action evading measurements.

Quantum optomechanics, the field that evolved from those developments, promises to provide motion and force detection near the fundamental limits imposed by quantum mechanics. The field provides the basis for the quantum state control of truly macroscopic objects and for experiments that may lead to a more profound understanding of quantum mechanics.

Light can interact with matter either resonantly or nonresonantly, and both interactions present challenges. Resonance can result in a large enhancement of an interaction, but it is limited to a narrow range of wavelengths. Nonresonant interactions, on the other hand, present the considerable advantage of being largely wavelength independent, but they produce a smaller effect. Cavity optomechanics combines the best of both worlds through the use of carefully engineered resonant structures.

The two books under review offer complementary views of those developments. *Quantum Optomechanics* is coauthored by experimentalist Warwick Bowen and theorist Gerard Milburn, major contributors to the field. It is a graduate-level text that focuses largely on the quantum theory of optomechanical systems and has little to say about experiments, except in very general terms. *Cavity Optomechanics: Nano- and Micromechanical Resonators Interacting with Light* is a collection of 12 invited articles by leading experts from both sides of the Atlantic. It is edited by Markus Aspelmeyer, Tobias Kippenberg, and Florian Marquardt, researchers who have achieved some of the field's most significant recent discoveries. It covers both classical and quantum aspects of optomechanics, with a good balance between theory and experiment.

Quantum Optomechanics assumes a high level of theoretical sophistication and is a challenging text, even for theoretically oriented students. That is most evident in the authors' inclusion of advanced concepts not typically covered in a graduate curriculum. An introductory discussion of the basic physics of optomechanical systems, perhaps in classical terms, would have helped reduce the steepness of the learning curve for newcomers. Furthermore, the exercises mostly fill gaps in derivations, and they will primarily be of interest to theory-inclined students. The book will therefore be most useful to readers who are already well versed in the basic physics of optomechanics and want to dig deeply into the quantum theory of detection, noise, quantum coherent control, and related topics.

Those theory-minded readers will find much to admire in the book. *Quantum Optomechanics* skillfully reviews a wealth of important results on those topics. For example, the book's clear and authoritative discussions cover the various troublesome noises, including measurement and back action, typical of quantum measurements. It also nicely treats the consequent standard quantum limit of mechanical position measurements. Advanced topics such as single-photon optomechanics receive their due, and the authors include a useful introduction to hybrid quantum systems—although perhaps a too brief one in view of the growing importance of the topic. The last chapter, on gravitational decoherence, gives a hint at one of the directions that might be opened up by the availability of quantum optomechanical sensors.

Cavity Optomechanics is more user-friendly. Although not a textbook, many of its chapters would be useful in a graduate course or could serve as a valuable introduction for newcomers. The book opens with some brief remarks by the editors, followed by a concise introduction to the theory of cavity optomechanics, with a simple classical description and a clear discussion of basic quantum aspects. The next chapters give an overview of significant advances in the field through 2014. They cover various topics from both theoretical and experimental points of view, including cavity systems with suspended mirrors, optomechanical crystal devices, LC circuits, ultracold ensembles of thousands of atoms, visible light, microwaves, and more. A final chapter on hybrid systems nicely complements the corresponding chapter in *Quantum Optomechanics*.

The chapters on hybrid systems are not the only point at which readers will find value in consulting both *Quantum Optomechanics* and *Cavity Optomechanics*. Together, the two books make for an authoritative introduction to optomechanics that will serve the needs of graduate students and more experienced researchers interested in moving into the fast-growing field. *Cavity Optomechanics* provides an introduction to many of the most interesting experimental systems, and *Quantum Optomechanics* brings readers up to speed on the state of the art of the theory. Students and researchers concentrating on experimental physics may find that *Cavity Optomechanics* is often sufficient. Theorists would be well advised to dig deep into *Quantum Optomechanics* as well.

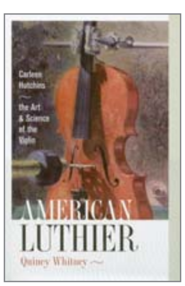
Pierre Meystre
American Physical Society
Ridge, New York

American Luthier

Carleen Hutchins—the Art and Science of the Violin

Quincy Whitney
ForeEdge, 2016. $35.00 (312 pp.).
ISBN 978-1-61168-592-3

I became interested in the musical acoustics of string instruments late in my career and missed meeting Carleen Hutchins. As I got to know the field, however, it became clear that for most of the second half of the 20th century, she was a dominant force in violin acoustics. Hutchins's enormous effort, accompanying struggles, and eventual triumph is captured in great detail by journalist and biographer Quincy Whitney in her book *American Luthier: Carleen Hutchins—the Art and Science of the Violin.*



Hutchins's life was, by any measure, remarkable. A Cornell-educated biology teacher and amateur violist, she took up lutherie (the building and repairing of string instruments) in 1947 at age 36 to occupy herself while expecting her first child. She carved the scroll of her first attempt, a viola, in the maternity ward. Later, juggling motherhood and lutherie, she would use a three-hole poacher in which she cooked eggs for her toddlers in two holes and warmed her glue pot in the third. Anyone who has used animal glue will probably cringe at the thought.

While being treated for breast cancer in 1956, Hutchins met Virginia Apgar, the doctor who developed the famous Apgar test administered to all newborn babies, and struck up a lifelong friendship with the fellow amateur violist. When the pair spotted a hospital telephone booth containing a piece of curly maple shelving that they fancied for a viola back, they planned and pulled off a now-famous heist to secure the desired wood. They replaced the shelf at dead of night with an equally attractive but acoustically useless piece of maple that Hutchins fashioned for the purpose and then cut to size on a toilet seat in the nearby ladies' room. Such was Hutchins's no-nonsense, get-on-with-it manner.

It was when Hutchins met retired Harvard physicist Frederick Saunders in 1949 that she set forth on her life's work. Saunders had been conducting acoustics experiments on whole violins. Hutchins suggested that to make any progress, Saunders would have to work with the individual plates, and that she could make those plates. In the absence of a useful mathematical model of the violin sound box (an absence that persists to this day, although fluid-structure coupled finite-element analysis is coming close), the only way to move forward was to build hundreds of instruments with variations in a dozen or so parameters. Needless to say, that was a Herculean task.

Over the next five decades, Hutchins built more than 300 musical instruments, mostly by herself, and concurrently learned their physics. Her aim was to bring the violin's power and clarity to the viola, cello, and bass, instruments whose lower strings are often hard to hear in ensemble playing. The result was a new "violin octet," which consisted of eight newly designed instruments whose string tuning collectively covered five octaves and brought an even "violin tone" to the whole playing range.

Apgar and Saunders were just two of many talented people who bonded with Hutchins. She plainly had an ease with the accomplished, and after a while she no longer had to seek them out: They beat a path to her door—literally, as she operated out of her own house. She counted fellow luthiers, physicists, and world-renowned musicians such as Yo-Yo Ma and Leopold Stokowski among her friends and admirers.

While researching *American Luthier*, Whitney interviewed dozens of people in the US and Europe. She intersperses the story with vignettes on historical topics that set the scene for Hutchins's acoustics work. Whitney also peers into the world of luthiers and violin dealers—upon which Hutchins did so much to shine the light of day—and discusses the still-vexed issue of the relative quality of old Italian violins versus fine modern instruments, which can differ considerably in cost.

I have some quibbles with the book, mostly points that should have been caught by an editor. First, although the book is intended for a nonexpert audience, occasionally terms and phrases like "Helmholtz mode" or "JASA," the abbreviation for the *Journal of the Acoustical Society of America*, pop up out of nowhere unexplained. Second, some of the physics explanations would confuse a layperson. For example, Whitney says "the rush of air exiting through the f-holes amounts to a ten mile per hour wind." I know what she means, but a person expecting to place a hand over a violin f-hole and feel a draft would be disappointed.

Since her death, Hutchins's fame seems to have faded somewhat, at least in part because of the failure of the conservative musical community to embrace her new instruments. Hutchins's work, however, was always going to be a tough sell to traditionalists. Thus *American Luthier* is a timely work, and I recommend it to anyone interested in musical acoustics or in Hutchins's extraordinary life.

Chris Waltham
University of British Columbia
Vancouver, Canada