G. D. Falksen, a science-fiction author, wearing a steampunk-style outfit that features an arm mechanism designed by the artist Thomas Willeford.

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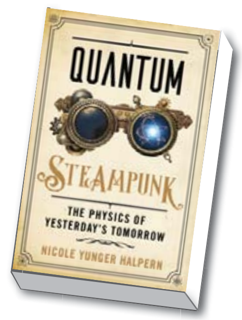
Quantum thermodynamics, today



Quantum Steampunk
The Physics of Yesterday's Tomorrow

Nicole Yunger Halpern
Johns Hopkins U. Press, 2022. $29.95

After hearing the impressive lecture Nicole Yunger Halpern delivered in Barcelona, Spain, upon receiving the biennial Ilya Prigogine Prize for Thermodynamics in 2019—the first time the prestigious award was given for a PhD thesis on quantum thermodynamics—I knew she would shine in the years to come. Only a few years later, Yunger Halpern has followed through on that promise with an entertaining book, *Quantum Steampunk: The Physics of Yesterday's Tomorrow*, that explains the essence and secrets of the many facets of quantum thermodynamics in layman's terms. The field has boomed in the past 15 years, in part thanks to Yunger Halpern: Despite her youth, she has already authored an impressive number of highly cited papers, some in collaboration with respected experts and renowned pioneers.

Steampunk is a literary and artistic genre in which Victorian-era settings are juxtaposed with futuristic technologies. Yunger Halpern argues that quantum (or quantum information) thermodynamics has a "steampunk aesthetic" because it applies physical concepts developed in the 19th century to cutting-edge quantum information science. To illustrate that idea, Yunger Halpern precedes each chapter with a short skit written in the style of fin de siècle British English that tells a brief story about Audrey and Baxter, the Victorian-era ancestors of quantum physics protagonists Alice and Bob. By adding literary flair to otherwise dry technical content, Yunger Halpern masterfully conveys in simple terms the variety of complex ideas that characterize the different subfields of quantum thermodynamics. Even if they lack the technical background needed to grasp all the details she discusses, lay readers will learn a lot and gain a clear picture of the goals, tools, and aims of those subfields.

It may seem churlish not to give *Quantum Steampunk* my full blessing. But I hesitate to do so because I wish Yunger Halpern had discussed subfields from other disciplines, such as engineering, that also contributed to the development of thermodynamics in the 20th century. For example, what today's quantum thermodynamicists call "second laws" parallel what engineers call "exergies." Those include investigating the maximum work that can be obtained from a system depending on its constraints, its interactions, and the types of thermal reservoirs it can access. Similarly, what today's quantum physicists call "free energy" parallels the engineering concept of available energy with respect to a thermal reservoir. That concept is well known and should not be confused with the traditional Helmholtz and Gibbs free energies of classical thermodynamics.

Nonequilibrium thermodynamics is another subfield that deserves more attention. At minimum it should be added to the list of related fields that Yunger Halpern believes should be bridged to quantum thermodynamics so that they can trade ideas, insights, and questions. Many new advances in the modeling toolboxes for nonequilibrium irreversible dynamics in various fields—including mechanical engineering, continuum mechanics, solid mechanics, chemical engineering, and mathematical physics—have converged on a common mathematical framework. That structure reveals a great law of nature that I like to call the "fourth law of thermodynamics," and it can also be formulated quantum thermodynamically.

I also take slight issue with one aspect of Yunger Halpern's description of qubits—namely, that they can have "temperatures below absolute zero." After all, Norman Ramsey demonstrated in his famous 1956 paper that "negative temperatures are hotter than positive temperatures" and that those temperatures characterize a set of equilibrium states that are neither below nor even close to absolute zero. Such states tend to give up energy much more readily than states with infinite positive temperature do.

It is also a bit disappointing that Yunger Halpern did not mention James Park and William Band in the brief sketch of the history of quantum thermodynamics in chapter 6. Admittedly, she is correct when she states that detailing the field's history in full would require another book, and she does list a 1978 paper by Park and Band in the references. But they deserve to be considered true pioneers for their still-overlooked general theory of empirical quantum state determination, which anticipated by three or four decades the field that has now been dubbed quantum state tomography.

Park also published a masterpiece on the "nature of quantum states" in 1968 that every quantum physicist must read, and he proved the no-cloning theorem in 1970, which was 12 years prior to the publication of the famous and often-cited papers by William Wootters, Wojciech Zurek, and Dennis Dieks. Park deserves to be mentioned to quantum steampunkers not only because of his truly farsighted and pioneering contributions but also for the depth and independence of his humble but crystal clear thoughts. His story should also serve as a warning to tomorrow's physicists that it is their duty to read many of yesterday's classic papers before writing new ones.

Despite my quibbles, *Quantum Steampunk* is an excellent introduction to a burgeoning field. I only hope that Yunger Halpern can find a way to widen the scope of the book in a future edition.

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