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Physics in Perspective

Book Reviews

Gian Francesco Giudice, *A Zeptospace Odyssey: A Journey into the Physics of the LHC*. Oxford and New York: Oxford University Press, 2010, ii + 276 pages. $45.00 (cloth).

In recent years there has been a great deal of expectation, even hype, for the launching of the Large Hadron Collider (LHC) at CERN. Numerous articles have appeared in newspapers and in science magazines. Some describe the construction of an accelerator composed of more than twelve hundred 15-meter long superconductor magnets placed in a 27-kilometer tunnel that courses between Switzerland and France, some on the colossal detectors, some on the anticipated physics–even some talk of the awaited discovery of the Higgs boson as the "god particle." These piecemeal descriptions may have left a rather confused picture for readers who are not experts in the field. There is now finally an authoritative and comprehensive nontechnical introductory account, written by the CERN theoretical physicist, Gian Francesco Giudice. The author has produced an engaging story of the LHC, giving the proper particle-physics background, an appreciation of the difficulty of constructing this mammoth machine at the technological forefront, and most importantly, giving an appropriate perspective of the anticipated physics discoveries.

As a way to aid the reader in visualizing the relevant physics regime that will be explored by the LHC, Giudice employs a helpful narrative device: the zeptospace. The high-energy machine designed to collide protons head-on at energy in excess of a thousand billion electron volts can probe a distance scale less than a hundred zeptometers (10^{-21} m). In this way, the LHC is presented as the spaceship that will explore the zeptospace and the accompanying detectors are the tele-microscopic lenses that can collect images of the physical events taking place in this infinitesimally small space.

The book is composed of three parts. Part I provides a concise history of particle physics up to the Standard Model, giving the necessary background from which one can understand the significance of the LHC physics. The exposition of particle-physics history is judiciously combined with amusing anecdotes of historical personalities in a way that brings life and color to what otherwise might be a dull narrative. So far the Standard Model of quantum chromodynamics and electroweak theory has met with success in every confrontation with experimental checks. The only confirmed evidence for physics beyond the Standard Model is the observation of neutrino oscillation indicating nonzero neutrino masses. (The Standard Model has all neutrinos being massless.) Of course, the theory has nothing to say about gravity, as it describes physics only down to the electroweak scale of a few hundred GeV, while quantum gravity operates at the Planck scale of 10^{19} GeV. (The extreme high energy reflects the extreme feebleness of gravitation.) Despite all its successes, the generally accepted view is that the Standard Model is only the low-energy approximation of some more fundamental theory. The LHC is built precisely for the purpose of exploring particle physics at a deeper level, to find the clues to the larger framework that will eventually supersede the Standard Model.

Part II of the book concerns the hardware: The accelerator itself as well as the accompanying detectors (especially the two main detectors with the acronyms of ATLAS and CMS). Giudice presents an account of the daunting task of building this colossal "microscope" with its thousands of magnets designed to carry electric current up to 12,800 A in order to reach a magnetic-field strength of eight Tesla, capable of bending the 7-TeV proton beams within the LHC tunnel. This can be feasible only if one uses superconducting electromagnets. This entails cooling something like 37,000 tons of material, made up of billions of kilometers of niobium-titanium wires, below its critical temperature of less than 2 degrees above absolute zero. This low-temperature regime has to be continuously maintained in a bath of liquid helium very close to its phase-transition temperature; any small disturbance can cause the "quenching" of the cryogenic system, resulting in the immediate shutdown of the accelerator. (After each such episode, to cool down the system again will take a period on the order of a month.) This is just what happened in September of 2008 (10 days after the LHC first achieved full circulation of the protons) when a defective splice caused the electric connection between two magnets to vaporize. This involved a shutdown of the LHC for more than a year so that all 24,000 splices, similar to the one that caused the accident, could be examined and suspected parts replaced. This just illustrates the difficult task of building so large a facility at such extreme physical conditions.

Part III of the book is devoted to the physics expectations at the LHC. The Standard Model has two principal parts: the gauge and the Higgs sectors. The part that describes the strong, weak, and electromagnetic interactions according to the gauge-symmetry principle is tightly constrained and all of the experimental successes are related to this sector of the theory. But the Standard Model is not complete without the Higgs sector. The Higgs phenomenon generates the (Lagrangian) masses for all particles. However, in contrast to the gauge sector, we are not as confident of the precise mechanism as how it is realized in the Standard Model. It is generally expected that the Higgs boson is a spin-zero elementary particle; however, it could be a composite entity, being the bound state of some other particles (for example, a spin-½ pair). Also, in the simplest version of the theory, there is only one physical Higgs boson, but there are no reliable principles that one can invoke to exclude the possibility of having multiple Higgs bosons. Thus, first among the LHC physics expectations is the discovery of the Higgs boson(s) and the exploration of its ramifications. Giudice explains the significance of this possible discovery quite appropriately. (No uncalled-for hypes here.)

One of the great puzzles of particle physics is the existence of at least two vastly different energy scales (the hierarchy problem): one being the Planck-energy scale characteristic of quantum gravity, the other being the electroweak scale being explored at the LHC. If Higgs particles are indeed the quanta of an elementary scalar field, then it is extremely difficult to understand how the lower electroweak scale can be preserved against the huge quantum fluctuation emanating down from the Planck scale. All this leads to the salient point as emphasized by Giudice: In discussing the Higgs phenomenon at the LHC energy, while it is quite reasonable to expect the discovery of the Higgs boson, it cannot be an end in itself; rather, it should be the beginning of a new chapter in physics exploration–the physics beyond the Standard Model and all of the ramifications of the Higgs mechanism.

If the Higgs is just the tip of an iceberg, what sort of submerged physics can one expect to discover at the LHC? Many physicists think it is plausible that the new physics will include "supersymmetry," which is a unique extension of the familiar Lorentz-Poincaré spacetime symmetry. It can be viewed as endowing spacetime with fermionic degrees of freedom. (Giudice gives a clever description of this "superspace" where the square areas vanish and the rectangular areas change sign when length and width are interchanged.) It predicts that every Standard Model particle has a "superpartner" that has exactly the same quantum number but with the spin differing by one-half unit. If this supersymmetry between bosons and fermions were exact, any pair of particle and superparticle would have identical masses, and such a feature would lead to the cancellation of each other's quantum fluctuation. Since this mass degeneracy is not observed in Nature, supersymmetry must be broken. However, for supersymmetry to be relevant in solving the above hierarchy problem, superparticle masses cannot be too much larger than the electroweak scale. Thus there is a reasonable chance that this new layer of matter will be discovered at the LHC energy. This will represent an extraordinary advance in our ever-deeper exploration of fundamental physics. For example, among this new layer of superparticles we should find a stable neutral superparticle (like a heavy neutrino, called neutralino) that would have just the properties to be the constituent of the "dark matter" required by modern cosmology. In this way, one finally would be able to study the dominant matter of the universe in a laboratory setting.

Particle physicists fervently hope that the LHC experiments will give guidance as how to move beyond our current understanding. In fact, to the practioners in the field, the "nightmare scenario" would be that the Standard Model Higgs boson would be found at the LHC, but nothing else– while the observed phenomenology would be logically complete, it would give us no clue as how we can proceed beyond the Standard Model. Of course, the opening of a new energy frontier usually brings about new discoveries and this "nothing but a simple Higgs" would be a "long-shot" possibility–perhaps just as long odds as the discovery of some unexpectedly new physics. In this connection the speculative idea of space has extra dimensions (beyond the familiar three) with a size larger than the zeptometer scale is also discussed in the book.

In summary, Giudice has written an authoritative, comprehensive and accessible account of the LHC facility and the expected physics. I recommend this book highly to all readers who would like to have a general introduction to the LHC physics.

Ta-Pei Cheng
Department of Physics and Astronomy
University of Missouri-St. Louis
St. Louis, MO 63121, USA
e-mail: tpcheng@umsl.edu

Weston M. Stacy, *The Quest for a Fusion Energy Reactor*. New York: Oxford University Press, 2010, 208 pages. $24.95 (cloth).

The *Quest for a Fusion Energy Reactor* is the autobiography of the American physicist and engineer, William M. Stacy, who led the American delegation to the INTOR (INternational TOkamak Reactor) Workshop. From 1978-1986, fusion scientists and engineers from the USSR, Japan, the European Community, and the USA met regularly to prepare first the specifications and then the design concepts for an internationally built controlled-fusion reactor. These specifications and design concepts became the basis for ITER (International Thermonuclear Experimental Reactor), whose construction has not yet begun at Cadarache, France, as of April 2010.

The author and his coworkers at INTOR are justifiably proud of their accomplishments. This was not only a remarkable scientific and organizational achievement; this workshop also played an important role in fostering détente between the Soviet Union and the West during the height of the Cold War.

In regard to the book, there are a number of topics that are very well done. The discussion of the internal politics of each of the participating countries is fascinating and described with great insight and understanding. Also, the way the work was divided among the various countries and then combined at various meetings is very informative and can serve as a model for future international scientific cooperation.

Unfortunately, the book has many failings. Much too much of the book is just a catalogue of all the meetings the author attended and who the other attendees were. Also, the author shares with us the hotels and restaurants he frequented. All this is information only the author and his co-workers would care about. What is missing in this book is the technical details to understand the challenges facing the design of a fusion reactor. The author does mention the major challenges: impurity control, plasma heating, tritium production, and the first-wall problem. The author does discuss the solution to the impurity problem in some detail—the diverter technology. However, the solutions to all of the other challenges are largely missing from the book. And the figures in the book are often confusing sketches that lack needed explanation and clarity.

Finally, I must end this review on a melancholy note. To this reviewer who is not in the field of plasma physics, I am more than ever convinced that a fusion reactor will not generate electricity in my lifetime or yours. As far as I know, the first-wall problem has not been solved. ITER is much too expensive and complicated to be completed, and if the leaders of the world come to their senses, should not even be started. (For readers who want an update of the status and problems with ITER, I recommend the article "ITER collaboration defuses standoff," *Physics Today* **63** (April 2010), p. 20.

The only fusion energy we should be significantly investing in is the fusion energy of the sun.

Bernard J. Feldman
Department of Physics and Astronomy
University of Missouri-St. Louis
St. Louis, MO 63121, USA
e-mail: feldmanb@umsl.edu

Bruce J. Hunt, *Pursuing Power and Light: Technology and Physics from James Watt to Albert Einstein*. Baltimore: Johns Hopkins University Press, 2010, 182 pages. $20.00 (paper).

About a third of the way through Bruce J. Hunt's marvelous little book on nineteenth-century physics, I stopped thinking about it as a book reviewer. Instead, I began to imagine ways that I could use it to retool my classes in the history of science and technology. Surely this is a good sign. Part of the Johns Hopkins Introductory Series in the History of Science, *Pursuing Power and Light* packs in an extraordinary amount of material in just 167 pages of lucid, entertaining, and (most importantly) comprehensible text. It is an ideal historical primer for students (and teachers), not only because of Hunt's gift of scientific explanation, but because of his convincing portrait of how closely scientific ideas developed in relation to changes in technology.

Although Hunt does not argue that technology always preceded science, he makes clear that it often did, and rarely neglects an opportunity to disown the twentieth-century idea that scientific ideas typically are the building blocks of new technology. As other historians have noted, the steam engine did more for science than science ever has done for the steam engine. The science of thermodynamics owes a great debt to the industrial revolution, just as electrical science developed under the pressures of expanding telegraph lines and submarine cables. When William Thomson was raised to the peerage in 1892, his friends joked that he should take on the mantle of "Lord Cable" rather than Lord Kelvin. This message comes across loud and clear in Hunt's telling, and it is a powerful theme for explaining the development of the physical sciences in the century prior to relativity, quanta, electrons, X-rays, and radioactivity.

One of the strengths of Hunt's narrative, for instructional purposes, is that it sets up clear conceptual dichotomies that are easy to follow. The reader comes away understanding why the Laplaceans favored the particle interpretation of light (rather than waves), for example, or why Carnot's disciples thought that heat was a real substance—caloric—that flowed through a steam engine (rather than a measure of energy, as later physicists believed). This approach conveys the scientific ideas in an intelligible way, and it also helps to identify the personal, social, or financial stakes in any given approach. Such stakes are especially evident later in the book as Hunt discusses the corporate battles over alternating electrical current and direct current.

The book also succeeds in highlighting the genuine conceptual dilemmas posed by nineteenth-century physics—not just for scientists but also for laypersons. For example, the notion of heat death, the ultimate running down of the universe, was a consequence of entropy that many observers found deeply troubling. Also, the notion that energy can neither be created nor destroyed did not spring merely from the weight of evidence; it was a powerful idea that resonated with many scientists. In particular, Michael Faraday, a sincerely religious man, saw the forces of nature as something only God had the power to make or erase.

The book's structure contains no great somersaults of innovation, but it is logical and extremely helpful in separating out several key areas of study. It begins with a discussion of the steam engine and the questions about heat efficiency that its use provoked, connecting James Watt's ingenuity with Sadi Carnot's early attempts to explain in mathematical terms what occurred. Then Hunt focuses on the efforts to devise a more thoroughgoing theoretical basis for the movement of heat, leading to concepts such as energy and entropy. Here he gives a detailed account of James Joule's paddle-wheel experiments, in which he attempted to show that work could be converted into heat, before going on to discuss how William Thomson, Rudolf Clausius, and others worked out the laws of thermodynamics. Another chapter is devoted to kinetic theory, including a very clear discussion of "Maxwell's demon" and its importance in pointing out some of the consequences of entropy. Hunt's chapter on electricity is especially good. Not only does it include a superb overview of how Faraday came upon his "lines of force," but it also reveals how intertwined this research was with the early days of telegraphy. If the narrative stumbles at all, it is only a slight bump in his discussion of electromagnetism—a topic Hunt knows quite well, as demonstrated in a previous book, *The Maxwellians* (Cornell University Press, 1991, 2005). His close reading of Maxwell is at times fascinating, but even the best students may struggle to comprehend all the implications of spinning vortex cells. But such dedicated students will be grateful for the helpful diagrams.

Other than the chapter on electromagnetism, the book is remarkably (and fortunately) light on equations, and Hunt leaves little doubt about what concepts are at stake and what personalities play important roles. This is particularly so toward the end of the book, when Hunt provides a riveting tale of how electricity came to be so pervasive in society, powering light bulbs and motors. Hunt tells the story of the acrimonious disputes between Edison and Westinghouse about alternating current and direct current, as electrical grids began to spring up all over the United States. The book finishes with the events that usually begin the tales of twentieth-century physics: the Michelson-Morley measurements of the speed of light, Einstein's theory of relativity, and Planck's quantum. In keeping with his theme, he notes that despite Einstein's fame as a theoretician, he gained many of his insights while poring over technological designs in a patent office.

Throughout the narrative, Hunt has helpfully encapsulated some of the key ideas in separate textual inserts, usually next to a graphic to illustrate the idea. These are short and to the point, invariably adding further clarity. Although Hunt has included some diagrams of his own (as in his discussion of kinetic theory), most of them are drawn from contemporary sources, a nice touch that helps to communicate not only the ideas but also how scientists and others might have visualized them at the time.

This book has three extraordinary merits: it is clearly a product of fine scholarship, it is a pleasure to read, and it has great pedagogical value. I plan to assign it in my classes. When William Thomson chose one word to sum up his five decades of research on the foundational principles of the physical world, it was "FAILURE." The same could never be said of Hunt's book, which succeeds in expressing the frustrations, motivations, and conceptual problems of nineteenth-century physics with erudition and style.

Jacob Darwin Hamblin
Department of History
Oregon State University
306 Milam Hall
Corvallis, OR 97331, USA
e-mail: jacob.hamblin@oregonstate.edu

Suman Seth, *Crafting the Quantum: Arnold Sommerfeld and the Practice of Theory, 1890–1926*. Cambridge, Mass. and London: The MIT Press, 2010, xix + 378 pages. $32.00 (cloth).

After some years in the shadows, the origins of quantum mechanics are coming back into the spotlight. Along the way, the shorthand story we have come to rely on—from Planck to Einstein to

Bohr, then from Bohr to Heisenberg and Schrödinger—has begun to look too simple. Suman Seth's book is a provocative and important contribution to this new wave of scholarship. His study will stir up debate for its clearly staked-out argument for the significance of Arnold Sommerfeld (1868–1951). What Seth intends is not a synoptic narration of the physicist's life, or even his work, but an analytical accounting of his scientific style and his influence. The materials drawn on include students' and colleagues' recollections, original manuscripts, and the massive collection of Sommerfeld's correspondence that has now been edited and made available in print and on CD. Unsurprisingly, given the rich terrain, Sommerfeld has increasingly attracted attention, and Seth makes a case that that attention pays off. The book's largest argument is about the nature of progress in the old quantum theory and the struggle between competing understandings of theoretical physics, as an outcome of which Sommerfeld's contributions ended up obscured.

In popular accounts, Sommerfeld shows up as the man who refined Bohr's atomic model with elliptical orbits. That picture neglects Sommerfeld's earlier work and his ongoing contributions. It also gives little grounds for understanding why Sommerfeld worked as he did. Among colleagues he was known as the author of *Atombau und Spektrallinien* (*Atomic Structure and Spectral Lines*), first published in 1919 and in its subsequent editions the key entry point into original research in the quantum theory of atomic structure. Sommerfeld was recognized, too, as the leader of the era's most successful school of theoretical physics: Pauli, Heisenberg, Bethe, Wentzel, Debye, Pauling, and many others. At the University of Munich he trained students who "can work out a problem and get an answer," in the words of one contemporary, Frederick Lindemann, "rather than the more abstract type who would spend his time disputing with philosophers." (p. 3)

Disputing with philosophers is not what Sommerfeld did. The implicit contrast is to colleagues such as Bohr. His style of physical research worked with concrete models, mechanisms, or data, and he taught his students how to work in this line. At the same time, his comments on "number mysteries" in atomic spectra could seem incompatible with a hardheaded empirical focus, not to say rational scientific thought. Seth wants to give us a new perspective on what are sometimes portrayed as Sommerfeld's deficiencies, even his contradictions. Through them Seth intends to illuminate the practice of quantum theory and the discipline of which it formed a part. His Sommerfeld is a reflective practitioner of physical theory in the contested period during which it took on its modern form.

Seth introduces several themes to get a grip on the diversity of Sommerfeld's work, and he picks out episodes and comparisons to give them substance. He is interested, first of all, in the fine structure of how Sommerfeld did physics. What he calls Sommerfeld's "physics of problems" engaged with real-world topics (for instance, fluid flow, gyroscopes, wireless telegraphy), worked from detailed electromagnetic or mechanical models, or stayed closely connected with empirical data. Seth suggests a root for this approach in Sommerfeld's career trajectory from mathematics to technical mechanics as a protégé of Felix Klein, and thence via a stint at an engineering school to the chair of theoretical physics in Munich. Seth offers this "physics of problems" as a rubric for a broad swath of Sommerfeld's theorizing, starting with his early work on electromagnetism and electron theory, tackling Planck's quantum of action in that context, offering his own "dynamical" account of the quantum (to adopt Langevin's label at the 1911 Solvay conference, in contrast with Planck's statistical picture), and putting it to work in detailed modeling for the Bohr atom. The "physics of problems" shows up, too, in Sommerfeld's work for the German military during the Great War, as Seth and others have taken pains to explore.

Seth follows this account of Sommerfeld's physics in two directions. One is pedagogy. We learn a lot about the practices and social arrangements of Sommerfeld's teaching, including lectures, seminars, and his "seminary" (almost a theorist's lab group), not to mention excursions to cafes and ski trips. There is general information about the skills Sommerfeld taught his students to use in tackling problems—"the tricks," as Heisenberg would put it retrospectively, contrasting them with Max Born's "techniques." (p. 58) We are given an example of how one of Sommerfeld's early students, Ludwig Hopf, adapted those skills when he was mobilized in the Great War to work on aerodynamics and aircraft design. Sommerfeld "taught creativity," Seth summarizes (p. 8), though this suggestive conclusion goes somewhat beyond the material offered.

Alongside this high-level argument about teaching, Seth considers a second dimension of the "physics of problems." This is how Sommerfeld's approach positioned him among practitioners of a competing "physics of principles." Physicists of the latter stamp started not from concrete models, examples, or data, but from general principles and theories. In the book they are epitomized by Max Planck, to start, to whom considerable space is devoted in analyzing his thermodynamic work on dilute solutions and radiation processes. Later in the book the "physics of principles" is filled out by reference to Einstein, Bohr, and possibly others. The more or less explicit argument is that Sommerfeld's "physics of problems" may have been important and effective in training up a great school of practicing theorists—but the glory went to the "physics of principles," with its appeals to abstraction, fundamentality, and eventually theoretical crisis.

There is a lot at stake in Seth's study, and he argues his case powerfully. Sometimes the translations from the German are odd, but the overall point still comes through. When Seth evokes Sommerfeld's "physics of problems," he offers an inventive way of thinking about this period and its challenges. And yet this "physics of problems" is not unique to Sommerfeld, though the book cannot take up much of its prehistory. It is also, Seth acknowledges, a fairly elastic category. It covers so much of what Sommerfeld did, over such a long stretch of time, that it sometimes seems to mean whatever Sommerfeld did that Planck, Einstein, or Bohr did not. It is most successful as an analytical category for Sommerfeld's earlier years, when it seems to describe a stable theoretical practice. It is trickier to bring to bear on the first half of the 1920s, when Seth hopes to use it to capture Sommerfeld's move from model-based explanations to numerical regularities in his work on atomic spectra. In general, as an account of the half-decade before the 1925–26 creation of quantum mechanics, the argument is clear regarding Sommerfeld and suggestive regarding the larger physical scene—but not completely persuasive when it tries, for instance, to mark out a clearly identifiable Sommerfeldian influence on Pauli and especially Heisenberg, both of them sitting in a force field that included Einstein, Bohr, and (relatively underappreciated here) Born.

Seth's study touches on a large number of domains. Whether or not it will win over the specialists in each is yet to be seen. But that is not the book's main challenge to the field. It aims to re-envision the prehistory of quantum mechanics and the early twentieth-century practice of theoretical physics, starting from a figure whose significance was played down by exactly the kind of physics he did. The story of quantum mechanics is not just one of critical ruptures at the level of principles, but of creative puzzle-solving in a near-Kuhnian mode. Seth's book offers up a great quantity of rich material, and there is plenty of room for scholarship building on it—on Sommerfeld and on the practice of theory.

Cathryn Carson
Department of History
University of California, Berkeley
Berkeley, CA 94720, USA
e-mail: clcarson@berkeley.edu

Barri J. Gold, *ThermoPoetics: Energy in Victorian Literature and Science*, Cambridge, Mass.: The MIT Press, 2010, x + 343 pages. $30.00 (cloth).

Physicists and poets, evolutionary biologists and novelists, tend to assume that the sciences and the humanities use different concepts of knowledge—that they are separate cultures, as C.P. Snow posited in 1959. But this divide is, as interdisciplinary scholars have increasingly shown, a twentieth-century notion; many writers in the nineteenth century viewed literature as complementing, rather than contrasting with science. James Clerk Maxwell composed verses on algebra and energy, while

Lord Alfred Tennyson knew the theories of Laplace and Joule and Charles Dickens was fascinated by Watt and Faraday. These crossings suggest that boundaries between disciplines were more porous than we might expect, and that the possibilities of mutual influence were many. Barri J. Gold's *ThermoPoetics: Energy in Victorian Literature and Science* explores this intersection. Physics, Gold argues, is "conducted in words," (p. 4) and she has written a compelling and often surprising study of the metaphors shared by literature and physics in the nineteenth century that taps into an already vigorous stream of interdisciplinary research on the mutual influence of science and literature. However, there is a key difficulty for Gold's project. Novelists like George Eliot often compared novel-reading to the testing of scientific hypotheses about the world, and claimed that such knowledge helped to educate readers, not just intellectually but ethically. But this is an analogy rather than a claim that literature and science collaborate, and if Gold's book were able to account for whether science and literature merely provide each other with analogies or whether something more is at stake, it would be a truly innovative interdisciplinary accomplishment.

In the term "thermopoetics," Gold suggests "mutual influence, common concerns, and even simultaneous discovery. And it gives us a sense of how … how poetry speaks to science, how it says in words what cannot yet be said in words, how tender, young, unformed scientific ideas reflect and inform the other concerns that pervade what we will loosely call a culture, and even how a culture prepares itself to embrace such ideas." (p. 35) Focusing on shifts in approaches to thermodynamics over the course of the nineteenth century, Gold tracks how these concepts relate to the idea of evolution that emerged at mid-century. What kinds of metaphors did nineteenth-century physicists use? When and how did poetry reference thermodynamic concepts? How did thermodynamic metaphors relate to the newly prominent idea of evolution? Why did writers invested in ideas of biological and moral development worry about entropy as "dissipation," a word with moral and political as well as energetic connotations? How did the rise of the concept of "energy" alter how scientific ideas were described? And why did novels at the end of the nineteenth century increasingly invoke entropy as a way of expressing social anxieties?

The idea that scientific texts are laden with metaphors that reflect cultural assumptions and values is not a new one. A mere three years after the 1859 publication of *The Origin of Species*, Karl Marx wrote, "It is remarkable how Darwin rediscovers, among the beasts and plants, the society of England with its division of labour, competition, opening up of new markets, 'inventions' and Malthusian 'struggle for existence'. … [I]n Darwin, the animal kingdom figures as civil society."* Yet biology's permeation with metaphor has garnered more than its fair share of attention; by focusing on physics, Gold's book addresses a significant gap in scholarship on the relationship between literature and science. Several now-classic works of the 1980s like Gillian Beer's *Darwin's Plots* and George Levine's *Darwin and the Novelists* offer clever readings of the metaphors at work in biological writings of the nineteenth century and examine, in nuanced and challenging ways, how novels by the likes of George Eliot, Charles Dickens, and Thomas Hardy reflect and respond to evolutionary thought. And especially since last year's 150th anniversary of *The Origin of Species*, studies of the cultural status of evolutionary biology have flourished. As Gold notes, nineteenth-century physics has received little such attention—a significant and, in fact, unjustifiable failure, given Victorians' fascination with what we would now call grand unified theories that unite physics, biology, sociology, and ethics, that reason upward from the motions of the atom to the machinations of an empire. If, as Marx's commentary indicates, Gold's method is hardly new, her attention to thermodynamics is. Gold argues that energy physics, even more than biology, explains widespread anxiety in the Victorian period about the possibility of progress; Victorian culture experienced both intense biological optimism and cosmic pessimism, a duality that finds expression in "the tension between conservation and dissipation that haunts the first and second laws of thermodynamics." (p. 40)

* Quoted in Hilary Rose and Stephen Rose, "Darwin and After," *New Left Review* **63** (May–June 2010), 93.

ThermoPoetics outlines a wide and varied strain of Victorian thinking about energy that attests strongly to the diversity and creativity of physics during this pre-quantum period. Gold traces the problems associated with the tension between the conservation and dissipation of energy from the work of Alfred, Lord Tennyson to Bram Stoker, and from Sadi Carnot to James Clerk Maxwell. What will draw the most admiration from readers, I suspect, are Gold's readings of works by writers who identified as scientists. She demonstrates, for example, that texts by early pioneers in thermodyamics like William Thomson, Sadi Carnot, and James Prescott Joule reflect the interests of elegy, and take on a consolatory tone. Her readings of Herbert Spencer and James Clerk Maxwell are fascinating. Spencer was an evolutionary optimist, committed to the morally and politically inflected concept of "unity" as well as to determinism. These investments led him to embrace the idea of "persistence of force," which, as he only gradually came to understand, conflicted with the concept of entropy. As for Maxwell, his poetic use of "force" as a metaphor for oppressive and outdated regimes of thought helped him to characterize the concept of "force" as a mathematical construct, and to see energy—aligned in his poems with the revolutionary overthrow of inherited systems and the expansion of empire—as the more powerful conceptual paradigm because it could not be so simply explained as a vector. Energy, for Maxwell, was no simple metaphor, no basic mathematical construct; as he wrote in his poem, "Report on Tait's Lecture on Force" (1876), energy, not force, revealed "[t]he hidden potency of cosmic dust."

Gold applies her readings of texts in physics to both poetry and novels. In an insightful and nuanced analysis of Tennyson's *In Memoriam* (the poet's long elegy, completed in 1851 after many years, for a dead friend), Gold questions the commonplace assumption that evolutionary thought explains the poem's vision of nature (famously "red in tooth and claw"). Seeking consolation after his friend's death, Tennyson turns to the conservation of energy as a source of cosmic optimism. Later in the Victorian period, however, the second law of thermodynamics commanded more attention, posing a problem for evolutionary thought. Entropy and evolution were thought to conflict because evolution, as many Victorians understood it, produces more order over time, while entropy produces less. As Darwin wrote in his *Autobiography*, "Believing as I do that man in the distant future will be a far more perfect creature than he now is, it is an intolerable thought that he and all other sentient beings are doomed to complete annihilation after such long-continued slow progress. To those who fully admit the immortality of the human soul, the destruction of our world will not appear so dreadful."* Though Gold could have been more direct about this tension between physics and biology, it often makes for fascinating discussions of works that have clear evolutionary commitments. In the second half of *ThermoPoetics,* Gold builds upon this analysis to explain how novels from the second half of the nineteenth century—*A Tale of Two Cities, Bleak House*, *The Picture of Dorian Gray,* and *Dracula*—explicitly reference the concept of energy. Their use of the term reflects contemporary scientists' emphasis on the second, rather than first law of thermodynamics. In each of these texts, Gold finds entropy, as energy loss, persistently to represent both social disorder (the common misreading of entropic dissipation) and social uniformity. Entropy, in these texts, represents the weakness of human constructs against the flux of physical matter. The weakness of human beings in the face of entropy, Gold suggests, corresponds to the conceptual weakness of "force" against the new supremacy of "energy."

ThermoPoetics explicitly addresses its argument to a generalist audience, and impressively, Gold manages a fine balance between informed analysis of physical concepts and discussion of literary works. If her assumption that the reader will be fairly familiar with the plots and contents of these works reveals a certain asymmetry in her project, a reader who *is* familiar with them—whatever his or her training—will find *ThermoPoetics* illuminating. Though this book tacitly presumes that the reader will be aware of trends in literary criticism of individual works, such

* Quoted in Gillian Beer, *Open Fields: Science in Cultural Encounter* (Oxford: Clarendon Press, 1996), p. 222.

awareness is not necessary to appreciate Gold's arguments. For example, Gold alludes to the fact that *Dracula* is usually taken by literary critics to suggest anxieties about the rising autonomy of women, as well as anxieties about Irish national identity, miscegenation, urban life, and new technologies for communication—but familiarity with the scholarship is not crucial to grasp that imagining the vampire as Maxwell's demon helps us see why his use of blood (human energy) is meant to be so horrifying.

Gold's interdisciplinary goals, however, impose limitations on the readings of literature *ThermoPoetics* undertakes. A reversal seems to happen in the book's second half. Gold, drawing on Thomas Kuhn and Bruno Latour, provides a Victorian case study of how scientific fact-making is a collective process, and that fiction can "participate in fact-making" (p. 153) by making use of scientific concepts. Yet it begins to seem more that fact-making can participate in fiction—that fiction serves fact. This approach risks giving the physics, in Gillian Beer's words, "overweening explanatory power."* From the perspective of a literary scholar, Gold's explanations of thermodynamics are straightforward, but she is careful to serve the physicists in the audience too, avoiding the oversimiplification of more complicated matters—for example, the relationship between the concepts of "force" and "energy." The same reader who will be relieved to find this material rendered accessibly will, I suspect, be frustrated by limitations in the literary readings, with the exception of the discussion of Tennyson's *In Memoriam*. Many of these readings remain stuck at identifying structural analogies between thermodynamic concepts—the engine, the heat sink, Maxwell's demon—and characters in these novels. And this frustration should be shared by those who approach *ThermoPoetics* with a background in the sciences not only because it predigests literature for ease of entry, but because it forestalls some of the really fascinating questions her method poses. In particular, I wondered why personification was such a prominent representational strategy in late-Victorian thinking about physics: Gold calls these figures "entropic individuals." (p. 227) If, on the one hand, we have Maxwell's demon, and on the other, such "heat sinks" or "entropic individuals" as Gold considers Dorian Gray's picture and Dracula to be, why did these writers choose to personify these concepts? The broader problem is that in analyzing novels (she does better with poems) Gold identifies structures (characters, plot sequences, descriptions) that resemble themodynamic concepts. But she does not identify an epistemological analogy to complement the structural analogy. How might the tension between conservation and dissipation have affected narrators' or characters' ways of knowing? How did anxieties about entropy alter novels' narrative strategies? Gold might have accounted for the changing approaches to the use of metaphor—and character as metaphor—with more nuance than she does here.

Ultimately Gold's project is, according to her own way of "reading" thermodynamic laws, a first-law kind of enterprise—productive if not truly new. Through her lively readings, Gold shows how the mutual influence of literature and physics yielded fruitful and dynamic metaphors for both. Certainly, Gold's *ThermoPoetics* offers a rich validation of Giambattista Vico's account of the "new science" of physics in 1709. As Vico wrote, "inasmuch as modern physics borrows its most sensuous images, expressive of natural causes, from mechanics, which it uses as its instrument, it endows poets with a treasure of new expressions."**

Elisha Cohn
UCLA Center for 17th- and 18th-Century Studies
University of California, Los Angeles
Los Angeles, CA 90095, USA
e-mail: elisha.cohn@gmail.com

* *Ibid.*, p. 235.
** Giambattista Vico, *On the Study Methods of Our Time,* translated by Elio Gianturco (Ithaca: Cornell University Press, 1990), p. 44.