Metascience (2011) 20:53–73
DOI 10.1007/s11016-010-9466-4

BOOK SYMPOSIUM

Revisiting the history of relativity

Richard Staley: Einstein's generation: The origins of the relativity revolution. Chicago: University of Chicago Press, 2008, x+494pp, $38 PB, $98 HB

Lewis Pyenson · Sean F. Johnston · Alberto A. Martínez · Richard Staley

Published online: 4 November 2010

Lewis Pyenson

Concluding the second and third volumes of his pioneering history of classical scholarship in 1908, John Edwin Sandys recalled an ancient Roman custom, according to which painted masks of ancestors occupied niches in the domestic atrium. On the occasion of a death in the family, each mask was replaced by a living representative, who took part in the funeral procession to the Rostra in the Forum. The ancestral likenesses then sat together while the next of kin recited their qualities and accomplishments, finally ending with the last to die (Sandys 1967, vol. 2, vii). In his literate oration for today's broader forum, *Einstein's Generation*, Richard Staley provides a new account of the last of the classical ancients, as they emerged to become the first of the physicist moderns. Staley's account, beginning in the 1860s, complements Einstein's own views, expressed in the book Einstein authored with Leopold Infeld, *Physik als Abenteuer der Erkenntnis*, where James Clerk

L. Pyenson (✉)
Department of History, Western Michigan University, Kalamazoo, MI 49008-5242, USA
e-mail: lewis.pyenson@wmich.edu

S. F. Johnston
School of Interdisciplinary Studies, University of Glasgow,
Rutherford-McCowan Building, Dumfries, Glasgow, Scotland G2 0RB, UK
e-mail: sean.johnston@glasgow.ac.uk

A. A. Martínez
Department of History, University of Texas at Austin, 1 University Station B7000,
Austin, TX 78712-0220, USA
e-mail: almartinez@mail.utexas.edu

R. Staley
Department of the History of Science, University of Wisconsin-Madison,
226 Bradley Memorial Building, 1225 Linden Drive, Madison, WI 53706-1528, USA
e-mail: rastaley@wisc.edu

Maxwell and Heinrich Hertz are prime movers for late nineteenth-century and early twentieth-century developments and where experimental results, notably by Albert A. Michelson, figure prominently.

Forests have been sacrificed in the name of generations.[1] It was the metaphor used by Helge Kragh in his history of quantum physics, and it was how, more than 30 years ago, Lewis Feuer understood Einstein's relativity. Staley's history of the transition from classical physics to relativity expands on Kragh's use of the metaphor without going in the direction of Feuer's complex, sociological theorizing.[2] For Staley, older physicists like Michelson and Max Planck belong to Einstein's generation. In this way, Staley modifies Planck's often-repeated observation about new ideas becoming established only with the death of superannuated disciplinary practitioners (Cohen 1985, 467–468).

The physics discipline, with firm representation in Europe and North America during the years 1870–1914, is the center of *Einstein's Generation*. Staley's narrative is innovative and thought provoking. He begins with the central activity of late nineteenth-century physicists, making precise measurements of fundamental physical constants by using undisturbed apparatus, and he focuses on one of the greatest American adepts of measurement, Albert Michelson, who, by 1900, was universally admired for his technical mastery of light. Staley shows how Michelson's work on the ether wind led physicists to question electromagnetic theory and how the work figured in the acceptance of Einstein's relativity. He examines the evidence for Lorentz transformations in the first decade of the twentieth century, emphasizing the close interaction between experimentalists and theoreticians. He convincingly contends that, by around 1910, classical physics was both defined and superseded by a new way of looking at physical reality, largely on the basis of rhetoric by leading theoretical physicists who assembled in 1911 at the first Solvay Congress.

Any scholar who has wrestled with Staley's topic knows how difficult it is to formulate a convincing argument. The merits of his book are grounded in close attention to 40 years of secondary writings, largely in English, as well as new light on significant archival material studied by other scholars. In a welcome tour de force, Staley provides admirable explanations of highly technical material, both experimental and theoretical. He is entirely at home in the primary published sources appearing in English, German, and French.

The international integrity of the physics discipline is highlighted in a close reading of publications resulting from the Paris Exposition of 1900. Nevertheless, the book signals 1910 as a crucial disciplinary turning point (it was a crucial year for the European mind generally, in the view of Virginia Woolf).[3] Before the first decade of the twentieth century, experimentalists employing precise mechanical measurements and theoreticians writing in German, English, and French determined

[1] For example, Marías Aguilera (1970); Strauss and Howe (1991), appendix A for a historical sketch; Roseman (1995).

[2] Kragh (1999); Feuer (1973), where Feuer unites Einstein with like-minded thinkers under the banner of a Marxian-Machian spirit of the times.

[3] Stansky (1996), among other studies.

the agenda of what became known as classical physics; after the first decade of the twentieth century, theoreticians, writing largely (but not exclusively) in the German language, promoted the new worldview known as modern physics, which became accepted first in the theory of relativity.

To say that late nineteenth-century physics was about precise measurement is to focus on the measuring instruments. Here, the machine shop set the pace: screws, gears, flat surfaces and the tools for making them; engines fueled by coal, electricity, and petrol; lenses for observing, large and small; and diffraction gratings produced by remarkable ruling engines. Physics depended on advances in mechanical technology, and physicists also occasionally brought new products to the market. Staley situates Michelson very well in this American industrial milieu, and he suggests why machines dominated physics in America until theoreticians found their voice in the second half of the twentieth century.

The industrial connection contributed, nevertheless, to a lack of disciplinary identity. Staley emphasizes Michelson's interaction with the machine-tool company of Warner and Swasey, which, along with Alvan Clark and Sons and John Brashear, was then equipping the large observatories that became, by 1900, the envy of Europeans. Astrophysics, to which the observatories turned, eroded the boundaries between astronomy and physics; industries based in chemistry and electrical engineering did the same, employing physicists by the hundreds. Disciplinary assignment at universities could be a matter of convenience, as it was in the attribution of the Nobel prizes.[4] Hermann von Helmholtz is emblematic in Germany: from medicine to physics to technology. Staley suggests permeable boundaries in his discussion of the physical chemist Wilhelm Ostwald and the mathematician and mathematical physicist Georg Helm. (Young Einstein, seconded by his father, inquired about an assistantship with Ostwald.) In France, a large chasm separated the exact sciences, which united mathematics, astronomy, and the mathematical parts of physics, from the experimental sciences, including both physics and chemistry. There is the elegant polymath Henri Poincaré—mathematician, physicist, astronomer, philosopher—who figures significantly in Staley's account, and Poincaré's temperamental opposite Pierre Curie, an experimentalist untutored in mathematics who could have trouble setting down a grammatical sentence. It seems, then, that many and diverse currents led to the triumph of the German-speaking theoreticians.

Whatever historical generations are about, sex is in the picture. *Einstein's Generation* makes only passing mention of conjugal union (Tatiana and Paul Ehrenfest). The inventory of binary stars in the formulation of the new physics, however, is significant enough to constitute a social revolution, with regard to both

[4] See Crawford (1984), 116–120, for politicking between the chemistry and physics committees over awarding the prize to cosmical physicist Svante Arrhenius (chemistry, 1903). The trajectory of Emil Bose over the first decade of the twentieth century is also illustrative. A doctoral student of Walther Nernst's at Göttingen, he took the *venia legendi* with physicist Oskar Emil Meyer at Breslau, and returned to Göttingen as Nernst's assistant before in 1904 becoming assistant to theoretical physicist Woldemar Voigt and directing the biweekly journal, *Physikalische Zeitschrift*. In 1906 he went to Danzig as professor of physical chemistry, and in 1909 he assumed direction of the physics institute in La Plata, Argentina. Nernst himself saw physical chemistry as ranging from mathematical physics to chemical kinetics (Pyenson 1985, 153–159).

the international nature of the unions and the international peregrination of the couples: the Curies (Marie and Pierre), the Clays (Tettje and Jacob), the Boses (Margrete and Emil), and the Einsteins (Mileva and Albert), in addition to the Ehrenfests. Paul Langevin's liaison with the widowed Marie Curie is revealing in this regard. Physicists, like other intellectuals (the very word intellectual became current in High Modernity), hooked up for love.[5] To this group must be added the young women physicists who chose not to marry, a decision that threatened their married, male colleagues. The domestic life of the Greats that has been thus far revealed to us (notably, Michelson and Einstein) points the way to a social history of the relativity revolution where attention is directed to the person with whom a physicist spent the most time.

The first decade of the twentieth century was indeed a watershed of two eras (Romein 1978). In view of their revolutionary rhetoric, therefore, it is relevant to ask how physicists responded to the astonishing currents around them in music, painting, and cinema; in conveyances on land, on sea and in the air; in regimes of alcoholic abstinence, vegetarian cuisine, and pacifist disengagement; in socialist militancy as well as in racist politics. We do not yet see clearly how these and other currents may have become part of the disciplinary paradigm of physics, as it was constituted around 1900. Staley has contributed significantly to a rich body of literature about physicists in the laboratory and at the writing desk. Attention may now profitably turn to the daily routine of physicists, including meals, sleeping arrangements, and laundry; recreations, including music and athletics; wealth and health; political and religious exercise; the newspapers they took and the novels they read. This focus is required to establish the place of the new physics of relativity in the High Modern Age, for our inclination, following 40 years of scholarship in social history of ideas, is to imagine that physicists adjusted their thought to make abstract formulations fit with the spirit of the times, as they perceived it.

Einstein's Generation radiates an encouraging and easy style, engaging the reader by drawing attention to the significance of texts and events. There is a great deal of first-person intrusion, both singular and plural, which guides a reader through the twists and turns of theme and instance. And there are plenty of turns. Just when we are ready to examine a stunning vista, the cicerone hurries us on to the next overlook. An example is the concluding discussion of the term "classical" physics *circa* 1900. Staley provides almost no anticipation of it in Neohumanism, architecture, music, or academic painting. (The Schulkrieg in Germany, the late nineteenth-century conflict between classicists and moderns, which had profound consequences for mathematics and physics in higher learning, receives only passing mention.) There is no complementary, sustained examination of "modern" physics, nor of the very word "revolution," as it was used by physicists and other intellectuals.[6]

[5] For one recent study of an intellectual couple from this time see Pyenson (2007), here p. xxx.

[6] It is interesting to read *Einstein's Generation* alongside Gay (2008) and Gray (2008). Both Gay and Gray find Modernism firmly established by the last quarter of the nineteenth century.

Narrative style, Hayden White affirms in his structuralist writings, is a basis for organizing historical scholarship. In White's terms, *Einstein's Generation* does seem to be contextualist in its mode of argument and liberal in its mode of ideological implication, and there is more than one hint of irony in its mode of emplotment.[7] Such an assignment, however, would do the book an injustice. It is a kaleidoscopic work, where the subject is divided into topics elaborated in recurring themes. This narrative feature is shared with works of High Modernity generally and with novels by writers accomplished in science, for example, Robert Musil, Hermann Broch, Ernesto Sábato, Vladimir Nabokov, and Thomas Pynchon. Part of the freshness radiating from Jacob Burckhardt's *Renaissance* and Thomas Carlyle's *French Revolution*, to mention only two early Modernist histories, stems from the way the authors weave themes into a larger tapestry. However else narrative may be reckoned, the kaleidoscopic approach finds a firm presence in writings about history of science. Kaleidoscopic exposition, which favors discrete articles over systematic books, suited the scientific formation of influential thinkers like George Sarton, William Osler, Alexandre Koyré, Otto Neugebauer, Joseph Needham, Thomas Kuhn, and Stephen Jay Gould.

Richard Staley contends that, at the onset of a new epoch, theory can be invoked both in the context of justification and in the context of creation. Theoreticians react to concrete particulars as much as they set the stage for new material constructions. In his thoughtful account, we find an Agenda for a Generation, to borrow from the 1962 Port Huron Statement of the Students for a Democratic Society. Staley shows that ideas have good currency today among historians—ideas, that is, freed from the fetters of dogmata. *Einstein's Generation* demonstrates that scholarship in the history of science now rides in the vanguard of intellectual enterprise.

Sean F. Johnston

This is a very good book, re-evaluating relativity physics in the context of its times. Richard Staley sets out to accomplish worthy and familiar historiographical aims: to reassess previous generations' scientific heroes; to embed intellectual achievement in its cultural framework; and to vaunt the role of instrumentation and empiricism in knowledge creation. The timescale of the book is a single generation, the 30 years between the Michelson-Morley ether drift experiment (1881) and the first Solvay Council and textbook focused on special relativity (1911). His attempt to "explore the way arcane results might carry the cultural freight of worldviews" (p. 3) largely succeeds.

But Einstein himself and even relativity—both key words in the title—are not the primary focus of this book. For example, the work and career of Albert Michelson vies for critical examination as a potential co-configurer of communities. There is a certain justice and incongruity in this approach. The American Michelson was a diffident supporter of relativity at the best of times and so could serve as an

[7] Pyenson (2005), 261–335, here pp. 7–8 of the unblemished reprint, *Three Graces* (Lafayette: Editions Giselle Calypso, 2005), available in the Harvard College Library.

historical counterfoil: he represents simultaneously one pole of the experiment–theory axis, membership in a nascent national community that was subordinate to Germany's scientific primacy, and resistance to the emerging ideas of modern physics. His significance to the book is belied by its promotion, however. Michelson's name does not appear in the rear cover synopsis, nor indeed among the two dozen physicists depicted and named on the front cover (several of whom, in fact, go unmentioned in the text). Nevertheless, in narrative terms Michelson's 'guest star' role in the story, even if un-advertised, is interesting and well presented.

The author deservedly highlights Michelson in two of the ten chapters of this book (nearly one-third of the text) and in his previous publications but could make the case more persuasively. Michelson's experimental rigor extended precision measurements in optics by orders of magnitude, and he applied his devices to new investigations in ways that inspired awe, if not emulation, by his contemporaries. Chapter 2 provides a narrative account of Michelson's velocity of light and ether drift research, detailing the naval and astronomical context in which the novel experimental apparatus evolved. In the following chapters, Staley argues that, despite this disciplinary linkage to astronomy, Michelson was able to co-opt research in optics and mechanics to pursue work in metrological standards. Given this important connection of physical standards to new physics—and the author's legitimate claims about the neglected role of empiricism—it would have been valuable to have devoted more attention to the German work in this field so closely linked to the transition to modern physics. At the fin de siècle, the Physikalisch-Technische Reichsanstalt melded optical research with industrial collaborations, yielding careful studies of blackbody radiation that culminated in the theoretical developments of Max Planck (Cahan 2004). The book devotes Chapter 6, however, to an equally impressive experimental tour de force, the studies of the electron by Walter Kaufmann.

The focus throughout these chapters is on experimental ingenuity and instrumental refinement and on the difficulties of connecting the interferometer with issues important to contemporary physicists. As Staley underlines, Michelson was dismayed at both the null outcome of the ether drift experiment and by the lack of interest shown by his contemporaries through the 1880s. During the following decade, critics analyzed the ether drift experiment to suggest subtle experimental limitations rather than unambiguous properties of the ether. The wealth of narrative description provided in these chapters hints that the considerable tacit knowledge required for successful interferometry may have convinced Michelson's peers that such experiments were untrustworthy and beyond wider application. Extreme instrumental elegance and experimental finesse could be interpreted as self-limiting, isolating the investigator rather than inaugurating a new research tradition. Michelson's 'facts' were contested, and his social influence, it seems, was slight.

As a famously ascetic investigator working in an environment bereft of a physics tradition, and who suffered graduate students ungladly, Michelson seems an unlikely candidate for discussion of the growth of new communities. The author observes that the young Michelson was indoctrinated into an active culture of experimentation in velocity of light measurements owing to patronage and genial competition in the USA, and to sojourns in Berlin, Potsdam and Paris. Even then, however, Michelson's experiments were not replicated or extended by others. In comparison with the book's ample depiction of experimental innovation and focus on instrumentation as a career theme, evidence of Michelson's sociological influence is comparatively sparse. It might be argued that, because his exploitation of the interferometer as a readily mutated instrument was to occupy much of his career, he can be characterized more accurately as a *research-technologist* (Joerges and Shinn 2001) than a physicist akin to his contemporaries in France and Germany. In fact, Staley notes the tensions in Michelson's relations with the physics community owing to his focus on "instrumental unity" (p. 69). Yet his claims concerning discipline formation are not well demonstrated because the social and intellectual attributes of Michelson's peers—the generation preceding and contemporaneous with Einstein—are sketched only selectively in subsequent chapters. In short, while presenting much historical material of great interest in its own right, the relevance of these chapters to the overall argument could be made more strongly.

Beyond the work of such iconic figures, though, the book seeks to highlight their community connections through public events. Two meetings of physicists provide contrasts that are comparable to those between Michelson and Einstein. The Paris Congress of 1900, organized by the French Physical Society, has faded from collective memory today despite commissioning papers from some of the most eminent contemporary physicists and attended by some nine hundred (more than half of all) practicing physicists. Occurring just over a decade later, however, the first Solvay conference is still celebrated as a seminal moment in the synthesis of a new physics and its adherents.

The book offers a more analytical core, however. Staley's stated theme concerns transformations. He offers a revisionist account of the classical–modern transition in physics and suggests other generic transformations, including those engendered by instruments, experiments, theories and disciplines. Malleability of interpretation—involving "subtle transformations in the meaning of the work" (p. viii)—is at the heart of this. Building on critical studies of a previous generation of historians of relativity, the book focuses on the work of some neglected key actors, and how a common understanding of Einstein's work developed among his contemporaries.

The book's attention to disciplinary formation, in particular, is a timely addition to current scholarship. Beyond the goal of corrective assessment of historical episodes, the book seeks to explore the opposing forces of disciplinary change and cohesion. This does not involve the formation of a new discipline, of course, as physics then had a long genealogy and established coterie of subject-specific and geographically-centered communities. Instead, it traces the shifting ideas of participants in this turn-of-the-century revolution. The author valorises the work and material culture of experimentalists such as Michelson and Kaufmann to obtain a more nuanced account of how support for relativity physics grew. Arguably, relativity physics was a looser coalition of interests than a genuine sub-discipline, although others certainly sprang up at this time: physical optics, recognized by a spate of early Nobel Prizes and instantiated in Albert Michelson's generic form of the interferometer—the heart of the Michelson-Morley experiment—is the prime example of a new intellectual union between experimental finesse and theoretical elegance.

In the Introduction, Staley motivates his study of what he dubs *disciplinary memory*. His term refers to practitioners' interpretive work to give meaning to innovative science by inter-relating old and new research techniques and findings. These physicists' histories, written shortly after or even during important episodes, are investigated to assess how "canonical narratives of disciplinary development" help to "inform physicists' sense of the nature, past and future of their discipline, and thereby contributes to their identity as a community" (p. 14). Not surprisingly to historians, the author shows that this memory is selective and that it neglects important aspects of physicists' work.

Part II, on the World's Fair and Congress of Physics in Paris in 1900, is a delightful evocation of the confluence of machine-centered modernism, national competition, and scientific expertise. The events illustrate shifting attitudes and goals. The intellectual and cultural atmosphere sometimes summarized as 'fin de siècle physics' is sketched well. In the decades straddling 1900, the new phenomena of rays (or particles?) were challenging the somewhat jaded attitude of late nineteenth-century physicists tying up loose ends in mechanics, thermodynamics and optics, and extending measurements to the ever-greater exactitude. Indeed, Michelson himself famously suggested that many of the great scientific advances of the nineteenth century had resulted from increasing experimental precision and that "our future discoveries must be looked for in the sixth place of decimals" (Michelson 1902, 24). As Staley illustrates, a cascade of experimental studies unsettled the snug arrangements of physics and its developing industrial alliances. The Congress chapter explores the existing goals, methods, and concepts of physics through the conference presentations of key physicists such as Poincaré and Kelvin. The book identifies the discovery of the electron as a seminal shift highlighted at the conference and important to the subsequent development of relativity (the empirical evidence for the electron and its interpretation by theoreticians occupies the third section, and one-quarter, of the book).

This historiographical approach of deconstructing the accounts of historical actors is fruitful but could be extended well beyond the study of a World's Fair, two international congresses and early syntheses of the relativity principle, as developed in Chapters 4, 5, 8, and 10. While emblematic, these public demonstrations of community and consensus provide a limited perspective. The Paris Congress attracted a significant fraction of the world's physicists, but their perceptions—as attendees rather than presenters—are difficult to discern. As a meeting reporter for the *Physikalische Zeitschrift* reported to his chagrin, there was no printed list of participants, and no designated pub to encourage collegiality! The author notes that "the appearance of an individual's work in these arenas rendered it representative" (p.135), but it might be argued that such representations were actively constructed to suit national and institutional objectives. As a sample of community, international exhibition and conference presentations may be skewed toward the more senior, higher status, and economically or politically powerful. While there is considerable merit in tracking this self-defining elite, it can constrain our notions of the intellectual community, leading to the practitioners' accounts addressed by disciplinary memory. I would argue, instead, for a more democratic approach. The formation, consolidation, and dissemination of disciplinary identities can, for example, be studied further by tracking cohorts and research networks [e.g., core-set analysis (James 1983)], shared practices and hardware (Galison 1997), and by tracing other expressions of nascent community perceptions and the related dimensions of professionalization and occupational niches (Johnston 2006). A more ethnologically and sociologically sophisticated analysis could be fruitful for understanding this period and its participants. On the other hand, given the ambiguity inherent in the book's title, "Einstein's generation" can, taken as a pun, fairly describe the concepts and support that he generated rather than the cohort in which he worked. In this respect, the book fulfills its aim.

Chapter 8, on the histories of relativity, uses a variety of mainly published sources to examine how Einstein's work was interpreted, evaluated, and assimilated by his contemporaries. The perceptive juxtaposition and analysis of accounts by key commentators—including Einstein, Lorentz, Planck, Minkowski, Sommerfeld, and a host of subsequent historians—indicate how an early plurality of opinion coalesced by 1911 to wide support for relativity theory. Even more satisfyingly, the subsequent chapter develops the useful point that 'classical' physics was an idealization first defined *en masse* after 1900 to serve as the background to 'modern' physics. This fascinating "story of a word" reveals that the label hid a lack of consensus about how the concepts of physics should be categorized and remodeled via relativity theory.

Overall, this book is a valuable addition to the literature. It redresses an imbalance in the historiography of relativity, transforming it from predominantly a theoretical achievement to a synthesis of experiment, theory, materiality, and scientific perceptions. In building toward this analytical conclusion its chapters offer an invigorating, if sometimes uneven, combination. Topics are heterogeneous and individualistic and range from electron apparatus to the Nobel Prizes; from a Gustav Klimt painting to the notion of rigid bodies; from manufacturers' exhibition displays to ontology [should the ether or the electron serve as "the core of a new worldview"? (p.219)]. This amalgam necessarily yields jarring perspectives and varying levels of detail more easily assimilable on the Chapter and Section level than as a monograph. Gaining a fuller sociological sense of "Einstein's generation" as a community of working scientists who melded theoretical concepts, zeitgeist and experimental innovations may demand even more discordant methods and a correspondingly difficult synthesis. While this implies a move further away from the neat practitioners' accounts, it offers a potentially more accurate, and ultimately satisfying, analysis.

This is no criticism of Richard Staley's achievement; he has provided a nuanced and multifaceted account of the rapid fin de siècle transition in physics, rehabilitating half-forgotten investigators and revealing the importance—and often neglect—of scientific craftsmanship and empirical evidence. In the process, his readable and eclectic book demonstrates the value of current historiographical approaches.

Alberto A. Martínez

In 1981, John Heilbron and Bruce Wheaton published a comprehensive bibliography on history of physics. They noted that "further [historical] work on Einstein or relativity is not a high priority." (Heilbron and Wheaton 1981, 1) Nevertheless, a growing army of writers continued to work on that; in 2005 alone, more than fifty books were published on these topics. The history of special relativity constitutes one of the largest branches of history of science. In the present essay, I discuss Staley's book in connection with some of the related literature, and I unabashedly take the liberty to trace some comparisons and contrasts to my own recent book, *Kinematics: The Lost Origins of Einstein's Relativity* (Johns Hopkins, 2009) as a way to elucidate Staley's direction. Inasmuch as recent books embody the bulk of an author's knowledge on a topic, my present comments constitute a dialogue between our books.

Staley makes an impressive, ambitious effort to interconnect adjacent areas of history of physics in multifaceted ways. To start, the book follows the works of a single man, Albert Michelson and his experiments; a meticulous, outstanding analysis. In later chapters, it moves to more general topics. Parallel to Peter Galison's interest in the standardization of timekeeping technologies, Staley analyzes the American efforts to standardize length measures, especially in the 1870s and 1880s, in connection with railways and industry. Michelson's innovative instrument functioned somewhat oppositely in industry and theoretical physics. Interferometry seemed to ascertain the reliable invariance of length, whereas in ether drift experiments it theoretically implied the contrary: the variability of moving lengths.

At this point, one might expect that Staley's narrative would move to optics in relation to the electrodynamics of moving bodies, Lorentz's theory, and the concerns that led Poincaré and Einstein to analyze the principles of physics. Instead, Staley takes a detour to discuss the Exposition Universelle of 1900, in Paris, and the concurrent Congress of Physics: a large, but forgotten gathering of physicists. As background to relativity, Staley first focuses on five decades in the life of one experimenter, followed by an international gathering that lasted only a few months. The narrative effect is jarring, but the connective threads are acceptable. For decades, relativity was misconstrued as the offspring of a particularly puzzling experiment, Michelson's, and an isolated creative individual, Einstein. Accordingly, it seems fair to begin a revisionist account by clarifying what Michelson did and by focusing on a networking community instead of one creative loner, Einstein. However, the Congress does not reveal much that is new, to illuminate the emergence of relativity physics. Yet Staley analyzes the formation of physicists' collective memories. American physicists eventually granted a prominent role to Michelson in the rise of Einstein's relativity; they learned to remember an event that apparently did not happen. Meanwhile, they promptly forgot a major international Congress that, in 1900, loudly rang bells of self-conscious modernity, a presumptuously historic turning point.

Staley next discusses the development of electron theories as a proper context for analyzing the rise of special relativity. But he scarcely discusses the emergence of Einstein's theory, turning instead to the Nobel prize and its earliest awards, to thus comment on how tales of individual discovery became increasingly common in physics. By this point, it is clear that this is non-linear history, which is fine, as we gain insights into well-known topics by setting them alongside neglected contexts.

However, the book pays a price: that it cannot stand alone as an introduction to the origins of relativity physics. Consider an example. We might expect that a book that focuses heavily on Michelson and relativity would clearly recapitulate Gerald Holton's findings on the lack of influence of Michelson's experiment on Einstein, say, by citing the evidence and summing it up. Instead, Staley discusses only a couple of well-known pieces of evidence, highlighting the apparent connection between Michelson's experiment and the rise of relativity physics. Staley writes "in 1907, Einstein assigns the Michelson-Morley experiment—by name—a central place in the development of the theory" (p. 313). Staley refers to Einstein's review article on relativity. He also cites a well-known letter of 1908 to Arnold Sommerfeld, where Einstein wrote: "if the Michelson-Morley experiment had not brought us into the greatest predicament, no one would have perceived the theory of relativity as a (half) salvation" (p. 315). Staley emphasizes these statements, thus recreating the old illusion, unintentionally, that Michelson's work was centrally important to Einstein as he formulated his theory. To the contrary, it would help readers to know that there are many pieces of historical evidence that jointly demonstrate that although the young Einstein vaguely knew about Michelson's experiment, it did not crucially influence his thoughts; it only consolidated impressions gained previously from other experiments. Moreover, other experiments, such as Fizeau's on light in moving water, and experiments on stellar aberration (especially Airy's with a water-filled telescope) were, by contrast, much more significant to Einstein, along with more abstract considerations.

We may clarify Staley's account by saying that Michelson's experiment was centrally important in the development of the physics of the FitzGerald-Lorentz transformations, whereas it scarcely contributed to Einstein's formulation of his theory. This is well known, and Staley seems to write fittingly when he differentiates between relativity *physics* and relativity *theory*. However, the distinction erodes because Staley writes about "relativity theory" as if it were the work of a community. Part of his interest is to trace how the collaborative work of several physicists became misattributed to just one man. Staley explains: "how what was initially regarded as an electrodynamic theory offering important insight into the electron—and as the fruit of collaborative labor—came to be viewed as a new theory of universal scope associated with Albert Einstein in particular" (p. 205). This is a provocative but problematic outlook. Instead, I would say that the equations for analyzing electrodynamics arose by collaborative efforts, but the theory of relativity (involving the replacement of Newton's mechanics) was formulated by Einstein, to justify such equations. There existed no collaborative theory initially; there were several distinct theories: Lorentz's, Cohn's, Abraham's, Einstein's, etc. Some physicists referred to the "Lorentz-Einstein theory" due to a failure to distinguish between the two (given apparently identical experimental consequences). But Lorentz and Einstein consistently maintained that theirs were two distinct theories. Staley points out that in 1906, Einstein once referred to "the theory of Lorentz and Einstein" (p. 308), in the singular; but such scant instances hardly entail that he or Lorentz considered their theories as identical. Staley's characterizations remind me of physicists who regard relativity mainly as the bare requirement that in inertial systems the laws of physics are Lorentz covariant.

Likewise, some other historians and philosophers, such as Galison and Harvey Brown, recently seem content to blur together the theories of Einstein and Lorentz. I do not think that this is historically or conceptually accurate or that it solves the problem of how to undermine the disproportionate credit that traditionally has been showered on Einstein.

Anyhow, Staley seeks to answer when and how German physicists came to regard Einstein as the theory's sole author. He does not directly state that Einstein was one of several authors of the theory, but Staley's words drift in that direction. Certainly, Einstein's theory owed greatly to previous developments in optics and electrodynamics, experimental and theoretical, but this does not move me to split the credit. Instead, I would say that much of the admiration that Einstein's theory receives should be directed at previous achievements in physics. I would not say that special relativity was invented by several individuals in distant cities, just instead that it was devised by one who incorporated other physicists' findings in a convenient, innovative way. And later, his theory was refined and elaborated by others, such as Planck, Minkowski, Ehrenfest, and Born.

Along the way, disagreements arose about the substance of the theory. Staley asks: How did special relativity's meaning become stabilized and propagate? He gives examples of how physicists handled the theory, but overstating the sum of such particulars. He writes: from 1908 onwards "a standardized reading of the physical consequences of relativity was developed in Germany." But this periodization remains unjustified, for there continued to arise interpretations and misinterpretations of relativity for decades (as Stanley Goldberg, Klaus Hentschel and Milena Wazeck have shown). Einstein himself modified his views on the theory, and he later blamed himself as the source of various misinterpretations. For example, Einstein originally characterized relativity as pertaining to rigid bodies, whereas the notion of rigidity later seemed incompatible with the theory. Contrary to the notion that while older physicists opposed Einstein's theory, younger physicists readily embraced it, Staley documents how physicists of Einstein's generation struggled too. Ehrenfest complained that works by Einstein and Minkowski were incomprehensible. Max Born blamed Einstein in 1909: "Einstein himself is to a great extent guilty of this mischief, that the one brilliant idea is nearly offset by an abundance of mathematical, logical, physical infamies and tactlessness" (p. 275).

Like my own work, Staley contributes to a historiographic departure from the portrayal of Einstein's 1905 work (epitomized by Arthur I. Miller's book of 1981: *Albert Einstein's Special Theory of Relativity*), that it was a beautifully compelling work of genius. No, that interpretation developed gradually, over decades. As Olivier Darrigol has previously argued, Einstein's account did not seem evidently superior to most physicists and mathematicians who worked on electron theory in the early 1900s. Staley's distinctive contribution, I think, is his emphasis on memory, asking how physicists collectively forgot apparently major events, while they concocted a convenient but fictitious history of physics.

Einstein's Generation has defects that can be classified as perspectival. In particular, there is an extensive, needlessly critical outlook on the works of past historians of relativistic physics. Staley criticizes "the customary approach to the *history* of relativity" (p. 295). But really, there exists no such thing—relativity histories exhibit a lack of consensus typical of some specialized fields of history. A few examples suffice: Arthur I. Miller (2001) emphasized alleged interconnections to developments in art (in his *Einstein, Picasso*); John Stachel argued that Einstein was probably influenced by a relative notion of time sketched by Hume; Galison argued that timekeeping technical problems influenced Einstein; John Norton conjectured instead that Einstein discovered the relativity of simultaneity by analyzing the experiments of Fizeau and aberration; and so forth. Now, Staley's text analyzes relations between the particular and the general, the individual and the community, the material and the cultural, the relative and the absolute; he aims to jointly convey experiment and theory, in their social and material underpinnings. He complains about historians not appreciating "the full range of issues" (p. 261). But such complaints are unwarranted because, well, no historian ever appreciates the full range of issues. Part of the nature of the business is to increasingly identify neglected dimensions and contexts that shed light on a topic and focus on those. In my own work, I studied the kinematic and algebraic roots of relativity, and I certainly do not blame Staley for not investigating these topics in his book, as we each choose whichever topics seem appealing or important.

Yet Staley repeatedly emphasizes that he highlights neglected historical dimensions. In view of his persistent critiques of historiography, I searched for a major shift of perspective that constitutes Staley's main contribution; but I have not found one. Instead, I find an assortment of fair historiographic adjustments, such as the following. Staley argues that the electron has been somewhat neglected in histories of relativity. He argues that experiments were more significant to the development of relativity physics than usually appreciated (he rightly argues that no one experiment was regarded as definitive proof). He claims that American astronomy, in the late 1800s, contributed to the rise of physics as a discipline to an extent that historians had not recognized. He characterizes the significance of the Solvay Council, of 1911, not for any substantial contributions to quantum theory, but for concocting a subsequently influential portrayal of the "classical" past. Staley makes various minor corrections; e.g., he rightly points out that Arthur I. Miller mistakenly claimed that in 1907 Einstein set Ehrenfest straight on relativity. Ehrenfest's critiques were lucid, and his analyses helped reshape special relativity. Staley also proposes a wealth of conjectures. He suggests that in 1905, Einstein knew of Kaufmann's 1903 experiments, which did not support his theory and that hence Einstein chose not to mention them in his paper of 1905, and that therefore, in 1907, he chose to refer instead to Michelson's experiment as central to the development of relativity. Whereas Miller had conjectured that the myth of the seminal role of the Michelson-Morley experiment began with the collection of articles edited by Otto Blumenthal in 1913, Staley conjectures that it may have begun with Einstein's 1907 review article on relativity. But such conjectures are not mutually exclusive, as some individuals were influenced more by one source and others by another. These are all fair, welcome, but relatively minor points of disagreement, so I do not think that they warrant the strongly revisionist tone.

Staley painstakingly struggles to break free of tradition, to eschew the usual historiographic categories, gaining one foothold here, another there, but yet he seems engulfed by tradition because his analysis refers so thoroughly to scholarly notions and debates. In my own book, I took a different approach. In view of the abundant disagreements in the historiography of relativity, I decided not to engage the scholarly literature in an extensive argumentative way but, instead, to focus on crafting mosaics of descriptive statements that reliably reflect primary sources. This difference in our approaches was fostered by our editors. I surmise that Catherine Rice and Jennifer Howard at the University of Chicago Press at least supported Staley's extensive discussions of historiography. By contrast, my editor, Robert Brugger, at Johns Hopkins, insisted that my book should include no overt mentions of historical literature, *none at all*, in its main text (claiming that such books become dated), and consequently I argued in order to keep the scant few mentions that in the end I included. Where I referred to the historiography, it was mainly to counter the otherwise plausible illusion that the material analyzed is self-evident (one aim was to illustrate how for decades specialists have misunderstood Einstein's expressions). It is not that *Einstein's Generation* lacks analysis of primary sources; to the contrary, it duly delves into many primary and neglected articles, and it includes abundant transcriptions of quotations, in the original German, in the footnotes.

Another major difference in approaches concerns the pursuits of conjectural history. Some writers claim that there exist nearly no traces of Einstein's pathway to special relativity, and so, they subsequently invent plausible explanatory stories. They claim that Einstein "may have" done this, he "must have" thought that, or that he "probably" knew this or that. Writers put much into Einstein's words, combing too closely for subtle meanings. The thoughtful interpretation of silence, and the multiplication of "may haves" with "could haves," is a trend that recurs in Staley's book (e.g., pp. 306–308). Instead, I systematically avoided such expressions and the urge to read between the lines. For example, in one chapter, I collected and chronologically assembled an extensive mosaic of definite relevant traces of Einstein's path to special relativity from 1895 to 1905, based on many contemporary and retrospective sources. Instead of expansive argumentation to explain why one piece of evidence is dubious or less important than as portrayed by another writer, I chose to convey judgments in the briefest way, by simply prefacing pieces of apparent evidence with single word qualifiers that cast doubt, in a scale of increasing plausibility: "Allegedly," "presumably," "apparently," "reportedly," "actually," etc. I thus avoided expansive historiographic deliberations in favor of writing definite statements, to use more ink to describe the past than to speculate upon it. I do not mind if historians wish to decipher silent gaps, but I think such speculative work should better take place on the basis of a fair and comprehensive accounting of extant evidence.

In light of Staley's work, I imagine that for some historians my book might seem strangely old fashioned, focusing for many pages on who did what, when, how, and why. But it was painstaking work! Years ago, Roger H. Stuewer taught me that some of the most difficult sentences to write are straightforward declarative statements, expressing what actually happened in the past, in a way acceptable to historians. There is something pleasant in histories in which writers stay out of the narration, keeping other historians and their squabbles out as well. But histories that thoroughly engage the academic literature are also valuable, and I admire Staley's wide-ranging labors to produce a rich and outstanding work in that genre.

Regarding again the old story that Michelson's crucial experiment inspired one individual, Einstein, to revise the foundations of physics, it is interesting to see how Staley's work and my own retain some semblance of its arch. Staley begins with Michelson, *in extenso*, and then diminishes and redistributes Einstein's authorship, focusing on connections to electron theory. I trace the history of kinematics and focus later on the biographical and conceptual details of Einstein's original formulation of a new kinematics, briefly including Michelson's experiment as a significant but minor influence. Whereas Staley begins by focusing on a single physicist, an experimenter, and subsequently moves to increasingly general topics, I begin instead from the general and move to the particular, finally focusing on a single theoretician, and his work. Staley and I agree on the importance of writing non-linear history, which involves threads that do not converge. We agree on the importance of discussing topics neglected by physicists. Yet despite Staley's portrayal of his work as more inclusive than most, there remains room for new writers who will synthesize a comprehensive history of special relativity.

Author's response: Richard Staley

In 1907, Albert Einstein wrote his first paper by invitation, penning a review of relativity for the *Jahrbuch der Radioaktivität und Elektronik* at the request of Johannes Stark. It offers a history of the subject, an overview of recent research by a handful of authors, and a new principle. The paper provided a brilliant demonstration of its author's ability to coordinate and direct the work of his contemporaries and received significant attention, but its impact was surely overshadowed by two papers that Hermann Minkowski published in 1908 and 1909. Einstein's review article has commonly been celebrated for its articulation of a new assumption, later termed the principle of the equivalence of a gravitational field and a frame of reference in constant acceleration. In my recent book, I draw attention to the creative role of its account of the origins and development of the field of research that Einstein was helping to shape. Although admittedly brief, this deserves to be thought of as the first history of relativity. I revisit it now partly in order to clarify a subtle point, which I think helps explain the diverse attitudes exhibited by the three reviews collected here. The central subject of my book is no single individual, but the physics community. Lewis Pyenson notes that and evocatively sketches several ways of engaging the cultural and social history of the period still more deeply. While welcoming the attention I pay to disciplinary formation, Sean Johnston recommends a more democratic, sociologically, and ethnographically informed approach. In contrast, Alberto Martínez—author of a rich account of kinematics that similarly aims to open relativity to new historical analysis—would bring me back to Einstein. I think the unease Martínez expresses toward some features of *Einstein's Generation* stems from his attitude toward the extent to which I have taken the community as my primary subject. Describing how I have done so may help explain, if not defuse, the defects of perspective and tone on which he comments.

Martínez's first critical argument is that the book cannot stand alone as an introduction to the origins of relativity physics, by which he means Einstein's theory. By way of example, Martínez notes that Gerald Holton has shown that the Michelson-Morley ether drift experiment was not central to Einstein's formulation of a new electrodynamic theory. In his view, I fail to clearly recapitulate this finding. Although in fact I state Holton's view directly (on p. 302), there is a reason for the brevity of my remarks on Einstein's investigative path. In *Einstein's Generation* I took a strategic decision to approach Einstein first through the perception of members of his community. Readers initially encounter Einstein's work through the lens of proponents of electron theory, who took a variety of stances toward testing, debating, and extending Einstein's work. Chapter 8 then considers the more or less brief participant histories in which a number of researchers, including Einstein, discussed the origins and changing interpretations of a field that most were happy to call relativity theory (Relativitätstheorie). In these writings, the achievements of Lorentz, Einstein, and Minkowski, among others, were continually being revisited. Analyzing them allowed me to explore how physicists themselves approached themes of discovery and distinction: we learn just how far discussions of its origins were integral to the development of relativity physics through to 1911.

In contrast to the great care I devote to analyzing changing perceptions and physicists' accounts in this period, I discuss Einstein's pathway to the theory only briefly and largely by reporting the views of previous historians, without developing an independent historical analysis of all the issues involved. The effect can evidently be unsettling; Martínez speculates on the drift of my views and thinks my approach unintentionally allows the unfortunate impression that the Michelson-Morley experiment was central to Einstein's path, contra Holton. But most readers will have learned a series of different lessons from my treatment, which begins in the 1870s with a detailed examination of Michelson's work. The first is that Michelson himself was primarily concerned with developing a new instrument (what became the interferometer), rather than with following up the theoretical consequences of his experiment. Second, readers learn that the experiment was integral to the evolution of Lorentz's theory of electrodynamics, stimulated particularly by Henri Poincaré's demand that Lorentz's theory satisfy a range of principles, including the principle of relativity. And thirdly, they learn that when it came to giving relativity a history in 1907, Einstein did not stress the steps of his own path but constructed a route in which the Michelson-Morley experiment held a central place. Further, he described his paper as summarizing the results of "the union of the H.A. Lorentz theory and the principle of relativity" (p. 311). Einstein clearly wrote for his community, adopting a generalized, representative perspective, and this surely underlines the point that the inception of his approach is only one of many different things we might want to learn about the development and propagation of relativity. But expressions like Einstein's—together with other physicists' continual negotiation of similarities and differences between approaches which they nevertheless linked with labels like Relativitätstheorie, "the Lorentz-Einstein theory," or still more extensive lists of pioneers—led me to use the term "relativity theory" inclusively and to describe this field as the fruit of collaborative labors, rather than associating it with Einstein's interpretation alone.

Martínez's arguments against this position rely on a number of misconceptions. The view certainly does not involve holding that each author who described or contributed to this developing approach held an identical interpretation. Nor does it imply that the diverse contributions that contemporaries associated under that umbrella (especially the work of Lorentz, Einstein, and Minkowski) cannot be regarded as constituting distinct theories—just so long as historical or conceptual relations between the different approaches were sufficiently important for contemporaries to link them. Indeed, as I document in detail, the participant histories I discuss continually address points of distinction at the same time that they establish continuities of one kind or another. For example, the experimentalist Walter Kaufmann wrote of testing the "Lorentz-Einstein fundamental assumptions" while offering the first extended discussion of the epistemological advantages of Einstein's approach over Lorentz's and describing their formal results as identical (pp. 242–44 and 303–305). The advantage of my approach to "relativity theory" thus lies in the sense it makes of a wide variety of particulars, encompassing at the same time brief remarks and extended discussion, and the perspective of both adherents and opponents. Rather than committing one to blurring essentially distinct approaches, it appropriately recognizes the interpretative flexibility characteristic of a period when, regardless of their own commitments, everyone concerned regarded relativity as being in the process of being articulated and elaborated. Further, my view that a standardized reading or shared understanding of the nature and consequences of relativity was developed by 1911 has important limits and is widely shared by other historians. It is true of a significant portion of the German physics community (as Stanley Goldberg helped show). This periodization and primary concern with the physics community is surely untroubled by the fact that alternative interpretations could be developed later and in wider communities, as Klaus Hentschel and Milena Wazeck have documented in studies of popular and philosophical writing in the 1920s. Finally, this formulation is not meant to deny the value of investigating those points of interpretation which establish Einstein's originality. Rather, it aims to provide an empirical characterization of the understanding of relativity and Einstein's work that emerged between 1905 and 1911. The distributions of credit in which I am interested are those of Einstein's community, rather than those of more recent analysts, or even my own.

This brings me to the perspectival defects that Martínez discerns in *Einstein's Generation*, concerning how I describe the relations between my work and that of other historians. Instead of a major shift in perspective, Martínez finds the book to present numerous fair historiographical adjustments. He thinks this sits awkwardly with what he regards as its extensive, needlessly critical outlook on earlier work, and "strongly revisionist" tone. Both my criticisms of earlier histories and claims to novelty are always stated in relation to specific scholarly aims or findings, but this is not evident in Martínez's account. So let me give some context to his main example. When in Chapter 8 I criticize "the customary approach" to the history of relativity, the phrase echoes Einstein's 1905 reference to typical approaches to electrodynamics. But is there such a customary approach to the history? Martínez denies this and rightly claims there is plenty of variety in the interconnections and influences discussed in the works of Miller, Stachel, Galison, and Norton he cites as examples.

But despite their excellence, all these works are similar in precisely the respects I stated in characterizing the customary approach: they focus on Einstein, on inception, and (though their aims render this less relevant and obvious in some cases), their accounts of other physicists are very often framed in evaluative contrast with Einstein, as reception accounts. What I say in Chapter 8 is that such asymmetries are often unrecognized (as Martínez might now agree) and that they have obscured many subtleties in the process by which relativity was developed. I have nothing against studies of Einstein and inception, evaluative contrasts, or reception accounts in themselves. But they can add up to promoting a misleading understanding of the physics community. So while there are certainly some sweeping aspects to my critique of earlier work (as well as the statement of a few ambitious research aims), I always thought the fruits of my approach would come in the details. On this score, my final observation is that Martínez finds my work to be bound up with tradition for a very good reason. This is because I was not struggling to break free from tradition or to eschew usual historiographical categories. Rather, I aimed to throw new light on several common assumptions by analyzing the original historical grounds for a few critical notions that have often been taken for granted by previous scholars (like Einstein's eminence and the transition from classical to modern physics). If I am lucky, far from dating my study, as Robert Brugger of Johns Hopkins University Press might fear, this dual investigation of period and present assumptions will have double purchase. It may also contribute to scholarly understanding of the relations between the work of science and its image, which should always be an important issue. I think Martínez shows me that it is still necessary to clarify these particular points of distinction.

Now some thoughts on methodology, for Martínez, Johnston, and Pyenson all focus on the character and content of my narrative, and it may be helpful to outline aspects of the technical foundations for *Einstein's Generation* from another perspective. Rather than eschewing inception and reception accounts, my work can be regarded as presenting a number of interlocking examples of that genre, but as a portrait of a community at work, it is especially critical to note both the unit of analysis at issue, and the plurality and diversity of the threads explored. Readers will appreciate that analyzing the inception and reception of *relativity theory* leads to a host of different forms of argument and a wider set of characters than focusing on *Einstein's theory*. Exploring Michelson's work, in part by studying the inception and reception of the *interferometer* as an optical instrument, led me gradually to recognize the pertinence of a still broader unit of analysis: *relativity physics*. As we know, Michelson sought to determine the relative motion of the earth through the ether, and this led Lorentz, Poincaré, and Einstein to extended discussion of relative and absolute space and time. But like many experimentalists, Michelson addressed the question of relative and absolute measures in several additional contexts (notably in his 1893 determination of the international meter in terms of the wavelength of spectral lines). Working in Germany and contributing to empirical knowledge of the *electron* (now we meet the inception and reception of work on a particle), Walter Kaufmann understood his test of relativity theory to rely indispensably upon absolute measures of the deflection of electrons by magnetic and electric fields. Kaufmann's practical experimental work engaged him in a dialog between relative and absolute measurements, and the increased precision required for the latter led him to incorporate advanced optical measurements of the kind Michelson helped pioneer. In addition, the integrity of Kaufmann's results depended upon the rigidity of his condenser plates, an empirical corollary to theoreticians' concerns with the concept of relativistic rigidity; and we can note that a 1907 replication of Michelson's 1893 determination of the meter was understood to provide the first convincing proof of the rigidity of that standard of length. Finally, Kaufmann's empirical concerns with relative and absolute may have helped him interpret Lorentz's 1904 treatment of electrodynamics in ways that assimilated it with those concepts, thereby helping Lorentz's work appear more like Einstein's than it may otherwise have. These subtle interrelations, direct and indirect, between practical and conceptual elements of experiment and theory have been largely invisible to historians of Einstein's theory. Thus, using a more inclusive set of analytic categories required examining several different groups in the physics community, as well as engaging with diverse materials and different levels of analysis. In *Einstein's Generation* I traced changing uses of apparatus, methods, and framing concepts—through research fields and across national borders and disciplinary subspecialisms—as well as tracking the inception and reception of key elements of experiment and theory. In the ensemble, I sought what I am beginning to think of as kaleidoscopic rigor.

In different ways, Lewis Pyenson and Sean Johnston explore how the understanding of the disciplinary fabric yielded by such a deliberately multifaceted approach might be extended and deepened. Pyenson's rich descriptive account offers many valuable suggestions oriented toward embedding physicists more thoroughly within the cultural and social history of the period, for example by complementing my study of the changing complexion of the concept "classical" with a more broad-seated examination of the cultural environment, and of physicists' use of concepts like "modern" and "revolution." As his account shows, we already have a great deal to work with, and several suggestive vistas (re sex, in addition to the work Pyenson cites, Deborah Coen's study of the Exners probably offers the most thorough realization of a family-based approach to the links between lives and ideas). I hope this book has indicated the value of exploring concepts and materials shared across several different contexts (recognizing the silences and elisions that shape visibility and memory in this process) and has illustrated the constitutive role of scientists' participant histories in shaping current perspectives, both by helping define, articulate, and communicate new research directions, and by mediating relations with broader publics. Two rather different but fruitful ways of following lines traced in *Einstein's Generation* still further beyond the physics desk and laboratory would be to develop a more wide-ranging study of the electron across disciplines and through public culture and a more fully realized understanding of the cultural significance of the relative and absolute in different domains.

Rather than the social history of ideas, Johnston focuses on their sociology and the limits of my analysis. He finds the latter revealed in the tension between the encompassing aim I state, to reflect the breadth and depth of work in physics as a whole, and the necessarily piecemeal approach demanded by my focus on the elements of relativity physics, the careers of Michelson and Einstein, two major conferences in which their work was discussed, and the 1900 World's Fair. Stating the inclusive but impossibly ambitious aim to study the whole of physics is important: it encourages the endeavor to test understandings formed around a limited subset of the physics community, closely defined theme, or specific subject against the diverse perspectives yielded by other bodies of work. But of course any particular approach toward such an encompassing aim raises new questions. Several of Johnston's critical suggestions stem from taking up elements already present in my discussion and exploring their implications within a still broader historical context, or in the light of more sharply defined methodological tools. With him, I agree that more ethnographically and sociologically sophisticated analyses would be fruitful. In fact, my approach has more than a passing resemblance to the studies Johnston mentions that track cohorts and research networks, examine shared practices and hardware, and trace still more democratically expansive expressions of nascent community perceptions (his study of holography provides an excellent model). For example, my focus on Michelson prevented me from realizing a full treatment of the relations between astronomy and mechanics in the US physics discipline. Yet identifying this complex of concerns as a particularly interesting locus for the relations between science and industry in the United States surely opens the possibility of testing the historical argument further. Similarly, readers will find that by combining an intimate study of Michelson's perspective on his research with a wide-ranging exploration of when and why others took up his work (instrument makers, experimentalists, and theoreticians all), my book has delivered a portrait of a fascinating sociological situation in which Michelson's role in the discipline was largely defined by delivering strategically important values or results, and a distinctive method, rather than by a mutual engagement in the practices of other scientists. Michelson forms a revealing contrast to Rowland in this regard; but surely more can be done to understand just how each figure shaped the physics community in the United States, and Johnston rightly suggests that the context for optical research in Germany is also ripe for further study.

Thus, *Einstein's Generation* sacrificed the historical breadth required to provide a truly comprehensive study of discipline formation to the selective aim of developing an account of relativity physics, and particular aspects of disciplinary identity. If the sociological and methodological features that Johnston mentions are less visible than they might be, this is partly a result of my narrative focus on story and historiography. And that brings me once more to Pyenson, who has already played such a creative role developing new narratives in the intellectual, cultural, and social history of relativity. My final challenge in writing this book was to find a better way of presenting what were initially developed as extremely long single chapters on, for example, the World's Fair *and* International Congress of Physics in 1900, or experiment *and* theory on the electron. These reflected my wish to work across categories I understood as limiting, in order to realize greater wholes and more subtle interrelations. Offering them to readers, I needed to break those units up again, yet only saw how to do so when I realized the possibility of developing an overarching part structure that would allow a more sharply faceted presentation of thematic interrelations across chapters. In other words, some features of the kaleidoscopic quality that Pyenson has characterized may have come late to this book. But just as *Einstein's Generation* sought to throw new light on elements that previous historians had taken for granted, I particularly appreciate Pyenson's discussions of narrative style, for they identify historical foundations for aspects of my own work and writing that would otherwise have escaped my attention.

Finally, I would like to thank Theodore Arabatzis for organizing such a stimulating group of responses and my wife Elisabeth Emter for several helpful suggestions.

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