Essay review: Cry 'Good for history, Cambridge and Saint George'?

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The Cambridge history of science, Vol. 5. The modern physical and mathematical sciences Mary Jo Nye (Ed.); Cambridge University Press, Cambridge, 2003, pp. xxix + 678, Price £95.00 hardback, ISBN 0-521-57199-5.

This volume is the third thus far published of *The Cambridge history of science*, planned in eight parts over the last decade by Cambridge University Press. Noting the incompleteness of George Sarton's heroic solo endeavour on a comparably magisterial scale (Sarton, 1953–1959), Cambridge general editors David Lindberg and Ronald Numbers adopted a more pragmatic multiple author approach in devising this new series. They devote the four latter volumes to that fertile wonder 'modern science', its modernity construed chronologically as the post-1800 era. While Volume 6 encompasses the biological and earth sciences (Bowler & Pickstone, forthcoming), Volume 7 deals with the social sciences (Porter & Ross, 2003), and Volume 8 examines the sciences in national and international setting (Livingstone & Numbers, forthcoming). Lindberg and Numbers thus circumscribe the territory of Volume 5 to be the history of physics, chemistry, astronomy and mathematics in the Euro-American world. Although this might seem a fairly conventional—even conservative—subject clustering, few historians would have felt undaunted by the heterogeneity of such material, the narrowness of the brief and the long two-century period of coverage. This volume must therefore be judged with sensitivity to the difficulties of leading thirty-seven scholars in diverse specialisms to produce a coherent product, and the sheer impracticability of Sarton's near-Shakespearean ambitions for unitary drama. Useful comparisons can thus be made with recent works that offer a multi-perspectival view over comparably broad terrain: John Krige and Dominic Pestre's stimulating and uncomplacent *Science in the twentieth century* (1997), and the more radically inclusive bibliographical essays in Arne Hessenbruch (Ed.), *The reader's guide to the history of science* (Hessenbruch, 2000).

In the thirty-three chapters of *The modern physical and mathematical sciences*, editor Mary Jo Nye attains a thematic cogency comparable in intention to that of Krige and Pestre's volume. Her choice of six headings is based primarily on discipline and period while maintaining sensitivity to chronology and broader historiographical considerations. The first two sections cover overarching historical categories: the 'public cultures' of the physical sciences, and the 'building' of the relevant disciplines analysed through places, instruments, and communication. Physics and chemistry dominate subsequent sections in the nineteenth and the twentieth century respectively, documenting a broad 'inward bound' shift toward atomic and molecular sciences. Following a broad conspectus of mathematics, astronomy and cosmology, the work's vibrant final section addresses 'problems and promises' in late twentieth-century science. Roughly equal coverage is thereby given to the two main centuries, with thirteen chapters devoted to both. In disciplinary terms, nearly a third of the chapters are dedicated to physics, six to chemistry and three or so to mathematics, astronomy and technological topics, with the remainder cultural or interdisciplinary in orientation. Given the diversity of authorial styles and assumptions, though, some tensions and discrepancies are inevitably generated in this organisational scheme, as is explored further below.

It is to Nye's credit that her contributors encompass both very senior names in the field as well as vigorous young blood, the majority producing articles well targeted to the graduate level researcher. The most recent generation of authors produce chapters notably more congenial to readers of a contextualist persuasion than the sedate internalism that marks out the 'received view'. Nevertheless, most chapters succeed in integrating both a narrative of key events, trends and issues, and an historiographical overview of the field. Some contributors over-cautiously confine themselves to offering a useful resume of standard literature within a conservative internalist framework, but the most valuable articles take forward the debates in their field while at the same time exploring overlaps and interactions with other scholarly domains. Thus at a time when history of the biomedical sciences is gaining ever greater popular attention, there is clearly evidence here that historians of the physical and mathematical sciences have by no means stood idly by awaiting oblivion.

Whereas some partisan editors might have sought to impose a party line on contributors, Nye facilitates an invigorating pluralism of views on how the field should be conceptualised and especially about which assumptions, explananda and interpretive approaches are most appropriate. A minority of contributors takes for granted the intellectual autonomy of their subject matter, but the majority examine how their science overlapped and interacted with other cognate subjects. Indeed most chapters helpfully consider the changing boundaries between scientific disciplines, a complex historical phenomenon that is surely essential to any broad study of the physical and mathematical sciences. Links with the biomedical sciences are examined by Yasu Furukawa, and Bettyann Holtzmann Kevles and the late lamented Larry Holmes. In a complementary vein Naomi Oreskes, Ronald Doel and James Fleming explore the connection with environmental sciences, while Ted Porter, Paul Josephson and Terry Shinn showing the intimate interconnections between the physical and social sciences.

That being said, surprisingly little attention is given to the dichotomy of ‘pure’ versus ‘applied science’ that was invented sometime in the middle of the period covered by this volume. *A fortiori*, little explicit consideration is given to the historical genesis or the historiographical tenability of this distinction. Fortunately each contributor on technological topics and most authors on physics evade this conceptual straitjacket to great effect. In particular, Michael Eckert, Jeff Hughes, Bruce Hunt, Alex Roland, Terry Shinn, Crosbie Smith and Robert Smith show how politico-technological imperatives supplied the funding, demand and sometimes the conceptual apparatus for many innovative forms of modern science in which engineering experts were closely involved. By contrast historians of chemistry and of quantum physics in this volume tend to offer idealised histories of putatively ‘pure’ sciences as if these were natural or self-evidently defined entities. These authors tend not to examine *how* such microsciences acquired their prestige and institutional support, nor whether this had anything to do with the enormously fine division of scientific labour uniquely possible in affluent military–industrial states. Had they done so, some interesting conclusions might have followed.

Indeed for all but the most abstruse domains of cosmology (Kragh) and quantum physics (Darrigol & Schweber), physics is presented here as being very much

concerned with the control of the material world, or at least in attempts to mitigate its uncontrollability. This is not just a trivial observation about the persistence of neo-Baconianism among historians of physical science: it is a point that lies at the origins of their profession and its very rationale. It was, after all, the great success of physical scientists in bringing political, economic and military advantage to their paymasters, and the promise of a science-enhanced future soon after World War II, that justified historians joining George Sarton in paying organised *professional* attention to science's past on a broad international canvas. The continued significance of techno-science, especially its biomedical varieties, as a driving force of civilisation certainly justifies the decision of Cambridge University Press to devote a whole eight volume series to the subject. Had the physical and mathematical sciences only ever been the lofty pursuit of truths yielding little socio-economic benefit, one wonders whether one rather smaller volume would have sufficed.

While the broader socio-historical significance of the physical sciences to non-scientists is explicitly considered by most contributors, it is only indirectly addressed in the editorial introduction. Nye does of course offer an agenda of common themes in attempt to lend cohesion to this kaleidoscopic volume. Notwithstanding her effective editorial structuring, and her inspiration of most contributors to write essays of the appropriate quality, her preliminary survey reinforces the suspicion that it is nearly impossible to summarise the overall thrust of this work in a manner catering for all tastes. Nye characterises the project in somewhat traditional terms as investigating a period in which mathematicians and scientists 'optimistically aimed' to establish conceptual foundations and empirical knowledge for a 'rational rigorous understanding' that was 'accurate, dependable and universal' (p. 1). She thereby downplays the significance of the recurrent crises, uncertainties and controversies that preoccupy the writings of more worldly historians. Who, for example, could deny the profound importance of vigorous, sometimes bitter, arguments over the viability of atomism, the characteristics and existence of the electromagnetic ether, the plausibility of quantum indeterminacy, the exasperating irreconcilability of quantum theory and relativity—let alone the prevalent difficulties in interpreting data at the limits of hi-tech instruments? Such debates, so crucial to driving the relevant fields forward—and making them so interesting to historians—indicate that the physical sciences have long survived without either uncontested foundations or univocal

rationality. The fact that at least some contributors do address these sorts of concerns is positive evidence, it must be reiterated, of the editor's clear liberality in allowing dissenting views to be heard.

Nevertheless for a volume that aspires to comprehensive coverage of the diverse historical cultures and historiographies of modern physical science, one longs for slightly more extensive reference to the well known work of Harry Collins (Collins, 1985 and Collins and Pinch, 1998) Andrew Pickering (Pickering, 1984), Simon Schaffer (Schaffer, 1994), Sharon Traweek (Traweek, 1988) and Norton Wise (Wise, 1995). A more audacious study might have cited their research to illustrate how post-Enlightenment physics has often been a localised, contingent and fallible affair despite being so thoroughly imbued with factory-bred methods of control. Alternatively it might have traced how much physical science was scent-marked with an unmistakeable whiff of masculinity and yet also subverted by a lingering indeterminacy in both the meaning and epistemological significance over even such key concepts as 'precision'. Such writers could perhaps more easily have been accommodated within the overtly pluralist understanding of science in Krige and Pestre's volume. Their introductory post-positivist overview allows various notion of science as a skilled technological endeavour; a collection of specialised institutions; a set of powerful managerial resources; an ensemble of disparate discourses; a route to social advancement, and yet also an often contested source of authority (Krige & Pestre, 1997, pp. xxi–xxv). Nye offers no counter-argument to such a fractured non-reductionist view of science, simply suggesting that 'postmodern' moves into subjectivity and relativism have, in her view, undermined the view that science is a reliable and privileged form of knowledge (p. 1). In a more positive vein she observes the resilient popularity of grand-narrative history of science, yet seemingly infers from its buoyant sales that it is the *right* way to write history of science (p. 2). Sceptics might judge this as evidence rather that big picture history is simply the most commercially successful form of our subject.

Another potentially fertile unitary theme proposed by Nye is Thomas Kuhn's oft-cited historiography of revolutions. Notwithstanding Steve Fuller's recent claims to the contrary (Fuller, 2000), she contends that Kuhn's account of everyday ('normal') science and revolutionary change might be a common reference point for her

contributors (p. 3). While some do indeed pick up this theme, positive evaluations of Kuhn are offered for other kinds of reasons. In his essay on ‘Intersections of physical science and Western religion’, Frederick Gregory suggests—albeit without explication—that Kuhn was important for showing how ‘context’ mattered in science (p. 48). Pamela Gossin’s piece, ‘Literature and the modern physical sciences’ notes how Kuhn, among others, effectively drew upon literary writers in his own work (p. 107); and in ‘Quantum theory and atomic structure, 1900–1927’, Olivier Darrigol sympathises equally much with Kuhn’s account of the origins of quantum discontinuity (pp. 331–32). But whereas Sungook Hong reminds us that Eugene Frankel had to augment Kuhn’s ‘revolution’ historiography to make it fit the history of optics (p. 275), David Rowe argues there is little agreement yet on the utility of Kuhn’s approach to the history of mathematics (p. 114). Then again Silvan Schweber finds Kuhn’s later ‘lexicon’ work most useful in understanding the history of quantum theory (pp. 376–377), while Helge Kragh denies outright that the cosmological innovations of 1917, 1930 and 1965 can be seen as Kuhnian revolutions at all (p. 536). And although Crosbie Smith accepts several of Kuhn’s valuable historical theses on the complex origins of energy conservation theory, he forcefully critiques the problematic notion of ‘simultaneous discovery’ that Kuhn deployed to explain its emergence in the 1840s–1850s (pp. 289–290). Thus we see again how Nye’s contributors take her editorial suggestions in rather disparate yet creative revisionist directions.

Less compelling, perhaps, is Nye’s account of how philosophy of science can inform the history of physics. This is clearly a key point for historians of the generation educated into the notion that philosophy of science and history of science could and *should* usefully support each other’s endeavours. This symbiotic relationship has been under some strain of late, with the two fields tending to go their own separate ways—sometimes even seeming to be working in opposition to each other. Nye herself freely admits that some historians of science no longer believe it possible to narrate a history of science predicated on a universal scientific ‘method’ (p. 2); but she then makes no attempt to rebut this claim. Without any apparent irony, however, the opening chapter ‘Theories of scientific method: Models for the physico-mathematical sciences’ is presented by Nye as examining what philosophical writers and scientific practitioners hoped to achieve by defining and employing ‘scientific method’. In fact Nancy

Cartwright, Stathis Psillos and Hasok Chang focus on historical plurality of *competing* methods: induction, deduction, Aristotelianism, Pythagoreanism and instrumentalism focusing on Duhem and Poincaré, mentioning Einstein and Descartes only in passing (pp. 21–25).

Drifting somewhat from its ostensible 'method' rubric, this chapter moves to the controversies over Bayesianism confirmation theory and scientific 'realism'—the latter being an area of rather greater interest to philosophers of science at present. Historians, by contrast, have been less inclined to follow this line, having been exasperated by tendentious forms of entity realism that purport to find inductive support for truth claims concerning the existence of unobservable theoretical entities. After all, the recurrent long-term *failure* of physical theories concerning phlogiston, caloric, electromagnetic ethers and atoms has made such 'entity' realism inductively untenable. Despite the historical rationale and likely readership of this volume, the authors nevertheless move with indecent haste to the all-too-familiar dismissal of this uncongenial view, simply advocating a form of entity realism that largely evades the sceptical force of historians' hard-won evidence (pp. 26–27). More careful consideration might have been given to the refined *structural* realist programme that avoids the referentially challenged ontological commitments of its rival, offering rather more to the historian mapping long-term continuities in the mathematical structures of theoretical traditions (Da Costa & French, 2003). Most helpful to the historian in this chapter is a short final section on 'experimental traditions' that properly engages with the socio-historical literature mentioned above. The erudite hand of Hasok Chang is clearly evident in the examination of how Victor Regnault and later Percy Bridgman sought to overcome the troublesome theory-ladenness of measurement work (pp. 32–35). Here is an exemplar of how philosophers of science can illuminate past forms of scientific practice—more useful to the historian than misguided attempts to hunt that elusive and enervated chimera, 'scientific method'.

That philosophical piece opens the apparently miscellaneous Part I, 'The public cultures of the physical sciences after 1800', that goes on to address the scientific relations of religion, women, popularisation and literature. Margaret Rossiter's 'A twisted tale' gives a characteristically rich survey of the often difficult position of female physicists and chemists, ironically juxtaposing their persistent and widespread

marginalization with the common recognition of Marie Curie as perhaps the most famous of all scientists in the twentieth century. Apart from identifying the powerful role of ‘gender stereotypes’, Rossiter is cautious about feminist attempts to explain the systematic marginalisation of female physicists by reference to a thorough-going ‘gendering’ of physics—save a nod to Traweek’s cogent ethnographic studies of women working in Japanese and US laboratories (p. 71). It would appear that neither Rossiter nor Nye are willing to entertain Sandra Harding’s radical proposal that the ‘masculine’ values pervading all aspects of physics is the primary obstacle to getting more women to become practitioners (Harding, 1986). Rossiter’s account could thus usefully have been supplemented by a study of masculine cultures in the physical sciences, as instanced in Wendy Faulkner and E. A. Kerr’s account of sex and gender in twentieth century science (Krige & Pestre, 1997, pp. 43–60). Equally much, Frederick Gregory’s fertile examination of ‘Intersections of Physical science and western religion’, might have benefited from the inclusion of more than one post-1997 source, for example John Brooke and Geoffrey Cantor’s excellent *Reconstructing nature: The engagement of science and religion* (Brooke and Cantor, 1998). Indeed readers might discern several reasons for the paucity of literature from the last six years in many chapters of *The Cambridge history of science, Vol. 5*.

Perhaps the best piece in the opening section is Pamela Gossin ‘Literature and the modern physical sciences’ which gives an impressively thorough account of the complex symbiosis of literature and science (pp. 91–109). Physical scientists, notably Richard Feynman, have long drawn upon literary techniques to ply their craft, while fiction writers—not least Bertold Brecht, Thomas Hardy, Mary Shelley, and Herbert George Wells—have drawn upon physical sciences to dramatic effect. Gossin’s study thus ably deconstructs the ‘two cultures’ debates that have too often served polemical rather than explanatory purposes in understanding relations between science and the public. By comparison David Knight’s piece ‘Scientists and their publics’ presents nineteenth century popularisation of science as very much a top-down affair, focused on the writers who supplied knowledge rather than on the discerning demand from a highly differentiated and ever-growing ‘public’ readership (pp. 72–90). To find reference to the now ten-year old classic study of such issues by Roger Cooter and Steve Pumfrey (Cooter & Pumfrey, 1994) one needs to turn to Bruce Lewenstein’s entry on popularisation in Hessenbruch’s *Reader’s guide* and the comparable piece by

Bernadette Bensaude Vincent in Krige & Pestre (1997, p. 338). A more inclusive historiographical survey of scientific publishing and the popular reading of science can be found in the scholarship of Jonathan Topham (2000).

Part II of Nye's volume is devoted to discipline building and contains two outstanding *longue durée* pieces that show how particular fields were transformed not merely by internal dynamics but by changing socio-institutional circumstances too. As Joan Richards has noted, sociological methods in history of science have not found favour with many historians of mathematics. To reconcile the internalists and externalists, David Rowe's 'Mathematical schools, communities, and networks' offers an 'actor-oriented, realistic approach' that takes seriously both mathematical ideas and their concrete contexts (p. 114). Addressing the expansion and specialisation in mathematics across France, Germany, Britain and the USA, facilitated by new means of communication, organisation and funding, Rowe ably shows how practitioners were transformed from fusty dry professors in 1800 to project-based team researchers in the post-Cold War era. Over the same period, Robert Smith shows how astronomy metamorphosed from a determination of celestial position by light telescopes to being a 'Very Big Science' with instruments both vastly larger and less earthbound, harnessing the electromagnetic spectrum and rocketry to answer much broader celestial questions (pp. 113–32). 'Remaking astronomy' rightly emphasises how Cold War funding and political imperatives facilitated astronomers' access to very high-tech instruments, epitomised in the Hubble telescope and Viking landers, to ask questions previously the province of theologians (pp. 154–73).

Bernadette Bensaude-Vincent's 'Languages in chemistry' focuses on the more restricted disciplinary thesis that 'chemistry is structured like a language'. She offers three tableaux of how linguistic disorder was resolved: Guyton de Morveau's incorporation of Lavoisier's new chemical taxonomy in the 1787 *Encyclopédie méthodique*; the harmonisation of notation in organic chemistry at the 1860 Karlsruhe Congress, and the Liège International Conference of 1930 that partially succeeded in rationalising terminology (pp. 174–190). By contrast Terry Shinn's meditation on 'The industry, research and education nexus' shows—*pace* Nye and Kuhn—that there are strongly non-universal characteristics even in the maturest scientific practices. His contextualist account yields perhaps not the subtlest of nation-centred

characterisations: Germany as the ‘paradigm of heterogeneity’; France as the ‘paradigm of homogeneity’; England as a ‘case of underdetermination’, and the USA as a case of ‘polymorphism’ (pp. 133–153). Least concerned with discipline is Arthur I. Miller’s chapter ‘Imagery and representation in twentieth century physics’ (pp. 191–215). Often inclined to psychological speculation and self-citation, this concludes unadventurously from studies on Einstein, Bohr, Heisenberg, Schrödinger, Salam, Yukawa Weinberg and Feynman that visualisation in physics has become ever more abstract. Readers might have found it easier to place Miller’s insight into its proper context had this volume included a broad disciplinary study of physics comparable to that supplied by Rowe for mathematics and Smith for astronomy. An appropriately inclusive study of how modern science depends on imagery and representation is Martin Kemp’s piece ‘Seeing and picturing’ in Krige & Pestre (1997, pp. 361–390).

The third section considers nineteenth-century physics and chemistry. In a period normally seen as marked by divergence and distinct disciplinary identity, both Hans-Werner Schütt’s ‘Chemical atomism and chemical classification’ (pp. 237–254) and Frederick Holmes’s study of ‘The physical sciences in the life sciences’ (pp. 219–236) fruitfully examine the complex interactions of physics to neighbouring disciplines. Whereas Holmes presents physics as the ‘master–subject’ laying down the agenda for physiology, Schütt radically suggests that chemistry and physics actually *converged* in the topics of thermodynamics, kinetics and electrochemistry (p. 240)—to which one might also add electron theory and radioactivity. Alan J. Rocke’s examination of ‘The theory of chemical structure and its applications’ (pp. 255–271) resembles Sungook Hong’s ‘Theories and experiments on radiation from Thomas Young to X-rays’ (pp. 272–288) in that both are sound recapitulations of the best literature in their respective fields. Moreover, both draw attention to relevant commercial links, Rocke to the artificial dye industry and Hong to the development of the wireless telegraph. However, both accounts discuss these as forms of ‘applied science’ rather than considering how the industries of dyeing, inorganic chemical manufacture, food, drink, gas and communications might sometime have been the driving forces for scientific innovation. For two historians of late nineteenth-century physics there are no such qualms about adopting a vigorous materialist historiography. In Bruce Hunt’s ‘Electrical theory and practice in the nineteenth

century'(pp. 311–327) and Crosbie Smith's 'Force, energy and thermodynamics' (pp. 289–310), 'theory' mutually entwines with 'practice' in ways that simply cannot be accommodated within a simplistic pure/applied model of science. These pieces give a clear leading role to engineers not only in developing key concepts for physical science, but in supplying a market for the new physical knowledge created in response to industrial need—not merely the musings of isolated natural philosophers.

Some pieces in Part IV on 'Atomic and molecular sciences in the twentieth century' forcefully bring home the rather familiar point that over the past hundred years the quantum sciences have become ever more abstruse in their pursuit of unworldly generality. That feature is common to the three rigorous chapters: Oliver Darrigol's on atomic structure from 1900–1927 (pp. 331–349), Silvan Schweber's on the move from quantum electrodynamics to the 'standard model' (pp. 375–395) and Ana Simões's account of the relations of chemical physics and quantum chemistry (pp. 394–412). Another, perhaps more telling, message is that the sciences undergoing most spectacular development in the twentieth century were those which were brought by state and industry into close symbiosis with the needs of global warfare. Jeff Hughes's excellently compact yet comprehensive essay on 'Radioactivity and nuclear physics' helps us to understand the limitations of the teleological 'bomb historiography' which has for too long encouraged us to accept nuclear weapons as some kind of naturalistic corollary to the development of subatomic physics (pp. 350–374). Michael Eckert emphasises that while 'Plasmas and solid-state science' predated World War II by several decades, the vast increase in post-war funding enabled plasma research to become a close adjunct of thermonuclear fusion and solid state physics to be an integral part of semiconductor electronics (pp. 413–428, esp. p. 418). Slightly understating the enormous value of 'Macromolecules' for industrial purposes, Yasu Furukawa lucidly explains how their structures and functions were understood as a result of cross-disciplinary collaborations between physicists, chemists and biologists (pp. 429–445). Notable among these were William Astbury who developed the X-ray crystallography of biological materials at the University of Leeds in the 1930s, and the famous duo of Watson and Crick who deployed this technique to unravel the double helix structure of DNA at Cambridge two decades later.

Like preceding sections, Part V on ‘Mathematics, astronomy and cosmology since the eighteenth century’ is constituted so as to maintain the sense of interplay between nominally distinct fields. Here, however, the interconnections between the fields covered—including astrophysics, statistical applications and geoscience—are rather less easy to tease out, except insofar as they are all global enterprises of one sort or another. Harking back to Rowe’s remarks we can see that Joan Richards excellent socio-institutionally attuned essay on ‘The geometrical tradition: Mathematics, space and reason in the nineteenth century’ (pp. 449–467) shares little common ground with Jesper Lützen’s robustly internalist tracing of the development of the ‘function’ concept in mathematics (pp. 468–487). A slightly more cohesive pairing is Johann Eisberg’s chapter on ‘Solar science and astrophysics’ (pp. 505–521) with Helge Kragh’s commentary on ‘Cosmologies and cosmogonies of space and time’ (pp. 522–537), the former explicitly cross-referenced to Robert Smith’s earlier chapter with which it shares some key concerns. Faced with this distribution of material across the sections, one starts to hanker slightly for a disciplinarily bounding that could have presented these three pieces side by side. The twenty-first century hypertext-aware reader will have little trouble cross-referencing between them, no doubt.

Most directly relevant to other chapters in this book is Theodore Porter’s ‘Statistics and physical theories’, which elegantly explains how physicists borrowed from the social sciences their methods for quantitative management of epistemological and ontological uncertainties (pp. 488–504). The most original chapter in this section is probably ‘The physics and chemistry of the earth’ in which Naomi Oreskes and Ronald Doel map the competition between geophysical (armchair) and geological (fieldwork) approaches to understanding the history of the earth since the early nineteenth century (pp. 538–557). They conclude that the history of earth sciences particularly well illustrates the ways in which ‘broader social demands have influenced not just the subjects but also the methods and values of science’ (p. 557).

In many respects the most fresh and exciting section of Nye’s volume is the concluding survey of ‘Problems and promises at the end of the twentieth century’. If readers had doubts about the wisdom of spending £95 on a collection of articles that mostly recapitulate and distil current knowledge, the book is rounded off with a collection that should feature widely in scholarly footnotes and on reading lists of

history of science classes. Alex Roland's typically pellucid 'Science, technology and war' outlines ten characteristic factors for the historical mapping of this controversial nexus (pp. 561–578). These range from the state funding/patronage of arms makers, to the secrecy of military science and technology to the pursuit of dual use technologies that can be deployed both in conflict and civic life. Paul Josephson, 'Science, ideology, and the state: Physics in the twentieth century' brings further to the fore the way in which physical science has a significance far beyond its importance for scientists (pp. 579–597). His chapter covers the three contrasting—yet somehow curiously congruent—cases of how government ideology has supported science for very specific nationalist reasons in the Soviet Union, Nazi Germany and the modern USA.

William Aspray then undertakes the awesome task of summarising 'Computer science and the computer revolution' in just seventeen pages (pp. 598–614). He wastes few words in articulating how the US State and companies vied for a stake in the new technology that would both immensely enhance the calculational power not only of the physical sciences, but also of commerce and Government—not unrelated domains after World War II of course. Echoing Holmes's piece, Bettyann Holtzmann Kevles shows the ubiquity of the physical sciences in medicine in supporting the development of ever more refined diagnostic and therapeutic technologies by ever more cross-disciplinary groupings of scientists (pp. 615–633). And as a cousin of Oreskes and Doel's paper, Jim Fleming's meditation on 'Global environmental change and the history of science' explicates the long and untidy history of conflicting theories of climate change that have lead to great public anxiety and government procrastination (pp. 634–650). As Fleming pithily asks concerning the failure of scientifically well informed US and UK governments to ratify the Kyoto Protocol on pollution controls: 'Isn't it time for historical, literary and other humanistic explorations and re-evaluations of environmental change as well?' (p. 650).

What then are we to make of these chapters as a whole? In her introduction Nye argues that the diverse contributions both demonstrate 'a wide and deep array of aims and strategies' for studying the history of the physical and mathematical sciences and also orientating the reader to what is yet to be done in the field. (p. 17). Inevitably such a finite volume leaves some gaps, and at least two obvious areas are missing

from this volume. Graduate students will have to look elsewhere for a detailed overview of the laboratory that is so well addressed in Nye's introductory level *Before big science* (Nye, 1996) and of the close links of late nineteenth century experimental science to spiritualism (Noakes, 1999). They might look in vain for any illustration of a coherent way of bringing together under one rubric the modern history of physical and mathematical sciences. As the prospects of fulfilling Sarton's Utopian dream of a complete and definitive history of science become ever more remote, the stoical reader might conclude melancholically that the sciences examined here might simply be too diverse to have their history narrated in a unitary fashion. But as Nye has enjoined us not to slide uncritically into postmodernist muddling, is there an approach left that can offer readers some hope?

A valuable insight in Bettyann Holtzmann Kevles's piece concerns the rise of interdisciplinary research in the late twentieth century. She shows, as Nye rightly stresses (p. 15), that the field of 'imaging science' and its associated journals now brings together mathematicians, physicists, biochemists, astronomers, engineers and neurologists who before 1970 would almost invariably have published in their narrowly specialist publications (pp. 632–633). Perhaps then the future of our field is that it should focus more on the increasing symbiosis of diverse sciences within both the political economy of natural knowledge and within the socio-economic–military contexts that have helped them thrive, especially since the rise of 'systems' approaches in World War II. Focusing on the fecund results of interdisciplinarity would offer an almost boundless range of unfolding utilitarian projects for scientists and their historians to consider without the unfortunate closure (and loss of jobs) that might result from merely seeking—and even finding—truth in science. Understanding the physical and mathematical sciences as open-ended and *useful* enterprises will enable us to write histories untrammelled by ill-grounded generalisations about scientists' allegedly philosophical aims or the unhelpful notion that the sciences have identifiably stable identities that propel them on well defined disciplinary paths toward some self-evidently identifiable Utopian future.

In most respects, Volume 5 in *The Cambridge history of science* deserves to be a standard reference volume for its field for the foreseeable future. One can only hope, though, that successor projects will find the inspiration to be less discipline-centred

and adopt more *daring* approaches. We need a successor to the oft-canonised George Sarton to show how many ways there are to slay the dragon of dreariness that still deters too many rising scholars from writing on the history of the physical sciences.

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