JOSEP SIMON*

Writing the Discipline: Ganot's Textbook Science and the "Invention" of Physics

ABSTRACT

The historiography of physics has reached a great degree of maturity and sophistication, providing many avenues to consider the making of science from a historical perspective. However, the big picture of the making of physics is characterized by a predominant narrative focused on a conception of disciplinary formation through leadership transfers in research among France, Germany, and Britain. This focus has provided the history of physics with a periodization, a geography, and a fundamental goal commonly considered to be conceptual and theoretical unification. In this paper, I suggest the interest of reassessing this picture by analyzing the temporal, national, and epistemological viewpoint from which it is written. I use for this purpose an exemplary case study: Adolphe Ganot's physics textbooks in France and their translation by Edmund Atkinson in England. In this context, I suggest future avenues for the study of the making of physics as a discipline, which consider the canonical role of textbooks in disciplinary formation beyond the Kuhnian paradigm.

KEY WORDS: nineteenth century, physics, discipline, unification, France, England, textbooks, pedagogy

> . . . historians who have aimed to write the history of a technical specialty have ordinarily taken the bounds of their topic to be those prescribed by recent textbooks in the corresponding field. . . .
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> . . . Textbooks and institutional organization are useful indices of the natural divisions the historian must seek, but they should be those of the period he studies.
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> —Thomas S. Kuhn (1976)[1]

*Josep Simon, GESCTP, Universidad del Rosario, Calle 63D No. 24 - 31, Bogotá, Colombia, josep.simon@urosario.edu.co.

The following abbreviation is used: *HSPS*, *Historical Studies in the Physical Sciences.*

1. Thomas S. Kuhn, "Mathematical vs. Experimental Traditions in the Development of Physical Science," *Journal of Interdisciplinary Science* 7, no. 1 (1976): 1–31, on 2, 3. Reprinted in *The*

Historical Studies in the Natural Sciences, Vol. 46, Number 3, pps. 392–427. ISSN 1939-1811, electronic ISSN 1939-182X. © 2016 by the Regents of the University of California. All rights reserved. Please direct all requests for permission to photocopy or reproduce article content through the University of California Press's Reprints and Permissions web page, http://www.ucpress.edu/journals.php?p=reprints. DOI: 10.1525/hsns.2016.46.3.392.

> In this view, the emphasis is on the *novelty* of the discipline-shaping problem definitions and concepts that will trigger a reorganization of the dimensions of the intellectual world, so that the new discipline is really without precedent. What is attractive of this version is that to some extent it handles physics as an invention, and thus it discusses the contingency of its genesis.
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> —Rudolf Stichweh (1984)[2]

INTRODUCTION

How can we characterize the emergence of physics as a discipline? There is obviously not a single answer, but a multiplicity of ways of defining the question and of answering it.[3] In their synthesis chapter "Physics," Jed Buchwald and Sungook Hong recognized that two major issues at stake were deciding *what* it encompassed and *when* it was formed.[4] This was not a simple task, according to them, because the subject matter of what we could call "physics" changed during the course of the nineteenth century. Mapping time and place in the formation of this discipline is a complex affair as well. However, neither time nor place seemed especially contentious for Buchwald and Hong: early on in their chapter, they established the place where physics was shaped as a discipline, as four nation states (Britain, Germany, France, and the

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Essential Tension: Selected Studies in Scientific Tradition and Change (Chicago: University of Chicago Press, 1977), 31–65, and first published in French in *Annales: Economies, sociétés, civilisations* 30, no. 5 (1975): 975–98.

2. Rudolf Stichweh, *Zur Entstehung des Modernen Systems Wissenschaftlicher Disziplinen: Physik in Deutschland* (Frankfurt: Suhrkamp, 1984), 98. All translations (from German and French) are by the author of this paper.

3. See Josep Simon, *Communicating Physics: The Production, Circulation and Appropriation of Ganot's Textbooks in France and England, 1851–1887* (London: Pickering and Chatto, 2011; currently Pittsburgh: University of Pittsburgh Press), 1 and 219 n. 1. This paper is part of a broader effort to reassess the role of education and textbooks in the making of modern science. See Josep Simon, "Physics Textbooks and Textbook Physics in the Nineteenth and Twentieth Centuries," in *The Oxford Handbook of the History of Physics*, ed. Jed Z. Buchwald and Robert Fox (Oxford: Oxford University Press, 2013), 651–78; "Textbooks," in *A Companion to the History of Science*, ed. Bernard Lightman (Chichester: Wiley-Blackwell, 2016), 400–13; and "History of Science," *Encyclopaedia of Science Education*, ed. R. Gunstone (Dordrecht: Springer Verlag, 2015), 456–59. I am currently developing this agenda through *Transnational Paradigm? Physics and Pedagogical Innovation in the Americas (1945–1975)*, a project funded by a Spencer Fellowship of the National Academy of Education.

4. Jed Z. Buchwald and Sungook Hong, "Physics," in *From Natural Philosophy to the Sciences: Writing the History of Nineteenth-Century Science*, ed. David Cahan (Chicago: University of Chicago Press, 2003), 163–95.

United States), and its time, as the turn of the twentieth century.[5] Although they admitted that their temporal choice was somewhat pragmatic, it was nonetheless prescriptive: these countries alone defined physics, and there, by that time, education, research, and professional self-awareness had led to the shaping of a coherent canon, which, for instance, was displayed in textbooks showing a homogeneous subject matter.

Buchwald and Hong's viewpoint was inspired and supported by the thesis and evidence in a classic article by Forman, Heilbron, and Weart: a comprehensive analysis of physics around 1900 through a quantitative analysis of resources in the form of staff, institutions, funding, publications, training, and careers.[6] Buchwald and Hong's periodization and geographical framework is grounded on that paper, but this pattern is a common feature in the historiography of physics.[7]

At the risk of providing just a rough characterization, if there is a big picture of the emergence of physics as a discipline, it has at least the following elements: the making of physics took place during the nineteenth century through successive research developments led respectively by French, British, and German practitioners. The process came about during the last decades of the century, and was complete by 1900. It consisted of the unification of hitherto isolated fields of enquiry into nature, through the replacement of the theory of imponderable fluids by the principle of energy conservation, together with the development of a compact theoretical, mathematical, and experimental approach. The emergence of physics as a discipline was characterized by extremely refined experimental practices and, especially, by global mathematization.[8]

Illustrative of this pattern is another 1970s classic paper by Thomas Kuhn, which discusses the creative tension between two pairs of traditions

5. Buchwald and Hong's inclusion of the United States indicates that they write on the nineteenth century, thinking about the twentieth century; but the United States has no relevance in their account, which is basically British, German, and French.

6. Paul Forman, John L. Heilbron, and Spencer Weart, "Physics circa 1900: Personnel, Funding, and Productivity of the Academic Establishments," *HSPS* 5 (1975): 1–185.

7. I do not to provide a genealogy of this pattern here, but its prevalence for decades is undoubtedly a sign of its significance. See, for instance, John Theodore Merz, *A History of European Scientific Thought in the Nineteenth Century* (Edinburgh: Blackwood and Sons, 1896–1914); Pierre Duhem, *La théorie physique, son objet, sa structure* (Paris: Marcel Rivière, 1906).

8. See, for instance, Iwan Rhys Morus, *When Physics Became King* (Chicago: University of Chicago Press, 2005); Peter M. Harman, *Energy, Force and Matter: The Conceptual Development of Nineteenth-Century Physics* (Cambridge: Cambridge University Press, 1982); Robert D. Purrington, *Physics in the Nineteenth Century* (New Brunswick, NJ: Rutgers University Press, 1997).

("mathematical" vs. "experimental") in the shaping of modern physics, and places this endeavor in the chronological and national framework described above.[9] In the 1980s, this scenario was re-enacted in *Intellectual Mastery of Nature*, a monumental work, which developed *in extenso* and in depth a big picture for the case of physics in the German-speaking academic world, following the historiographical foundations outlined by the works of Forman, Heilbron, and Weart, and by Kuhn, among others.[10] This is the pattern in which Buchwald and Hong's piece is set, with relevant additions that take into account the practical turn and the rise of cultural approaches in history of science, leading to a major emphasis on three elements: experiment, technology, and demonstration.[11]

The history of physics has attained a great degree of sophistication, and is able to offer a wide range of perspectives and approaches that account for its practices and its cultural impact.[12] However, with regard to disciplinary foundations, the general structure of the big picture has changed little. Its homogeneity contrasts with the more pluralistic approaches attempted in the historiographical development of neighboring disciplines such as chemistry. In the last few decades, the history of chemistry has undergone major changes through the substitution of simple narratives of origins and revolutions by a plural set of explanations, factors, and approaches, aimed at characterizing discipline-building and historical change.[13] This reminds us of the difficulty of building a comprehensive narrative characterizing a single discipline over

9. Kuhn, "Mathematical vs. Experimental" (ref. 1).

10. Christa Jungnickel and Russell McCormmach, *Intellectual Mastery of Nature: Theoretical Physics from Ohm to Einstein*, 2 vols. (Chicago: University of Chicago Press, 1986).

11. A similar pattern in terms of geography and time appears in more recent syntheses. Morus's and Hunt's excellent big pictures offer, though, a rich narrative built around popularization and experimental demonstrations, and engineering and technology, respectively, which take us a long way further than what Buchwald and Hong accounted for. Morus, *When Physics Became King* (ref. 8); Bruce J. Hunt, *Pursuing Power and Light: Technology and Physics from James Watt to Albert Einstein* (Baltimore: Johns Hopkins University Press, 2010).

12. For nineteenth-century physics, see, for instance: Crosbie Smith and M. Norton Wise, *Energy and Empire: A Biographical Study of Lord Kelvin* (Cambridge: Cambridge University Press, 1989); Morus, *When Physics Became King* (ref. 8); and Hunt, *Pursuing Power and Light* (ref. 11).

13. See, for instance, Bernadette Bensaude-Vincent and Isabelle Stengers, *A History of Chemistry* (Cambridge, MA: Harvard University Press, 1996); Bensaude-Vincent, "Chemistry," in Cahan, *From Natural Philosophy to the Sciences* (ref. 4), 196–220; José R. Bertomeu-Sánchez, Duncan Thorburn Burns, and Brigitte Van Tiggelen. eds., *Neighbours and Territories: The Evolving Identity of Chemistry* (Louvain-la-neuve: Mémosciences, 2008); Jonathan Simon, "The Chemical Revolution and Pharmacy: A Disciplinary Perspective," *Ambix* 45, no. 1 (1998): 1–13.

several centuries, as well as of general problems in the history of science, ranging from the scarcity of rigorous new accounts of science over the *longue durée*, to the still exceptional character of work accredited by a good knowledge of primary sources and historiographical approaches from more than one national context.[14]

The standard big picture of physics expresses anxiousness to determine the temporal, geographical, and conceptual origin of the discipline as known today. Problematizing time and geography is obviously a major task in the historian's mission, and defining periods, national cases, and broad processes of change is a standard strategy to write a big picture account of a historical object. Nonetheless, this anxiety has perhaps contributed to produce a historical narrative that overshadows the multidirectional and diverse nature of physics as an enterprise.[15]

In his study of the making of physics in nineteenth-century Germany, Rudolf Stichweh proposed several ways of studying the formation of scientific disciplines. The second epigraph at the start of this paper expresses his reflection on the methodological interest of thinking through discontinuities. Stichweh considered that a useful strategy to historicize "physics" could be to present "physics" as a nineteenth-century "invention," thus making the contingency of its origin a central object of discussion. Historians of physics have in fact produced thoughtful accounts of various efforts that contributed to a new conceptual framework aimed at overcoming the disunity between different areas in the study of physical knowledge about nature. Furthermore, these historical accounts translate into our own terms what was indeed an existing preoccupation among nineteenth-century practitioners.

However, the road to theoretical unification, mathematization, and the principle of energy conservation has often been presented as an irreversible process, as if one looked back at "physics" from the watchtower of a theoretical physics research institute around 1900. The picture is not only conceptual, it relies on institutional and professional elements that were investigated in depth by Forman, Heilbron, and Weart, by Jungnickel and McCormmach, and by

14. Josep Simon and Néstor Herran, "Introduction," in *Beyond Borders: Fresh Perspectives in History of Science*, ed. Josep Simon and Néstor Herran (Newcastle: Cambridge Scholars Publishing, 2008), 1–23; Josep Simon, "Cross-National Education and the Making of Science, Technology and Medicine," *History of Science* 50, no. 3 (2012): 251–56.

15. An exception to this trend is Richard Staley, "On the Co-Creation of Classical and Modern Physics," *Isis* 96, no. 4 (2005): 530–58, and *Einstein's Generation: The Origins of the Relativity Revolution* (Chicago: University of Chicago Press, 2009).

Wise and Smith, among others. However, with regard to the standard big picture, historians have clearly given a driving role to conceptual structure in defining periodization and national distribution.[16] This genealogy of physics might be the best we (can) have right now, but undoubtedly not the only one possible. Challenging it is a good exercise that can help us to problematize constructively its intellectual foundations—especially since, contrary to Stichweh's expectations, the problematization of time, place, and origins has been a matter not extensively discussed in the recent historiography of physics.

This paper aims to pinpoint weaknesses in this general narrative and to suggest alternative options, by presenting evidence arising from a case study focusing on historical objects, specifically textbooks, that occupy a place both traditional and marginal in the historiography of physics.[17] I will first present this case study and the reasons why it is, in my opinion, endowed with explanatory power and exemplary value. Second, I will describe how the big picture of physics as a discipline would look if we moved the viewpoint of the standard historiography to a different place, time, and epistemological ground. Thus, by stressing the significance of textbook physics for writing comprehensive accounts of discipline formation, I will question the timing, national distribution, and conceptual emphasis characterizing the current historiographical synthesis of nineteenth-century physics.[18]

TEXTBOOK SCIENCE

In his path-breaking analysis of discipline formation, Stichweh noted that the analysis of discontinuity is only one among five complementary approaches.[19] In addition, Stichweh's work has contributed to reinforcing the importance of teaching in disciplinary formation. Further work by Kathryn Olesko on German physics and other contributions on French and British physics have

16. See refs. 8, 10, and 12.

17. Simon, "Physics Textbooks" and "Textbooks" (ref. 3).

18. Although the focus in this paper is on the narratives of origin characterizing the historiography of physics with regard to its disciplinary formation in the nineteenth century, my proposal connects in several ways with the suggestions made by Richard Staley for reassessing the history of twentieth-century physics. Richard Staley, "Trajectories in the History and Historiography of Physics in the Twentieth Century," *History of Science* 51, no. 2 (2013): 151–77.

19. The four others are Differentiation, Residual disciplines (resulting from the processes of differentiation), Synthesis, and Integration. For more details on Stichweh's approach, see Stichweh, *Zur Entstehung* (ref. 2), 96–98.

emphasized the importance of the interface between secondary and university education to understand the formation of physics as a discipline. Whereas most research in the history of the making of physics in the nineteenth century has focused on scientific elites and research in higher education institutions, these contributions emphasize that in this period, the secondary school curriculum played a major role in the shaping of university physics, rather than vice versa.[20] Thus, a key definition of discipline would be that of "knowledge assembled to be taught."[21]

The focus of this paper is therefore on textbooks rather than research papers. The opening quote in this paper indicates the standard use of textbooks as historical "indices" of the boundaries of a scientific discipline. The importance that Kuhn gave to textbooks as both agents and representatives of "normal science" is well known.[22] A Kuhnian approach underlies Buchwald and Hong's argument that homonogeneity in the subject matter of physics textbooks in Britain, France, and Germany at the turn of the twentieth century is an indication of the fact that this period and these places define the making of physics as a discipline. Remarkably, neither Buchwald and Hong, nor Forman, Heilbron, and Weart did any research on textbooks for their papers. For them, measuring physics basically meant measuring the production of research papers, together with other disciplinary and professional aspects, including student recruitment, but not pedagogical practice and textbooks. In my work I have argued that this is a typical perspective arising from Kuhn's characterization of textbooks as dogmatic and education as indoctrination, particularly biased by Kuhn's (and our) own contemporary experience, and evidentially weak.[23] In contrast, Jungnickel and McCormmach have offered a more balanced account, placing greater emphasis on research journals in the making of theoretical physics in Germany, yet paying due attention to teaching and textbook writing as fundamental aspects of the nineteenth-century physicist's job.

20. Kathryn Olesko, *Physics as a Calling: Discipline and Practice in the Königsberg Seminar for Physics* (Ithaca, NY: Cornell University Press, 1991); Graeme Gooday, "Precision Measurement and the Genesis of Physics Laboratories in Victorian Britain" (PhD dissertation, University of Kent, 1989); Simon, *Communicating Physics* (ref. 3).

21. Kathryn Olesko, "Review: *Zur Entstehung des Modernen Systems Wissenschaftlicher Disziplinen: Physik in Deutschland*," *Isis* 76, no. 4 (1985): 607–8.

22. T. S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962); Simon, "Physics Textbooks" (ref. 3).

23. Simon, "Textbooks," (ref. 3).

Going a step further, in this paper, I propose that we place textbooks at the core, by considering the production of textbook physics as a creative enterprise that played a major role in the shaping of physics as a discipline in the nineteenth century. I argue that textbooks can have an important role as agents at the crossroad of governments, markets, schools, and universities, which shape pedagogical and scientific outlooks, and cultural and national ideals. A textbook embodies a course syllabus and a pedagogical and narrative rationale linked to a particular institutional and educational context, and it addresses captive readers. Successful textbooks are periodically reissued to find new customers, since formal education can provide a regular supply of purchasers to authors and booksellers. The success of a textbook depends on the ability of its author and publisher to ensure that students and teachers use their book. Textbooks are often reissued to meet changes in educational curricula and policy, but as we shall see, also in response to scientific change.[24] Thus, I suggest a way of reassessing the importance of textbooks in discipline making, but also of performing a methodological exercise that can help us to see more clearly the weaknesses of the current historiographical narrative of physics as a discipline, contributing thus to strengthen it further.[25]

The paper characterizes physics through the analysis of successive editions of Adolphe Ganot's *Traité Élémentaire de Physique Expérimentale et Appliquée* and its translations into English.[26] The potential exemplarity of this study is based on the fact that, during the second half of the nineteenth century, Ganot's *Traité*, both original and in translation, became the standard introductory work in physics worldwide. No physics textbook appears to have had as many editions and translations, or to have been used so widely in the nineteenth century.

24. This paper focuses on textbooks, as representatives of a broader and dynamic context, which includes the institutions in which textbooks were used and the actual pedagogical practices they were part of. Space does not allow further development of these equally important aspects, which I have treated elsewhere: Josep Simon, "Secondary Matters: Textbooks and the Making of Physics in Nineteenth-Century France and England," *History of Science* 50, no. 3 (2012): 339–74, and *Communicating Physics* (ref. 3), 171–211.

25. Simon "Physics Textbooks" (ref. 3), "Textbooks" (ref. 3), and *Communicating Physics* (ref. 3), 14–18.

26. Adolphe Ganot, *Traité Élémentaire de Physique Expérimentale et Appliquée* (Paris: Chez L'Auteur-Éditeur, 1851) and *Elementary Treatise on Physics, Experimental and Applied* (London: H. Baillière, 1861–1863). Following its third edition (1868), the *Treatise* was published by Longmans, Green & Co. Ganot (1804–1887) self-published the *Traité* until his retirement. He then sold the rights to Hachette, which published its nineteenth (1884) and subsequent editions, all bearing Ganot's name by contract.

Moreover, Ganot's textbooks can be considered as the synthesis of a tradition of textbook physics that had emerged in France in the second half of the eighteenth century and became consolidated around the central decades of the nineteenth century.[27] Paradoxically, although French physics during the second half of the nineteenth century has attracted the interest of some historians,[28] it is usually considered irrelevant in the big picture. Historians commonly contend that French contributions made a key international impact through the Laplacian physics program in the early nineteenth century. However, by the 1840s, the efforts cascading toward the final expression of the principle of energy conservation were concentrated in Britain and Germany; according to this picture, France had become peripheral and thus irrelevant for the standard narrative. This case study questions this conceptual framework, since it is unable to explain, for instance, why Ganot's *Traité*, translated into English by Edmund Atkinson, was the most widely used physics textbook in British schools and early college instruction during the second half of the nineteenth century.

In the first part of this paper, I present Ganot's textbooks and the readerships that allowed them to become a physics canon. In the second part, I analyze the contents of successive editions of these textbooks and their English translations, with a special focus on the elements that coordinated Ganot's physics. The last three sections of the paper are devoted to discuss three of these major elements: theoretical pluralism, pedagogical truth and experimental unity, and theoretical skepticism, respectively. As a result, I propose a characterization of nineteenth-century physics and contrast it with the account provided by standard big pictures in the history of physics.

GANOT'S TEXTBOOKS: A PHYSICS CANON

Adolphe Ganot published his *Traité* in 1851 after working twenty years as a science teacher in France. Between 1851 and 1884, he produced eighteen editions of his *Traité*, selling 204,000 copies.[29] During the nineteenth century,

27. Simon, *Communicating Physics* (ref. 3), 26–40.

28. See, for instance, Daniel Mitchell, "Measurement in French Experimental Physics from Regnault to Lippmann," *Annals of Science* 69, no. 4 (2012): 453–82; and Faidra Papanelopoulou, "Gustave-Adolphe Hirn (1815–90): Engineering Thermodynamics in Mid-Nineteenth-Century France," *British Journal for the History of Science* 39, no. 2 (2006): 231–54.

29. Data consigned next to the title page of Ganot, *Traité*, 1880 edition (ref. 26).

the *Traité* was translated into thirteen languages.[30] Although the translation of French physics textbooks into other languages was common in this period, Ganot's textbooks were certainly amongst the most widely translated.[31] The first English translation of his *Traité* was prepared by Edmund Atkinson, chemist by training and physics teacher by occupation, between 1861 and 1863. Between 1861 and 1898, Atkinson produced fifteen editions of the *Elementary Treatise on Physics, Experimental and Applied* (Fig. 1). By 1881, it had sold no less than 52,000 copies.[32] During the second half of the nineteenth century, Ganot's physics had a wide readership, both in French and in translation, on five continents. In this period, Ganot's *Traité* and *Treatise* conferred high prestige to their author and translator, and they became standard as introductions to physics worldwide. Both textbooks sold an impressive number of copies, consistently above the average in the physics textbook marketplace. The frequent periodicity, high number of editions and translations, longevity, and large print runs leave no doubt about the importance of Ganot's physics in the nineteenth century science book market.[33]

During the second half of the nineteenth century, Ganot's textbook physics was acknowledged as the standard introduction to physics almost everywhere.[34] In France, reviewers recognized its pioneering status and its wide use

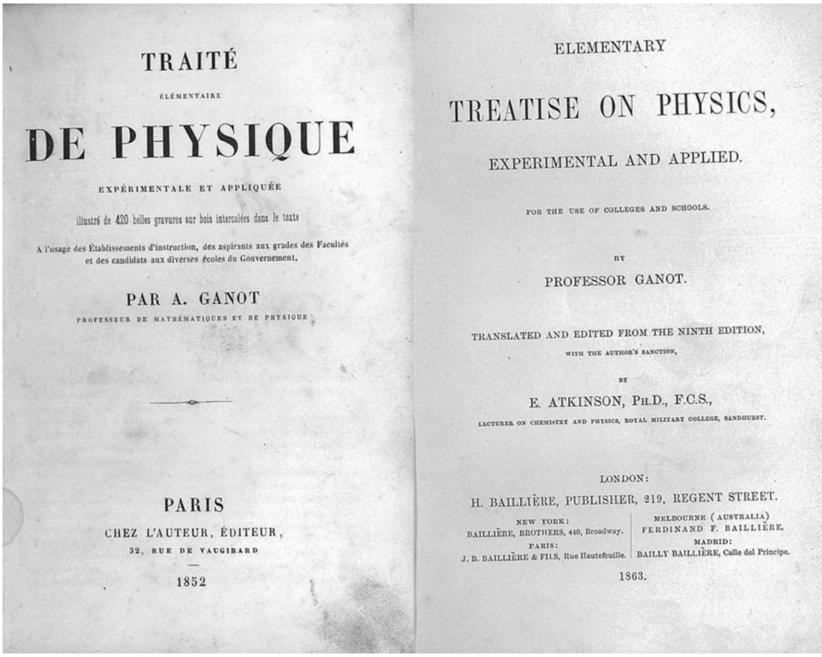
30. The *Traité* was translated into Italian (1852), Spanish (Madrid, 1856), Dutch (1856), German (1858), Swedish (1857–60), Spanish (Paris, 1860), English (1861–63), Polish (1858), Bulgarian (1869), Turkish (1876), Serbian (1876–77), Chinese (1897–98), and Russian (1898). Dates between brackets indicate the year of first editions; in most cases, there was more than one edition. The Spanish and English editions were almost as numerous as the French. The English editions were commercialized in the United States under agreement with New York publishers.

31. See, for instance, H. W. Paul, "The Role and Reception of the Monograph in Nineteenth-Century French Science," in *Development of Science Publishing in Europe*, ed. A. J. Meadows (Amsterdam: Elsevier, 1980), 123–48.

32. Calculation is based on print runs mentioned in Atkinson's correspondence with his publisher. Archives of the House of Longman 1794–1914, Atkinson Letters (1867–1900), Reel 64, ProQuest microfilm edition.

33. Ganot and Atkinson progressively increased the print runs of their books. The largest print run they attained was 20,000 copies for the eighteenth edition of the *Traité* (1880). In nineteenth-century England, some science books matched or surpassed the number of copies of Atkinson's *Treatise,* and in certain cases those of Ganot's *Traité*. However, it was rare to maintain such large print runs during so long a period. For quantitative and qualitative evidence, see Simon, *Communicating Physics* (ref. 3), 12, 14, and note 16, on 223–24.

34. Only a few studies analyze the presence of Ganot's textbooks on a national scale, and there is no space in this paper to provide appropriate reference on all the places where they were used. However, it is easy to find reference to them in school and university syllabi across Europe and in places as far away as Mexico, Argentina, India, and Japan.



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FOR THE USE OF COLLEGES AND SCHOOLS.
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LONDON:
H. BAILLIÈRE, PUBLISHER, 219, REGENT STREET.
NEW YORK: BAILLIÈRE, BROTHERS, 440, Broadway.
PARIS: J. B. BAILLIÈRE & FILS, Rue Hautefeuille.
MELBOURNE (AUSTRALIA) FERDINAND F. BAILLIÈRE.
MADRID: BAILLY BAILLIÈRE, Calle del Principe.
1863.

FIG. 1. Title pages of the first editions of Ganot's *Traité* and *Treatise*. Note that this is a reprint of the first edition of the *Traité*, published in 1851, and of the *Treatise*, which appeared first in two parts between 1861 and 1863. *Source*: Adolphe Ganot, *Traité élémentaire de physique expérimentale et appliquée* (Paris: Chez L'Auteur, Éditeur, 1852), and *Elementary Treatise on Physics, Experimental and Applied* (London: H. Baillière, 1863).

among secondary school students and those preparing to pursue university degrees in science, engineering, and medicine.[35] In England, some reviewers equated the progress of science in school education to the pace of publication of successive editions of Ganot's textbooks, and these found a standard position in the reading lists of the main schools and colleges teaching science, in universities, military academies, and medical schools.[36] Ganot's textbooks had

35. P.-H. Ledeboer, "Bibliographie: [review of the new editions of Ganot's *Traité* and *Cours*, revised by G. Maneuvrier and published by Hachette]," *La Lumière Électrique* 26, no. 50 (1887): 545–46; Abbé Moigno, "Traité Élémentaire de Physique Expérimentale et Appliquée et de Météorologie, par M. A. Ganot," *Cosmos* 2, no. 19 (1853): 513–14; Dr. Quesneville, "[Review of Ganot's *Traité Élémentaire de Physique* (11th ed.) and *Cours de Physique* (2nd ed.)]," *Le Moniteur Scientifique* 5 (1863): 847–48.

36. Including colleges and schools such as Wellington, Cheltenham, Rugby, Manchester Grammar School, Christ's Hospital, King's College School, Rossall School, Winchester, Taunton College School, Eton, Marlborough, the schools integrated in the Science and Art Department

also a major impact in the United States: they occupied a canonical place in the anxieties and cultural productions of science students at Harvard College, the Massachusetts Institute of Technology, and the University of Michigan,[37] and appeared on the reading lists of the major Eastern and Western colleges,[38] technical, military, and medical colleges,[39] and major women's colleges[40] teaching science.

This factual evidence could be interpreted as a clear example of Kuhnian "normalization" and Foucauldian "disciplinarization."[41] Indeed, the large number of editions of Ganot's textbooks and their extended use in formal education supports their understanding as representations of "normal science" or "disciplined training," or—taking a step forward—not merely representations, but agents of the enforcement of scientific norms and discipline that represented the structure of physics. However, this approach assumes too often that there is a pre-established and well-defined disciplinary field, "physics," which textbooks such as those by Ganot contributed to maintain or to consolidate, but never to shape or to change. This could be partly true in a period of "normal science," following Kuhn's terminology, but not really in a context of discipline formation. Ganot's textbooks obviously did not appear in a vacuum; their appearance was possible because there was a substantial activity in physics teaching and research. However, Kuhnian assertions about textbooks are to a certain extent based on cultural and historiographical prejudices that place textbooks as a low-rank activity on

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scheme, the universities of Oxford and Cambridge, the Yorkshire College, the Queen's Colleges in Belfast and Cork, the Royal Military Colleges at Sandhurst and Woolwich, and the London and Edinburgh medical schools. See Simon, *Communicating Physics* (ref. 3), 179–85.

37. G. M., "Over the Way," *The Tech* 4, no. 9 (1885): 111; T. C. Pease, "Grinding," in *Verses from the Harvard Advocate* (Cambridge: Charles V. Sever, 1876), 27–30; The Secret Societies, "Public Trial and Execution of Ganot Physicus," *University Palladium* 25. no. 1 (1873): 81; C. F. Thwing, "College Instruction," *Scribner's Monthly* 14, no. 5 (1877): 706–12; E. L. Youmans, "Notes," *Popular Science Monthly* 10, no. 3 (1877): 639.

38. For instance, Harvard, Yale, Johns Hopkins, Princeton, Amherst, Columbia, New York, Rutgers, Dartmouth, Cornell, Middlebury, Vermont, Bowdoin, Trinity-Hartford, Carleton, Michigan, West Virginia, Ohio Wesleyan, and Vanderbilt.

39. For instance, MIT, Maryland Agricultural College, Virginia Military Institute, U.S. Naval Academy. Many of those cited in ref. 34 had also a strong medical side (e.g., Yale, Johns Hopkins, Michigan).

40. For instance, Vassar and Mount Holyoke.

41. See Andrew Warwick and David Kaiser, "Conclusion: Kuhn, Foucault, and the Power of Pedagogy," in *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, ed. David Kaiser (Cambridge, MA: MIT Press, 2005), 393–409.

the ladder of scientific practice.[42] These preconceptions are likely to fit together with the necessary erasure of fine-grained detail required by big picture narratives, but they are not based in substantial evidence, whether we focus on elite practitioners or actors with a more humble historical status such as Ganot and Atkinson.[43]

In fact, if we look at nineteenth-century perspectives on the role of physics textbooks, it is clear that for contemporary practitioners, compressing all knowledge of a subject into several hundred pages, including a comprehensive narrative, was not a simple or uncreative job. The task of writing textbooks was considered to have special relevance and be particularly necessary both to provide a coherent picture of a subject and to communicate research efficiently. Furthermore, in nineteenth-century France, for instance, being recognized as a *savant* did not meant automatically being acknowledged as a good teacher, speaker, or textbook writer, and sometimes the first category was considered to counterindicate the latter set of qualities.[44] The disciplinary expansion of physics resulted from the growing impact of the subject in society, driven by developments in a wide range of contexts including industrial and academic research, popularization, and education. With regard to formal education, it is remarkable that for the first time physics was taught systematically, and that the expansion of secondary education and the production of general textbooks had an important role in multiplying the public of physics from a few to thousands.[45]

This is particular true for Ganot's textbooks, which not only had a large impact in the classroom but also extended their influence to informal education, general reading and popular science audiences, and research practices—especially those connected to the design of scientific instruments or industrial

42. Simon, "Physics Textbooks" and "Textbooks" (ref. 3); J. H. Brooke, "Introduction: The Study of Chemical Textbooks," in *Communicating Chemistry: Textbooks and Their Audiences, 1789–1939*, ed. A. Lundgren and B. Bensaude-Vincent (Canton, MA: Science History Publications, 2000), 1–18.

43. See, for instance, the discussion of Thomson and Tait's efforts to define physics, in Crosbie Smith, *The Science of Energy: A Cultural History of Energy Physics in Victorian Britain* (London: The Athlone Press, 1998), 175–76.

44. See Simon, *Communicating Physics* (ref. 3), 69–70; F. Waquet, *Parler comme un livre: L'oralité et le savoir (XVIe–XXe siècle)* (Paris: Albin Michel, 2003).

45. Moigno, "Traité Élémentaire de Physique" (ref. 35); Simon, "Secondary Matters" (ref. 24); Saigey, "[Review of Pouillet's Élémens de Physique Expérimentale et de Météorologie (1827–30)]," *Bulletin des sciences Mathématiques, Physiques et Chimiques* 14 (1830): 388–92; Francoeur, "[Review of Despretz's *Traité Élémentaire de Physique*]," *Revue Encyclopédique* 25 (1825): 465–67.

machines, but not those involving a high mathematization.[46] Practitioners such as William Thomson (1824–1906), William Crookes (1832–1919), Sebastian de Ferranti (1864–1930), and Zénobe Gramme (1826–1901) used Ganot's textbook physics in the context of research.[47] Crookes suggested the usefulness of textbooks, such as those by Ganot, for the research chemist requiring in daily practice quick access to experimental data on the physical behavior of materials.[48] Thomson indicated the relevant use of Ganot's textbooks for the physicist and engineer, requiring detailed descriptions of the most recent inventions in fields such as electromagnetic and lighting technologies (see Fig. 2).[49] Gramme, of international fame for his contribution to the invention of the electro-magnetic dynamo, found Ganot's *Traité* a major reference work for study and creative inspiration.[50] Ferranti acknowledged that it was the reading of Ganot's textbook and its diagrams of Ampère's laws that had been his main source of inspiration for the development of the basic mechanism of his most successful commercial electricity meter.[51]

Ganot's textbooks had originally been conceived as works for secondary school education and the preparation of examinations for entering science, engineering, and medical university studies. However, numerous and frequent editions, every two or three years, included changes well beyond the introduction of new syllabi in successive educational reforms. In his revisions, Ganot was especially attentive to the rapid developments in physics, and thus each edition included updates, from months to just a few years after the relevant research papers were published. In certain cases, especially in the field of instrument and technological designs, novelties often appeared at the same

46. For a detailed account of Ganot's readerships in France and England, see Simon, *Communicating Physics* (ref. 3), 171–211.

47. These are just a few illustrative cases. Ganot's textbooks were used by many other industrial researchers and inventors (e.g., Thomas Alva Edison).

48. Note that Crookes's reference was partly indirect and meaningful because Ganot's *Treatise* included an index at the end of the book from its second edition. William Crookes, "[Review of *Agenda du Chimiste, 1877, à l'Usage des Ingénieurs, Physiciens, Chimistes, Fabricants de Produits Chimiques, &c.*]," *Chemical News* 36, no. 24 (1877): 88–89.

49. William Thomson, letter to Thomas Andrews, 4 Mar 1863, in *The Life of William Thomson, Baron Kelvin of Largs*, ed. Silvanus P. Thompson (London: MacMillan and Co., 1910), 426–27.

50. Jean Pelseneer, *Zénobe Gramme* (Bruxelles: Office de Publicité, 1944), 10–13, 30–31.

51. Sebastian Z. de Ferranti, "On the Ferranti Electricity Meter and its Evolution," *Transactions of the Royal Scottish Society of Arts* 14 (1898): 52–56. I thank Graeme Gooday for pointing me at this reference.

time or even earlier in Ganot's textbooks than in other type of publications, almost at the same pace that they were being created in the workshop.[52]

The widespread use of Ganot's textbooks and their status as classroom mainstays, along with their utility in popularization and research, give them the status of a physics canon. According to Kuhn, we can consider textbooks as useful indices of discipline formation and as gatekeepers of "normal science." However, here I argue that they can have a much more active role as they not only reflect knowledge but also contribute to transform it. Ganot's textbooks had a significant and an active role in the shaping of nineteenth-century physics, and therefore analyzing their structure and narrative is particularly relevant in helping us to characterize physics as a discipline.

THE NATURE OF THE CANON: GANOT'S PHYSICS IN COMPARATIVE PERSPECTIVE

As we seek to understand the meaning of physics according to Ganot and Atkinson, we are faced with the analysis of the structure, order, and narrative of their texts. In this section, I work toward a definition of Ganot's and Atkinson's physics by providing a general overview of the structure and order of physics according to their books, and the narrative connections that gave coherence to their texts and thus to their physics. Atkinson's physics obviously had a lot in common with that of Ganot, as Ganot's text was the basis for his writing. Nevertheless, as all readers (and translators) do, he performed a creative appropriation of the original text, providing it with distinctive meanings. Furthermore, Atkinson's edition of Ganot's physics was driven by his own use of the book in teaching, his reaction to reviews of his successive editions, and direct contact with British colleagues, engaged like him in physics teaching.

In the first article of his *Traité*—unchanged through successive editions—Ganot defined the aim of physics as "the study of the phenomena presented by bodies, as long as these do not experience changes in their composition." In contrast, chemistry dealt with more or less profound changes in the nature of bodies.[53] Atkinson's *Treatise* closely followed this definition. Ganot and Atkinson provided a simple definition of physics, which placed it both in

52. See, for instance, the use of Ganot's *Traité* as a reference source in F. Moigno, "Exposition Universelle de 1867," *Les Mondes* 15, no. 9 (1867): 359–80.

53. Ganot, *Traité,* 1851 edition (ref. 26), 1.

relation to and in opposition to chemistry. Other textbook authors had previously, or contemporaneously, stressed the same point.[54] This definition was also in agreement with the French school curriculum, which nonetheless integrated physics and chemistry syllabi until the mid-1860s.[55] Since the early nineteenth century, French physics textbooks were generally restricted to the study of the imponderable fluids of heat, light, magnetism, and electricity, preceded by the basic elements of mechanics and the phenomena of liquids and gases (hydrostatics, hydrodynamics, and pneumatics). Their structure was informed by the late eighteenth-century standard division of *la physique* into *physique générale* and *physique particulière*, corresponding, respectively, to mechanics and to experimental science devoted to the study of heat, light, magnetism, and electricity.[56]

In 1827, the physicist and textbook author César Despretz considered that, because physics was composed of many independent parts, unlike chemistry, authors had the freedom to decide the order in which subjects would be treated in their textbooks, once mechanics (understood as the general properties of matter and the theories of gases and steams) had been introduced.[57] A review of Despretz's textbook stressed that, among science textbooks, those of physics were the most difficult to write, as this branch of knowledge was in fact composed of several distinct sciences.[58]

By mid-century, the general tendency in the design of physics textbooks was to name their basic parts as "books." This classical designation stressed the independence of the different subjects comprising physics. Every book was divided into chapters, each of which was structured into articles with a continuous numbering from start to end. In 1851, Adolphe Ganot structured his *Traité* as nine books devoted to the general properties of matter and movement, gravitation and molecular attraction, liquids, gases, acoustics, caloric, light, magnetism, and static and dynamical electricity, respectively, with an appendix on

54. Abbé Haüy, *Traité Élémentaire de Physique* (Paris: Vve Courcier, 1821), iii; John Tyndall, "On the Importance of the Study of Physics as a Branch of Education for all Classes," in *Lectures on Education Delivered at the Royal Institution of Great Britain* (London: John W. Parker and Son, 1854), 171–214, on 176.

55. Based on a survey of the official texts compiled in Bruno Belhoste, Claudette Balpe, and Thierry Laporte, eds., *Les Sciences dans l'Enseignement Secondaire Français. Textes Officiels* (Paris: INRP-Éditions Economica, 1995).

56. Buchwald and Hong, "Physics" (ref. 4); Maurice Crosland and Crosbie Smith, "The Transmission of Physics from France to Britain: 1800–1840," *HSPS* 9 (1978): 1–61, on 5.

57. César Despretz, *Traité Élémentaire de Physique* (Paris: Chez Méquignon-Marvis, 1827), i.

58. Francoeur, "[Review of Despretz's *Traité*]" (ref. 45).

meteorology. In this typical structure, the order of each "book" was open to the initiative and interpretation of its author, for—as previously mentioned—each of these areas of research was, to a considerable extent, independent.

The order in Ganot's *Traité* was similar to that of previous textbooks, except that he placed the book on acoustics immediately after the general introductory books (devoted to the basic phenomena in solids, liquids, and gases), and the book on light just after that on heat. Light and heat occupied thus the central pages. The position of acoustics in the *Traité* differed from previous standard textbooks such as those by Claude Pouillet and César Despretz. In contrast, it agreed with those of Jean-Baptiste Biot and Eugène Péclet.[59] The reason for placing acoustics immediately after the study of solids, liquids, and gases was the conception that sound propagated through vibration of these ponderable media. On the other hand, the central position of heat and light in the *Traité* was certainly because these were, during the central decades of the century, the most topical areas of research in physics. This status was transferred decades later to dynamical electricity—placed at the end of Ganot's textbook before its meteorology appendix.[60] Accordingly, major French textbooks, whose first editions were published during the 1860s and 1870s, now included the book on electricity in their central pages.[61] Some of them placed the book on acoustics immediately before that on light, as a way of stressing the new mechanical view of physical agency as vibrations in the ether, which connected the study of sound and light.[62] This order also coincided with that of most secondary school and *baccalauréat ès-sciences* syllabi.[63] In spite of this, the arrangement of Ganot's *Traité* remained stable in successive editions, supervised for more than three decades by its author.[64] Nonetheless, Ganot

59. Claude Pouillet, *Élémens de Physique Expérimentale et de Météorologie* (Paris: Chez Béchet jeune, 1827); Despretz, *Traité* (ref. 57); J.-B. Biot, *Précis Élémentaire de Physique Expérimentale* (Paris: Deterville, 1817); Eugène Péclet, *Cours de Physique* (Marseille: A. Ricard, 1823–1825).

60. See Christine Blondel, "Les Physiciens Français et l'Électricité Industrielle à la Fin du XIXe Siècle," *Physis* 35 (1998): 245–71.

61. Charles Drion and Émile Fernet, *Traité de Physique Élémentaire* (Paris: Victor Masson et fils, 1861); Jules Jamin, *Petit Traité de Physique* (Paris: Gauthier-Villars, 1870); A. Privat Deschanel, *Traité Élémentaire de Physique* (Paris: L. Hachette et Cie, 1868).

62. Jamin, *Petit Traité* (ref. 61), v–vi.

63. Belhoste et al., *Les Sciences dans l'Enseignement* (ref. 55).

64. A reason for this was also technical and financial. Techniques such as stereotyping, which allowed labor saving for books with many successive editions, also led to keeping as much as possible of previous editions and including most changes and additions in new pages, which were added at the end of chapters or "books."

reflected the differential subject development of research in physics in this period by his discrimination in introducing new text and illustrations in the different books constituting the *Traité*.

Ganot introduced new material in every new edition of his textbook, increasing its length by roughly 200 to 300 pages over thirty years, but additions affected some books more than others. In 1851, the books on caloric, light, and electricity were the lengthiest parts of the *Traité*, each constituting a fifth of its pages. This proportional distribution was roughly maintained in successive editions, but the length of the book on light suffered a slight progressive decrease, ending up, in 1880, in third position in terms of quantitative importance with a sixth of the textbook. Instead, the exposition of dynamical electricity within the book on electricity expanded rapidly: whereas in 1851, it represented only an eighth of the *Traité*'s pages, by 1860, it had equaled the size of the book on light. Furthermore, since 1855, the book on electricity was split into two books, corresponding to its previous divisions, static and dynamical. Hence, from the 1860s, electricity was the topic with the lengthiest coverage in the *Traité*, closely followed by caloric or heat, and light. In contrast, the subjects with the lowest quantitative presence in Ganot's textbook were meteorology and magnetism.

Each of the *Traité*'s books was broken into chapters devoted to the exposition of the different physical phenomena observable in nature, or through experiment in the cabinet of physics, the physics laboratory, or the machine shop. The number of chapters varied in relation to book length. Ganot's aim was to provide pedagogical expositions of each chapter topic that occupied no more than thirty pages. Although, unfortunately, there are no extant records of Ganot's pedagogical practice (besides the *Traité*), this chapter length was surely related to the time management of Ganot's courses.

The topics requiring, in Ganot's opinion, lengthier treatment were expounded in chapters divided into several parts, but Ganot intended to provide a comprehensive picture of physics, thus some chapters could occupy only a few pages if he thought the importance of the topic required its introduction. All the *Traité*'s books contained an introductory chapter, in which the fundamental notions were explained, and a chapter especially devoted to scientific instruments. Introductory chapters expounded basic phenomena, experimental principles, and very briefly, their theoretical background. The description of scientific instruments was not only developed in special chapters, but pervaded all the *Traité*. In addition, the *Traité* could also be read as a succession of numbered articles from its first page to the end. It is through the articles that Ganot developed the long-range narrative of his textbook.

After the introductory exposition of basic notions, principles, and theories, the core of the *Traité*'s books was constituted by articles describing pedagogical demonstrations and expounding experimental procedures and results, including minute descriptions of experimental set-ups and instruments supported by illustrations and numerical tables reporting experimental data. Mathematical analysis was limited to the use of simple arithmetical proportions and calculations. In certain cases, equations with a higher algebraic content were introduced—in small type at the end of articles—for more advanced readers. The selection of pedagogical illustrations, their performance through the manipulation of instruments, and their precise exposition were crucial aspects in Ganot's textbook physics.

Ganot's expository style was not different from that of journal papers that focused on experimental research.[65] In such research papers, one could typically find, first, an introduction to the problem tackled using a historical account, which described the different experimental procedures and the instrumental arrangements used by previous contributors to this field of research, and explained their virtues and shortcomings. Second was a minute description of the apparatus and methods used in experimental research, including reference to the specific instruments employed and their makers. Third, results were presented through text, numerical tables, explanatory diagrams, and a parsimonious use of algebraic expressions.

Ganot's articles generally followed this pattern, including in each case some or all of these ingredients. Historical introductions were a permanent feature of each of the parts of the *Traité*, which was characteristic of the time and connected to standard patterns of research practice and publication that linked experimental discovery with the history of invention. The historical method had an important connection with the method of experimental science, and in this sense, with the configuration of a disciplinary identity distinct from mathematics.[66]

The pedagogical economy of Ganot's writing supposed that when he introduced a topic by establishing its historical record of research, he cited the names of its major actors, but rarely their publications. Ganot provided explicit source references in only three cases. First, he cited journal papers, pamphlets,

65. See, for instance, Émile Verdet, "Recherches sur les Phénomènes d'Induction Produits par les Métaux Magnétiques ou non Magnétiques," *Annales de Chimie et de Physique* 31, 3e série (1851): 187–216.

66. Eugène Péclet, *Traité Élémentaire de Physique* (Paris: Chez L. Hachette, 1838), iii; Hippolyte Fortoul, "Instruction pour la Mise à l'Éxecution du Plan d'Études des Lycées," in Belhoste et al., *Les Sciences dans l'Enseignement* (ref. 55), 321–73, 351, and 437–38.

and treatises covering advanced topics for which he could not develop a full account within the pedagogical boundaries of the *Traité*, but deemed necessary to note for their scientific relevance. These references were also intended to be indications of further reading for the student. Second, Ganot provided explicit references when he introduced matters that he considered still lacking general consensus. In this context, he abandoned his role as narrator and transferred this voice to authoritative authors of journal papers and treatises tackling the controversial topic. This pattern was especially important in relation to the exposition of the different theoretical frameworks presented during the century to promote the internal cohesion of physics. Through successive editions of his textbook, Ganot's writing ended up integrating these debatable questions within a pedagogical account devoid of source references, concurrently illustrating and contributing to the emergence of consensus. Third, Ganot often inserted direct source references in relation to particular instruments, noting that he had seen an instrument at the workshop of a maker, and that he had then produced a textual description and visual reproduction (illustration) based on direct observation. Direct reference to instrument makers tended to disappear in successive editions of the *Traité* through Ganot's rewriting of its text. Thus, the *Traité*'s illustrations, originally representations of a local (Parisian) production, subsequently started to acquire a more universal quality, that of the *standard*, in parallel to the extensive national and international circulation of Ganot's textbooks and their engravings.

Illustrations were accompanied in the first editions of the *Traité* by indications of the real size of the instruments represented. Furthermore, instrument parts and mechanisms were tagged with letters, used in the text to describe them and their mechanisms and manipulation. Interestingly, the practice of tagging instrument parts was, in this period, standard practice in the drawing of industrial machine plans, aimed at guiding their assemblage in the factory.[67] Ganot's *Traité* was thus an exceptional repository of the most advanced instrument design available in the workshops of the leading Parisian makers and the important international connections of their trade (see Fig. 2). Moreover, Ganot's textbook incorporated very quickly descriptions and illustrations of new instruments linked to this trade. Examples of these instruments include: Morin's apparatus and Walferdin's maximum thermometer, designed in 1850, and presented by Ganot only a year later; Duboscq's electromagnetic regulator

67. J. M. Edmonson, *From Mécanicien to Ingénieur: Technical Education and the Machine Building Industry in Nineteenth-century France* (New York: Garland, 1987).

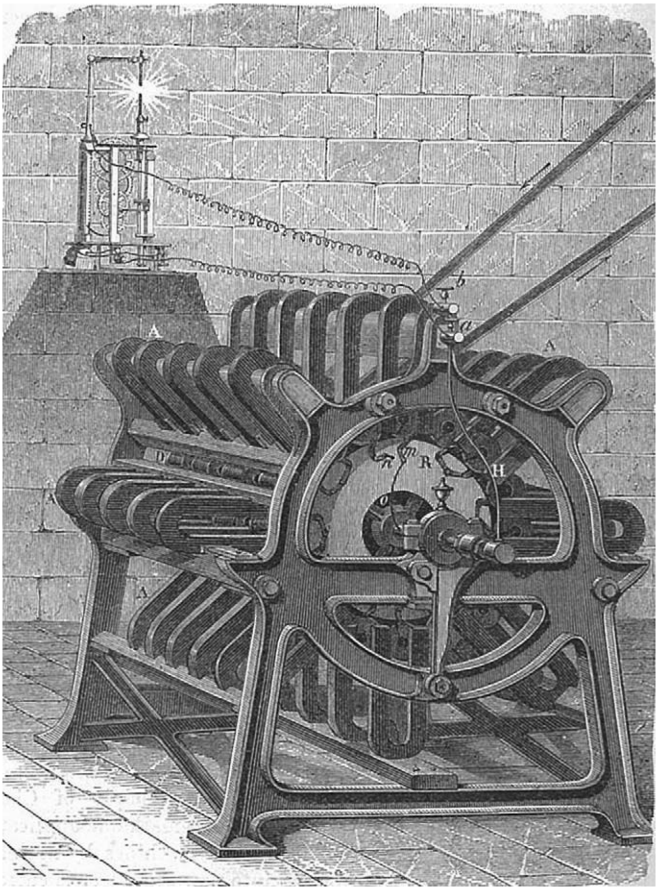

FIG. 2. Magneto-electric machine designed by the Belgian engineer Florise Nollet and perfected by Joseph van Malderen, drawn at the workshop of the Compagnie l'Alliance in Paris. Used in lighthouses, in this figure the machine provides light to an arc lamp with a Serrin regulator. William Thomson used this illustration for research purposes and was able to see the Alliance's machine in the 1862 International Exhibition in London. *Source*: Adolphe Ganot, *Elementary Treatise on Physics, Experimental and Applied* (London: H. Baillière, 1863), 696.

and Foucault's apparatus to measure the speed of light, included in the *Traité* in 1851; and Serrin's electrical light regulator, included in 1860. Each of these instruments was included in the textbook the same year as they were presented at the Académie des Sciences.

Ganot was also quick to provide accounts and illustrations of instruments of foreign design, although he was limited by the availability of sources of knowledge in Paris. His major sources in this context were the international exhibitions held in the city and the local distributors for foreign instrument making firms. Thus, for example, his 1868 textbook included a magneto-electric machine presented by William Ladd in Paris in 1867, and a machine of the same type by Henry Wilde, presented in London in 1865.[68]

Experiment, instrument making, and pedagogical logic were thus major characteristics of Ganot's *physique*. By contrast, mathematics was scarce in the *Traité*, as in many other French physics textbooks of the period. The narrative and order of Ganot's *physique* was characterized by a phenomenological introduction to nature, a historicist approach to the definition of problems and questions, an inductivist approach to solving these problems and the resulting creation of knowledge, and a strong focus on instrument making and manipulation. The overall structure of Ganot's *physique* gave a central place to the study of heat, light, and dynamical electricity, and, without rejecting them, gave a minor role to theory and mathematics. In spite of these general trends, each of the books in Ganot's *Traité* displayed some particularities. The book on light was especially geometrical and instrumental, the book on heat was especially experimental, and that on electricity, especially instrumental and applied. The books on static electricity and magnetism were particularly focused on pedagogical demonstration.

Atkinson's *Treatise* contained, like Ganot's *Traité*, all the parts of physics within the same textbook, divided into "books" within the same volume. He reproduced the structure and order of books in Ganot's *Traité*, and translated their names literally—except for *calorique*, now "heat"—and this basic structure was preserved throughout successive editions of the textbook. Thus, like in the *Traité*, the central books in the *Treatise* were those on heat and light. And as in the French case, the order of subjects in English natural philosophy textbooks diverged; but conventionally, the elementary notions of mechanics, hydrostatics and hydrodynamics, and pneumatics were placed at the beginning, whereas the order of the study of caloric or heat, light, and electricity varied.

Atkinson introduced new material in every new edition of his textbook, increasing its length by around 100 pages over twenty years. This rate was similar to, although slightly lower than, that of the *Traité* in the same period.[69]

68. Ganot, *Traité*, 1868 edition (ref. 26), 814–18.

69. Between the 1860 and 1880 editions, the *Traité* length was increased by 18 percent (148 pages). Between the 1861–1862 and 1881 editions, the *Treatise* length was increased 13 percent (108 pages).

Atkinson was more selective in the introduction of new content, whereas Ganot tended to be more comprehensive. As with the *Traité*, additions affected some books more than others. In 1863, the books on heat, light, and electricity were the lengthiest parts of the *Treatise*, each constituting around a fifth of its pages. Like the *Traité*'s ninth edition (on which the first edition of the *Treatise* was based), the lengthiest book was that on heat, followed by the books on dynamical electricity and on light. This proportional distribution was roughly maintained. The exposition of dynamical electricity within the book on electricity grew quickly, equaling in 1881 the length of the book on heat. Electricity was thus the most important subject in terms of book length in the *Treatise*, as it was in the same period in the *Traité*. In fact, Atkinson followed Ganot in all matters related to book structure and order, and he included most of the contents present in successive editions of the *Traité*. The narrative structure of the *Treatise* was also driven by numbered articles from start to end. This structure was unusual for an English physics textbook published during the first half of the century, but subsequently became generalized.[70]

Several aspects distinguished Atkinson's textbook narrative from that of Ganot. Atkinson used more synthetic sentences. He often reduced the length of historical introductions, modified certain examples by using a different pedagogical approach, and in certain parts he used more mathematical equations, especially in the introductory sections on mechanics. An important change in Atkinson's editions, which to a certain extent was connected to the different educational and printing cultures in England, was its elimination of the typographical marks that assisted Ganot in targeting different readerships, discriminating more advanced subjects and treatments, and introducing material that was still controversial. In the English edition, sections in small type were in certain cases eliminated or rewritten, but in general, they were introduced straight into the main text. Hence, some of the more advanced and mathematical content in Ganot's *Traité* was given in the *Treatise* an authoritative stamp withheld in the French original. In addition, Atkinson supplemented Ganot's

70. Textbooks such as those by Arnott and Hogg did not use articles, but in contrast, those by Bird and Lardner, which were closely connected to preparation for examinations, did use them. Neil Arnott, *Elements of Physics, or Natural Philosophy, General and Medical: Explained Independently of Technical Mathematics* (London: Thomas and George Underwood, 1827); Jabez Hogg, *Elements of Experimental and Natural Philosophy* (London: Ingram and Cooke, and Co., 1853); Golding Bird, *Elements of Natural Philosophy; Being an Experimental Introduction to the Study of the Physical Sciences* (London: Churchill, 1839); Dionysius Lardner, *Hand-Book of Natural Philosophy and Astronomy* (London: Taylor, Walton, and Maberly, 1851–1853).

references to new research contributions by providing more specific and often exact accounts, and explicit reference to British and German sources.[71]

Thus, Atkinson's *Treatise* was more mathematical and assertive on contemporary research. In this context, he stressed the importance of the dynamical theory of heat and the connective role of mechanical explanations, unifying the study of light, heat, and sound. Surprisingly, Atkinson did not apply the same zeal to argue for the unification of electricity and magnetism. On the other hand, he preserved the *Traité*'s focus on experiment, pedagogical demonstration, instrument design, and (French) instrument making. Moreover, Atkinson usually respected the (multi-)national distribution and attribution in Ganot's accounts, but in certain cases, he stressed the contribution of British actors mentioned by Ganot or added British actors not mentioned by him.

Atkinson's major original contributions to the differentiation of the *Treatise* from the *Traité* consisted of the introduction of new content in relation to British research in experimental physics and instrument design, and his complete renovation of the *Traité*'s section of problems to adapt it to English conceptions and practices of physics and pedagogy. In successive editions of the *Treatise*, Atkinson complemented Ganot's accounts with additions expounding the most recent work of British physicists in fields such as heat, telegraphy, and electrical standards.[72] Furthermore, Atkinson added accounts on instruments designed by British physicists or instrument makers.[73] Most of these were introduced in the book on dynamical electricity, which was also the book that underwent the most changes in the *Traité*, but was also a field in which British physicists and engineers introduced many new developments that had an international impact. Nonetheless, Atkinson also added new accounts of British instruments in the books on sound, light, and heat, among others.

However, Atkinson's edition of Ganot's textbook in English was conservative due to pedagogical, technical, and financial limitations. Although he introduced significant changes to the *Traité*, he preserved the structure and most of the contents of Ganot's textbook. Atkinson trusted Ganot's experience and skill as a teacher and textbook writer. Ganot's textbook had served Atkinson—as it had many other English physics teachers—in configuring his lessons and teaching practice at the beginning of his career, and his preparation of successive editions

71. Ganot, *Treatise*, 1866 edition (ref. 26), 115, 363.

72. See, for example, Ganot, *Treatise*, 1868 edition (ref. 26), 793–800.

73. Ibid., 637–38, 675–76, 763, 796.

in English had gone together with his maturation as a physics teacher.[74] Thus, Atkinson respected Ganot's textbook and was cautious in modifying it. In addition, his translation and edition was constrained by the technical and financial basis of the English edition.[75] Still, Atkinson's physics was more British than Ganot's. It was slightly more advanced and more mathematical; it replaced Ganot's historicist approach with a more direct narrative, which added emphasis on pedagogical communication. Ganot and Atkinson also maintained some differences in their attitude toward theory, although overall a pluralistic and skeptical approach to theory characterized their texts.

THEORETICAL PLURALISM

The discussion of the role of theory in Ganot's and Atkinson's texts is particularly relevant in the assessment of their narrative efforts to provide a coherent and compact picture of physics, which involved the conceptualization of how to connect its different parts, represented by books in the *Traité* and the *Treatise*. However, as we shall see, Ganot and Atkinson in general prioritized other narrative strategies.

At the end of the *Traité*'s introductory chapter, Ganot stated that the nature of the agents or natural forces causing physical phenomena was unknown to mid-nineteenth-century science. However, in his opinion, the most accepted hypothesis was that of considering physical agents as imponderable fluids spread in the universe. Their effects, caused by "particular movements impressed to their mass" (understanding that the mass of these fluids was imperceptible) were physical phenomena. Five agents caused the latter, namely, universal attraction, caloric, light, magnetism, and electricity. Nonetheless, according to Ganot, consensus seemed to be on the way in admitting that all five could probably be related to a single source.[76]

74. Another example, for instance, is that of the Cambridge wrangler James Maurice Wilson, who relied on Ganot's textbook when teaching physics at Rugby as he was new both to the job and to experimental physics. James Maurice Wilson, *James M. Wilson: An Autobiography, 1836–1931* (London: Sidgwick & Jackson, 1932), 62.

75. Atkinson and his publisher had to rely on Ganot's production of textbook illustrations for successive editions of his textbook, since their cheapness and quality were irreproducible in England. Moreover, because of the large sales and thus print-runs of the English editions, like Ganot, they stereotyped the book. Both aspects constrained Atkinson's new editions. See Simon, *Communicating Physics* (ref. 3), 150–56, and ref. 64 in this article.

76. Ganot, *Traité*, 1851 edition (ref. 26), 3.

For fifteen years, Ganot communicated to his readers this conception of agency in physical phenomena. Subsequently he modified his approach, talking of a unique "ether" and the correlation of forces. Atkinson subscribed to Ganot's definition of physics and followed his approach to physical agents, but he introduced the concept of the ether fluid only in 1875, almost a decade after Ganot, and never mentioned the correlation of forces.[77] Nonetheless, since the first edition of the *Treatise*, Atkinson attributed greater relevance to the dynamical theory of heat than Ganot. Furthermore, among his original contributions was also an article on the principle of the conservation of energy, introduced in the *Treatise* in 1868.[78]

Ganot's and Atkinson's exposition of physical agency was partly Laplacian, at least in their allegiance to forces instead of energy. Their work is framed in a period in which a focus on forces and particles was arguably starting to lose strength against energy and ether. However, the former approach was still in use in, for instance, major investigative enterprises as the work of mathematical physicists such as Wilhelm Weber on electrodynamics.[79] Ganot used the concepts of ether and correlation of forces long after their emergence and apogee—according to historians of physics—and his physics remained practically alien to the principle of the conservation of energy. Atkinson's approach was similar, but he showed affinity for this principle, considered by historians to have had a major role in the constitution of physics as a discipline.

A theoretically driven observer of Ganot's and Atkinson's physics, informed by the current standard historiography of the subject, would perhaps consider that the picture of physics displayed by these two authors was incoherent and anachronistic. Of course, historians of physics know that the major conceptual and theoretical changes that shaped nineteenth-century physics did not occur or become generalized immediately. This was a slow process of change and cannot be described by a linear and perfectly rounded narrative. However, faced with the current big picture of nineteenth-century physics, Ganot and Atkinson endorsed theoretical frameworks that were not to endure, and they did not endorse with the expected vigor, the new theories when they started to gain ground. In this context, though, it is worth stressing that their texts were particularly not dogmatic, as they did not adopt a unique theoretical approach,

77. Ganot, *Treatise*, 1875 edition (ref. 26), 3.

78. Ganot, *Treatise*, 1863 edition (ref. 26), 341–44.

79. See Robert Fox, "The Rise and Fall of Laplacian Physics," *HSPS* 4 (1974): 89–136; Jungnickel and McCormmach, *Intellectual Mastery of Nature* (ref. 10), 139–46; Hunt, *Pursuing Power and Light* (ref. 11), 95–98, 104.

but prioritized different options in each case, driven by pedagogical and scientific reasons. Thus, they showed both their advocacy for theoretical pluralism and their greater epistemological emphasis on aspects other than theory. The pedagogical work of Ganot and Atkinson is perhaps not comparable to the research production of Weber and Maxwell, for instance, but this is different from postulating that it is less meaningful.

PEDAGOGICAL TRUTH AND EXPERIMENTAL UNITY

The production of Ganot's and Atkinson's textbooks relied on the work of researchers. Their transformation of journal science into textbook science and the circulation of their textbooks was governed by a timing obviously different from that of writing, publishing, and circulating papers in specialized physics journals. The readers of these textbooks and these research papers were also different in both type and size. It makes sense to admit that Ganot's and Atkinson's physics lagged behind contemporary published research, and therefore that their textbooks were outdated in certain aspects of physical theory. At the same time, two factors deserve emphasis. First, the production of a textbook like theirs was not merely an assembly of research papers. The whole was greater than the sum of the parts. Ganot and Atkinson made decisions on what to include and what to discard in their textbooks, and they contributed thus to define the disciplinary boundaries of physics. Second, even if their textbooks were anachronistic, they were the canonical texts used extensively to introduce students to physics. The impressive size of the readerships of Ganot's and Atkinson's physics indicates the necessity of considering them as they were, and here we propose to take them as they are to see what type of account emerges with regard to nineteenth-century physics, and how this might help us to rethink the current historiography of physics.

During the first decade of the century, the Laplacian program had intended to reduce all physical phenomena to the action of molecular forces. This theoretical framework pervaded the French foundational textbooks of René-Juste Haüy and Jean-Baptiste Biot. It was also closely followed, from the late 1820s, by authors such as Eugène Péclet. During the first half of the century, all French textbook authors considered imponderable fluids to be the agents of the effects observed in nature as heat, magnetism, electricity, and light. Some of them agreed that research in physics might reduce the number of agents considered, or that they might even all be reducible to a single source, but they commonly accepted that their nature was currently unknown and did not express great concerns for such uncertainty. Historians of physics have in general evaluated this fact in a dramatic light, foreseeing in what was described by Robert Fox as "conceptual agnosticism," one of the causes of the alleged subsequent decay of French physics.[80] However, this picture fails to portray the fundamental traits of French physics during most of the century. As much as the Laplacian program mattered, physics textbooks show that, as expressed by historical actors themselves, other more fundamental questions defined physics in this period. The fundamental cohesion of French physics was not based on theory, but on experimental precision and experimental illustration.[81] As we have seen through Ganot's mid-nineteenth-century perspective, a third factor intervened in interaction with these two: instrumental design.

In 1816, in defending his Laplacian program of mathematization of experimental physics, Biot recognized that in France and Britain a more important role was commonly given to purely experimental methods.[82] A decade later, Despretz considered that acquiring experimental methods potentially applicable to real life was one of the major virtues of giving physics a central place in a good education.[83] In the 1830s, Péclet considered experiment to be the core of physics, on which the stability of hypothesis and theory depended.[84] Pouillet claimed, "it is through experimental researches that new facts are discovered and not through mathematical speculations," and like Auguste Pinaud, he considered the experimental method to be the guarantee of an accurate and efficient pedagogy.[85] From the 1850s, Ganot's *Traité* reinforced this trend, and through its focus on "applied physics" and the communicative power of its use of scientific instrument illustration, it further enhanced the role of instrument making in physics. Almost two decades later, Augustin Privat Deschanel followed the pattern of Ganot's textbook and stressed the virtue of learning the experimental method in developing a critical spirit, compared to the greater rigidness and narrowness imposed by mathematics.[86]

80. Fox, "The Rise and Fall," (ref. 79), 127–32.

81. Francoeur, "[Review of Despretz's *Traité*]" (ref. 45).

82. Jean-Baptiste Biot, *Traité de Physique Expérimentale et Mathématique* (Paris: Chez Deterville, 1816), xj.

83. Despretz, *Traité* (ref. 57), pp. ii–iii.

84. Péclet, *Traité* (ref. 66), ii.

85. Claude Pouillet, *Élémens*, 1832 edition (ref. 59), ix–x; Auguste Pinaud, *Programme d'un Cours Élémentaire de Physique* (Toulouse, Paris: Bon et Privat; L. Hachette et Cie, 1848), viii.

86. Privat Deschanel, *Traité* (ref. 61), i.

This emphasis on experiment pervaded physics textbooks, being compendia of experimental procedures, meticulous descriptions of instruments and experimental sets, and compilations of experimental data. In this context and for pedagogical reasons, mathematical analysis was often relegated to footnotes or to paragraphs in small type, while numerical tables compiling experimental data and results were numerous. Moreover, French authors stressed their greater confidence in inductive laws than in hypotheses such as the Laplacian forces. In the nineteenth century, Jean-Baptiste Biot observed that, in fact, this feature emerging in French physics was characteristic in Britain. As has been pointed out by Crosbie Smith, it was a feature of Scottish natural philosophy, which was at the core of the development of British physics.[87] But it was also a common position in France, contributing to the questioning of the overly exclusive national characterization displayed by the standard historiography of nineteenth-century physics.[88] In spite of this, Ganot did provide accounts of the theoretical framework of physics and its changes during the second half of the century. However, as I have suggested, his approach in this matter contrasts with the standard periodization of the formation of physics as a discipline.

THEORETICAL SKEPTICISM

After fifteen years of subscribing to a Laplacian view of physical agency, Ganot progressively abandoned this perspective. In the first chapter of the 1866 edition of his *Traité*, he presented the principle of the existence of a unique fluid called ether—the vibration of which could account for the phenomena of light, heat, magnetism, and electricity—as a natural development of the physicists' mission of reducing all imponderable fluids to a single source (included since the first edition of his *Traité*). Ganot considered that this was the view for which increasingly more consensus was held in physics. He did not speak for himself alone, though, but also for the authoritative opinion of certain physicists. Ganot cited the French translation of William Robert Grove's *On the Correlation of Physical Forces* (originally published in 1846, in French a decade later, and reprinted in 1867), of John Tyndall's *Heat, a Mode of Motion* (1863,

87. Crosbie Smith, "'Mechanical Philosophy' and the Emergence of Physics in Britain: 1800–1850," *Annals of Science* 33, no. 1 (1976): 3–29.

88. See Faidra Papanelopoulou, "The Emergence of Thermodynamics in Mid-Nineteenth-Century France: A Matter of National Style?" in Simon and Herran, *Beyond Borders* (ref. 14), 249–67.

French translation 1864), and of Angelo Secchi's *L'Unità delle Forze Fisiche* (Italian 1864, French 1869). In 1868, Ganot added reference to a monograph based on papers on radiant heat presented by Tyndall between 1865 and 1866 at the Royal Society, compiled and translated into French in 1867.[89] Moreover, he stressed further that, therefore, all physical phenomena could then be connected to mechanical causes and that the language of imponderable fluids was no longer adequate, in consonance with the new ideas in physics. Accordingly, from 1868, Ganot substituted the term "caloric" with "heat."[90] In 1870, as an extraordinary measure, he included a note opposite the *Traité*'s title page stating that he had introduced in his book the dynamical theory of heat and:

> The hypothesis of imponderable fluids, abandoned everywhere, has been replaced by that of a unique fluid. It is a hypothesis substituted to another, it is true; but the new hypothesis is simpler and represents the dominant ideas today. We shall add that these modifications had been presented with the greatest reservation, and ensuring that they do not trouble the habits of teaching.[91]

As suggested by Ganot's declaration, although acknowledging the necessity of introducing this new theoretical framework, he was cautious for two reasons: first, that in spite of authoritative consensus, the new theory was as hypothetical as the old; second, that pedagogical communication, rather than theoretical principle, was his main priority. Furthermore, Ganot had in fact already provided an account of the mechanical theory of heat as early as 1855.[92] As a combination of these aspects, the structure and order of Ganot's textbooks did not experience significant changes in its successive editions. Moreover, by 1880, Ganot's exposition of the theoretical framework of physics had remained that of ether and the correlation of forces, and he never introduced reference to the principle of the conservation of energy, which according to the standard historiography of physics, had increasingly gained ground since the late 1860s.

The low priority conferred to theory by Ganot is again suggested by the fact that since the first edition of the *Traité*, he clearly expressed his aim at pedagogical and experimental unity, in contrast with his pluralistic approach to theory, even if the latter contributed to restrain the intellectual and narrative coherence of his textbook. Thus, Ganot did not have any problem with

89. For more detail see Simon, *Communicating Physics* (ref. 3), 145 n. 107.
90. Ganot, *Traité*, 1868 edition (ref. 26), 3–4.
91. Ganot, *Traité,* 1870 edition (ref. 26).
92. Ganot, *Traité,* 1855 edition (ref. 26), 354.

introducing in different parts of his book accounts of research that contradicted clearly the basic theoretical framework expounded in its introductory chapter. In its first edition, the *Traité*'s introductory articles of the books on caloric and on light gave an account not only of the imponderable fluid explanatory framework, but also of that of the wave theory and ether. Moreover, in these books he provided detailed accounts of the works of Macedonio Melloni and Augustin Fresnel, among others, who had an important and well-documented role in the fall of Laplacian physics.[93] Furthermore, Ganot admitted that research in physics proved that the wave theory was the only admissible explanation of these two physical phenomena.[94] In this new perspective, the atypical position of Ganot's book on light—just after that on caloric—gained a rationale not foreseen by its author.

Ganot's prioritization of pedagogy over theory is also illustrated by his exposition of magnetism in the *Traité*. Since its first edition, he acknowledged that, despite the common use of the hypothesis of two special magnetic fluids, magnetism was most probably not a result of their mutual action but of currents of a single electrical matter, and that this hypothesis had in addition the advantage of linking the theories of magnetism and electricity. In spite of this, he stuck to the two-fluid hypothesis because, as he declared, it provided a simple and efficient means of pedagogical explanation and demonstration.[95] The same problem and solution appeared in Ganot's exposition of electricity.

Ganot was not concerned with going against (mere) hypothesis when the efficiency of pedagogical communication was at stake. Thus, the basic structure of his physics did not change in accordance with any of the unifying principles he expounded. Ganot did acknowledge the importance of connecting conceptually the different areas of research constituting physics, but he did not give great importance to theoretical principles on physical agency. Instead, his conception of physics as a discipline emphasized accuracy in the observation and description of physical phenomena, and in the description and practical knowledge of experimental procedures, experimental sets, and scientific instruments.

What was the rationale connecting the different books of Atkinson's *Treatise*? In this matter, Atkinson followed Ganot's text only partially. In his introduction

93. Fox, "The Rise and Fall" (ref. 79); Robert H. Silliman, "Fresnel and the Emergence of Physics as a Discipline," *HSPS* 4 (1974): 137–62.

94. Ganot, *Traité*, 1851 edition (ref. 26), 201–2, 337–38.

95. Ibid., 479.

to physical agents, he was more categorical in stressing the mere hypothetical character of imponderable fluids. In this sense, he preferred to omit Ganot's (Laplacian) speculation about the possibility of rendering, in the future, these various agents to a single source, and substituted for it a more concise and skeptical appraisal of the "imponderable fluid" explanatory framework.[96]

Consequently, in the introduction to the book on heat, this difference in stress appeared again. Both Ganot and Atkinson explained the imponderable fluid and the wave theories, and agreed that the latter was to prevail. However, whereas Ganot declared that, in spite of this, he was going to use the fluid theory for pedagogical reasons, Atkinson resolved instead that, consequently, his approach would consider heat as a form of motion. Furthermore, at the end of the book, he appended an original four-page chapter on the dynamical theory of heat that gave accounts of the work of Carnot, Mayer, and Joule, including three original illustrations. In its closing paragraph, he stressed that the work of Joule, Thomson, and Rankine in Britain, Mayer, Clausius, and Helmholtz in Germany, Clapeyron and Regnault in France, and many others, had contributed to establishing this theory as a fundamental principle in scientific research.[97]

In the introductory section of the book on light, Atkinson endorsed Ganot's approach, which stated that Fresnel's research had shown the undulatory character of light, and Atkinson added some experimental data supporting this theory. In addition, while acknowledging Fresnel's fundamental role, he emphasized the precursory role of British natural philosopher Thomas Young, where Ganot had only cited him among other important contributors to the field. Most importantly, Atkinson added a closing paragraph stressing the connective character of the undulatory theory for the phenomena of light, heat, and sound. In the introduction to the book on electricity, Atkinson eliminated Ganot's discussion about the nature of electricity, expressing that the prevailing uncertainty on this matter had led to work within a framework of mere hypothesis. However, in the discussion of the two prevailing explanations, Atkinson followed Ganot's account literally, privileging the most suitable for pedagogical reasons while stressing the hypothetical character of both.[98]

In the 1870s, Atkinson was criticized by George Rodwell, also a science teacher and textbook writer, for not having reworked the *Traité* into a textbook

96. Ganot, *Treatise* 1863 edition (ref. 26), 2–3.
97. Ibid., 188.
98. Ibid., 345–46.

displaying the new structure of "Thomsonian physics," as communicated in 1867 by the natural philosophy textbook of William Thomson and Peter Guthrie Tait.[99] In fact, the only textbook published in this period that fully integrated the framework of the conservation of energy principle in its writing was that of Balfour Stewart, published in 1870.[100] Atkinson had introduced an article on this subject at the end of the first book of the *Treatise* as early as 1868, which Rodwell considered too short.[101] As a reaction, Atkinson expanded this section in the following edition of his textbook, to include a lengthy discussion of work and energy in the context of this new theory. The same year, Atkinson's translation of Helmholtz's lecture on the conservation of forces had been published. Although Helmholtz's theory was partly Laplacian, Thomson and other promoters of the new physics soon enlisted him in support of their cause.[102]

In fact, during the central decades of the century, the imponderable fluid theory was still prevalent in British natural philosophy textbooks. Those authors who mentioned the existence of new theoretical explanations, usually stuck— completely or partially—to the traditional framework. For instance, in 1851, Robert Hunt, professor of mechanical science at the Government School of Mines, noted the many criticisms in the literature against the caloric fluid, but adopted this concept, considering that it had many advantages.[103] In 1859, Dionysius Lardner devoted a whole chapter of his *Hand-Book* to the theory of undulation as applied to solids, liquids, and gases, and remarked on the critical role that his theory played in the explanation of the phenomena of sound, heat, light, and the imponderable agents. However, in the book on optics, after describing the two available theories of light, he avoided declaring his preference by quickly transferring to the exposition of optical phenomena, a necessary procedure, in his opinion, to understand one or the other theory.[104] In 1861, Jabez Hogg described the principle of the conservation of energy as "the most important progress in Natural Philosophy by which the present century is distinguished," and he gave an account of the research of Joule, Helmholtz,

99. George F. Rodwell, "Ganot's Physics," *Nature* 5, no. 8 (1872): 285–87.

100. Balfour Stewart, *Lessons in Elementary Physics* (London: Macmillan, 1870); William Thomson and Peter Guthrie Tait, *Treatise on Natural Philosophy* (Oxford: Clarendon Press, 1867).

101. Ganot, *Treatise*, 1868 edition (ref. 26), 103.

102. Hermann von Helmholtz, *Popular Lectures on Scientific Subjects* (London: Longmans, Green and Co., 1873); Smith, *The Science of Energy* (ref. 43), 13.

103. Robert Hunt, *Elementary Physics: An Introduction to the Study of Natural Philosophy* (London: Reeve and Benham, 1851).

104. Lardner, *Hand-Book* (ref. 70).

and Thomson. However, in the sections on heat, light, and electricity, he conflated the wave-ether and imponderable fluid theories.[105]

As in the case of Ganot's *Traité* and Atkinson's *Treatise*, these examples are signs of the lack of consensus around the new mechanical frame, and of pedagogical pragmatism driven by habit (that is, an intellectual but also practical resistance to change). If we take at face value how physics is presented in these textbooks, their priorities represent their relative emphasis on different ontological and epistemological perspectives. Although the aforementioned authors echoed Ganot's and Atkinson's presentation of physics, they were less explicit in why they did so. Nonetheless, for what concerns Ganot and Atkinson, it is clear that they considered very often that the theories they were using—even if potentially outdated—had pedagogical virtues that made them more useful. Their value was measured pedagogically and not just theoretically or experimentally. This is relevant because the result went beyond a strictly educational setting, since Ganot's and Atkinson's textbooks presented a picture of physics that had a large impact among nineteenth-century readers.

CONCLUSION

Ganot's physics was characterized by its emphasis on experiment, instrument, and machine design, low mathematization, and a theoretical pluralism that also included a high degree of skepticism for theory. These elements contributed to a coherent and compact picture of physics, which pervaded the teaching of physics in France and England. Ganot and Atkinson acknowledged the importance that debates and research programs for theoretical unification had in contemporary physics, yet they recognized the relevance of other aspects in building a comprehensive picture of physics. How can we understand this case in the current historiographical framework?

In this framework, French physics after the 1820s would be characterized by a "theoretical agnosticism" that led to its decreasing influence on the international scene. This was the result of downplaying the golden legacy of the Laplacian program. After the theoretical tenets of that program were rejected, their intellectual space was not filled by a theoretical framework having analogous orthodoxy.

105. Jabez Hogg, *Elements of Experimental and Natural Philosophy* (London: H. G. Bohn, 1861).

In the second half of the nineteenth century, French physics was indeed characterized by theoretical heterogeneity. Moreover, textbooks such as those by Ganot and Atkinson did not reproduce faithfully what was contemporaneously happening in research or journal physics, according to historians of physics. They displayed a different epistemological agenda and a different narrative. It is fair to admit, then, that the theoretical heterogeneity of Ganot's and Atkinson's accounts was related to their relative speed and ability to translate journal science into textbook science. It would also be possible to claim that this heterogeneity involved a certain level of intellectual incoherence. However, this mode of reasoning postulates a status for theory and for theoretical unity, which is partial or, at least, should be discussed further.

Overall, Ganot's and Atkinson's downplay of theory and mathematization and, in particular, the principle of energy conservation, highlights that, contrary to the traditional historiographical picture of physics, this principle was not adopted everywhere as an ideal solution to the alleged problems of physics. It makes clear that the theoretical base of the unity of nineteenth-century physics put forward by the standard big picture is perhaps more an idealized picture than a comprehensive narrative and results from selecting a particular set of physics practitioners and emphasizing their claims on the role of the unification impulse. Furthermore, this case study suggests that there is evidence to question the traditional periodization and national distribution, which considers that the crucial period for the making of physics as a discipline was the late nineteenth century and that mainly British and German contributions mattered in this context.

Ganot's physics offers a big picture of the making of physics in which mid-nineteenth-century developments are core, and it displays the diversity of epistemological frameworks and practices coexisting in physics in different periods and places. If we take this into account, the alleged incongruence of presenting or even mixing rival theoretical frameworks becomes less of a problem than an opportunity. In nineteenth-century France and England, textbook physics was especially characterized by experimental description instead of theoretical closure, and in contrast to the views of the standard historiography, textbooks were not mere repositories of "normal science" but had latitude to communicate rival claims and matters about which there was a lack of consensus. Thus, nineteenth-century physics could have other elements articulating its unity such as experiment, instruments, and pedagogy.

This case study does not ignore that in the nineteenth century, there were traditions different from the one represented by Ganot, such as mathematical physics, and that theoretical unification played an important role in the making of physics as a discipline. However, I argue that these traditions—already well represented in the standard historiography—are insufficient to characterize the emergence of physics as a discipline. Although Ganot's textbooks might be downplayed in a traditional Kuhnian picture, I suggest that in fact, for their large readerships and international circulation, they can be endowed with a canonical value as sources for the history of physics. The extended use of Ganot's textbooks across different contexts, ranging from education to research, as well as their lasting impact, makes them excellent sources to characterize this process. Ganot's textbooks can be rightly said to have played an important and active role in the shaping of physics in the nineteenth century.

The aim of this paper has not been to assert that physics is more French than commonly thought. But this discussion of periodization and national distribution is intended to emphasize that a big picture based on the aggregation of national pictures and a succession of leadership transfers that are nationally characterized, will be insufficient, by nature, to provide an accurate international picture of physics. Thus, it is a call for further cross-national and comparative work analyzing the multifarious cultures of nineteenth-century physics across national boundaries, for the development of a more historically accurate analysis assessing the flexible boundaries between the communication and the making of science, and for acknowledging the important role of pedagogy and textbooks in the making of physics.

ACKNOWLEDGEMENTS

I am grateful to Bruce Hunt, Richard Staley, and Alexei Kojevnikov for their generous reading, constructive criticism, and critical suggestions on an earlier draft of this paper.