What Have the Historians of Quantum Physics Ever Done for Us?

MASSIMILIANO BADINO*

Abstract. Once one of the main protagonists of history of science, the historiography on quantum theory has recently gone through a process of reconfiguration of methods, research questions and epistemological framework. In this paper, I review the recent developments and propose some reflections on its future evolution.

INTRODUCTION

In many respects, the twentieth century was the century of Quantum Physics. After Planck's discovery of the quantum of action, which occurred in 1900, the theory grew up to become not only the most successful scientific endeavor of all times, but a cultural force in its own right, able to permeate our worldview, to reconfigure old problems, to create new avenues of research, to provide an almost inexhaustible reservoir of witty jokes and even to infiltrate show business. But the twentieth century also saw the institutionalization of history of science as a discipline. It was therefore almost inevitable that the latter, eager to carve out its own space in modern culture, looked to the former as a first choice topic. For quantum physics is not just a cornerstone of contemporary science, it is first and foremost, a great scientific revolution. And, we all know, history of science cannot resist the attraction of revolutions.

Quantum physics and relativity, alongside other notable conceptual upheavals such as Copernicanism, Newtonianism and Darwinism, were unsurprisingly the favorite playgrounds of history of science during its infancy. But now it would appear that history of science has come of age and has, to a certain extent, freed herself from those early infat-

* Universitat Autonoma de Barcelona – CEHIC, Mòdul de Recerca C, Carrer de Can Magrans, s/n Bellaterra 08193, Spain. E-mail: massimilianobadino@gmail.com

uations. The history of quantum physics -- or HQP for short -- no longer features so prominently in non-specialized journals, and its presence in major conferences is not as constant as it used to be.

What I aim to do in this paper is to demonstrate that HQP is still a lively and productive field of research. I begin by painting, admittedly with a very broad brush, the evolution of this historiography for those who are not familiar with it.[1] Next, I will discuss the production in HQP over the past 15 years, picking up three main themes.[2] Finally, I will reconnect with the title of this paper and take on the specific contribution of historians of quantum physics for the history community at large.

Figure 1. The 1998 cover of Physics World jokingly illustrates the vagaries of quantum information (courtesy of *Physics World*)

THE BEGINNINGS OF HQP

Let me begin with summarizing the story of our field. Quantum physics went historical almost at the outset. From the 1930s on, important physicists, Léon Rosenfeld being the most prominent example, appreciated the necessity to look backwards to better under-

stand the way forward.[3] The results of their efforts, although still useful, were methodologically dangerous for at least two reasons. First, they defined their subject exclusively from the point of view of working physicists, a tendency that, as we shall see later on, has permeated HQP as a whole. Second, some of those works were, at times tacitly, at times overtly, at times inadvertently, in the service of one or another of the many schools, approaches and interpretations that fought for hegemony in quantum physics. We should therefore look at these early steps as preliminary chartings of a new territory and be ready to take them with a pinch of salt.

Professional historians took over only in the 1960s.[4] The most mature outcome of this period is certainly Max Jammer's *The Conceptual Development of Quantum Mechanics* (Jammer 1966) a book that, despite being exactly 50 years old, has maintained a surprising freshness. The title of Jammer's volume is less innocent and more programmatic than it appears at first sight. On the one hand, he tells the story of the *conceptual* development of quantum mechanics, that is to say, he characterizes his approach outright as intellectual history. On the other hand, Jammer also tells the story of the conceptual development of *quantum mechanics*, that is, for him the story culminates in the momentous events taking place from 1925 on and must be organized accordingly.

These two methodological choices were internalized by subsequent writers and shaped much of the work of the late 1960s and early 1970s. Historians attacked paper after paper, equation after equation, experiment after experiment with the goal of reconstructing the path from Planck's quantization in 1900 to matrix and wave mechanics in the mid-1920s. Scholars of the caliber of Thomas Kuhn, John Heilbron, Russell McCormmach and Martin Klein historically scrutinized Einstein's wave-particle duality, Bohr's atomic model and the problems of spectroscopy, to mention just a few examples.[5]

In the early 1960s, the project 'Sources for the History of Quantum Physics' took off under the directorship of Thomas Kuhn with the assistance of John Heilbron, Paul Forman and Lini Allen. The major outcome of the project was the Archive for the History of Quantum Physics (AHQP) in which the editors collected, catalogued and microfilmed a monumental amount of letters, unpublished manuscripts and—most importantly—interviews with the still living protagonists of the quantum epic. It took some time for

specialists to navigate through this ocean of new documents, but when they finally familiarized themselves with the Archive, it provided an invaluable tool to supplement papers and other published material.

In the late 1970s, several novel theoretical options started to appear in the form of various 'turns'. Although the identity of the historians of science was badly shaken as they were asked to be cultural scholars, social experts, political scientists, anthropologists and ethnographers almost in the same breath, the new trends stimulated intense and fruitful discussions in many quarters of the history of science and science studies. HQP was slow to react to the methodological turmoil. The tradition of intellectual history and the special attention to technical aspects remained largely dominant through the 1980s, despite the contributions of sociologically-minded scholars such as Andrew Pickering and Trevor Pinch.[6] However, a new brand of historians was emerging, one increasingly sensitive to the new ways of approaching the inquiry into the past.[7]

As the end of the century approached, the fire smoldering under the ashes finally started to burn. The journal *Studies in History and Philosophy of Science* was the quickest to capture the change of mood. In 1998, the editorial board published a special issue edited by Peter Galison and Andrew Warwick dedicated to the 'Cultures of Theory'. Like the Spanish Inquisition, nobody expected such a juxtaposition and the editors were well aware of that. After all, historical and philosophical accounts of scientific theories had traditionally made next-to-zero use of the concept of 'culture'.[8] Galison and Warwick approached this challenge by laying down a number of driving questions: 'What kind of pedagogy forms the theorists a community wants? How much mathematical rigor is appropriate in theoretical physics within a given community? How do theorists and experimentalists interact, who leads and who follows?' (Galison and Warwck 1998, 288). With these questions, Galison and Warwick tried to give programmatic form to a widespread sense of unease about the traditional way of doing history of physics. They forcefully argued that it was high time to incorporate concepts and methods of cultural, social and political history in the time-honored mainstream of intellectual history.

In hindsight, it is safe to claim that much of the ensuing work in HQP was inspired, if not outright implied, by the agenda laid down by Galison and Warwick in that introduction.

Or more simply, times were finally ripe for some turn in this field as well. In the remainder of this paper, I will explore the features and implications of this turn. As it would be hopeless to paint a full portrait in the space at my disposal, I will organize my analysis along three multiply interconnected axes: That is sources, narratives and philosophy.

SOURCES

As historians we all know that any human activity advances by combining tradition and innovation. Historiography does not differ in this respect, so it is not surprising that HQP is still largely done with the same material as in the previous century; that is written texts. Published or unpublished, private or public, rough or polished, finished or unfinished, systematic or accidental, the written word remains our main link to the past. But the ways we deploy this link have certainly changed in an interesting way over the last decade or so. In this regard, the expansion of digitization technology has contributed enormously to increase the quantity and availability of documents. If one can survive the nostalgia for dusty volumes and fragile microfilms, it is surely a reassuring feeling to have an increasing amount of papers, manuscripts and letters just a couple of clicks away. One major example is the digitization carried out at the Max Planck Institute for the History of Science in Berlin under the umbrella of the Quantum History Project led by Christoph Lehner and headed by Jürgen Renn and Matthias Scheffler.[9] This endeavor has brought to specialists not only a massive quantity of primary and secondary sources, but also the entire Archive for the History of Quantum Physics, now available online for research.

The improved accessibility of texts and the enlargement of electronic repositories have made it much easier to discover new connections, patterns and influences, and to unearth new stories and new characters. For instance, just when it seemed that we knew all that was worth knowing about Heisenberg's *Umdeutung* paper, Michel Janssen and Tony Duncan managed to demonstrate that the American physicist John Van Vleck came, very close to the same result (Duncan and Janssen 2007a, 2007b). Van Vleck was working in Minnesota, a place not quite as glamorous as Göttingen, although he was able to ground his approach on the imposing American tradition of celestial mechanics. As a

consequence, his papers are much easier reading than Heisenberg's and they shed new light on the genesis of quantum mechanics.

As hard to believe as it may be now, the USA was a periphery in the landscape of 1920s physics, but instances of exciting science did exist (see, e.g., Sopka 1988). Increasingly aware of that, many historians have recently attempted to break the circle of the usual suspects and cast an inquiring gaze on unlikely protagonists and fringe research. Take the case of two very recent books, Olival Freire's *Quantum Dissidents* (Freire Jr 2015) and David Kaiser's *How the Hippies Saved Physics* (Kaiser 2011).[10] Working on slightly different issues, both authors have described how a crowd of outcasts refused to abide by the shut-up-and-calculate attitude of post-war physics and so kept the fire of philosophical thought burning until it generated thrilling fields of research such as quantum information. To tell their stories, Freire and Kaiser had to mine literature that had never been mined before and consider people who had never been considered before.

Our attitude toward correspondence is evolving as well. Previously, letter exchanges were looked upon either as collections of facts complementary to research papers or as reference material for amusing anecdotes. This view has started changing since Mara Beller's landmark book *Quantum Dialogue* (Beller 1999), in which she argues that the correspondence between the founders of the Copenhagen School reveals a network of intellectual as well as emotional relations in stark contrast with the official image derived from their publications. More importantly, it also discloses the internal disagreements and the progressive construction of consensus that led to the Copenhagen interpretation (Camilleri 2009a). Drawing on Beller's insights, historians of quantum physics have developed a more nuanced attitude toward correspondence. It is now more and more common to approach it as a means to uncover methodological biases, to map out allegiances and tensions, to challenge established wisdoms and to contrast public and private self-images.[11]

Some historians have also dug into sources that, although available in earlier decades, were scarcely used. That is the case of the important paper by Christoph Lehner and Christian Joas (Joas and Lehner 2009) and the thick volume by Guido Bacciagaluppi and Antony Valentini (Bacciagaluppi and Valentini 2009). Both works are concerned with

recovering marginalized ideas by looking more closely into texts, such as Schrödinger's notebooks and the 1927 Solvay Conference Proceedings, that specialists had previously only browsed through. Unsurprisingly, the emergence of new textual resources has gone hand in hand with a process of reassessing crucial junctions in HQP such as the onset of quantum theory,[12] the troublesome transition from Old Quantum Theory to Quantum Mechanics,[13] and the first steps into quantum field theory and quantum electrodynamics.[14]

Correspondence and conference proceedings are 'texts in action'. They are meant to capture on paper an ongoing process of communication and therefore possess a performative value. Other sources that fall into the same category and have now become very popular are pedagogical texts. The emergence of pedagogy as a site of production of scientific knowledge as well as dissemination of norms and values is arguably the most important methodological innovation of the last two decades and has been explored in a number of ways. In several papers and especially in his fascinating *Drawing Theories Apart*, David Kaiser has described how, after having raised many eyebrows among the experts, the Feynman diagrams spread throughout American physics by means of face-to-face pedagogical interactions happening at different places and stored in memories, recollections, letters and interviews. As he puts it: 'In almost every case, some form of informal personal communication -- usually of an explicitly pedagogical kind, such as an adviser mentoring graduate students, or postdocs working closely together -- can be traced behind the scene of physicists' uses of Feynman diagrams' (Kaiser 2005a, 13).[15]

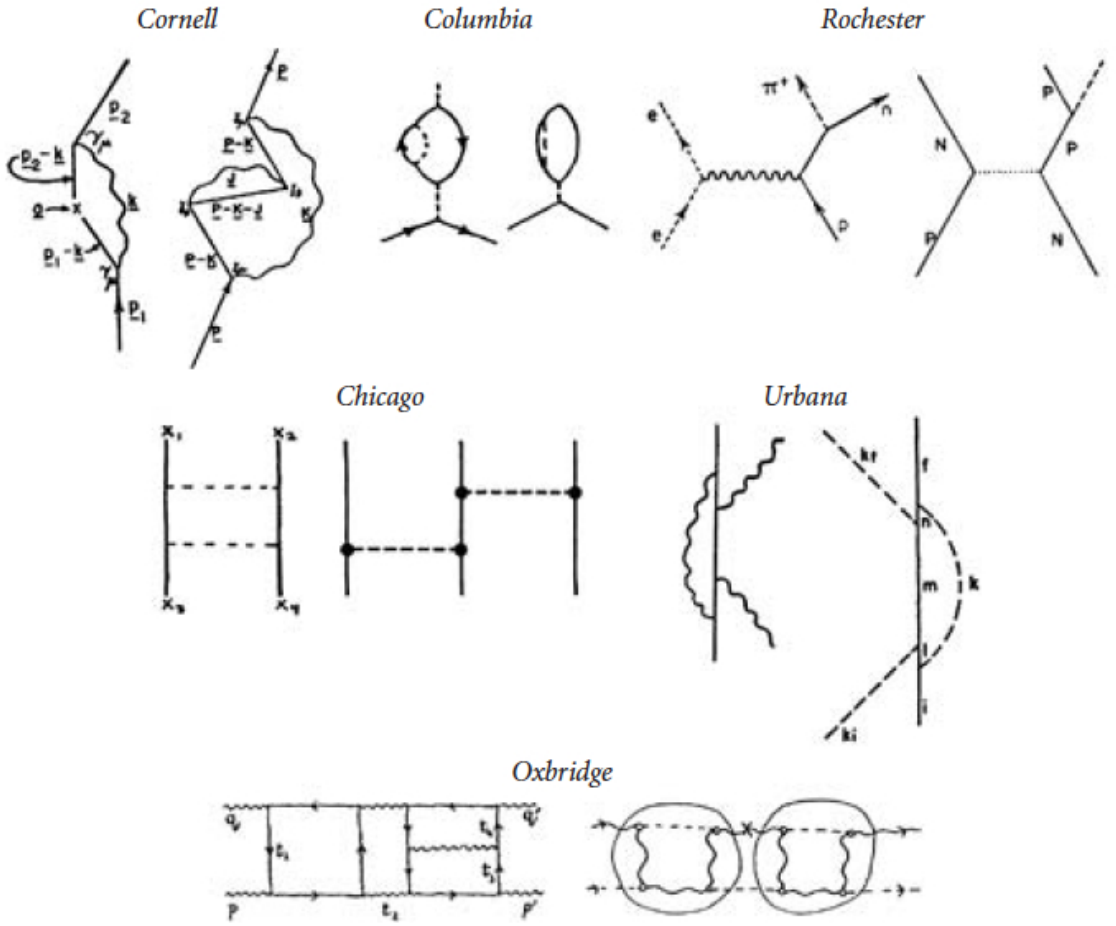


Figure 2. The power of pedagogy: different ways of drawing the Feynman diagrams in different schools (from Kaiser (2005, 21); courtesy of University of Chicago Press)

Among the pedagogical tools recently scrutinized by historians of quantum physics, textbooks deserve a special place. Two collections of essays, one edited by David Kaiser, the other edited by Jaume Navarro and myself, have assembled a battery of case studies demonstrating the multiple virtues of textbooks (Kaiser 2005b; Badino and Navarro 2013b). The latter volume focuses specifically on quantum physics from 1900 to the 1930s and shows that, *pace* Kuhn, textbooks are indeed effective historiographical resources especially when they happened to be produced in a period of scientific turmoil. For in such a period they reveal aspects of scientific activity that are often invisible in research papers, such as the dynamic interplay and integration of established knowledge and new research priorities or the personal agenda of their authors (Badino and Navarro 2013a).

NARRATIVES

I now move on to my second theme -- the narrative forms in which HQP has been recently cast. In the 1960s and 1970s, historians loved to deal with the conceptual development of quantum mechanics, as Jammer had it. That is to say, they were mainly concerned with stories about the deeds of white, male, Northern European, atomic theorists. In the last decade, almost all these restrictions have been challenged.

To begin with, the very idea of the quantum community has been enlarged considerably beyond the circle of atomic theory. To give an example, the essays in the volume I edited with Jaume Navarro have demonstrated that in the 1910s and early 1920s quantum physics was being studied and discussed by a much more rich, curious and variegated public than is commonly thought.[16] Admittedly, very few of these offbeat practitioners managed to give lasting contributions, but if we extend our perspective beyond equations and theories, we realize that this Quantum Underground, to borrow a wonderful expression by Clayton Gerhart, played a crucial role in consolidating and disseminating quantum physics in the scientific community at large.

If we want to narrow our perspective down to equations and theories, though, we may look at recent attempts to retrieve overshadowed research traditions, such as the so-called thermodynamic way to quantum mechanics. While Bohr, Sommerfeld, Kramers, Heisenberg, Pauli and the rest of the Copenhagen-Munich-Göttingen gang were racking their brains over atomic spectra and arcane numerology, other physicists were pondering the no less mysterious interplay between radiation theory and statistical mechanics, which gave rise to oddities such as indistinguishability, wave-particle duality and non-additive entropy. This train of thought, which had such reputable supporters as Planck, Einstein and Ehrenfest, paved the way to quantum statistics, Schrödinger's wave mechanics and quantum field theory, but it has kept a low profile among historians, until very recently.[17]

Not even the monopoly held by theory has escaped the questioning. Although we are accustomed to read narratives on the *theoretical* development of quantum physics, several authors have recently highlighted the role of applications and experiments not only in

backing up theories, but also in keeping disciplinary unity, fostering new questions, refining old concepts and setting new research agendas. This revamping of the interest for material culture has not been limited to classical experiments of old quantum physics (see, for instance, Gearhart 2010, 2014), but has also reached the history of solid state physics and quantum optics (Bromberg 2008; Silva and Freire Jr 2012; James and Joas 2015; Bromberg 2016).

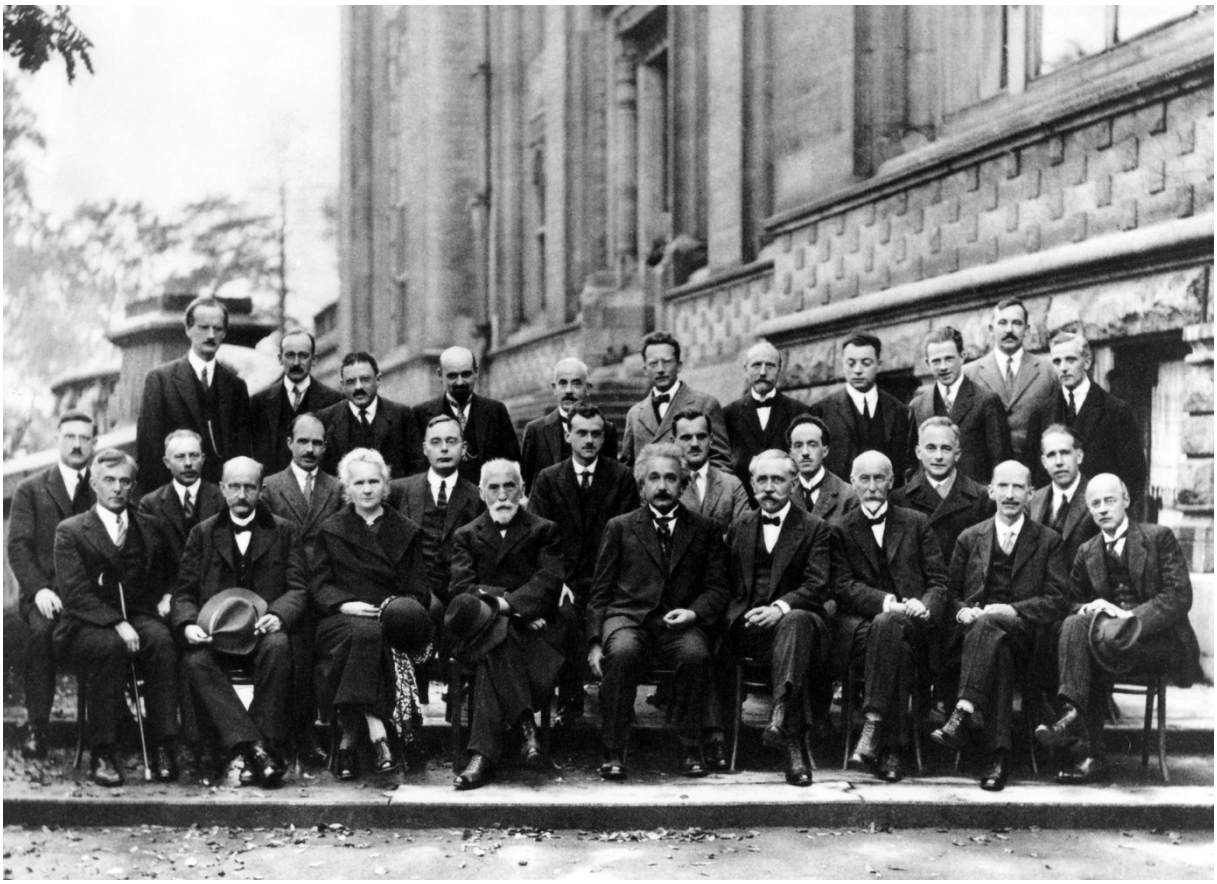
Finally, writers have moved the spotlight into the grey zones in which quantum physics blends with other disciplines/theories. I can only give two examples here, which would deserve a thorough discussion.[18] One is the much-awaited book on the emergence of quantum chemistry by Kostas Gavroglu and Ana Simoes, in which they show how physicists, chemists and mathematicians contributed with their own agendas to the construction of this in-between discipline (Gavroglu and Simões 2011).[19] The other is the exciting work on the interrelations between quantum theory and relativity, particularly quantum gravity, pioneered by Craig Callender[20] and now actively pursued by Alex Blum, Jürgen Renn, Dean Rickles and Matthias Schemmel at the MPI in Berlin.[21] By exploring the emergence of the concept of a 'Final Theory' as a purely physical-mathematical construction and how this concept affected theoretic practices and standards, this project aims at providing a long-term account of the development of contemporary physics.

Where HQP lags shamefully behind other kinds of histories -- and philosophy of science as well -- is in the incorporation of geographical and gender perspectives. There has been a reassuring increase of studies on quantum physics in European and World peripheries, such as Spain, Italy, Russia, India, China, Japan and South America, but much work still needs to be done.[22] Analogously, the narratives remain as male-dominated as the discipline as a whole. Only very recently, historians have begun to appreciate the contribution of women -- there have been, for example, some studies on Hertha Sponer (Maushart 2011), Maria Göppert-Mayer (Masters 2013) and Grete Hermann (Bacciagaluppi and Crull 2016) alongside a steady fascination for Marie Curie -- but there is still a very long way to go before justice is done.

This proliferation of stories and approaches has led to the adoption of more flexible historiographical categories such as style, research school and tradition, now part of the historian's basic weaponry. More importantly, although specialists are still mainly occupied with the quantum theory and its cognitive vicissitudes, they now understand the intellectual life of a theory in a much broader way to include social, institutional, political and cultural aspects. As a consequence, narratives have become more fine-grained and complex. Thus, Kaiser's book on Feynman diagrams focuses primarily on the evolution of a formal tool, but examining the institution of post-docs in America was essential to his argument. Or, to give another instance, although Olival Freire dives deeply into the technical and philosophical intricacies, he also claims that one cannot understand the emergence of an autonomous field of research devoted to the foundations of quantum physics without considering that most of its early practitioners were political radicals. By the same token, Alexei Kojevnikov has illuminated the multiple paths through which physics can become a political metaphor, especially in totalitarian societies.[23] In these, and other, examples one can observe a progressive hybridization of the venerable tradition of intellectual history with presuppositions, methods and argumentation techniques already used in other areas of historical research. HQP may not have become cultural, social or political through and through yet, but it is moving toward a sort of New Intellectual History. This New Intellectual History hinges on the axiom that meanings and epistemological validations do not only depend on the cognitive development of a science, but also call into action the social, political and cultural contexts in which its practitioners shape their ideas, values, norms, political preferences, pedagogical strategies and cultural priorities.

The genre most affected by this reshuffling of narrative styles is certainly biography. In the last 15 years, historians have produced plenty of biographical stories about the protagonists of the quantum revolution. Some of these accounts follow the familiar path of intellectual history. For instance, the volumes of Helge Kragh on Bohr (Kragh 2012), Charles Enz on Pauli (Enz 2002) and Michael Eckert on Sommerfeld (Eckert 2013) are excellent scientific biographies that highlight their subjects' scientific production and do not shy away from technical analysis. But two other sub-genres have emerged, which I

would call, for lack of better terms, interpretative and socio-political biographies respec-



tively.

Figure 3. Highest IQ picture ever: 17 out of 29 participants of the 1927 Solvay Conference were or would become Nobel Laureates.

In Suman Seth's work on Sommerfeld, for example, the biographic material is arranged according to a more general interpretative theme, that is the tension between the physics of problems and physics of principles (Seth 2010). He argues that, while other scientists such as Planck or Einstein, were concerned with high-level, intellectual speculations, Sommerfeld and his students loved to get their hands dirty with concrete problems. In this way, Sommerfeld's scientific life becomes the entry point into broader issues such as the value of pedagogy, the variety of research styles and different perceptions of crisis and revolution.

Examples of political biographies are Anja Jacobsen's work on Léon Rosenfeld, (Jacobsen 2007) and the two volumes on Heisenberg by Cathryn Carson (Carson 2010) and David Cassidy (Cassidy 2008).[24] In these books, the protagonists are examined in their relation with the public sphere and the role of the scientist as a player in the social and political arena. Particularly thorny is the case of Heisenberg, a conflicted man living in conflicted times. Looking at Heisenberg from slightly different angles, Cassidy and Carson manage to give masterful treatments of the complexity of scientists' positions in modern society, their political and moral predicaments, their social responsibility and, ultimately, of the cultural authority of science among policy makers and laymen.

PHILOSOPHY

I now come to my last theme, the encounters between HQP and philosophy of science. These have been encounters of several types. I said earlier that quantum physics went historical very soon after its acceptance as a distinct field of research, but in fact it went philosophical even sooner. Already in the late 1920s, it was clear that quantum mechanics entailed a number of odd epistemological and metaphysical consequences and that some of its solutions were, at times, even more puzzling than the original problems. First Bohr and later Heisenberg explicitly tied the Copenhagen Interpretation with philosophical positivism, although Mara Beller and others have claimed that this was shrewder propaganda than genuine philosophical commitment. Be that as it may, quantum physics has been a powerful magnet for philosophers right from its inception.

However, the relation between history and philosophy in this particular case has been even more troublesome than usual. Part of the reason lies in the fact that the philosophy of quantum physics was immediately colonized by logical positivism, an intellectual movement famously indifferent, if not overtly hostile, to history and contextualization. As a consequence, history and philosophy remained sharply and blissfully separated.

Contrary to what one might expect, when logical positivism began to lose its grip, things did not get any better. Instead, they worsened. The work of Kuhn, Hanson and Feyerabend provided historians with a more flexible methodological vocabulary, which, however, seldom matched that of their philosophical colleagues. One telling example is the

term ‘theory’. Much philosophical work assumes theories to be well-defined units of analysis, but historians have grown increasingly skeptical that such a thing exists in science. David Kaiser put it best when he wrote:

> Try as we might, we will never come across a “theory” in the flotsam and jetsam of our sources -- and thus we should be wary of letting the categories of “theory construction and selection” direct our historical analysis. Instead, when we inspect the materials with which theoretical physicists have worked, night and day, we see tinkering and appropriation of paper tools -- tools fashioned, calculations made, approximations clarified, results compared with data, interpretations advanced, analogies extended to other types of calculations or phenomena and so on. “Theories” do not appear, nor is it clear where they might even be found. (Kaiser 2005a, 377)

The evaporation of the traditional notion of a theory has made it difficult to keep the conversation flowing between historians and philosophers. One option recently explored has been to shift the unit of analysis toward the concept of ‘practices’. Rendered in terms of how scientists manipulate symbols, solve equations, represent results, interpret charts and, to put it briefly, do things on paper and in the lab, epistemology and metaphysics become historically and culturally situated and still maintain their conceptual cogency. In my own work on Planck, for instance, I have abandoned the usual distinction between classical and quantum theory of radiation to zoom in on how Planck used formal resources such as the Fourier series to shape his own view of the electromagnetic field (Badino 2015).

Other writers have tried to bring historians and philosophers around the same table by re-assessing the philosophical positions of the protagonists of the quantum revolution with the help of substantial historical research. This has been the strategy followed by Alisa Bokulich in her study on the classical/quantum divide (Bokulich 2008) and by Kristian Camilleri in his book on Heisenberg’s interpretations of quantum mechanics (Camilleri 2009b). Both authors have effectively demonstrated that this approach can help reveal the bearing of philosophical thought on historiographical research.[25]

These efforts to foster a profitable dialogue between history and philosophy of science resonate with recent endeavors to establish more robust international platforms where such a dialogue can take place. Through a series of biannual conferences and special issues in academic journals, the Society of Philosophy of Science in Practice (SPSP) and the Integrated History and Philosophy of Science Network (&HPS) have contributed enormously to the development of new theoretical frameworks in which both historical and philosophical work can fruitfully cooperate.[26] Judging from the start, the prospects of these approaches are bright. On the one hand, philosophers interested in scientific practices have benefitted from the abundance of historical material, first-hand accounts and scholarly reconstruction accumulated by the specialists over the past decades, on the other, historians have realized that philosophy is not only confined to the lofty foundational issues, but also the epistemological and ontological presuppositions of specific practices can be historiographically relevant.

WHAT HAVE THE HISTORIANS OF QUANTUM PHYSICS EVER DONE FOR US?

In coming to the conclusion of this article, I want to come back to my initial 'Montypythonian' question. Let's assume that you grant me all the points I have made so far. Still, you may legitimately be unsatisfied. Apart from expanding the notion of historical sources, looking at them in a different way, deepening our understanding of patterns and connections, appropriating methods and techniques from cultural history, adding a social and political dimension to the topic, developing the genre of biography, improving the interface with philosophy, what have the historians of quantum physics ever done for us?

Let me tackle this question from a broader angle. In the last decade, a hot debate has been stirring the usually sleepy world of academic history. We can dub it the *longue durée* affair. The peak of this affair was reached two years ago when Jo Guldi and David Armitage published their controversial *History Manifesto* (Guldi and Armitage 2014). In the book, Guldi and Armitage argued vigorously against the tendency to balkanize history and favor microscopic, short-term studies over long-term analyses. They went so far as to claim that, in this way, historians are abdicating their role as intellectual guides of society and are relinquishing any chance to act as a reforming force in political life.

Historians of science, who have been busy with this issue at least since the early 1990s,[27] reacted quickly to Guldi and Armitage's provocation, but with a characteristic twist. For many of us, the trouble with microhistory is not only about the narrowing of the time span, but also the overspecialization of some studies or, to put it differently, what I would call the 'verticalization' of the discipline. More experienced scholars than myself have already warned against archival fetishism, self-reference and hyperlocalization, to mention just a few of the symptoms of 'short-termism'. We do not need to abandon the tool of the case study, but we probably need to make it less vertical and more exportable. As Robert Kohler wrote, 'we just need to do what we do as specialists in a way that invites comparisons and synthesis, interests other specialists, and eases the labors of those rare comparatists and synthesizers'.

As a highly technical field of study, history of science is at the same time more prone to and more deeply affected by this problem. So it might at first sound paradoxical that one should look to HQP, a dauntingly technical discipline itself, for any sensible suggestion. But, in fact, I see the recent developments in this historiography evolving toward a more user-friendly and comparative approach. As we saw earlier, historians of quantum physics have progressively reconfigured the tradition of intellectual history to embrace research techniques and styles of argumentation derived from cultural and social history. It is important to appreciate that the technical aspects of quantum theory are still pivotal, but the very idea of what is theoretical knowledge and what can determine its evolution has been definitely enlarged. The use of pedagogy as a historiographical category is the most conspicuous example of how to combine technical details and larger context. This New Intellectual History, as I called it earlier, relies on a broader definition of the intellectual life of a theory and encourages analyses of the process of knowledge production from multiple angles and with multiple narratives.[28] In other words, it is precisely the ability to build on an imposing tradition of very technical analysis and to combine it with concepts and methods of cultural and social history, that qualifies HQP as an interlocutor not only for other fellow historians, but also sociologists, cultural theorists and, why not, the general public. Thus, when seen in synoptic perspective, HQP appears as a conceptual laboratory where the science of the working scientist is put in conversation with the science of the cultural historian and where new and exportable methods are

being elaborated to deal with an otherwise very technical topic. I truly believe that what is happening right now in HQP could be beneficial for history as a whole and that historians of science should be keeping a watchful eye on it.

ACKNOWLEDGEMENTS

The research for this paper has been supported by the Marie Sklodowska-Curie Actions, grant no. PIOF-GA-2013-623436. I am indebted to Alexander Blum, Olival Freire Jr., David Kaiser, Christoph Lehner, Jaume Navarro, Fedra Alessandra Pizzato, Jürgen Renn, Aaron Wright, and two anonymous referees for having improved the quality of the paper through discussions, suggestions and criticisms.

Bibliography

Aaserud, Finn. 1990. Redirecting Science: Niels Bohr, Philanthropy, and the Rise of Nuclear Physics. Cambridge: Cambridge University Press.

Ankeny, Rachel, Hasok Chang, Marcel Boumans, and Mieke Boon. 2011. "Introduction: Philosophy of Science in Practice." *European Journal for Philosophy of Science* no. 1 (3):303-307. doi: 10.1007/s13194-011-0036-4.

Arabatzis, Theodore, and Don Howard. 2015. "Introduction: Integrated History and Philosophy of Science in Practice." *Studies in History and Philosophy of Science* no. 50:1-3.

Arabatzis, Theodore, and Jutta Schickore. 2012. "Introduction: Ways of Integrating History and Philosophy of Science." *Perspectives on Science* no. 20 (4):395-408.

Armitage, David, and Jo Guldi. 2016. "Longing for the Longue Durée." *Isis* no. 107 (353-357).

Bacciagaluppi, Guido, and Elise Crull. 2016. Grete Hermann — Between Physics and Philosophy. New York: Springer.

Bacciagaluppi, Guido, and Antony Valentini. 2009. Quantum Theory at the Crossroads: Reconsidering the 1927 Solvay Conference. Cambridge: Cambridge University Press.

Badino, Massimiliano. 2009. "The Odd Couple: Boltzmann, Planck and the Application of Statistics to Physics (1900-1913)." *Annalen der Physik* no. 18:81-101.

———. 2010. "Das Verfolgen einer Idee: Plancks Theorie idealer Gase." In *Max Planck und die Moderne Physik*, edited by Dieter Hoffmann, 135-148. Berlin: Springer.

———. 2012. "Productive Conservatism: Planck's Second Theory of Radiation." *Annalen der Physik* no. 524:A29-A31.

———. 2013. "Dissolving the Boundaries between Research and Pedagogy: Otto Sackur's Lehrbuch der Thermochemie und Thermodynamik." In *Research and Pedagogy. A History of Quantum Physics through its Textbooks*, edited by Massimiliano Badino and Jaume Navarro, 81-99. Berlin: Edition Open Access.

———. 2015. The Bumpy Road: Max Planck from Radiation Theory to the Quantum (1896-1906). New York: Springer.

Badino, Massimiliano, and Bretislav Friedrich. 2013. "Much Polyphony but Little Harmony: Otto Sackur's Groping for a Quantum Theory of Gases." *Physics in Perspective* no. 15:295-319.

Badino, Massimiliano, and Jaume Navarro. 2013a. "Pedagogy and Research. Notes for a Historical Epistemology of Science Education." In *Research and Pedagogy: A History of Quantum Theory through its Textbooks*, edited by Massimiliano Badino and Jaume Navarro. Berlin: Edition Open Access.

———. 2013b. Research and Pedagogy. A History of Quantum Physics through its Textbooks. Berlin: Edition Open Access.

Banerjee, Somaditya. 2014. "C. V. Raman and Colonial Physics: Acoustics and the Quantum." *Physics in Perspective* no. 16:146-178.

———. 2016. "Transnational Quantum: Quantum Physics in India through the Lens of Satyendranath Bose." *Physics in Perspective* no. 18:157-181.

Behrens, Carl E. 1943a. "Atomic Theory from 1904 to 1913." *American Journal of Physics* no. 11:60-66.

———. 1943b. "The Early Development of the Bohr Theory." *American Journal of Physics* no. 11:135-147.

———. 1943c. "Further Developments of Bohr's Early Atomic Theory." *American Journal of Physics* no. 11:272-281.

Beller, Mara. 1999. Quantum Dialogue: The Making of a Revolution. Chicago: University of Chicago Press.

Blight, Neville Melton. 1923. The Evolution and Development of the Quantum Theory. London: Arnold.

Blum, Alexander S. 2015. "QED and the Man Who Didn't Make It: Sidney Dancoff and the Infrared Divergence." *Studies in History and Philosophy of Modern Physics* no. 50:70-94.

Blum, Alexander S., and Christian Joas. 2016. "From Dressed Electrons to Quasiparticles: The Emergence of Emergent Entities in Quantum Field Theory." *Studies in History and Philosophy of Modern Physics* no. 53:1-8.

Blum, Alexander S., Jürgen Renn, Dean Rickles, and Don Salisbury. 2016. *Quantum Gravity in the First Half of the 20th Century: A Sourcebook*. Berlin: Edition Open Access.

Bokulich, Alisa. 2008. Reexamining the Quantum-Classical Relation. Beyond Reductionism and Pluralism. Cambridge: Cambridge University Press.

Bromberg, Joan Lisa. 2008. "New Instruments and the Meaning of Quantum Mechanics." *Historical Studies in the Physical Sciences* no. 38:325-352.

———. 2016. "Explaining the Laser's Light: Classical Versus Quantum Electrodynamics in the 1960s." *Archive for History of Exact Science* no. 70:243-266.

Brush, Stepher G. 2007. "How Ideas Became Knowledge: The Light-Quantum Hypothesis 1905-1935." *Historical Studies in the Physical Sciences* no. 37:205-246.

Büttner, Jochen, Jürgen Renn, and Matthias Schemmel. 2003. "Exploring the Limits of Classical Physics: Planck, Einstein, and the Structure of a Scientific Revolution." *Studies in History and Philosophy of Modern Physics* no. 34:37-59.

Callender, Craig, and Nick Huggett. 2001. Physics Meets Philosophy at the Planck Scale: Contemporary Theories in Quantum Gravity. Cambridge: Cambridge University Press.

Camilleri, Kristian. 2007. "Bohr, Heisenberg and the Divergent Views of Complementarity." *Studies in History and Philosophy of Modern Physics* no. 38:514-528.

———. 2009a. "Constructing the Myth of the Copenhagen Interpretation." *Perspectives on Science* no. 17:26-57.

———. 2009b. Kristian Camilleri: Heisenberg and the Interpretation of Quantum Mechanics—The Physicist as Philosopher. Cambridge: Cambridge University Press.

Camilleri, Kristian, and Maximilian Schlosshauer. 2015. "Niels Bohr as Philosopher of Experiment: Does Decoherence Theory Challenge Bohr's Doctrine of Classical Concepts." *Studies in History and Philosophy of Modern Physics* no. 49:73-83.

Carson, Cathryn. 2010. Heisenberg in the Atomic Age: Science and the Public Sphere. Cambridge: Cambridge University Press.

Cassidy, David C. 2008. Beyond Uncertainty: Heisenberg, Quantum Physics, and the Bomb. New York: Bellevue Literary Press.

Chemla, Karine. 2016. "Reading The History Manifesto as a Historian of Mathematics in Ancient China." *Isis* no. 107:324-333.

Chwolson, Orest D. 1927. *Die Physik 1914-1926*. Brauschweig: Vieweg.

Crowther, Karen, and Dean Rickles. 2014. "Introduction: Principles of Quantum Gravity." *Studies in History and Philosophy of Modern Physics* no. 46:135-141.

Darrigol, Olivier. 1986. "The Origin of Quantized Matter Waves." *Historical Studies in the Physical Sciences* no. 16:197-253.

———. 1988. "Statistics and Combinatorics in Early Quantum Theory." *Historical Studies in the Physical Sciences* no. 19:17-80.

———. 1991. "Statistics and Combinatorics in Early Quantum Theory, II: Early Symptoma of Indistinguishability and Holism." *Historical Studies in the Physical Sciences* no. 21:237-298.

———. 1992. From c-Numbers to q-Numbers: The Classical Analogy in the History of Quantum Theory. Berkeley: University of California Press.

———. 2002. "Quantum Theory and Atomic Structure, 1900-1927." In *The Cambridge History of Science*, edited by Mary Jo Nye, 331-349. Cambridge: Cambridge University Press.

de Chaderevian, Soraya. 2009. "Microstudies versus Big Picture Accounts?" *Studies in History and Philosophy of Biological and Biomedical Sciences* no. 40:13-19.

Desalvo, Agostino. 1992. "From the Chemical Constant to Quantum Statistics: A Thermodynamic Route to Quantum Mechanics." *Physis* no. 29:465-537.

Duncan, Anthony, and Michel Janssen. 2007a. "On the Verge of Umdeutung in Minnesota: Van Vleck and the Correspondence Principle. Part One." *Archive for the History of Exact Science* no. 61:553-624.

———. 2007b. "On the Verge of Umdeutung in Minnesota: Van Vleck and the Correspondence Principle. Part Two." *Archive for the History of Exact Science* no. 61:625-671.

———. 2008. "Pascual Jordan's Resolution of the Conundrum of the Wave-Particle Duality of Light." *Studies in History and Philosophy of Modern Physics* no. 39:634-666.

———. 2014. "The Trouble with Orbits: The Stark Effect in the Old and the New Quantum Theory." *Studies in History and Philosophy of Modern Physics* no. 48:68-83.

Eckert, Michael. 2013. Arnold Sommerfeld: Science, Life and Turbulent Times 1868-1951. Berlin: Springer.

———. 2015. "From Aether Impulse to QED: Sommerfeld and the Bremsstrahlen Theory." *Studies in History and Philosophy of Modern Physics* no. 51:9-22.

Enz, Charles P. 2002. No Time to be Brief: A Scientific Biography of Wolfgang Pauli. Oxford: Oxford University Press.

Findlen, Paula. 2005. "The Two Cultures of Scholarship." *Isis* no. 96:230-237.

Forman, Paul. 1968. "The Double Riddle and Atomic Physics c. 1924." *Isis* no. 59:156-174.

———. 1971. "Weimar Culture, Causality, and Quantum Theory, 1918-1927: Adaptation by German Physicists and Mathematicians to a Hostile Intellectual Environment." *Historical Studies in the Natural Sciences* no. 3:1-115.

Freire Jr, Olival. 2015. The Quantum Dissidents. Rebuilding the Foundations of Quantum Mechanics (1950-1990). Berlin: Springer.

Freire Jr, Olival, Osvaldo Pessoa Jr., and Joan Lisa Bromberg. 2011. *Teoria quântica: estudos históricos e implicações culturais*. Salvador: EDUEPB.

Galison, Peter. 1997. Image and Logic: A Material Culture of Microphysics. Chicago: University of Chicago Press.

Galison, Peter, and Andrew Warwck. 1998. "Introduction: Cultures of Theory." *Studies in History and Philosophy of Modern Physics* no. 29 (3):287-294.

Gavroglu, Kostas, and Ana Simões. 2011. Neither Physics Nor Chemistry: A History of Quantum Chemistry. Cambridge, MA: MIT Press.

Gearhart, Clayton A. 2002. "Planck, the Quantum, and the Historians." *Physics in Perspective* no. 4:170-215.

———. 2010. ""Astonishing Successes" and "Bitter Disappointment": The Specific Heat of Hydrogen in Quantum Theory." *Archive for History of Exact Science* no. 64:113-202.

———. 2013. "Fritz Reiche's 1921 Quantum Theory Textbook." In *Research and Pedagogy. A History of Quantum Physics through its Textbooks*, edited by Massimiliano Badino and Jaume Navarro, 101-116. Berlin: Edition Open Access.

———. 2014. "The Franck-Hertz Experiments, 1911–1914 Experimentalists in Search of a Theory." *Physics in Perspective* no. 16:293-343.

Greenspan, Nancy T. 2005. The End of the Certain World: The Life and Science of Max Born. New York: Basic Books.

Gross, Ari. 2012. "Pictures and Pedagogy: The Role of Diagrams in Feynman's Early Lectures." *Studies in History and Philosophy of Modern Physics* no. 43:184-194.

Guldi, Jo, and David Armitage. 2014. *The History Manifesto*. Cambridge: Cambridge University Press.

Hakfoort, Casper. 1991. "The Missing Syntheses in the Historiography of Science." *History of Science* no. 29:207-216.

Hanle, Paul A. 1977. "The Coming of Age of Erwin Schrödinger: His Quantum Statistics of Ideal Gas." *Archive for History of Exact Science* no. 17:165-192.

Hartz, Thiago, and Olival Freire Jr. 2015. "Uses and Appropriations of Niel Bohr's Ideas About Quantum Field Measurement, 1930-1965." *Scientia Danica. Series M, Mathematica et Physica* no. 1:397-418.

Heilbron, John. 1964. A History of the Problem of Atomic Structure from the Discovery of the Electron to the Beginnings of Quantum Mechanics, University of California, Berkeley.

———. 1967. "The Kossel-Sommerfeld Theory and the Ring Atom." *Isis* no. 58:336-364.

———. 1968. "Quantum Historiography and the Archive for History of Quantum Physics." *History of Science* no. 7 (1):90-111.

———. 2016. "Are Historians Fit to Rule?" *Isis* no. 107 (350-352).

Heilbron, John, and Thomas S. Kuhn. 1969. "The Genesis of Bohr's Atom." *Historical Studies in the Physical Sciences* no. 1:211-290.

Hermann, Armin. 1962. Dokumente der Naturwissenschaften. Abteilung Physik. Stuttgart: Battenberg.

———. 1965. "Arthur Erich Haas und die erste Quantenansatz für das Atom." *Sudhoffs Archiv* no. 49:255-268.

———. 1968. "Die frühe Diskussion zwischen Stark und Sommerfeld über die Quantenhypothese." *Centaurus* no. 12:38-59.

Hirosige, Tetu, and Sigeo Nisio. 1964. "Foundation of Bohr's Theory of Atomic Constitution." *Japanese Studies in the History of Science* no. 3:1-28.

Hoffmann, Dieter. 2008. Max Planck: Die Entstehung der modernen Physik. Munich: C. H. Beck.

Holmes, Frederick L. 2003. "The Longue Durée in the HIstory of Science." *Historical Studies in the Physical Sciences* no. 25:463-470.

Holton, Gerard. 1973. Thematic Origins of Scientific Thought: Kepler to Einstein. Cambridge, MA: Harvard University Press.

Hund, Friedrich. 1967. *Geschicthe der Quantentheorie*. Mannheim: Bibliographisches Institut.

Ito, Kenji. 2002. Making Sense of Ryoshiron (Quantum Theory): Introduction of Quantum Physics into Japan 1920-1940, Harvard University.

———. 2013. "Superposing Dynamos and Electrons: Electrical Engineering and Quantum Physics in the Case of Nishina Yoshio." In *Traditions and Transformations in the History of Quantum Physics*, edited by Shaul Katzir, Christoph Lehner and Jürgen Renn, 183-208. Berlin: Edition Open Access.

Jacobsen, Anja. 2007. "Leon Rosenfeld's Marxist Defense of Complementarity." *Historical Studies in the Physical Sciences* no. 37:3-34.

James, Jeremiah, and Christian Joas. 2015. "Subsequent and Subsidiary? Rethinking the Role of Applications in Establishing Quantum Mechanics." *Historical Studies in the Physical Sciences* no. 45:641-702.

Jammer, Max. 1966. The Conceptual Development of Quantum Mechanics. New York: McGraw-Hill.

Joaquim, Leyla, Olival Freire Jr, and Charbel N. El-Hani. 2015. "Quantum Explorers: Bohr, Jordan, and Delbrück Venturing into Biology." *Physics in Perspective* no. 17:236-250.

Joas, Christian, and Christoph Lehner. 2009. "The Classical Roots of Wave Mechanics: Schrödinger's Transformations of the Optical-mechanical Analogy." *Studies in History and Philosophy of Modern Physics* no. 40:338-351.

Jordi Taltavull, Marta. 2016. "Transmitting Knowledge across Divides: Optical Dispersion from Classical to Quantum Physics." *Historical Studies in the Physical Sciences* no. 46:313-359.

Kaiser, David. 2002. "Nuclear Democracy: Political Engagement, Pedagogical Reform, and Particle Physics in Postwar America." *Isis* no. 93:229-268.

———. 2005a. Drawing Theories Apart. The Dispersion of Feyman Diagrams in Postwar Physics. Chicago: University of Chicago Press.

———. 2005b. Pedagogy and the Practice of Science. Historical and Contemporary Perspectives. Cambridge, MA: MIT Press.

———. 2005c. "Training and the Generalist's Vision in the History of Science." *Isis* no. 96:244-251.

———. 2011. How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival. New York: W. W. Norton.

Kaiser, David, Kenji Ito, and Karl Hall. 2004. "Spreading the Tools of Theory: Feynman Diagrams in the USA, Japan, and the Soviet Union." *Social Studies of Science* no. 34:879-922.

Katzir, Shaul, Christoph Lehner, and Jürgen Renn. 2013. Traditions and Transformations in the History of Quantum Physics. Berlin: Edition Open Access.

Klein, Martin J. 1962. "Max Planck and the Beginnings of the Quantum Theory." *Archive for the History of Exact Science* no. 1:459-479.

———. 1963. "Planck, Entropy and Quanta, 1901-1906." *Natural Philosopher* no. 1:82-108.

———. 1964. "Einstein and the Wave-Particle Duality." *Natural Philosopher* no. 3:3-49.

———. 1965. "Einstein, Specific Heats, and the Early Quantum Theory." *Science* no. 148:173-180.

———. 1967. "Thermodynamics in Einstein's Thought." *Science* no. 157:509-516.

———. 1970. Paul Ehrenfest. Vol. 1: The Making of a Theoretical Physicist. Amsterdam: North-Holland.

Kohler, Robert E. 2005. "A Generalist's Vision." *Isis* no. 96:224-229.

Kojevnikov, Alexei. 1999. "Freedom, Collectivism, and Quasiparticles: Social Metaphors in Quantum Physics." *Historical Studies in the Physical Sciences* no. 29:295-331.

———. 2004. Stalin's Great Science: The Times and Adventures of Soviet Physicists. London: Imperial College Press.

———. 2011. "Philosophical Rhetoric in Early Quantum Mechanics, 1925-1927: High Principles, Cultural Values, and Professional Anxieties." In *Weimar Culture and Quantum Mechanics*, edited by Cathryn Carson, Alexei Kojevnikov and Helmut Trischler, 319-348. London: Imperial College Press.

———. 2012. "Probability, Marxism, and Quantum Ensembles." *Yearbook of the European Culture of Science*:211-235.

Kox, Anne J. 2013. "Hendrik Antoon Lorentz's Struggle with Quantum Theory." *Archive for History of Exact Science* no. 67:149-170.

Kragh, Helge. 2012. *Niels Bohr and the Quantum Atom*. Oxford: Oxford University Press.

Kuhn, Thomas S. 1978. Black-Body Theory and the Quantum Discontinuity, 1894-1912. Oxford: Oxford University Press.

Lacki, Jan. 2000. "The Early Axiomatizations of Quantum Mechanics: Jordan, von Neumann and the Continuation of Hilbert's Program." *Archive for History of Exact Science* no. 54:279-318.

———. 2004. "The Puzzle of Canonical Transformations in Early Quantum Mechanics." *Studies in History and Philosophy of Modern Physics* no. 35:317-344.

Livingstone, David N. 2003. Putting Science in Its Place. Geographies of Scientific Knowledge. Chicago: University of Chicago Press.

Masters, Barry R. 2013. "The Origins of Maria Göppert's Dissertation on Two-Photon Quantum Transitions at Göttingen's Institutes of Physics 1920-1933." In *Traditions and Transformations in the History of Quantum Physics*, edited by Shaul Katzir, Christoph Lehner and Jürgen Renn, 209-230. Berlin: Edition Open Access.

Maushart, Marie-Ann Maushart. 2011. Hertha Sponer: A Woman's Life as a Physicist in the 20th Century, "So You Won't Forget Me". Durham, NC: Duke University Press.

McCormmach, Russell. 1966. "The Atomic Theory of John William Nicholson." *Archive for the History of Exact Science* no. 2:160-184.

———. 1967. "Henri Poincaré and the Quantum Theory." *Isis* no. 58:37-55.

Mehra, Jagdish, and Kimball Milton. 2003. Climbing the Mountain: The Scientific Biography of Julian Schwinger. Oxford: Oxford University Press.

Mehra, Jagdish, and Helmut Rechenberg. 1982-2001. *The Historical Development of Quantum Theory*. 6 vols. New York: Springer.

Monaldi, Daniela. 2009. "A Note on the Prehistory of Indistinguishable Particles." *Studies in History and Philosophy of Modern Physics* no. 40:383-394.

———. 2013. "Early Interactions of Quantum Statistics and Quantum Mechanics." In *Traditions and Transformations in the History of Quantum Physics*, edited by Shaul Katzir, Christoph Lehner and Jürgen Renn, 125-147. Berlin: Edition Open Access.

Monk, Ray. 2013. Robert Oppenheimer: His Life and Mind. New York: Random House.

Navarro, Jaume. 2013. "Teaching Quantum Physics in Cambridge: George Birtwistle and His Two Textbooks." In *Research and Pedagogy. A History of Quantum Physics through its Textbooks*, edited by Massimiliano Badino and Jaume Navarro, 231-247. Berlin: Edition Open Access.

Nisio, Sigeo. 1966. "From Balmer to the Combination Principle." *Japanese Studies in the History of Science* no. 5:50-74.

———. 1967. "The Role of the Chemical Consideration in the Development of Bohr's Atomic Theory." *Japanese Studies in the History of Science* no. 6:26-40.

Oreskes, Naomi. 2016. "Let's Make History More Welcoming." *Isis* no. 107:348-350.

Park, Buhm Soon. 2009. "Between Accuracy and Manageability: Computational Imperative in Quantum Chemistry." *Historical Studies in the Physical Sciences* no. 39:32-62.

Pérez, Enric. 2009. "Ehrenfest's Adiabatic Theory and the Old Quantum Theory, 1916–1918." *Archive for History of Exact Science* no. 63:81-125.

Pérez, Enric, and Tilman Sauer. 2010. "Einstein's Quantum Theory of the Monatomic Ideal Gas: Non-Statistical Arguments for a New Statistics." *Archive for History of Exact Science* no. 64:561-612.

Perovic, Slobodan. 2006. "Schrödinger's Interpretation of Quantum Mechanics and the Relevance of Bohr's Experimental Critique." *Studies in History and Philosophy of Modern Physics* no. 37:275-297.

Reiche, Fritz. 1922. Die Quantentheorie: Ihr Ursprung und ihre Entwicklung. Berlin: Springer.

Rickles, Dean, and Alexander S. Blum. 2015. "Paul Weiss and the Genesis of Canonical Quantization." *European Physical Journal H* no. 40:469-487.

Rickles, Dean, Steven French, and Juha Saatsi. 2007. *The Structural Foundations of Quantum Gravity*. Oxford: Clarendon Press.

Romano, Antonella. 2016. "The History Manifesto, History of Sceince and Big Narratives: Some Pending Questions." *Isis* no. 107:338-340.

Rosenberg, Charles. 1987. "Editorial: Isis at Seventy-Five." *Isis* no. 78:515-517.

Rosenfeld, Leon. 1936. "La première phase de l'évolution de la théorie des quanta." *Osiris* no. 2:149-196.

———. 1958. "Max Planck et la définition statistique de l'entropie." In *Max Planck Festschrift*, edited by Bernhard Kockel, Wilhelm Macke and Achilles Papapetrou, 203-211. Berlin: Deutscher Verlag der Wissenschaften.

Rubinowicz, Adalbert. 1933. "Ursprung und Entwicklung der älteren Quantentheorie." In *Handbuch der Physik*, 1-82. Berlin: Springer.

Schweber, Silvan S. 1994. QED and the Men Who Made It: Dyson, Feynman, Schwinger, and Tomonaga. Princeton, NJ: Princeton University Press.

———. 2015. "Hacking the Quantum Revolution: 1925-1975." *European Physical Journal H* no. 40:53-149.

Secord, James. 1995. "Introduction." British Journal for the History of Science no. 26 (387-390).

Seth, Suman. 2010. Crafting the Quantum: Arnold Sommerfeld and the Practice of Theory. Cambridge, MA: MIT Press.

Shapin, Steven. 2005. "Hyperprofessionalization and the Crisis of Readership in the HIstory of Science." *Isis* no. 96:238-243.

Silva, Indianara, and Olival Freire Jr. 2012. "The Concept of the Photon in Question: The Controversy Surrounding the HBT Efffect circa 1956-1958." *Historical Studies in the Physical Sciences* no. 43:453-491.

Singh, Rajinder. 2002. "C. V. Raman and the Discovery of the Raman Effect." *Physics in Perspective* no. 4:399-420.

Sopka, Katherine. 1988. Quantum Physics in America: The Years Through 1935. New York: American Institute of Physics.

Staley, Richard. 2013. "Trajectories in the History and Historiography of Physics in the Twentieth Century." *History of Science* no. 51 (2):151-177.

ter Haar, Dirk. 1967. *The Old Quantum Theory*. London: Dover.

van der Waerden, Bas L. 1967. *Sources of Quantum Mechanics*. Amsterdam: North Holland.

Von Reichenbach, Maria Cecilia. 2009. "Richard Gans: The First Quantum Physicist in Latin America." *Physics in Perspective* no. 11:302-317.

Warner, John Harley. 2004. "Grand Narrative and Its Discontents: Medical History and the Social Transformation of American Medicine." *Journal of Health Politics, Policy, and Law* no. 29:757-880.

Wolf, Johanna. 2014. "Heisenberg's Observability Principle." *Studies in History and Philosophy of Modern Physics* no. 45:19-26.

Wright, Aaron Sidney. 2016. "A Beautiful Sea: P. A. M. Dirac's Epistemology and Ontology of the Vacuum." *Annals of Science* no. 73:225-256.

Wüthrich, Adrian. 2011. The Genesis of Feynman Diagrams. New York: Springer.

Zinkermagel, Henrik. 2016. "Niels Bohr on the Wave Function and the Classical/Quantum Divide." *Studies in History and Philosophy of Modern Physics* no. 53:9-19.

---

[1] Reviewing their own production seems to be a recurring preoccupation of historians of physics. For earlier examples see (Heilbron 1968; Staley 2013).

[2] Let me add a word of caution. The scholarly production in HQP has been disseminated via an ever-growing variety of avenues in the last 15 years. It would be hopeless to map all the papers, journals, proceedings, books, collections, online publications and magazines about the topic, so I have chosen to confine myself to the main and more accessible journals. The bibliographical references in the following pages are meant to give a sense of the various tendencies in HQP and should not be taken as an exhaustive list.

[3] See especially (Rosenfeld 1936, 1958); other remarkable examples are (Reiche 1922), (Blight 1923), (Chwolson 1927), and (Rubinowicz 1933). Working physicists contributed extensively to the history of their own topic also later, see e.g., (Hund 1967), (ter Haar 1967), and (van der Waerden 1967).

[4] There were historical studies as early as the 1940s, such as Carl Behrens' work on the development of atomic theory (Behrens 1943a, 1943c, 1943b). Interestingly, one can find a large number of biographies and collections of papers (e.g., volumes dedicated to Planck, Ehrenfest, Debye and Kramers among others) published in the 1950s, an essential preparatory work for the boom in the 1960s. For an extensive bibliography see (Heilbron 1968).

[5] See (Heilbron and Kuhn 1969), (Kuhn 1978), (Heilbron 1964, 1967), (Forman 1968), (McCormmach 1966, 1967), (Klein 1962, 1963, 1964, 1965, 1967, 1970). HQP was not a purely American research field: Armin Hermann in Germany (Hermann 1962, 1965, 1968) and Tetu Hirosige and Sigeo Nisio in Japan (Hirosige and Nisio 1964), (Nisio 1966, 1967) also importantly contributed to the early phase of the discipline.

[6] Although often criticized, one cannot avoid mentioning the monumental multi-volume work of Jadgish Mehra and Helmut Rechenberg (Mehra and Rechenberg 1982-2001). One distinctive trait of the research in HQP during the 1980s and 1990s is that it expanded the scope to include systematically the early days of quantum mechanics and the emergence of quantum electrodynamics. Olivier Darrigol (Darrigol 1986, 1988, 1991, 1992) and Sam Schweber (Schweber 1994) were among the pioneers of this new wave of HQP.

[7] To be sure, Gerard Holton's and, especially, Paul Forman's explorations of the intersections between physics and culture date back to the early 1970s (Forman 1971; Holton 1973), although they were only intermittently followed along this path of research. In the ensuing decade, Finn

Aaserud's work on Bohr's activity as a science manager is also worth mentioning (Aaserud 1990).

[8] Not by chance, an important exception was precisely Galison's work during the 1990s (Galison 1997).

[9] The digitalization of the AHQP has been only one the outcomes of the Quantum History Project, arguably the largest research endeavor in HQP of the last 15 years. It has been carried out as an innovative joint project with the Fritz Haber Institute and has involved several in-house historians, philosophers and working physicists as well as a vast network worldwide. The output of the project is massive, consisting in three conferences (in Berlin 2007, Utrecht 2008, and Berlin 2010), plus a recent follow-up conference (San Sebastian 2015), two doctoral dissertations, and countless publications some of which will be mentioned in the following sections. Representative samples of the scholarship produced by this project are the special issue of *Studies in History and Philosophy of Modern Physics* (volume 40, issue 4, 2009) on the 2008 Utrecht Conference and the volume (Katzir, Lehner, and Renn 2013) on the 2010 Berlin Conference.

[10] As institutional settings matter particularly in present day research, it is important to stress that Freire's work matured within the context of his direction of the undergraduate and graduate program of the Universitade Federal da Bahia (Salvador, Brazil), which is the broadest program dedicated entirely to HQP. Besides providing its several students with funding opportunities for student exchanges and archival research, the program has also organized numerous opportunities for interactions between early career and established scholars see, e.g., (Freire Jr, Pessoa Jr., and Bromberg 2011).

[11] As an example of recent attempts to reassess the role of correspondence see (Wright 2016).

[12] See, e.g., (Gearhart 2002; Büttner, Renn, and Schemmel 2003; Brush 2007; Badino 2009, 2012; Kox 2013; Badino 2015).

[13] See (Lacki 2000, 2004; Perovic 2006; Duncan and Janssen 2014; Jordi Taltavull 2016).

[14] See (Duncan and Janssen 2008; Blum 2015; Eckert 2015; Hartz and Freire Jr 2015; Blum and Joas 2016).

[15] Feynman diagrams have been among the most popular topics in HQP during the 2000s and continue to exert a steady attraction. See e.g., (Wüthrich 2011) and (Gross 2012).

[16] See, for example, (Badino 2013; Gearhart 2013; Navarro 2013).

[17] Paul Hanle, Olivier Darrigol and Agostino Desalvo were among the first to draw attention on the thermodynamic way to quantum mechanics (Hanle 1977; Darrigol 1991; Desalvo 1992; Darrigol 2002) and their lead has been followed with increasing enthusiasm in the 2000s, see for example (Monaldi 2009; Pérez 2009; Badino 2010; Pérez and Sauer 2010; Badino and Friedrich 2013; Monaldi 2013).

[18] It is also worth mentioning a recent attempt at looking more carefully into the intricate relation between quantum physics and biology (Joaquim, Freire Jr, and El-Hani 2015).

[19] On this issue see also (Park 2009).

[20] (Callender and Huggett 2001).

[21] See especially (Rickles, French, and Saatsi 2007), the special issue of *Studies in History and Philosophy of Modern Physics* (Crowther and Rickles 2014), and the recent works (Rickles and Blum 2015) and (Blum et al. 2016).

[22] Admittedly, a fully-fledged geographical approach to science is in itself rather recent, usually related to David Livingstone's seminal study (Livingstone 2003). A by no means exhaustive list of works exploring locally situated HQP includes (Ito 2002; Singh 2002; Kaiser, Ito, and Hall 2004; Kojevnikov 2004; Von Reichenbach 2009; Ito 2013; Banerjee 2014, 2016).

[23] (Kojevnikov 1999, 2011, 2012); see also (Kaiser 2002).

[24] Other protagonists of the quantum theory who received a new biographical treatment in the last 15 years are Max Born (Greenspan 2005), J. Robert Oppenheimer (Monk 2013), Max Planck (Hoffmann 2008) and Julian Schwinger (Mehra and Milton 2003).

[25] See also (Camilleri 2007; Wolf 2014; Camilleri and Schlosshauer 2015; Zinkermagel 2016) as further examples of this approach.

[26] For the manifestos of these approaches see (Ankeny et al. 2011) and (Arabatzis and Schickore 2012; Arabatzis and Howard 2015).
[27] Reflections on the role of *longue durée* in history of science come back at least to Charles Rosenberg's *Isis* editorial (Rosenberg 1987) and continued with a special issue of the *British Journal for the History of Science* (Secord 1995), a focus section in *Isis* (Findlen 2005; Kaiser 2005c; Kohler 2005; Shapin 2005) and climaxed in the recent viewpoint section in the same journal dedicated to discuss the implications of *The History Manifesto*, see especially (Armitage and Guldi 2016; Chemla 2016; Heilbron 2016; Oreskes 2016; Romano 2016). See also (Hakfoort 1991; Holmes 2003; Warner 2004; de Chaderevian 2009).
[28] For a recent contribution along these directions see (Schweber 2015).