INTEGRATING HISTORY AND PHILOSOPHY OF SCIENCE

Problems and Prospects

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Chapter 9
Hidden Entities and Experimental Practice: Renewing the Dialogue Between History and Philosophy of Science

Theodore Arabatzis

9.1 Introduction

The voluminous literature on the relationship between history of science and philosophy of science has been one-sided—occupied for the most part with the significance of the former for the latter. Historically oriented philosophers of science have viewed the history of science as a repository of empirical material for testing philosophical theories of scientific rationality or scientific change. Historians of science, on the other hand, have often doubted the "pragmatic value" of the philosophy of science (Buchwald 1992, 39). Even philosophically inclined historians, such as Thomas Kuhn, have denied the relevance of "current philosophy of science . . . for the historian of science" (Kuhn 1977, 12).[1] The widespread skepticism, among historians, about the historiographical utility of philosophy of science may have been reinforced by some philosophers' forays into history of science, which were blatantly insensitive to the categories of historical actors (see, for instance, Lakatos 1970). Be that as it may, philosophy of science, as I have argued elsewhere, may enrich historiography by scrutinizing the philosophical underpinnings of historiographical categories and choices (Arabatzis 2006a). When I advocate a philosophical historiography of science I do not, thereby, recommend the importation of ready-made philosophical positions into historiography. Rather my point is that an engagement with certain philosophical issues and debates may deepen historical analysis. If none of the available philosophical positions can do justice to the complexities of the historical record, then philosophically inclined historians of science should develop their own historiographically-driven philosophy of science.

[1] I should note that this asymmetry is primarily a feature of Anglo-American history and philosophy of science. In France, on the other hand, history of science has had a much stronger connection to philosophy of science, as testified to by the work of Georges Canguilhem and Michel Foucault. For this point, I would like to thank Bernadette Bensaude-Vincent and Henning Schmidgen.

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In the process, they may come up with novel philosophical insights (cf. Chapter 8 by Chang, this volume).

Let me present very briefly two examples from my previous work that illustrate in a concrete manner what I have in mind. The first concerns scientific discovery (see Arabatzis 2006b). The apparently descriptive statement "X discovered Y" involves an epistemic judgment, namely that the evidence mustered by X was sufficient to establish Y's existence. Furthermore, the concept of scientific discovery has a realist flavor: if something is discovered then it is ipso facto real. Thus, by employing scientific discovery as a historiographical category, one runs into the issue of scientific realism. In order to narrate a discovery-episode historians would profit from taking into account the complexities of that issue. To identify the object of a discovery and those who were responsible for it calls for conceptual analysis, on top of empirical research. The point of such an analysis should be, in my view, to chart a neutral ground that is shared by realists and anti-realists alike and, thus, to enable the narration of discovery episodes that would be equally acceptable to both groups.

My second example concerns the philosophical issue of conceptual change and its implications for choosing the subject of a historical narrative. If concepts evolve and cease to refer to the same entities, as Kuhn and Feyerabend have famously argued, then, prima facie, they are not good candidates for historical subjects. The fluidity of scientific concepts seems to preclude the possibility of framing coherent historical narratives around them. Quentin Skinner has made this point in no uncertain terms:

> as soon as we see there *is* no determinate idea to which various writers contributed, but only a variety of statements made with the words by a variety of different agents with a variety of intentions, then what we are seeing is equally that there *is* no history of the idea to be written. (Skinner 1969, 38)

In my work on the history of the electron I tried to address Skinner's challenge, as regards the history of scientific concepts. To that effect I have drawn upon the considerable philosophical literature on conceptual change in science. In the process I hope I have shed new light on some of the philosophical issues involved. It would take me too far astray to present, even in outline, this literature and my own take on it.[2] For our purposes here, the important point is the relevance of a philosophical issue to a historiographical problem.

In this paper I want to investigate further the prospects of integrated history and philosophy of science, by examining how philosophical issues concerning experimental practice and scientific realism can enrich the historical investigation of the careers of "hidden entities", entities that are not accessible to unmediated observation. Conversely, I will suggest that the history of those entities has important lessons to teach to the philosophy of science. Thus, my aim is to indicate some ways in which the dialogue between history and philosophy of science could be renewed.

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[2] I refer the interested reader to (Arabatzis 2006a).

9.2 Why Use the Term "Hidden Entities"?[3]

Let me start with a comment on my choice of terms. I have chosen the term "hidden entities" instead of other more familiar terms, such as "unobservable entities" or "theoretical entities", for the following reasons. First, I wanted to avoid the thorny issues surrounding the observable-unobservable distinction. This distinction immediately invites questions about the boundary between the observable and the unobservable and about its epistemic significance. Forty five years ago Grover Maxwell argued that it is not possible to draw a sharp dividing line between the observable and the unobservable realms and, therefore, the distinction in question lacked any epistemological and ontological significance (Maxwell 1962). This issue has been debated by philosophers of science ever since, especially after Van Fraassen reinstated the distinction and placed it at the centre of his constructive empiricist epistemology. The advantage of using the term "hidden", in this respect, is that we leave open the possibility of the hidden becoming disclosed.

Second, I have also avoided the term "theoretical entities", even though I used it elsewhere, because it conveys the misleading impression that hidden entities do not transcend the theoretical framework in which they are embedded. In fact, these entities are trans-theoretical objects, which cut across different theories or even entire disciplines. Several philosophers of science have stressed their trans-theoretical character. On the one hand, philosophers such as Nancy Cartrwright and Ian Hacking have emphasized the synchronic dimension of the trans-theoretical character of hidden entities. Witness Cartwright's remark concerning "the electron, about which we have a large number of incomplete and sometimes conflicting theories" (Cartwright 1983, 92). On the other hand, philosophers such as Dudley Shapere and Hillary Putnam have pointed out the diachronic dimension of the trans-theoretical character of hidden entities, that is, the fact that these entities are usually the objects of consecutive scientific theories. Furthermore, the term "theoretical entities" undervalues completely the fact that many of the entities in question become experimental objects that are investigated in the laboratory, often without any guidance from a systematic theory about their nature.

Of course, I could have used other terms, such as "inferred entities" or "hypothetical entities". For the period in which my work has focused so far (the late nineteenth and early-twentieth centuries) the terms "hidden" or "invisible" entities have the additional advantage that they denote a category of historical actors, atomists and anti-atomists alike. Heinrich Hertz, for instance, pointed out in his posthumously published *Principles of Mechanics* (1894) that "the form of the atoms, their connection, their motion in most cases—all these are entirely hidden from us" (Hertz 1956, 18). The lack of direct epistemic access to those characteristics of atoms, however, did not diminish Hertz's long-time conviction in the atomic constitution of matter

[3] I have borrowed this term from the title of an international laboratory for the history of science organized by the Dibner Institute in June 1998.

and in the possibility of determining some of the hidden properties of atoms (e.g., their size) experimentally (cf. Lützen 2005, 46, 55–56).[4]

Another well-known advocate of the atomic theory, the French experimental physicist Jean Perrin, described the aim of science in these colourful terms:

> In studying a machine, we do not confine ourselves only to the consideration of its visible parts . . . We certainly observe these visible pieces as closely as we can, but at the same time we seek to divine the *hidden* gears and parts that explain its apparent motions.
>
> To divine in this way the existence and properties of objects that still lie outside our ken, *to explain the complications of the visible in terms of invisible simplicity*, is the function of the intuitive intelligence which, thanks to men such as Dalton and Boltzmann, has given us the doctrine of Atoms. (Perrin 1916, vii)

Furthermore, according to Perrin, the line between the visible and the invisible may shift as a result of technological developments (ibid.). As a matter of fact, he strived throughout his career to lift the veil that hided molecular reality and to render molecular motions visible (see Nye 1972, 54; Bigg 2008).

Anti-atomists also employed a similar terminology. In an impassioned advocacy of "energetics" Pierre Duhem claimed that its principles "do not aspire at all to resolve the bodies we perceive or the motions we report into imperceptible bodies or hidden motions" (Duhem 1913/1996, 233). In stark contrast to the "neo-atomists", he thought that the hidden realm behind the phenomena is not epistemically accessible (ibid., 238; cf. Nye 1972, 166).

As a final example, consider Henri Poincaré's response to the popular fin-de-siècle view that the history of scientific theories resembles a heap of "ruins piled upon ruins" (Poincaré 1905, 160; cf. Nye 1972, 35–38). He argued that the prima facie plausibility of that view derived from neglecting to attend to the proper aim of scientific theories. The aim in question, according to Poincaré, is not to reveal the hidden objects that give rise to physical phenomena, because "Nature will hide for ever [those objects] from our eyes" (Poincaré 1905, 161). Rather, the aim of theorizing is to discover "The true relations between these real objects". These "are the only reality we can attain" (ibid.). Furthermore, the discovery of these relations is an enduring achievement that will not be undermined by the subsequent development of science. Thus, Poincaré's relational realism makes possible to salvage the continuity and permanent value of scientific knowledge.

Notwithstanding the popularity of the term "hidden" among historical actors, in our constructivist age this term may have some objectionable overtones, suggesting a pre-existing reality waiting to be disclosed. I think, however, that one may adopt a distinction between a hidden and a manifest realm, while remaining neutral in metaphysical disputes concerning the nature of reality.

[4]It should be noted that in the *Principles of Mechanics* Hertz used the term "hidden" mainly in connection with mass. The introduction of "hidden masses" served a theoretical purpose, namely to dispense with the notion of force. I would like to thank Giora Hon for pointing out to me the nuances of the term "hidden" in Hertz's text.

9.3 A Glance at the Role of Hidden Entities in the History of the Physical Sciences: The Historical Roots of a Philosophical Problem

The explanation of phenomena by postulating hidden entities has been a significant aspect of the sciences, at least since the seventeenth century. Think, for instance, of the central tenet of the mechanical philosophy, namely that the fundamental constituents of the world are imperceptible material particles in constant motion. Those particles were introduced for explanatory purposes, to accommodate various phenomena within a mechanical framework. Descartes, for instance, attempted to account for magnetic attraction by postulating screw-shaped particles, "which in passing through the pores in magnets and iron, drive the air from between the two and cause them to move together" (Westfall 1977, 37). In the following centuries we witness a multiplication of hidden entities, many of which were introduced for a similar reason, that is, to accommodate, within a mechanical framework, phenomena that were not easily susceptible to mechanical explanation. In the eighteenth century, for example, subtle fluids were posited to make mechanical sense of phenomena, such as electricity and magnetism, which seemed to involve action at a distance. Those imponderable fluids were supposed to be self-repelled and attracted to matter, which they permeated. By the end of the eighteenth century they had proved their fertility and promised to offer a unified quantitative framework for investigating electricity, magnetism, light, heat, and combustion (Heilbron 1993). Similarly, in the nineteenth century the "luminiferous" ether was put forward to incorporate light within a mechanical framework. The subsequent development of field theory led to a unification of light with electromagnetic processes and an identification of the optical and the electromagnetic ether. By the last quarter of the nineteenth century, the prospects of understanding a dazzling variety of disparate phenomena as manifestations of a hidden mechanical medium seemed bright indeed (Cantor and Hodge 1981).

Furthermore, the mechanical tradition was reinforced by the postulation of another hidden entity, the atom, which was originally invoked by John Dalton in response to problems in meteorology and chemistry. In the latter its main functions were to simplify, systematize and explain empirical regularities, such as the laws of definite and multiple proportions. It was soon appropriated by physicists, who employed it to develop a successful mechanical account of heat as a form of motion. Throughout the century, however, many scientists thought of atoms as dispensable fictions and the question of their ontological status remained open (Gardner 1979; Chalmers 2009; Rocke 2010). In the early-twentieth century the atomic debates were finally resolved, mainly as a result of Perrin's experimental investigations of Brownian motion which provided striking evidence in favor of the existence of atoms. The subsequent development of microphysics led to a real explosion in the number of the hidden constituents of matter, ranging from electrons to quarks.

This brief and impressionistic historical sketch indicates that hidden entities have often (always?) been introduced for explanatory purposes. Some of them (e.g., the subtle fluids) were subjected to experimental investigation, whereas others (e.g., the ether) were resistant to experimental detection. Thus, entire domains of theoretical and experimental practice have been structured around hidden entities. This fact alone would suffice to render these entities historiographically significant. Furthermore, they are puzzling from a philosophical point of view. Several of them, notwithstanding their explanatory fertility, turned out to be fictitious. Phlogiston, caloric, and the ether, to mention the most salient cases, are no longer recognized as real entities. For this reason, perhaps, the philosophical literature concerning hidden ("unobservable"/"theoretical") entities has focused on the problem of scientific realism, that is, on the grounds that we have for believing in their existence.

Among the origins of this problem is the so-called underdetermination of theory by evidence, namely the fact that there can be more than one hypotheses or theories that are compatible with the phenomena. This problem had been discussed since antiquity. The introduction and proliferation of hidden entities, however, made it more intractable. Any inductive generalization faces "horizontal" underdetermination, but with the hypothetical postulation of entities "underneath" the phenomena one has to worry also about "vertical" underdetermination.[5]

9.4 Bypassing Underdetermination: Cartwright and Hacking on Entity Realism

There have been various attempts to come to terms with the problem of underdetermination. The one I will discuss here was put forward by Ian Hacking, who tried to bypass this problem by focusing on experimental practice and the specific mode of causal reasoning that is employed in that practice. A similar view has been adopted and further developed by Nancy Cartwright. Instrumentation and experimentation, in Hacking's and Cartwright's view, can provide, under certain circumstances, unmediated (largely theory-free) access to the hidden reality behind the appearances. Hacking has argued that the manipulation of hidden entities in the laboratory compels us to be realists about them. The uses of hidden entities as investigative probes and as engineering tools leave little room for doubting their existence. Hidden entities cease to be hypothetical when we succeed in manipulating them. For instance, the reality of electrons is beyond reasonable doubt, since we have devices with which we can spray them. In Hacking's seductive words, "if you can spray them, then they are real" (see Hacking 1983, 22ff.). Of course, it may turn out that our theoretical representations of electrons and their properties are mistaken, but it is highly unlikely that electrons will turn out to be fictitious. Cartwright concurs:

> I agree with Hacking that when we can manipulate our theoretical entities in fine and detailed ways to intervene in other processes, then we have the best evidence possible for our claims about what they can and cannot do; and theoretical entities that have been

[5] I borrow these terms from (Worrall 2000).

warranted by well-tested causal claims like that are seldom discarded in the progress of science. (Cartwright 1983, 98)

This version of realism, as many commentators have pointed out, faces several difficulties.[6]

9.5 Problems of Entity Realism: A Role for History of Science

Perhaps the main difficulty is that Hacking begs the question by assuming "what is under dispute", namely that we can spray electrons (cf. van Fraassen 1985, 298). The identification of an act of laboratory manipulation with the spraying of electrons cannot be the premise of an argument purporting to demonstrate the existence of electrons.[7] To put it another way, our confidence in the existence of electrons must precede our claim that in a certain laboratory setting we manipulate electrons (cf. Seager 1995, 467–68). Of course, "manipulation" is a success term—we cannot manipulate something that does not exist (cf. Nola 2002, 5). Perhaps that is why Hacking calls his "conclusion . . . obvious, even trifling" (Hacking 1983, 146). The real question, though, concerns the identity of the objects we manipulate.

I will call this difficulty "the manipulation of what?" problem: before we invoke manipulability as a demonstrative principle, we need to identify the entity that we manipulate. There are experimental situations, however, where we manipulate *something* without knowing *what kind of thing* we manipulate. For instance, in the last quarter of the nineteenth century several physicists manipulated cathode rays, experimental objects that were produced in the discharge of electricity through gases at very low pressure.[8] The identification of cathode rays with electrons at the end of the nineteenth century revealed that the earlier manipulations of cathode rays had been, in fact, manipulations of electrons. Prior to that identification, however, the physicists who manipulated cathode rays did not know what kind of thing they manipulated. Hacking has claimed that "from the very beginning people were less testing the existence of electrons than interacting with them" (Hacking 1983, 262). Actually, people were interacting with electrons well before they even suspected their existence. Thus, manipulability, by itself, cannot establish the existence of, say, electrons, as opposed to cathode rays or an "I know-not-what" something (cf. Achinstein 2001a, 412; Boon 2004, 229).

To put it another way, the "material realization"[9] of an experiment can be compatible with a plurality of descriptions (and theoretical interpretations) of what is going on in the experiment. Since the material realization of an experiment underdetermines its theoretical interpretation, the question "What entity is being manipulated

[6]See, for instance (Arabatzis 2001; Elsamahi 1994; Gross 1990; Morrison 1990; Reiner and Pierson 1995; Resnik 1994).

[7]See the illuminating discussion in (Suárez 2008, 154).

[8]For a concise history of those objects see (Arabatzis 2009a).

[9]The term is from (Radder 1995, 69).

in the experiment in question?" cannot be answered merely on the basis of the experimental operations performed by the experimenter. The epistemic gap from our manipulations of "apparent" entities to the existence of hidden entities can only be bridged by our representations of the hidden world.

And this brings me back to the problem of underdetermination. One would expect that theoretical explanations as well as entity-based explanations of phenomena face equally this problem. Nancy Cartwright, however, has argued that there is an asymmetry in these two kinds of explanation. Only entity-based explanations are exempt from underdetermination:

> We can infer the truth of an explanation only if there are no alternatives that account in an equally satisfactory way for the phenomena. In physics nowadays, I shall argue, an acceptable causal story is supposed to satisfy this requirement. But exactly the opposite is the case with the specific equations and models that make up our theoretical explanations. There is redundancy of theoretical treatment, but not of causal account. (Cartwright 1983, p. 76)

The problem here, as I see it, is that Cartwright assumes that the current absence of alternatives implies the absence of alternatives period. One could very well conceive of the existence of two or more causal accounts of the same phenomena, based on the existence of altogether different entities. After all, in the history of the sciences there have been such cases—for instance, a phlogiston-based and an oxygen-based account of combustion (Arabatzis 2001, S534; Carrier 1993, 401–03). I don't see how this possibility could be excluded (cf. Clarke 2001, 719; Gelfert 2003, 248). Actually, a proponent of "experimental realism", Mauricio Suárez, has admitted this possibility. According to Suárez, "We arguably once had causal warrant for phlogiston but no longer do." And Priestley "was led by his prior belief in phlogiston to interpret all his experimental manipulations as providing grounds for the nonredundant role of phlogiston in the explanation of combustion" (Suárez 2008, 156, 157). This is exactly right, but, *pace* Suárez, I think that the phlogiston case undermines entity realism, by showing that the non-redundancy of entity-based causal explanations may be just a temporary feature of our knowledge. Even if, at a given stage of scientific development, we lack more than one causal explanation of certain phenomena, the future development of knowledge may bring to light "unconceived alternatives".

I have argued, so far, that the putative manipulation of a hidden entity is not a sufficient criterion for establishing its existence. Is it a necessary one? In response to his critics, Hacking has recognized the variety of standards of proof, in addition to manipulability, that are brought to bear, *within* scientific practice, on the existence of hidden entities.

> My experimental argument for entity realism may imply a sufficient (epistemological) condition for holding that an entity exists. But it does not imply a necessary condition. There may be many kinds of evidence that an entity exists. I hold only that manipulationability is the best evidence. (Hacking 1995/1996, 540)

Thus, manipulability should not be interpreted as a necessary condition for belief in the existence of a hidden entity. A difficulty remains, however: within scientific practice manipulability is sometimes (often?) not considered the "best proof" or the "best evidence" in favour of an entity (Gelfert 2003; Massimi 2004; Morrison 1990). So if we applied Hacking's criterion we would, sometimes, end up accepting entities that are contentious among the relevant experts or even admitted to be fictitious. In other words, the criterion may recommend ontological commitment even in cases where the scientific community has not unambiguously decided in favour of the existence of an entity.

Cartwright's exclusive emphasis on causal inference faces the same problem. Consider her account of

> the radiometer, invented by William Crookes in 1853. It is a little windmill whose vanes, black on one side, white on the other, are enclosed in an evacuated glass bowl. When light falls on the radiometer, the vanes rotate. It was . . . agreed that the rotation is due to the action of the gas molecules left inside the evacuated bowl. . . . in 1879 James Clerk Maxwell, using the kinetic theory of gases, argued that . . . differential heating in the gas produces tangential stresses, which cause slippage of the gas over the surface. As the gas flows around the edge, it pulls the vanes with it.
> . . .
>
> The molecules in Crookes's radiometer are invisible, and the tangential stresses are not the kinds of things one would have expected to see in the first place. Yet, . . . I believe in both. I believe in them because I accept Maxwell's causal account of why the vanes move around. (Cartwright 1983, 5–6)

As with Hacking's manipulability criterion, the problem here is the anticipation of the verdict of the scientific community. Molecules remained controversial entities till the beginning of the twentieth century. Apparently, many physicists and chemists were not (and, I think, should not have been) swayed by Maxwell's causal account of the radiometer's function to believe in molecules. The moral of this case is that philosophers of science should not anticipate (or even supplant) the judgements of the scientific community by oversimplifying the issues at stake. Rather they should attend to the multitude of theoretical and experimental practices that are brought to bear, over extended periods, on the existence of hidden entities. Philosophy of science has to accommodate the complexity of its subject matter. To that effect, history of science has an indispensable role to play.

9.6 Towards a Historiographically Adequate Philosophical Attitude

It is clear, to my mind at least, that manipulability cannot get around the hypothetical status of hidden entities. Is there a philosophical attitude towards those entities that can do justice to their history? Among other things, we have to do justice to the historical fact that important scientists believed passionately (and, I think, for good reasons) in entities that turned out to be fictitious. We have to understand, *in epistemic terms*, how it was possible, or even reasonable, for a physicist of J. J. Thomson's caliber to claim in 1909 that "The ether is not a fantastic creation of the speculative philosopher; it is as essential to us as the air we breathe" (Thomson 1909, 267). In the same vein, we should be able to fathom Lord Kelvin's belief that "We know the luminiferous ether better than we know any other kind of matter in some particulars. ... we know more about it than we do about air or water, glass or iron" (Kelvin 1904, 10–11). By immersing ourselves in the theoretical, instrumental, and experimental practices of past scientists, in their "virtual reality" as it were (Seager 1995), it becomes possible to understand the plausibility, coherence, and success (relative to the then current epistemic standards) of their beliefs. Thus, it will occasion no surprise that the scientists in question developed an, often strong, conviction in the reality of their objects of study. At the same time, however, the fact that some of those objects have perished motivates us to distance ourselves from the ontological commitments of the historical actors. Thus, the attitude I am recommending drives a wedge between immersion in a worldview (and a set of practices) and belief in the hidden entities associated with it. It has some parallels with Husserl's *epoché*, an attitude of abstention from ontological questions. I will call it "attitude of ontological bracketing".[10]

9.7 Sidestepping the Problem of Realism

The attitude of ontological bracketing does not amount to antirealism. The realism issue concerns the proper epistemic attitude towards contemporary science, whereas the attitude I'm recommending is directed towards the scientific past. To extend the scope of this detached attitude to present-day science, one would have to show that contemporary science is epistemically on a par with past science. Furthermore, the aim of ontological bracketing is to sidestep the normative aspects of the problem of realism and focus on issues which, though related to it, have a predominantly descriptive and interpretative character. I will touch upon three of those issues:

First, there is a descriptive counterpart to the normative philosophical problem. How do the scientists themselves become convinced that a hidden entity is real? Although I hesitate to give a simple answer to such a complex question, I would stress two factors that are important in this respect: The first factor has to do with theory. The empirical adequacy, the explanatory power, and the fertility of the theory positing a hidden entity are usually considered among the most important reasons for believing in its existence.[11] The second factor is related to experiment. The over-determination of a hidden entity's properties in different experimental settings is often an important reason in favour of its existence. For example, in the late nineteenth century the charge to mass ratio of the electron was determined by different methods and in different kinds of experiments: on cathode rays, on ß-rays, on thermionic emission, and in spectroscopy. The approximate agreement of the results obtained convinced many physicists that electrons were real entities (see Arabatzis 2006a). Another prominent example concerns the resolution

[10] I would like to thank Mitchell Ash for pointing out the similarities between Husserl's ontological attitude and the historiographical-cum-philosophical stance I am trying to articulate. Cf. (van Fraassen 1980a, 81).

[11] The importance of these values of theory appraisal for the realism debate has been stressed by Ernan McMullin. See, for instance (McMullin 1984).

of the atomic debates in the early twentieth century. Perrin's convergent multiple determinations of Avogadro's number, on the basis of very different experimental procedures, tipped the scales in favor of the existence of atoms.[12]

The second issue concerns the role of experimentation on hidden entities in the construction of their representations. How do scientists infer the characteristics of such entities by experimenting on them? Here I will draw on two philosophers: Pierre Duhem and Norwood Russell Hanson. As Duhem argued, a hidden entity is associated with a constellation of effects: an electric current, for instance, "may manifest itself not only in mechanical effects but in effects that are chemical, thermal, luminous, etc" (Duhem 1954, 151). What we need to understand in specific cases is how these different effects are held together as manifestations of a single entity.[13]

Furthermore, we need to understand how specific characteristics are attributed to those entities. Hanson's remark that "The idea of ... atomic particles is a conceptual construction 'backwards' from what we observe in the large" is particularly helpful in this respect (Hanson 1963, 47). When an experimentally produced phenomenon is attributed to a hidden entity, the characteristics of the phenomenon that are of interest to the scientist(s) must be linked with the putative properties and behaviour of the entity in question. As Cartwright has put it, echoing Hanson's idea,

> Given our general knowledge about what kinds of conditions and happenings are possible in the circumstances, we reason backwards from the detailed structure of the effects to exactly what characteristics the causes must have in order to bring them about. (Cartwright 1983, 6)

For instance, in late nineteenth-century spectroscopy the phenomena observed in the laboratory had three salient characteristics: the frequency, intensity, and polarization of spectral lines. Once spectral lines were attributed to a hidden entity, the electron within the atom, their characteristics had to be linked with the properties and behaviour of that entity. The frequency, intensity, and polarization of spectral lines were correlated with the frequency, amplitude, and direction of vibration of the electron within the atom. In that way, experimentally obtained information guided the articulation of the representation of the electron.

A related question concerns the *measurement* of hidden entities. Since the late nineteenth century various properties of hidden entities have been measured, the mass and charge of elementary particles being among the most prominent. How is it possible to measure something that is hidden? The process of measurement in this case is very similar to Newton's "deduction from the phenomena". Given the hypothesis that an entity exists and that it is subject to certain laws, it is possible to use experimental results to fill in the blanks in the description of the entity. Thus, the measurement of hidden entities can be represented as "the continuation of theory construction by other means" (van Fraassen 1980b, 673). Again, one sees the potential significance of philosophy of science to history of science. Philosophical

[12] See (Nye 1972, 160ff). This episode has been the subject of divergent philosophical analyses. See, for instance (Cartwright 1983; Salmon 1984; Achinstein 2001b; van Fraassen 2009).

[13] For a preliminary attempt to answer this question, see (Arabatzis 2006a).

views about the character and function of hidden entities may stimulate and enrich historical analysis.

We should grant, I think, that theory is crucial for the experimental investigation of hidden entities. We should still ask, however, whether these entities qua experimental objects have any independence from their theoretical representations. In other words, do they have a life of their own? I think that they do, and this is an insight of lasting value in Hacking's and Cartwright's "experimentalism" that is borne out by the history of hidden entities. A substantial part of our knowledge of them derives from experiment and is, in an important sense, independent from theory. First, it is often the case that scientists are involved in exploratory experimentation on hidden entities, without being guided by a full-fledged theoretical account of their nature (Clarke 2001, 711; Steinle 1997, 2002). That was the case, for example, in experimentation on cathode rays during the last quarter of the nineteenth century (Hiebert 1995). Furthermore, experimentally determined properties of hidden entities are often incorporated into very different theoretical representations of them. Scientists who may disagree about the ultimate nature of those entities may come to agree about their experimentally determined properties. Those properties may, in turn, become essential for identifying their carriers in different experimental settings. For instance, J. J. Thomson in England, Walter Kaufmann in Germany, and Paul Villard in France had very different ideas about the ultimate nature of cathode rays. Thomson identified them with subatomic particles; Kaufmann represented them as ether waves; and Villard believed that they were charged hydrogen particles. All of them, however, agreed on the value of their mass to charge ratio.[14] Finally, the existence of conflicting theoretical representations of a hidden entity does not necessarily call into question its identity in experimental contexts. For example, in the early twentieth century several incompatible accounts of the shape and structure of the electron were put on the table. Those accounts led to different predictions about the velocity dependence of the mass of the electron. Walter Kaufmann's experiments on β-rays (high speed electrons) were set up to resolve that issue. What is significant for my purposes is that the entities experimentally investigated by Kaufmann were taken, by all parties in the dispute, to be the common referent of the divergent theoretical representations of the electron (see Arabatzis 2009b; cf. Galison 1997, 812–13).

9.8 Concluding Remarks

To conclude, I hope I have showed that our understanding of hidden entities and their role in experimental practice can be enhanced by adopting an integrated historical-cum-philosophical approach. On the one hand, philosophical reflection on the problem of entity realism has a lot to gain by examining historically how those entities were introduced and investigated. On the other hand, the historical

[14] See (Arabatzis 2004; Lelong 2001).

analysis of the careers of those entities may profit from philosophical reflection on their existence and their role in scientific practice.

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