Hidden entities and experimental practice: towards a two-way traffic between history and philosophy of science

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1. Introduction

The significance of the philosophy of science for understanding historically scientific practice has not been sufficiently appreciated. Of course, the relationship between the history of science and the philosophy of science has been discussed extensively. The discussion, however, has been one-sided—occupied for the most part with the importance of the history of science for the philosophical understanding of science. Most commentators have viewed the history of science as a repository of empirical material for testing philosophical theories of scientific rationality or scientific change. On the other hand, there has been very little discussion of the ways in which the philosophy of science can enrich historiographical practice. Some authors have even denied that the philosophy of science has anything to offer to historians of science. Thomas Kuhn's words are characteristic: "I do not think current philosophy of science has much relevance for the historian of science" (Kuhn 1977, 12). Kuhn made that statement in the 1970s, but it captures the attitude of many historians ever since. The historians' skepticism towards the historiographical value of philosophy of science may have been justified, in view of some procrustean attempts to "apply" philosophical theories of scientific change to historical case studies. Nevertheless, as I have argued elsewhere, philosophy of science has a significant historiographical role: to analyze the philosophical presuppositions of historiographical categories (e.g., the category of scientific discovery) and choices (e.g., choosing the subject of a historical narrative). (See Arabatzis 2006.) When I say that historians may profit from philosophy of science I do not have in mind philosophical positions that can be adopted wholesale in historical interpretation; rather my point is that an awareness of certain philosophical issues and debates may enrich historical work. Conversely, by drawing on those issues for the purposes of historical interpretation one may come up with novel philosophical insights. Here I agree fully with Hasok Chang (Chang 2007).

Let me present very briefly two examples from my previous work (Arabatzis 2006) that illustrate in a concrete manner what I have in mind. The first concerns scientific discovery. The apparently descriptive statement "X discovered Y" embodies an evaluative judgment, namely that the evidence presented by X demonstrated Y's existence. Furthermore, the concept of scientific discovery has realist presuppositions: if we discover something then, no doubt, this something exists. Thus, scientific discovery, as a historiographical category, is bound to the issue of scientific realism. In order to narrate a discovery episode the historian should be aware of the complexities of that issue and take into account that the apparently innocent question "when and by whom was something discovered?" is not merely a request for factual information but requires conceptual analysis. 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 make possible the construction of historical narratives that would be acceptable to audiences of different philosophical persuasions.

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. In view of conceptual variance it seems to be impossible to construct a coherent narrative of the development of a concept. 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 vis-à-vis the history of scientific concepts. To that effect I have drawn upon the considerable philosophical literature on meaning change. 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.[1] For our purposes here, the important point is the relevance of a philosophical issue to a historiographical problem.

In this talk I want to investigate further the prospects of integrated HPS, by examining how philosophical issues concerning experimental practice and scientific realism can enrich the historical investigation of the careers of "hidden entities," entities

[1] I refer the interested reader to Arabatzis 2006.

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 illustrate the possibility of a fruitful two-way traffic between history and philosophy of science.

2. Why use the term "hidden entities"? [2]

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

[2] 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.

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 19^{th} and early 20^{th} centuries) the terms "hidden" or "invisible" entities have the additional advantage that they denote an actors' category. Heinrich Hertz, for instance, in his posthumously published *Principles of Mechanics* (1894) remarked that "the form of the atoms, their connection, their motion in most cases – all these are entirely hidden from us" (Hertz 1956, 18). And 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.
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> 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.)

In our constructivist age, the term "hidden" 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.

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 17^{th} 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 (e.g.

Descartes' corpuscles) were introduced for explanatory purposes, to accommodate various phenomena within a mechanical framework. In the following centuries we witness a multiplication of novel entities, most of which were introduced for similar reasons, that is, to accommodate within a mechanical framework phenomena that were not easily susceptible to mechanical explanation. For example, the 18th century subtle fluids were posited to make mechanical sense of phenomena, such as electricity and magnetism, which seemed to involve action at a distance. Similarly the 19th century luminiferous ether was put forward to incorporate light within a mechanical framework. Thus, many of the hidden objects of 18th and 19th century natural philosophy were introduced in response to a conceptual difficulty faced by the mechanical tradition, which could not tolerate the obscure phenomenon of action at a distance.

In the 19th century, other hidden entities, such as the atom, were invoked to systematize and explain empirical regularities (e.g., the laws of definite and multiple proportions). Many scientists, however, thought of "atoms" as dispensable fictions and the question of their ontological status remained open throughout the century. And, finally, in the 20th century, with the birth of microphysics and genetics, we witness a real explosion in the number of the hidden entities that populate the world, ranging from various elementary particles to genes.

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. While they had been focal points of theoretical and experimental investigation, several of them turned out to be fictitious. For this reason, perhaps, the philosophical literature concerning these 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.[3]

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

This version of realism, as several commentators have pointed out, faces several difficulties.[4]

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[3] I borrow these terms from Worrall 2000.

[4] See, for instance, Arabatzis 2001, Elsamahi 1994, Gross 1990, Morrison 1990, Reiner and Pierson 1995, Resnik 1994.

5. Problems of entity realism: a role for history of science

5a. Perhaps the main difficulty is that the premise of Hacking's argument, namely that we can spray electrons, begs the question by assuming "what is under dispute" (van Fraassen 1985, 298). "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 very description of an act of laboratory manipulation as "spraying of electrons" presupposes the existence of electrons. To put it another way, our confidence in the existence of electrons must precede our claim that we successfully manipulate electrons (cf. Seager 1995, 467-468).

5b. A related difficulty is what I will call the "manipulation of what" problem: before we invoke manipulability as a demonstrative principle, we need to identify the entity that we manipulate. In many experimental situations we manipulate *something* without knowing *what kind of thing* we manipulate. For instance, in the last quarter of the 19th century several physicists manipulated cathode rays, experimental objects that were produced in the discharge of electricity through gases at very low pressure. The identification of cathode rays with electrons at the end of the 19th 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 2001, 412; and Boon 2004, 229).

To put it another way, the "material realization"[5] 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 in the experiment in question?" cannot be answered merely on the basis of

[5] The term is from Radder 1995, 69.

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.

5c. 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, 401-403). I don't see how this possibility could be excluded (cf. Clarke 2001, 719 and Gelfert 2003, 248).

5d. 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 1995/96, 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.
>
> …
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> 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 20th 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 replace) 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 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.

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" (J. J. Thomson 1909, 267). 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 how 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. Lacking a better term, I will call this attitude "methodological agnosticism".

7. Sidestepping the problem of realism

Methodological agnosticism does not amount to antirealism. Rather it is an attempt 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.[6] I will touch upon three of those issues:

[6] The distinction between the normative and the descriptive is a vexing one. For an illuminating discussion see Fagan 2007.

7a. To begin with, 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 would hesitate to give a simple answer to such a huge 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.[7] 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 19th and the early 20th centuries 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.

7b. 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.[8]

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, p. 47). When an experimentally produced phenomenon is attributed to a hidden entity, the characteristics of the phenomenon that are of interest to

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

[8] For a preliminary attempt to answer this question, see Arabatzis 2006.

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 19th 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 views about the character and function of hidden entities may guide historical analysis.

7c. 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". A considerable part of our knowledge of hidden entities derives from experiment and, in an important sense, is partly 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 19th 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.[9]

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 (cf. Achinstein 2007). On the other hand, the historical 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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[9] See Arabatzis 2004 and Lelong 2001.

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