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On the Historicity of Scientific Objects

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Abstract The historical variation of scientific knowledge has lent itself to the development of historical epistemology, which attempts to historicize the origin and establishment of knowledge claims. The questions I address in this paper revolve around the historicity of the objects of those claims: How and why do new scientific objects appear? What exactly comes into being in such cases? Do scientific objects evolve over time and in what ways? I put forward and defend two theses: First, the ontology of science is so rich and variegated that there are no universally valid answers to these questions. Second, we need a pluralist account of scientific objects, a pluralist metaphysics that can do justice to their rich diversity and their various modes of being and becoming. I then focus on hidden objects, which are supposed to be part of the permanent furniture of the universe, and I discuss their birth and historicity: They emerge when various phenomena coalesce as manifestations of a single hidden cause and their representations change over time. Finally, I examine the conditions under which an evolving representation may still refer to the same object and I illustrate my argument drawing upon the early history of electrons.

Knowledge claims, as well as the methods and practices that give rise to them, have changed over time. Historians and philosophers of science have amply documented the historicity of epistemic practices. Forms of explanation and argumentation, methods for acquiring knowledge, epistemic categories and values have been shown to vary considerably over time. Think, for instance, of the shift from the teleological explanations favored by Aristotelian natural philosophy to the mechanical explanations espoused by seventeenth-century natural philosophers; or of the transition from the ancient ideal of certain knowledge, based on apodeictic

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demonstrations from indubitable premises, to the early modern admission of merely probable knowledge, derived from experimentally established matters of fact; or, finally, of the historical vicissitudes of the notion (and associated practices) of objectivity between the eighteenth and the twentieth centuries (Daston and Galison 2007). This historical variation has lent itself to the development of historical epistemology, which, in my understanding, attempts to historicize the origin and establishment of knowledge claims.[1]

The main question I will address in this paper is whether (and in what sense) the objects these claims are about are historical entities, that is, whether (and in what sense) they change over time.[2] The special sciences have their own objects. Scientists observe, individuate, represent (verbally, pictorially, mathematically, materially), and experiment upon the objects that they study. One aspect of the historicity of scientific objects is evident: new objects (e.g., electrons, genes) appear and old objects die out (phlogiston, the ether, etc.). How does a new scientific object appear (or pass away)? What accounts for its birth (or death)? What exactly comes into (or out of) being in such cases? Furthermore, what happens after the emergence of a scientific object? Does it evolve over time and in what ways?[3]

To address these questions we have to take into account that the career of scientific objects has three different (*albeit interacting*) components: first, their individuation—the boundaries that carve out an object out of a larger domain; second, their representation—their beings objects of theoretical discourse and experimental modeling; and, third, their observable or experimental manifestations—their being objects of observational or experimental traditions. Each of these components may change: their boundaries may shift, their representations may get modified, and their experimental manifestations may evolve.[4] Perhaps the most important component, as regards the question of the historicity of scientific objects, is that of their individuation.

I will put forward three theses: First, the ontology of science is so rich and variegated that there are no general answers to the questions I raised above. A glance at a recent collection on *Biographies of Scientific Objects* (Daston 2000) would suffice to lend plausibility to this thesis. How could we give a unified account of objects as diverse as dreams, the ether, value, and the center of gravity of the earth, to mention just a few of the objects studied in the aforementioned collection?

[1] Let me note a caveat here. The historicity of knowledge should not be conflated with the relativity of knowledge. The former does not preclude, I think, the possibility of trans-historical evaluation of past knowledge, as implied by the latter. For instance, some scholars have admitted that epistemic "standards change in myriad ways" (Buchwald and Franklin 2005, p. 2), while distancing themselves from the "tendency to regard science as purely local and contextual" (ibid., p. 1). At any rate, this is a complex issue that goes well beyond the scope of this paper.

[2] This question has been raised in Bruno Latour's provocative essay "Do scientific objects have a history?" (Latour 1996). The way I tackle it, however, is very different from Latour's.

[3] These questions are mostly about the surface features of the historicity of scientific objects. This is not to deny that these features are products of deeper and culturally situated processes.

[4] Note that although these components have to be distinguished for analytical purposes, in practice they are often entangled. The individuation of objects in observational contexts and their identification in experimental situations is made possible by certain aspects of their representation. For a clarification of this point I am indebted to Ursula Klein. Cf. Arabatzis (2008).

Fleeting and real, permanent and fictitious, socially constituted, and mathematical entities, among other things, would have to be brought under a common framework. Furthermore, the individuation of observable objects (e.g., material substances) is rather different from the individuation of theoretical objects (e.g., those referring to sub-microscopic constituents of matter). In the former case it is much easier than in the latter to have criteria for individuating an object that are independent from theoretical accounts of its nature. An illustration of this point is provided by the history of chemical substances in the eighteenth-century. The individuation of most of those substances was uncontroversial, whereas their composition was a contentious issue.[5] Thus, the question of the historicity of scientific objects has to be raised and addressed at a local level, the level of particular kinds of objects.[6] My second thesis will be that the rich variety of scientific objects underlies the need for a pluralist account of scientific objects, a pluralist metaphysics if you will, that can do justice to their rich diversity and their various "modes of existence".[7] Third, I will argue that the representation of an object and its experimental manifestations may change without destabilizing the identity of the object in question, provided that the criteria or practices involved in its individuation do not change.

In the remaining part of my talk I will look more closely at a particular kind of scientific objects, non-historical natural kinds that are not accessible to unmediated observation. I will discuss their birth and possible historicity, illustrating my analysis with examples from the history of a salient object of physics and chemistry, the electron.[8]

1 The Varieties of Scientific Objects: Some Preliminary Distinctions

Let me first highlight the diversity of scientific objects by throwing in some distinctions that, I think, would be useful to keep in mind when we study these objects:

- Naturally occurring entities (e.g., planets) versus artificially produced entities (e.g., genetically modified organisms)
- Naturally occurring regularities (e.g., the retrograde motion of the planets) versus phenomena created in the laboratory (e.g., the laser). The latter may or may not have a counterpart in nature.
- Historical entities (e.g., species) versus entities that are not supposed to have a history (e.g., electrons).[9]

[5] See Klein and Lefèvre (2007).

[6] Cf. Galison (2004).

[7] Cf. Latour (2008).

[8] The reader may be struck here by a prima facie paradox: the possible historicity of a non-historical entity! The paradox dissolves if, as I will argue below, we distinguish a representation from the thing it stands for. There is nothing paradoxical about a historically developing representation that attributes a non-historical character to its referent.

[9] Cf. Hacking (2002, p. 11).

- Stable objects (e.g., rocks) versus fleeting objects (e.g., clouds or dreams)[10]
- Objects accessible to unaided observation versus indirectly observable, or even in principle unobservable, objects.
- Objects of theoretical discourse without experimental counterparts (e.g., the Higgs field) versus objects of experimental investigation that have not (yet) been embedded in a developed theoretical framework (e.g., electricity in the eighteenth-century).[11]

This tentative and incomplete taxonomy throws into relief the complexity of the ontology of science and lends some initial plausibility to my plea for a pluralist account of scientific objects.[12]

Some of the above distinctions are not sharp. As with most distinctions, there are many borderline cases, where it is hard, or altogether impossible, to decide on which side of the divide they belong. This holds particularly for the distinctions between the natural and the artificial and between the observable and the unobservable. Take the former distinction first. Whereas in some areas of fundamental physics or cosmology there are entities (e.g., black holes) whose properties are beyond the realm of human intervention, in other more applied contexts the distinction between the natural and the artificial loses its bite altogether. What is, for instance, the status of a genetically engineered organism such as the oncomouse or an artificially created element such as plutonium? Thus, I agree with Bernadette Bensaude-Vincent and Bill Newman that "instead of opting for an absolute distinction of quality between the artificial and the natural, one should accept only a gradual distinction of degree" (Bensaude-Vincent and Newman 2007, p. 2). Yet, they admit that "whatever the rational arguments against the dichotomy between art and nature, it remains implicit in all human actions and indispensable for understanding them" (ibid., p. 16). Similarly, I think that a distinction between natural and artificial objects is important for understanding the different ways in which they come into being. The theoretical and taxonomic reasoning which transforms natural entities, properties, and processes into scientific objects differs in kind from the material interventions that produce artificial scientific objects. The latter distinction, between the observable and the unobservable, is also a vague one, as argued by its opponents (e.g., Grover Maxwell 1962) and admitted by its advocates (e.g., van Fraassen 1980). Observation by means of instruments, from simple (such as a magnifying glass) to complex (such as an electron microscope), makes it particularly hard to draw a principled distinction between the observable and the unobservable realms. Such a distinction would have to be independent of the technological sophistication of the available means of observation; but more on this below.

[10] Cf. Daston (2008). The time-scale of observation is the crucial parameter here, since changing objects are more difficult to identify than stable objects. The difficulties are particularly acute when an object changes very rapidly. In those cases its identification depends on sophisticated instrumentation. See Canales (2009).

[11] For the Higgs field see Kaiser (2006), and for electricity in the eighteenth century see Steinle (2002).

[12] I am aware, of course, that it is not possible to do justice to the abundance of scientific objects within the confines of an article. My only excuse for the programmatic character of this paper is that it is part of a long-term project where various philosophical issues in the historiography of science will be explored in detail.

Be that as it may, the value of the above classification of scientific objects does not depend on the existence of any sharp boundaries. Rather, it lies in indicating that the questions regarding the birth and historicity of scientific objects admit different answers depending on the particular kind of scientific objects we are dealing with. Let me broach a few salient cases. The first concerns naturally occurring objects that are accessible to unmediated observation. Here, I think that three questions are crucial:

1. How and why do scientists focus their investigative gaze upon these objects?[13]
2. How are they picked out from the wider domain that contains them? How are boundaries drawn in that domain? In other words, how are these objects individuated?
3. How do these boundaries change over time?

The familiar example of planets may illuminate these questions. Several philosophers of science, most prominently Kuhn, have exploited this example for philosophical purposes. Planets were selected out of the wider domain of heavenly bodies. They were grouped together because they shared a property. They moved ("wandered") against the background of fixed stars. This common property held them together. Thus, what came into being when planets emerged as an object of study was a particular classification of heavenly bodies, which persisted for a very long time. During that period, the astronomers' knowledge of the motion of planets evolved considerably, whereas the classification of heavenly bodies remained intact. Planets persisted as stable scientific objects, until the rise of Copernican astronomy challenged the criterion that held them together. With the shift to a heliocentric astronomy the celestial grouping changed: now planets were held together by a different property, their revolution around a common center, close to the sun. The criterion that enabled the individuation of planets as a distinct kind was *conceptually constitutive* of their being as scientific objects. The users of the term "planet" picked out its referents by means of that criterion. In its absence, there would be no planets, but only an amorphous domain of heavenly bodies. Thus, whether a heavenly body is classified as a planet depends on the criteria of planethood, which are, thus, constitutive of planets qua scientific objects. A glance at the recent controversy over the status of Pluto, which ended up with its demotion to "dwarf planet", suffices to bring this point home (Messeri 2010).

Let me move to a second case, the case of phenomena (e.g., the laser) or entities (e.g., GMOs) created in the laboratory. These objects often do not exist prior to their manufacture in the laboratory.[14] Thus, their existence depends on human practices in a straightforward sense: the artificial laboratory conditions that make possible

[13] Cf. Daston (2000, 2008).

[14] Cf. Hacking (1983); Rheinberger (1997). It is not always possible to know whether a laboratory phenomenon does (not) occur 'in the wild'. One needs to know whether the laboratory conditions that give rise to the phenomenon in question are encountered in nature. Some phenomena that were first produced in the laboratory were later observed in a natural setting. The magnetic splitting of spectral lines, for instance, was first created in Zeeman's laboratory and then observed in the sun (del Toro Iniesta 1996). The important point, for my purposes, is that certain phenomena are brought about as a result of human intervention, which may, of course, reproduce natural processes outside of the laboratory.

their creation are *causally* (*materially*) *constitutive* of their existence. These objects come into being, in the strongest sense of the term, as novel material entities or processes, and may pass away if the conditions that enabled their coming into being cease to be in place.

The final kind of objects that will occupy me in the rest of this paper is hidden entities (indirectly observable or in principle unobservable).[15] Here the question of their coming into being as scientific objects is more complex. This is indicated by the historical fact that these entities (e.g., atoms) have often given rise to protracted ontological disputes. Furthermore, they lack many of the properties (e.g., color) that characterize manifest objects. Their existence is postulated for explanatory purposes (or otherwise inferred) before they become the focus of further investigation. The theoretical postulation of (or inference to) their existence inaugurates their career as scientific objects. Thus, our knowledge of them is always mediated by our theories. This does not mean that the existence of those objects is necessarily tied to any particular explanatory theory of their characteristics and behavior. Such a theory may not even be available. Following Ian Hacking and Peter Galison, we should distinguish different levels of theory, ranging from fundamental theories with a wide scope to specific models of particular phenomena. Armed with this distinction, we can inquire about the kind of theoretical knowledge that enables the inference from certain phenomena to their hidden cause. I will have more to say below on how hidden entities become scientific objects. Here let me just point out that they are usually conceived as natural kinds, which existed before their detection in the lab and their representation by scientists. To put it in stronger terms, representations of hidden entities often have a built-in presupposition, namely that the entities in question had been there before they became objects of investigation. Their detection and manipulation in the laboratory are not supposed to be constitutive of their existence.

Thus, naturally occurring manifest entities, laboratory phenomena, and their hidden causes come into being as scientific objects for different reasons and in different ways. The first emerge as scientific objects when they are tied together by means of new concepts; the second become scientific objects when they are experimentally produced; and the third come into being as scientific objects when their existence is postulated for explanatory purposes (or otherwise inferred from the phenomena). Hence the need for a pluralist conception of scientific objects, a historical ontology that would do justice to their various modes of being and becoming.[16]

My pluralist approach to scientific objects can encompass, I hope, other accounts of scientific objects in the literature on historical epistemology. In particular, it can incorporate Hans-Jörg Rheinberger's notion of "epistemic things", objects which emerge and develop in the context of experimental systems and whose existence depends on the conditions of their production in the laboratory. The reality of epistemic things, according to Rheinberger, derives from "their resistance, their

[15] I prefer the term "hidden entities", rather than "unobservable entities", because it fends off questions about the precise boundary between what can and cannot be observed (see Sect. 1 above). What is hidden, at a certain stage of technological development, may come to light as a result of progress in instrumentation. For more discussion of this point, I refer the interested reader to Arabatzis (2011).

[16] Cf. Hacking (2002); Klein and Lefèvre (2007).

capacity to turn around the (im)precisions of our foresight and understanding" (Rheinberger 1997, p. 23). To put it another way, we are convinced that the objects we deal with in the laboratory are real because they resist our attempts to manipulate them. This negative realism about epistemic objects is an attractive option, although not the only one. A more neutral possibility would be to interpret the capacity of epistemic objects to surprise us as a dissonance between different ingredients of experimental practice: high-level theory, models of the phenomenon under investigation, our understanding of the apparatus we employ, and the material realization of the experiment (cf. Hacking 1992). Furthermore, the realism question, as I indicated above, takes a different form for different kinds of objects. For instance, with respect to manifest entities which are outside our realm of intervention, such as planets, it concerns the character of their classification: Do these entities form a natural kind that reflects a pre-existing order in the world? Since we lack the capacity to manipulate them, this question has to be answered on some other grounds.

2 Remarks on the (Conceptual and Causal) Constitution of Scientific Objects

What I've said so far indicates that the formation and the historicity of scientific objects have to be understood along two dimensions: a conceptual (representational, theoretical) and a causal (interventionist, experimental, material). At the one end of the spectrum, there are entities (e.g., planets) which are causally independent from our investigative practices. We cannot manipulate those entities and thereby shape their characteristics; they lie beyond the sphere of our material influence. Their individuation as scientific objects is a conceptual affair. At the other end, there are entities (e.g., cloned animals) and phenomena (e.g., the laser) that are brought into existence by our causal intervention in the natural order. Our experimental practices are, then, constitutive of these objects.[17]

In between these two extremes, one finds regularities (e.g., about electricity) and entities (e.g., the electron) that are represented by novel scientific concepts and brought into the domain of experimental practice. They are detected and investigated by means of instruments and experimental set-ups. Clearly the role of technical apparatus is crucial in the detection and investigation of these objects. This role, however, can often be understood in epistemological, as opposed to ontological, terms: in many cases scientific instrumentation makes possible the detection of an object and the exploration of its properties, without, however, bringing that object into being. This is not to deny, of course, that there are cases (e.g., in microphysics or molecular biology) where instrumentation is constitutive of the very existence of scientific objects.[18]

Notwithstanding the intertwinement of our representational and experimental practices with the objects that we represent and probe experimentally, there are at

[17] Cf. though the qualification in fn. 14 above.

[18] Cf. Arabatzis (2003, p. 439). The "intersections" between scientific objects and scientific instruments in the history of the life sciences are insightfully explored in Rheinberger (2010).

least two reasons for distinguishing scientific objects from their representations and the experimental practices associated with them.[19] First, a representation focuses on certain aspects of the object (the "relevant" aspects) at the expense of others.[20] Representations are interest-driven and do not exhaust all the properties of the objects they stand for. Think, for example, of a map.[21] If we obliterated the distinction between an object and its representation we would lose sight of the inexhaustible character of scientific objects. Furthermore, it would not be possible to misrepresent an object.

The second reason for granting a (partial) autonomy to scientific objects, a relative independence from their representations and the experimental practices centered on them, has to do with the possibility of communication and genuine disagreement among scientists. If every change in the representation or the practices in question amounted to a change in the represented or manipulated object, then genuine disagreement in the sciences would become impossible. It would turn out that scientists, purporting to investigate a single object but representing it differently (or probing it in different ways), would be talking past each other, since they would refer to altogether different objects.

This is not to deny that a part of a representation is conceptually constitutive of the represented object, that it enables the individuation of the object. I mentioned above the case of planets. They were supposed to wander in the heavens, carried by crystalline spheres. Their former property was conceptually constitutive of their being planets, whereas the latter was not.

We may now see the limits of the historicity of scientific objects. Pace some commentators, who have suggested that we should abolish the distinction between scientific objects and our knowledge of them,[22] the historicity of scientific knowledge does not imply the historicity of its objects. Our knowledge of an object may change without affecting the theoretical criteria or the experimental techniques we use to individuate it. For instance, our current knowledge of electrons differs radically from the way they were understood in the late nineteenth-century. There is a sense though in which our knowledge of electrons, throughout its history, has latched on the same object. (See below.)

3 On a Particular Variety of Scientific Objects: Permanent (and Hidden) Natural Kinds

In the rest of the paper I will focus on objects that are supposed to be part of the permanent furniture of the universe. These objects (e.g., electrons) are not supposed to have a history, at least if we take at face value the accepted scientific story about

[19] The following remarks have been prompted by Latour's attempt to dispense with the distinction between objects and their representations. See Latour (1999). Cf. Bloor (2005, p. 300).

[20] Cf. Cartwright (1989, pp. 191ff).

[21] Cf. Giere (2006).

[22] Cf., for instance, Latour's claim that "objects and knowledge of objects are similarly thrown into the *same* Heraclitean flux" (Latour 2008, p. 86).

them. Typically, whether we are talking about the subtle fluids of the eighteenth-century or the various elementary particles of twentieth-century physics, they are not accessible to unaided observation. My main focus will be their birth and historicity. These objects emerge when various phenomena coalesce as manifestations of a single hidden entity. This happens because the phenomena in question have some, qualitative or quantitative, features in common. For example, combustion, calcination (oxidation), and respiration are made possible by the presence of atmospheric air. In the eighteenth-century, those different phenomena were grouped together as manifestations of the escape of phlogiston; the common role of air in all three phenomena was to absorb the phlogiston that was given off. Typically, after the postulation of hidden objects, their representations change over time. Therein lies their historicity. Under certain conditions, however, an evolving representation may still pick out the same "thing". This happens when the observable (experimental) manifestations of an object remain stable or expand in a cumulative fashion.[23]

This stability or cumulative expansion has two interrelated aspects. One aspect lies in the persistence or cumulative expansion of a body of observation sentences describing the purported manifestations of the hidden object in question.[24] For instance, after the 'discovery' of positrons, there has been an expanding body of sentences about the tracks of positrons in cloud chambers. As Hacking pointed out, "The theory [of positrons] might be abandoned or superseded by a totally different theory about positrons, leaving intact what had, by then, become the class of observation sentences represented by 'that's a positron'." (Hacking 1983, p. 179) To put it another way, the sentences describing the purported manifestations of hidden entities in the laboratory can be robust, even across radical changes in the way these entities are represented. Among the sources of this stability is, I think, the persistence of relatively 'low-level' beliefs about the behavior of these entities in experimental settings.

And this brings me to the second aspect of the experimental stability of hidden entities. This aspect stems from the double lives that these entities lead: as theoretical objects and as experimental objects. These interacting lives are, partly, independent from each other. Experimental objects are partly independent from their theoretical counterparts. Peter Galison, among others, has stressed this point (Galison 1997). Extending Galison's idea, I would argue that the parallel lives of hidden entities, in theoretical discourse and in the laboratory, have different rhythms. These different historicities, as it were, may allow for radical changes in their theoretical description without a threat to their identity. As I have argued elsewhere, the (putative) experimental manifestations of hidden entities such as the electron provide a way to identify them across theoretical ruptures. The traces of these entities in various experimental situations are not attributed to different entities whenever theories change. Furthermore, experimentally obtained information about these entities has a robustness that is not affected by theory change. For example, the experimentally obtained charge to mass ratio of the electron survived

[23] For a detailed argument see Arabatzis (2006).

[24] I take it, as cogently argued by Putnam (1962), that "observation sentences" can contain theoretical terms referring to hidden entities.

radical changes in its theoretical description.[25] Something similar may hold about properties such as mass or temperature. That is, experimental operations may provide a stable backdrop of meaning against which one can identify those properties before and after a scientific revolution.[26] Thus, the experimentally obtained traces of an object and the experimental operations associated with it are often more robust than its theoretical description. In any case, the stable identity of scientific objects (both entities and properties) cannot be presumed prior to historical research, as it often happens in the philosophical literature on conceptual change, but has to be investigated empirically.[27]

4 From Cathode Rays to Electrons: "The Persistence of a Scientific Object"[28]

Let me now take up some of the issues I raised, in the context of the early history of electrons. By the end of the nineteenth-century electrons had surfaced in a variety of theoretical and experimental contexts. The results of four different fields (electrochemistry, electromagnetic theory, spectroscopy, and cathode rays) converged to support the existence of a novel subatomic constituent of matter. From the very beginning of their career as scientific objects, electrons had two faces, a theoretical and an experimental. On the one hand, they were posited to account for certain difficulties that had emerged in the theoretical exploration of the ether. On the other hand, their existence was suggested by several experimental developments in electrolysis, in the discharge of electricity through rarefied gases, and in spectroscopy. That was evident to contemporary observers. Paul Langevin, for instance, referred to "the double base on which rests the idea of the electron; on the one hand … the exact knowledge of the electromagnetic ether which we owe to Faraday, Maxwell, and Hertz, and on the other hand … the experimental evidence brought forward by the recent investigations into the granular structure of electricity".[29]

A key event in the emergence of electrons qua scientific objects was the resolution of the cathode ray controversy. There were two opposing views concerning the constitution of cathode rays, a phenomenon produced in the discharge of electricity through gases at very low pressure. British and French scientists, who maintained the first view, identified cathode rays with streams of charged particles. Some German physicists, who advocated the second view, identified them with processes in the ether. The controversy subsided in 1897, when J. J. Thomson showed that they were composed of "corpuscles", minute charged particles. Two technical achievements were instrumental in Thomson's demonstration. First, he was able to deflect cathode rays by an electric field. The previous failure of Hertz to produce that phenomenon had been interpreted as evidence for

[25] See Arabatzis (2006).

[26] See Chang (2008).

[27] Cf. Rheinberger (2005, pp. 408–409).

[28] I borrow this term from Chang (2008).

[29] Langevin (1904, p. 156).

the ethereal nature of cathode rays. Second, from their electric and magnetic deflections he measured, indirectly, their mass to charge ratio (*m/e*). It turned out that the value of *m/e* was three orders of magnitude smaller than "the smallest value of this quantity previously known, and which is the value for the hydrogen ion in electrolysis".[30]

In Thomson's experiments on cathode rays the mode of interaction with the investigated objects changed. Thomson was able to do things on them that had not been previously possible. Furthermore, he was able to measure those objects, to cull information from them that had not been previously available. Did Thomson's objects of study change as a result of his experimental interaction with them? I do not think so. What changed was their representation. Cathode rays were now represented as minute particles, universal constituents of all atoms. If electrons were to play a role in the explanation of phenomena outside the walls of Thomson's laboratory, the experimental setup that had been used for their detection could not be constitutive of their existence. Moreover, electrons were investigated in different experimental settings, where the experimental conditions were not the same. In addition to cathode ray tubes, they were detected in magneto-optic experiments, and, later, in cloud chambers. If experimental conditions were constitutive of the objects of experimentation, it would turn out that the objects investigated in those different experimental settings were not the same.

Far from threatening the identity of the electron, its experimental manifestations may provide the key for its synchronic and diachronic identity as a scientific object. Consider, first, the synchronic identity of the electron. In early twentieth-century physics β-rays (high speed electrons) were employed as a tool to adjudicate between contemporary electromagnetic theories, which gave different accounts of the electron's shape and structure. First, the theory developed by Max Abraham implied that the electron was a rigid sphere with a uniform (surface or volume) distribution of charge, whose shape was not affected by its motion through the ether. Second, according to H. A. Lorentz's theory of electrons and Albert Einstein's relativity theory, the electron was deformable and contracted in the direction of its motion. Third, Alfred Bucherer and Paul Langevin suggested that a moving electron would be deformed but its volume would remain constant. All of those theories implied that the mass of the electron depended on its velocity. However, their quantitative predictions about that dependence differed. Walter Kaufmann undertook an experimental research program that aimed at elucidating the nature of the electron's mass and its variation with velocity. He determined the velocity dependence of the charge to mass ratio of β-rays, on the basis of their electric and magnetic deflections. His results seemed to contradict the predictions of the "Lorentz-Einstein" theory and to favor the theories of Abraham, Bucherer, and Langevin.[31] The important point for my purposes is that Kaufmann's experiments provided a middle ground that enabled the comparative evaluation of competing representations of the electron's shape and structure. All parties agreed that the experimental

[30] Thomson (1897, p. 310). For more information about the history of cathode rays and a detailed bibliography, see Arabatzis (2009a).

[31] The previous passage is adapted from Arabatzis (2009b).

counterparts of those competing representations were the entities investigated by Kaufmann. The existence of incompatible representations of electrons did not raise doubts about their identity in experimental contexts.[32]

Let us now consider the diachronic identity of the electron. Ever since its appearance in the late nineteenth-century the representation of the electron has been in constant flux. Its career cut across the momentous revolutions of early twentieth-century physics, which altered beyond recognition the electron qua theoretical object. As represented in the late 1920s, the electron appears to be a very different animal than its late nineteenth-century counterpart. Around the turn of the century, the electron was represented as a structure in the ether, whose trajectory in space could be visualized. After the quantum mechanical revolution and the demise of the ether, the electron was endowed with non-visualizable properties (e.g., spin) that could not fit its classical persona. Is it at all plausible to suggest that physicists were still talking about the same object? I think it is. A case can be made for the electron's stable identity, despite the radical alteration of its representation. Here I can only provide a mere outline of a proposal I developed elsewhere, a proposal which capitalizes on the dual character of the electron, as a theoretical and experimental object. When a theoretical object evolves it may still refer to the same entity, on two related conditions: First, the experimentally determined properties of the entity in question should remain (approximately) stable. That is, those properties that have been inferred from the entity's purported behavior in experimental settings should not be affected by theory change. Second, the experimental situations associated with an evolving theoretical object should exhibit a cumulative development. That is, the experimental manifestations of its hidden referent, the experimentally obtained phenomena attributed to it, should expand in a cumulative fashion. Indeed, the career of the electron qua experimental object has that cumulative character. Ever since its birth as a scientific object, the experimentally determined properties of the electron, such as its charge to mass ratio, remained robust across theory change. Furthermore, the experimental phenomena attributed to it (cathode ray experiments, magneto-optic effects, β-rays, cloud chamber tracks, etc.) continued to grow.[33]

Regardless of my reading of the history of the electron, I hope to have shown that there are many kinds of scientific objects, whose historicity may take different forms, depending on the particularities of each kind. One thing is clear to my mind: an understanding of the various modes of the historicity of scientific objects requires an integration of philosophical analysis and historical investigation.

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32 Cf. Galison (1997, pp. 812–813); and Staley (2008, pp. 219–259).

33 See Arabatzis (2006).

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