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Experimental Individuation and Philosophical Retail Arguments

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Abstract: This paper aims to defend the use of the notion of experimental individuation, which has recently been developed by Ruey-Lin Chen, as a criterion for the reality of theoretical entities. In short, when scientists experimentally individuate an entity, a realist conclusion about that entity is warranted. We embed this claim regarding experimental individuation within a framework that allows for other criteria of reality. And we understand so-called retail arguments regarding the reality of a particular theoretical entity as arguments that concern choosing an appropriate criterion of reality for that entity and determining whether the relevant first-order scientific evidence satisfies that criterion. We argue that such retail arguments are philosophical because defending criteria of reality, and showing that they are or are not satisfied in particular cases, involves work that is distinctively philosophical. And we illustrate this philosophical work by applying our criterion of experimental individuation to three historical cases: Davy's potassium, Lavoisier's muriatic radical, and Thomson's electrified particles.

Keywords: individuation, scientific realism, retail arguments, experimentation

1. Introduction

The goal of this paper is to introduce experimental individuation as a relatively theory-independent criterion for granting the reality of theoretical entities. The notion of experimental individuation has been developed by Chen (2016, 2018), who has focused on the issue of individuality rather than that of reality. We propose to use Chen's notion as a criterion of reality. We argue that demonstrating the experimental individuation of an entity constitutes a good reason to be a realist about that entity. Conversely, if scientists cast doubt on the prospects of experimentally individuating an entity, that doubt sometimes constitutes a good reason to be an anti-realist about that entity.

When we put forward experimental individuation as a criterion of reality, we don't hold that it is the only criterion of reality, and we don't attempt to generalize it to all of the entities posited by our best theories. Rather, we admit that it has limited applicability and that there are other valid experimental and theoretical criteria of reality.

As a consequence, applying the criterion of experimental individuation to a particular entity in a particular case requires a retailist approach to the scientific realism debate. We take the term 'retailist' from Park (2016), and use it to denote those approaches to the realism debate that focus on the truth of particular theoretical claims and the reality of particular entities rather than theories and entities in general. This sort of approach was originally proposed by Magnus and Callender (2004), who argue that we ought to abandon "wholesale arguments," which are "arguments about all or most of the entities posited in our best scientific theories," and embrace "retail arguments," which are "arguments about specific kinds of things such as neutrinos, for instance" (2004, p. 321).

In our paper, we understand the contrast between retailism and wholesalism in the following way. Retailists do not attempt to generalize their conclusions based on the investigation of one case to other similar cases, while wholesalists do. Each scientific case, whether similar to a previously examined one or not, must be investigated individually by analyzing the details of the scientific practices involved. To put the point another way, wholesalists generalize a single criterion of reality to all of the entities posited by our best theories. In contrast, retailists hold that we should not generalize any criterion of reality that is successfully applied to one particular case to all cases—different cases may require different criteria.

We take the retailist approach to the realism debate to be promising because it fits well with many cases in the history of science. By arguing, within a retailist framework, that experimental individuation serves as a relatively theory-independent criterion of reality, we aim to promote the retailist approach. We argue that articulating and defending such a criterion, and determining whether it is satisfied, involves distinctively philosophical work that goes beyond the first-order scientific evidence. And we distinguish between what we call *scientific retail arguments*, which do not go beyond the first-order evidence, and *philosophical retail arguments*, which involve determining whether or not the first-order evidence satisfies some criterion of reality.

To that end, we proceed as follows. Section 2 introduces our retailist approach, develops the notion of a philosophical retail argument, and distinguishes that notion from the notion of a scientific retail argument. Section 3 puts forward experimental individuation as a criterion for the reality of theoretical entities. In section 4, we apply this criterion to three historical case studies: the discovery of potassium, the elimination of the muriatic radical, and the measurement of the electron's mass-to-charge ratio. In the course of discussing these case studies, we develop three philosophical retail arguments regarding the reality of these three entities. We do so in order to defend our claim that experimental individuation can serve as a criterion of reality and show that applying it involves distinctively philosophical work. Section 5 provides some further defense of our criterion by arguing that its relative theory-independence makes it preferable to more theory-dependent criteria. In section 6, we conclude.

2. Philosophical Retail Arguments

Our claim that experimental individuation can serve as a criterion of reality is situated within a retailist framework that allows for other criteria of reality. In this section, we first introduce retailism and then develop the notion of a philosophical retail argument.

In order to grasp what retailism is, it's useful to begin with the position to which it is opposed, namely, wholesalism. Wholesalism comes in a number of varieties. One is standard scientific realism (e.g., Putnam 1978; Boyd 1981), which is a position regarding theories in general. The basic idea is that the success of our best theories warrants the claim that they are at least approximately true, as well as the claim that the theoretical entities that they posit exist. Some forms of anti-realism (e.g., van Fraassen 1980) are also wholesalist positions, insofar as they typically involve endorsing claims about theories in general and denying that success warrants the two claims endorsed by proponents of standard scientific realism.

These positions are wholesalist because, as Magnus and Callender (2004) argue, their proponents attempt to support them by engaging in wholesale arguments. Magnus and Callender focus on two examples of such arguments. First of all, there is the no-miracles argument (NMA), according to which the success of our best theories would be a miracle if those theories weren't at least approximately true. Second, there is the pessimistic meta-induction (PMI), which uses past successful-but-false theories as an inductive basis for concluding that our current successful theories are false as well. NMA is taken to support "[w]holesale realism," which "seeks to explain the success of science in general"; and PMI is taken to support "wholesale anti-realism," which "seeks to explain the history of science in general" (2004, p. 321).

Magnus and Callender propose that we ought to replace wholesale arguments with retail arguments, and wholesalism with retailism. Unlike wholesale arguments, the scope of a retail argument is restricted to a particular theory or a particular kind of theoretical entity. By shifting the focus from theories in general to theories in particular, philosophers can dissolve the traditional realism debate and abandon wholesalism for retailism. Retailism, as Magnus and Callender understand it, amounts to the position that "realism and anti-realism are options to be exercised sometimes here and sometimes there" (2004, p. 337), which opens up the possibility that "[t]here may be good reasons to be a realist about neutrinos, an anti-realist about top quarks, and so on" (2004, p. 333).

A number of philosophers have defended positions similar to Magnus and Callender's retailism. For example, Saatsi adopts the retail-wholesale metaphor, and attempts to determine whether particular realist arguments are "more form-driven (wholesale) or more content-driven (retail)" (2010, pp. 10-11). Form-driven arguments "attempt[] to justify some inductive inferences by reference to some general formal attribute unifying all these inferences," while content-driven arguments "take there to be more justificatory analysis to be done on [a] case-by-case basis by taking into account what these inferences are about" (2010, p. 11). Saatsi goes on to argue that content-driven arguments are preferable to form-driven ones. While his distinction is, strictly speaking, different from Magnus and Callender's, the obvious similarities between the two distinctions are presumably what lead Saatsi to employ their terminology. To take another example, Fitzpatrick defends what he calls the "local strategy," according to which "the best foundation for a realist attitude towards a particular theoretical claim of modern science … is the weight of the particular first-order evidence that led scientists to accept the claim in the first place" (2013, p. 143). Fitzpatrick acknowledges that his "thesis is similar to that of Magnus and Callender," and states that he "agree[s] with this move towards retail arguments" (2013, p. 142).

As we stated in section 1, we propose another way to contrast retailism and wholesalism, namely, in terms of criteria of reality. In order to conclude that a particular component of a theory (for example an entity or a structure) exists, retailism allows for the use of distinct criteria of reality in different cases and contexts while wholesalism requires the use of only one criterion. To put the point another way, wholesalists adopt a single criterion while retailists allow for one or more criteria of reality. In our view, the main insight of Magnus and Callender, Saatsi, and Fitzpatrick is that the details matter when determining what components of our theories we ought to commit to. However, if the details matter only to the extent that those details do or do not satisfy a single criterion of reality, then it seems that we have a wholesale argument instead of a retail argument. We take it that the details also matter for determining which of several distinct criteria of reality are appropriate and applicable to a given case, which is why we understand the contrast between retailism and wholesalism in the way we have proposed.

Understood in this way, the contrast between retailism and wholesalism concerns argumentative strategy as opposed to the theoretical content to which retailists and wholesalists commit.[1] When it comes to a particular theory, a retailist and a wholesalist may indeed commit to some of the same content. But the wholesalist will generalize the criterion of reality applied to the content to all cases, while the retailist will not generalize the applied criterion to other cases—in each individual case the retailist should search for an appropriate criterion.

This brings us to the central element in the retailist's argumentative strategy, namely, the retail argument. One issue regarding retail arguments is whether they go beyond science into philosophy.[2] Magnus and Callender give no indication that retail arguments go beyond the first-order scientific evidence. According to them, we should "answer the question, 'Are there atoms?', by referring to the same evidence scientists use to support the atomic hypothesis" (2004, p. 321). And while Saatsi argues that "content-driven realist arguments are bona fide philosophical arguments" (2010, p. 26), arguments can be more or less content-driven, and he admits that "[f]ully content-driven" arguments are "[s]cientific arguments" (2010, p. 11).

According to our way of understanding it, retailism does go beyond science into philosophy. The first-order scientific evidence that scientists present must satisfy some kind of criterion or other in order to warrant a realist attitude towards a particular theoretical claim, entity, structure, etc. Our focus in this paper is on entities. While scientists often argue that a particular kind of entity exists, their arguments detail the first-order evidence for the existence of that kind of entity without invoking a criterion of reality that this evidence satisfies. Because scientists are silent on this matter, it takes some philosophical work to articulate criteria of reality, determine which criteria are appropriate and applicable to a particular case, and assess whether or not the first-order evidence satisfies a particular criterion once it is deemed applicable. Upon doing so, it's possible for philosophers to conclude that the evidence does not satisfy the most appropriate criterion, and to disagree with a scientist's judgment that some evidence supports the claim that a particular kind of entity exists. The fact that retailists can disagree with scientists' judgments shows that retailism does not amount to merely repeating evidence first put forward by scientists—it involves going beyond science into philosophy.

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[1] We thank an anonymous reviewer for pointing out this important distinction. It's worth noting that so-called selective realist positions differ from one other and from other positions in the realism debate, not in terms of the argumentative strategy they adopt but in terms of the theoretical content to which they are committed. For example, entity realists commit to the reality of entities, structural realists to structures, and deployment realists to theoretical components that contribute to generating novel predictive successes.

[2] Dicken (2013) raises an important challenge to retailism on this basis. Responding to this challenge falls outside of the scope of the present paper.

In sum, our understanding of retailism allows us to maintain that the first-order evidence is crucially important. It also allows us to admit that issues in the realism debate are not settled by first-order evidence alone—they also require distinctively philosophical argumentation. And it provides us a way to go beyond that evidence in terms of criteria of reality that are philosophical, at least in the sense that such criteria have traditionally played a role within the realism debate. Identifying and defending criteria of reality, and showing that the evidence does or does not satisfy them, involves work that is distinctively philosophical.

We illustrate these ideas in terms of a case from the history of science. This case concerns Thomson's work on cathode rays and his determination of the mass-to-charge ratio (*m*/*e*) of the electron. According to the official website of the Nobel Prize, it was because of this work that Thomson "received the Nobel Prize in 1906 for the discovery of the electron, the first elementary particle."[3] Thomson (1897, 1967[1906]) hypothesized that cathode rays are currents of "carriers of negative electricity" or "corpuscles"—what we now know as electrons.[4] His hypothesis was not only about the nature of cathode rays, but also about the interaction among cathode rays and other theoretical entities such as electrostatic fields and electrons. In order to determine the mass-to-charge ratio, he measured the deflection of cathode rays passing through an electrostatic field, the strength of the electrostatic field, and other related magnitudes. He interpreted the value that he obtained for *m*/*e* in light of his hypothesis, and his experimental results confirmed that hypothesis.

However, one might ask how it's possible to infer from Thomson's experimental confirmation of his hypothesis to the claim that he had thereby demonstrated the existence of the electron. Philosophers can engage with such a question. And regardless of the answers they provide, they must at least defend those answers by invoking some kind of criterion for concluding that the evidence that scientists have offered does or does not constitute a demonstration of the existence of a given entity. To take one example of such a criterion, Hacking (1983, p. 23) suggests manipulation: "if you can spray them then they are real." While Thomson manipulated cathode rays, he did not manipulate electrons, and so, according to Hacking's criterion, Thomson did not offer evidence strong enough to demonstrate the existence of electrons. To take another example, there is what Psillos (2005, pp. 398-399) calls "the only workable criterion of reality," which is "the explanatory criterion: something is real if its positing plays an indispensable role in the explanation of well-founded phenomena." Suppose for the sake of argument that Thomson's electron was explanatorily indispensable but not manipulable in the late nineteenth century. Consider two wholesalists, one of whom employs Hacking's criterion

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[3] Retrieved January 27, 2016 from http://www.nobelprize.org/educational/physics/vacuum/experiment-1.html. See also Harré (2002[1981]) and Whittaker (1989).

[4] For the identification of Thomson's corpuscles with electrons, see Rutherford (2004[1904], p. 53) and the reprint of Thomson (1897) in Magie (1969, pp. 583-597), in which Magie makes the identification.

as the sole criterion of reality, while the other employs Psillos's criterion. These two wholesalists will come to conflicting conclusions, with one claiming that Thomson's evidence doesn't support the claim that the electron exists, and the other claiming that it does, respectively. Insofar as the disagreement between these two wholesalists concerns their chosen criterion of reality, their disagreement is, at least in part, a philosophical one. Similarly, a retailist who attempts to determine which of these two criteria is most appropriate in this case, or whether a third criterion is more appropriate, is engaging in a task that is distinctively philosophical.

At this stage of our argument, the important point is not whether Psillos or Hacking is correct. It is that providing a criterion for granting the reality of a theoretical entity, assessing the appropriateness of that criterion for the case at hand, and determining whether or not the evidence that scientists have offered satisfies that criterion, constitutes a way for philosophers to engage with retail arguments. Scientists are the ones who initially put forward retail arguments; they offer the first-order scientific evidence. Retail arguments, in Magnus and Callender's sense, are what we call *scientific retail arguments*. We choose this label because retail arguments, for Magnus and Callender, do not go beyond the first-order scientific evidence, and because we want to contrast such arguments with what we call *philosophical retail arguments*. These arguments concern choosing an appropriate criterion of reality for a particular case and determining whether or not the first-order evidence presented in a scientific retail argument satisfies that criterion. In short, a philosophical retail argument results from the application of a criterion of reality to a scientific retail argument. Such arguments are philosophical because it is a distinctively philosophical task to identify a criterion of reality and determine whether or not it is satisfied in a given case.

One might be skeptical about our claim that such work is distinctively philosophical. Chang's work on the relationship between the history of science and the philosophy of science provides an additional line of defense for our claim. Chang (2012a, p. 110) holds that "it is instructive to try seeing the history–philosophy relation as one between the concrete and the abstract . . . We cannot understand scientists' actions, not to mention judge them, without considering them in abstract terms (such as 'confirmed', 'coherent', 'observation', …" Determining whether or not some first-order scientific evidence satisfies a particular criterion of reality involves applying abstract concepts—most notably, the criterion—to concrete cases. It also involves making judgments—most notably, about whether, in light of the criterion, the evidence does or does not suffice to establish the existence of a particular entity. If the work involved in advancing what we call a philosophical retail argument doesn't count as philosophical, then neither does the kind of work in the history and philosophy of science that Chang has in mind. But if we conceive of philosophical work along the lines that Chang suggests, the notion of a philosophical retail argument gives us a way of avoiding the charge that retailism does not go beyond science into philosophy. It provides a way of developing retailism into a position that is distinctively philosophical.

3. Experimental Individuation as a Criterion of Reality

Our goal in this section is to discuss how to understand experimental individuation and why it can serve as a criterion of reality for theoretical entities. We begin with the observation that individuation and ontological commitment are connected. When scientists are ontologically committed to the theoretical entities they posit, this commitment involves not just a belief that the entities exist, but also a responsibility to demonstrate their existence. Scientists may be able to individuate an entity theoretically. But individuating an entity in a theory is not sufficient to demonstrate that it exists. Demonstrating the existence of a posited entity often requires scientists to produce an individual instance or sample of that entity by performing an experiment, i.e., to experimentally individuate it. When scientists haven't yet tried to experimentally individuate a posited entity, or when they repeatedly try and fail to do so, their ontological commitment to that entity is doubtful.

At this point, we should distinguish *theoretical individuation* from *experimental individuation*. Scientists theoretically individuate an entity if, in the course of theorizing, they describe a set of properties and behaviors of a posited entity by which they can identify it and distinguish it from other entities. However, these descriptions by which scientists theoretically individuate entities require evidence. Scientists can offer evidence for the existence of a theoretical entity if they produce an instance or sample of such an entity by performing an experiment. In doing so, they individuate an entity experimentally.

The relationship between theoretical individuation and experimental individuation is much the same as the relationship between theory and experiment more generally. Various worries about the theory-ladenness of experimentation are relevant here. If a theoretical hypothesis yields a prediction regarding some experimental result, the result may be interpreted in light of the hypothesis. Moreover, since a theoretical hypothesis may involve two or more theoretical entities and their interactions, it can be difficult to show that an experiment produces an instance or sample of the target entity, i.e., that it experimentally individuates that entity. And it can be difficult to judge whether an experiment produces a real individual, as opposed to a mere phenomenon that results from experimental apparatuses and their interactions with experimented objects. For these reasons, a conception of experimental individuation that is sufficiently independent of theoretical interpretation is needed.

Is there such a conception? One candidate is Hacking's (1983, p. 23) manipulation criterion, which we mentioned in section 2. Perhaps experiments that individuate entities are experiments that manipulate them. However, since experimenters can manipulate not just real individuals, but also mere phenomena, manipulation is not sufficient for experimental individuation.[5] Chen (2016) takes manipulation, along with two other conditions, namely, separation and maintenance of structural unity, as necessary and jointly sufficient conditions for the experimental individuation of a theoretical entity. In short, experiments that produce individuals are experiments that separate individuals from their surrounding environments, manipulate them, and maintain their structural unity throughout the process. Importantly, Chen's further conditions ensure that the manipulated object is a real individual as opposed to a mere phenomenon. Since mere phenomena can't be separated from the environments in which they become manifest, Chen's separation condition avoids the problem of mistaking a mere phenomenon for a real entity. We return to this point in section 5, where we draw upon the case studies we discuss in section 4 in order to demonstrate more fully the extent to which this account of experimental individuation is sufficiently theory-independent.

Importantly, the criterion of experimental individuation has limited applicability because it can only be applied to cases in which scientists perform experiments on purported entities. Chen (2016) has discussed cases of experimental individuation from physics (the creation of Bose-Einstein condensates) and biology (genetic engineering). And later in this paper, we discuss two cases from chemistry (the discovery of potassium in section 4.1 and the elimination of the muriatic radical in section 4.2) and another case from physics (Thomson's work on cathode rays in section 4.3). Physics, chemistry, and biology provide the most favorable cases for our criterion. But it's not clear that our criterion is applicable to all of the experimental sciences, since it's not clear what experimental individuation would amount to in, say, experimental economics or psychology. And it is inapplicable to branches of science that do not make use of experiments, for example, astronomy for much of its history. Our criterion is only applicable to cases that involve the performance of experiments on purported entities.

Our criterion may seem to have limited applicability in another sense, namely, that it is only applicable to entities that are individuals. Some theoretical entities, like the chemical substances named by mass terms like 'water,' 'phlogiston,' and 'oxygen,' are paradigm cases of non-individuals. It's therefore not immediately obvious how we can appeal to the notion of experimental individuation when it comes to such entities. However, this sort of limited applicability is only apparent. We propose to apply our criterion to chemical substances by considering the experimental individuation of samples of such substances, as we illustrate in section 4.1 in terms of the discovery of potassium. Since samples count as individuals, our criterion is applicable to cases involving non-individuals like chemical substances.

That said, the applicability of our criterion is still limited, in which case it's reasonable to admit other criteria of reality in addition to the criterion of experimental

[5] Bueno (2018) argues for a similar point from an empiricist perspective. He uses three cases of trapping quantum particles in experiments in order to argue that Hacking's manipulation criterion cannot successfully serve as a criterion of reality.

individuation. Other criteria of reality include observation, exploration, and measurement. While we may not be able to experimentally individuate celestial bodies, astronomers' observations of those bodies constitute a good reason to be a realist about them. Seismologists' explorations of the earth's core by means of seismic waves constitute a good reason to be a realist about it, though there's no way to experimentally individuate it. And although physicists working in the late nineteenth and early twentieth centuries were not able to experimentally individuate atoms, the fact that they were able to measure the value of Avogadro's number in distinct ways constitutes a good reason to be a realist about atoms.

More generally, experimental individuation is sometimes not possible, either due to (1) technological limitations or to (2) the fact that the (purported) entity in question is not the sort of thing that can be individuated experimentally. Upon examining the details of a particular case, one may come to the conclusion that adopting a realist attitude towards a particular posited entity *prima facie* requires the experimental individuation of that posited entity or of a sample of that posited entity. In such cases, if neither (1) nor (2) is the case, experimental individuation is an appropriate criterion of reality to apply, and it is not merely a sufficient condition for reality but also a necessary one. In such cases, failure to experimentally individuate a posited entity or sample of a posited entity constitutes a good reason to be an anti-realist about that entity. However, when (1) is the case, we can admit other criteria of reality while maintaining that experimental individuation would still constitute strong evidence for the reality of the entity. And when (2) is the case, we can admit that the criterion of experimental individuation is inapplicable and rely on other criteria. Hence, experimental individuation as a criterion of reality is not applicable to theoretical entities in general. As a result, a wholesale argument based on this criterion is untenable, and our view that experimental individuation is one of several criteria of reality fits naturally into the retailist framework that we introduced in section 2.

4. Three Historical Case Studies

In this section, we use three cases from the history of science to discuss how experimental individuation is used as a criterion of reality. In cases in which an instance or sample of a posited entity is required for demonstrating its existence, we find that scientists often try to settle the ontological status of the entity by attempting to experimentally produce such an instance or sample. However, they do so without explicitly invoking or relying on experimental individuation as a criterion of reality—their goal is merely to offer an instance or sample. In cases in which scientists succeed in offering an instance or sample, they tend to conclude that the entity exists. Repeated failure leads scientists to either conclude that it doesn't exist, or else search for other ways to demonstrate its existence.

It's worth first clarifying the role that these case studies play. If we were to claim that our criterion of experimental individuation can simply be read off of these case studies, then it's not clear that articulating and defending a criterion of reality would take us beyond science into philosophy. In order to defend against this objection, we begin by emphasizing that, in some cases, experimental individuation is merely implicit in scientific practice. When Chen initially proposed his conception of experimental individuation, he presented it as a conception that is "implied by the use of certain experimental techniques" and "drawn from the performance of related experiments" (2016, pp. 354, 355). In other words, this conception is not something that scientists have articulated explicitly, and it takes some philosophical work to show how experimental individuation is implicit in experimental practices and applicable as a criterion of reality. In other cases, experimental individuation is not implicit in scientific practice, for example, when scientists have no intention to isolate an instance or sample of a posited entity or have not succeeded in doing so. In some such cases, experimental individuation is nonetheless an appropriate criterion of reality to apply because an instance or sample of a posited entity is *prima facie* required in order to demonstrate its existence. And importantly, it takes some philosophical work to show this.

One more clarification is in order. In some of the case studies that follow, our judgment regarding the existence of a particular kind of entity matches the judgment of the scientists we discuss. One might object that we therefore aren't really going beyond science into philosophy. In order to respond to this objection, we begin by noting that scientists' reasoning tends to operate at the level of the first-order evidence and to concern how that evidence supports or tells against various claims and hypotheses—this is a scientific retail argument. Scientists tend not to conduct their reasoning in terms of whether or not this first-order evidence satisfies a criterion of reality like experimental individuation. Our goal in examining these case studies is to make explicit the criterion of reality (namely, experimental individuation) that is *prima facie* appropriate for the entities in question, determine whether the first-order evidence satisfies that criterion, and thereby advance philosophical retail arguments. In cases where we come to the same conclusions as the scientists involved, it should be emphasized that we do so via a different route. Scientists reach their conclusions via the first-order evidence, whereas we reach our conclusions by considering whether or not this evidence satisfies the criterion of experimental individuation.

4.1 A Realist Conclusion Regarding Davy's Potassium

To begin with, we will discuss Davy's discovery of the element potassium. Davy first isolated potassium by decomposing potash, which he did by means of electrolysis (1808, pp. 4-5). He was the first to decompose potash, though for some time, chemists suspected it to be a compound, and so it was an outstanding problem to discover the constituent elements of potash—the posited entities in this case.[6] Davy acted on a small piece of moistened potash with a Voltaic battery. As a result, at the negative surface of the battery Davy observed the appearance of "small globules having a high metallic lustre, and being precisely similar in visible characters to quicksilver" (1808, p. 5). In the lecture in which he reports these results, Davy goes on to write: "These globules, numerous experiments soon shewed to be the substance I was in search of, and a peculiar inflammable principle the basis of potash" (1808, p. 5). And later in the lecture, he proposes the name "Potasium [sic]" for the basis of potash (1808, p. 32).

This experiment, on its own, did not demonstrate the experimental individuation of a sample of potassium. However, this experiment, combined with other experiments that Davy conducted, collectively satisfy Chen's three conditions for experimental individuation.

First of all, there is Chen's separation condition: scientists must separate the entities that they produce "from their environments" (2016, p. 348), and "from the experimental instruments that may have helped produce [them]" (2016, p. 365). In order to determine whether his results depended on the platinum instruments that he used, Davy performed a number of experiments using a variety of other materials, including copper, silver, and gold (1808, p. 5). And in order to determine whether his results depended on the fact that he conducted his experiments in the open atmosphere, he performed similar experiments in a vacuum (1808, p. 5). In all of these cases, he obtained the same results. These experiments collectively show that Davy had separated potassium from its surrounding environment (including the atmosphere and the other components of potash), and from the instruments that he used, thereby satisfying Chen's separation condition.

Second, there is Chen's condition regarding the maintenance of structural unity. Chen understands structural unity as the idea that "the components of an individual are structured into a whole in some specific manner" (2016, p. 358). Davy encountered a number of difficulties when it came to maintaining the structural unity of the globules of potassium that he had produced because "they acted more or less upon almost every body to which they were exposed" (1808, p. 10). One of the first things Davy notes about the globules is that they did not last long—the ones that did not explode immediately after forming soon lost their metallic luster and became "covered by a white film" (1808, p. 5). Davy identifies this film as pure potash, and explains how it attracts moisture from the atmosphere, converting the globule into a saturated solution of potash (1808, p. 7). Eventually, Davy discovered one substance on which potassium did not have much of an effect, namely, recently distilled naphtha (1808, p. 10). He used that fluid to preserve globules of potassium, and he was able to examine the properties of potassium in the atmosphere by covering the globules with a thin film of naphtha. This method allowed Davy to maintain the structural unity of potassium, thus satisfying Chen's condition.

[6] See Lavoisier (1965[1789], p. 156).

Third, there is Chen's manipulation condition. Chen understands this condition in terms of the "instrumental use" of an object "to investigate other phenomena of nature" (2016, p. 358). Towards the end of the lecture in which he reports the electrolytic decomposition of potash, Davy conjectures that the globules of potassium he isolated "will undoubtedly prove powerful agents for analysis; and having an affinity for oxygene [sic] stronger than any other known substances, they may possibly supersede the application of electricity to some of the undecompounded bodies" (1808, p. 44). Making good on this conjecture would amount to showing that chemists can use potassium to decompose previously undecomposed substances, thereby satisfying Chen's manipulation condition. And in the following year, Davy (1809, pp. 76-77) and also Gay-Lussac and Thénard (1808), made good on this conjecture by using potassium to extract the oxygen from a previously undecomposed substance, namely, boracic acid, thereby decomposing it.

Our approach yields the following picture of this case. Davy gives us a scientific retail argument, in which he presents some first-order scientific evidence for the existence of potassium. As we have seen, Davy separates samples of potassium from their surrounding environment, manipulates them, and maintains their structural unity; he thereby experimentally individuates samples of potassium. And while Davy does all these things, he does not attempt to support his claims by appealing to the satisfaction of criteria like manipulation or experimental individuation. To put the point another way, he shows how to experimentally produce samples of potassium and demonstrate their properties without claiming that, because we can individuate such samples, we are justified in adding potassium to the list of chemical substances. His reasoning thus remains at the level of the first-order evidence. In contrast, we have just presented a philosophical retail argument which shows that Davy's argument satisfies Chen's three conditions, and thereby satisfies our criterion of experimental individuation. In that case, we draw the conclusion that we ought to be realists about potassium.

4.2 An Anti-realist Conclusion Regarding Lavoisier's Muriatic Radical

For our second case, we will discuss the elimination of the muriatic radical, a hypothetical component of hydrochloric acid.[7] Scheele was the first to decompose this acid, which he called "acid of salt," and he identified its constituent substances as phlogiston and "dephlogisticated acid of salt" (1931[1774]). However, it was a matter of some controversy whether he had succeeded in decomposing hydrochloric acid. According to Lavoisier's oxygen theory of acidity, all acids are composed of oxygen (the principle of acidity, i.e., that which gives acids their acidic properties) and a radical, which can be either a simple substance or a compound (1965[1789], pp. 65, 115). Neither Scheele nor any other chemist had been able to extract the oxygen from hydrochloric

[7] See Hricko (2018) for a detailed discussion of this case.

acid, which Lavoisier called "muriatic acid." And so Lavoisier held that it remained undecomposed; and, in accordance with his theory, he hypothesized that it must contain oxygen combined with what he called "the muriatic radical" (1965[1789], pp. 71-72). As for Scheele's dephlogisticated acid of salt, Lavoisier held that it is a compound of muriatic acid and oxygen, which he called "oxygenated muriatic acid" (1965[1789], p. 73), which we now know as chlorine. Lavoisier thereby theoretically individuated the muriatic radical as that substance which combines with oxygen to form muriatic acid, which, in turn, is converted into oxygenated muriatic acid (i.e., chlorine) by means of combining with even more oxygen.

But theoretical individuation is a mere belief, and as such, it was not enough to settle the ontological status of the muriatic radical for the chemistry community at the time. Chemists reasoned that, if the radical were to exist, they should be able to isolate it. And so, for some time, chemists attempted to decompose muriatic acid, and thereby isolate the radical. When we consider things in terms of the satisfaction of criteria of reality, their attempts to do so made sense since experimentally individuating the radical requires isolating a sample of it. Moreover, experimentally individuating the radical would have settled its ontological status, just as Davy's experimental individuation of potassium settled its ontological status.

The case of the muriatic radical culminates with an argument, due to Davy (1810, pp. 235-236), that casts serious doubt over the existence of the radical. Davy emphasizes the results of various experiments that he and other chemists performed, which show that what Davy called oxymuriatic acid (i.e., oxygenated muriatic acid or chlorine) combines with hydrogen to form muriatic acid. And he goes on to discuss those experiments that seem to show the decomposition of oxymuriatic acid into oxygen and muriatic acid. Davy observes that in these experiments, water is always present. And he concludes that the oxygen that such experiments produce results from the decomposition of the water, not from the decomposition of oxymuriatic acid, which has not been demonstrated. Davy later went on to argue for the elementary nature of this latter substance, and proposed a new name for it: "Chlorine" (1811, p. 32). To be sure, Davy (1811, p. 35) does state that "[t]here *may* be oxygene [sic] in oxymuriatic gas; but I can find none" (1811, p. 35, Davy's emphasis). And in a letter to Berzelius, Davy writes: "I think it *probable* that [chlorine] contain[s] oxygene [sic] … but it is absolutely necessary to distinguish between what is *very probable* and what is *known"* (1813, Davy's emphasis). If oxymuriatic acid doesn't contain oxygen, and muriatic acid contains oxymuriatic acid and hydrogen, then muriatic acid doesn't contain oxygen either. To adopt Davy's later terminology, the only components of muriatic acid are hydrogen and chlorine. Based on this view of the components of muriatic acid, Davy argued that Lavoisier was in error while Scheele was basically correct (1810, pp. 236-237). This perhaps surprising endorsement of Scheele results from Davy's identification of Scheele's dephlogisticated acid of salt with oxymuriatic acid, i.e., chlorine; and from the fact that Davy, like a number of latter-day phlogiston theorists, identified hydrogen with phlogiston.[8] The claim that muriatic (hydrochloric) acid is made up of hydrogen and dephlogisticated acid of salt, even if terminologically problematic, is essentially correct. Lavoisier, however, was in error since hydrochloric acid contains no oxygen, thus falsifying his oxygen theory of acidity. At any rate, Davy's arguments eventually convinced the chemistry community to eliminate the muriatic radical from chemistry.

Although Davy's argument is a scientific retail argument, when we consider this case in terms of criteria of reality, we come to the same conclusion regarding the non-existence of the muriatic radical. Once again, the most appropriate criterion is experimental individuation. As we discussed in section 3, in some cases, experimental individuation is not an appropriate criterion, either because of technological limitations, or because the purported entity is not the sort of thing that one could experimentally individuate. In this case, neither of these considerations apply. Failures to experimentally individuate the muriatic radical could not be explained away in terms of technological limitations since Davy presented an alternative explanation for these failures, namely, that muriatic acid and oxymuriatic acid do not contain oxygen. Moreover, the muriatic radical was conceived of as a chemical substance. Samples of chemical substances are required to demonstrate their existence, and are precisely the kinds of thing that can be experimentally individuated. In this case, then, experimental individuation is not merely a sufficient condition for concluding that the muriatic radical exists, but also a necessary one. And so, we have a philosophical retail argument for an anti-realist attitude towards the muriatic radical.

We draw the following three morals from this case. First of all, if scientists can experimentally individuate an entity, that is a sufficient reason to be a realist about that entity. Second, when experimental individuation is a necessary condition for reality, failure to experimentally individuate a theoretical entity is a sufficient reason to conclude that the entity does not exist. Third, theoretical individuation is not sufficient to establish the existence of a theoretical entity since, as this case illustrates, theoretical individuation is sometimes possible even if experimental individuation is not. In sum, according to the criterion of experimental individuation, one has sufficient reason to draw an anti-realist conclusion regarding Lavoisier's muriatic radical.

Before moving on, it's worth noting that NMA-inspired wholesale realism may encounter some trouble in accommodating this case. For many wholesale realists, the sole criterion of reality for theoretical entities concerns whether those entities were posited in the context of a successful theory—if they were, then we should conclude that they are real. Lavoisierian chemistry is often taken to be a paradigm case of successful science while phlogistic chemistry is often excluded as such. For example, Hardin and Rosenberg (1982, pp. 609-610) claim that Lavoisierian chemistry is a mature science, while

[8] See Kirwan (1789, pp. 4-5).

phlogistic chemistry is not, and Psillos (1999, p. 291) argues that 'phlogiston' was a non-referring term. In that case, it follows that the oxygen theory of acidity is at least approximately true, and that the entities that it posits, including the muriatic radical, exist.[9] On the other hand, if 'phlogiston' is a non-referring term, then the phlogiston theory is either false or lacks a truth-value, and so dephlogisticated acid of salt does not exist.[10] However, some philosophers (Ladyman 2011, pp. 98-99; Lyons 2002, p. 70) have argued that phlogistic chemistry was a successful science. In that case, wholesale realists would have to conclude that both the muriatic radical and dephlogisticated acid of salt exist. The problem is that both conclusions are implausible. It seems much better to conclude that Lavoisier's muriatic radical doesn't exist, while Scheele's dephlogisticated acid of salt does. When it comes to this case, retailism does a better job than wholesalism since our retailist position secures an anti-realist result regarding the muriatic radical. If there are good reasons to conclude that Scheele experimentally individuated a sample of dephlogisticated acid of salt, then our position can also secure a realist result regarding that substance. However, this is a contentious conclusion for which we cannot offer an argument here.[11]

4.3 An Indefinite Conclusion Regarding Thomson's Electrified Particles

Thomson's work on cathode rays is our third case. Cathode rays are a kind of luminous phenomenon within a discharging tube. They are produced by the discharging from the cathode when the barometric pressure within the tube is extremely low. Scientists in the nineteenth century wondered what cathode rays are. By 1883, two rival hypotheses about the nature of cathode rays were proposed. One claimed that cathode rays are ethereal waves; and the other that they are electrified particles. Hertz supported the former hypothesis and designed an experiment to confirm it, while some English scientists, including Thomson, supported the latter hypothesis. Against this background, Thomson performed his own experiments.[12]

Thomson (1897) designed a new type of cathode ray tube (Fig. 1) to perform a deflection experiment. Thomson's thought was that a cathode would produce both electric currents and cathode rays when discharging, and that, in order to determine the

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[9] One might suspect that Lavoisier's error regarding muriatic acid was disconnected from the main posits of his oxygen theory. However, Chang (2012b, p. 8) identifies Lavoisier's theory of acidity as one of "[t]hree major pillars of Lavoisier's system of chemistry," and points out that Lavoisier chose the term 'oxygen' (which literally means 'acid-generator' in Greek) because of its central role in his system as the acidifying principle (2012b, p. 9).

[10] It's worth noting that neither Hardin and Rosenberg nor Psillos discuss dephlogisticated acid of salt. That said, it follows from Psillos's claims regarding the reference of 'phlogiston' that dephlogisticated acid of salt is a non-existent entity.

[11] See Hricko (2018, pp. 273-275) for a retail argument for this conclusion regarding Scheele's dephlogisticated acid of salt.

[12] For a detailed history, see Buchwald (1995a, 1995b).

composition of cathode rays, it would be necessary to eliminate the electric currents and experiment with purified cathode rays. Purification is the function of the cylindrical metal ring *B*, which absorbs the electric currents leaked from *A* and thus ensures that the ray passing through *B* is pure. Thomson found that the purified cathode ray was deflected when it passed between the plates *D* and *E*, thus confirming that cathode rays are made up of negatively electrified bodies.

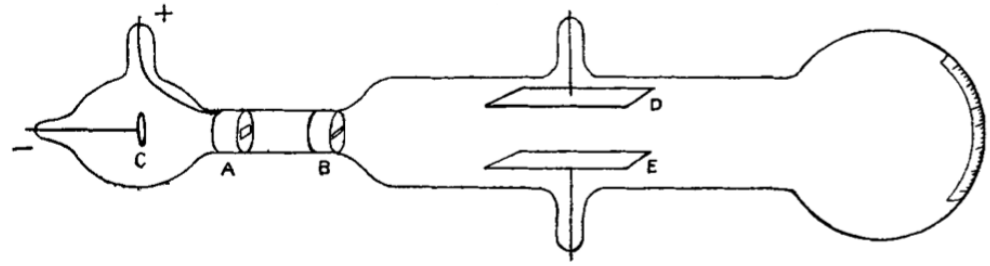

Fig. 1 Thomson's cathode ray tube in 1897, reproduced from Thomson (1897, p. 296)

While Thomson's experiment satisfies Chen's conditions when it comes to cathode rays, he didn't thereby experimentally individuate the electrons that make them up. Thomson succeeded in *separating* cathode rays from currents; purifying them with the metal ring *B*, and thus *maintaining their structural unity*; and *manipulating* them by deflecting them with an electrostatic field. According to Chen's conditions, one can say that Thomson experimentally individuated cathode rays and demonstrated that they are currents of negative electricity. But Thomson *hypothesized* that the currents consist of electrified particles that are separable individuals. Therefore, the experimental individuation of these electrified particles is a reasonable and applicable criterion for granting their reality. Because Thomson hypothesized that the particles are separable individuals but did not experimentally individuate them, he did not demonstrate their existence but only indicated the possibility that they exist. After all, in the late nineteenth century, it was possible to conclude that the difficulty in isolating a single particle was due either to technological limitations, or to the possibility that cathode rays are not the kind of entity that consists of separable particles. In this case, experimental individuation is merely a sufficient but unnecessary condition for granting the reality of Thomson's particles. Hence, the proper response to the scientific retail argument that Thomson gives us is neither realism nor anti-realism, but rather an indefinite conclusion regarding the existence of electrons as particles, at least until there is a conclusive philosophical retail argument.

One may argue that, by determining the value of m/e, Thomson's argument satisfies some kind of measurement criterion of reality, and so his argument provides a reason to take a realist attitude towards electrified particles. However, one should note that Thomson's measurement of *m/e* is theory-dependent, because the equation he uses to compute the value of *m/e* presupposes that cathode rays consist of particles. Through the equation $I = H\rho = mv/e$, Thomson derived the following equation:

$$m/e = I^2Q/2W$$

Q represents the quantity of electricity carried by those particles, where $Q = Ne$ (*N* is the number of particles passing across any section of the beam at a given time and *e* is the charge of a single particle); *W* is the kinetic energy of the particles and *v* is the velocity of the particles such that $W = 1/2(Nmv^2)$; and $I = H\rho$ in which ρ is the radius of curvature of the path of these rays in the magnetic field *H* (Thomson 1897, pp. 302-303). In the derivation of *m/e*, Thomson presupposed that cathode rays are composed of electrified particles by supposing $Q = Ne$. Before his experiment, no other experiments had been performed to demonstrate this presupposition. This makes his experiment and measurement theory-dependent. Based on another hypothesis, one may reasonably interpret *m/e* as the charge carried by a mass unit of cathode rays which consists of a kind of non-discrete matter rather than separable particles. We can make this interpretation clearer by using an analogy: When one measures the mass-to-volume ratio of water, one does not demonstrate that water consists of separable particles. Similarly, by measuring the mass-to-charge ratio of cathode rays, Thomson did not demonstrate that cathode rays consist of separable particles. As a consequence, Thomson could offer only theory-dependent evidence for realism about electrified particles, evidence that does not conclusively settle the issue.[13] After all, if Thomson were to claim that cathode rays consist of non-discrete matter, then his experiment would demonstrate the existence of cathode rays as electrified matter.

In this case, the criterion of experimental individuation is applicable and it leads to an indefinite conclusion regarding Thomson's electrified particles. To be sure, experimental individuation of electrified particles is not implicit in Thomson's practice since he did not individuate them. However, if we operate under the belief that electrified particles are individuals, isolating an individual or sample in order to demonstrate the existence of such particles is a reasonable requirement. After all, scientists working in the late nineteenth century did not know whether individuating electrified particles was possible with advances in technology and experimental design, or impossible due to the true (perhaps non-discrete) nature of cathode rays. It is therefore reasonable to expect such scientists to design and perform experiments that aim to isolate an electrified particle. Therefore, according to the criterion of experimental individuation, the existence of electrified particles was not conclusively demonstrated by Thomson's work.

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[13] Hacking (1983, pp. 22-23) draws a stronger conclusion when he claims that he would not have been a realist about electrons even in 1908, when Millikan measured the charge of the electron.

Today, we know that, according to quantum mechanics, isolating an electron is theoretically impossible. Hence, experimental individuation may no longer be an appropriate criterion for this case even though it was an appropriate criterion in 1897. And so we have an example in which experimental individuation as a criterion of reality is inapplicable to a particular case.

5. Theory, Experiment, and Individuation

The concerns about the theory-dependence of criteria that we discussed in relation to Thomson's work lead us to defend experimental individuation as a criterion of reality in another way. We will argue that it is a relatively theory-independent criterion of reality.

Chen (2016, pp. 354-355) argues that his characterization of experimental individuation is theory-independent in the following way. He follows Radder (1995) and Chen (2007) in distinguishing three parts of an experiment: its design, its performance, and the interpretation of its results. Chen admits that the design of an experiment and the interpretation of its results may depend on theory. But the performance of an experiment, along with the results that it yields, are at least causally independent of theory, since they result from the actions of experimenters. Insofar as Chen's three conditions are implicit in the performance of experiments, their satisfaction is causally independent of theory as well. To put it another way, whether an experiment has succeeded in separating an entity from its environment, manipulating it, and maintaining its structural unity is a theory-independent matter. That said, in order to interpret whether an experiment satisfies these conditions, one may end up making use of theory.

We acknowledge that theory and experiment can often be intertwined in various ways. That said, if experimental individuation is to serve as a criterion for the reality of theoretical entities, it's beneficial for it to be characterized in a relatively theory-independent way. We now discuss two ways in which our criterion is better than more theory-dependent criteria.

First of all, our criterion provides a reason to take a realist attitude towards entities posited in theories that are not among our best theories. For example, one may want to take a realist attitude towards Scheele's dephlogisticated acid of salt even if one is unwilling to count Scheele's phlogiston theory among our best theories. In that case, a theoretical justification of this realist attitude won't work. However, if Scheele experimentally individuated dephlogisticated acid of salt, then our criterion provides a reason to be a realist about dephlogisticated acid of salt. More generally, there are cases in which unsuccessful theories are associated with successful experimental practices, and in such cases, attempts to justify realism by appealing to the explanatory successes of theories simply won't work. If we want to justify a realist attitude towards an entity in such a case, we must appeal to the success of experimental practices, and our criterion of experimental individuation presents a way of doing so.

Second, our criterion meets Stanford's (2006, pp. 166-169) prospective applicability condition. According to this condition, criteria of reality should not just be applicable in retrospect. Instead, it should have been possible to apply such criteria in the past to then-current science, without knowing about future scientific developments; and it should be possible to apply those criteria to present-day science as well. The primary motivation for this condition is that it is question-begging to use our present theories to identify the components of past theories that we ought to be realists about, since the truth of our present theories is one of the central issues about which realists and anti-realists disagree. Our criterion satisfies this condition, and one of the reasons why it does so is that it is relatively theory-independent. In order to apply our criterion, we must determine whether particular experimental practices succeeded in experimentally individuating a particular entity. And there is no need to make use of present-day theory in order to determine whether past experimental practices were successful in this regard, as we illustrated with the case of Davy's discovery of potassium. It is sufficient to examine the experiments themselves in order to apply our criterion.

6. Conclusion

We have argued that experimental individuation can be used as a relatively theory-independent criterion of reality. We have embedded this claim regarding experimental individuation within a retailist framework that allows for other criteria of reality. And we have illustrated this retailist approach by developing three philosophical retail arguments based on three case studies from the history of science: an argument for realism about potassium, an argument for anti-realism about the muriatic radical, and an argument for an indefinite conclusion regarding Thomson's electrified particles. These arguments are philosophical because assessing whether a particular criterion is appropriate for a case and showing that such a criterion is or is not satisfied in a given case involves going beyond scientists' own presentation of the first-order evidence. And they are retail arguments because they concern the reality of particular kinds of theoretical entities, and because the criterion of reality that we appeal to cannot be generalized to all, or even most, theoretical entities.

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