

Classificatory norms in scientific practice:
the unobjective but rational *chemical element*.

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Abstract

It is often presumed that empirical considerations provide epistemic objectivity for claims about the boundaries and classification of scientific categories. This has seemed especially plausible in chemistry. Focusing on the category *chemical element*, we describe two 20th century developments that undermine epistemic objectivism about it. But our second thesis is that, in practice, this shortfall is bridged by relying on a little-recognized species of pragmatic norm: classificatory norms. We contend this precludes the objectivity, yet ironically affords the rationality, of related category and classification claims.

1. Introduction.

How in practice do scientists determine where to draw category boundaries?

Compared to many of the questions that philosophers ask about scientific categories and classification, that one gets little attention. It is more epistemic (or methodological) than, say, widely-discussed metaphysical questions about scientific categories. We are interested in it partly because we think addressing it with a focus on scientific practice bodes ill for a range of objectivist metaphysical positions. But the epistemic question is interesting for other reasons too, and here we'll restrict our focus to it, and the challenges it presents to a typically unexamined *epistemic objectivism* about scientific categories and classification.

We focus on practice in chemistry, a domain often regarded as a bastion of classificatory objectivity¹—in particular, on how views about the category *chemical element* were (and were not) defended during two 20th century episodes. This will allow us to argue for an epistemic anti-objectivism that is surprising partly because it still allows for proposals about category

¹ Famous examples outside philosophy of chemistry include Putnam and Kripke (Putnam 1975; Kripke 1980); within present philosophy of chemistry, Scerri is a well-known objectivist about *chemical element*. Note such popular objectivisms are compatible with conventionalisms about the Periodic Table of Elements, which have become wide-spread (Scerri 2007, 277–78).

boundaries to be more or less *rational* in virtue of the operation of classificatory norms that we'll uncover and describe.

More specifically, we'll argue for two theses. First:

Short-Fall: sometimes, empirical considerations alone fall short of stance-independently justifying theories about which conditions are the constitutive ones for a scientific category.²

Our second thesis is related:

Bridging-By-Norms: in some cases of classificatory short-fall, scientists bridge the epistemic gap by relying on classificatory norms.³

² Philosophers of science have long discussed the extents to which empirical considerations leave theory choice undetermined. But there has been scant attention in this literature to theories about category constitution in particular, which differ in various ways from the theories usually investigated.

³ A typical classificatory norm is a pattern of classificatory *behavior or belief* that stems from some people *preferring*, implicitly or explicitly, to behave or believe in such-and-such a way under certain conditions. (See Bicchieri (2017) for such a view of norms.) Consequently, classificatory norms differ from extra-empirical virtues, which are more like favored *properties of theories*. Unlike extra-empirical virtues, specifically *classificatory* norms have received scant notice or investigation.

In addition to arguing for those two theses, we will briefly remark on the prospect for reasonable appeals to classificatory norms that allow for some proposed category boundaries (and some related classificatory claims) to be more rational than others. But prior to arguing for our theses, let us clarify them.

2. Clarifications of Short-Fall and Bridging-By-Norms Theses.

By ‘empirical considerations’ we include appeals to observational data, and to theories that are widely deemed highly confirmed.

Regarding a category’s constitutive conditions, we mean those conditions in virtue of which (in usual circumstances) a thing satisfying them belongs to that category.⁴ Some metaphysical objectivisms imply that for many scientific categories, which conditions are constitutive of belonging is an objective matter. The epistemic objectivism more relevant here is about the supposed justifications of theories about constitutive conditions of categories. It says that in some and perhaps many cases, the considerations advanced in support of the theory suffice to objectively justify the truth of its proposals about which conditions are constitutive. We will presume such considerations objectively justify a theory about

⁴ Using our terminology, the category *chemical element* is supposed to be a piece of the world that science attempts to track with the concept CHEMICAL ELEMENT.

constitutive conditions *only if* the favoring they provide the theory is *independent of our mere mental stances* towards those considerations.

One can fail to meet that necessary condition on objective justification in obvious ways, such as via wishful thinking, where one *wants* certain considerations to favor the truth of a particular theory about category constitution, while having little or no evidence or reason to complement that desire. In our chemical cases, wishful thinking isn't an issue. Something much less obvious is going on. Chemists are, perhaps very rationally, relying on widespread implicit norms in order to support their theories about the constitutive conditions of *chemical element*. To the extent that relying on such norms involves relying on various mental stances of peers within a scientific community (see Bicchieri 2017), it precludes the objectivity of justification in question.

3. Lumpers vs. Splitters, ~1910–1920s.

The first of the two 20th century episodes we investigate played out in publications and meetings from about 1910 into the 1920s, in the wake of emerging details about atomic structure. There was a dispute about, roughly, whether and in what way the discovery of isotopy should revise Mendeleev's 19th century view that each *place* in the Periodic Table represents exactly one distinct chemical element. By 1910 that view was widespread, despite questions remaining about the exact *sequences* of elements within the Table (Scerri 2007). We

can understand those who then took isotopy to then challenge Mendeleev's view as splitters, and those who defended it as lumpers.

To see this, consider some context and details. Frederick Soddy is often credited with discovering isotopy.⁵ He first proposed the idea in 1911 and introduced the term 'isotope' to chemistry in 1913.⁶ He did not describe isotopy in terms of protons or neutrons, because neither had been discovered yet. He based his proposal largely on investigations of decay chains that indicated more than 30 different species of element, called "radioelements", over a stretch of the Periodic Table where just 11 elements were so far acknowledged (Choppin et al. 2013). Each of these radioelements was then said to be an isotope, with "mesothorium" and "thorium X" as examples (Scerri 2007, 177). Nowadays we regard each of these as isotopes of radium—as mere variants of that element. But when Soddy proposed the existence of isotopes, some researchers, especially the radiochemist and discoverer of protactinium Kazimierz Fajans, urged that each isotope was its own chemical element (Scerri 2000). Researchers like Fajans were thus splitters in the sense that they saw some places in the Periodic Table as subsuming or splitting into multiple elements rather than representing just one element each. Those who resisted this while nonetheless granting the existence of isotopes, e.g., those who

⁵ Others are recognized as anticipating aspects of it, including William Crookes as early as 1886 (Scerri 2007, 176).

⁶ As Scerri notes (2007, 312), Soddy got the term from Margaret Todd.

grouped isotopes such as “thorium X” and “mesothorium” together as mere varieties of one element, can be understood as lumpers.

An implication is that splitters and lumpers were operating with incompatible theories about the constitutive conditions of the category *chemical element*. It is difficult to pin down these theories because they were in flux and usually implicit rather than explicit throughout the period of opposition. But we can get far enough to see how the theories support our Short-Fall thesis.

What made for the differences between places in the Periodic Table? More than 30 years earlier, Mendeleev had thought the answer was a mix of differing atomic weights and chemical properties. But by 1910, physicists were using electron scattering experiments to investigate the structure of chemical constituents. Subsequently, as Scerri helpfully recounts (2007), over the course of the next 13 years several researchers—including Rutherford, Barkla, van den Broek, Moseley, and Chadwick—used and developed this and related work to motivate a shift, from understanding chemical element identity in terms of atomic weights and chemical properties, to understanding it in terms of *atomic number* equated with (an early notion of) positive nuclear charge. In making that idea explicit in its 1923 definition of ‘chemical element’ (Aston et al. 1923), the IUPAC was stating a view that had been implicitly held by many chemists since the work of van den Broek and Moseley 10 years earlier.

Summarizing these developments, we can say that between 1913⁷ and 1923 lumpers widely recognized the following theory of the constitution of the *chemical element* category:

Positive Charge Theory:

Any thing is a chemical element if and only if:

- (a) it is a category, a species, of atom,⁸ and
- (b) all atoms of this species have the same atomic number, which = nuclear positive charge, and
- (c) only atoms of this species have that atomic number.

Splitters such as Fajans rejected this when urging that isotopes of the same atomic number are each distinct elements in their own right, which effectively denied part (c) of what we've termed the Positive Charge Theory.

⁷ This year for the theory rather than 1910 because it wasn't until 1913 that van den Broek had finished disconnecting the identity of atomic number from atomic weight in favor of atomic charge.

⁸ Although part (a) of the definition now seems unremarkable, there are complications (Scerri 2000), which were influentially discussed by Paneth (e.g., Paneth 1962a, 1962b). Although splitters sometimes appeal to these complications, their position didn't require them and we'll set them aside here.

In light of this opposition, recall our Short-Fall thesis. It says that sometimes empirical considerations alone fall short of stance-independently justifying theories about which conditions are the constitutive ones for a scientific category. We'll now argue this was the case in the opposition between lumpers who supported the Positive Charge Theory and splitters who rejected it.

Empirical results were certainly relevant. A rapid succession of detected differences between radioelement isotopes in decay studies, for example, fueled dispute (Scerri 2007). However, no such empirical findings, on their own, stance-independently justified either accepting or rejecting (c). This may sound odd, given that by the 1930s virtually all chemists were lumpers and today you would earn incredulous stares if you proposed that isotopes of the same atomic number are distinct chemical elements. But this paradigm example of classificatory consensus owes in part, we submit, to widespread implicit agreement on classificatory norms—not just to impressive empirical findings.

To appreciate this, consider how splitters dug in their heels even when lumpers generated impressive empirical results that seemed to favour lumping. One set of such results were negative—the inability, despite repeated attempts, to *chemically* distinguish the isotopes that were being discovered (Scerri 2007, 177). Another set were positive—showing extensive chemical *similarities* between isotopes of shared atomic number. As just one example, Fritz Paneth and György von Hevesy reported on electrochemical experiments in 1914 that “observed voltage was found to be constant, regardless of the proportion of the two isotopes [of bismuth] present in the sample” (Scerri 2000, 63). A main way that splitters objected was

by contesting the results. Fajans, for instance, disputed the bismuth results and insisted against Paneth and von Hevesy that the compared isotopes were distinct elements (Scerri 2000, 65).

This has the surface appearance of making this moment in the dispute turn solely on an empirical matter. But one very probable reason why Fajans contested the empirical results was that he roughly shared with his opposition a norm that leant classificatory relevance to the results—something like:

Elemental Relevance Norm: If you are determining whether different isotopes are instances of the same chemical element, and the empirically detected differences between them seem small or unimportant in comparison to the empirically detected similarities between them, then judge that the differences lack elemental relevance and the isotopes are instances of the same chemical element.

It would have been odd for Fajans to contest the empirical results were he not presuming something like the view captured in that norm. Why worry (as he did) about reported *similarities* if you're not basing your classification claims on some judgment about the *relevance of* reported similarities vs. differences?

Something like the Elemental Relevance Norm also helps clarify the importance that a distinction between chemical and physical properties was eventually deemed to have in these debates. Even Fajans eventually bowed somewhat to this distinction (Scerri 2000, 64). Researchers also began appreciating more classificatory *relevance* in the distinction. They can be understood as doing this via the Elemental Relevance Norm, where the physicalness, so-to-speak, of differences is presumed to give a reason for counting those differences as small or

unimportant in comparison to the many similarities deemed chemical. Seen in this light, the role of that norm has probably increased significantly over time, as we've retained what is effectively a lumpers' view of *chemical element* despite discovering many further physical differences between isotopes of atoms that share their atomic number. Norms like the Elemental Relevance Norm allow people to acknowledge that *physical* differences between uranium isotopes, for instance, are relevant—even dramatically important—to a great many things (including the energy industry and warfare), without conceding that the very specific issue of the constitutive conditions of a *chemical* category is one of those things.

The Elemental Relevance Norm also appears alive and well today, as claims that the recently increasing number of known chemical differences between isotopes are not yet numerous or important enough to challenge lumpers (e.g., Scerri 2007, 279, 327) seem most charitably interpreted as implicitly involving reliance on that norm.

Of course, none of this is to criticize any particular stance on or use of the norm, nor any associated relevance assumptions or claims. Indeed, we reckon that reliance on the norm was and continues to be quite rational, an issue we return to below. But recognizing the rationality or wisdom of a norm's role is to already grant its operation alongside empirical data, which is our point here. In effect, by zeroing in on one dispute about the category *chemical element* we have supported our Short-Fall thesis by elaborating and supporting our Bridging-By-Norms thesis.

4. Protons vs. Electrons, ~1930s–Present.

The second 20th century episode we discuss is not so much an explicit dispute as it is an implicit opposition between two theories about the constitutive conditions of *chemical element*, only one of which is explicitly wide-spread. It is an opposition that most experts do not even acknowledge, even though their explanatory and classificatory practices generate it. It starts from a curious relationship between two underlying views about elements that are perhaps as close to unanimous as two views can get.

The first of these underlying views, and the acceptance of it, are indicated in the fact that nearly all experts today hold to a descendant version of the 1923 IUPAC definition of ‘chemical element’. In light of what was learned about proton counts later than 1923, this descendant version defines ‘chemical element’ explicitly in terms of those counts: a chemical element is, in the sense in question, “a species of atoms”, where each of these species is made up of “all atoms with the same number of protons in the atomic nucleus” (IUPAC 2019).

Correspondingly, the received theory about the nature of the *chemical element* category is that atomic proton count is *the* central condition—it is what ontologically makes an atom the kind of element it is. In table 1 we’ve summarized this more precisely as the *Proton Count Theory*, using single asterisk marks to indicate parts of the theory that contain revisions to the Positive Charge Theory that is associated with the older (1923) IUPAC definition of ‘chemical element’. The revisions simply involve referring to proton count rather than nuclear positive charge.

Table 1

Three Different Theories about the Constitutive Conditions of the Category *Chemical Element*

Proton Count Theory	Electron Configuration Theory	Proton & Electron Theory
<p>Any thing is a chemical element if and only if:</p> <p>(a) it is a category, a species, of atom, and</p> <p>(b*) all atoms of this species have the same atomic number, which = proton count, and</p> <p>(c*) only atoms of this species have <i>that</i> atomic number.</p>	<p>Any thing is a chemical element if and only if:</p> <p>(a) it is a category, a species, of atom, and</p> <p>(b**) all atoms of this species have the same ground state electron configuration, which = ...</p> <p>(c**) only atoms of this species have <i>that</i> ground state electron configuration.</p>	<p>Any thing is a chemical element if and only if:</p> <p>(a) it is a category, a species, of atom, and</p> <p>(b***) all atoms of this species have the same atomic number, which = proton count, and the same ground state electron configuration, which = ...</p> <p>(c***) only atoms of this species have <i>that</i> atomic number, and <i>that</i> ground state electron configuration.</p>

NOTE.— For simplicity we have not fully elaborated conditions (b**) and (b***), which would involve referencing, e.g., the first, second, third, and fourth quantum numbers, the Pauli exclusion principle, the Aufbau principle, and the Hund principle (Scerri 2007, 233ff.).

The second unanimous (or very nearly so) underlying view, existing alongside the Proton Count Theory, is about explanation. As Scerri succinctly puts it, “it is the electron that is mainly responsible for the chemical properties of the elements” (Scerri 2007, 160). In other words, the main thing that explains—causally or otherwise—most properties and behaviors of respective chemical elements is their respective electron configurations. This isn’t to say that proton count has *zero* role to play in such explanations. Number of protons helps determine and influence atomic forces and structure, and interacts with electron configuration and behavior, and these things also *help* explain features and behaviors of chemical elements, e.g., why atoms of sodium together react as they do with atoms of chlorine. And of course, other variables aside from just proton count and electron configuration are also parts of any *complete* explanations of elemental features and behaviors. But the resounding view is that electron configurations do most of the explaining, with other variables often being negligible—hence the preceding quote from Scerri.

So when it comes to *explanations* about elements in reactions, electrons are deemed central. But when it comes to element *identity*, and so the constitutive conditions of the *chemical element* category, the consensus is that proton count is central and there is no reference to electrons.

This is curious because it seems to conflict with a norm that prioritizes explanatorily-central conditions when theorizing about a category’s constitutive conditions—a norm that operates in many other areas of science. It may be that this norm is popular with respect to

categories of a certain general sort, so we should first clarify this and how the *chemical element* category seems to be of that sort.

Many categories consist in *patterns of linked variables*. Disease categories are a vivid example, with one disease often being distinguished from others by how it consists in recurring (across cases) linkages between two types of variables: characteristic symptoms or effects, on one hand, and their causes, on the other. Recent work clarifies that other biological categories are like this too (e.g., [Suppressed-for-review]). Although these examples involve cause and effect variables, key variables may be of other sorts, that is, with determination relations other than causation between them.

The category *chemical element* seems a paradigm example of a linked variable category. It appears to consist in a set of distinct patterns of linkage—some associated with one element, others with other elements—between particular sets of chemical properties or behaviors, and the conditions in each case that are mainly responsible for bringing about those properties and behaviors. What makes these patterns alike are the sorts of variables involved. Whether we're talking about the element *chlorine*, or *gold*, or *hafnium*, etc., there are certain types of links between the chemical properties of those elements, on one hand, and the conditions responsible for those properties, on the other. Chlorine displays certain properties of reactivity due to conditions involving electron configuration. Gold displays different properties of reactivity, but similarly due to conditions involving (different) electron configuration.

Now here is the associated implicit norm that seems widespread:

Main Explanatory Variables Norm: If you are determining which conditions are constitutive of a category that consists in patterns of linked variables, then prioritize those conditions that are the main explanatory factors for the other variables within the patterns in question.

Were experts spelling out conformity with this norm in the *chemical element* case, they would note what is distinctive about the elements that exemplify the category. Each exhibits patterns of chemical properties and behaviors, explained by a combination of variables. What are the main explanatory variables? According to them: electron configurations. They then would, presumably, propose electron configurations to be constitutive of the category *chemical element*—either fully constitutive or partly constitutive, as represented in the theories stated in the middle and right-hand columns of table 1—by referring to those configurations in their definition of ‘chemical element’. But as we have seen, they don’t do that.

Why does it seem experts in chemistry don’t follow the *Main Explanatory Variables Norm* that is common in many analogous cases in science? Why not connect the issues of explanation and identity? Two different answers come to mind.

One is that perhaps appearances are misleading here—that, actually, chemists *are* following this norm. Perhaps we have expressed the norm in too coarse-grained a way to see this. A more fine-grained version could distinguish between *proximate* and *distal* explanatory variables, allowing appeal to more distal variables to abide the norm. Some authors argue, for instance, that while electron configurations or structure are the main *proximate* variables that explain elemental properties and behaviors, electronic structure is in turn determined or

explained by proton count (nuclear charge) (Hendry 2012, 266). Proton counts may then be the main *distal* variables that explain elemental properties and behaviors, bringing the consensus view about element identity into one kind of harmony with the consensus view on element explanations.⁹

The second type of answer takes appearances at face value, conceding that chemists aren't following the *Main Explanatory Variables Norm*. But if they aren't, it is very probably because they are following *other* norms given priority over that one. One likely other norm in this case would trade on a seemingly perfect correlation between atomic number and ground state electron configuration, along with a penchant for simplicity. This norm grants that electron configurations are the main explanatory variables, but emphasizes that each ground state configuration always corresponds with exactly one atomic number. And appealing to these atomic numbers is simpler than appealing to ground state electron configurations, in that reference to proton count is less complicated and more concise than reference to the quantum numbers and associated quantum mechanical principles (see table 1) that give the ground state electron configurations. This is to recognize three rather than just two linked variables: first, the chemical properties and behaviors, second the electron configurations that explain those

⁹For discussions of chemistry-physics relationships that may provide other grounds for arguing that chemists are abiding the *Main Explanatory Variables Norm* after all, see Scerri (2007).

properties and behaviors, and third the simpler atomic numbers that are explanatorily negligible but which correlate perfectly with the explanatory electron configurations. The norm in question would then imply that when determining constitutive conditions under such circumstances, we should prioritize the third variables, the simpler ones—the atomic numbers in this case—rather than the main explanatory variables with which they correlate:

Perfect Correlation Simplicity Norm: If you are determining which conditions are constitutive of a category that consists in patterns of linked variables, and in addition to one type of variable that is mainly explained by another there is also a third type of variable that is simpler than the explanatory variables but correlates perfectly with them, then prioritize those simpler correlated variables as constitutive of the category in question.¹⁰

This norm is tempting because it buys helpful simplicity at little cost. Indeed, following it in practice would seem to come with *zero* risk of recognizing different element boundaries than someone who instead recognizes ground state electron configurations as constitutive. Put

¹⁰ Note that this norm is recommending that the simpler variables that correlate with the explanatory ones (but which are not themselves explanatory) be prioritized when specifying constitutive conditions. Some alternative strategies that view the simpler variables as themselves explanatory (or close enough proxies for what is explanatory) would signal operation of the *Main Explanatory Variables Norm*.

differently, the three theories in table 1 certainly differ, but are, so far as we know, coextensive in application.

There may also be other norms that tacitly trump the *Main Explanatory Variables Norm*. It has been widely noted that through the years in which a consensus built around defining ‘chemical element’ in terms of atomic number, the element concept in chemistry was being used to capture units that survive chemical change—what survives of sodium and chlorine, respectively, for example, when each seems to give way as they combine to form a salt (Scerri 2000). This may seem to privilege atomic numbers over electron configurations because the former survive such reactions while the latter change. Expressing this sort of privilege, for instance, Hendry writes that “whatever earns something membership of the extension ‘krypton’ must be a property that can survive chemical change, and therefore the gain and loss of electrons” (Hendry 2012, 266). Perhaps this indicates:

Unchanging Constituents Norm: If you are determining which conditions are constitutive of a category, then prioritize those that remain unchanged in persisting category members, over those that change in category members.

That is probably too simplistic as stated though. Only somewhat sloppy adherence to it would in fact privilege the Proton Count Theory over the other two theories in table 1 because an atom’s *ground state* electron configuration—the structure its electrons *would* take were it in a neutral ground state—is a *disposition*, sometimes retained when the ground state happens not to obtain, e.g., during chemical reactions. So if experts really do tacitly rely on the *Unchanging Constituents Norm* in a way that trumps the *Main Explanatory Variables Norm*,

then it would probably be a more sophisticated version that implies a preference for unchanging *manifest* properties rather than unchanging dispositional ones.

There are surely other plausible candidates for norms that experts have leaned on if they indeed have opted against the *Main Explanatory Variables Norm*. The overarching point is that either way, norms are involved. If appearances are misleading and at least some chemists have kept elemental explanation and elemental identity connected, it seems they have deployed the *Main Explanatory Variables Norm*; if for some or all chemists the appearance of disconnecting these things is instead accurate, then norms seem to help support that disconnection. Either of those paths to selecting the widely accepted Proton Count Theory over the other theories in table 1 leads through norms in addition to empirical considerations.

5. Conclusion.

Our intention in this short paper is to show how classificatory shortfall (our first thesis) with bridging by norms (our second thesis) occurs even for a chemical category alleged to enjoy a great deal of classificatory objectivity. Uncovering such shortfall bridging in two 20th century episodes in chemistry challenges an epistemic strand to that alleged objectivity, given what the norms in question and epistemic objectivity were clarified in section 2 to involve. Admittedly, this does not constitute an argument that classificatory shortfall with bridging by norms is inevitable (for a more general case, see [suppressed-for-review]). But it may surprise many that it happens at all.

Beyond our main goal of arguing that this happens in surprising contexts, we also briefly noted that the rationality of involved classificatory decisions can survive the loss of objectivity we've documented. To support that as a thesis additional to the two we've argued for here would require another paper. But the prospects should now seem favorable: given the extent to which classificatory norms are shared, can pragmatically aid attainment of goals in a research community, and are continuous with the theories in which they are embedded, the classificatory decisions they guide can be properly seen as rational in a robust sense despite lacking epistemic objectivity. Such rationality may come to seem especially important if the problems we've posed for an epistemic objectivism about categories are found to also cast doubt on more metaphysical objectivisms about them.

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