

How chemistry shifts horizons: element, substance, and the essential

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Abstract In 1931 eminent chemist Fritz Paneth maintained that the modern notion of “element” is closely related to (and as “metaphysical” as) the concept of element used by the ancients (e.g., Aristotle). On that basis, the element chlorine (properly so-called) is *not* the elementary substance dichlorine, but rather chlorine as it is in carbon tetrachloride. The fact that pure chemicals are called “substances” in English (and closely related words are so used in other European languages) derives from philosophical compromises made by grammarians in the late Roman Empire (particularly Priscian [fl. ~ 520 CE]). When the main features of the constitution of isotopes became clear in the first half of the twentieth century, the formal (IUPAC) definition of a “chemical element” was changed. The features that are “essential” to being an element had previously been “transcendental” (“beyond the sphere of consciousness”) but, by the mid-twentieth century the defining characteristics of elements, as such, had come to be understood in detail. This amounts to a shift in a “horizon of invisibility” brought about by progress in chemistry and related sciences. Similarly, chemical insight is relevant to currently-open philosophical problems, such as the status of “the bundle theory” of the coherence of properties in concrete individuals.

Keywords Substance · Element · Priscian · Metaphysics · Bundle theory · Polysemy of chemical terms · Paneth · Elementary substance

Introduction

Each year millions of young people hear what ought to be an inspiring story—the tale of how patient, skillful, and creative work, over many centuries in various parts of the world, has come together (especially during the first half of the twentieth century) to produce a coherent and understandable account of the inner nature of all the stuff that constitutes our

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world. On the basis of that story, beginning students of chemistry can now provide convincing answers to questions that perplexed powerful thinkers of ancient, medieval, and early-modern periods. Two reasons that some students of elementary chemistry do not find that story to be of great interest are that they have heard parts of it before and they lack appreciation of thought-patterns that dominated historical periods far removed from their own. Another reason is that the intellectual achievement of modern chemistry has not yet been properly integrated into contemporary philosophy.

This paper considers a classic paper by a famous chemist that reviews pre-modern developments in the concept of “chemical element,” and also deals with parts of a recent book that shows how ancient philosophic controversies still influence chemical language. Both of these topics suggest how chemistry is relevant to currently open problems in philosophy—for example, to the status of “the bundle theory” of how properties cohere in concrete individuals.

Element

Austrian chemist Friedrich Adolf (“Fritz”) Paneth (1887–1958) is justly famous for several specific scientific achievements, including showing (in 1927) that when tetraethyllead decomposes (in a stream of gas in a closed system) decomposition products cause disappearance of metallic mirrors located far from the place of decomposition. This shows that reactive fragments exist long enough to traverse considerable distance, even though they are not stable products of the reaction. This was the first convincing demonstration of the existence of what are now known as “free radicals.” In “The Epistemological Status of the Concept of Element”—a paper based on a lecture delivered at Königsberg in 1931—Paneth reviewed ancient, medieval, and early-modern notions of the elements and provided an influential analysis of the modern concept of chemical element (Paneth 1931/2003).

One of the main goals of Paneth’s lecture was conclusively to refute a conclusion on which many prior authors had reached consensus. Most of the authors quoted by Paneth had agreed that the modern concept of “chemical element”—as clarified by Lavoissier as a chemical substance that could not be broken down into component substances by chemical means—was quite different from the more “metaphysical” notions of element held by the alchemists, the medievals, and the ancients (e.g., Aristotle [383–322 BCE]). Paneth disagreed with that conclusion, pointing out that Lavoissier’s requirement that the chemical elements must be able to be isolated in a pure state was not an absolute one—fluorine and radium had been accepted as elements even though they had not been isolated.

Thus we consider the great advance due to Lavoissier to consist in this: he did not limit the number of chemical basic substances *a priori*, but he demanded that they could, in principle, be prepared as non-decomposable substances. ... However, as is shown particularly clearly by those cases in which the demand for preparability was dropped, the “metaphysics” of the concept of element is not touched by this. (Paneth 2003, p. 128)

Paneth maintained that, at its core, the modern concept of chemical element is just as “metaphysical” as the ancient notion was. Indeed, he claimed that the modern concept is quite close to the ancient one—which is described by Aristotle as follows.¹

¹ English translations of Aristotle are taken from Barnes 1984. The original Greek text of *Metaphysics* was consulted in Page et al. (1933/1935).

We call an element (*stoichion*, “simple part”) that which is the primary component immanent in a thing, and indivisible in kind into other kinds.... [T]hose who speak of the elements of bodies mean the things into which bodies are ultimately divided, while they are no longer divided into other things differing in kind; and whether the things of this sort are one or more, they call these “elements.” *Metaphysics, Book V* (Δ) (1014^a, 26–35),

Polysemy

Paneth claimed that the word “element” (as used in contemporary chemistry) has a twofold meaning. He maintained that this single word has two quite distinct connotations (Paneth 2003, p. 129).² (This is what linguists call “polysemy” or “amphiboly.”) In the German-language original, Fritz Paneth followed previous usage and employed “*einfacher Stoff*” and “*Grundstoff*” for the two alternative meanings of the term “element.” The translator (Fritz Paneth’s son, philosopher of science H. R. Post³) rendered these two alternative designations into English as “simple substance” and “basic substance,” respectively.

In Paneth’s view, the word “element” designates, on the one hand, a stable material that cannot be decomposed by chemical means—this is *einfacher Stoff*, “simple substance.” (The term *einfacher Stoff* had traditionally been used by German-speaking chemists to identify single-element materials—as contrasted with multi-component compounds, *zusammengesetzte Stoffe*.) However, the same word, “element,” also designates, on the other hand, each of the components that together comprise any more-complex chemical compound. Each such component is properly designated as *Grundstoff*—“basic substance.” (Some earlier authors had used the word *Grundstoff* in this sense and in similar senses, but this designation was by no means as well established as was “*einfacher Stoff*.”) Using this terminology, “the element chlorine” as Cl₂, the gas now preferentially called “dichlorine”—with green color and pungent odor—is considered to be a “simple substance” (*einfacher Stoff*). In contrast, “the element chlorine” as it exists in carbon tetrachloride would be a “basic substance” (*Grundstoff*)—and as such has *no sensible properties* (color, odor, etc.).

Chemistry as “transcendental”

Eric Scerri⁴ holds that Dimitri Mendeleev’s (1834–1907) success in developing the periodic table was connected with his subtle use of the double meaning of the concept of a chemical element. (Scerri 2000) The next-to-last sentence in Fritz Paneth’s paper is: “The concept of element must be taken in its naïve-realistic sense when meaning simple substance, but understood as transcendental when meaning basic substance.” Scerri (2000)

² The linguistic peculiarity (polysemy) that Paneth pointed out for chemists’ use of the word “element” is not an isolated case. Chemists have a general tendency to use one and the same word to designate two related but different types of items: on the one hand, an independently existing material “stuff”—and, on the other hand, something that is a part of another thing and does not have its own independent existence (for examples, please see Earley 2006).

³ Post anglicized his family name on relocating to England.

⁴ At King’s College of The University of London: H. R. Post was the mentor of the Ph.D. thesis of Eric Scerri, editor of this journal.

avoided using the word “transcendental” by calling *Grundstoff* “abstract element.” Later, Scerri used the designation “element-1” for *Grundstoff*, and “element-2” for *einfacher Stoff* (Scerri 2003). Paneth included a note on his use of the word “transcendental” in his paper: “I wish to emphasize particularly that, following Hartmann, I am using the word “transcendental” in its epistemological sense only, i.e., meaning “beyond the sphere of consciousness.” (Paneth 2003, note 3, p. 138).

Many early-twentieth-century German chemists were familiar with the philosophy of Immanuel Kant (1724–1804). Kant had used the word “transcendental” frequently, and in a rather different sense than Paneth employed.

I apply the term *transcendental* to all knowledge that is not so much occupied with objects as with the mode of our cognition of those objects, so far as this mode of cognition of these objects is possible *a priori*. (Kant 1781/1952, p. 20)

Kant distinguished the realm of observable “phenomena” from the “transcendental” realm of “noumena” (things as they are “in themselves”).

[A]ll our intuition is nothing but the representation of phenomena: ... the things which we intuit are not in themselves so constituted as they appear to us ... What may be the nature of objects considered as things in themselves and without reference to the receptivity of our sensitivity is quite unknown to us. ... Supposing that we should carry our empirical intuition even to the very highest degree of clearness, we should not thereby advance one step nearer to the knowledge of the constitution of objects as things in themselves. (Kant 1781/1952, pp. 29–30)

Following philosopher Eduard von Hartmann (1842–1906), Paneth used “transcendental” not in the full Kantian sense, but only to indicate lack of accessibility to ordinary human perception (“beyond the sphere of consciousness”).

The German language has two words, *Stoff*⁵ and *Substanz*, that are generally translated into English by the word “substance.” It is interesting to note that Paneth uses the word *Stoff* throughout his paper when referring to ordinary chemical substances (“a substance”)—but he switches to *Substanz* on two occasions where a sense close to “essence” (“the substance”) is implied⁶ (Paneth 1931, pp. 117–118).

Simple substances?

Dihydrogen (H₂), dioxygen (O₂), white phosphorus (P₄), yellow sulfur (S₈), and buckminsterfullerene (C₆₀) would all be designated as “simple substances” according to Post’s translated version of the Paneth scheme. Those substances are indeed “simple” in the sense that they cannot be resolved into several components by ordinary chemical means—but they definitely are not “simple” in the sense of having no internal structure. Each of these substances has a distinctive molecular architecture that determines the properties of that material. The physical and chemical properties of buckminsterfullerene are quite different from those of graphite—although both substances are forms of “the element carbon.” Those differences in properties stem directly from differences in internal (molecular) structures of the two substances.⁷

⁵ Buchler (2004) pointed out that the German term *Stoff* does not carry the same philosophic freight as the English word “substance” does.

⁶ I defer to others who may know whether or not such usage is widespread.

⁷ Buckminsterfullerene consists of quasi-spherical C₆₀ molecules. Graphite consists of planar sheets of carbon centers arranged in a “chicken-wire” pattern.

Paneth points out that many chemical elements have several “allotropic forms.” He clearly recognized the awkwardness of the use of “simple substance” in reference to allotropes. Paneth noted the desirability of a change in nomenclature. He suggested that different names should be used for different allotropes—as O₃ is designated “ozone.” He also recommended that different names be used for elements when they are elementary substances and when they are components, as is done in German only for the element carbon—that element is designated by one word (*Kohlenstoff*, carbon) as a component and by another word (*Kohle*, charcoal) as an elementary substance. But he wrote, regretfully: “However, I do not, of course, wish to suggest a linguistic reform impossible to carry out so late in the day, but only to point out what would seem to be indicated in the interest of logic.” (Paneth 2003, p. 132).

Element and substance

Paneth’s *Grundstoff* designates the carbon in carbon tetrachloride, the oxygen in water, and the titanium in titanium dioxide. Paneth argues convincingly that the central and essential part of the concept of “element” is that of “basic substance,” *Grundstoff*. That is, the word “element” should properly be assigned to the *components* of specific stuffs rather than to substantial materials. On the basis of Paneth’s reasoning, we may suppose that the use of the word “element” to denote elementary substances (*einfacher Stoffe*, simple substances) derives from fairly recent laboratory practice involved in demonstrating the identity of candidate elements. The fundamental notion of “element” is *Grundstoff* rather than *einfacher Stoff*—and the “transcendental” nature of the meaning of *Grundstoff* is common to both ancient and modern notions of “element.”

Post’s translation of *Grundstoff* as “basic substance” is more problematical than his use of the designation “simple” for elementary substances—because the main thrust of Paneth’s paper clearly implies that a *Grundstoff* is *not* “a substance.” The term “a substance” is used in general speech, and in philosophy, in a sense that is close to, if not quite the same as, how that term is used in chemistry. Millikan (2000) defines “a substance” as designating any entity that can interact so as to provide information that might be useful for future interactions. The traditional notion of “a substance” has two main features. The most ancient Indo-European sources (Greek epic poetry of Homer and Sanskrit *Vedas*) indicate that *persistence* (e.g., being alive) was the original meaning of “being” (Kahn 1973). Stability over time (however brief) is taken as a centrally important aspect of whatever can properly be said “to exist.” The term “a substance” is traditionally taken to designate something that exists over a “significant” period of time.

A second traditional requirement of “a substance” (properly so-called) is “independent” existence.⁸ The carbon in carbon tetrachloride does not fulfill this requirement—items of this sort necessarily exist as parts of more-inclusive wholes. On that basis, what Paneth designated *Grundstoff* (and referred to as “transcendental”) is not “a substance”—as that term is used in chemistry, in philosophy, and in the general discourse of speakers of English.

⁸ Baruch (Benedict) Spinoza (1632–1677) took this requirement especially seriously. He concluded that—since all things are more or less connected to each other—there can be no more than one substance, properly speaking.

“A substance” versus “the substance”

Modern chemistry deals with the characteristics of “chemical substances”—and how such substances change into other substances. It is often reported that ancient philosopher⁹ also had been concerned with “substance.” How ancient and modern notions of substance are related is not often discussed.

The *Shorter Oxford English Dictionary (SOED)* lists 13 distinct connotations of the modern English word “substance.” The first meaning is: “The essential nature or part of a thing, etc., essence: ...” Chemists may be surprised to learn that the meaning that corresponds to “chemical substance”—“a particular kind of matter, especially one of a definite chemical composition”—ranks only as number 5 in the *SOED* list of meanings of the English word “substance.” Ordinary speech emphasizes the difference between the meaning of the word “substance” that is most relevant to chemistry and the more usual meanings of the word by a special use of definite and indefinite articles. Each specific chemical compound is properly designated “a substance”; but the essential part of any narrative is correctly called “the substance” of that story. Failure to recognize the difference between these two quite distinct meanings of “substance” can be (and historically has been) the source of much confusion and misunderstanding.

Contemporary translations generally render the name of the first and most important of Aristotle’s “categories”⁹ as “substance.” Aristotle used the Greek word “*ousia*” as the title of his first category. *Ousia* is the Greek noun formed on *ousa*, the feminine present participle of the Greek verb “to be,” *einai*. Correspondingly, “beingness” would be the English noun derived from “being,” the present participle of the verb “to be.” *Ens* is the present participle of the corresponding Latin verb, *esse*—“entity” would be anglicized version of a Latin noun formed on that participle. Like the English word “substance,” the Greek word *ousia* has several meanings—each rather different from the others. Owens (2007, p. 16) pointed out that the English word “entity” could properly be used to translate *ousia* wherever that word occurs in Aristotle’s writings—but because “entity” is unambiguous (i.e., it lacks a variety of meanings) such translations would have to be supplemented with notes to clarify in which of its several senses *ousia* was used in each context. The fact that “substance” has been generally used to translate “*ousia*” is connected with the multiple meanings that “substance” has in contemporary English. However, in turn, that polysemy of the English word probably derives, in large part at least, from the complexity of the usage of *ousia* among the ancient Greeks. Owens also notes (2007, p. 15) that a common meaning of *ousia* in Modern Greek is “property”—in particular, those possessions that establish or confirm the social status of a person. (To illustrate the corresponding use—meaning 11—of the English word “substance,” the *SOED* quotes Thackeray: “He was a man of some substance.”) Many of the otherwise-puzzling features of Aristotle’s use of *ousia* may seem less odd if one keeps in mind that *ousia* may well also have had that social significance in ancient times.

In Aristotle’s *Categories*, *ousia* primarily refers to a concrete individual (a specific, complete thing)—this ox, that tree—but it also has other, secondary, meanings:

Ousia—that which is called an *ousia*—most strictly, primarily, and most of all—is that which is neither said of a subject nor in a subject, e.g., the individual man or the individual horse. But in a secondary sense, those things are called *ousia* within

⁹ The categories are: substance, quantity, qualification, where, when, being-in-a-position, having, doing, being affected (*Categories*, I^o 25).

which, as species, the primary *ousia* are included; also those which, as genera, include the species. For instance, the individual man is included in the species “man,” and the genus to which the species belongs is “animal”; these therefore—that is to say the species “man” and the genus “animal”—are termed secondary *ousia*. *Categories* (2^a, 11–16),

By “in a subject,” Aristotle means “what is in something, not as a part, and cannot exist separately from what it is in.” (*Categories* 1^a, 24–25).

Kohl (2008) has argued that, in *Categories*, it is “subjecthood, conceived in a certain way” that is Aristotle’s criterion for designating both concrete objects and “substance universals”—the species and the genus—as *ousia*. Kohl (2008, p. 158) concludes that Aristotle considers concrete objects as *ousia* because each can be discussed in terms of its species, its genus, and its many other characteristics (properties). That is, species, genus, and diverse properties all can be “predicated” of a concrete individual. Species and genera also can be discussed in terms of the properties that pertain to them (properties can be predicated of species and genera as well as of concrete individuals)—so these universals are also *ousia*, though in a secondary sense. In both cases, it is the capability to function a “subjects” for discussion (“subjecthood”) that distinguishes *ousia* from whatever else there may be. Putting abstract universals in the same category with concrete individuals could conceivably predispose an unwary person to the error that Whitehead (1925/1967, pp. 51–58) called “the fallacy of misplaced concreteness”—erroneously assigning the status of concrete existence to abstractions.

Aristotle’s later views

There is a profound ambiguity (polysemy, amphiboly) in Aristotle’s use of *ousia*. In the *Categories* that single word refers both to a specific existing individual, and also to the genus and to the species to which a particular individual belongs—these are quite different meanings. In the early work *Categories*, Aristotle was careful to characterize his use of *ousia* as “primary *ousia*” or “secondary *ousia*.” He does not do this in the later work *Metaphysics*. Although in *Categories* (2^b 29–30) the author restricts the use of *ousia* to concrete objects, species and genera, in *Metaphysics* he also applies the same term (*ousia*) to the “essence”—the “whatness,” the specific set of defining characteristics—of any individual. He also applies the same term to the “substratum” (*hypokeimenon*)—something that in some sense supposedly “underlies” each concrete entity. Thus, in *Metaphysics VII (Z)* we have not just primary *ousia* and secondary *ousia* as in *Categories*, but rather *ousia*₁, *ousia*₂, *ousia*₃, and *ousia*₄ which would translate into four varieties of “substance”: substance₁, substance₂, substance₃ and substance₄.

The word *ousia* is applied if not in more senses, in at least four senses, for both the essence, and the universal, and the genus, are thought to be the *ousia* of each thing, and fourthly the substratum (*hypokeimenon*). Now the substratum is that which everything else is predicated, while it is itself not predicated of anything else. And so we must first determine the nature of this; for that which underlies a thing primarily is thought to be in the truest sense its *ousia*. And in one sense matter (*hyle*) is said to be the nature of the substratum, in another, shape (*morphos*) and in a third the compound of these. *Metaphysics, Book VII (Z)*, 1028^b, 35–36,

According to Aristotle's understanding, matter and form are "in" every ordinary concrete thing in the sense of "in" spelled out in *Categories*. That is, matter and form do not exist as *parts* of the thing and, strictly speaking, neither matter nor form exists "independently"—that is, outside of the concrete thing in which it is. Famously, Plato held that "forms" could somehow exist apart from any concrete thing—and Aristotle denied this doctrine, in so far as it applied to ordinary things.¹⁰ However, Aristotle did recognize "separated substances" (Owens 2007: 21ff) in his discussion of the causes of motion of celestial objects, (*Metaphysics, Book XII (A)*).

Priscian (fl. ~ 520 CE)

Study of Latin grammar was a main component of the meager educational opportunities that were available to Europeans during the interval from the fall of the Roman Empire to the beginning of the medieval universities in twelfth century. A single book dominated academic instruction in grammar during this long period. That was the *Institutiones Grammaticae* of Priscianus Caesariensis (generally known as "Priscian"). Priscian was born of Greek parents in Roman North Africa, and flourished in the imperial court at Constantinople in the early sixth century, CE. Anneli Luhtala has recently published (2005) a careful study of the relationship between grammar and philosophy near the end of the Roman Empire—with special attention to the sources that Priscian used.

It is largely because Priscian decided to translate the Greek word *ousia* by the Latin *substantia* (rather than by some word related to *ens*) that *ousia* is now usually translated into Latin as *substantia*, into English as "substance," and into related words in other European languages. (Where *ousia* appears un-translated in otherwise translated quotations given in this paper, the translator had used "substance.") Priscian's grammatical system effected a kind of compromise among some of the many philosophical approaches that competed vigorously when the Roman Empire flourished. These traditions included (among others) the Peripatetic school that stemmed from Plato and Aristotle, Neo-Platonism (e.g., Plotinus), and Stoic Philosophy. (Luhtala 2005, pp. 79–90).

The Peripatetics, following Aristotle, held that each individual being (*ousia* in its primary sense) consists (somehow) of "matter" (*hyle*) and "form" (*morphos*). Stoic philosophers agreed with the doctrine that Plato had outlined in *The Sophist*—that only what had causal power could properly be said "to exist" (Armstrong 2004, p. 37)—but they further held that only "bodies" (*corpora*) could cause (or suffer) effects. They also held that each individual thing consisted (in a sense) of two "substrates"—an underlying "being-in-itself" and "quality." But the Stoics clearly taught that neither of those two "substrates" could exist in isolation. (Long and Sedley 1987).

In stark contrast to this "materialistic" outlook of the Stoics, the Neo-Platonists developed the strand of Plato's thought that emphasized the independent existence of "forms." Neo-Platonists taught that "behind" and "under" the "surface" phenomena that present themselves to human senses, there are three *hypostases* (i.e., "what stands under")—"The *Psyche*" ("The World Soul"), "The *Nous*" ("The Divine Mind"), "The One" ("The Absolute"). These *hypostases* were considered to be "higher spiritual

¹⁰ Aristotle occasionally also used the word *ousia*, as well as the words *hypostasis* ("what stands under") and *hypoikeimenon* ("what lies beneath"—translated as "substratum" in the quotation from *Metaphysics VII (Z)* given in the text) to designate "the objective reality" (as opposed to "the outer form") of a thing—"the substance" as contrasted with "a substance."

principles” (“*arche*”)—each was more “sublime” than the preceding one. The One (“the most sublime”) was said to generate The *Nous*; The *Psyche* was considered to “emanate” from The *Nous*. The *Psyche* was held to have fashioned the cosmos that we perceive.¹¹

Priscian’s Latin grammar

Apollonius Dyscolus was an influential grammarian who flourished in Alexandria in the 2nd Century CE. He published an extensive grammar of the Greek language that was strongly influenced by Stoic thought. This work was widely used and extensively quoted by grammarians during the late Roman Empire. A part of Apollonius’s discussion of word order is translated as:

The noun necessarily precedes the verb because disposing and being disposed are properties of bodies and naming pertains to bodies, on which depend the properties of the verb, namely action and undergoing action. (Luhtala 2005, p. 86), 97

This discussion clearly presumes the Stoic understanding that everything that really exists can be referred to “bodies.” When he compiled his Latin grammar—several centuries after Apollonius had written his Greek grammar—Priscian followed that earlier author quite closely. Many long and important passages of the earlier work are incorporated directly into the later work by word-for-word translation. However, Priscian (or perhaps earlier intermediate sources, now lost, that he followed) made some important variations away from the text that Apollonius had produced. At the text location corresponding to the quotation from Apollonius concerning word order that was given above, Priscian’s text translates as:

The noun is necessarily placed before the verb because action and undergoing of action are properties of a substance, in which name-giving takes place, on which depends the property of the verb, namely action and undergoing of action. (Luhtala 2005, p. 86)

Mention of “bodies” is gone. *Substantia*—the Latin equivalent of *hypostasis*, the Greek word that designated a Neo-Platonic “spiritual principle”—is substituted for “body.” This alteration (and others like it) may signal a major shift in philosophic understanding—or might only indicate an expedient compromise made by practical grammarians with limited interest in interminable philosophic debate. (Let’s call it “Priscian’s Compromise.”) Priscian understood (or misunderstood, or modified) the earlier text of Apollonius in a peculiar way—apparently ignoring Stoic doctrine that nothing existed apart from bodies. Priscian was a grammarian, not primarily a philosopher. For his purposes, it may have been quite sufficient that people *speak as if* there were some *hypostasis* (what later philosophers call a “bare particular”) that “stands under” the properties of whatever it is that each sentence concerns (This would be what grammarians now call “the subject”—literally “what is thrown under.”).

Alcuin of York (732–804) disseminated Priscian’s work through the cathedral schools and other educational institutions that were set up in Western Europe during the “Carolingian

¹¹ It now seems trivial to observe that one may know that a Phoenix is a bird that can rise again from its own ashes without expecting that any individual that fills that description exists in fact. This distinction between “essence” and “existence” was much debated by the medievals—and was not nearly as clear to the ancients as it may be to us (Owens 2007, pp. 22–23).

Renaissance” of the eighth century (Shimizu 1999) Priscian’s discussion of nouns was studied (either directly or through secondary sources) by every pre-medieval student and scholar, all across Europe, during a period spanning several centuries. That widespread instruction established the generally accepted but largely unexamined presupposition that some “substance” somehow “stood under” the apparent properties of every “thing.” The Latin word “*substantia*,” a literal translation of the Greek “*hypostasis*,” became the generally-used translation of the Greek *ousia*. One long-term result of Priscian’s Compromise was that when the word “substance” eventually emerged in modern English, it did so with much of the polysemic complexity that had characterized *ousia* in Ancient Greek. The use of “substance” in chemistry retains little, if any, of that complexity.

In twelfth-century France, Peter Abelard (1079–1144) recognized that the grammatical system that Priscian had cobbled together was philosophically awkward (Shimizu 1999) In the thirteenth century, Thomas Aquinas (1224–1274) introduced the notion of “*suppositum*” (usually rendered in to English as “supposit”—“what is placed under”) to replace the primary sense of *ousia* as an individual existent that had been largely displaced by the polysemic word *substantia* (Tomarchio 1991) In the eighteenth century, David Hume (1711–1776) rejected the whole notion of “substance” (and John Locke’s [1632–1704] related idea of “substratum”) and suggested that concrete things were “bundles of properties.” Recently some philosophers have endorsed (e.g., Hochberg and Mulligan 2004) the theory that entities are collections of “tropes” (property-instances). However, responses to the obvious question of what holds properties or tropes together in their aggregates (e.g., Robb 2005) are not fully convincing.

Moving horizons of chemistry

When Paneth delivered his 1931 speech, a major shift in the official chemical understanding of the concept of “chemical element” was well underway. Factors that contributed to that shift included the discoveries of the periodic table of the elements, and of the nuclear nature of the atom. Final pieces of the puzzle were the realization that chemical elements generally had several “isotopes”—varieties of a given element with different masses—and the identification of the neutron as an uncharged particle of the same mass as the positively-charged proton. After extensive and spirited discussion (with Paneth as a prominent participant), the International Union of Pure and Applied Chemistry adopted a new definition of a chemical element in terms of the positive charge on the atomic nucleus—the “atomic number” *Z*. By this new definition, any atom whose nuclear charge is 17 is an atom of chlorine—having an atomic number of 17 is the *essential characteristic* of the element chlorine. The newer definition of element did not concern whether an element is “a substance” (substance₁—*ousia* in the sense that Aristotle designated “primary” in *Categories*) but rather pertains to the “whatness” of “essence” of each element (substance₃—*ousia* in the third of the four senses mentioned in *Metaphysics V (A)*).

As Paneth correctly pointed out, an element properly so-called—what Paneth designated *Grundstoff* (“basic substance” in Post’s translation)—does not have sensible properties. The chlorine in carbon tetrachloride is not green, gaseous, pungent, or toxic, as dichlorine—an elementary substance (*einfacher Stoff*, “simple substance”)—certainly is. This does not mean that “the element” properly so-called (*Grundstoff*) has *no* specific characteristics—only that the properties that the element does have are “transcendental” in Paneth’s restricted epistemological sense, i.e., “beyond the sphere of consciousness”. The element chlorine has the characteristic “atomic number” of seventeen. This is the defining

characteristic (“essence”) of that element—“*the substance*”—substance₃—of the element as Aristotle had defined that term. That property is not accessible to ordinary human perception, but it can be ascertained by a more or less complex procedure of reasoning based on measurements using several technological methods and instruments.

This outlook does not seem consistent with Kant’s phenomena/“noumena” distinction—if the second Kant quotation given earlier is interpreted to hold that the essential natures of things are forever unknowable (“transcendental” in some absolute sense). The revised IUPAC definition of the chemical elements certifies that development of a number of experimental techniques and instruments, and cumulative theoretical and conceptual advances extending over several centuries, had gradually culminated in an irreversible extension of human comprehension so that the essence of elementarity now was understood. Persons committed to Kant’s philosophy may well have found this interpretation unacceptable. There is an interesting parallel with Paneth’s demonstration of the real existence of “free radicals.” Paneth’s reactor with remote metallic mirror brought short-lived entities that had previously been merely hypothetical “within the sphere of human consciousness” in a certain sense. But skepticism about the “real existence” of free radicals persisted in some quarters for many years.

Poet O. B. Hardison (1989) described “a horizon of invisibility”—the line that separates what we now can see, given the conceptual and technological resources we have available, from what we cannot (yet) recognize. The discovery of the substance₃ of (chemical) elementarity (as recognized by the IUPAC action) resolved a question that had engaged astute thinkers for millennia—but also opened a host of further questions: What holds protons and neutrons together in atomic nuclei? Why are some isotopes unstable?, etc. Discovery of the essential nature of the chemical elements teaches that horizons of invisibility are not permanently fixed (as Kant seems to have held) but rather they are movable. Other questions that have long puzzled investigators will eventually yield to patient, creative, and skillful research. But however horizons of invisibility may shift, there always will be deeper aspects of nature that remain to be investigated. Perhaps this is a more appropriate way to interpret Kant’s doctrine of the inscrutability of “things-in-themselves.”

Two modest proposals

The main thrust of Paneth’s paper was that the concept of “element” (as used in contemporary chemistry) is closely related to—and just as “metaphysical” as—the corresponding concept used by the ancients, medievals, and alchemists. He held that the designation “element” properly belongs to what he calls *Grundstoff*—an ultimate constituent of a chemical substance—rather than to stable substances that cannot be decomposed (*einfacher Stoffe*), such as those that figured in Lavoisier’s definition of a chemical element. On this basis, a more appropriate (though less literal) translation of Paneth’s *einfacher Stoff* into English would use the term “elementary substance” rather than “simple substance” or “element” for stable materials containing only one element. (This has been done in this paper.) The word “element” would then be available for exclusive use as an English translation of “*Grundstoff*.”¹² The revised IUPAC definition of “element” is more consistent with Paneth’s “metaphysical” concept than it is with the

¹² This usage should not be taken to suggest that “elements” (as such) have independent existence. Our present intuition that “elements” have independent existence stems from the unfortunate custom of referring to stable materials such as yellow sulfur as “elements,” rather than as “elementary substances.”

earlier custom that identified “the elements” with stable elementary substances. This rather minor linguistic refinement would be directly in line with the main thrust of Paneth’s paper. It would resolve the troublesome polysemy to which he called attention. It would also much improve the clarity and consistency of chemical language, reduce misunderstanding, and achieve much of what Paneth hoped to achieve by his own nomenclature-reform suggestions.

Philosophical debate on how properties cohere in concrete individuals proceeds with vigor, but with minimal attention to modern chemistry. But contemporary chemistry has a highly nuanced and rather complete understanding of natural things that seems to be quite different from usual philosophical speculations. Chemical language has as many subtle features as any natural language: current philosophical debates cannot adequately be resolved with tourist-guidebook familiarity with that arcane dialect. Chemists and philosophers of chemistry (e.g. Harré ~~forthcoming~~; Earley 2008), can usefully contribute to current philosophical discussions of whether individual entities should be considered as bundles of properties, collections of tropes, bare particulars—or treated in ways that are quite different from any of those approaches. Such discussion must be postponed to another occasion.

Acknowledgements This research was supported, in part, by a grant from the Graduate School of Arts and Sciences of Georgetown University. The author is grateful to two anonymous reviewers for helpful suggestions and to Prof. Klaus Ruthenberg and to Dr. Martin Holzhaus for providing the German text of Paneth’s original paper.

References

(2008). doi: 10.1007/s10698-008-9052-7

- Armstrong, D.M.: Truth and Truthmakers. Cambridge University Press, Cambridge (2004)
- Barnes, J. (ed.): The Complete Works of Aristotle. Princeton University Press, Princeton (1984)
- Buchler, J.: Chemistry seen as molecular architecture and notes on the German term ‘Stoff’. In: Sobczyńska, D., Zeidler, P., Zielonaka-Lis, E. (eds.) Chemistry in the Philosophical Melting Pot (Dia-Logos 5). Frankfurt am Main, Peter Lang (2004)
- Earley, J.: Chemical ‘substances’ that are not ‘chemical substances’. *Philos. Sci.* **73**(5), 841–852 (2006). doi: 10.1086/518743
- Earley, J.: How philosophy of mind needs philosophy of chemistry. *HYLE Int. J. Philos. Chem.* **14**(1), 1–26 (2008)
- Hardison Jr., O.B.: Disappearing Through the Skylight. Viking/Penguin, New York (1989)
- Harré, R.: Trope Theory and the Ontology of Chemistry. *Found. Chem.* (forthcoming)
- Hochberg, H., Mulligan, K. (eds.): Relations and Predicates. Ontos Verlag, Frankfurt (2004)
- Kahn, C.: The Verb “Be” in Ancient Greek. Reidel, Dordrecht (1973)
- Kant, I., Meiklejohn, J.M.D., Hutchins, R. (ed.): The Critique of Pure Reason trans. Great Books of the Western World, vol. 42. Britannica, Chicago (1781/1952)
- Kohl, M.: Substancehood and subjecthood in Aristotle’s categories. *Phronesis* **53**, 152–179 (2008). doi: 10.1163/156852808X278712
- Long, A.A., Sedley, D.N.: The Hellenistic Philosophers, 2 vols., pp. 165, 172–174. Cambridge University Press, Cambridge (Quoted in Luhtala 2005, p. 85) (1987)
- Luhtala, A.: Grammar and Philosophy in Late Antiquity: A Study of Priscian’s Sources. John Benjamin, Amsterdam (2005)
- Millikan, R.: On Clear and Confused Ideas: An Essay on Substance Concepts. Cambridge University Press, New York (2000)
- Owens, J.: Aristotle’s Gradations of Being in Metaphysics E-Z. St. Augustine, South Bend (2007)
- Page, T., et al. (eds.): Aristotle, the metaphysics, vols. 1 and 2. In: The Loeb Classical Library. Harvard University Press, Cambridge, (1933/1935)
- Paneth, F.: The epistemological status of the concept of element. *Found. Chem.* **5**(2), 111–145 (1931/2003)
- Paneth, F.: Über die erkenntnistheoretische Stellung des chemischen Elementbegriffs. *Schriften der Königsberger Gelehrten Gesellschaft.* **8**(4), Halle: Max Niemeyer (1931)

- Robb, D.: Qualitative unity and the bundle theory. *Monist* **88**(4), 466–492 (2005)
- Scerri, E.: Realism, reduction, and the intermediate position. In: Bhushan, N., Rosenfeld, S. (eds.) *Of Minds and Molecules: New Philosophical Perspectives on Chemistry*, pp. 51–72. Oxford University Press, New York (2000)
- Scerri, E.: Response to Vollmer's review of minds and molecules. *Philos. Sci.* **70**, 391–398 (2003)
- Shimizu, T.: Words and concepts in Anselm and Abelard. In: Biard, J. (ed.) *Langage, sciences, philosophie au XIIe siècle*, pp. 177–197. Vrin, Paris (1999). http://www.l.u-Tokyo.ac.jp/~shimizu/medieval/word_concept.pdf
- Tomarchio, J.: The emergence of the supposit in a metaphysics of creation. In: *Paidia: Papers of the 20th World Congress of Philosophy*, Boston, MA (1991). <http://www.bu.edu/wcp/Papers/Medi/MediToma.htm>
- Whitehead, A.N.: *Science and the Modern World*. Macmillan, New York (1925/1967)