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Paneth, Kant, and the philosophy of chemistry

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Abstract Immanuel Kant has built up a dualistic epistemology that seems to fit to the peculiarities of chemistry quite well. Friedrich Paneth used Kant's concept and characterised simple and basic substances which refer to the empirical and to the transcendental world, respectively. This paper takes account of the Kantian influences in Paneth's philosophy of chemistry, and discusses pertinent topics, like observables, atomism and realism.

Keywords Paneth · Kant, basic and simple substances · Metaphysics · Transcendental · Antirealism

Introduction

Until recently, Immanuel Kant has been considered as the one philosopher who neglects chemistry in terms of its scientific status. In his earlier writings, Kant in fact claimed that a proper science should contain a reasonable amount of mathematics (a view which he held throughout his work). He therefore classified chemistry as a "systematic art". In a schematic figure of Kant's hierarchy of sciences (entitled "natural philosophy") chemistry would fit into the improper (uneigentlich) or empirical or applied branch rather than to that of the mathematized, logical sciences (Fig. 1).

In 1931, the mature Austrian chemist Friedrich Paneth (1887–1958), for example, said:

> If one accepts this definition [that in any particular discipline of the study of nature one can find only as much actual science as there is mathematics], Kant is perfectly right not to include chemistry amongst the sciences, since chemistry is essentially non-mathematical. (Paneth 1931, p. 7)

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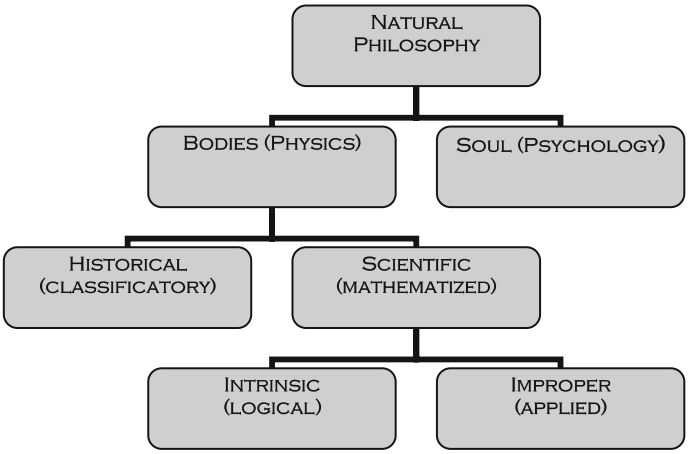

Fig. 1 The hierarchy of sciences according to Immanuel Kant

According to Paneth, the kernel of chemistry is non-mathematical. Thus, he points out in the same paragraph, that Kant was considerably more correct than later philosophers and scientists who expected the transformation of chemistry into physics. Nevertheless, Paneth also claimed that Kant had an extremely narrow, and "probably inappropriate conception of science". Referring to chemistry, he claimed:

> Some of its fields, particularly so-called physical chemistry, admittedly now include so much mathematics that they would presumably satisfy Kant's definition … (Paneth 1931, p. 7)

Having stated this, Paneth opened the door of the reductionism debate, on which he held an anti-reductionist view. This view will not be discussed further here.

Recent studies particularly by Friedman (1992), Nayak and Sotnak (1995), Rothbart and Scherer (1997) Carrier (2001), and van Brakel (2000, 2006) have shown that Kant's philosophy in general is able to grasp topics raised by chemistry, and that Kant on the one hand did have considerable knowledge of contemporary chemistry and, on the other hand, particularly in his post-critical works, by no means underestimated this "systematische Kunst". The present contribution, however, is about another aspect of the relation between the *philosopher-scientist* Kant and the *scientist-philosopher* Paneth. In particular it tries to show that this relation of Paneth to Kant is something different than, as van Brakel 2006 has pointed out, the "occasional opposition … to Kant" within history and philosophy of chemistry. In the following section I shall give an overview of Paneth's motivation for getting involved in philosophical questions about chemistry.

A crisis caused by isotopes

Unlike many chemists, Friedrich Paneth was deeply interested in the historical roots and philosophical foundations of science in general and of chemistry in particular throughout his entire scientific life. He read primary sources from antiquity (e.g., pre-Socratics, Aristotle), and the Renaissance (Boyle), from classical (e.g., Spinoza, Kant, Mill) and contemporary authors (e.g., Rickert, Schlick, Meyerson, Bachelard, von Hartmann), and

was well aware of the main achievements and developments of philosophy (for an overview of his contributions to the humanities see Dingle and Martin 1964).

The discovery of isotopes and radioactivity meant that it was no longer strictly the case that atoms of each element as listed in the Periodic Table could be considered identical. In addition, in the process of radioactive decay, one element was destroyed and a new element was created. Paneth was among the first to grapple with the implications of these discoveries for the most fundamental concepts in chemistry, and had serious disagreements with colleagues about these implications (cf. van der Vet 1979). Already since 1912 (mostly together with von Hevesy) he had published on general problems of isotopy (see bibliography in Dingle and Martin 1964), and in 1916 he produced an article entitled "On the concept of element and atom in chemistry and radiology" in Ostwald's *Zeitschrift für Physikalische Chemie* (Paneth 1916). In this article Paneth discussed the central concepts of the chemical sciences, namely *substance* and *element*, the understanding of which had fallen into crisis (Kragh 2000). In a systematic survey of the concepts of *element* and *atom* he referred critically to what Wilhelm Ostwald had called "law of substance" (Stoffgesetz). With the latter, Wilhelm Ostwald had claimed that two chemical substances are identical with respect to all properties if they are identical in a few of these (Ostwald 1909, p. 48). Paneth explicitly denied the validity of this expression—if taken literally—because isotopy, considered as one of these properties, had made it invalid (Paneth 1916, p. 181).

> Today we know that a total conformity of most of the properties does not exclude greater or smaller differences referring to certain other properties … [the question arises] whether or not the predominant number of properties could be sufficient [to call two substances by the same name]. (Paneth 1916, p. 181)

Ostwald, without any doubt, would not have accepted isotopy or atomic numbers as (specific) properties of chemical species because these would not have been representable in terms of his phenomenological and operationalistic epistemology. However, Paneth conceded that a strict interpretation of the denial of the law of substance would lead to a devaluation of the concept of the element within chemistry. As an example, he took the following fictional case: A chemist compares two samples of lead, one of which with the atomic weight 207.2 (element A), and the other with the atomic weight 206.0 (element B). When mixed, these elementary samples would yield a substance that fits the requirements to call it an element, although its atomic weight could be 206.6. The application of the law of substance would force the chemist of this story to call the mentioned isotopic mixture a new element (element C): "He has synthesized a new element out of two!" (Paneth 1916, p. 182) Accordingly, any chemist could make an unlimited number of elements by simply mixing portions of different isotopes. Similar to uncreatability (Unerschaffbarkeit) and indestructibility (Unzerstörbarkeit), it would also be necessary to abandon the idea that there was a limited number of basic chemical substances (Paneth 1916, p. 182). Hence, Paneth suggested the following:

> The mentioned difficulties can be overcome if one does not demand the identity of all properties to denote two elements by the same name, but rather to be content with the equality of the chemical properties. (Paneth 1916, p. 183)

Accordingly, Paneth not considered atomic weight as a chemical property, and suggested the following definition:

> Two elements are called the same if they, once mixed, cannot be separated by any chemical means… By this sentence we express that we consider isotopes as the same

> element because their inseparability is a characteristic property. (Paneth 1916, p. 183)

It is noteworthy that this definition is operational and phenomenological. It is operational because it delivers a kind of recipe on how to treat two substance samples in order to differentiate or identify them, and it is phenomenological because it uses real, macroscopic material only, rather than an atomistic vocabulary. Also noteworthy is the fact that the *Deutsche Atomgewichtskommission* and the *International Committee on Chemical Elements* of the *IUPAC* (founded in 1919) followed Paneth's suggestion of the element definition in 1921 and 1923, respectively, though ironically not the mentioned one from 1916 (see, for more of the historical background, Kragh 2000). Since the third decade of the twentieth century, chemical elements worldwide were officially considered to "consist of atoms of the same proton number". In his 1916 paper Paneth did mention this definition (Paneth 1916, p. 194) but did not emphasize it. In later publications, he repeated it (e.g., Paneth 1920, p. 842).

The next section is devoted to the influence of Kant on Paneth, and what the latter made out of it with respect to philosophy of chemistry.

The Königsberg tradition

Although Paneth in his earlier writings has been sympathetic to phenomenalistic points of view, at least referring to the definition of chemical elements, there was no longer any consensus regarding phenomenological, non-atomistic approaches to the foundations of main concepts in chemistry later. Referring to ancient atomists and their reception, and more particularly to the theoretical work of contemporary anti-atomists, Paneth said in 1931:

> We wholly disregard here the deliberations of Wald and Ostwald, who depart from the usual notion of element and follow their own anti-atomistic lines of thought. (Paneth 1931, p. 9)

But František Wald (1861–1930) did not at all refer to the naïve-realistic concept of "preexisting" elements. Accordingly, "… to depart from the usual notion of element…" is literally correct as far as Wald's later work is concerned. He emphasized the constructive act and the operational aspects of how chemists consider substances as "element", "compound", or "pure substance", respectively (Ruthenberg 2008). According to Wald elements were not *natural kinds* because *all* substances were *preparations* to him. However, this approach should have found agreement on Paneth's side because it was as skeptical as he was with respect to naïve-realism. Wald would have had no problems with Paneth's early operational element definition, but the "official" *IUPAC* definition would by no means have fitted his phenomenalist concept.

The source of the quotation discussed here is the already mentioned lecture presented in Königsberg entitled *Über die erkenntnistheoretische Stellung des chemischen Elementbegriffs*, and is Paneth's main philosophical contribution. In his introduction, Paneth discussed the question of why chemistry has been of only minor interest to philosophers. He came to the conclusion that the deficient chemical knowledge of philosophers is primarily responsible for the neglect of chemistry in the humanities. The two main topics of the Königsberg lecture were the question of persistence of elements in compounds and the problem of reduction of chemistry to physics. With respect to the former topic, Paneth

now—in contrast to his earlier statements—suggested a dualist interpretation of the notion *element*. This distinction clearly marks the difference between two traditional conceptions of element that are often conflated. If we say, as did Boyle, that elements are the last products of analysis, then we are using the concept of empirical entities, which Paneth, like before him Mendeleev (see e.g. Paneth 1936, and Scerri 2007, pp. 120–121) and Urbain (see, e.g. Kragh 2000, p. 443) called "simple substances" (*einfache Stoffe*). However, if we think of elements as the ultimate constituents of matter that are invariant during chemical reactions, we are dealing with the concept of "basic substances" (*Grundstoffe*). Using a different terminology, simple substances could be regarded *observables*, basic substances *non-observables or unobservables*. Obviously, this concept is a reverberation of the dualistic Kantian epistemology. According to Kant, the simple bodies are *phaenomena* and do belong to the empirical world whereas the basic substances cannot be observed directly and therefore belong to the realm of the *noumena*. Hence, Paneth expanded his former merely phenomenological point of view of 1916 and added the realm of transcendental ideas to his philosophy of chemistry.

As can be inferred from a brief look into the historical sources, the use of the term *simple substance* is a very old one, much older than the Königsberg lecture (note e.g. Lavoisier 1790[1]; see also our discussion below). Hence this term can be considered as well-introduced. Because of this, a re-naming, as Earley (2008) is suggesting, is only partly useful. However, there are more serious arguments against Earley's criticism. His suggestion to call Paneth's simple substances "elementary substances" which he substantiates with the necessity to account for allotropy does not clearly enough differentiate the empirical substances from those theoretical entities to which dualist epistemologists like Kant and Paneth refer to. If, according to that epistemological framework, the adjective "elementary" was used in such a term it still carried its double-meaning (empirical and transcendental), thus it would make the interpretation of that term ambiguous. In another line of argumentation Earley points out that the simple substances "are not simple", by which he means that one word is used to designate a particular simple element (like "carbon") even in those cases in which several allotropic forms (like "buckminsterfullerene" and "graphite") are meant. However, Paneth addressed that point and made it clear that this linguistic difficulty is specific to chemistry, and he used, among others (almost) the same example, namely carbon and its allotropic representations, as he put it, charcoal, diamond and graphite (Paneth 1931, p. 153). Accordingly, there is no need to search for an unequivocal expression: As to elements, chemical language is (and remains) bifurcated. It was the recognition and awareness of just this fact from which Paneth started his epistemological (rather than linguistical) enterprise. Summing up his discussion of the designation of the different aspects of elements, he said:

> … using the two terms, we may say that the important advance in Lavoisier's definition of element lay in inferring the existence of a basic substance from each simple substance found experimentally.
>
> He added the following footnote to that statement:
>
> For the sake of simplicity we ignore here the possibility that a simple substance may occur in allotropic forms. (Paneth 1931, p. 154)

[1] On page 175 of the English translation of the *Traité élémentaire de Chimie* (1789), Lavoisier gives his definition of the concept as the legend of a table: "Simple substances belonging to all the kingdoms of nature, which may be considered as the elements of bodies.".

Hence, we may conclude that the empirical simple substances may come in varieties of forms, and nonetheless may be associated with the same transcendental basic substances. However, to speak of "differences in internal (molecular) structures of the two substances" (Earley 2008) namely buckminsterfullerene and graphite, means—in Paneth's terminology—to speak of *transcendentals* and therefore no longer about *simple substances*. As far as the author is concerned it seems to be useful not to lightheartedly mingle the dualist epistemology discussed here with views from prevailing micro-physicalism, for instance.

Similarly to the point about allotropes, the objection against the term *basic substance* (rather than the translated German original *Grundstoff*[2]) in Earley 2008 has a mere linguistic character. Paneth claimed that these *Grundstoffe*, although being *real* entities, are non-observables, and accordingly they are not substances in the customary chemical sense. However, to translate the artificial name used by Paneth (respectively his son and translator of the Königsberg lecture Heinz Post) with "element" which Earley suggests is just the opposite of what Paneth intended when he introduced the "double meaning" (Paneth 1931, p. 156) of this central chemical concept and two distinct notions. It makes no difference whether we use notions like "basic substance", "element", "Grundstoff", in every one of these attempts we can by no means escape the (at least) ambiguity of our chemical language. Moreover, the argument that Paneth's *basic substances* are not substances at all applies equally to the notion *element*. The concept of nuclear charge (atomic number) is theoretically linked to or corresponds to the empirical simple substance concept (like any imaginable concept of a *chemical* element in the future will do).

In the Königsberg lecture, Paneth explicitly used the terminology of Eduard von Hartmann (1843–1906), who had developed a revised form of Kant's epistemology. Von Hartmann's version particularly referred to a change of perspective: he called his system "transcendental *realism*"—which Paneth was fond of—in contrast to Kant's "transcendental *idealism*". Von Hartmann described the difference between these two as follows:

> […] whereas the latter [transcendental idealism] *denies* the transcendental meaning, validity, and usefulness of the forms of thinking and reckoning, and therewith of the entire contents of consciousness, the former [transcendental realism] *claims* these; while the latter declares every proposition about the thing in itself (even whether or not it exists) to be impossible, the former *exclusively* seeks the epistemological meaning of the contents of consciousness in the indirect information which it infers about the things in themselves. (Hartmann 1885, p. 6; emphases original)

In the present article we are not going to follow the question whether or not von Hartmann was describing Kant's position correctly (please refer to the vast secondary literature about Kant's epistemology).[3] As to the present purpose it is sufficient to sort out Paneth's motivation for referring to von Hartmann's position. As a natural scientist, Paneth seemed to prefer to stay "grounded", which means he avoided getting too close to the assumed speculative and agnostic part of Kant's position.[4] Referring to an analysis of *The*

[2] Although the word *Element* (from the Latin *elementum*) is used in the German language, too, Paneth did not use it. He presumably preferred *Grundstoff* because it has a much more neutral connotation than the historically biased *Element*. The alternative *Urstoff* is normally used in poetical surroundings and to some extend old-fashioned. When discussing cosmological questions, German-speaking physicists use *Urmaterie* rather than *Urstoff* (which by the way is absolutely correct as to the early universe).

[3] A more detailed discussion of the Kantian background and von Hartmann's interpretation can be found in the author's *Das Kantsche Echo in Paneths Philosophie der Chemie*, *Kant-Studien*, forthcoming.

[4] However, this position could be interpreted to be considerably more realistic than the common opinion claims, as Michael Friedman (1992) has shown.

Epistemological Standpoint of the Ancient Atomists—which is Sect. 3 of the Königsberg lecture—he concluded:

> As a result of these observations we affirm that some Greek thinkers had already realized that it is the aim of the natural sciences to find the laws of a world that is objectively real, whose changes are indicated in our consciousness by processes quite different in kind; and that to understand the change of properties of substances we require transcendental hypotheses. (Paneth 1931, pp. 13–14)

Already Kant himself, however, has made clear that there is no shortcut from experience with empirical substances to the foundations of chemistry. In his *Critique of Pure Reason*, he said:

> Es war schon viel, daß die Scheidekünstler alle Salze auf zwei Hauptgattungen, saure und laugenhafte, zurückführen konnten, sie versuchen sogar auch diesen Unterschied bloß als eine Varietät oder verschiedene Äußerung eines und desselben Grundstoffs anzusehen. Die mancherlei Arten von Erden (den Stoff der Steine und sogar der Metalle) hat man nach und nach auf drei, endlich auf zwei, zu bringen gesucht; allein damit noch nicht zufrieden, können sie sich des Gedankens nicht entschlagen, hinter diesen Varietäten dennoch eine einzige Gattung, ja wohl gar zu diesem und den Salzen ein gemeinschaftliches Prinzip zu vermuten. (Kant 1781/1787 A 652–653)
> (It was considered a great step when chemists were able to reduce all salts to two main genera—acids and alkalis; and they regard this difference as itself a mere variety, or different manifestation of one and the same fundamental material. The different kinds of earths (the stuff of stones and even that of metals) chemist have endeavoured to reduce to three, and afterwards to two; but still, not content with this advance, they cannot but think that behind these diversities there lurks but one genus—nay, that even salts and earths have a common principle.)

What Kant referred to here were examples of chemical attempts to get from observations in the empirical world to notions in and entities about the transcendental world (cf. Fig. 2). Metaphysical or transcendental assumptions (here we can use these expressions as synonyms) are considered by both Kant and Paneth to have a central role in the philosophy of science. Accordingly, scientists (and even more philosophers of science) should not take the existence of entities corresponding to theoretical notions like *atom*, *electron, radical,* and *orbital* at face value. It is subject to convention and therefore historically contingent which entity is regarded as *real* in a scientific community at a certain stage.[5] Nevertheless, whether or not one tends to a realistic approach referring to the mentioned chemical entities, the starting point of investigation inevitably lies in the *Lebenswelt* of humans. (The latter may be a trivial but often overlooked point at least in the discourse of modern philosophy of chemistry.)

The cited passage of the *Critique of Pure Reason* indicates that the history of the application of the notion *basic substance* (Grundstoff) reaches back even before Lavoisier. Additionally, even the expression *simple substance* can be found in the *Critique*. In the

[5] As Ursula Klein has convincingly shown (in particular for 18th and 19th century organic chemistry) already the concept of substance underlies historical changes in a more than trivial sense. She differentiates her approach from the entity realism of Ian Hacking: "I consider experimental production and individuation of objects to be part of their "constitution", and my concept of "historical ontology" differs in this respect from Hacking's." (Klein 2008, p. 42).

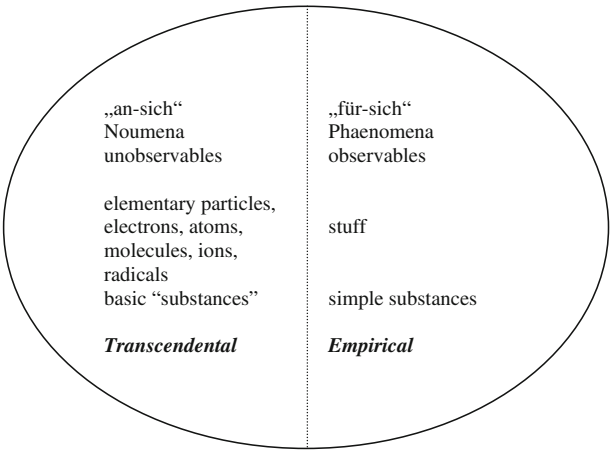

Fig. 2 Schematic representation of the dualistic Kantian epistemology as adopted by Friedrich Paneth

pertinent passage which is part of the *second antinomy*, Kant discussed the mereology of substances and the monads of Leibniz. Then he said:

> Und da ich nur in Ansehung des Zusammengesetzten die einfachen Substanzen, als deren Elemente, beweisen will, so könnte ich die These der zweiten Antinomie die transzendentale *Atomistik* nennen. (Kant 1781/1887 A 442, emphasis original)
> (And as I wish to prove the existence of simple substances, only in relation to, and as the elements of, the composite, I might term the thesis of the second Antinomy, transcendental *Atomistic*.)

The cited thesis of the second antinomy claims that all compounds (zusammengesetzte Substanzen) consist of simple parts (Kant A 434).[6] Although the quoted sentence should be interpreted carefully because the notions of *substance* and *elements* express different meanings here than in modern chemistry, and although this piece of text stands in a larger and complicated contextual framework, we might consider it as a possible source of inspiration for later scholars of the chemical sciences. Paneth knew Kant's work considerably well (see e.g., Paneth 1941). It is very likely that he read the *Critique* quite early in his life. However, the assumed inspiration turned to the opposite direction with respect to the interpretation of simple substances: Whereas Kant—at least in the cited passage—associated these with something transcendental,[7] Paneth used the notion to denote empirical entities. Hence, Paneth may have been inspired by Kant, but he obviously did not simply adopt the meaning of “einfache Substanz”. How simple and basic substances are related is the main question of the following section.

Transcendentals, borders, intermediate positions

Although there is not a strict and stable border or distinction between the empirical and the transcendental realm the shifting of notions and entities between both areas seem to be most interesting for philosophical reflections. (cf. Fig. 2)

[6] Note that this thesis is circular: Composed substances must contain parts by definition.

[7] Kant by the way was not fond of the concept of *atomism*.

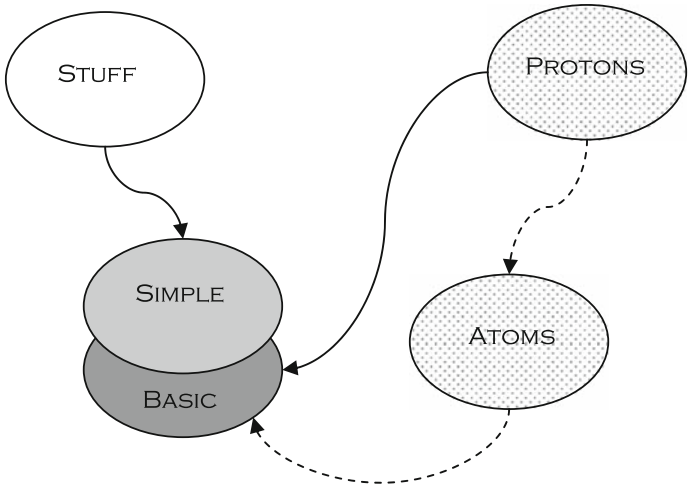

Fig. 3 Interrelations of central notions in Paneth's epistemology of chemistry. The dotted lines denote that atomism is an unnecessary concept for the understanding of simple *and* basic substances

It has to be emphasized that Paneth explicitly used the Kantian concept for epistemological purposes (Paneth 1931, pp. 3–4).[8] Accordingly, he had no strong interest in answering questions like: Do atoms exist? However, although he, as a prominent and extraordinarily successful radio chemist, did not deny the usefulness of atomism as a theoretical approach, and he claimed that the atomic concept is not a prerequisite for a proper empirical definition of chemical elements (cf. Fig. 3):

> The atomic theory can, it is true, contribute enormously to—indeed, may be necessary for—visualising how the basic substances persist in simple substances and compounds; but the concept of basic substance as such does not in itself contain any idea of atomism. It was, after all, while explicitly rejecting atomism that Lavoisier carried this concept to victory; and also in more recent times, there were, and are, chemists who avoid the atomic theory but retain the elements, including, of course, elements in the sense of basic substances. (Paneth 1931, p. 155)

Referring to the last passage of this statement, Paneth mentioned Ostwald—this time by far more friendly than in the sentence already cited (Paneth 1931, p. 9)—and Le Chatelier[9] in a footnote. Again it has to be highlighted that the most consistent operational and phenomenalist approach was delivered by František Wald, who denied the realistic interpretation of the notion of the element. What this meant to him was that the "elements" of the chemists are prepared substances, and the naïve-realistic notion of "preexisting elements" is a preconception. Presumably, Paneth only knew the earlier works of the

[8] In this footnote he said: "I wish to emphasise particularly that, like Hartmann, I am using the word 'transcendental' in its epistemological sense only, i.e. meaning 'beyond the sphere of consciousness'".

[9] Henry Le Chatelier (1850 – 1936), a French application-oriented chemist with strong affinities to chemical thermodynamics, published the now so-called *Le Chatelier principle* in 1887 (which originated from van't Hoff, see Laidler 2001). The work Paneth was referring to is Le Chatelier 1913 in which the author neglected "hypotheses about the constitution of matter" and claimed: "It is merely a question which is decided not by reasons but by inclination" (Le Chatelier 1913, p. XIV).

Bohemian scholar (such as Wald 1895, 1896), in which the latter still used "constituents" in the sense that these are used in the Gibbsean phase rule and in thermodynamics. In their most idealized form, these constituents imply elements.

Paneth's dualistic position is difficult to describe by simple designators. Eric Scerri suggested the following:

> … Paneth's philosophical message was to suggest that chemists typically adopt an intermediate 'position' between what he termed naïve realism and a metaphysical view. (Scerri 2005, p. 130)

However, the expression "intermediate position" for Paneth's point of view,[10] or that of chemistry as a whole, or at least for his description of the standpoint of chemists regarding elements, is rather questionable. It is questionable because the relation of the transcendental and the empirical world is not symmetrical. Although one most prominent aim of natural science is to uncover "what lies behind" our observations there is no choice for chemists: they have to start with real stuff portions, with samples of compounds from their *Lebenswelt*. To put chemistry in between the "two worlds" with respect to its epistemological position is misleading because we can only properly interpret the dualistic view by thinking of *both* worlds as unity.[11] As Paneth more consistently put it "…oscillation [Schwanken] between the naïve-realistic and the transcendental meanings…" of the terms of the dualistic concept (Paneth 1931, p. 158).

The handling of and the talk about submicroscopic entities like radicals, molecules, atoms, protons, and electrons is always indirect, or mediated by, measurement devices, instruments, microscopes, spectrometers, et cetera. All these devices consist of substances, and all of them " contain" hypotheses and theories, thus the danger of getting into circular argumentation must not be underestimated. Whether one holds a fundamental culturalist point of view (like, as to the philosophy of chemistry, Nikos Psarros 1999) to cope with this situation, or a somewhat more pluralistic standpoint: Scientific investigations are always performed in one direction and follow the regime of theoretical, or metaphysical austerity. As to the non-observables, a claim of their existence is not necessary in the first place; they are always situated in a specific hypothetical and empirical or experimental context. It rather seems to be due to conventions whether or not certain entities are assigned to reality. The transition from the transcendental to the empirical is not as simple as the scientists themselves usually take it. In fact there are entities we can call *empirical* like the manifest substances (like Paneth's simple substances), and there are entities which are represented by specific experiments and particular reasoning only, like electrons. In the introductory book on his *entity-realism*, Hacking claimed that entities should be considered *real* if they can be manipulated in the course of an experiment. If electrons can be sprayed, they are real (Hacking 1983). As far as the author is concerned this kind of realism is too pragmatic in so far that it leaves out the possibility of further scientific development. Take the entity *electron*. At the moment, we do not have a uniform picture of these entities at all: In some experiments they behave like charged particles; in other experiments they can only be considered and calculated as waves; for most "usual" situations we believe in their

[10] In his book on the Periodic Table, Scerri assigns this "intermediate position" to Mendeleev (Scerri 2007, p. 120). In a more recent contribution, he uses the expression "dual sense" which appears to be much more suitable (Scerri 2009).

[11] Joachim Schummer critizes the "ontological doubling of elements" suggested by Paneth and claims the physicalistic epistemological models to be unsuitable for chemistry (Schummer 1996, pp. 234–235). This serious attack and Schummer's own position will be discussed elsewhere.

stability, for reasonably high energy levels they might not be stable; their mass as particles can generally be transferred into radiation energy, and so on.[12] So what does it mean to speak of the *reality* of electrons? Isn't the talk of scientists (and philosophers of science) about the existence of theoretical entities like quarks, neutrinos, electrons, and atoms merely a talk of an "as if"? Without any doubt the science of substance change can make use of these theoretical concepts, but to believe in the reality of these entities is a vaulting ambition and simply not neccessary.[13] Therefore, I prefer to consider electrons (and similar entities) *theoretical entities* and, like other antirealists like Kant, Mach, Wald, and van Fraassen prefer to emphasize the empirical and constructive aspects of scientific enterprises.

Obviously, Paneth considered the historical development, in particular the theoretical dynamics of chemistry. In his early writings, he preferred a Lavoisierian type of element definition, which is the classical operational definition, as we have seen already. Ironically, his struggle for a preservation of the specific core of chemistry was foiled … by himself. Using his suggested epistemology, how do we have to think the connection of the empirical observations and theorizing about what lies behind? What is the relation of a simple substance and its basic "correlate"? In contrast to Sharlow (2006), I would prefer to consider basic substances—which are no substances at all in the narrow sense—theoretical concepts rather than existing things. Without going into too much detail, I would like to emphasize the basic concept in which Kant took an agnostic point of view as to the *Ding-an-sich*. Although atoms and molecules might not be things in themselves—perhaps they do not even come close—all these non-observables are man-made (by thinking and experimenting) to a certain extent which the observables are not.

Thus my answer to the question about the correlation between simple and basic substances would be threefold. First, the basic substances are non-observables and rather concepts than concrete objects. They are not bearers of properties. Second, in contrast to the simple substances, the concept of basic substance carries a considerable amount of metaphysics (which is a prerequisite for good science). Third, there are borderline cases which suggest that the concepts of some entities can pass the interface between the transcendental and the empirical world due to the progress in scientific inquiry. That means we are capable of shifting the border[14] to some extend by applying our experimental virtues.

Fritz Paneth was certainly not the only chemist who was influenced by the philosophy of Immanuel Kant, but he at least is one of those who took this influence explicitly and seriously.

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[12] In his book on "Philosophical Instruments", Daniel Rothbart puts it quite similar reviewing Hacking: "Between the proper use of the term 'electron' and the efficient use of electrons is a complex network of mediating agents, both human and nonhuman. Theories come and go, but the causal properties of certain entities deployed for purposes of research remain." (Rothbart 2007, p.4). Rothbart claims that Hacking, in his later writings, shifted his view to a culturalist or antirealist position which he seems not willing to subscribe to.

[13] In contrast to the standpoint advocated here Bernadette Bensaude-Vincent points out that Hacking's position is close to that of chemists, and she calls the later "operational realism" (Bensaude-Vincent et al. 2008, p. 52).

[14] *Shifting the border* between the transcendental and the empirical realm is closely related to the question whether or not one can draw the distinction between observables and unobservables. A recent attempt to answer this question positively from the point of view of constructive empirism is Muller and van Fraassen 2008.

polish his style. He is also grateful for all comments out of the ISPC group during the paper sessions of the San Francisco Symposium 2007, which was brilliantly organized and hosted by Tami Spector at the University of San Francisco. In particular he thanks Joseph Earley, Rom Harré, and Eric Scerri. The participation of the symposium was possible due to a travel grant from the Catholic University of Leuven (KUL), Belgium. Referring to research stays at the Institute of Philosophy of the KUL in 2006 and 2007, during which the main parts of the present contribution came into being cordially thanks go to Jaap van Brakel.

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