CHAPTER 4

KANT'S LEGACY FOR THE PHILOSOPHY OF CHEMISTRY

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INTRODUCTION

Kant's relation to chemistry is ambiguous. Did he make detailed contributions to the chemistry of his time (Carrier 1990)? Or was he a dilettante (Heinig 1975)? Did he revise his transcendental and/or metaphysical system under the influence of the work of Lavoisier (Dussort 1956)? Or is his statement that chemistry is not a proper science his final judgment? The latter view has had a large impact on both scientists and philosophers. Scarcely known is that in later life Kant may have changed his mind. Research on Kant's *Transition* or *Übergang*—his thinking after he had written the three *Critiques* and the *Metaphysical Foundations of Natural Science*—has only recently come off the ground. In the first part of this chapter, I shall show how a few lines from Kant have had a disproportionate influence on how philosophers and scientists have tended to see the relative status and relation of physics to chemistry. In the second part, I shall try to make sense of Kant's later views on chemistry and how that ties in with his philosophy.[1]

THE STANDARD RECEPTION OF KANT'S VIEW ON CHEMISTRY

Though Kant made brief comments about science in his *Critique of Pure Reason* and in the *Prolegomena to Any Future Metaphysics*, his most developed views can be found in the preface of his *Metaphysische Anfangsgründe der Naturwissenschaft* of 1786 (further *MAdN*).[2] The title of the latter already indicates that science is only possible because of certain metaphysical foundations.

Kant's use of the term "science" is somewhat ambiguous; moreover, we have to be aware of the difference in use of terms such as "doctrine," "theory," "science," *Wissenschaft*, "physics," "natural science," "natural history" in Kant's time and modern (equally ambiguous) terminology. For Kant, science comes under the more inclusive concept of doctrine (Plaass 1994, 232). The "doctrine of nature" can be divided into "historical doctrine of nature" and "natural science" (4: 468). Under "doctrine" (or description or history) of nature would presumably come biology, empirical psychology, geography, and so on.

D. Baird et al. (eds.), Philosophy of Chemistry, 69–91.

According to Kant, natural science is "proper" (pure) to the extent that it "treats its object wholly according to a priori principles" (4: 468): "only that whose certainty is apodeictic can be called science proper." In contrast, improper science instead draws on laws of experience (mere regularities, subject to Hume's scepticism); improper science is also called "systematic art or experimental doctrine" (4: 473). However, no matter how "undeveloped" a doctrine of nature, they all draw on the faculty of judgment and in that sense have an ultimate orientation toward the goal of natural science proper (4: 469).

Natural science proper is physics. It has a pure and applied part. The pure part is strictly apodeictic (proper in the strong sense). The applied part needs the "assistance of principles of experience" (4: 469) and is proper in the weak sense. An example of strong/pure and weak/applied proper science would be pure and applied geometry. Physics is based on *a priori* principles, both from mathematics and philosophy (a metaphysics of nature):[3] "natural science proper presupposes metaphysics of nature" (4: 469).[4] The use of mathematics introduces the pure part of science, and at the highest level of abstraction there is the metaphysical *a priori*.

Chemistry is based on *a posteriori* principles only. Sciences like chemistry are rational (because they use logical reasoning), though not *proper* sciences, because they miss the basis of the synthetic *a priori*. Chemistry can be "a systematic art or experimental study" (4: 468), but never a proper science, because chemical phenomena do not lend themselves to the mathematical treatment connecting them to the *a priori*: "a doctrine of nature will contain only so much science proper as there is applied mathematics in it."[5] Probably the most famous quote on chemistry from Kant is the following:[6]

> So long, then, as there is for the chemical actions of matter on one another no concept which admits of being constructed, i.e., no law of the approach or withdrawal of the parts of matters can be stated according to which (as, say, in proportion to their densities and suchlike) their motions together with consequences of these can be intuited and presented a priori in space (a demand that will hardly ever be fulfilled), chemistry can become nothing more than a systematic art or experimental doctrine, but never science proper; for the principles of chemistry are merely empirical and admit of no presentation a priori in intuition. Consequently, the principle of chemical phenomena cannot make the possibility of such phenomena in the least conceivable inasmuch as they are incapable of the application of mathematics (4: 470–471).

Chemistry is not even applied theoretical science, in the sense that the geometry a carpenter uses is applied science. Chemistry rests *only* on empirical principles. A chemical science, which would be constituted on *a priori* metaphysical and mathematical principles is, in the present state of the discipline, not possible.[7] Chemistry would only achieve the status of proper science if its concepts of given objects were arrived at by means of the presentation of the object in *a priori* intuition.[8] Hence, an empirical science such as chemistry uses a rational method of inquiry, but is not a *proper* or pure science; it is *not* an *eigentliche Wissenschaft* (proper science). Hence:

> the most complete explication of certain phenomena by chemical principles always leaves dis-satisfaction in its wake, inasmuch as through these contingent laws learned by mere experience no a priori grounds can be adduced (4: 469).

Moreover, in the crucial passage, Kant not only says that chemistry does not count as a proper science because it uses no mathematics, but that this requirement would be difficult *ever* to fulfil.[9]

Hence, for the "received" Kant a necessary requirement of "proper" science is its tie to metaphysics and mathematics. The idea that "proper" science uses mathematics has continued to the present day, though the metaphysics has been dropped. To put it crudely, the logical positivists threw out metaphysics, replacing it by logic and aligning the latter with mathematics as the "metaphysical foundation" of all "proper" science.[10]

IMPACT OF KANT'S VIEW THAT CHEMISTRY IS NOT AN *EIGENTLICHE WISSENSCHAFT*

Kant's earlier views on science have been extremely influential, far beyond his followers and the narrow circle of Kant specialists. In the English-speaking world, Kant's view that chemistry is not a genuine science is "exemplified by its place in William Paley's *Natural Theology*, the mandatory textbook read by every Cambridge gentleman throughout the nineteenth century" (Nye 1993, 5). The chemist Meyer (1889, 101) in an address delivered to *The Association of German Naturalists and Physicians*,[11] later published in translation in the *Journal of the American Chemical Society*, mentions in passing that Kant's view on chemistry was referred to in the *Deutsche Rundschau* of November 1889. Paneth [1931 (1962, 7–8)] argues that Kant's definition results in an extremely narrow and inappropriate conception of science and he declares "chemistry, too, [is] a true science, even in those branches where it contains little or no mathematics."[12] But such occasional opposition from chemists to Kant's views has never become influential.[13]

More recent examples of the ubiquitous influence of Kant's view are found in the philosophy of nature; for example, Hartmann (1948) says: "all of chemistry that is lawlike is pure physics." In 1949, the physicist and philosopher of science Dingle put it in stronger terms:[14]

> The truth is that chemistry indeed has no place in the strict scientific scheme. . . . Chemistry rightly figures prominently in the history of science; in the philosophy of science it should not figure at all.

Even more recently, in 1994, the quantum chemist Bader, echoing Kant, but explicitly adding a reductionistic picture, wrote:[15] "A scientific discipline becomes exact, in the sense that predictions become possible, as soon as the classification represents the physics that underlies an observation." And at a philosophy of chemistry conference in 1996,[16] Frenking (1998, 106–107), a theoretical chemist, discussing the autonomy of chemistry, says:

> Chemistry would become revolutionised in 1927, now that the very basis of all chemical phenomena, i.e. the chemical bonding, was understood for the first time. Chemistry as true science is still in a developing stage because quantum chemical research of the many chemical phenomena is still in an infant stage.

Although he does not refer to Kant, it seems more than plausible that his "true science" is a descendent of Kant's *eigentliche Wissenschaft*. Similarly, Arabatzis (1998, 155) suggests that the conflict between physicists and chemists over the electron was "fully resolved" with "the advent of the exclusion principle, spin, and eventually quantum mechanics." With the advance of quantum chemistry, according to which chemistry would be fully reducible to physics, chemistry would finally have reached the status of a proper science. Finally, Mainzer argues (at the same conference) that chemistry has become a *science* in the sense of Kant, because it uses ever more mathematics:

> Chemistry is involved in a growing *network of mathematical methodologies and computer-assisted technologies* with increasing complexity. Thus chemistry, is a *science* in the sense of Kant, but with changing frontiers (Mainzer 1998, 49, emphasis in original).

BRIEF DIGRESSION ON DIRAC

Since the advent of quantum mechanics, in addition to Kant's "chemistry is not an *eigentliche Wissenschaft*," an obligatory reference to Dirac's authority has been used to justify the reduction of chemistry to physics, i.e., to the proper mathematics of quantum mechanics.[17] Dirac (1929) said:

> The underlying laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that exact applications of these laws lead to equations which are too complicated to be soluble.

One could consider this the 20th century culmination of Kant's view.[18] Like Kant's view, Dirac's remark is referred to in lectures for a general audience of scientists in a way that suggests everybody knows it. Usually the reference is uncritical, e.g., by Noble laureate Mulliken in *Physics Today* (1968);[19] only rarely is the reference to Dirac more critical.[20] Dirac's view fit "the times," because logical positivism not only replaced metaphysics by logic, but stressed the unity of science: all sciences were to be reduced to physics.

BRIEF DIGRESSION ON PSYCHOLOGY

In the preface of the *MAdN* Kant also says that psychology is even further removed from proper science than chemistry.[21] Even an experimental psychological science is not possible. Hence, psychology may not even be an "improper science." The relevant passages are difficult to interpret, and there are some ambiguities if one compares it with older texts of Kant. In the 19th century, this led to extensive debates among interpreters. Some scholars even went so far as to say that the often-quoted passage where psychology is demoted as a possible science, is an oversight, inconsistent with the rest of Kant's writings (Drews 1894, 259). Instead, it was suggested that in fact psychology might score better as a "proper science" than chemistry: Kant worked with the distinction of "bodily nature" (*res extensa*) and "thinking nature" (*res cogitans*). And in his lectures on metaphysics of 1765/1766 Kant described psychology as the "metaphysical empirical science of people"[22] and used the expression *mathesis intensorium*, suggesting that even if it were not so at the moment, psychology nonetheless could become a proper science. However, this refers to Kant's "pre-critical" years and hence does not bear on the issue of proper science as discussed in the *MAdN*.

Moreover, Kant's later negative remarks concerning psychology becoming a science are directed at a particular type of psychology, viz. that which is introspection-based.[23] That is not science at all; not even improper science. In contrast, Kant's writings and lectures on anthropology contain much that might now be called psychology, and anthropology is for Kant a respectable empirical science.[24] Moreover, the *mathesis intensorum* remained of crucial importance for Kant in his critical period.[25] One can find in Kant a foreshadowing of psychophysics, which quantifies and mathematizes perception; this is the *mathesis intensorium*.[26] So what is now called psychophysics might even become a proper science. However, Kant did not consider that part of psychology.[27]

ANOTHER KANT

In retrospect, looking at the whole of Kant's philosophical career, Lequan (2000, 5) has suggested that chemistry plays a double role for Kant; on the one hand, it is part of physics or natural science; on the other, it serves as an analogy, metaphor, or paradigm for the method of critical philosophy.[28] Though in the pre-critical period, chemistry plays a rather peripheral role, in his later work it gets its revenge. Kant's increasing interest in chemistry can be discerned from 1780 onwards, coming more and more to the fore towards the end of his life. In 1786, chemistry was still a simple empirical art—a "counter model" to proper science. However, in the *Reflections on Physics and Chemistry*[29] of the late 1790s and in the *Opus postumum* (further *OP*)[30] of the same period, his interest in the work of contemporary chemists moved center stage and became an integral part of his philosophical project.[31]

At first, the double role of chemistry created for Kant a kind of paradox. On the one hand, as part of natural science, chemistry was not a proper science (because it was "merely" empirical); on the other hand, chemistry stands as a paradigm for the method of critical philosophy (e.g., the methods of analysis, separation, purification, and synthesis are shared by chemistry and philosophy).[32] Perhaps neither philosophy nor chemistry can be mathematized, but they have something else: their constructive method. Chemistry as a *practical* science or art is more like moral science than like physics. For example, Kant says that "a procedure which resembles chemistry," is a procedure needed in the analysis of moral common sense—what Körner (1991) has referred to as "the quasi-chemical method."[33]

On the other hand, chemistry presents the philosophy of nature with new problems, "unbeknownst to mathematical physics," viz. to give an account of the variety of substances. Not being able to give a philosophical account of the variety of substances, Kant started to see as a gap in his philosophy.[34] An important reason for the "gap"

Kant identified in his philosophy in later life, is that if the synthetic *a priori* has to guarantee the possibility of all experience, much is missing if one is stuck with only physics (i.e., Newtonian mechanics). As he already says in his physics lectures of 1785, the *Danziger Physik*:[35]

> Chemistry has raised itself to greater perfection in recent times; it also rightfully deserves the claim to the entire doctrine of nature: for only the fewest appearances of nature can be explained mathematically—only the smallest part of the occurrences of nature can be mathematically demonstrated. Thus, e.g., it can, to be sure, be explained according to mathematical propositions when snow falls to the earth; but why vapors transform into drops or are able to dissolve—here mathematics yields no elucidation, but this must be explained from universal empirical laws of chemistry . . .

This "gap" leads to Kant's *Übergang* or *Transition* project (see below).

REREADING THE "RECEIVED" KANT

If one takes seriously Kant's lifelong occupation with chemistry, the older passages can be read in a less dismissive light. Dismissing the passage in the preface of the second edition of the *Critique of Pure Reason* of 1787, where Kant mentions Stahl, Toricelli, and Galilei, as "merely" referring to empirical "non-proper" science would put the emphasis wrongly. For Kant, these scientists illustrate the "Copernican revolution" of actively posing questions to nature and Kant praised Stahl in particular for devising experiments to answer theoretically significant questions.[36]

The first thing to note is that Kant's aim is not reductive. His view is not that to be "a proper science," it must be reducible to mathematical physics. The problem we are addressing is situated between two three partitions. On the one hand to be a proper science, mathematical, metaphysical, and principles specific to that science should be clearly separable (kept in their own domain); on the other hand, their relations should be laid out. Against the background of this tripartite scheme, there are three possible prospects for chemistry, following Lequan's (2000) reconstruction:

(i) to become a proper science in the strict sense; constituted by purely philosophical principles, i.e., completely *a priori*;
(ii) to become a proper science in the weak sense (containing a pure and applied part);
(iii) to remain an improper science, i.e., systematic and rational, but merely experimental or descriptive in the sense of offering experimental generalizations, not necessary laws of nature.

Here, "improper science" is still science: it is systematic; it may use mathematics, but it is fully dependent on empirical generalizations—to be distinguished from *mere* description (which may be an "art," governed by reflexive judgment, but without much of "grounds and consequences" and no prospect of using mathematical tools).

On balance it seems that Kant would favor the middle option for both chemistry and physics (in the modern sense of these terms). For chemistry, to achieve the status of proper science in the weak sense, laws in mathematical form have to be found for the affinities between substances,[37] and the universal laws for the attraction and repulsion between substances (Lequan 2000, 19).[38] For this, it will be necessary to find the proper "simple quantities" and the relevant extensive and intensive magnitudes. One mark of the imperfection of chemistry is that it cannot properly define its subject matter: it has no neat metaphysical picture of what makes possible the variety of substances.[39] In order to achieve the status of proper science in the weak sense, not only should chemistry use mathematics, it should also resolve the metaphysical issue of the possibility of *a priori* knowledge concerning the variety of substances.

Though chemistry can only achieve the status of proper science in the weak sense, it has other characteristics that give it a high status for Kant. I already hinted at this when I mentioned the analogies Kant sees between the methods of chemistry and philosophy.[40] One might speculate that if chemistry would rise to the status of proper science in the weak sense, it would still have a double or even dialectical role. On the one hand, through its connection with the *a priori* of mathematics and of the metaphysics of providing an *a priori* account of the variety of substances via the transcendental side of his dynamic theory of matter (see below), it would become part of physics in the sense of natural science proper (having a pure and an applied part). On the other hand, it would keep (or even strengthen) its position of becoming an analogical model for all inquiry that is not "dominated" by mathematics; thus having a unifying function—a theme later developed by Hegel.

Therefore, the notorious passages in the preface of the *MAdN* should not be read excluding chemistry from ever becoming a proper science. If a universal law of "affinity" could be formulated capable of explaining *a priori* the attractions and repulsions between substances, i.e., the relative distances among parts of matter, then chemistry would become a proper science.[41] This should give, perhaps not an *a priori* way of calculating the densities of all materials, but it should be able, in principle, to describe all possible chemical reactions.

THE OPUS POSTUMUM OR ÜBERGANG

At the end of his life, Kant came to realize that something was missing in his system. In the years 1796–1803, he was working on a draft of a work he had entitled *Transition from the Metaphysical Foundations of Natural Science to Physics*.[42] It is usually referred to as the *OP*; although among the hundreds of pages of text, there is at best the draft of one chapter; the rest is "working notes."

For a long time, it was assumed that Kant could not have done any serious philosophy in his old age. Typically, Adickes, charged with editing the *Akademie Ausgabe*, says that in the 1790s Kant could not have been following the chemical literature seriously.[43] Kant's *OP* appeared in German (in the Academy edition) after more than a century of problems delaying its publication. And what was published is generally considered a mess, random texts without editing.[44] The first abridged English edition appeared in 1993.[45] However, it is now generally agreed that Kant's *Transition* project has to be taken seriously.

From correspondence with Kiesewetter,[46] we know that Kant was thinking of his new project before 1795 and perhaps as early as 1790; but he started on it only in 1796 and more intensely from 1797 onwards. Visiting friends testify to the importance this project had to Kant. In reviewing this episode Marty (1986, VI) uses the expression "chef-d'œvre" to emphasize the project's importance. Kant's old age only started to interfere seriously with his project from 1800 onwards.

Kant had become convinced that a new *a priori* science must be added to his 1786 *MAdN*. Without this new *a priori* science, the "pure doctrine of nature" remains incomplete.[47] In a letter to Garver he says:[48]

> The project on which I am now working concerns the "Transition from the metaphysical foundations of natural science to physics." It must be completed, or else a gap will remain in the critical philosophy (1798, 12: 257).

And in the *OP*:

> These two territories (metaphysics of nature and physics) do not immediately come into contact; and, hence, one cannot cross from one to the other simply by putting one foot in front of the other. Rather, there exists a gulf between the two, over which philosophy must build a bridge in order to reach the opposite bank, for, in order for metaphysical foundations to be combined with physical (foundations) (which have heterogeneous principles) mediating concepts are required, which participate in both (1798, 21:475).

Kant here comes back on his famous statement in the *Critique of Judgement* (1790) where he says in the preface: "hereby I bring my entire critical undertaking to a close" (5: 170). Reality (the world of experience) is only partly determined by Newtonian mechanics. The world of substances and their properties remains ununderstood; the variety of substances (as apparent in their properties) remains completely unaccounted for (in terms of a metaphysics of nature). For example, the concept of gold encompasses an indefinite number of properties, which only experience can reveal. But they belong to reality too. So how can the whole world of experience be categorically encapsulated? That is the main question of the *OP* according to Heyse (1927) and more recent interpretations can be considered to be a variation on this theme. Kant's more concrete problem was: How to relate the diversity of substances to the metaphysical concept of matter. The *MAdN* provided only an analysis of "matter in general," and not the "doctrine of body" (which would include the density of bodies) it had claimed and intended.

In the 18th century, there were two competing theories of matter: the corpuscular and the dynamic concept. The first was a form of atomism: all physical objects are composed of minute and discrete parts distributed in the void. According to the dynamical concept, which Kant supported and developed, substances are constituted by the interplay of moving forces. Substance is definable in terms of the moving forces of attraction and repulsion. The well-known distinction between primary and secondary properties does not exist on the dynamic account of matter: *all* properties of matter can be understood in terms of attraction and repulsion. There are no corpuscular primary properties. All "Kantian" properties are relational and equally manifestations of the activity of those fundamental forces that present material reality to the knowing subject (Edwards 2000, 110). In the *OP*, using the concept of ether (see below), the concept of a universal continuum (or plenum) of material forces is made the centerpiece of Kant's dynamical theory of matter. Chemistry can only be transformed into a proper science (in the weak sense) by being grounded in this dynamical theory of matter, which provides the possibility of a mathematization of "secondary" qualities. When focusing on these fundamental dynamic forces in the *OP*, physics and chemistry often seem to merge for Kant (more or less as in modern physical chemistry).[49]

Kant disagrees with the "ridiculous" solution of the atomists, to presuppose one primordial type of homogeneous matter and reduce the qualitative differences between substances to differences in quantity. He argues explicitly against explanations of differences in density along atomist's lines. Both atomists and the appeal to metaphysical monads reduce matter to mathematical points, which denies the great variety of substances.[50] Kant says that the chemist is mistaken if he thinks that through analysis one can obtain elements that are "absolutely simple."[51] Kant is a partisan of a continuum thesis (at least as a regulative idea). His theory of matter is dynamist, plenist, and continualist and stands in sharp contrast to that of Boyle and Newton.[52]

Westphal (1995, 403) has argued convincingly that the central problem that the *MAdN* left for the *OP* to sort out was to explain how equal volumes of different basic matters could differ in density. Density is central to Kant's problem.[53] The failure of Kant's dynamic theory of matter in the *MAdN* was to give a proper account of density, as well as related notions such as cohesion, rigidity, and friction.[54] In addition to density, in particular an account of cohesion has to be given in order for balance scales to have any form and function at all. Only the first part of the *MAdN*, the "Phoronomy" escapes unscathed in the *OP*.[55] In the *OP*, he aims at a new "transcendental dynamics." Kant's "moving forces" are at the bottom of anything that happens, including how matter can affect our sensory organs. This also leads to a new theory of "self-positing" (Förster 1989). We can only see objects if we first identify ourselves as beings, who are centers of active force. Hence, we perceive ourselves and objects through our dynamic interaction.

The relation of the *MAdN* and the *OP* has been the subject of extensive Kant scholarship, which as yet has not brought about consensus.[56] Perhaps, the wisest option is to see the *OP* as not so much different in content from earlier work, but representing a change in perspective. The "gap" Kant speaks of is the need to give a unified account of all systematic disciplines. He has dropped particular worries about this or that science being proper or not; even if not proper, it has to be included somehow. Further, in Kant's later work, mathematics is demoted from a model to be imitated in metaphysics to a mere auxiliary aid.[57] The domain of science is to be identified "topically"; the aim is not to produce empirical laws by simple reflection. The "scientific" problem of how to account for the "hanging together" of bodies (in different states of aggregation),[58] is so central for Kant, because it is the linchpin of how to account for the "hanging together" of systematic knowledge.[59]

Hence, the *Übergang* is supposed to fill the gap in the structure of Kant's science of nature (*Naturlehre*) and thus fill out the architectural plan of his transcendental philosophy. The transition from the metaphysical principle to the empirical part of physics and chemistry hinges on the systematic formulation of a dynamical theory of matter. Some will argue that even more is at stake here, viz. that it is not so much filling a gap, but a complete revamping of the conditions of our experience of objects *in general*.

ON THE CALORIC ETHER AND THE VARIETY OF SUBSTANCES

The "gap" in Kant's philosophy of nature has to be closed by a dynamic theory of matter, which leads to the central role of a "world ether" or "caloric ether."[60] The ether is a universal continuum of dynamic forces (attraction and repulsion) of matter and the material basis for the interaction between all empirically observable bodily entities. Moreover, it is the carrier of all phenomena of heat and light. Kant's dynamic theory of matter is the necessary precondition of all experience. Therefore, the concept of matter is both empirical and *a priori* (21: 289); and similarly for the concepts of caloric (*Wärmestoff*) and ether. I will use the terms "caloric" and "ether" interchangeable,[61] as Kant does most of the time in the *OP*.[62]

In the *MAdN*, the ethereal caloric is nothing more than a hypothetical substance, but in the *OP* it is elevated to the rank of transcendental philosophy.[63] One could see the *MAdN* as giving an account of "the One," i.e., matter *per se*, whereas the ether of the *OP* provides the basis for the multiplicity and heterogeneity of matter.[64] For Kant, space is neither empty nor homogeneously filled, but filled with caloric ether to varying degrees and he advocates an explanation of the variety of substances in terms of a varying distribution of the ether over space and the qualitative variation in the combination of original dynamic forces.

The ether or caloric is a kind of primordial fluid element. It is an elastic fluid that fills the universe. It has both matter- and wave-like characteristics. It is the cause of the difference between heat and cold and explains since the origin of the universe rarefication and condensation (concentration) of matter. It is "fluidity itself," the condition for all fluidity. The fundamental "state of aggregation" is the fluid ether; solidity derives from it. It constitutes all chemical substances and envelops them. It is the matrix of all bodies. It is the "mother of all matter" from which all bodies derive their cohesion.[65] The "internal proportion" of ether (in interaction with the moving forces) determines not only the chemical "type," but also the state of aggregation (solid, liquid, vapor). Kant does not make a big distinction between physical and chemical "mixing"; in fact, his model of chemical reaction is very similar to Aristotle's model of homogeneous "mixts."[66] The only difference is the (ir)reversibility. In a chemical reaction, there is a complete reciprocal penetration, possible because of the infinite divisibility, resulting in a homogeneous combination. A chemical reaction takes place if the attractive forces of chemical affinity outweigh cohesive attraction.

Similarly, the notion of caloric is conceived as an expansive substance, endowed with strongly repulsive and penetrating forces. When caloric permeates material bodies, its vibrations intermix their parts. Kant's notion of the ethereal caloric can be seen, in retrospect, as combining aspects of Lavoisier's caloric theory and the kinetic theory of heat. The properties of the *Wärmestoff* (or *Äther*) determine the sensible properties of matter.[67]

There exists only one "generic" matter (not matter*s*), whose elements are qualitatively different. Kant's dynamical theory of matter entails that his notion of (chemical) element is qualitative (not quantitative as in atomistic theories).[68] The most important of all problems is how to move from the general concept of matter to *a priori* knowledge of the variety of chemical substances [such as nitrogen, carbon, oxygen, hydrogen: (22: 360)] and their differing densities (e.g., that of water and mercury). In order to understand the differences between substances, Kant adds to the dynamic hypothesis of two moving forces the ether hypothesis.

Matter in general is made possible by the inseparable bond between attraction and repulsion. Because the proportion of these forces may vary, the possibility of an infinite variety of chemical substances is given. Hence, the "first causes" are not mechanical (as in atomist theories), but physico-dynamic.[69] The interaction between the omnipresent ether and the two originary forces creates the specific differences between "types" of matter. Each chemical substance is characterized by a quantity of ether and three forces [universal attractive force, "proper" repulsive force, and "proper" attractive force (chemical cohesion)]. Hence, the ether is the ultimate origin of the variety of substances (together with the two moving forces).

Kant distinguishes four "elements," although they are very different from Aristotelian elements.[70] They stand more for classes of chemical reactions. The ether or caloric is a "fifth essence" (replacing phlogiston as "mysterious" fifth essence).[71] The caloric ether is categorically an *a priori* given "stuff," which is the foundation of the variety of substances and their properties. It implies, for example, that the statement that all matter can be weighed is not an empirical observation, nor is it an analytic statement concerning the concept of matter. It expresses the condition that has to be presupposed to make experience of "quantity of matter" possible.[72]

The ether fulfills several functions for Kant.[73] It is necessary because it makes possible all quantification of matter, in particular weighing bodies on a balance.[74] Further, it has both a cosmological significance and has the status of a "special" (chemical) element. From a cosmological point of view, chemistry is superior to the other natural sciences, because cosmology needs the notion of ether.[75] The ether provides the subject-independent "causal" basis for the perception of any and all external objects. It is necessarily real in order to account for the phenomena, i.e., it is a necessary condition for all experience. It fulfills the function of a middle concept that Kant is looking for to "fill the gap." As a necessary condition, it cannot be identified by empirical means.[76] Empirically, the ether is a "pure hypothesis" (its existence is problematic); but from the transcendental point of view, it is a postulate of purely speculative reason (its existence is necessary).It is a categorical given, which therefore requires a new "deduction" of the categories (Lehmann 1963). Whether Kant succeeded in actually "proving" his "solution" of closing the "gap" is an open question.[77]

KANT AND THE CHEMICAL REVOLUTION

In 1786, Kant still seems to doubt whether chemistry is just an art, not even an improper science, but he tends to favor the latter and hopes for more in the future, because of its double role (the analogy between the art of chemistry and philosophy). In the 1786 preface of *MAdN*, Kant denies the status of proper science to chemistry, but this has changed in the later *Reflections* and the *OP*.

Friedman (1992) ascribes Kant's *Transition* from *MAdN* to *OP* primarily to the influence of Lavoisier's "new chemistry." He shows that by 1785 Kant has become aware of the new discoveries in pneumatic chemistry; between 1785 and 1790 he had assimilated the developments in the science of heat; between 1790 and 1795 he had completed the conversion to Lavoisier's system of chemistry.[78] The *Reflections on Physics and Chemistry* of the late 1780s and the early 1790s mention Lavoisier's antiphlogistic theory of combustion. Around 1790, Kant connected the caloric theory of gases with the problem of solidity and the concept of latent heat.[79] In his 1792–1793 *Lectures on Metaphysics* (*Metaphysik Dohna*), Kant associates the science of chemistry with Lavoisier's doctrine of the composition of water.[80] By 1795 (after some intermediate stages), Kant acknowledges as a "very plausible hypothesis" that water is constituted by hydrogen and oxygen.[81] Moreover, around 1795 Kant develops his own version of the caloric theory of the states of aggregation.[82] In the 1797 preface to the *Doctrine of Right*, Kant has Lavoisier "represent" chemistry (instead of Stahl).[83]

Hence, it may be surmised that from 1795 onwards, under the influence of the work of Lavoisier, Kant considers chemistry to have achieved the status of proper science (in the weak sense). But the change was slow and Stahl was not simply dismissed: he had prepared the way, because he tried to use *a priori* principles to "order" chemistry. Also Kant's transition from phlogiston to oxidation was slow; for some time Kant seems to have used "oxidation" and "dephlogistination" as synonyms.

According to Schulze (1994, 40n), Friedman overlooks that the *OP* is not merely a revision of Kant's theory of matter in the light of new scientific developments, but a revision of fundamental traits of his whole philosophy. He argues (1994, 105 and *passim*) that the *OP* is an extension of Kant's metaphysics of nature, making explicit room for a philosophy of nature in between metaphysics and empirical science, in particular by providing "middle concepts" (such as the caloric ether) to connect the "purely" *a priori* and the "purely" empirical.[84] Also Edwards (2000) accuses Friedman (1992) of serious misreadings and misinterpretations of the *OP*,[85] as does Westphal (1995, 412–413). The latter criticizes Friedman's claim that Kant was motivated to integrate chemistry and the theory of heat with mathematical physics, because Friedman does not address the question why Kant in 1798 "rejected the mathematical model." Nor does he explain why Kant,

> focuses on physics and repeatedly formulates his project in terms of a transition to *physics* . . . he extensively discusses this . . . transition to physics without mentioning chemistry or biology . . . Physics should not be stressed so often or so centrally . . . if Kant's problem was only to relate physics with the other new physical sciences.

I think Friedman's critics are right when they argue that Kant was deeply dis-satisfied with the *MAdN* (or even his whole critical philosophy), but the other disagreements are easily resolved. Kant uses the term "physics" often in a sense in which it includes all "new physical sciences" (Westphal's term). Kant's view of mathematics as the "ideal" model changed, because he realized that he would not be able to account for the experience of the variety of substance on the basis of a metaphysics modeled on mathematics: hence his tripartite "pact" between philosophy, mathematics, and natural science.

Without entering the exegetical battle and acknowledging that the hermeneutic circle is never closed, in defense of Friedman it can be said, as Dussort (1956) had noted too (see also Lequan 2000), that there are many things about the "chaotic" texts of the *OP* that support a "chemical" biased reading, i.e., taking as central focus the "gap" of not being able to connect the variety of substances (and their phenomenal properties) to the *a priori*; and seeing Lavoisier's work as a clue to closing the gap. First, at no point is there any reference to phlogiston in the *OP*. On the other hand, the notion of caloric occurs on almost every page. Although Lavoisier did not invent the term "caloric," he certainly made it respectable. Second, the caloric ether starts to take on the role of transcendental object, something most interpreters agree on. Third, Kant explicitly uses the term "physics" now such as to include chemistry.[86] Further, there is Kant's constant preoccupation with the use of the workings of a balance for weighing, which is relevant for various reasons.[87] Furthermore, Lavoisier's account of weighing, and explanations of states of aggregation, are similar to those of Kant. Finally, Dussort points to similarities between the philosophical views of Lavoisier and those of Kant, in particular the assumption crucial to Kant that sensation (experience) must be based on the movement of matter.[88]

CONCLUDING REMARKS

There seems little doubt that Kant followed the developments in chemistry of his time carefully (leaving aside the question whether he made any substantial contribution to it). In 1804, an obituary of Kant appeared in the *Neues allgemeines Journal der Chemie* by the editor of this journal, who praised Kant's wide knowledge of chemistry and the attention he devoted to it. There is also no doubt that Kant was the first to give chemistry a central place in his (later) philosophy. This was later followed up by Schelling and Hegel.[89] This development in natural philosophy has been of little relevance to 20th century philosophy of science, but at least those philosophers gave chemistry some serious thought. The same cannot always be said of those who quoted Kant's notorious suggestion that chemistry is not an *eigentliche Wissenschaft*.

Given the dominant view in the past few centuries on the relation of chemistry and physics, greatly stimulated by Kant's comment that chemistry is *not* an *eigentliche Wissenschaft*, there is every reason to be suspicious of Kant scholars who underplay the impact of the "chemical revolution" on Kant's thinking. This suspicion is kept alive by tiny oversights. For example Förster (1993, xxv), the editor of the first (abridged) translation of Kant's *OP* in the "definitive" *Cambridge Edition of the Works of Immanuel Kant* and author of numerous publications on the *OP*, refers to Kant's *Reflections on Physics and Chemistry* as "*Reflexionen* on physics." Of course, he could justify this by saying that Kant himself says explicitly in one of these reflections that chemistry is part of physics.[90] Nevertheless, I find it significant that Förster did not take the trouble of quoting the title in full (or instead use an acronym such as *Refl.* or *RPC*).

I tend to favor the part of Dussort's, Friedman's, and Lequan's interpretation that puts considerable emphasis on the impact the "chemical revolution" had on Kant's thinking, without denying at the same time the "bigger" metaphysical ramifications for Kant(ians). The two views are not incompatible if one assumes that from the beginning Kant was concerned to fit it all neatly together. And as he says in the *Danziger Physik*, before he had started on the *Transition* project, there was a gap in his philosophy. The "chemical revolution" could help to close the gap between (all) sciences of nature and philosophy—basically the gap between giving an account of matter in general and giving an account of the variety of substances.[91]

Perhaps one possible confusion in reading Kant through modern eyes is that for us the change from Stahl to Lavoisier is a "chemical revolution," whereas for Kant, it is precisely that period that brings chemistry into the domain of science, loosing its alchemist roots, and like Kant's *Critiques*, aimed to be rid of dogmatic philosophy.[92] Both chemistry and philosophy operate with regulative ideals on a road of historical progress and proper science. The *preface* of 1786 represents chemistry in its adolescence (Lequan 2000, 41). In the *Reflections* and the *OP* chemistry gets its proper place being tied to the central ether concept, which is empirical, transcendental, and cosmological.

Kant had always been against atomism and his resolution to explain the variety of substances was to introduce an ether or caloric and the principle of two fundamental opposing dynamic forces. His notion of ether not only was an empirical hypothesis, but a transcendental principle; in that sense it was part of philosophy, not of chemistry. Hence, this suggested the need for a second Copernican revolution, or at least "filling a gap" in his philosophy. Given the crucial *philosophical* importance of the problems thrown up by chemistry, perhaps the notion of science had to be rethought such that chemistry could be a proper part of it. Whether it would be called part of physics would then be a terminological matter. Physics, chemistry, philosophy, and mathematics could become one seamless whole, without each losing its autonomy, or at least that is what I suggest Kant would suggest.[93]

NOTES

1. All quotes taken from Kant in this text refer to the *Akademie Ausgabe* (giving volume and page number), Kant's collected works published between 1900 and 2000; only page numbers of the *Critique of Pure Reason* (*KrV*) are given in the well-known A/B format. English translations have been consulted where available. German citations in the notes are always from the *Akademie Ausgabe*.
2. See for the argumentative structure of the *MAdN*, the *Metaphysical Foundations of Natural Science*, for example, Plaass (1994) and Watkins (1998). Quotations from the *MAdN* in English are from Ellington (1970).
3. According to von Weizsäcker (in Plaass 1994, 174) the *MAdN* deals with "the conditions under which—in modern terminology—the assignment of physical meaning to mathematical concepts is possible."
4. One should distinguish here between "the transcendental part of the metaphysics of nature" and "a special metaphysical natural science" (4: 470).
5. All systematic knowledge can be called science (4: 468). If the systematicity is that of a connection of "grounds and consequences," science is rational.

6. "So lange also noch für die chemischen Wirkungen der Materien auf einander kein Begriff ausgefunden wird, der sich konstruieren läßt, d.i. kein Gesetz der Annäherung oder Entfernung der Teile angeben läßt, nach welchem etwa in Proportion ihrer Dichtigkeiten u.d.g. ihre Bewegungen samt ihren Folgen sich im Raume a priori *an*schaulich machen und darstellen lassen (eine Forderung, die schwerlich jemals erfüllt werden wird), so kann Chemie nichts mehr als systematische Kunst oder Experimentallehre, niemals aber eigentliche Wissenschaft werden, weil die Prinzipien derselben bloß empirisch und keine Darstellung a priori in der Anschauung erlauben, folglich die Grundsätze chemischer Erscheinungen ihrer Möglichkeit nach nicht im mindesten begreiflich machen, weil sie der Anwendung der Mathematik unfähig sind."
7. Cf. *Danziger Physik* [1785 (29: 97)]: "Die Mathematik reicht gar nicht zu, den chemischen Erfolg zu erklären oder man hat noch keinen einzigen chemischen Versuch mathematisch erklären können; daher ließ man die Chemie aus der Naturlehre aus, weil sie keine Prinzipien a priori hat."
8. This requirement follows from the fact that chemistry would be (part of) a proper science of *corporeal* nature (B202).
9. Cf. the words "ever" (*jemals*) and "never" (*niemals*) in the citation from (4: 470–471). In the *Critique of Practical Reason*, Kant suggests that chemistry might achieve *a priori* natural laws "if our insight went deeper" (5: 26).
10. According to Miller and Miller (in Plaass 1994, 156) Kant's notion of proper science limits "the everyday objectificational paradigm to only what can be described in terms of spatio-temporal determinations" because this "is necessary to assure the kind of reproducibility and measurability needed for mathematization of nature." Such reproducibility demands the experimental isolatability characteristic of modern physical sciences.
11. The *Gesellschaft deutscher Naturforscher und Ärzte*.
12. In particular, many German chemists seem to have wrestled with Kant's assessment of chemistry.
13. Ellington (1970, 8n), the translator of the *MAdN*, makes the following "excuse" for Kant: "The beginnings of the modern science of chemistry were made by Lavoisier shortly before the *MAdN* appeared in 1786. Kant did not foresee the development of atomic physics, which was to make chemistry a science." I will come back to Kant and Lavoisier below.
14. Dingle (1949) adds: "Reluctant as I am, and as a loyal physicist should be, to say anything good of chemistry, I cannot deny that, quite apart from its necessity for the amenities of life, it has been indispensable in making possible the rapid progress of physics."
15. Bader, Popelier and Keith (1994, 620): "Eine wissenschaftliche Disziplin beginnt mit der empirischen Klassifizierung von Beobachtungen. Sie wird exakt in dem Sinne, daß Vorhersagen möglich sind, sobald die Klassifizierung die Physik widerspiegelt, die einer Beobachtung zugrunde liegt."
16. The *3rd Erlenmeyer-Colloquy for the Philosophy of Chemistry* (Janich and Psarros 1998).
17. For a review of the complexity of the relation between molecular chemistry, quantum chemistry and quantum mechanics see van Brakel (2000, Chapter 5).
18. Later Dirac (1939) contemplated a further Pythagorean reduction: "If we express the present epoch, 2×10^9 years, in terms of a unit of time defined by the atomic constants, we get a number of the order 10^{39}, which characterizes the present in an absolute sense. Might it not be that all present events correspond to properties of this large number, and, more generally, that the whole history of the universe corresponds to properties of the whole sequence of natural numbers?"
19. For the enormous impact of the Dirac citation see van Brakel (2000, 120).
20. An example is Hoffmann (1998, 4) who says in a "viewpoint paper" presented at a meeting honouring pioneers of computational quantum chemistry: "only the wild dreams of theoreticians of the Dirac school make nature simple."
21. "But the empirical doctrine of the soul must always remain yet even further removed than chemistry from the rank of what may be called a natural science proper. This is because mathematics is inapplicable to the phenomena of the internal sense and their laws . . . But not even as a systematic art of analysis or as an experimental doctrine can the empirical doctrine of the soul ever approach chemistry, because in it the manifold of internal observation is separated only by mere thought, but cannot be kept separate and be connected again at will; still less does another thinking subject submit to our investigations in such a way as to be conformable to our purposes, and even the observation itself alters and distorts the

state of the object observed. It can, therefore, never become anything more than a historical (and as such, as much as possible) systematic natural doctrine of the internal sense, i.e., a natural description of the soul, but not a science of the soul, nor even a psychological experimental doctrine." (4: 471)

22. "Nachricht von der Einrichtung Vorlesungen Winterhalbenjahren von 1765–66" (2: 316): "metaphysische Erfahrungswissenschaft vom Menschen." Cf. *MAdN* (4: 470): "a pure doctrine of nature concerning determinate natural things (doctrine of body and doctrine of soul) is possible only by means of mathematics."
23. Cf. citation in note 21.
24. According to Makkreel (2001), for Kant, psychology, history, geography, and especially anthropology do not come in the category of science in the sense that physics is a science. They are systematic disciplines that are guided by reflective rather than determinate judgement, guided by a *practical* idea of the "best world". It is important to note that though such disciplines can never claim to become exact sciences, this does not undermine their objectivity for Kant. Similarly, Roqué (1985) argues that Kant relegates self-organization to the realm of reflective judgement, not to Newtonian-type science. Here, self-organization refers both to biological organisms and autocatalytic chemical reactions (which would have, in Kant's terms, an intrinsic physical end).
25. See B207f.
26. See A179/B221, where Kant seems to suggest that the intensity of color experiences is ordinally and cardinally measurable. Cf. Sturm (2001, 168) and for a more detailed account Nayk and Sotnak (1995), who argue that we can ascribe to Kant the view that psychometrics (or psychophysics) could be a proper science, but we can never apply mathematics to the psyche and elevate psychology to the status of a proper science.
27. For Kant, there is a connection between sense perception and chemistry via what is now called neurophysiology, cf. (7: 157; 12: 34).
28. Cf. notes 32 and 33.
29. This is a selection of 63 text fragments (14: 63–537); in the notes referred to as *Refl.*
30. All citations in English from the *OP* are from Förster (1993).
31. According to Lequan (2000, 6n, 81n), Kant was familiar with the work of Priestley, Scheele, Cavendish, Muschenbroek, Crawford, Boerhaave, Beccher, Macquer, De Luc, Hube, Girtanner, Gren, Hagen, Hales (and of course Stahl and Lavoisier), cf. (11: 185). Apart from absorbing and reworking their theories he also asked colleagues at the University of Köningsberg to do experiments for him (Förster 1993, 275n90). This may explain the comment by a chemist of Kant's time that "es sei ihm unbegreiflich, wie man durch bloße Lektüre ohne Hilfe anschaulicher Experimente die ganze Experimentalchemie so vollkommen wissen könne" (Groß 1912, 129).
32. See for a comparison of the philosopher and the chemist using a synthetic method Bxxi; for the method of analysis or separation see B870 and (5: 163); for the method of abstraction (8: 199).
33. Kant, *Critique of Practical Reason* (1787): "a process similar to that of chemistry, i.e., we may, in repeated experiments on common sense, separate the empirical from the rational, exhibit each of them in a pure state, and show what each by itself can accomplish" (5: 163); for a direct comparison of the philosopher and the chemist on this point see (5: 92). Cf. as well the *Vorarbeiten zur Rechtslehre* (23: 284): "der Analogie zwischen dem Lavoisierschen System der chemischen Zersetzung u. Vereinigung und dem moralisch-practischen der gesetzlichen Formen u. der Zwecke der practischen Vernunft."
34. Kant scholars disagree about where exactly the gap should be located (whether it is a methodological gap or more serious), but there is no doubt that the term "gap" is appropriate to indicate the seriousness of what is missing in Kant's system hitherto (apart from the fact that Kant repeatedly uses the term himself). Edwards (2000, 152f), who stresses continuity in Kant's philosophy, also uses it: "(Kant's) transitional science is supposed to fill in a gap in the structure of the Kantian metaphysics of nature (and thus fill out the architectural plan of Kant's transcendental philosophy). The actual passage from metaphysical principles to the empirical part of physics is supposed to take place by means of the systematic formulation of a dynamical theory of matter. This theory of matter is founded on the concept of a cosmic aether."
35. "Die Chemie hat sich in neueren Zeiten zur großen Vollkommenheit emporgehoben; sie verdient auch mit allem Recht den Anspruch auf die gesamte Naturlehre: denn nur die wenigsten Erscheinungen

der Natur lassen sich mathematisch erklären—nur der kleinste Teil der Naturbegebenheiten kann mathematisch erwiesen werden so z.B. kann es zwar nach mathematischen Lehrsätzen erklärt werden: wenn der Schnee auf die Erde fällt; wie sich aber Dünste in Tropfen verwandeln oder auflösen können, hier giebt die Mathematic keinen Aufschluß sondern dies muß aus allgemeinen Erfahrungs Gesetzen der Chymie erklärt werden . . . " (29: 97–98; cf. 29: 100).

36. There are already traces of the influence of the "new chemistry" in the first *Critique*, second edition (1787), where Kant adds a physico-chemical example (state transition from fluidity to solidity) to the transcendental deduction (B162); though he still mentions Stahl's theory of the calcination of metals (Bxiii). Stahl's phlogiston theory is still in full force in the *Danziger Physik* of 1785, e.g. (29: 163).
37. Some will say that "substances" should be understood here as "corporeal substances in motion." I have to leave the question of how to take Kant's notion(s) of substance in the *OP* largely unresolved. This is an issue that would deserve further study to assess the relation of Kant and the philosophy of chemistry.
38. Kant did not seem to be aware of the work of J.B. Richter who obtained his doctorate at Königsberg in 1789 with a dissertation on *De usu matheseos in chymia*, an early attempt at what later came to be called the theory of combining proportions (culminating in the work of Dalton). Cf. Friedman (1992, 339n167). In connection with Kant, Heinig (1975) notes that as early as 1741, Lomonossov had written about "the elements of mathematical chemistry." This is a work in which Lomonossov aims to prove all chemical theorems, modeling his method on that of Euclid, starting from atomistic presuppositions: "Wohl verneinen viele daß man der Chemie die Prinzipien der Mechanik zugrunde legen und sie zu den Wissenschaften zählen kaan; aber er verneinen dies solche, die sich in dem Dunkel verborgener Eigenschaften verirrt haben und nicht wissen, daß man in den Veränderungen der gemischten Körper stets die Gesetze der Mechanik beobachten kaan . . . " (Lomonossov 1961, 72).
39. Kant notes that in studying substances chemistry is limited in three ways: (i) by time, because nature has had aeons to bring about chemical changes; (ii) their products are never as pure as natural products; (iii) only a few of the substances found in nature can be made artificially. For Kant there is no sharp boundary between inorganic, organic, and biochemistry; crystallization for example has many of the characteristics of living processes for him.
40. Lequan (2000, 112–117) gives a useful overview of different places where, for Kant, chemistry provides theoretical models for meteorology (8: 323–324), cosmology (8: 74), psychology (8: 456), medicine (7: 193, 287, 293), and others. Chemistry is also the background for physiological processes that "create" secondary properties of objects (5: 349; 6: 400) For example, in the *Anthropology from a Pragmatic Point of View* (7: 177), Kant draws an analogy between the catalytic function of chemical affinity when discussing the role of the "sensory productive faculty of affinity" in social discourse: "The word affinity (*affinitas*) here reminds one of a catalytic interaction found in chemistry, an interaction analogous to an intellectual combination, which links two elements specifically distinct from each other, but intimately affecting each other and striving for unity with each other, whereby the combinations creates a third entity that has properties which can only be brought about by the union of two heterogeneous elements."
41. See the first part of the citation in note 5. Cf. Carrier (2001), Lequan (2000, 12).
42. *Übergang von den Metaphysischen Anfangsgründen der Naturwissenschaft zur Physik*. For exegesis see contributions in Bad Homburg (1991), Hoppe (1969), Tuschling (1971), Mathieu (1989), Schulze (1994), Lequan (2000). There is by far no consensus how to interpret the *Übergang*. Förster (1991) comments that in the Kant literature "herrscht darüber weitgehend Ratlosigkeit."
43. "Auf jeden Fall kann keine Rede davon sein, daß Kant in den 90er Jahren hinsichtlich der chemische Literatur auch nur einigermaßen auf dem laufenden gewesen wäre" (Adickes 1924, I, 63f). Perhaps Adickes' judgement was colored by his frustration expressed in a note of six pages appended to a sentence at (14: 489), quoted in note 78 below, where he says: "Doch ist es mir, trotz langen Suchens in der chemischen Literatur der letzten und auch der früheren 80 er Jahre des 18. Jahrhunderts, nicht gelungen, einer Stelle habhaft zu werden, die Kant als unmittelbare Vorlage hätte dienen können" (14: 491).
44. "Die Bände XXI und XXII tragen den prätentiösen Titel *Opus postumum*, aber sie bieten keine Ausgabe der Vorarbeiten Kants zu seinem geplanten Werk, sondern drucken die zufällig zusammengeratene

Papiermasse aus dem Besitz der Familie Krause ab. Die Herausgeber erzeugen durch die blinde Wiedergabe der Notizen den Eindruck, der alternde Philosoph habe nicht mehr zwischen einer Ätherdeduktion und seinen Rotweinflaschen unterscheiden können" (Brandt 1991, 8). Regarding the fragmentary character of the manuscripts and the resulting difficulties for any systematic interpretation of the *OP* see Adickes (1924, 36–154), Tuschling (1971, 4–14).

45. There have been several editions in French and other languages. All editions are abridged, partly because Kant started the same project over and over again; hence, there is considerable repetition. As to the specific interest to chemistry the *OP* should be studied in connection with the *Reflections*, in particular 20, 21, 40–45, 54, 63–66, 73–74, 79.
46. Letter from Kiesewetter dated June 8, 1795: "Sie haben schon seit einigen Jahren einige Bogen dem Publiko schenken wollen, die den Übergang von Ihren metaph. Anfangsgründen der Naturwissenschaft zur Physik selbst enthalten sollten u(nd) auf die ich sehr begierig bin." (12: 23)
47. Rothbart and Scherer (1997) refer to Friedman (1992) and mention the requirement that Kant needs "a 'transition', filling the gap on *a priori* grounds between the metaphysical foundations of nature, a pure product of thought, and nature," but they do not seem to have picked up the relevance to Kant's *Übergang* of developments in chemistry. The same applies to many other Kant scholars.
48. See also his letter to Kiesewetter dated October 19, 1978: "with that work the task of the critical philosophy will be completed and a gap that now stands open will be filled. I want to make the 'Transition from the Metaphysical Foundations of Natural Science to Physics' into a special branch of natural philosophy (philosophia naturalis), one that must not be left out of the system." (12: 258) English translations of Kant's correspondence are taken from Zweig (1999).
49. At several places Kant says that chemistry is part of physics or that they are both part of natural science. For example *Refl.* 61: "Chemie ist bloß physisch" (14: 470) and in the *OP*: "Die ganze Chemie gehort zur Physik—in der Topik aber ist vom Übergange zu ihr die Rede" (21: 288); "Die Chemie ist ein Theil der Physik aber nicht ein bloßer Übergang von der Metaph. zur Physik.—Dieser enthält blos die Bedingungen der Möglichkeit Erfahrungen anzustellen." (21: 316). Cf. "This property, however, belongs to physics (chemistry) as a system" (22: 138); and also (7: 177n; 14: 40; 22: 161; 4: 530).
50. Moreover, there is no experience of atoms or monads or mathematical points (21: 218; 22: 555).
51. For example he says in *Refl.* 45 that a drop of salt water put in an ocean of sugar water will give salt throughout.
52. "Matter does not consist of simple parts, but each part is, in turn, composite, and atomism is a false doctrine of nature." (22: 212; cf. 22: 554, 611) First, extension and impenetrability are not primary properties of matter but derive from more fundamental forces; second, matter fills space completely; third, matter is infinitely divisible—there are no atoms (Carrier 2001). For an overview of the different positions held on the divisibility of matter from Kant's *Monadologia physica* to the *MAdN*, see for example Malzkorn (1998).
53. Carrier (2001, 228n14) has suggested [referring to (4: 526)] that Kant might have recognized that the density of macroscopic bodies is affected by a host of causes other than fundamental forces.
54. Hence, the numerous times he discusses theses notions in the different parts of the *OP* and also in the *Reflections*.
55. For Westphal, the issue is important because of the "problem of circularity" in the *MAdN*, which was already pointed out by reviewers during Kant's life. I will not enter into this difficult interpretative issue. Allegedly, Kant would have discovered the circularity in his definition of the quantity of matter around January 1792. The *MAdN* has four chapters: *phoronomy*, in which "motion is considered as pure quantum" (here "matter" only figures at an extremely abstract level); *dynamics*, in which "motion is regarded as belonging to that quality of the matter under the name of an original moving force"; *mechanics*, which is more or less what we might call mechanics: describing the motions of material objects; and *phenomenology*, in which "matter's motion or rest is determined . . . as an appearance of the external senses" (4: 477). Dynamics studies the quality of substances in terms of the fundamental dynamic forces. More precisely: the quality of matter in so far motion is determined by an originary moving force. See discussion in Lequan (2000, 23–27, 57–62).

56. See Bad Homburg (1991, xii–xiii), Friedman (1992), Tuschling (1971), Mathieu (1989). Kant briefly discusses the dynamic theory and the problem of the specific differences in density in the *MAdN* at (4: 530–535).
57. "For mathematics is the finest instrument for physics and the knowledge which falls therein (for that mode of sense) but it is still always only an instrument for another purpose." (22: 490; cf. 21: 105, 139)
58. The state of aggregation and what substance it is depends on the ratio of attractive and repulsive forces (21: 382).
59. See also Edwards (2000) on the *Grundsatzes der Gemeinschaft*. According to Kant there has to be a "community of substances" because this is needed for the unity of the world, in which all phenomena must be interlaced; "die Erklärung der Möglichkeit der Gemeinschaft verschiedener Substanzen, durch die sie ein Ganzes ausmachen" [Preisschrift über die Fortschritte der Metaphysik, 1791 (20: 283)]. Cf. A218/B265 and (17: 97, 580; 21: 374, 600).
60. That is, experience in the sense of something that can be an object of the external sense; not experience "in general" (as dealt with in the *KrV*).
61. "Caloric" is one of Kant's lifelong "invariants," only adjusted by new developments in chemistry; see for example (2: 184–185; 29: 119; 21: 522).
62. See (14: 287–291), though there are places where Kant distinguishes between ether and caloric (*Wärmestoff*). On the issue of using *ether* and *Wärmestoff* often interchangeably see Schulze (1994, 134–141). See for a more or less complete inventory of occurrences in Kant's text, Schulze (1994, 137); for Kant's own formulations of the properties of caloric, see (21: 605, 610; 22: 550–551) and in particular (22: 214): "This aether (the only *originally* elastic matter; the name of fluid would not, however, apply to it), moving as elastic matter in straight lines, would be called light material; when absorbed by bodies, and expanding them in all three dimensions, it would be called caloric." Other congeners of caloric and ether Kant uses include *Elementarstoff*, *Weltstoff*, *Urstoff*, *Lichtstoff*. For a detailed but concise "definition" of Kant's ether concept, see Edwards (1991, 91f), who suggests that ether, caloric, and light matter designate "the universal field-entity" constituted by the activity of the action of attractive and repulsive forces (ibid. 155).
63. *OP* (21: 571): "Der Übergang der metaph. Anf. Gr. der NW zur Physik geschieht eben durch die Idee von Wärmestoff welcher darum kein blos hypothetischer sondern der allein all Körper in allen Räumen Erfahrungsmäßig leitende und continuirlich in Einer Erfahrung zusammenhängende Stoff sein muß." In the *Reflections*, the ether does not only appear as the foundation of all forms of cohesiveness, but also as the "matrix of all bodies." See in particular *Refl.* 44. Each body is more or less "saturated" with ether. The ether "inside" and "outside" forms a continuum (*Refl.* 52). However, how to take these statements will depend strongly on how one interprets Kant's use(s) of *Wissenschaft* and *ether* in the *OP*.
64. And, crucially, "Die Heterogeneitaet bringt die Perceptibilitaet hervor." (21: 611) Plaass (1994, 293) suggested that already in the *MAdN*: "Kant is just barely able to derive how matter of different densities is necessarily (i.e., *a priori*) possible, namely, by means of the necessary opposing interplay (limitation) of repulsion (reality) and attraction (as its negation)."
65. See *Refl.* 41 and 44.
66. Cf. Carrier (2001, 223) and (4: 530): "Wenn aber zwei Materien und zwar jede derselben ganz einen und denselben Raum erfüllen, so durchdringen sie einander." For Aristotle's "mixts" see *De generatione et corruptione*, 327a, and Needham (1996).
67. This is a somewhat speculative statement with which not all Kant scholars will agree. In support, one could point to (21: 223, 563, 576, 579, 600; 22: 160, 161, 551).
68. See (22: 13, 205–212, 474).
69. "Die erste Ursachen sind nicht mechanisch, sondern dynamico physisch." (14: 211) The idea is worked out further in the *OP* (22: 205, 239–240, 474). Cf. *Refl.* 41, 43 (14: 165, 270).
70. Kant's notion of element would warrant separate attention. Cf. Carrier (2001), B673–681, (29: 161–166, 341–361). Kant followed Stahl in having five elements, which for him were more like regulative ideas of reason and can never be identified empirically. Kant's understanding of these elements changed over time under influence of developments in chemistry. Kant's theory of elements in the *KrV* is transcendental (not empirical or metaphysical).
71. For an early example of phlogiston as fifth essence in Kant's writings, see (1: 212).

72. Förster (1989, 36); Hoppe (1991, 60; 1969, 99); Mathieu (1989, 70); Friedman (1992, 297).
73. Carrier (1991, 223) suggests that Kant's use of the words *Wärmestoff* and *ether* in the *OP* is threefold; it has a transcendental, a chemical, and a cosmological function.
74. As Lequan (2000, 92n) notes, considering the ether as a necessary hypothesis is not an invention of Kant. The same view can already be found in the article "Heat" in Gehler's *Physikalisches Wörterbuch*.
75. For Kant, both cosmology and chemistry had always been closely related to the notion of ether (cf. his *Theory of Heavens* of 1755); also (4: 534).
76. On the question whether it is an empirical physico-chemical hypothesis or a transcendental *a priori* truth see (21: 216–217, 551, 535–536; 22: 217, 550) and discussion in Lequan (2000, 89–98).
77. I leave the difficult interpretative issues concerning Kant's *Ätherbeweise* in the *OP* to the Kant specialists: Edwards (2000, 152–157), Schulze (1994), Friedman (1992, 293–341), Mathieu (1989, 231–271), Förster (1991, 41–45; 1989), Lehmann (1963).
78. Vasconi (1996, 157) suggests "it is reasonable to assume that Kant was already familiar with the new discoveries as early as 1793," referring to a letter from Erhard (11: 408), which refers to Girtanner's *Anfangsgründe der antiphlogistischen Chemie*, of which Kant had been sent a copy. The first mention of Lavoisier is in *Refl.* 66, around 1789–1790 (14: 489): "Nach Lavoisier, wenn etwas (nach Stahl) dephlogistirt wird, so kommt etwas hinzu (reine Luft); wird es phlogisticirt, so wird etwas (reine Luft) weggenommen."
79. Cf. (21: 417, 424).
80. "Ist Wasser Element? Nein denn es läßt sich noch auflösen, es besteht aus Lebensluft und brennbarer Luft, und wir nennen etwas was keine Spezies enthält elementarisch" (28: 664); see also *Refl.* 73.
81. In an enclosure to a letter to S.T. Soemmerring of August 10, 1795: "Das reine, bis vor kurzen noch für chemisches Element gehaltene, gemeine Wasser wird jetzt durch pneumatische Versuche in zwei verschiedene Luftarten geschieden." (12: 33). In the *Physische Geographie* (1802) Kant writes (following Gehler): "das Wasser (besteht) aus Wasserstoff und Sauerstoff, und zwar in einer Mischung die bei einhundert Theilen, 15 des ersten und 85 des letßten enthält" (11: 184).
82. *OP*, around 1795 (21: 453): "What is chemistry? The science of the inner forces of matter." The distinction between fluid and rigid bodies cannot be explained without invoking different intensities of cohesion. Kant borrows from Leibniz the idea that the liquid state is the originary state from which the solid and vapour state derive (he also refers to Thales). Metaphysically this is supported by the chemical and cosmological supremacy of the primordial fluid element, viz. the ether. See further previous section.
83. (6: 207): "there is only one chemistry (that according to Lavoisier)." But Kant still writes in the same book: "Chemists base their most universal laws . . . entirely on experience" (6: 215). In the *Anthropology from a Pragmatic Point of View* of 1798, we can read (7: 326): "What a mass of knowledge, what discoveries of new methods would now be on hand if an Archimedes, a Newton, or a Lavoisier with their industry and talent would have been favored by Nature with hundreds of years of continuous life without the loss of vital power?" The translation is from Dowdell (1978) who informs us (p. 288n119) that Kant substituted "Lavoisier" for "Galilei" in the manuscript stage. Quotations in English from the *Doctrine of Rights* are taken from Gregor (1991).
84. Hence, he also dismisses Tuschling's (1971) view, who suggested that the function of the *OP* was merely to resolve some inconsistencies in the concept of matter as outlined in the *MAdN*.
85. See in particular notes 4, 5, 12 of his Chapter 8.
86. See references in note 49.
87. See for example (21: 294, 299; 22: 136–137, 158, 587). For the significance of the ether in explaining the working of a balance, see Hoppe (1969, 99). One might say that Lavoisier's work, in which the use of a balance played a crucial role, made possible the application of mathematics to chemistry. Cf. *Refl.* 66 (14: 489–494); Adickes dates this text at about 1789 (based on the ink used). This is the year Lavoisier published his *Traité élémentaire de chimie*.
88. Laplace, *Œvres* (II, 645): "En général, nous n'avons de sensation que par le mouvement; en sorte qu'on pourrait poser comme un axiome: point de mouvement, point de sensation . . . Ce principe s'applique au sentiment du froid et du chaud." For Lavoisier's views on this, see in particular his *Réflexions sur le*

phlogistique of 1783 (*Œvres*, II: 623–655). Duhem (1899, 214) quotes Lavoisier as saying: "la science des affinités est à la chimie ordinaire ce que la géometrie transcendante est à la géometrie élémentaire" (without giving a reference). This could be read as a Kantian influence on Laplace.

89. According to Lequan (2000, 122), Hegel completed Kant's project and elevated chemistry fully to the rank of proper science. Moreover, developing the analogical role model of chemistry, with Hegel chemistry became philosophical and philosophy became chemical.
90. The confusion of thinking that Kant only focuses on physics in the *OP* arises, because it is true that Kant often uses the term "physics" to cover both physics and chemistry. For example (22: 501): "As a science of experience, however, physics is naturally divided into two subjects. The one is the subject of the forms in action and reaction of forces in space and time. The other is the complex of the substances which fill space. The one could be called the systematics of nature, the other is called (following Linnaeus) the system of nature." However, other passages make clear that he might also call the former physics and the latter chemistry (see citations in note 49). In the end, the question whether Kant would locate his "gap" or "transition" in connection with physics or chemistry is neither here nor there.
91. Cf. my distinction between "the ontology of *matter in general*, to be dealt with in relation to developments in micro- and astrophysics" and "the ontology of *particular kinds of matter*, i.e., chemical kinds" (van Brakel 1991). Cf. Kant's "matter in general" (21: 307) and "der Gemeinschaft verschiedener Substanzen" (21: 571).
92. Cf. "Critique stands in the same relation to the common metaphysics of the schools as chemistry does to alchemy" (4: 366—*Prolegomena*).
93. I am greatly indebted to Martin Moors who helped me to grapple with the intricacies of Kant's philosophy of nature. This research was supported by a grant from FWO-Vlaanderen (project number 1.5.012.02).

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