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Metachemistry

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In: Jean Pierre Llored (ed.)The Philosophy of Chemistry: Practices, Methodologies, and Concepts,
Newcastle: Cambridge Scholars, 2013, pp. 725-743

ABSTRACT

The term "metachemistry" was introduced by Gaston Bachelard and served primarily to identify the need for a Whiteheadian ontology that could draw lessons from chemistry and that would hold for all of the sciences. This paper will follow Bachelard's proposal only to a very limited extent and take the notion of "metachemistry" in a different direction. Where Bachelard considered chemistry a pure science in its own right and generalized from a specific state of its development, “metachemistry” is in the following thought to provide general insights from an understanding of chemistry as an impure technoscience. The difference between metaphysics and metachemistry therefore signifies a shift in the kinds of questions one asks about the sciences and the technosciences and the kinds of answers one might expect. In respect to chemistry, this would amount to abandoning the question about the specific character of chemistry as opposed to physics. Instead of chemistry aspiring to hold its own in the pantheon of the sciences, the notion of metachemistry refers to chemistry as a technology for bringing forth new things. In respect to the implicit presuppositions of knowledge production, metaphysics refers to the conditions that allow for the scientific representation of facts while metachemistry to the conditions for the technoscientific realization of things. Arguably, Lavoisier's dictum that "there is nothing new in art and nature" is a precondition for scientific explanation and representation, but the alchemical tradition in all of chemistry and now, for example, in nanotechnology subverts this dictum permanently.

META-QUESTIONS

Though it is hardly known or used at all, lacks a common definition, and sounds like a pun, the word "metachemistry" is no stranger than its well-established counterpart "metaphysics."[1] Indeed, as soon as one begins to clarify the meaning or use of "metaphysics," the need for something like metachemistry becomes readily apparent.

Metaphysics has nothing much to do with physics in a narrow, disciplinary sense, but it has everything to do with knowledge of the physical world, and thus with a kind of science of which physics is often taken to be the prime exemplar. If knowledge of the physical world consists in holding true beliefs about this world, metaphysics asks what the world must be like such that there can be knowledge of it. In the language of Kant, metaphysics concerns the conditions for the very possibility of an agreement between a representation and what it represents.[2] Accordingly, metaphysics has considered the notion of substance and those features of the world that persist through time – we can have knowledge about things if the world is such that at least some facts about it persist through time, otherwise we would have fleeting impressions only, but no beliefs that are true today and remain true. For that reason, metaphysics has also been concerned with the causal law or assumption of causality. If things happened spontaneously and without cause, we could not discern relations between events that are subject to representation. And thus metaphysics can be said to explore the many aspects of the "aboutness"-relation between knowledge claims and the world. And this relation, or so it is thought, absorbs much of epistemology and all of scientific knowledge: For theories, hypotheses, and other propositions to be true, they have to say something about something in such a way that there can be a lasting, non-accidental agreement between theory and reality, mind and world, the proposition and what it represents. All this may seem to be so obvious that it hardly requires stating – and with it comes the sense that metaphysics is an utterly familiar enterprise, no matter how confusing one may find it or worthy of critique.

While it may hold for physics that it seeks knowledge about the world and produces a theoretical representation of reality, this does not hold or holds only partly for chemistry. At the very least, chemistry serves as an example that the production of knowledge does not issue in theories only or even primarily, but that it issues also in compounds, industrial processes, testing routines and

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1 An internet search in March 2012 produces a moderate number of hits for "metachemistry" but it is readily apparent that there are mostly incidental uses and no common definition. The more specific search "Bachelard metachemistry" leads to only a small number of hits, indicating that Bachelard's neologism hasn't caught on.

2 As he set out to produce the first of his *Critiques*, Kant identified in a letter to Marcus Herz the question that "contains the key to the whole secret of hitherto still obscure metaphysics." This question is: "What is the ground of the relation of that in us which we call representation to the object?" (Quoted in the introduction by Guyer and Wood to Kant 1997, pp. 47f.).

laboratory techniques. And instead of using predictions to test the agreement between representation and reality, the criterion of knowledge consists, for example, in the ability to move back and forth between synthesis and analysis.[3] So, rather than query the "aboutness"-relation between knowing subject and the world, it might be of equal interest to ask about the productive relation of knowing and doing and its conditions of possibility – about "working knowledge," in other words: knowledge that is implicated in what works and that issues in pieces of work.[4] Here, for example, one might discuss Bachelard's "realization of the real" (Bachelard 1968, pp. 47f.) or Peirce's "reality as normal product of mental action" (1871, p. 91). Different from idealism or a constructivism that is opposed to realism, such explorations would aim to show that the world is reliable and robust due to the ways in which human agency is built into works of art, technology, or science, and inversely, that the world is built into human work.[5] Similarly, we might question the fundamental distinction of *physis* and *techné* and the many associated distinctions such as the ones between organism and artifact, nature and culture, cause and reason. These questions might lead to an understanding of powers and affordances, works and worlds that cuts across discovery and invention, what is found and what is made. Whereas – despite all their claims to novelty – process philosophy, dynamic conceptions of nature, or theories of self-organization merely propose alternative ways of properly representing reality, the attempts to articulate the preconditions and limits of working knowledge are metachemical.

This first approach at distinguishing metaphysics and metachemistry is perfectly general. Moreover, it might appear that many thinkers have taken steps towards metachemistry, even without calling it that.[6] So far, then, the term "metachemistry" has done little more than suggest that metaphysics revolves around representation, scientific experience, and the possibility of forging and

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3 It is worth entertaining as a thought experiment how much would be left of chemistry if it was stripped of words but consisted of routines e.g. to exhibit products in the back and forth between analytic and synthetic procedures. Indeed, quite a lot might be left, but whether it is a little or a lot, it would need to be reconstructed metachemically as a productive, non-representational kind of knowledge.

4 Baird speaks of "working knowledge" in one chapter of his *Thing Knowledge*. This is closely related but not identical to the notion I am trying to articulate here, namely one of knowledge that is specifically acquired to make things work and that is exhibited and validated by the works (of art, of technology, of science or technoscience) that issue from it (2004, pp. 12, 48 and 66; Baird and Nordmann 1994). In search for the right expression I have tried "*Fertigkeitswissen"* (2011), "knowledge of control" (2012) and often refer to knowledge that consists in the acquisition and demonstration of (basic) capabilities (of control), including capabilities of manipulation, modeling, visualization. "Working knowledge" may turn out to be the most apt expression.

5 The work of Bruno Latour (e.g., 1999) comes to mind here but also that of Martin Heidegger (e.g., 1967) and others.

6 I leave open here whether and where in the philosophical tradition one might find metachemical approaches already. While I am quite sure that process philosophy, theories of dynamic systems, self-organization, or emergence do not offer such an account, it might be more promising to look towards phenomenology or pragmatism. Charles Sanders Peirce, for example, compelling considers in tandem the production of knowledge and the production of reality, and he considers this not only as a human activity but as one of the universe. To read Peirce in this way requires severing his supposed affiliation with Popper and exhibiting his proximity e.g. to Latour (Nordmann 2009).

securing some kind of agreement between mind and world.[7] And once one appreciates this limited brief of metaphysics, there is room for the metachemical alternative and the attendant recognition that it is far less developed and that, in particular, we have no clear conception of working knowledge and thus of a kind of knowledge that is not about something and that is not true or false in virtue of how the world is. And if chemistry really does involve the production of such knowledge, we can see that the philosophy of chemistry is a place to look for contributions to the development of metachemistry.[8]

A chemically informed, otherwise programmatically metaphysical philosophy of science has contributed to this by way of Gaston Bachelard's *Philosophy of the "Non"* which introduced the term "metachemistry" (Bachelard 1968, 1981).[9] On very different grounds than Bachelard's, the philosophy of chemistry contributes now to the development of metachemistry, paradigmatically Bernadette Bensaude-Vincent and Johnathan Simon's *Chemistry – The Impure Science* (2008).

By looking in the following at Bensaude-Vincent and Simon's work first, one can see how it accords with the general characterization of metachemistry. And from this point of view, one can also see how this metachemical project picks up on Bachelard's conception and where it differs from it. This reframing of Bachelard's original project will bring to light that the different questions of metaphysics and metachemistry arise not from the disciplinary juxtaposition of physics and chemistry. Instead, they arise from the juxtaposition of physics as a science and chemistry as a technoscience – where technoscience is nothing more or less than research that does not produce knowledge *about* the world but produces working knowledge. Negatively defined, technoscience is impure in that it abandons the work of separating representations from what they represent, of separation the work of technology or culture from the work of science or nature. Positively defined, technoscientific research takes place in a technological setting and in a technological manner in that it develops and achieves basic capabilities for controlling processes and phenomena, even where

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7 To be sure, metaphysics does not imply a commitment to "representationalism" and to the idea that knowledge consists in the making of pictures. But the discussion of representationalism and its limits, and the many proposals of how to ground the possibility of agreement between mind and world in something other than likeness, all concern metaphysics. Likewise, metaphysical questions of "grounding the possibility of agreement between mind and world" do not imply a commitment to realism but might lead to idealist, positivist, or processualist positions, some of which will "anti-metaphysically" reject the metaphor of "grounding" and replace it with more positivist or empiricist accounts. These are the familiar debates in the tradition of metaphysics, broadly construed, yet limited to an interest in what the world must be like or how it must be conceived so that it can be known by the mind in the form of propositions and theories.

8 Again, the philosophy of chemistry cannot possibly be canvassed here. Papers like Newman 1989, Schummer 2003, or Bernal and Daza 2010 come to mind, and of course, the work to be discussed further along in this paper.

9 The title of Bachelard's book was translated *Philosophy of No* but this is misleading in that Bachelard refers to non-Aristotelian logic, non-Euclidean geometry, or non-Lavoisian chemistry – where the "non" signifies not outright negation but a next stage in the development of science, namely a stage that in Hegelian fashion sublimates (overcomes and includes) the previous stages. Accordingly, Bachelard speaks of non-Lavoisian chemistry as "dialectizing" and differentiating the conception of substance in Lavoisian chemistry (1981, 59).

that control might consist in the ability to exhibit surprising things – and thus, technoscience is defined as the kind of research that requires not metaphysics but metachemistry.[10] So, while at first it might appear to be a subtle point that metaphysics and metachemistry do not owe to the difference between physics and chemisty but to the difference between physics as science and chemistry as technoscience, this point involves quite a lot – in particular, a genuine appreciation of impurity and of chemistry as an impure (techno)science.[11]

PURE AND IMPURE

Metaphysics is all about purity, and from a metaphysical point of view the apparent impurity of chemistry is a blemish that needs to be cleared up. This concern with purity comes with the turf if one wants to account for the aboutness-relation: In order to understand how a representation can agree with what it represents or how a proposition is true of some state of affairs, things need to be held apart before they can be related to one another. Since scientific vocabularies and technical procedures usually define the objects of study, one needs to determine as precisely as possible what concepts, representational devices and experimental techniques do, and at what point they are confronted with mind-independent features of the world – features that can warrant agreement of theory and reality. Especially with the tradition of Kantianism, a lot of effort has gone into specifications of empirical content, such efforts have established an ideal of pure science which has proven enormously influential even though it is continuously under threat of being exposed or debunked.[12] For the most part the philosophy of chemistry has inherited this metaphysical brief when it seeks to define a specifically, purely chemical manner of representing specifically, purely chemical objects or processes. This concern for the disciplinary identity of chemistry aims to remove the blemish of impurity especially in regard to physics and the notion that the better part of chemistry is physics and the rest a kind of ill-understood, application-oriented craft.[13] Indeed, much of the philosophy of chemistry is informed by the suspicion that chemistry as we see it today is not real chemistry but a kind of physics. And even those who think that today's chemistry is real

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10 For this definition of technoscience and its precursors see Bensaude-Vincent et al. 2011 and her paper within this volume.

11 Indeed, the point can be pushed further by taking the case back to physics: The different questions of metaphysics and metachemistry arise from the juxtaposition of physics as a science and physics as a technoscience – as soon as one begins to appreciate the impurity of physics as craft or technology.

12 We owe to Michael Friedman the recognition of the pervasiveness of the Kantian tradition in canonical philosophy of science (e.g., Friedman 2001).

13 The remainder of this and the following two paragraphs are incorporated from a review of Bensaude-Vincent and Simon's book in Nordmann 2010.

chemistry are prone to query what aspects of contemporary chemical research are beholden to physics, where chemistry becomes chemical, and how it is that chemistry is by no means inferior to physics. Rather than take their problems from the discipline as they find it, they therefore tend to remind chemists of who they are or who they ought to be. In particular, many philosophers of chemistry shift attention from immutable physical processes at the atomic and molecular levels to chemistry as an art of transmutation, that is, of changing one kind of physical stuff into another. Accordingly, philosophers of chemistry often contradict the ''official'' story of modern chemistry's separation from alchemy as a feat that was accomplished for good by its founding father Lavoisier. Instead, they tend to take seriously the alchemical origins of chemistry and carefully account for the vestiges of alchemical thinking.

In *Chemistry: The Impure Science* Bernadette Bensaude-Vincent and Jonathan Simon depart from this tradition in the philosophy of chemistry by offering a far more radical proposal. They want to save chemistry not from physics but from metaphysics, that is, from the concern to establish the peculiar dignity and purity of chemistry. Rather than establish its disciplinary identity in the concert of scientific disciplines, Bensaude-Vincent and Simon treat chemistry as an eclectic ensemble of ideas and practices. If it is defined at all, this impure science is defined by its technoscientific ambitions which provide a common bond that extends from alchemy all the way to nanotechnology.[14] Instead of beginning with chemical substance, with elements and compounds, with analysis and synthesis, with reaction, process, and complexity, the book therefore begins right in the middle with DDT and Bakelite, with impurities that include environmental pollution and the transgression of traditional divisions between nature and artifact, science and technology. And yet, its argument for chemistry as an impure science does not rely on fashionable notions of hybridity. What puts chemists in the midst of things is their predicament of being ''condemned to stumbling their way through the darkness, trapped at the level of phenomena and never having access to the underlying substantial reality, knowing only the outcomes and not the reasons'' (2008, 62). This predicament, however, is not to the detriment of chemistry. Whether at the phenomenological level of observing chemical reactions or at an analytic level of instrumentally engaging with molecular structure, chemists always encounter matter in its material aspects, that is, superficially. Their different ways of experiencing and dealing with chemical matter treat atoms, molecules, and macroscopic samples on the same plane ontologically — there is not one reality behind the other, there is nothing underlying or hidden or true beneath the phenomenological, superficial, or illusory

14 Perhaps, the final punchline of this book can be put as follows: Nanotechnology shows that chemistry never ceased to be alchemy.

(2008, 145, 204). Accordingly, the standard metaphysical question of positivism versus realism fails to gain traction (2008, 199): On the one hand, chemists claim a positivistic attitude that sticks to sense data and does not infer a true reality behind the appearances, on the other hand they work with valences and bonds, with atoms and molecules in a manner that takes these to be unquestionably real. Similarly, the metaphysical question of reductionism is not germane to chemistry. The question presupposes that the levels between which chemists move with great facility can be held apart and queried for their relations. It thereby presupposes also that chemistry and physics can be considered as distinct even while chemistry appropriates so much of physics.

One might now be tempted to consider what Bensaude-Vincent and Simon call the chemists' ‘‘operational realism’’ as a metaphysical stance of its own which involves a theory of matter that defies classical categories. But again, they insist that this is not an alternative metaphysics (2008, 143–145), in part because chemists are not sufficiently interested in clarity and distinctness, and do not hold consistency to be a very high value (2008, 3). For example, the problem of the mixt has never been resolved or displaced by the notion of a compound, corpuscularism still haunts atomism, elements coexist with principles, and the periodic table remains both a practical tool-box and a foundational system (2008, 124–126, 135–138, 160, 170–172). Chemistry's challenge to philosophy is therefore not that it requires better rational reconstructions of its implicit metaphysics so as to hold it distinct from physics and biology. Rather, the challenge is to appreciate that the elements of the periodic table are analytic objects for conceptual manipulation and at the same time empirical objects for material manipulation (2008, 192). Or, to put it differently, the challenge is to see that even without a theory of matter, chemists develop notions of matter that allow them to interpret reality (2008, 145) – that they do theoretical work even as they eschew consistency and do not refer appearances to true underlying realities. From the midst of the mixt, so to speak, Bensaude-Vincent and Simon call for a philosophy of science that abandons its interest in purifying the impure science of chemistry by using metaphysics as an instrument for the clarification of principles, concepts, and commitments.

To be sure, the rejection of the metaphysical brief is not enough. In the end, an account is needed of just how chemists do theoretical work without applying theories, and how they can interpret reality through conceptions of matter that are implicit in their practice and do not amount to representations of what matter, or of what chemical reality is. Here Bensaude-Vincent and Simon's account is tantalizing sketchy and merely suggestive. And here, it is fruitful to look back at Gaston Bachelard's *Philosophy of the Non*.

Bachelard's Metachemistry

Bensaude-Vincent and Simon refuse to consider chemistry metaphysically and take seriously its character as an impure science or technoscience. From their point of view, the impurity of chemistry, its ontological indifference (Galison 2006, also Daston and Galison 2007, p. 393, 414) and lack of concern with the structure of reality is an asset and not a blemish. It underwrites chemistry's productivity of compounds, materials, procedures, techniques, and models. Metaphysical questions of realism versus constructivism do not gain traction and can neither impeach nor underwrite chemical knowledge. But for all these evidences of their metachemical orientation,[15] Bensaude-Vincent and Simon do not invoke "metachemistry" to designate their project. Indeed, they explicitly deny that they are continuing "Bachelard's project of constructing a metachemistry as the chemical counterpart to metaphysics" (Bensaude-Vincent and Simon 2010, 382). The reason for this is obvious enough. In contrast to metachemistry as introduced quite generally above, Bachelard proposes the term in order to articulate the significance of an emerging new science that creates in its wake also a new philosophy (1984, 3). He pursues a "presentiment of a profound revolution in chemical philosophy," and as part of this imminent revolution, "metachemistry would already seem to be a possibility" (1981, 53). Through a succession of epistemic breaks, each saying "no" to a conception of substance that came before it, contemporary mid-20th century chemistry finally allows for a metachemical conception of substance. And thus, Bachelard's "metachemistry" marks a clean break with the past and serves in his historical reconstruction to purify one notion of substance, and one idea of chemistry in contradistinction to others. Quite evidently, this entire program and philosophy of scientific history is caught up in a metaphysical concern with successive modes of representation, and it runs counter to Bensaude-Vincent and Simon's conception of chemistry as an impure technoscience that represents a tradition of practice that ranges at least from alchemy to nanotechnology.[16] And thus, when Bachelard writes that "[m]etachemistry would be to metaphysics in the same relation as chemistry to physics" (1968,

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15 More evidences could be added, especially as they describe physics as adhering to a deductivist project of representation, whereas chemistry is viewed technoscientifically not as providing a picture of reality or theoretical understanding, but as a manner of working with materials and other tools to produce new materials.

16 "This leads us to reject the quest for metachemistry and instead to pose the question: to what extent can our epistemological, ontological and anthropological characterization of chemistry be extended to the entire realm of contemporary practices in the natural sciences?" Bensaude-Vincent and Simon identify another pertinent limitation of Bachelard's thinking: "By emphasizing the technological component of chemistry, he promoted this science as a model for a new philosophy of science, a rational materialism based on phenomenotechnics. However, the technological dimension of science in Bachelard's works is confined to his views of an instrument as a 'reified theorem' and chemical synthesis as the concrete expression of a human project" (2010, 382). – As opposed to Bensaude-Vincent and Simon, Bachelard wants to strictly distinguish chemistry from alchemy even though, arguably, his notion of the „realization of the real" applies equally well to chemistry and to alchemical routines of purifying and transmuting material stuff as well as the souls of the alchemists.

45; 1981, 53), he operates, despite himself, with a metaphysical conception of chemistry as a discipline *sui generis*, namely a discipline characterized by a distinctive mode of representing its objects.

But even if one agrees with the rejection of Bachelard's program, his conception of metachemistry is still fruitful and was meant by Bachelard to provide insight beyond a particular epoch in the history of science. Like many dialectical thinkers and also like contemporary philosophers of technoscience, he explores a contemporary state of development only to discover that it serves to describe all of history.[17] The metachemical conception of substance, in particular, allows one to conceive the entire succession of conceptions of substance as a trajectory that, in effect, dissolves the very notion of substance as something persistent that might serve as an object of representation. The ultimate substance of 'substance' is its own history of rationalizations and conceptualizations and their associated practices (1968, 44, 72f., 76).

> Metaphysics could have only one possible notion of substance because the elementary conception of physical phenomena was content to study a geometrical solid characterized by general properties. Metachemistry will benefit by the chemical knowledge of various substantial activities. It will also benefit by the fact that true chemical substances are the products of technique rather than bodies found in reality. This is as much as to show that the real in chemistry is a realization. (1968, 45)

When Bachelard speaks of "[c]hemical knowledge of various substantial activities" this conception includes the above-mentioned working knowledge of techniques which can participate in material agencies so as to afford substances as works of chemistry. That the real is a realization (rather than, say, a discovery or a construction) appears to be a general point about the technosciences which do not seek primarily to represent and understand the world but which, impurely, combine various productive agencies. Here, Bachelard's notion of metachemistry agrees with the general meaning assigned to it above. Substance conceived metaphysically refers to the persistence or obduracy of features of a mind-independent reality – it is a subject of representation only if the propositions about those features say something that is not already known. This 'substance' is introduced as an unknown, at least as yet unknown nature of things which persists so that we can gain knowledge of it., "[F]or a chemist who has just realized a synthesis, chemical substance must, on the contrary, be equated with what one knows about it" (1968, 47) and, in particular, what is known in the process

[17] Donna Haraway, Bruno Latour, or Andrew Pickering discovered technoscience as a contemporary hybrid of science and technology ("these can no longer be distinguished") and went on to say that there was never a pure science anyhow, and that all previous attempts to juxtapose science and technology were ideological ("there was never a proper distinction"). This universalizing move has been criticized by Rabinow 1997. – Along similar lines, Bachelard can be found claiming Mendeleef's tables as the birthplace of metachemistry (1981, 58).

of making. If chemical substance is thus tied to knowledge, it is not a definite something or mere substrate that endures through time. Instead, it is at all times fully realized as just what it appears to be, and at the same time it never stays the same as it becomes transformed in processes of making, remaking, and learning to make. As an indefinite "something out there" – like a material probe for chemical analysis or an apparent disorder presented at a clinic – the substance enters into a series of interactions that produce determinate things that are characterized by their performance, functionality, or affordances. That substance is always no more and no less than what we know about the techniques of exhibiting it, underwrites Bachelard's curiously rationalistic story of successive epistemic breaks but agrees also with Bensaude-Vincent and Simon's picture of chemistry as treating all modes of chemical experience on the same plane.

Bachelard describes the trajectory of successive states of knowledge or competence in terms that were later echoed by Bruno Latour (Nordmann 2006). This trajectory becomes visible "when one of the variables included in the representation is *time* and the other variable corresponds to some characteristic of substance" (1968, 64). In this kind of graph, Bachelard suggests, one can plot the definition or institution of substance. The choice of variables avoids the metaphysical presupposition that there is a stable "it" that is being represented with ever greater accuracy: the probe and the disorder are perfectly well-known and can be described in great detail before chemical composition is revealed or a specific disease defined. The apparent constancy of this "it" emerges only from a continuity of interaction and its narrative order – it is the story of interactions that build upon one another and accrue competences or knowledge to produce behavioral performances that fix a common referent that has always been there (Latour 1996, Latour 1999, pp. 145-173). In the context of this storyline, substances result from the accumulation of more and more characteristics: They appear to become more articulate and better articulated as they incorporate "more and more of the conditions needed to detect them" (1968, 59). Considered along the continuous path of this trajectory, substances become increasingly reliable or stable actors in experimental and technological interactions, that is, as the situations are defined and become defined in which they will assert themselves in certain ways. The trajectory is therefore graphed in reference to two variables: The time that passes as the collective work of science goes on, and a scale that registers the accumulation of characteristics with which the substance becomes identified. 50 years later, the graph envisioned by Bachelard was actually produced by Bruno Latour with respect to Pasteur's experiments and the "discovery" of Tasmania (1990). [18]

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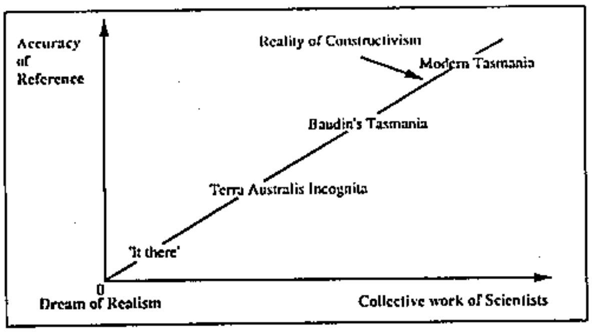
[18] To be sure, the graph that here appears to be co-produced by Bachelard and Latour brings out a tension in Bachelard's account: The graph highlights the continuity of a process through which some "it" becomes ever more definite and through which the real is determined, that is, the continuous accumulation of characteristics (this continuity also accords with Peirce's philosophy). Bachelard, of course, is also likely to point out the discontinuity of epistemic breaks – and he is thereby closer to Bensaude-Vincent and Simon's account which implicitly rejects the teleology of a continuous trajectory of realization.



Despite its curiously Hegelian notion of an advancement of thinking about substance that has reached a particular stage during the first half of the 20th century, Bachelard's historicist and technological understanding of substance as substance-in-the-making thus meets up with the perfectly general account of Bruno Latour. Accordingly, Bachelard's idiosyncratic notion of metachemistry offers one avenue towards making more precise the general and vague conception at the opening of this chapter.

Working Knowledge

On the basis of these rather principled and conceptual considerations, we can finally turn to technoscientific practices that call for metachemical reconstructions. For each of these practices one should ask what specific relation they forge between knowing and making. So far, chemistry came in through the work of Bensaude-Vincent and Simon as a prominent exemplar of an impure technoscience. Also, chemistry came into play with Bachelard's contrast of physical or metaphysical substance (a geometrical solid characterized by general properties) and chemical or metachemical substance (the material stuff that enters the laboratory and through constant reworking becomes a product that affords particular interactions). When we here go on to cite examples of technoscientific practice that call for metachemical reconstructions, chemistry appears as before now and there – prominent but by no means privileged.

Of the following examples of technoscientific method, the one that is most intimately tied to the relation of knowing and making is the demand that chemical analysis needs to be matched by synthesis. This demand, in turn, is emblematic of the entire tradition of Baconian science (Smith 2004, 239) and it has just recently attracted attention in the field of Synthetic Biology with its frequent invocation of Richard Feynman's dictum "What I cannot create, I do not understand" which seems closely related at first sight to "what I cannot synthesize, I have not analyzed." In all likelihood, however, this dictum takes on a different meaning when it moves from the blackboard of a physicist who is committed to a scientific ideal of theoretical understanding to a research community that prizes making and building. It needs to be appreciated in respect to the metaphysical conceptions that can underwrite agreement theory and reality and in respect to the metachemical conceptions that can underwrite the participation of human agency in material agency. In particular, does Feynman's dictum provide a necessary condition for understanding, for successful and complete analysis – where the ability to create or synthesize is conclusive evidence that validates a theory or proposed analysis? On this interpretation, understanding is intellectual and consists in a representation or mental model of a phenomenon, and the ability to create confirms the mental model. While this is probably what Feynman meant to say, at least some proponents of Synthetic Biology take his statement as providing a sufficient condition "what I create, I thereby also understand" (again, see Benner and Sismour 2005). This reading is unintelligible and must be rejected as long as understanding is tied to the aboutness-relation and as long as it concerns the relation of mind and world. On a metachemical reconstruction it might become intelligible – if, for example, the ability to create is taken as a form of successful participation in the world, a sign of having achieved a feeling for the behavior of a physical system.[19]

If the realization of the real involves participation in the real, the separation of mind and world as separate spheres is no longer possible – and with that, there is also no separation between the superficiality of mere appearances and the depth of explanatory structures behind the appearances. And thus, we are back in the midst Bensaude-Vincent and Simon's account and in the midst of the impure where metaphysical debates about foundationalism, reductionism, positivism vs. realism do not gain traction. This holds also for questions of compositionality – is water made up of the two components hydrogen and oxygen, or is there salt in the sea?[20] As before, this question requires different treatment in the context of seeking to know the world representationally by way of true propositions, and in the context of knowing the world technologically in the course of acquiring capabilities of control. That the whole might be more than the sum of its parts and similar notions are necessary metaphysical devices to represent systems and a special class of properties that are now called emergent. At the same time, mereological notions of components and systems can be considered grammars of chemical practice that regulate the movement of researchers between atoms and elements, molecules and bulk matter, and the devices that address and interact with them.

[19] Feynman's statement has also been understood as a modern formulation of Giambattista Vico's *verum factum* principle which places a limit on the ability to understand nature as something that humans have not created and therefore will never properly understand (Schummer 2011, 136-147).

[20] The following remarks are inspired but do not begin to do justice to Harré and Llored (2011).

Molecules do not "emerge" from atoms, and certainly they do not "self-organize." Instead a certain organization of technical attention, one that includes mereological conceptions but also laboratory apparatus and physical samples, affords molecules or affords atoms or even affords commonplace bulk matter: "There is no sodium in salt, but salt affords sodium" (Harré and Llored, 2011, 70). Mereology (and similarly, causality) as a grammar for interaction with the world is always implicated in the relation of making and knowing. When technoscientists in their laboratory show that this process yields that outcome or that they can reliably produce a surprising effect or that in this probe they can isolate that trace element, these capabilities involve par excellence an implicit or explicit conception of parts and wholes, constituents and components, structures and functions, of bits as distinct from parts, of fusions as distinct from sums. A similar point can be made in regard to causality: implicit knowledge of what kinds of actions are necessary and jointly sufficient to produce a certain kind of effect involves a conception of the ways in which the work of people upon material stuff is productive and affords works of art, of engineering, or of technoscience.

To be sure, a lot of further detail is required here: Technoscientific working knowledge participates in the world by way of producing works that afford activities and things (Harré 2003). This sets it apart from a magical mode of participation that seeks to change the world through the manipulation of signs. A voodoo doll that is in some ways similar to a human being if only, say, by sharing a lock of hair with that person, does not represent or symbolize her. Instead, it is an icon which shares in the reality of that person such that actions on the doll are simultaneously actions towards that person. In contrast, working knowledge participates in the world through the technological creation of works, as, for example, in alchemy, chemistry, and nanotechnology. Here too, this involves the creation of iconic devices that share in the reality of something else. One such device would be a so-called CAVE-environment that allows researchers to interact "face to face" with molecules, which includes not only to see but even to feel molecules as molecules "see" or "feel" each other. This is accomplished by entering a cave-like three-dimensional simulation model and by experimentally intervening in a scaled-up molecular world by pushing and pulling and thus experiencing binding forces first-hand in this substitute environment. Since the CAVE has many features of reality packed into it (not unlike that lock of hair), action performed in its environments are thought to be actions on the "real" physical entities (which is how one can speak of simulation *experiments*).[21] And as in pre-modern magical thinking (Foucault 1973), the mere likeness or similarity of two things suffices to infer a common cause – since an experimentally obtained and a

[21] This point can be extended to many simulation models, animal models, and generally „models for“ in contrast to „models of“ (Fox Keller 2000).

calculated image look alike, one infers that they owe to the same causal dynamic, even if this dynamic is implemented in the computer in one case and an experimental system, in the other case. That the similarity of things should testify to their participation in a shared reality and that this should underwrite causal inferences is difficult, if not impossible to reconstruct with classical epistemology which seeks to avoid circularity by ensuring that evidence is independent from and external to theories and their models. As opposed to voodoo, however, causal inferences from a CAVE environment or from a genetically engineered animal model for a human disease are by no means unfounded. They are underwritten by the technical construction of the substitute reality and all the theoretical as well as working knowledge that goes into it (Reinhardt 2006).

To conclude this cursory list of research practices that call for a metachemical conception of knowing and making in the world, here is an immersive routine of working knowledge that produces participation in a system through a process of taking on ever more features of the world such that it can finally serve as a substitute for it. This is the routine that Hasok Chang has identified for the construction of measuring instruments and that is now being explicitly transferred from software engineering to the construction of synthetic organisms (Chang 2004, O'Malley 2009).[22] The iterative loop looks simple enough. It begins with an analysis that is used to construct a model that then exhibits some behavior. Here the second cycle begins with an analysis of the behavior of the model that informs the correction of the model that then exhibits a somewhat different behavior. And thus commences a process of tuning a model to exhibit a desired behavior which is similar, perhaps, to a complex behavioral pattern that is observed in the "real" world. By incorporating more and more knowledge of that world into the corrections of the model, the model gains in complexity and participates ever more deeply in the workings of the world.[23] This iterative process thus began with an aboutness-relation and a classic notion of representation but moved on to produce a working knowledge that has become reliable due to a process of assimilation: The researchers began with an analysis of a process or phenomenon, event or situation that led to the construction of an initial model that represented the situation in question. But with each subsequent iteration they absorb more and more of the world into the model – they no longer analyze the situation in order to speak about the world, but they analyze the behavior of the model in order to imitate the world. The researchers thus gain a feeling for the behavior of the complex system that is growing up under their

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22 Chang takes Peirce's epistemology of self-correction as a model for this process of iteration. But rather than tending to the limit of a frequency, the iterative self-corrections of measuring devices resemble the technological model from software engineering.

23 This is an instance also of what Andrew Pickering calls *the mangle of practice* (1995) – attempting to differentiate and specify what is glossed over and lumped together by the notion of the "mangle."

hands, and they lose analytic or theoretical understanding in the form of intellectually tractable claims about the world (cf. Lenhard 2011). Their realization of the real follows a metachemical trajectory: they gradually incorporate more and more of the world into their works and thereby learn to know it. And thus, if metaphysics is concerned with what the world must be like in order to support aboutness-relations, the task of metachemistry is to explore how the working knowledge of researchers affords works of technoscience that share in the same reality as the works of nature, and moreover, to explore the significance of the participation of works in the world and of the world in the work of technoscience

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