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BOOK SYMPOSIUM

Ask not what philosophy can do for chemistry, but what chemistry can do for philosophy

Bernadette Bensaude-Vincent and Jonathan Simon: *Chemistry: The Impure Science*. Imperial College Press, London, 2008, xii + 268 pp, UK£37.00 HB

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In this book Bensaude-Vincent and Simon offer up a refreshing and innovative introduction to the history and philosophy of chemistry, the like of which is not to be found anywhere in the extant literature to the best of my knowledge. Right from the introduction the authors locate chemistry squarely in the material and social worlds of its practices, and a sustained commitment to that contextualization gives their philosophical discourse a distinctive flavour. Each chapter revolves around a conceptual theme, instead of treating a specific chronological period or a particular area of chemistry and its application. This thematic organization brings freshness, and helps to shake up some standard assumptions and tropes. What the authors give us is a series of interlinked essays rather than a systematic presentation, but I think that is a strength in this case. In my view the book gets better and better as it progresses, partly because the authors seem more sure-footed about the material treated in the later chapters, and partly because the unconventional links they make

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become more convincing as more pieces of the puzzle are put into place. On the whole the writing is engaging and accessible, while the content is firmly rooted in specialist research by the authors themselves and numerous others. The bibliography is excellent, with a manageable number of well-chosen sources that would be useful for readers to follow up on. This book would be suitable for students at various levels and interested lay readers as well as practising scientists, yet it would also have much to teach professional historians and philosophers of science.

I have some small complaints, and I want to get them out of the way before I carry on with more important and positive comments. The standard of editing in this book leaves something to be desired, and this is the press's responsibility at least as much as the authors'. It seems to me that editorial standards have been deteriorating even at some of the more reputable presses, and errors do slip in unless the authors are very vigilant. I regret that this wonderful book is marred slightly by spelling errors (e.g., "barimetric" on 82, "Indeeed" on 83, and "principle" for "principal" on 127), strange capitalisation ("wall street" on 27 and the "Ancient Classical World" on 120), unconventional formatting (in chapter 2, book titles are put in quotes *and* italics), run-on sentences, missing commas in appositives, and also simple sloppiness (e.g., a stray reference in the text instead of a proper endnote, on 79).

There are also some detailed points of content that do not seem to me quite correct. I think "Jean Antoine Deluc" (89) was meant to be the Genevan polymath Jean-André Deluc. I don't think Lavoisier at any point would have taken inflammable air (hydrogen) as a component of atmospheric air (83), though I may be wrong there. In the top line on 103, "synthesis" should be "analysis". DDT is not an organophosphate (17), but an organochlorine. Michael Polanyi did not have a significant Cambridge connection as far as I know (instead, he taught at Manchester after leaving Berlin), and I wouldn't have thought crystallography was his main claim to fame in science (67). Less trivially, it does not seem right to say that the ancient atomic and element theories both shared "the idea that the world should be conceived of as being primarily phenomenal, in the sense of being a collection of phenomena" (115). Concerning analytical chemistry, there are two rather subtle points: it is not quite right to present Liebig's combustion analysis as a prime example of reagent-based analysis (74), and analysis conceived as detection rather than decomposition is not something new brought about by twentieth-century instruments but merely a return of the old conception from traditional reagent-based analytical chemistry (77). Readers should also be warned that some of the chapter titles are not really indicative of the actual content; for example, do not jump into chapter 3 ("The damnation of the alchemist") expecting an in-depth discussion of alchemy, or into chapter 4 ("The space of the laboratory") expecting a sustained focus on physical space as such.

Having said all that, I now return to the more major points, about which I have hardly any complaints. The purpose of the rest of this essay is to highlight the most interesting and valuable aspects of the book, adding some points for further discussion.

(1) This book will be particularly instructive because its philosophical base is different from what most Anglophone readers are accustomed to. The authors draw

their inspiration from a broad philosophical literature, not just the standard canon of Anglo–American philosophy of science. Important philosophers who provide inspiration for the discourse in this book include Bachelard, Duhem, Comte, Arendt, and even Rousseau, Kant and Cassirer; there is hardly any mention of Kuhn, Popper, Lakatos, Hempel, Quine, Putnam, van Fraassen or, heaven forbid, Kripke or Lewis. More specifically on the history and philosophy of chemistry, too, there are instructive discussions of various modern authors whose work is not widely known, such as Monique Lévy (on reductionism), Marika Blondel-Mégrelis (on Auguste Laurent), Christiane Buès (on the concept of the mole), and Britta Görs (on nineteenth-century chemical atomism), to mention just a few. We also get an effective introduction to Bensaude-Vincent's own numerous valuable contributions, some of which are only in French. It would be useful to take the publication of this book as an occasion for making further efforts at the bridging of the disparate scholarly communities separated by linguistic and national barriers.

(2) The authors make a very effective push for a practice-focused philosophy of science, offering a very different set of themes and arguments from the preoccupations of the kind of philosophy of chemistry that one often finds at the Philosophy of Science Association (PSA) conferences and such venues. I must confess that I have a clear bias here, as one of the organisers of the new Society for Philosophy of Science in Practice (SPSP). Bensaude-Vincent and Simon are not just issuing a slogan or displaying an outlook: their focus on practice has some concrete payoffs. Among other things, it gives plausibility to the authors' counter-intuitive sweep from the very practical issues of pollution and the social image of chemistry to the very esoteric and abstract issues of realism and reductionism. This unlikely coupling works well by the end of the book, where the discussion of agency and capacities leads to a critical examination of the aspirations of nanotechnology, and then of the general mission of chemistry in society. It does not work so well in the early parts of the book, when the authors' practice-focused philosophy has not been spelled out or seen in action yet.

(3) One of the most refreshing challenges that this book poses to run-of-the-mill philosophy of science is in its treatment of scientific realism. The authors present "operational realism" (206) as a common attitude of working chemists, which we philosophers can perhaps learn from: chemists accept "the reality of the tools with which they do their chemical work"; this is distinguished from instrumentalism, which tends to be dismissive about the reality of the conceptual tools one uses. Operational realism is akin to Hacking's "entity realism" as the authors note, but Bensaude-Vincent and Simon go one step further than Hacking by granting operational reality to abstract concepts as well as concrete entities. More generally, their view is that ontology springs from activity. We should ask "what ontology is appropriate to [chemists'] scientific practice." The realism debate can usefully be re-oriented as follows: "Rather than framing the preliminary epistemological debate in terms of the question 'what can one know?' it might be better to pose the question 'what can one do?' and then examine the ontological consequences." (201) With this re-orientation, the authors are also able to give subtlety to their historical discussions, avoiding the pigeon-holing of historical figures into facile dichotomies. For example, they give an instructive discussion of Kekulé's puzzling anti-realism

about atoms (188–191), and remind us that Comte was not an anti-realist (181). These ideas about realism deserve further elaboration and critical attention.

(4) It is a common complaint that philosophers' view on science has been distorted by an undue attention to physics (especially theoretical physics), and it is a complaint made with good effect in this book, too. The authors argue that paying close attention to chemistry would help us, and I could not agree more. But what exactly the benefits would be remains slightly unclear. I think in some places Bensaude-Vincent and Simon over-emphasise the difference between chemistry and other sciences. My inclination is to think that a proper attention to chemistry would also help us by letting us realise how much like chemistry other sciences are (and unlike how we had imagined them to be). In other words, I think chemistry exhibits with particular clarity some characteristics that are shared by many other sciences; in that sense chemistry is a paradigm of science, not an exception. For example, it is true that chemistry creates its own objects (chapter 6), but so does biology these days as the authors do mention. Physics creates its objects in a subtle yet important way when it carefully produces controlled phenomena in the laboratory, and more bluntly when it smashes high-energy particles together in ways that do not happen in nature, at least on earth. The authors are also correct to point out that chemistry deals in capacities, but most other sciences do as well; after all, Nancy Cartwright, whom they cite in this connection, developed her ideas about capacities by thinking about physics and economics, not chemistry. But perhaps there are some ways in which chemistry really is fundamentally different from most other sciences? If so, that is not articulated so convincingly in this book.

(5) In any case, there is a great deal of thought-provoking discussion throughout the book about the relation between chemistry and physics. Chapter 8 ("Chemistry and Physics") focuses on this issue explicitly, but there is much interesting material in other chapters, too, for example in chapter 11 ("Atoms as Fictions"), where the common notion of atoms coming from modern physics is shown to have distorted the historiography of chemical atomism. The main issue that divides physics and chemistry emerges as a type of reductionism: can the numerous and varied qualities of substances all be understood as arising from the most fundamental attributes of matter, the so-called primary qualities of position, shape and motion? Bensaude-Vincent and Simon clearly endorse chemistry's refusal to "disqualify" matter. The concluding passage of chapter 8 is worth quoting in full, as it is one of the places where we can see some key themes of this book coming together:

> "Matter without qualities, matter that is necessarily informed by something else, matter whose phenomenal place in the world depends solely on its form and motion is simply inadequate for dealing with the rich active world encountered in the chemist's laboratory. Chemistry's theatre cannot dispense with its players, who are individuals with the capacity to act and react, and whose existences are interwoven in a complex web of relationships. Thus, chemistry's drama is inevitably richer than the reductive dream that has been characteristic of the history of physics." (151)

Here I think the authors identify a deeply important point. I would merely like to reinforce a qualification already present at the end of the passage I have just quoted:

not all physics is the same (nor all chemistry), and if chemists have rebelled against the reductive and bare ontology of physics, then so have some physicists, such as Philip Anderson with his insistence on the autonomy of the ontology of macro-level physics. To me, what happens in much of today's theoretical chemistry does not seem all that different in character from what happens in theoretical condensed-matter physics.

(6) I think that the authors put their fingers on a very important issue when they emphasise chemistry's struggle over the centuries with the distinction between the artificial and the natural. This theme, rightly, plays out in several different chapters. It is very useful to have the emphasis in chapters 2 and 3 on the negative image of chemistry arising from a common reaction against the artificial. Chemistry has been tainted with the image of the Faustian ambition, going back to the real Doctor Faustus, a sixteenth-century alchemist (36). Bensaude-Vincent and Simon advocate a far-reaching solution to this problem: "It is, then, possible to envisage a new configuration of chemistry reshaped as a technoscience capable of integrating culture and society into its practice, and thereby able to overcome the secular conflict between nature and artefact." (243) This vision, which they sketch out in chapter 14 ("Towards a responsible chemistry"), is certainly attractive, though its discussion is all too brief in this book. I hope it will stimulate much debate and soul-searching.

This book is not only an exciting addition to the literature in the history and philosophy of chemistry, but a great contribution to the philosophy and history of science and technology in general. I hope it will find a wide variety of readers all over the world.

Alfred Nordmann

Philosophers of physics and of biology tend to take their questions and problems from the discipline under consideration—they provide conceptual clarification, articulate implicit presuppositions, reconstruct laboratory practice, or intervene in debates. In this sense, they begin from a position of deference towards physics and biology, respectively. This does not hold for the philosophy of chemistry. Much of it 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 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 philosophical ways of thinking about science that take physics as its primary exemplar. They thereby also want to save it from most extant philosophy of chemistry with its 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 that provide a common bond that reaches from alchemy to nanotechnology. Indeed, the final punchline of this book can be put as follows: Nanotechnology shows that chemistry never ceased to be alchemy.

Though much of its argument remains sketchy, it is hard to overestimate the interest and significance of this book. Rather than seek fault with particulars, this review therefore seeks to prepare for a more general discussion of three of its most salient features: (1) How does the understanding of chemistry as an impure science emerge from the need to abandon metaphysical questions about chemistry's distinctness from physics? (2) What is the technoscientific ambition of chemistry that it shares with alchemy and nanotechnology? (3) And what does this view of chemistry as an impure technoscience imply for the philosophy of physics and the philosophy of science, more generally?

(1) Instead of beginning with chemical substance, with elements and compounds, with analysis and synthesis, with reaction, process, and complexity, the book 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" (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 (145, 204). Accordingly, the standard metaphysical question of positivism versus realism fails to gain traction (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, the authors insist that this is not an alternative metaphysics (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 (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 (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 (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 (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. The philosophical predilection for doing so, they suggest, owes much to the privileged relation of physics and metaphysics which has produced a mythical conception not only of science but also of how to individuate the special sciences as autonomous disciplines.

(2) Bensaude-Vincent and Simon's criticism of attempts to distinguish chemistry by means of conceptual clarification and metaphysical analysis is a recurrent theme in their book. It is less clear what a philosophy of impure science might look like. Where chemistry begins and ends, in the midst of things, it encounters the materiality of matter at all scales, and materiality is what nature is (145, 204). Such statements show the way but are hardly satisfactory as yet. The same can be said for the suggestion that chemists produce theories to interpret reality without specifying how these theories can be identified and validated: In which sense is the chemist's "work with the hand … theoretical in its implications and abstraction" (94f.)? The authors go a little further when they maintain that it is not ontology that distinguishes physics from chemistry but practice (168). And while it is ontology that might distinguish alchemy from chemistry and chemistry from nanotechnology, it is technoscientific practice that unites them. This pair of claims is another recurrent theme of the book and appears most strikingly in the assessment of Lavoisier's significance. His "process of division and subdivision constitutes a veritable 'transmutation' of these natural substances by means of time-consuming experimental work, not without parallels to the alchemical tradition" (70). This experimental work consists in the purification of substances that are divested of their natural origins and thereby become commensurable samples of well-defined

elements or compounds in chemical laboratories. The philosopher of chemistry and chemical philosopher Gaston Bachelard therefore maintained that the chemically real results from the work required to realize it. Bensaude-Vincent and Simon insist that Bachelard's "rational materialism" characterizes alchemy as much as it does chemistry, even if Bachelard himself denies the alchemical origins of this notion (94f.). In alchemy, this work of purification and transmutation was to involve not just the materials that are weighed and manipulated in the laboratory but also the souls of the experimenters themselves. But chemistry developed an "overweening hubris" of its own (51): The purified chemical substances "can be compared to wild animals that have been domesticated … as aids in exploring the untamed jungle" (71). Here, chemists enter a "wily game with nature" in which new molecules are generated, effects produced, and properties observed that were not to be expected from the theories and laws that might have informed the chemist's thinking. Their domesticated laboratory entities are not idealizations which somehow instantiate a telling feature of nature as a whole. Rather the chemist's new molecules open a new space of possibilities, they are agents or probes that explore as well as populate an as yet unexplored jungle of interactions (192). And here, as the latest development, the vestiges of alchemy in chemical practice link up with the "Faustian ambitions" of nanotechnology to remake the world atom by atom, molecule by molecule (9). Where practical manipulation serves as the ultimate proof of veracity, the ambition to perfect nature and to invest it with symbolic or technical value creates a world in which things are not immutably what they are but always on the verge of what they can become. To be sure, a lot of work remains to be done to elucidate chemical practice as it appears in the light of alchemy and nanotechnology, i.e., in the light of technoscience.[1]

(3) The weakest chapter of this book appears to be chapter 4 with its seemingly simple-minded juxtaposition of physics as a theoretical, indeed deductive science and chemistry as a practical laboratory science (also 107). However, to pounce on this depiction is to concede Bensaude-Vincent and Simon's point. Most contemporary historians and philosophers of physics will probably come to the "defense of physics" and maintain that it is a laboratory and experimental science, too, and that it does not actually rely on a conceptual and theoretical hierarchy that reduces it to calculation and deduction. By pointing out that physics, too, involves tinkering, local fitting of models and phenomena, and indeed a good bit of construction, these critics claim a disciplinary impurity of physics that renders it unfit as an idealized model of an idealized conception of science. But this is precisely what the authors of this book aim for: In a first step—the one they explicitly take—they criticize attempts to measure chemistry against a mythical conception of a science in such a way that chemistry has its own way of seeing the world which is complementary to physics, biology, or sociology, and in such a way that chemistry has its own methods and theories, metaphysics and ontology. By abandoning this perspective on chemistry and viewing it as an impure technoscience, they challenge us to take the

[1] By way of disclosing potential conflicts of interest, the author of these lines should admit that he is engaged with Bernadette Bensaude-Vincent in a project to elucidate the genesis and ontology of technoscientific objects.

second step of looking at physics in just the same way. And if one accepts this challenge (as many science studies scholars have begun to do at least implicitly) one does so at the peril of forgetting what this mythical thing called "science" was all about. Also, by accepting this challenge, one surrenders the stereotypical view of chemistry as subservient to physics and its scientific quest for a theoretical understanding of the world, and adopts instead (as many science policy makers, funding agencies, research institutions, and scientists are doing) a view of physics as handmaiden to chemistry in the technoscientific pursuit of innovation.

Authors' reply

Bernadette Bensaude-Vincent and Jonathan Simon

We would like to start by thanking Hasok Chang and Alfred Nordmann for taking the time to read our book and for presenting such thought-provoking reflections. We are, of course, delighted that their comments are largely positive and that they encourage us to push forward the line of thought developed in *Chemistry: The Impure Science*.

This response will turn around the question of scientific disciplines, both old and new, in a somewhat paradoxical way. In the first part we will question the specificity of chemistry with respect to the philosophical position developed in our book. Overall, we can only agree with the criticism raised by both commentators that chemistry is not as different from the other sciences as we seem to imply. In the second part, we will respond to Nordmann's interest in the nanosciences by considering new interdisciplinary domains of scientific research that might argue in favour of the 'chemical thinking' developed in our book as providing the appropriate philosophical basis for their analysis.

Both commentators pose the question in one way or another of whether our observations and elaboration of a 'productive' philosophy that lead into an operational realism are limited to chemistry and whether the same argument might not apply just as well to physics, to biology or to any other science. As Chang points out, we mobilize a dichotomy between physics and chemistry that cannot survive detailed scrutiny (of the historical or contemporary situation); that physics is exclusively interested in the ultimate causes responsible for what one can experience in the world and that chemistry limits its ambitions to a functional knowledge of the 'superficial' properties of matter, its disposition to enter into combination or transform its chemical properties. There are different tendencies within physics as there are different approaches within chemistry, but conventional philosophy of science pushes us towards caricature rather than subtle characterizations of science. Hempel's philosophical version of a law of nature—all ravens are black—is a long way from the kind of conclusions an organic chemist could hope to draw from his or her engagement with reagents at the laboratory bench. As Chang suggests in his commentary, an acceptance of the inadequacy if not irrelevance of the approach that has dominated the field since WWII would demand a profound

re-thinking of the curriculum of philosophy of science courses around the world. While we hope that our book could contribute to just this kind of reform, we have to concede that our philosophical stance is not fully enough developed to achieve this goal.

Noting that we "want to save chemistry not from physics but from metaphysics, that is, from philosophical ways of thinking about science that takes physics as its primary exemplar," Nordmann clearly recognizes that our project was to initiate new perspectives in the philosophy of science. Our aim was not, however, to continue Bachelard's project of constructing a metachemistry as the chemical counterpart to metaphysics.[2] We recognise the pertinence of Bachelard's thought, notably the central role he gave to operations when he defined chemistry as "a science of effects" rather than a science of facts.[3] 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. Furthermore, Bachelard assumed that his metachemistry was appropriate only for the science of his time, and he went on to describe eighteenth-century chemistry as typical of the undisciplined fantasy that characterizes the thinking of a pre-scientific age. 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? Just as historians are aware that their reconstruction of the past is shaped by the present, philosophers should understand that present norms and values are being projected onto their descriptions of science. In other words, by equating 'impure science' with technoscience and present-day chemistry, are we providing a paradigm for an early twenty-first century scientific style?

Although we do want to take chemistry seriously, we are not aiming to establish the essence of chemistry—the search for a chemical core as it has been termed[4]—but rather to explore a tradition that has been at the margins of philosophical concerns. The aim is to re-vitalize—or at least encourage (along with Hacking, Chang and others)—a counter-current in the philosophy of science. Today, the stark choice of camps between logical positivism and social constructivism does not do justice to the philosophical richness of scientific practice. It is clear that any philosophy of science looking at laboratory practices rather than at the linguistic construction of scientific statements about the world has to pay attention to the role of instruments, protocols, technologies, funding, etc. All these actors that the STS movement has brought to the front of the stage have not yet been mobilized by most

[2] On Bachelard's metachemistry see Alfred Nordmann, "From Metaphysics to Metachemistry" in Davis Baird, Eric Scerri, Lee McIntyre (eds.), *Philosophy of Chemistry: Synthesis of a New Discipline*, Boston Studies in the Philosophy of Science, Dordrecht: Springer, 2006, pp. 347–362.

[3] Bachelard, *Le Pluralisme cohérent de la chimie moderne*, Paris, 1930, pp. 228–229.

[4] Joachim Schummer (1998). "The Chemical Core of Chemistry I: A Conceptual Approach", *Hyle*, *4*(2): 129–162.

philosophers of science. We hope, in all modesty, that our book will help to introduce them into such philosophical discussions.

Turning now to nano-sciences and other such emergent fields, we can note that Marcellin Berthelot's famous claim that 'chemistry creates its object'—the leitmotif of our book—no longer applies exclusively to chemistry. The ambition of knowing through making that we described as typical of chemistry is shared to various degrees by Materials Science and Engineering, Bioengineering and Nanotechnology. They all turn material structures—crystals, macromolecules, DNA, bacteria, etc.—into dispositions or functionalities. They all reconfigure natural substances as tools in the hands of designers for the purpose of realising technological projects. In the age of post-genomics the question of what one can do with DNA is as much governed by unforeseen limits to manipulation (and the new possibilities they open up) as by formalized (universal) predicted potential. In addition, the current shift observed in biology from a descriptive to a constructive approach suggests a parallel between the history of chemistry and the history of biology. The emergence of "synthetic biology" can be understood as analogous to "synthetic chemistry", a term coined when chemistry moved from the analytical paradigm to the synthetic paradigm in the course of the nineteenth century. Molecular biology and genome sequencing can thus be reconceptualized as a kind of analytical biology that paved the way for the emergence of synthetic biology.[5] Formerly based on observation and analysis, biology was among the sciences that "do not possess their object," but it is now capable of verifying its conjectures, leading many synthetic biologists to quote Richard Feynman with approval: "What I cannot create I do not understand". In both cases the creative power of synthesis is not confined to practical outcomes but also covers theoretical understanding.

Chemistry is constitutive of a number of technosciences and unsurprisingly many chemists have been able to jump on the bandwagon and find a niche in the most fashionable trends of current science. However, it seems to us that chemistry throughout its long history has accumulated such a capital of knowledge and know-how about individual materials that chemists should resist the temptation to assimilate matter with information and should instead warn their colleagues against an excess of ambition. Through many centuries of exploring the potential of materials, of successful and disastrous industrial activity, chemists have learnt that nature is not simply a malleable space of unbounded possibilities that can be turned into consumer goods. They should thus be in a position to moderate the ambient technological optimism and promote a more responsible technological culture.

Finally, we apologize for any errors that may have crept into our book due to inattention, but we are comforted in our belief that its philosophical message is of potential interest to a wide public of philosophers and scientists, and not just chemists.

[5] The parallel has been developed by Yeh Brian J., Lim Wendell A. (2007) "Synthetic Biology: Lessons from the history of synthetic organic chemistry", *Nature Chemical Biology*, 3: 521–525.