This volume connects chemistry and philosophy in order to face questions raised by chemistry in our present world. The idea is first to develop a kind of philosophy of chemistry which is deeply rooted in the exploration of chemical activities. We thus work in close contact with chemists (technicians, engineers, researchers, and teachers). Following this line of reasoning, the first part of the book encourages current chemists to describe their workaday practices while insisting on the importance of attending to methodological, metrological, philosophical, and epistemological questions related to their activities. It deals with sustainable chemistry, chemical metrology, nanochemistry, and biochemistry, among other crucial topics. In doing so, those chemists invite historians and philosophers to provide ideas for future developments. In a nutshell, this part is a call for forthcoming collaborations focused on instruments and methods, that is on ways of doing chemistry.

The second part of the book illustrates the multifarious ways to study chemistry and even proposes new approaches to doing so. Each approach is interesting and incomplete but the emergent whole is richer than any of its components. Analytical work needs socio-historical expertise as well as many other approaches in order to keep on investigating chemistry to greater and greater depth. This heterogeneity provides a wide set of methodological perspectives not only about current chemical practices but also about the ways to explore them philosophically. Each approach is a resource to study chemistry and to reflect upon what doing philosophy of science can mean.

In the last part of the volume, philosophers and chemists propose new concepts or reshape older ones in order to think about chemistry. The act of conceptualization itself is queried as well as the relationships between concepts and chemical activities.

Prefaced by Nobel Laureate in Chemistry, Roald Hoffmann, and by the President of the International Society for the Philosophy of Chemistry, Rom Harré, this volume is a plea for the emergence of a collective cleverness and aims to foster inventiveness.

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Jean-Pierre
Llored

The Philosophy of Chemistry

Practices, Methodologies, and Concepts

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Edited by
Jean-Pierre Llored

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INTRODUCTION

JEAN-PIERRE LLORED

This volume originates from the international workshop in philosophy of chemistry at the CREA (Centre de Recherche en Epistémologie Appliquée) on Saturday September 11, 2010, in Paris. This meeting was supported by the Ecole Polytechnique, the CREA, and the Doctorate School of the Ecole Polytechnique. I thank all those institutions again for making this event possible.

First and foremost, I would like to introduce the road that leads from this workshop to the whole book so as to help readers understand what is actually at stake within this collective project.

It might be of interest to readers to understand how one chemist turned to philosopher of chemistry. I was first trained as a chemical engineer before becoming a French professor 'agrégé' in chemistry. I decided to resume my studies in philosophy from the outset in order to take distance from my current activities and to acquire a basic knowledge in philosophy. I am thus studying history and philosophy of science in parallel with my professional life. I obtained a master's degree in history and philosophy of science under the direction of Bernadette Bensaude-Vincent, and I am now finishing my PhD work in philosophy under the supervision of Michel Bitbol at the Ecole Polytechnique and that of Isabelle Stengers at the Free University of Brussels.

Having the opportunity to meet most of the researchers in this field of studies, I envisaged inviting some chemists, historians, and philosophers of chemistry to take part in a round table of discussions of common interests in order: (1) to investigate some key chemical concepts, (2) to query how to study chemistry as a science, and (3) to encourage philosophers, chemists, and historians to enter into a constructive dialogue with one another. The Paris workshop partly crystallized those preliminary purposes.

Bernadette Bensaude-Vincent introduced this meeting by proposing a reflection upon the techno-scientific aspect of chemistry. In this respect, she explained what she calls the 'impurity' of chemistry. Eric Scerri then proposed an overall view of the philosophy of chemistry while pointing

out new potential roads to explore. Michel Bitbol and I developed a work based on the study of different chemical practices, past and present, in order to query how a relational form of philosophy can be developed and related to the chemists' works that we analyzed. Pierre Lazlo presented a study of the concept of 'transition state' from an historical standpoint. François Pépin, a French specialist of Denis Diderot, highlighted some aspects of Diderot's philosophy and demonstrated how to connect them with current philosophical debates about chemistry. Joseph Earley sharpened and deepened his previous work on chemical closures in which he proposed a philosophical understanding of how different chemical individuals can 'hold together' under certain conditions. Rom Harré introduced and further developed his concept of affordances within the framework of chemistry. In so doing, he also pointed out how the Wittengsteinian concept of 'hinge' could be of importance for the future of the philosophy of chemistry. Isabelle Stengers eventually summed up the whole day's work while providing interesting insights about chemistry, its history, its singularity from other sciences and especially from physics, and its new challenges from our society. An intense and helpful debate then took place between the different participants. Chemists (engineers, technicians, researchers, industrialists and scholars, and teachers), historians, philosophers, and many other researchers from various fields (biology, ecology, physics, material sciences, and sociology) were engaged in discussions about: (1) the autonomy of chemistry, (2) some metrological and ethical problems raised by current chemistry, (3) the role and the interest of cooperation between different types of expertise, and (4) the role of instruments in the history of chemistry. It was a very good day of positive discussions during which some ready-made answers were put aside in order to let people really express what they have in mind as regards their own activities. When we cease to identify ourselves to the roles we play within specific professional domains, the debate sometimes turns out to be genuine and done with simplicity!

My aim in setting up this meeting was also to ensure that philosophers who come from divergent philosophical backgrounds remain interconnected by means of fruitful debates, which would include chemists. Notwithstanding their differences we can go beyond them, because I believe that philosophers of chemistry who are working on analytical studies of aspects of chemistry can collaborate with those who are developing an historical epistemology of chemical practices. These perspectives offer many opportunities for a wider and deeper understanding of chemistry. Differences in approaches, methodologies, and concepts are a starting point for further enquiries. They are springs for creativeness.

Michel Bitbol then advised me to publish the proceedings of this workshop. I followed his advice, and I widened the scope of the volume by including many other historians, philosophers, sociologists, risk experts, metaphysicians, epistemologists, anthropologists, and chemists from all over the world. This enlarged team gave rise to the present volume. I thus assembled most of the different researchers I had previously met in different conferences with the hope of encouraging them to interact further with one another. In this respect, the networking of teams of research underpinned the project and remained always present in my mind.

Readers will not find any teleological scheme within this volume, nor will they find any research on consilience, the concept introduced by William Whewell. This book is even less an attempt to reduce the diversity of the various perspectives into a unique scheme. On the contrary, it tries to make those approaches *coexist* without any kind of assimilation. In doing so, we hope to express the heterogeneity of the different activities which are subsumed under the global label 'chemistry'. This book tries to make further studies co-emerge in future research.

Chemistry is not solely a system of propositions, a social product, or a set of conventions or of practices, among other possible definitions. It is neither exhaustively social nor simply logical. It is both and more. There is no 'logotheoretical' primacy to use Gilbert Hottois's turn of phrase (Hottois, 2004), nor is there primacy given to human interests and social constructions. Every experimental arrangement, every system of chemical equations, every complex of chemical problems, and every relation with the rest of the society demand to be investigated. We need to intensify an epistemology of *detail* that is to say a 'distributed' philosophy to use Gaston Bachelard's turn of phrase in *The Philosophy of No* (Bachelard, 1940 [1968]). In this respect, the aims of the present volume are manifold, but the essentials are: (1) to strengthen international interactions to study chemical activities, and (2) to foster new approaches to encourage the debate about chemistry. We must pave the way for cooperation within which the existing approaches as well as the emerging ones will become related to one another in such a way that it will not be possible to privilege one aspect over another. They will stand in a binding reciprocal interaction. In brief, we seek to create a dynamic perspectivism whose *geometral* is chemistry. We need at the same time to understand this type of geometral and what we actually subsumed under the word 'chemistry'. Is this word *the* unique reference of the activities that it encompassed or the result of a loose family resemblance to refer to the second Wittgenstein?

In his book, *Human Understanding*, Stephen Toulmin asserts that: "Men demonstrate their rationality, not by ordering their concepts and beliefs in tidy formal structures, but by their preparedness to respond to novel situations with open minds*."* (Toulmin, 1972, pp. vii-viii) New ways of doing chemistry demand that heterogeneous teams of researchers work together in order to face new challenges concerning our lives from within the world that chemistry has done so much to reveal to us. In order to meet this demand, I have divided the book into three main parts and urged all the authors from the outset to fit their contributions into this global scheme.

The first part encourages current chemists to describe their workaday practices while insisting on methodological, metrological, philosophical, and epistemological questions related to their activities. In doing so, those chemists invite historians and philosophers to provide future developments. In a nutshell, this part is a call for forthcoming collaborations focused on *instruments* and *ways of doing* chemistry.

Some researchers were uneasy about taking part in this project, given the tile reference to the philosophy of chemistry. But all of them agreed to contribute because they have been querying their own activity for a long time and because they have been looking for clarification about what they call some 'dark aspects' of their own work. The idea was thus to follow chemical current ramifications and take them seriously not only in their various manifestations but also by considering the *problems at stake* and the *contexts* of *ongoing projects*. This part thus asks questions such as: How do current chemists develop their knowledge? What can we learn from new chemical practices? What are the roots of their workaday modern creativity? What about their many strategies to describe the world as a network of interdependencies?

I believe that before commenting on the gap between the aims of chemistry and its social representations, and before announcing the rise of a new green and sustainable chemistry, we should make sure that we understand existing ways of doing chemistry. At the same time we should query the thresholds of meaning that exist in chemical discourses and their status in the economy of knowledge, their entanglement with the discursive systems of other sciences pure and applied, and their expectations of developments in the future. A return by philosophers to studies of laboratory practice is of interest. It paves the way for studies of local practices and unveils interactions between science, industry, society and even humanity in general. In turning to these studies many chemists, philosophers, and risk experts highlight and put into question some new faces of chemistry. In doing so, they consider both the operative and the

performative frameworks of chemistry that is to say the very possibility for chemistry to transform the world as well as its very ability to symbolize it.

Following this line of reasoning, Minh-Thu Dinh-Audouin, a French organic chemist working for the French journal 'L'Actualité chimique', first proposes an overall view of the current chemists' activities. This preliminary panorama encompasses soft chemistry, sustainable chemistry, and many other new chemical trends, and focuses its attention on the current process of reorientation and reshaping of chemistry. Sylvain Caillol, a specialist of sustainable chemistry and the director of the European chemical chair for a sustainable development CHEMSUD, studies how chemists reduce environmental impacts and above all how they contrive and develop new tools (concepts, devices, and so forth) in order to achieve this goal. In this respect, he scrutinizes what 'eco-design' means from within chemists' work while putting the methodology involved in the determination of a chemical 'life cycle' into question. He thus paves the way for an epistemological enquiry about the methods and the explanations used by chemists in such contexts of doing. Olivier Godard (expert in econometrics) then analyses how the precautionary principle can be connected with chemical risks. In doing so, he points out that there is no alternative but to pursue detailed investigations about the meanings of chemical risk assessments and the way by which they could be related to ethical questions. As a consequence, Godard studies chemistry envisaging its close dependence on norms, laws, political decisions, and social pressure.

Stéphane Bouchonet and Saïd Kinani, two experts in analytical chemistry, then ask the question of how new knowledge and know-how arise in analytical chemistry. They query how the couplings between analytical methods are achieved with the view to respecting norms and standards for the environment. In so doing, they raise the current problem of the meaning of their analysis in particular when chemists have to cope with the absence of a 'blank matrix'. It is the very process from which chemists give sense to their analytical results that, according to them, deserves to be looked at in somewhat more detail, and especially the way chemists define and prepare 'chemical references' which allow them to calibrate their methods and to quantify other chemicals. Their contribution to this volume was important because such methodological and metrological aspects of the chemists' work need to be further studied from an epistemological standpoint. Metrology and analytical procedures should enter into the epistemological domain of chemistry in so far as they are the 'hinges' around which all analytical reasoning turns. It is all the

more important that chemists never cease to set-up new couplings between methods in order to reach smaller quantities of compounds. The course of the environmental norms depends on such a current work.

The other contributors of this part bring to light that the coherence of chemistry as well as its 'margins' are constantly in question. Joachim Schummer, chemist and philosopher of chemistry, deepens the understanding of the role and the place of chemistry within the domain of nanotechnology. Jean-Baptiste Renard and Gwenaël Berthet, experts in instrumentation, query the interdependence of different specialties within the domain of the chemistry of the stratosphere. They provide the readers with metrological insights and reflections about interdisciplinary practical networks. Once again the instruments and the procedures are worth examining more closely in order to grasp what is at stake in current chemical activities. The same holds for the frontier between chemistry and biology. Gucki Riva Alessandra, Alain Hénaut, and Daniel Daugeron, three experts in biology, metrology, and instrumentation, investigate the current relations between chemistry and biology by focusing their work on the example of microarrays. They highlight how the trainings of the researchers and the different crossroads within particular projects of research were of paramount importance to understand the rise of such a new technique. They also explain how microarrays modified the practices of the scientists involved in such projects. The last team of researchers composed by Stéphane Sarrade (a chemist expert in sustainable process using supercritical carbon dioxyde), Anne Aimable and Roberta Brayner (chemists respectively experts in ceramics and biomineralization), Mathieu Rozé (chemist expert in polymerization and material sciences), and I (chemical engineer and student in philosophy) investigate the role of interfaces in chemistry. In line with the French philosopher François Dagognet (1982), we focus our attention on the physicochemical interfaces as well as the interfaces between different specialties or those between scholars and industrialists from within a particular research program. As Joseph Rouse asserted: '[…] what results is not a systematic unification of the achievements of different scientific disciplines but a complex and partial overlap and interaction among the ways those disciplines develop over time.' (Rouse, 1996, p. 177) Interfaces push chemists to think about composition, arrangement, size, and structure at the same time. Interfaces also query Thomas Kuhn's concepts of paradigm and of scientific community. The last paper develops those aspects in order to express how the concept of interface is promising to envisage chemistry philosophically. Rom Harré's proposal of an open conclusion for the first part goes beyond its scope and paves the way for further

developments. He brings together instrumentation, affordances, and chemical mereology as key issues for further study in the future.

The second part of the book illustrates the multifarious ways to study chemistry and even proposes new approaches to do so. Each approach is interesting and incomplete but the emergent whole is richer than any of its components. Assembling without assimilating or reducing is not as unreachable as it is often alleged to be. It is nevertheless not a simple experience. Analytical works need socio-historical expertise as well as many other approaches in order to keep on exploring chemistry. Interfaces and flux between those approaches might turn out to be starting points for further philosophical investigations. This heterogeneity provides a wide set of perspectives not only about current chemical practices but also about the ways to explore them. Each approach is a *resource* to study chemistry and to reflect upon what *doing philosophy of science* can mean.

We need every expertise, from analytical philosophy to historical epistemology and from pragmatic approaches to neo-Kantian ones, to quote but a few. The different approaches offer opportunities for a deeper scrutiny of chemistry. The philosophy of chemistry more than ever needs to define international programs of research in order to make intellectual progress about the nature of science, human knowledge, and humanity. We need analytical philosophical approaches in the same way we need constructivist ones and other new perspectives. Those approaches are interdependent; their argumentation should co-evolve towards finer analysis. Their conjunction is possible and their articulation is necessary and always provisory. One of the positions that I would like to dwell on in some detail within this second part of the volume is precisely how every approach is of importance for the study of chemistry and how a wider understanding of chemistry *emerges* from their complementarity. Networking is a good way to make a group creativity emerge. Connecting researchers enables us to transform current approaches and to arouse thought gradually.

The second part is divided into six types of perspectives, which are as many ways of studying chemistry. This type of classification is always arbitrary and closer attention will easily reveal that those styles of work are not independent from one to another. Moreover, I do not claim any form of exhaustiveness. This ‘classification’ is merely a tool for framing my presentation while leaving open any connection between the approaches involved and possible forthcoming ones.

This second part first focuses on historical studies of chemical activities. Historicizing epistemology is still a challenge and the roads to achieve this historicization are multifarious and winding as Hans-Jörg Rheinberger has shown (Rheinberger, 2010). What remains nevertheless

important for this volume is to point out how historical surveys can provide philosophers with crucial elements in order to develop their own perspectives. At the same time, it is worth noticing the subtlety of the differences between those historical approaches. There is no unique way of doing history of science. Much depends on the topic being studied, the socio-political and cultural contexts, and the historians themselves. The following studies thus express various types of historical research that are useful for widening our understanding of chemistry. Eric Scerri (chemist and philosopher of chemistry) develops the topic of the lecture he delivered during the Paris workshop. Ana Simões and Kostas Gavroglu (historians of quantum chemistry and epistemologists) show how history enables chemists and philosophers to understand the chemical bond better. Marina Banchetti-Robino (historian and philosopher) draws her attention to the relevance of Boyle's chemical philosophy for contemporary philosophy of chemistry regarding questions related to reduction of chemistry to physics, emergence, and so forth. François Pépin develops the idea he proposed during the Paris workshop about Diderot's philosophy while stressing its interest for contemporary philosophy. Voillequin Baptiste (chemist, historian and philosopher of chemistry) queries historical methodology by evoking the case of catalysis in France. He refers to Latour and ethno-methodology. Dominique Pécaud (sociologist of science) uses history in order to develop 'a political form of epistemology' according to his own turn of phrase. To do so, he refers to Swift, Comte, Berthelot, and others, so as to study the relationships between agricultural chemistry and agriculture. The transformation of the world by chemistry remains at the very heart of Pecaud's work.

The second type of perspectives envisages chemistry as a 'techno-science'. This concept is used by Latour and many others to describe current scientific innovations and doings. It often raises controversies and passionate philosophical debates that invoke issues of ideology. Is a chemistry a techno-science and in which sense? What is the interest, if any, of such a concept regarding current chemical activities? How does this concept renew the understanding of science? Those questions and many others are open. In order to clarify the situation, Gilbert Hottois (philosopher), who first conceptualized and proposed the concept of techno-science, was asked to recall his initial understanding of this concept and to explain how he connects it with chemistry. Bernadette Bensaude-Vincent and Ursula Klein (historians and philosophers of chemistry) then develop their own different approaches. Bensaude-Vincent explains to what extent chemistry can be envisaged as a techno-science. Klein focuses her work on the relationship between materiality and

abstraction in modern chemistry. Once again, the diversity of approaches is at the very heart of this part in order to figure out what is at stake in this debate and to explain why chemistry has an important part to play in it.

The third type of perspectives envisages chemistry as a field of practices as well as a field of knowledge. This part can be partly related to what philosophers call the 'practical turn'. Philosophers consider what chemists are doing (symbolization, conceptualization, creation of instruments, devices, synthesis of new chemical bodies, and so forth) in their everyday activities. Rein Vihalemm (philosopher of chemistry) asks the question: What is a Scientific Concept? He develops some considerations concerning chemistry in a practical realist philosophy of science in order to answer his question. He introduces a new form of practical realism. In line with the lecture that we gave during the Paris workshop, Michel Bitbol (philosopher of quantum mechanics) and I scrutinize different chemical practices in order to identify and to create a relational philosophy that fits them. Following Denis Diderot, the later Wittgenstein, and Roald Hoffmann, we aim to return to the laboratory as the centre of research and to create a philosophical approach from within chemistry. Our work is simply applying concepts that were developed in other domains on chemistry but takes chemistry as a starting point for a particular philosophy, if any. Pierre Laszlo (chemist and historian of chemistry) enters into more technical details about chemical analysis and describes the process of dematerialization related to them. Manuel Bächtold (physicist and philosopher of science) who cleverly develops a pragmatic approach of quantum physics proposes a pragmatic study of the atomic model in chemistry. Andrew Pickering (one of the 'Pilgrim Fathers' of the practical turn) then proposes an innovative paper entitled 'The Tao of chemistry' in which he emphasizes the process and the ongoing transformation of chemical practices as well as that of chemicals themselves. Flow and change are the cornerstones of his approach. Hasok Chang (philosopher of science) envisages the philosophy of chemistry as a complementary science. He explains how the history and the epistemology of chemistry enable philosophers and chemists to reopen their understanding of previous chemical failures in order to explore new chemical possibilities of action.

In the fourth types of perspectives, three prominent philosophers of sciences were invited to develop a transcendental approach for chemistry. Olimpia Lombardi and Mariana Córdoba propose a Kantian approach for the philosophy of chemistry and Sami Pihlström explains how it is possible to connect a pragmatically naturalized transcendental philosophy of science with the philosophy of chemistry. The conditions of possibility

of the chemical practices are stressed from within the context they are embedded in.

The fifth group of perspectives is related to analytical perspectives and metaphysics. Robin Findlay Hendry (philosopher of chemistry) develops three metaphysical issues in the philosophy of chemistry, that is to say issues about substances, structure, and their relation to reduction of chemistry to physics. Paul Needham (philosopher of chemistry) focuses his work on mereological structures in chemical substances and their transformations. In doing so, he proposes an analytic perspective on the historical development of these concepts. Once again, Paul Needham scrutinizes the parts/whole reasoning in chemistry with an astonishing sense of detail. Anna Ciaunica-Garrouty (philosopher of science), who has not previously worked on chemistry, was asked to adapt and to develop her promising work regarding the relations between the levels of organization by including chemical individuals into the topics of her reflections.

Joseph Earley was asked to propose an open conclusion for this whole second part. Stepping back, he has developed an astute reflection upon how those perspectives hold together.

In the last part of the volume, philosophers propose new concepts or reshape older ones in order to think about chemistry. In line with the lectures they gave during the Paris workshop: (1) Rom Harré develops the concepts of affordances and hinges in order to focus his work on the *interaction* between chemists and the world and to highlight how chemical knowledge and know-how revolve around 'hinges' in the Wittgensteinian meaning of this word. Those concepts are of paramount importance for thinking about our actions upon the world and the kind of knowledge scientists can reach as regards the world; and (2) Joseph Earley develops his three concepts of chemical closures and queries their epistemological significance. He proposes a way of developing a processual philosophy of chemical transformations within a second paper. José Chamizo (chemist) then proposes to reevaluate the concept of chemical experiment. Once again, doings and laboratories are the starting points for a new conceptualization. Isabelle Rico-Lattes (chemist) and Laura Maxim (expert in ecology and in communication sciences) explore chemical practices in order to develop the concept of 'sustainable' chemistry. They shape and deepen their concept from within their work developed on the terrain of environmental regulations (REACH). Alexandru Manafu (philosopher of science) then proposes a concept of emergence for chemistry. Michel Bitbol develops a new concept of downward causation without referring to any 'foundations'. This paper is crucial in so far as it

provides philosophers of chemistry with new arguments to think about a whole, its parts, and the surroundings all at the same time. In this respect, Michel Bitbol's book '*De l'intérieur du monde*' might become a springboard for the philosophy of chemistry in general because of its understanding of the relations/*relata* interdependency (Bitbol, 2010). William Goodwin (philosopher of science) draws attention to the concept of structure and connects it with the question of reduction between disciplines. He exemplifies his statement by considering the relationship between organic chemistry and quantum chemistry. Last but not the least, Alfred Nordmann (philosopher of science and technology) develops the concept of 'metachemistry' by considering the specificity of techno-science and Bachelard's phenomenotechnique. He thus tailors a novel concept different from that of 'metaphysics'.

Let us consider this whole collective work as a simple *tool* tailored to encourage deeper and wider forthcoming works and to stimulate stronger cooperation. I hope that it will help this community of researchers to share their interests for chemistry with philosophers and researchers coming from other realms. I hope it will spark the interest of students in this domain of philosophy. In editing this volume I have aimed at respecting the diversity of the different approaches, as exemplified in the many books previously published in this field. More than ever we need to be open-minded in order to face the new challenges that chemistry imposes. Philosophy is derived from the Latin 'philo-*sophia'*. *Sophia* is always related to open-mindedness. In this respect, philosophy is a 'love affair', but a love of another kind that needs to be continuously transformed and adapted to the changing human contexts. To my mind, chemistry can provide philosophers and researchers in general with other tools in order to think about humanity, science, and our life in this world. It is precisely the theme of the global conclusion of this volume.

I would like to conclude this introduction by expressing my special thanks to the experts who gave me invaluable advice in order to improve and deepen this volume. I thus thank in alphabetic order: Anne Aimable, Marina Banchetti-Robino, Michel Bitbol, Anna Ciaunica-Garrouty, François Dagognet, Joseph Earley, Alessandra Gucki Riva, Rom Harré, Alain Hénaut, Roald Hoffmann, Pierre Lazlo, Muriel Le Roux, Olimpia Lombardi, Alexandru Manafu, François Pépin, Jean-Baptiste Renard, Eric Scerri, and Rein Vihalemm. I also thank the CREA, the Ecole Polytechnique, and its Doctoral School. I particularly want to thank Michel Bitbol for his trust, his advice, and his stimulating 'philo-*sophia*'. I would like to express my gratitude to Rom Harré for his generous and helpful presence. His deep philosophy gave me the energy to achieve this project. I thank

Marina Banchetti-Robino. Her support and friendship were crucial, especially during the very last stage of the editing process. In the same vein, I thank Clevis Headley for his relevant comments. I express my sincere appreciation to François Dagognet, my professors Isabelle Stengers and Bernadette-Bensaude-Vincent, and those who gave me the will to resume my studies in history and philosophy of chemistry, that is to say: Joseph Earley, Robin Findlay Hendry, Roald Hoffmann, Ursula Klein, Pierre Lazlo, Paul Needham, Mary Jo Nye, John Perkins, Eric Scerri, Joachim Schummer, Eugen Schwarz, Brigitte van Tiggelen, and Rein Vihalemm. I thank the Supramolecular and Molecular Photophysics and Photochemistry laboratory (ENS Cachan, France), Philippe Petit and Anthony André (CIAT group, Culoz, France), and Chérif Matta (Mount Saint Vincent University, Canada) for allowing me to use images representing their daily activities. I am grateful to Mélissa Druet for her imaginative drawings and to Yohan Bonafé for designing the cover page of this volume. I would like to insist on the high-quality work done by the Cambridge Scholars Publishing team. Last but not the least, I warmly thank my family: Marie-Louise and Alphonse, Marie and Miguel, Gisèle and Pierre, Jérôme and Estelle, Kévin, Inès, and Enzo.

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GLOBAL CONCLUSION: INVESTIGATING THE INTERPLAY BETWEEN CHEMISTRY, CHEMICAL PRACTICE, AND PHILOSOPHY

JEAN-PIERRE LLORED

The practitioners of "green" chemistry and of nanochemistry as well as the great names of earlier quantum chemistry, to cite but a few examples, do not form homogeneous communities. Like the chemists of the emerging organic field of research during the 19th century, they encompassed multifarious ways of doing chemistry. In addition to the various `communities' of chemists there were sources of both knowledge and know-how coming from many other domains of sciences, and, sometimes, from society. Ana Simões and Kostas Gavroglu clearly point out this diversity as regards quantum chemistry. In the same vein, other studies within this volume demonstrate that green chemistry is not a delineated field. The term "green chemistry" does not have a unique reference. A chemist who optimizes an extraction process using a supercritical fluid does not make use of the same chemical practice as does a specialist in molecular assembly using transition metals. They are both chemists and mostly use the same molecular representations, but they do not have the same chemical culture and know-how. Moreover, they do not use the same *resource*s in the same *sites* with the same *aims*: their scientific "forms of life" and "styles of work" differ.

It is not solely *the conjunction but, above all, the mutual interferences between those forms of life and the translations from one to another* that are subsumed under the label "green chemistry". Moreover, those forms of chemical life themselves are at stake within current research programmes. This volume thus strengthens an image of chemistry constantly adopting new techniques and concepts and pushing on the frontiers of neighbouring fields of science.

In her book, *The Invention of Modern Science*, Isabelle Stengers asserts that science is a process rather than a product; it is creative rather than

foundational; it creates truths rather than "The Truth". Its action introduces novelty into the world; it "makes a difference". She upholds the view that a scrutiny of a scientific "event" is basic for grasping scientific novelty and evolution, without accepting ready-made philosophical dichotomies such as theory and observation, fact and law, and so on. We thus have to "follow the process" in so far as the process is precisely what is at issue (Stengers, 2000). It is important, first of all, to scrutinize what is happening in actual laboratories, as well as the procedures followed there. In this respect, studying chemistry philosophically requires the integration of chemists' own questioning into the global pattern of the investigation of nature. This is what this volume genuinely achieves. In doing so, it fills a gap in the philosophy of science, in so far as it closely associates chemists from various domains to the epistemological and philosophical investigations that are relevant to them. In so doing, it integrates chemical practices into the philosophical adventure in a manner different from the tradition; that is to say, by means of collaborations between chemists, historians, and philosophers. We begin by examining what chemists are doing mainly in order to: (1) investigate chemistry, (2) think about methodologies, and finally (3) create or reshape concepts. In doing so, we highlight how chemistry is changing in relation with other human domains. This road leads us to query how new chemical practices emerge and how they are reinterpreted by the chemists themselves. We then stress how this study is important for philosophers in order to think about science.

In his *Brown Book*, Wittgenstein shows that there is no sharp boundary around a generic term (Wittgenstein, 1969). Its unity is thus the result not of a strict identity or of a unique reference but, on the contrary, of a network of overlapping resemblances, none of which run through the totality. "Similarities" imply subtle "differences", not identity, direct foundation, or reference. We are dealing here with differences *in kind*; a family resemblance is not an open door to an infinite conjunction under the same denomination. Grouping incompatible rules of grammar and empirical propositions under the same label leads to a category mistake. The labels 'sustainable chemistry', 'green chemistry', and others all refer to their own background with their own practices, goals, representations, know-how, and resources. Family resemblance makes the coexistence of different meanings and their interaction possible depending on the *contexts* of use and what chemists aim at doing. Family resemblance may afford a "coherent pluralism" at a particular time, to use Bachelard's turn of phrase (Bachelard, 1932). This pluralism implements the narrative reconstruction

that chemists develop *a posteriori* regarding their own activities, in order to build a community identity and to gain legitimacy.

Assigning new meanings, new roles within hierarchies, and new relevant goals and methods to the different protagonists and institutions that are involved in the process of innovation is a "political" task. There is nothing transcendent in this story, no real primary "frontier" between the inside and the outside of a particular chemical domain. There is only an "immanent process of deterritorializations and reterritorializations", to use Deleuze and Guattari's terminology (Deleuze and Guattari, 1987). Bachelard has already declared that "[e]ach interesting problem, each experiment, or even each equation required a philosophical reflection of its own" (Bachelard, 1940, 1968). Without the multiplication of perspectives, there is no objectivity! The study of details is, therefore, of primary importance. To achieve this, we need each and every kind of expertise. In this respect, instead of opposing alleged philosophical 'traditions', philosophers should delineate a problem, for example, the study of the ontological status of chemistry. They should envisage how the different approaches provide them with complementary perspectives in order to: (1) clarify the questions at stake, and (2) find solutions, even if these remain partial and provisory. In this respect, a new perspectivism should hold the different philosophical approaches together, while respecting their differences and being open to the creation of new ones. This heterogeneity provides a wide set of perspectives, not only about current chemical practices but also about the ways to explore them.

Each approach is a *resource* for studying chemistry and for reflecting upon what *doing philosophy of science* can mean. We thus need to study: (1) the language of chemists, as well as the history of chemistry as a record of discoveries and conceptual and experimental innovations, (2) the balance between justifications for beliefs from logical reasoning and from local truth conditions and criteria, as well as social and political influences on beliefs, (3) chemical symbols, as well as chemical transformation of the world, (4) interrelations between sciences, as well as those between sciences and humanity in general, (5) chemistry in industry, as well as academic research, (6) networks of communication, as well as chemical instrumentation, (7) history of chemistry as well as history *tout court*, (8) philosophy of chemistry and of other sciences, as well as anthropology of science, and (9) the many other perspectives that will emerge for exploration and construal.

Chemistry is neither exhaustively social nor purely logical. Notwithstanding their ever-open dimensions, the definition and the study of chemistry need *cooperation* between heterogeneous perspectives that

explore their multifarious faces. “Socially embedded” does not amount to “socially determined”. Nor does “truth justification procedure” mean that “chemistry is a primarily theory-oriented activity only”. Each approach stresses a particular side of the study among many others. The challenge is to hold those perspectives together without necessarily referring to any kind of consilience or teleology and, above all, by avoiding any overly enthusiastic form of assimilation. Following this line, all the resources should be taken into account. There are textbooks, archives, chemical literature, case studies, laboratories, instruments, symbols, “paper tools” (iconographic representation, formula, pictures, diagrams, etc.), chemical concepts and devices, networks of communication, social laws and norms, human values, metaphysical assumptions, public opinion, factories and sites, human life and ethics, among many other factors. We have to envisage the circulation of concepts, methodologies, and devices from one domain to another, and to identify the questions at stake in relation to all this activity with the rest of human life.

Isabelle Stengers suggests distinguishing between two modes of propagation of concepts. The first is achieved through diffusion. In this case, the disciplinary origin of the concept is recognized, and we operate in the context of an openly metaphorical use. The second case evolves as an epidemic. The source of the concept is forgotten, and the concept is presented as “pure”, as cut off from natural language, and it appears as defined by the formalism of the science that it helps to organize (Stengers, 1987). In a complementary, though different perspective, Deleuze and Guattari give an account of a composite knowledge formation by putting forward the thesis of mobility inherent to the concept that joins together components that come from other concepts, which answers other problems and other supposed co-creations. According to them, a concept does not require only one problem under which it alters or replaces preceding concepts but, rather, a *crossroads of problems* in which it is combined with other coexistent concepts (Deleuze and Guattari, 1991, 1996).

This approach is all the more relevant because it entails that chemists have to face new problems and are formulating new questions and framing new devices, concepts, and methods in order to deal with these problems. For instance, they have to reshape their ways of doing chemistry in order to control the environmental impact of their activities. Additionally, ethical concerns percolate through chemical grounds, while chemistry provides philosophers with new problems that may drive an evolution of ethics itself (see Godard’s paper in this volume). A careful philosophical study is therefore needed to follow this interrelation between chemistry and ethics. Chemists also have to deal with mereological issues, such as

the integration of the size of nanoparticles into previous compositional and structural schemes in order to think about chemical reactivity. The way they think about a chemical "whole", its parts, and the surroundings is, therefore, also changing (Llored, forthcoming). Additionally, the integration of chemistry into the work of the material sciences, biology, physics of the environment and space, and toxicology forces chemistry to adapt its mode of existence to such multifarious backgrounds.

Epistemologists and philosophers should scrutinize all these issues by employing different approaches. They can scrutinize how new quantum models arise and gain their theoretical legitimacy, while keeping in touch with the coupling of instruments that enable chemists to follow a transformation (as that of mass spectrometry and liquid chromatography, for example). As Stéphane Bouchonnet and Saïd Kinani point out in this volume, philosophers and historians should investigate the way chemists synthesize a "blank matrix" in order to give sense to the determination of a chemical quantity. In doing so, they should query how models, norms, metrology, and societal expectations hold together at a particular time. They can investigate how chemists and (eco)toxicologists work with one another in order to assess the toxicology of a mixture of compounds and how, in turn, both this knowledge and those analytical methods influence new concepts, such as the life cycle of a product or that of an ecodesign for a new community.

The "practice turn" in contemporary philosophy, the sociology of sciences, and the "symmetric anthropology" of science have already emphasized the above-mentioned dynamic aspects of sciences, while advocating a return to the study of instruments and laboratory life. Many prominent researchers, such as Michael Lynch, Karin Knorr Cetina, Bruno Latour, Andrew Pickering, Ian Hacking, Michel Callon, David Bloor, Steve Woolgar, to name only a few, have widened and deepened our views on the sciences. However, these crucial works were mainly concerned with physics and sometimes with biology, but rarely with chemistry. Is it so surprising? I do not think so. Chemistry had to fight its way against other sciences in order to be acknowledged as an independent discipline with its own concepts and methods. In the same vein, the philosophy of chemistry needs to find its place within mainstream philosophy of science. Things are changing thanks to the works proposed by the philosophers of chemistry themselves and because of the evolution of our models and understanding of sciences and society.

This is not the way the story ends. We do not simply have to connect researchers from heterogeneous fields and to integrate chemists into philosophical areas *as if* chemistry were not transforming our world. We

also have to understand that chemical instruments are not solely "allies" in discursive strategies. They also produce chemicals that change our lives, transform our society and values, and act upon the world. We *do not completely control* the consequences of this production and, thus, our future is already at stake. We sometimes succeed in determining the relative toxicity of chemicals. This is a matter of effort, skill, and creativity. But we are still investigating methods that could enable us to assess the toxicity of a mixture of compounds. Chemicals "A" and "B" can act upon us in such or such way, but the mixture "A + B" sometimes displays emergent effects. This is a familiar theme in pharmacology where the interaction between medicines is a matter of great importance. In their daily activities, chemists, nanochemists, and ecotoxicologists are essentially facing this kind of problem. In doing so, they allow for new sense to emerge from instruments, coupling of methods, and previous chemical and biological explanations and theories. We thus need to scrutinize how those methods are construed in order to better understand the role and the status of what Rom Harré calls the "apparatus/world complex".

Chemistry is not about the world as it is, allegedly independently of us. In the same vein, chemistry is not about the projection of the knowing subject's categories, whatever may be the nature of this individual or collective knowing subject, and no matter how the categories may be considered, that is, ahistorically or as evolving with time. Rather, chemistry is about the interaction between subjects and the world. Rom Harré reminds us that we should not ignore the contribution of our apparatus to the form and qualities of the phenomenon. According to Harré, the question "In what form does metallic sodium exist before the electrolysis begins?" is illegitimate, in so far as metallic sodium is not something preexisting but is, rather, afforded by our actions! So, according to Harré, back inference from phenomena created in Bohrian artifacts, complexes of world and equipment, is problematic since there are ontological questions that remain to be solved (Harré, 2003). Chemistry and the other physical sciences are, therefore, about "affordances". We know what "the apparatus/world complex" affords, no more and no less. Rom Harré invites us to recast the metaphysics that informs our experiments, and he paves the way for further investigations in this direction that could be based on chemistry. Following his line of reasoning, I claim that all we know concerns the products of interactions, no matter how real, dispositional, or functional their status may be in the economy of knowledge. It is only too easy to take plausible explanatory models of the unknown inwardness of natural beings for reality.

In a complementary perspective, Andrew Pickering and Ursula Klein are querying our dialectic of "resistances and accommodations" to use Pickering's expression (Pickering, 1993). Klein never ceases to analyze the relations between materials and our conceptions about them (Klein and Spary, 2010). She even identifies forms of independence between what she calls "materiality" and theories, depending on the periods and the problems at stake. Following this line of reasoning, chemistry could provide philosophers with a new understanding of our interaction with the world and could enable them to develop new models of human knowledge and action. This is why we need to better understand the metrological aspects of chemistry, the construction of instruments, the coupling of methods, the ways conclusions are drawn from chemical analysis, and the role of "blank matrix". This is why the first part of the volume emphasizes methodological and instrumental aspects, while the second part concerns methodologies and the last part concerns concepts. This is also the reason why Harré, Klein, Chamizo, Nordmann, Bouchonnet, Kinani, Renard, Berthet, Bitbol and I are querying the instrumental aspects of chemical practice within this volume. In line with Holmes and Levere (2000), our collective work is a plea for further investigation regarding the manner in which instruments and materials are co-adapted within chemical works, in order to understand the world that we are transforming. In this respect, Rom Harré proposes that we should reshape our understanding of instruments by construing a new metaphysics for experiments (Harré, 1986, 2003, 2004). The door is thus open to chemistry in the philosophical realm.

Undeniably, we are changing the world by means of chemicals. We are transforming ecosystems, society, the stratosphere, and the human body. We, therefore, have to face the consequences of our actions. This is why a pragmatic study of chemistry must be developed. Accordingly, in this volume, we have tried to integrate this way of thinking into a global reflection about chemistry. This is also the reason why we propose studies about sustainable chemistry and chemical risks. My aim, in suggesting this collection of studies, was to integrate these perspectives into the domain of the philosophy of chemistry by reflecting upon current chemical practices. Godard, Rico-Lattes, Maxim, and Caillol have thus opened the door for further studies, particularly regarding: (1) the anthropology of chemical risks, (2) the epistemology of sustainable chemistry, and (3) the interplay between ethics, moral philosophy, and science.

I repeat once again that we know the actions of the molecules "A" and "B" but not those of their mixture. We also know that their joint toxicity depends upon the size of the particles and not solely upon their composition.

Toxicity, that is to say the dangerous action upon life of our own productions, partly or fully escapes our expectations and their foundation in our rational schemes. The world cannot be considered to be quiet and inert. We act upon the world and we have to face the consequences of our actions. The world thus enters into the laboratory from the very outset of chemical design (Llored, 2011). This aspect of chemical work should be taken into account by epistemologists and philosophers, in order to grasp the significance of the changes evident in current chemistry.

This is precisely why we need to connect the different existing philosophical perspectives, while creating new ones. Symbols are as important as actions. Philosophy suffers from too many dichotomies. The challenge, therefore, is to create and to allow different points of view to co-exist without assimilating them into a unique scheme. If we accept, with Rom Harré (2006), that all boundaries between scientific realms or between philosophical approaches are "complementary", in so far as they use different modes of access (cognitive or "instrumentariums"), and if we accept, with Quine (1966), that each realm has its own methods, concepts, representations, and "relative ontology", then we can take our distance from those dichotomies. So what about the alleged dichotomy between "analytical philosophy" and "continental philosophy"? Division is a useful tool for organizing the content of education programmes and for beginning conceptual analysis, but not for much else. In the same vein, philosophers interested in practical studies sometimes reject the idea of philosophy as revealing the logical forms of propositions, and conversely. The trouble is that we need both approaches and many others, all directed to the same problems of interpretation and understanding of practices like chemistry. *Connections are translations: they transform the approaches engaged by them.* Connections enable the different perspectives that are at stake to co-evolve, sometimes by strengthening their arguments, sometimes by changing their conceptual basis. To the extent that the future of life is at state and that philosophy of science needs to incorporate moral considerations, we should question these dichotomies and look for new concepts, innovative methods, and novel practices, that is to say, for new ways of doing philosophy of science *tout court*.

Following Gilbert Hottois (1996, 2004, 2013), who first introduced the term "technosciences", we can conclude that studying sciences philosophically needs: (1) no "logotheoretical" primacy, (2) no primacy for human interests and social constructions because of the way the world resists our incursions, and (3) multifarious temporalities within which we engage in it. We have to consider *homo loquax* as well as *homo faber*. Philosophers should not reduce practices to their symbolic aspects but

must also account for their operative and performative transformation of the world. Within some contexts, the interplay between technique and science is so strong that it practically becomes impossible to draw a sharp delineating line between them. We must, therefore, grasp the emergent whole philosophically. Hottois reminds us that technoscience is primarily concerned with the mutation and the possible disappearance of humankind due to the effects of our actions on the world. We have thus to recontextualize our human condition within the temporality of the universe, from the perspective of our possible extinction. According to Hottois, we must avoid the philosophical mistake of reducing the understanding of technosciences to anthropological and antropomorphic standpoints. He, therefore, pleads for a "trans-anthropological" account of technosciences. In this respect, we should consider the radical alterity and openness of the future in the long run. No one can actually foresee what our actions, including those that are chemically based, are likely to bring about in an extremely remote future. The power and the possibilities involved in technoscience go beyond the classical understanding of "technique" as the externalization of latent human capacities, as well as beyond the teleology and the eschatology related to it (Hottois, 1996). The technosciences go beyond our anthropological differences from other species, namely the symbolic singularity of our forms of life. This anthropological stance is itself shaken by internal and external non-symbolic processes. We have to accept that the naturalization of the anthropological difference is primarily concerned with its operationalization. Theoretical descriptions, symbolizations of all kinds, and the reflections they enable can only interact with this operationalization, without either anticipating it or being able to replace it (Hottois, 1996, 2004).

The naturalization of our anthropological difference from the rest of the universe is the result of a natural, physical, causal, and non-necessary operativity, that is to say, it is open to the intervention of technique. Symbols are not a starting point. The remote future is a challenge to conceptualization. We should not deprive ourselves from considering its development. However, the temporality engaged by technosciences can neither be symbolized nor historicized from the outset: we cannot put its actualization aside. The time of eschatology and imagined utopias has vanished. Our relation with the world is not basically symbolic but is, rather, technical and operative. We participate in the production of the future. We interfere with the processes of nature and society by resistances and accomodations. We must, therefore, recognize that the dynamic of anthropological processes is at least partly independent from symbolic activities (Hottois, 1996). We have thus to contrive a new interplay

between philosophy, techniques, and the sciences. The operative universality of technosciences is likely to interest philosophers in search for universality. However, universality has to be understood from the viewpoint of an operative causality. The technosciences should require the universality of philosophy as the unique appropriate kind of symbolic interrelation (Hottois, 1996, 2012). Technosciences explore the cosmos, nature, and living systems; they are non- or trans- anthropological and, sometimes, they are considered to be inhuman. A practical epistemology and philosophy of science is needed to articulate symbols and technosciences differently and to face the crucial societal choices and ethical problems of the present. The epistemological studies of practices should provide philosophers and other members of society with interesting information that will enable them to take distance from hasty idealizations and to sharpen the debate. In this respect, chemistry should help philosophers to create new bridges between symbols and action, representing and intervening (Llored, 2012). This is what this collective book partly aims to do.

This volume is about cooperation between researchers and it calls for further studies. These interconnected perspectives turn out to be valuable tools that allow philosophers to contrive new concepts or to reshape older ones, while rethinking the relationship between ways of doing science and philosophy. The cooperation between philosophical approaches is a good way to make a new understanding of science, technology, and society and of their interrelation, *co-emerge within a creative act*. It is also a chance for developing new arguments within each perspective and to contrive novel approaches. In doing so, one should take the constitutive role of the mode of access – cognitive or instrumental - into account in order to investigate the interplay between phenomena and knowledge at a particular time and to find solutions to the new challenges that chemists, as well as lay people, have to cope with in order to preserve (bio)diversity and to think about life *from within* our world (Bitbol, 2010). This is also why ethics, philosophy of science, political, and moral philosophies are likely to interact. But this aspect will be further studied in a forthcoming second collective volume.

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This volume connects chemistry and philosophy in order to face questions raised by chemistry in our present world. The idea is first to develop a kind of philosophy of chemistry which is deeply rooted in the exploration of chemical activities. We thus work in close contact with chemists (technicians, engineers, researchers, and teachers). Following this line of reasoning, the first part of the book encourages current chemists to describe their workaday practices while insisting on the importance of attending to methodological, metrological, philosophical, and epistemological questions related to their activities. It deals with sustainable chemistry, chemical metrology, nanochemistry, and biochemistry, among other crucial topics. In doing so, those chemists invite historians and philosophers to provide ideas for future developments. In a nutshell, this part is a call for forthcoming collaborations focused on instruments and methods, that is on ways of doing chemistry.

The second part of the book illustrates the multifarious ways to study chemistry and even proposes new approaches to doing so. Each approach is interesting and incomplete but the emergent whole is richer than any of its components. Analytical work needs socio-historical expertise as well as many other approaches in order to keep on investigating chemistry to greater and greater depth. This heterogeneity provides a wide set of methodological perspectives not only about current chemical practices but also about the ways to explore them philosophically. Each approach is a resource to study chemistry and to reflect upon what doing philosophy of science can mean.

In the last part of the volume, philosophers and chemists propose new concepts or reshape older ones in order to think about chemistry. The act of conceptualization itself is queried as well as the relationships between concepts and chemical activities.

Prefaced by Nobel Laureate in Chemistry, Roald Hoffmann, and by the President of the International Society for the Philosophy of Chemistry, Rom Harré, this volume is a plea for the emergence of a collective cleverness and aims to foster inventiveness.

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