The Philosophy of Chemistry

The Philosophy of Chemistry: Practices, Methodologies, and Concepts

Edited by

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TO ROM HARRÉ, MICHEL BITBOL,
MARINA BANCHETTI-ROBINO,
AND MY PARENTS

TABLE OF CONTENTS

Preface xiii
Roald Hoffmann
Nobel laureate in Chemistry

Preface xvii
Rom Harré
President of the International Society for the Philosophy of Chemistry

Introduction 1
Jean-Pierre Llored

Part I. Exploring Chemical Practices

The New Challenges of Current Chemical Practices 14
Minh-Thu Dinh Audouin

Life Cycle Assessment and Ecodesign: Innovation Tools for a Sustainable and Industrial Chemistry 34
Sylvain Caillol

The Precautionary Principle and Chemical Risks 65
Olivier Godard

The Limits of Modern Chemical Analysis: Metrological and Epistemological Insights 97
Stéphane Bouchonnet and Saïd Kinani

Interdisciplinary Issues in Nanoscale Research 121
Joachim Schummer

Chemistry of the Stratosphere: Metrological Insights and Reflection about Interdisciplinary Practical Networks 138
Gwenaël Berthet and Jean-Baptiste Renard

Current Relations between Chemistry and Biology: The Example of Microarrays 155
Alessandra Gucki Riva, Alain Hénaut and Daniel Daugeron

Chemistry and Interfaces 172
Anne Aimable, Roberta Brayner, Jean-Pierre Llored, Mathieu Rozé and Stéphane Sarrade

Conclusion: Chemistry as Practice 202
Rom Harré

Part II. Methodologies: How to Study Chemistry?

Historical Approaches

Philosophy of Chemistry: Where has it been and Where is it Going..... 208
Eric Scerri

The Chemical Bond: Some Historical Insights..... 226
Kostas Gavroglu and Ana Simões

The Relevance of Boyle's Chemical Philosophy for Contemporary Philosophy of Chemistry 240
Marina Paola Banchetti-Robino

Diderot, Philosopher of Chemistry, from the Enlightenment to Contemporary Science..... 266
François Pépin

Social Dynamics of Science in the Making 286
Baptiste Voillequin

Agricultural Chemistry, Agriculture and What will Happen to the World: Considering Swift, Comte, Berthelot and Some Others 300
Dominique Pécaud

Techno-scientific Approaches

Some Remarks on the Origin, Scope and Evolution of the Notion of "Technoscience" 320
Gilbert Hottois

Chemistry as a Technoscience? 330
Bernadette Bensaude-Vincent

Materiality and Abstraction in Modern Chemistry 342
Ursula Klein

Practical Approaches

What is a Scientific Concept? Some Considerations Concerning Chemistry in Practical Realist Philosophy of Science 364
Rein Vihalemm

From Chemical Practices to a Relational Philosophy of Chemistry 385
Jean-Pierre Llored and Michel Bitbol

Chemical Analysis as Dematerialization 416
Pierre Laszlo

A Pragmatic Approach to the Atomic Model in Chemistry 426
Manuel Bächtold

The Tao of Chemistry 452
Andrew Pickering

Complementary Chemistry 465
Hasok Chang

Transcendental Approaches

A Kantian Perspective for the Philosophy of Chemistry 478
Mariana Córdoba and Olimpia Lombardi

Pragmatically Naturalized Transcendental Philosophy of Science and Philosophy of Chemistry 491
Sami Pihlström

Analytical Approaches

Three Metaphysical Issues in Chemistry 510
Robin Findlay Hendry

Mereological Structure in Chemical Substances and their Transformations: An Analytic Perspective on the Historical Development of these Concepts 527
Paul Needham

Relations between Levels from a Chemical Perspective 558
Anna Ciaunica-Garrouty

Conclusion: What has Philosophy to do with Chemistry? 575
Joseph E. Earley, Sr.

Part III. Concepts

Affordance and Hinges: New Tools in the Philosophy of Chemistry 580
Rom Harré

Three Concepts of Chemical Closure and their Epistemological Significance 596
Joseph E. Earley, Sr.

An Invitation to Chemical Process Philosophy 617
Joseph E. Earley, Sr.

About the Chemical Experiment 628
José A. Chamizo

Sustainable Chemistry 640
Laura Maxim and Isabelle Rico-Lattes

Concepts of Emergence in Chemistry 659
Alexandru Manafu

Downward Causation without Foundations 675
Michel Bitbol

The Significance of Structure: Quantum Chemistry and Organic Synthesis 706
William Goodwin

Metachemistry 725
Alfred Nordmann

Global Conclusion: Investigating the Interplay between Chemistry, Chemical Practice, and Philosophy 744
By Jean-Pierre Llored

Contributors..... 756

PREFACE

ROALD HOFFMANN

From its beginnings, chemistry has posed a problem for philosophy. Why? Because this science, or the set of transformative protochemical crafts that comprised it before it became a science, did not fit well into philosophical categories, at least. Chemistry dealt with matter, and with its transformations. Quantification, better said measure, mattered – witness the papyrus recipes for indigo dyeing, the medieval prescriptions for making soap, or, still later, the signed protocol of Lavoisier's experiments decomposing and reconstituting water. But somehow change, the Heraclitean turn, rather than measure was (and is) the defining life thread of chemistry. Changes are often slow, as in the cycles of life. What impressed was dramatic change – the red crust formed on mercury heated in air, the way, still impressive today, that salt differs from sodium and chlorine.

There was certainly a place for matter and its transformations in an Aristotelian, experience-rooted world view – but less so when quantification took prime place. As Michael Weisberg has said, 'The problem for chemistry (and biology) in a post-Cartesian/Newtonian/Kantian philosophical world is that it looks a little too much like alchemy and not enough like Science.' Some of chemistry fit the quantifying mold. Or could be made to fit. But the defining bold changes never did fit, I think. And neither did the way chemists dealt with acquiring knowledge, especially when the microscopic perception of inner atomic and molecular structure became important. Lacking microscopes to reveal inner structure, in wonderful ways of knowing without seeing, moving ahead on meager clues, making molecule C from molecule B, that in turn from molecule A, all without really thinking through the ambiguities of the supposed knowledge of A or B – all that could be exasperating, or so I imagine, to those steeped in sound epistemological analysis. It was almost enough to put a philosopher in bed with a social constructionist of science.

We have come some way out of this initial quandary, and as these volumes, recent conferences, and much good thought and writing show, philosophy is in the midst of a real encounter with chemistry. The inherently synthetic nature of the chemical enterprise is being recognized,

with its special consequences, with links to ethics and aesthetics. As is the variety of ways in which chemical analysis proceeds. Even if people are still mostly talking past each other, applying only their own philosophical perspectives to the molecular science, there is a nice -- and fitting I think -- feeling of flux in the current philosophical discourse on chemistry.

Let me suggest some directions for the future philosophy of chemistry:

1. A recognition that the networks of communication of a field of knowledge shape understanding. And actually define the way the parts emerge from the whole. I have in mind the creative foment of the vast chemical literature, rivaled in the scriven (now word-processed) ways of knowing only by the biomedical literature. There is something organic here, the way chemical papers, read and cited, intertwine the way grass roots tangle and hold the soil. I have a feeling that the web of the literature is not only a communication device, but shapes individual actions, synthetic or analytical, in chemistry. That's also why it is so exciting (or frightening, for a chemist held back by conservatism rooted in age), to see changes in information technology affecting irreversibly the manner in which chemical information is communicated. Is there a philosophy of networks of knowing?

2. No question that reflection should be encouraged among a generally unreflective bunch of people in the trade. I am beating my own drum here, of course, but also pointing to chemists who have thought and written of their own world, people such as Pierre Laszlo and Jerry Berson. They are privy to the cognitive structures of the discipline, to Michael Polanyi's tacit knowledge. Polanyi himself was influenced in his philosophy, as Mary Jo Nye's recent book shows, by his own successes and failures in physical chemistry. The people I would urge the trade to encourage are chemists who *understand*, and if they also think about how and why they understand, this gives their work extraordinary value.

3. One can understand from the outside, too. Here is a welcome confluence of the history and philosophy of chemistry (or any science). For today's scientists have a very hard time getting into the mind-set of their predecessors. The cult of the new has them. Historians have cultivated the drive that empowers immersive patience, to learn the byways by which people thought a hundred or two hundred years ago. Larry Holmes's studies of Lavoisier's notebooks have led to important philosophical points about how chemical knowledge forms. In another context, the history of a phenomenon or concept in chemistry has to be taken into account in looking at any chemical work. If someone invokes "steric effects" or "aromaticity" as explanatory features, they are making connections with a historical tradition, one that may in turn have evolved;

aromaticity today has a different connotation from what it had a century ago.

4. Perhaps I am playing out my poetic predilection for seeing the world in a blade of grass, and just that drop of dew on that blade of grass, but I think that if we are to gain a philosophical understanding of chemistry today that we need more contemporary case studies. A detailed taking apart of a recent paper (and not yet another study of the Watson and Crick world-shaker) can be revealing in the extreme. One should read closely, with empathy for the authors' multifold struggle as they try to understand, to impress their colleagues, to convince.

By analyzing specific chemical papers with the full apparatus of philosophical thinking, seeing how the work functions as epistemology, narrative, and rhetoric, one gains insight into the complex world of the modern chemist. Reading closely several such papers leads to intimacy, a feeling that one knows how people think in the field. The philosophical background of the close reader of the individual work provides the analytical tools for adding value to this intellectual enterprise. For getting more out of those chemical papers than the people who wrote them, struggling for understanding, thought was in them.

If I were teaching a course in the philosophy of chemistry; I would ask each student to do a paper analyzing in depth a contemporary chemical article for the philosophical notions, explicit and implicit in each. And the study of recent papers might endow the metadiscourse of philosophy of science with one of the striking features of the subject, chemistry, itself. Which has added some 70 million compounds to what nature has provided us.

5. Both paradigmatic science and philosophy have trouble with the psychological, inherently subjective. My reflection on the remarkable network of chemists and chemistry is that the psychological intertwines with the logical, and that the fabric the two shapes is the way reliable knowledge and understanding forms. The facts are mute, and so, even within the confines of a tradition-bound mode of communication, a perforce subjective narrative of discovery and understanding must form. The scientific article, the conference (a 19th century creation, grown to epidemic proportions post-World-War II), create a constricting format in which people report work, claim priority and understanding, deny it. Citations are co-opted in creative, rhetorical ways. Psychological insight is needed to make sense of this playground of creation.

The psychological enters in another way, in shaping not only the aspirations of young chemists entering the field, but also the way they design their research, the questions they ask, and ultimately the proofs

they choose to provide for details in their chemistry. Virtue ethics, long neglected, has had a revival; "virtue science" may not even be defined. What I mean by the phrase is that young scientists (or older ones) model their work, sometimes subconsciously, on that of others they perceive as possessing innate quality, or gaining desired recognition. The outcome may laughable to bad – some scientists in China today imitating the hype level of their American protagonists. Some of it is much better -- R.B. Woodward or E.J. Corey serving as inspirations for two generations of synthetic organic chemists. My claim is that "virtue science" is pervasive. And that it influences the smallest level of scientific argument – for instance in looking for proof for a mechanism of a reaction in the detection of an intermediate more than in the kinetics of the process. With time, the small things, done originally in subconscious imitation, have a way of becoming the standard *modus operandi*.

Chemistry is cultural evolution at its best – human beings learning how to transform the natural, creating the new, and understanding the nature of these transformations on the microscopic and macroscopic levels. Some for good, some for… the less desired in us. It is important to think about how chemists gain or think their hard-won knowledge; how their tools, real and conceptual, affect their perception, and what they accomplish. I think philosophy, if it involves itself pragmatically in the realities of today's chemistry, has much to add to our understanding of this beautiful way people have crafted of knowing and transforming the world.

PREFACE

ROM HARRÉ

From its modern beginnings in the fifteenth and sixteenth centuries philosophy of science was comprised mainly of reflections on chemistry – the science of the transformation of substances from one kind to another – spontaneously or by manipulation. The works of Francis Bacon, Thomas Harriot, Robert Boyle, and John Locke are much concerned with the nature and possibilities of such transformations. The interest in changing one substance or a combination of substances into some new identity was the core of alchemy. Later, in the late seventeenth and eighteenth century's reflections on the nature of physics became more prominent – for example in the discussions on the nature of space and time that were the core of the discussions between Leibniz and Newton's `front man' – Samuel Clarke. The laws of motion of the constituent atoms or corpuscles of matter as then conceived were those that had been developed by Galileo and Newton. Was chemistry already reduced to a branch of physics?

While this problem has been a fruitful meeting point between philosophy of chemistry and chemical theory and research there have been other important points of contact. How is it that molecules have properties some which are not shared with any of their component atoms – the problem of *emergence*? Chemistry is based on various *causal principles* and processes by which it establishes methods for analysing complex entities into their components. Causal interventions are developed by means of which the properties of material substances can be changed. Is the concept of causality in chemistry something unique to the science, or is it just a local version of more general causal concepts? From the beginning chemists have tried to set up *classification systems* to arrange the material stuffs of the world in coherent and useful ways. The final development of the classifying urge came in the periodic table of elements – and recent publications on this subject have shown just how complex are the philosophical problems that it raises. Does the role played by physics in proposing and testing hypotheses about the forces by which atoms are held together into molecular complexes show that chemistry as an autonomous

science with its own field of enquiry and its own methods of research could be and perhaps should be *reduced* to a branch of physics?

What can we learn as philosophers from the study of chemistry? Does the reasoning about parts and wholes that is central to chemical thought fit well with the standard rules of mereology, the logic of part-whole relations? For example, in mereology if A is a part of B and B is a part of C, then A is a part of C. Is this rule still valid when it comes to chemical wholes and their parts? Yet more recently another aspect of mereology has caught the attention of philosophers of science. It seems to be a basic rule of mereology that the products of an analytical procedure applied to some substance are to be treated as constituents of the substance from which they have been derived. There are many exceptions to this mereological principle and discussion of these exceptions has led to the importing of a new concept into philosophy chemistry – the affordance – what a substance displays on being acted on by a particular manipulation in a particular environment. According to the theory of affordances every type of manipulation produces its own type of affordances. Are electrons really constituents of molecules or must we conclude from the theory of molecular orbitals that it would be better to treat them as affordances?

The philosophical issues just outlined take their start from reflections on what chemists do and say and on studies of experimental manipulations and chemical theories. However it may be that chemistry can be used to throw light on issues that have arisen in general philosophy. A striking example is the question of whether there is any use in retaining a distinction between the real and the nominal essences of things and stuffs. What do kind terms like `water' refer? Is it the everyday liquid which we use in ordinary life or does the growth of chemical knowledge oblige us to say that whatever may be the surface appearances of a liquid is only `water' if it is `H_2O'? More precisely do the criteria of identity for water change when we know from chemical research that it is H_2O? Of course, any chemist will tell you water is not H_2O but a shifting collection of various molecules. Related to this debate is the question of the nature of properties on the substances we run across in everyday life, and bring into our laboratories for study. Are properties just the sensory appearances of things? Considering this question takes us into deep metaphysical and ontological waters – such as phenomenalism, logical positivism, and other general orientations in philosophy.

However, a new dimension of philosophy of chemistry has opened up with the realisation that the way our everyday lives are lived, whatever role in society we occupy and increasingly it seems where ever we are on the surface of the earth, the chemical environment is the key to many and

perhaps the most important aspects of human well being. We might call this interest `social-chemistry'. How can chemists devise processes for the production of goods and services that are acceptable as contributions to the conditions of life? How can chemistry contribute to the immense task of repairing the damage to our environmental conditions by the exploitation of the chemistry of the past? Entering into ethics we might ask should chemists scrutinise any project they are recruited to carry through with attention to the effects its fulfilment might have on themselves and others? This issue was also raised again and again in the past and still is far from settled. Should our utopias be technical triumphs as prophets of the early 20th century, such as H. Wells thought, or is utopia to be brought about by curbing of the techno-urge to more and more sophisticated and elaborate devises for living?

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