

CHAPTER 1

INTRODUCTION: CHEMISTRY AND ITS DISCONTENTS

Look around you! How many of the objects in your immediate environment are products of synthetic chemistry? Of course, the answer to this question will depend on where you are. For those of our readers fortunate enough to be trekking through a rain forest in Costa Rica, perhaps the clothes you are wearing and the ink on the pages of this book are the only such products. For the majority of you reading this book in your home, your office or your classroom, much of what surrounds you is made of a combination of synthetic polymers, usually coloured using synthetic dyes made in factories that transform petroleum into the rainbow of colours so characteristic of contemporary interior design. In many modern environments — the interior of an aeroplane, a train or a car — it is probably easier to try to pick out the few materials that are not synthetic chemicals (metal, wood, leather, cotton, wool, brick, plaster, etc.) and assume that the rest is fabricated from petroleum-based rubbers, plastics or other synthetic polymers. Even natural materials are now usually covered by some synthetic coating, and few paints or lacquers are made entirely of naturally occurring materials.

Whether we like it or not, chemistry has transformed our lives: refining the petrol for our cars, providing the microchips for our computers, and producing medicines for chemotherapy, to cite but three examples. It would be hard for someone in the industrialized world to imagine a world without the contributions of this particularly productive science. Nevertheless, this claim that chemistry has transformed our lives — usually accompanied by the implicit message that it has changed our lives for the better — evokes

a cynical response from many people. While we have to accept the evidence of our own eyes that chemical products are everywhere, and accept that it is today impossible to close the Pandora's box that is the synthetic chemical industry, there are many who suspect it is not an unmitigated good and that those who argue for the positive image of the industry are not being entirely honest with the public or with themselves.

The most sensitive point of criticism for modern chemistry is undoubtedly the issue of environmental pollution. Indeed, chemistry has been implicated either directly or by association in many of the most prominent cases of industrial pollution. The chemical industry has a long history of polluting the air, water and soil, which dates back several centuries. Considering only the twentieth century, it has been responsible for a number of major catastrophes including the mercury poisoning that killed thousands in Minamata in Japan as well as the escape of deadly gas in Bhopal in India, which we shall be discussing in more detail in Chapter two. Events like these have turned the chemical industry into an emblem for the relationship of exploitation that exists between capitalists and labourers, between rich and poor, and, more recently, between North and South. Of course, many industries exploit inequalities between the West and the developing world (manufacturers of shoes, toys and clothing, to name but three) in order to increase their profits or simply to survive. Nevertheless, due to its long history of environmental pollution and the ubiquity of synthetic waste products such as plastic bags, rubber tyres, etc. in the industrialized world where chemical goods are consumed, chemistry has become a particularly visible symbol of this inequality and exploitation. Chemistry is too often seen as an impure science; contaminating the soil, poisoning our water, and polluting the air that we breathe.

The Philosophy of Chemistry

This image problem is not confined to the chemical industry, however, but also affects the academic discipline of chemistry. The subaltern status of chemistry is as old as the discipline itself. Even as it first established itself as

an independent scientific discipline in the eighteenth century, it was regarded as being intellectually inferior to mathematics and physics.¹ Chemistry continues to be perceived as a dirty, messy science that lacks the rigour associated with physics, its disciplinary neighbour, qualifying it once again as an impure science. Twentieth-century physicists were only too ready to repeat Rutherford's alleged condemnation of all other disciplines: "there is only physics, the rest is stamp collecting". In more recent times, chemists have seen physics fall from grace in many universities and research institutes. The end of the cold war put an end to many ambitious physics-based projects like Ronald Reagan's Star Wars initiative. As a result, student enrolment in physics has dropped across many American campuses, mirroring this reduction in funding. No doubt the most significant symbolic setback for modern physics was the refusal of the American Congress to fund the Superconducting Super Collider in 1993. Of course, one does not need to be an astute observer of science to remark that it was not chemistry that took the lead from physics as the 'hot' science at the close of the twentieth century, it was biology, and more specifically genetics. Indeed, chemistry has never assumed great prestige in the context of the university, and the history of this neglect of chemistry, whether merited or not, will form one of the central themes of this book.

Despite the changing academic hierarchies of the modern sciences measured in terms of funding and salaries, for many people theoretical physics remains at the top. This is particularly true for philosophers, whose primary interest in science is to find the keys for solving the "big" philosophical questions that have dominated the history of Western philosophy. What is the ultimate nature of the cosmos? Where do we come from? How does our universe work? etc. From this perspective, chemistry holds little interest for philosophers. A central aim of the current volume is to try and turn this philosophical perspective on its head. We will be making a strong argument for the philosophical interest of chemistry based precisely on the fact that it is an "impure science"; that it mixes science with technological applications, that it eschews high theory, and that it does not hold consistency to be its highest value. Philosophers have all too often denigrated chemistry because they considered its methods and achievements from the standpoint of the standards and values of physics. We want

to argue that looking more closely at the chemists' practical approach is more philosophically interesting than applying tired philosophical dogmas associated with an ultimately unfruitful reductive vision of science.

We are far from being the first to adopt such an approach. In this respect, the present book is similar to other works in the philosophy of chemistry, notably those of Davis Baird, Eric Scerri, Joachim Schummer and Jap van Brakel.² Although we do not agree with these authors in every respect, we are nevertheless arguing in the same sense, hoping to establish an independent philosophy of chemistry. Our ultimate aim is to challenge the hegemony of a particular positivist conception of the philosophy of science as it is taught in philosophy departments around the world.

The Image of Chemistry

Why, one might ask, does chemistry suffer from this particular negative image? To add insult to injury, despite its apparently transgressive position, chemistry does not even seem to convey the excitement associated with other sciences. Watching the film *Matrix*, we can see that even computing, which is not generally regarded as the most exciting subject in the modern curriculum, has a thrilling "dark side," mirroring the fact that computers and robots have become emblematic of humanity's potential to overcome and improve its lived environment, rather than destroying it. While in the 1950s it was atomic physics that was at the root of science-fiction thrillers, not since Mary Shelley's *Frankenstein* has chemistry inspired this kind of fearful excitement.

A long history lies behind the particular image we have developed of chemistry. Today, this vision is changing in response to the rise of the nanotechnologies, which have opened up new perspectives in terms of the public's appreciation of chemistry. In the pages that follow, therefore, we will discuss the question of why chemistry suffers from an image problem by examining various philosophical questions with the aid of a number of historical reflections. Thus, by the end of the book, we hope to have put the tools in place for responding to the question of why chemistry has a particularly bad image. This analysis requires a long detour through the history and the philosophy of chemistry, which reflects the fact that the public image of chemistry does not result from a specific and fixed modern situation but has deep cultural roots.

The idea that chemistry is an impure science does not only come from its links to pollution. Chemistry is also considered impure because of its hybrid nature, its constant mix of science and technology. As we will be arguing in what follows, chemistry serves as the archetypal techno-science, unable to restrict itself to the high-ground of pure theory, but always engaged in productive practice. When we look back to past philosophers like Denis Diderot or Gaston Bachelard, we can see that the idea that there are two kinds of science — theoretical and practical — is nothing new. Indeed, Diderot explicitly favoured empirical sciences that relied on the work of the hand over pure theory, condemning the construction of theoretical systems as ultimately fruitless. Nevertheless, in the course of the last two centuries, the rise of modern physics has promoted pure theory over other forms of science, making it natural to characterize those that rest at the level of practice as impure if not degenerate. Of course, considering chemistry as impure is ironic in light of the fact that one of the central goals, if not the major obsession of chemistry, has been to purify substances.

The Goals of the Book

What we do in this book, therefore, is to reflect on the image of chemistry by referring to the philosophy of chemistry. Furthermore, we anchor this philosophy of chemistry in a reading of the history of chemistry. Nevertheless, this is not an introduction to the philosophy of chemistry in the traditional sense of a straightforward textbook that “objectively” summarizes current positions, but rather an introduction to our own particular philosophy of chemistry which stresses the fact that this philosophy emerges from the chemist’s constant practical engagement with matter. Nor is it intended to be a philosophically oriented introduction to the history of chemistry, there are already books available for those who are seeking this kind of treatment.³ The present work is best described as a historically based introduction to the philosophy of chemistry, and, as we have already said, our own particular interpretation of this philosophy. While in the pages that follow, we do raise some of the most important issues relating to chemistry that have marked the history of philosophy, we will not, as should become clear, simply offer new responses to the questions that are traditionally posed. Instead, we aim to elaborate a new

approach to the philosophy of chemistry, answering questions when we feel that they are relevant, but otherwise not hesitating to shift the ground of debate elsewhere. This is the means we use to elaborate a new philosophy of chemistry. If, by the end of the book you are convinced, or are prepared to entertain the proposition that you can know the material world as well if not better by making and doing things rather than by constructing theories, then we will have succeeded in conveying our central message.

The Structure of the Book

Following this brief introduction, we explore the negative image of chemistry starting with its reputation as a polluting science. Thus, we consider the pesticides and plastics that were once considered the heralds of a brave new world, but have since come to be regarded as chemistry's harbingers of doom. These synthetic chemicals were originally produced and sold as a panacea, meant to satisfy the booming demands of the post-war consumer. However, in less than fifty years, we have seen them acquire an unenviable reputation as poisons and pollutants. Thus, we set the stage of chemistry as an impure science in the sense of a science wedded to a global industry generating toxic substances that have indelibly marked our planet. In Chapter three, we place this tarnished image in the context of a much longer history. Here, we consider the heritage of the alchemical tradition, and in particular, the unbridled ambitions of those who sought to transcend nature by transforming it. Indeed, in successive parts of this book, we follow the Faustian ambitions of challenging nature, and ultimately, imitating life itself, into nineteenth-century organic chemistry, which, through the idea of total synthesis, revived many of these ancient ambitions in a new form. Finally, we ask whether nanotechnology has inherited the same or similar ambitions.

The next section takes us into the characteristic space of the research chemist: the chemical laboratory. Originally the exclusive realm of the chemists, the laboratory remains their privileged site of practice, a place where they produce both theory and substances. Indeed, we want to place special emphasis on this idea that theory and substance are co-produced by the chemist in the laboratory. In this realm, the chemists' intuition — or their

tacit knowledge — is sovereign and leads them to transcendent feats of productivity, not only in the transformation of the material world, but also, as we want to emphasize, in the generation of theory. It is this theory, indissociable from an intimate contact with the potential and limits of the material world, that is at the base of a philosophy characteristic of chemistry. We argue that while this distinctive philosophy has been dismissed by philosophers as an impure product of an impure science, it should instead be seen as the central appeal of chemistry for philosophers. We believe that it is up to philosophy to re-assess and try to understand chemistry rather than it being up to chemists to fit their science into the outworn axiomatic mould of traditional philosophy of science.

We continue this reflection on the importance of the laboratory and experimental culture for the chemist with a more detailed case study from the end of the eighteenth century. Thus, in Chapter five, we consider Lavoisier's spectacular public demonstrations of the analysis and the synthesis of water, and how he marshalled the forces of experiment to convince others of his views of matter. Chapter six leads us into a consideration of organic synthesis as a field where theory and practice are particularly entwined. It is in the context of organic synthesis in particular that reactions are developed as useful tools, with industrial applications never far from chemists' considerations. We see how the creative power of organic chemists even led them to dream of creating the whole of life from scratch.

With Chapter seven, we enter into more familiar philosophical territory. Here, we address the problem of the "mixt" with respect to the various traditions of elements that have traversed the history of chemistry. The mixt — a chemical combination composed of elements but not bearing the same properties as the constitutive elements — is a core issue for any philosophy of matter. We argue for the value of the Aristotelian approach in this domain, which, with its notion of potentiality, provides a vocabulary for dealing with this vexing problem of the mixt or compound versus the constitutive element. The next two chapters deal with the philosophical clash between chemistry and physics, not interpreted as two different academic disciplines but as two different approaches to matter. Thus, the interest of chemists is in the property-bearing principles that animate the chemical reactions they provoke, observe and instrumentalize in their laboratories, while that of the physicists is the ultimate causes that lie

hidden behind the sensible phenomena. This confrontation, expressed in terms of elements versus atoms leads us to a consideration of Mendeleev's conception of the element, which is a key historical and philosophical concept in chemistry.

Treating Mendeleev allows us to address the issue of reductionism, which becomes particularly important following the introduction of quantum mechanics early in the twentieth century. Indeed, Mendeleev's epoch-making periodic table reflects a subtle abstract philosophical understanding of the element that was severely put to the test by the discovery of isotopes and the birth of atomic physics. In Chapters ten and eleven, we address the question of positivism, as chemists have often been dismissed as naïve positivists, particularly when they stubbornly refused to accept the existence of atoms in the nineteenth century. We will explore the tradition of positivism from Comte to Mach and show how chemistry both is and is not positivist in its approach. Two chemist-philosophers, Ostwald and Duhem allow us, nevertheless, to see the limits of certain forms of positivism in the context of chemistry. The discussion of atomism raised by positivism also allows us to explore the variety of atomisms that have existed and continue to exist. Thus, the periodic table embodies a distinctive chemist's atomism focused on the atom as a node of chemical relationships.

Chapter twelve represents the clearest, most direct presentation of our own philosophical position, which we term "operational realism". We regard this as being implicitly or explicitly the characteristic philosophical stance of the chemist in the laboratory. The attention that chemists pay to the specificities and idiosyncrasies of the chemical materials they have in their hands or manipulate with the aid of instruments is what sets them apart from theoretical physicists. This should not, however, be used as an argument against the philosophical legitimacy of chemistry, which neither addresses the "essential" questions nor seeks *the* unified theory, but rather as a basis for rethinking the terms of philosophy of science. Thus, we offer a strong argument in favour of a reconsideration of the problematic of the philosophy of science with chemistry occupying the place it merits.

We close the book with some reflections on nanotechnology and the profound transformations that the past few decades have wrought on chemistry and its neighbouring disciplines. Indeed, we pose the question

of whether nanotechnology marks the end of chemistry as a discipline. Whatever the ultimate response to this question, it is impossible to deny a strong continuity in the relationship between science and society in the transition from chemistry to nanotechnology. A re-examination and renewed interest for the natural at the level of the nanometer has also seen the resurrection of the Faustian ambitions associated with chemistry in the past. Nanotechnology seeks not only to mimic nature, but also to outdo it, with increasing numbers of scientific visionaries heralding the mastery of artificial life and self-propagating nanomachines.

In Chapter fourteen, in guise of a conclusion, we turn to consider the ethical issues raised by the whole history of modern chemistry and how these might be addressed as we move into the era of nanotechnology. We suggest some general philosophical guidelines that could help to structure a new ethics appropriate for contemporary research in the context of the ongoing nano-revolution.

References

1. J. Simon (2005) and A. Donovan (1993).
2. D. Baird *et al.* eds (2006), J. Schummer (2003), J. van Brakel (2000).
3. A. Donovan (1993).
4. In particular, we recommend B. Bensaude-Vincent and I. Stengers (1996).