What is Chemistry?

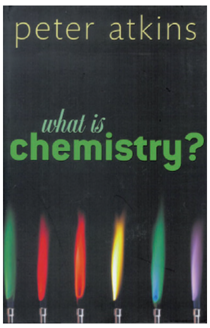
This is a wonderful little book that does great service to chemistry by showing its many good aspects. There are very few chemists or science writers who popularize chemistry and write about its beauty, utility, and importance. Roald Hoffmann did that in his many books and essays (such as *The same and not the same*, *Chemistry imagined*, and so on). Philip Ball wrote about the "beautiful experiments in chemistry" in his book *Elegant Solutions*, Hugh Aldersey-Williams wrote about the cultural history of the elements in his book *Periodic Tales*, Natalie Angier wrote about chemistry and the structure of the atom in her book *The Canon*. Even I contributed my share, in the essay "Chemistry—A Central Pillar of Human Culture"[1]. However, this book is different in its approach. It reads like a speech of a great orator or an advocate speaking to the public, his grand jury. In the preface, Atkins states that chemistry appears smelly and awful, and he wants to change this and show that chemistry contributes to culture, and that if we take chemistry away the result is a human disaster—"life would be nasty, brutish and short". The end of the book is the end of the speech, and Atkins writes: "I hope these pages have erased to some extent those memories that might have contaminated your vision of the extraordinary subject, and that you have shared a little of that pleasure [that modern chemistry inspires]." Atkins uses in his "speech" a lean language, laden with condensed information, and thus it reads like an explosive poetry: compelling, intense, and beautiful.

The book consists of seven chapters (like the "seven pillars of wisdom"—Proverbs, Chapter 9, Verse 1?), which start with the origins of chemistry and end by discussing its future. Chapter 1 deals with alchemy, which provided the "compost from which real science emerged". Atkins discusses the role of balance, and how this led eventually to atoms, "the currency of chemistry". He then goes on to explain what he means by that: "Look at a tree: you are seeing atoms. Look at this page: you are seeing atoms. Touch your face: you are touching atoms. All is chemistry …". He then discusses the branches of chemistry and explains them succinctly. One aspect that may annoy some readers is Atkins's hierarchy of sciences: chemistry imports from physics, and "biology is an elaboration of chemistry". I doubt whether many biologists would agree. I think this reductionist approach ignores the special aspects of biology, which makes it distinct from chemistry. Chemists such as Pauling have contributed to the creation of chemical biology, but biology is not just an elaboration of chemistry, in the same way as chemistry is not an elaboration of physics.

Chapter 2 discusses the principles and concepts of chemistry. Here Atkins starts with the Periodic Table, which "summarizes relationships between elements and plays a crucial role in organizing information about them". He then discusses the model of the "nuclear atom", and uses the metaphor of a football in a football stadium (this powerful metaphor has also been used by Angier and by this reviewer). Then Atkins explains how the proton becomes the organizing quantity of the Table (here I have to differ, since I think the electron is the organizing quantity of the Periodic Table and of the whole of chemistry). Atkins then steps into quantum mechanics, and in a few bold brush strokes he discusses the atom in terms of "clouds of probability" and the "creation" of shell structure, which ultimately explains "periodicity and familial relationships [among atoms]". Based on the shell structure, he explains the various bond types: ionic (the ions pull one another by electrostatic attractions), covalent (by spin locking), and metallic (waves of the electron sea).

Chapter 3 focuses on the principles of chemistry: energy and entropy. He calls energy "a river of understanding in chemistry". He then states the 1st Law (the energy of the universe is constant), and the 2nd Law (the quality of the energy degrades in any process—the entropy increases). He maintains that only reactions that result in degradation of energy can occur naturally, and he argues against the chemist's view that reactions occur when the energy is reduced. Although Atkins prefers his interpretation of the "driving force" of chemical processes, he admits that the chemist's rule of thumb works. Furthermore, because of the shell structure of the atom, energy is also the organizer of the Periodic Table. He discusses endothermic reactions, which clearly occur because of the 2nd Law, and adds: "often the two [energy and entropy] lead to the same conclusion, but in all cases entropy is the property to consider." I found this part to be somewhat dense, and lacking the flow of the rest of the book. In the last part of the chapter, Atkins discusses reaction kinetics and mechanisms, and how chemists detect an energy barrier (using temperature changes). He then moves on to catalysis and states that "life is the embodiment of catalysis". He explains equilibrium as a dynamic state, and describes how Haber and Bosch tilted this equilibrium, and "in so doing fed the world".

In Chapter 4, Atkins defines four basic processes, which typify all chemical reactions: electron transfer, proton transfer, radical transfer, and two-electron reactions (such as Lewis base reactions, which bring color in complexes). This may be fine, but what about cycloadditions? He ends the



What is Chemistry?
By Peter Atkins. Oxford University Press, Oxford, 2013. 144 pp., hardcover, £ 11.99.—ISBN 978-0199683987

chapter with a discussion of chemical synthesis, especially in organic chemistry.

Chapter 5 is devoted to the various techniques of chemistry, starting from the techniques of the alchemists, and continuing all the way to modern ones such as chromatography, spectroscopy, mass spectrometry, NMR spectroscopy, X-ray crystallography, STM, AFM, combinatorial chemistry, and quantum-mechanical computations. Each technique is explained with one or two lucid and descriptive sentences. For example, infrared spectroscopy "… is very helpful for analyzing groups of atoms in a complex molecule, because a CH_3 group, for instance, can waggle around with one energy and a CO group … with a different energy". About X-ray crystallography, he writes: "In biology, structure is crucial to function. Structure is almost everything in chemistry …" About combinatorial synthesis, he summarizes: "[in former times,] chemists were proud to have made and identified 10,000,000 compounds. Now they might make several times that number in a month, and only occasionally bother to determine what they have made. Such is progress."

In Chapter 6, Atkins describes the achievements of chemistry, by starting with the statement: "Without chemistry we are back to the Stone Age." He then proceeds to tell the reader about these achievements in a clever way: "by considering the famous elements of antiquity: earth, air, fire and water". Chemistry has enabled us to use the treasures of the earth to our benefit, to dig up the black oil and refine it to petroleum. Yes, petroleum, which is much maligned today as the source of many evils. Chemists extracted nitogen from the atmosphere and harnessed it to feed the world. Chemists extracted chlorine from the sea and used it to purify water, which is "the enabler of life", and the creator of cities, of societies. Among the many achievements of chemistry, Atkins discusses the understanding of the world around us, and he ends the chapter on a high note: "We understand, through chemistry, the flavours of foods, the colours of fabrics, … the changing colours of foliage… Not every moment in our lives do we need to turn on understanding … But chemistry adds a depth to this delight, for … we can look beneath and enjoy the knowledge that we know how things are."

In Chapter 7, Atkins discusses the future of chemistry, by extrapolating from the new developments that are already at hand. In a breathtaking text, he outlines an exciting chemical future. He discusses the potential of femto- and attosecond techniques, of studying the chemistry of a single molecule or of a few molecules; for example, it takes 275 H_2O molecules to make ice. He speaks about new forms of matter from cold chemistry, and of materials with quantum-chemical behavior from nanoscience, which will require the development of new synthetic methods. He mentions that some such materials have already been made and incorporated into solar cells, and used as sensors of glucose in the blood. He lists the nanorods, nanowires, and nanotubes that have been created, and could in future be integrated into nanomachines and nanocomputers. He describes how chemists have already contributed to the miniaturization of computers, and adds that it is now time to progress to molecular computing, using the ability of molecules to switch forms as a new form of memory. Chemists can harness reactions to be used as input and as output, e.g., by light emission (and, I would add, why not also heat emission to be used in quantum computing?). As an example of data storage, Atkins mentions DNA, and adds that when these data are retrieved it produces an organism. In my view, the DNA does not merely store data—it stores the entire software for making the organism. In fact, the recent success of the Venter group to synthesize this software, so that when introduced into the cell it produced the organism (as highlighted recently in *Angewandte Chemie*[2]), is a hugely important advance, with biologists/chemists playing God. Atkins then goes on to mention the future role of chemists in deciphering how "memories", which are certainly chemical in nature, are being encoded. He discusses the development of proteomics for eradicating human disease, and of catalysis for better engines. (Also, in my view, computational chemistry, which is mentioned here only in passing as a companion tool to proteomics, will play a major role in many fundamental developments in chemistry). Finally, Atkins writes about the future role of fundamental research in chemistry. According to him, "Fundamental research is absolutely vital … for it leads on to unforeseen discoveries, … and unforeseen applications of extraordinary brilliance". He mentions the recent discovery of molecular triple-4-knots in nature, and ends by commenting: "Such is the joy, the intellectual pleasure, that modern chemistry inspires."

Here and there I have added my own comments, but not as criticism. However, my main point of criticism is that this wonderful little book does not have literature references. I found that to be a disadvantage.

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DOI: 10.1002/anie.201400523

[1] S. Shaik, *Angew. Chem.* **2003**, *115*, 3326; *Angew. Chem. Int. Ed.* **2003**, *42*, 3208
[2] U. T. Bornscheuer, *Angew. Chem.* **2010**, *122*, 5357; *Angew. Chem. Int. Ed.* **2010**, *49*, 5228

