whereas those explaining the latter by the so-called accelerator experiments.

Of special note is the description of the high-energy astrophysical neutrinos which are explored through such novel experiments at the IceCube experiment in the South Pole that uses clear, naturally occurring ice in the icesheets of the Antarctic.

The present reviewer is also particularly impressed by the chapter on model building. Of special note is the importance given to the see-saw mechanism proposed independently by (a) P. Minkowski, (b) T. Yanagida, (c) the group of M. Gell-Mann, P. Ramond and R. Slansky and (d) R. N. Mohapatra and G. Senjanovic, which appeals to grand unified theories to produce such small masses for neutrinos. This is another example of theory being far ahead of experiment.

Although there have been phenomenal successes in the field of neutrino physics, many questions remain to be answered. In particular, future experiments will shed light on the actual mass hierarchies, since the present information is only on the mass square differences. More needs to be learnt on the issue of the mixing matrices. As mentioned earlier, the fact that neutrinos are electrically neutral implies that they could be either 'Majorana' (named after the romantic and tragic figure Etorre Majorana) or 'Dirac' (named after the eminent physicist Paul Dirac). In the event that they are Majorana, there would be no distinction between neutrinos and anti-neutrinos. Future experiments, including those that are looking for so-called neutrinoless double-beta decay will shed light on this question. Perhaps future accelerator experiments will shed light on the nature of the neutrinos. Doubtless the planned neutrino telescopes will shore up our knowledge of astrophysical and cosmogenic neutrinos. Many of these issues are touched upon in the chapter entitled 'Summary and outlook'. In short, this exciting book takes the reader through a grand tour of the physics of neutrinos and is a delightful read.

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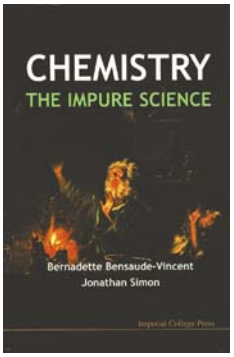

Chemistry – The Impure Science. Bernadette Bensaude-Vincent and Jonathan Simon. Imperial College Press, 57, Shelton Street, Covent Garden, London WC2H 9HE. 2010. xii + 268 pp. Price: US$ 97.00.

The twilight years of the eighteenth century signalled a paradigm shift in chemistry that kindled the dawn of modern chemical science[1]. In 1785, Lavoisier showed the public that water thought to be an element from the days of Aristotle is not so. Thomas Jefferson, amongst many other things, was also a chemistry fan with a library of his own[2] and in 1786 he wrote, 'There are some things in this science (chemistry) worth reading'. Nearly 200 years later Nobel Laureate Cyril Hinshelwood would rejoice, 'Chemistry: that most excellent child of intellect and art'. Today chemistry is able to tell us a lot about the world at molecular level as well as at higher levels of aggregation and the future is full of promises[3]. On the other hand, chemical technology has transformed our lives[4].

But there has also been discontent in the academia and the public on grounds of philosophy and health. Like, chemistry is empirical and less fundamental than physics; it promotes consumerism via industries that mass-produce and pollute the environment; it creates artificial objects and is tainted with its alchemical history and so on. The authors of this book are experts of history and philosophy of science, and they sum up the situation by qualifying 'chemistry as the impure science'. They search for the roots of the problem in the history of chemistry, chemical industry and prevalent philosophical and cultural outlooks. They uphold the philosophical legitimacy of chemistry and suggest some ways to improve the image of chemistry. A summary of the book follows.

In chapter 1, the goals and structure of the book are enumerated. In public perception nothing puts chemistry on the spot more than its association with pollution (chapter 2). As an illustration, the ups and downs of the pesticide and polymer (plastics) industries which symbolized the 'brave new world' in the 1960s and 1970s are presented. With pollution control and other improvement steps in place, today's public appreciates the benefits of chemistry but they remain suspicious of it. The memory of war gases and recent accidents like those in Sevoso, Bhopal and Toulouse is not easily forgotten. In chapter 14 which concerns ethical issues it is suggested that apart from greater respect for the environment and stricter risk assessment at the stage of designing products, the scientific and technological choices should be a collective decision involving both chemists and the public. The authors envisage chemistry as a technoscience which can integrate culture and society into its practice.

An image problem originating from Western social roots is much older than that due to pollution. This is the anti-Aristotelian transgression of the frontier between the natural and the artificial attempted by medieval alchemists (chapter 3). But alchemy was not all in vain. Lead may not have become gold, but alchemists acquired real expertise in handling materials and performing reactions. They catalysed the advent of European chemical industry as early as the seventeenth century, which flourished into the next century with patronage of governments seeking economic progress. The natural–artificial crossover theme did not die either. In 1791, Leblanc made artificial (synthetic) soda and above all Whöler made artificial urea in 1828. Chemistry was thus challenging a fundamental social and cultural dogma and has therefore been 'perceived as a threat to Western civilization'. However, the wall between the living and the inanimate worlds continued to loose ground through the nineteenth and twentieth centuries, particularly during the second half of the latter century and now in the nanoworld (chapter 13) it is in virtual ruins.

The laboratory, an isolated space to labour and to know, was also invented by the alchemists. It remained an exclusive place for chemical actions till other experimental sciences emerged and adopted it. The evolution of the chemical laboratory over the past 300 years is sketched in chapter 4. In 1785, Lavoisier used his laboratory for the first time to make

a public demonstration of science in action – his revolutionary experiments showing that water is not an element but is a compound of hydrogen and oxygen (chapter 5). But preconceptions of matter handed down from Greek times (chapter 7) were too deep-seated in the psyche to be easily uprooted. It is an irony that those who remained unconvinced included Priestley and Cavendish – the discoverers of oxygen and hydrogen! Nearly a 100 years later Berthelot invented in 1876 the famous edict, 'Chemistry creates its own object'. Synthesis is the driver of chemistry in 'a world of material interactions, governed as much by intuition and imaginative innovation as by systematic use of theoretical knowledge and logic' (p. 113). A few episodes from the history and philosophy of organic synthesis are examined in chapter 6.

Since the days of Kant in eighteenth century, physics was seen as presenting the 'royal road' to ultimate knowledge about the 'real world' that lies behind the world of appearances. The antonym of this doctrine of 'realism' is 'positivism' which abhors metaphysical constructs and works purely on the evidence of senses. Chemistry grew up in the tradition of positivism (chapter 10). Physicists' quest for the essence of matter starts by considering it as a Cartesian substance characterized by its extended form and motion only. To the chemist every substance is an individual that acts in its characteristic way with other substances weaving a pattern of interrelationships (chapter 8). Mendeleev invented the periodic table by observing such patterns. Later quantum theory provided an electronic basis for the table. But Dirac's claim that 'physical laws necessary for… whole of chemistry were now completely known', is but an unrealistic overarching of reductive realism (chapter 9). Actually 'chemistry's drama is inevitably richer than the reductive dream that has been characteristic of the history of physics' (p. 151). It is primarily due to the prevailing steadfast positivism that even eminent chemists were unwilling (p. 193, 'who has ever seen a gaseous molecule or an atom?') to accept atoms and molecules as anything other than metaphysical objects till early twentieth century (chapter 11).

An allegorical representation of the *Opus*, the 'great work' of the alchemists.

After looking at chemistry's concerns over centuries, the authors reject the view that the foundation of chemistry is embedded in some more fundamental science. They uphold this in terms of what they call 'operational realism' (chapter 12). The essence is that there is no ultimate hidden reality behind the phenomenal world of the chemist. All that is present are material agents that act to create a web of relationships with one another allowing emergence of new properties. Chemists also have a large body of theoretical knowledge which again does not seek to represent any ultimate structure of the material world. The authors argue that the acceptance of a multiplicity of modes (like physicist's mode, chemist's mode, etc.) of engaging with reality will end the unproductive enterprise of reductionism.

Now to some comments. The names of chapters and sections in this book have a semipopular streak. The lucid text is enlivened with numerous quotations from eminent philosophers and men of science, and there is an 18-page bibliography and an index. Several figures of historical interest are displayed and these include Lavoisier's expensive 'gazometer' instrument (p. 91) and a representation of Kekule benzene by six acrobatic monkeys (p. 189). The fascinating painting on the cover depicts an elderly alchemist in a state of trance facing a fiery transformation in the light and shade of his laboratory. It is an interesting and informative book with the expected emphasis on the philosophical side. Having enjoyed reading it, I recommend it to chemical libraries and to individuals with a taste for history and philosophy of chemistry.

The authors' philosophical stand (operational realism) on chemistry appears to be quite appropriate. On the research ground, however, philosophical differences have hardly barred areas of physics, chemistry and biology from unerringly moving closer and closer for decades at an accelerating pace. For long we have been used to the binary names physical chemistry and chemical physics, biophysics and physical biology as well as biochemistry and chemical biology. The borders of individual disciplines are inherently porous and this gets more and more exposed to us as we learn more and more. Nobel awards in chemistry in recent years have prompted an editorial where a fervent call is made to researchers in chemistry, 'to embrace the far and influential reach of chemistry... Disciplines are human constructions – the conservative, compartmentalizing affliction of academia. The world is one, and our best minds and hands have moved with facility across disciplinary lines, using tools of chemistry to chart emerging territory in biology. And vice versa. The star materials of the condensed matter physicist had to be synthesized by chemical techniques; the Fourier transformation and the mass spectrometer brought us new chemistry[5].'

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