Some Lessons from the Story of Chemistry

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Note from the Editor: The story of chemistry has many facets and in a book by this title, the author has brought out many interesting examples to establish and thread together the story of Chemistry. It may be worthwhile for some of us to read this interesting book published by University Press with ISBN 81 7371 530 0

In 1953 Stanley Miller proved by a simple experiment that the basic building blocks of life – the amino acids – could be synthesized in the primordial environment of the earth that contained methane, ammonia, carbon dioxide and water vapour. It is established today that the life is initiated and sustained at all stages by hundreds of chemical reactions occurring in the living cells on demand and DNA is the master architect possessing the blue prints of the million forms of life. Whether it is the living form or the non-living, chemistry is the driving principle in its life cycle. Moreover, one of the most fascinating aspects of chemistry is the dramatic variation in the properties of many materials - a nectar changes to a poison - with a small change of just a few atoms here and there. It also depends on how a particular chemical is used. Ammonia, which has saved the billions from hunger by increased food production through N-based fertilizers, has also killed millions by explosives and gunpowder, which can be manufactured only by using ammonia as the starting material.

Thus, chemistry touches every aspect of our life, but we are largely ignorant of it. A general reader has access to many popular books in the various areas of physics and astronomy, but in the area of chemistry it is virtually nil, particularly in our country. One common perception is that chemistry, dealing with thousands of diverse reactions involving molecules of complicated structures, is a difficult subject, and this is partially true. But still, chemistry is an integral part of natural science, and so its development is intertwined with the development of scientific thought in general. In his famous Faraday Lecture to the Royal Society of Chemistry in 1889, Mendeleev said, "***While science is pursuing a steady onward movement, it is convenient from time to time to cast a glance back on the route already traversed, …...***" **Pries**tley argued that writing a history of science is important since it shows how human intelligence discovers and directs the forces of nature. The history of science also illustrates the general progress of mankind.

In many countries the scientific temperament is inculcated in the children through continuous exposure to Science Museums, Science Parks and Home Laboratories. Such temperament is necessary for developing an innovative skill towards solving problems, for invention of new tools and equipments, and in the discovery of new scientific theories. The books on the History of Science and Philosophy play a vital role in this regard. Therefore, it is a regular subject of study in many Universities and Technical Institutions, whereas neither this is a part of curricula in our country nor we have any good books on this subject. The Story of Chemistry is aimed to fill this gap and to create awareness on the need of such study.

The Story of Chemistry is a chronicle of the development of chemical principles from the pre-historic age to modern times particularly up to 1930s when the concepts of chemical bonding were established. It attempts also to establish that the scientific developments happen primarily through an evolutionary process, which is driven mainly by the economic and social needs. We talk of Newton, Faraday, Madam Curie or Einstein, and marvel at their intellectual capacity, and wonder whether another Einstein or Newton or Curie or Faraday would ever be possible. By attributing the developments thus to individuals only, we essentially neglect the influence of any sociological laws on the course of human history, whereas these laws, as have been proved by now thoroughly through the course of evolution, are no less rigorous than the physical laws – only these are so complex that these are not apparent to the most, nor their mathematical and predictive modelling is possible at the existing level of knowledge. The Story of Chemistry would show that throughout history many important developments in chemistry have occurred as dictated by the necessity of the existing socio-economic conditions, and have evolved almost in the same manner as in the anthropomorphic evolution. The individuals have, of course, contributed – but it is again a complex product of geography, religion, social climate, and economics and of the inherited or mutated genes.

Many discoveries are considered as a boon from serendipity. But a close look would reveal that the economic imperative and the social needs were the two real drivers in many of these discoveries. Of course, there have been instances of an element of chance, but invariably the chance has always favoured that mind which is knowledgeable and inquisitive. We may cite some examples. Priestley is considered as the 'king of serendipity' because of many of his fortuitous discoveries of which he himself was not conscious in the beginning. But when we consider that he was a totally amateur chemist and did not have any prior exposure to electrical phenomena, but still could write an authoritative book on electricity within almost one year of his meeting with Benjamin Franklin and his initiation into scientific research, then we know that Priestley was no ordinary chemist – he had a depth of intellect far superior to that of the common mortals. This is exemplified further by his 'fortuitous' selection of mercury as the liquid over which he collected many new gases such as ammonia, hydrogen chloride and oxygen. The first two would never have been possible, if he had taken water as the collection medium following the established procedure. What shall we call it – serendipity or the masterstroke of a genius?

Similarly, Rutherford placed the zinc sulphide screen behind the α-emitter in the Scintillation Counter for measurement of any large angle scattering of α-particles. The small angle scattering itself was very difficult to detect due to its limited occurrence within the angle of observation and the very faint intensity of the scintillations. Moreover, any large angle scattering was then not present within the horizon of any concepts. And still Rutherford placed the screen at that location and a young man of 20, who did not have any previous exposure to this type of experiment, could detect the scattering within a couple of days! We should not ascribe the discovery to chance, but to the exceptional talent of Rutherford to perceive the things much beyond the levels of the scientists of the common milieu and to the extraordinary skill of Marsden for critical observation.

At the same time, can we totally rule out the role of chance? Just one instance may be sufficient to illustrate the point. In 1766, Priestley was teaching languages in Warrington Academy. He had already published two books and got recognition as an intellectual. But he had no training or exposure to scientific research. Then one day he was going to London to meet some friends and in this long journey Benjamin Franklin happened to be his companion in the coach. Franklin was an expert on electricity and he motivated Priestley to carry out researches in electricity. That was the beginning of Priestley as a chemist and his life was changed forever thereafter. Now, if in the carriage to London, some one else other than Franklin had been the companion of Priestley, then what Priestly would have done in pursuit of his intellectual curiosity – still, research in chemistry or teaching languages in Warrington academy? It is an interesting question whose answer we do not know.

Some of the major discoveries in chemistry were undoubtedly dictated by the needs of the society. We know, Courtois changed the seaweed in his furnace and discovered iodine. But he changed the seaweed because he was searching for a better source of saltpetre, which was in short supply due to the blockade of the sea routes to France by the British, and saltpetre was required to make gunpowder. France was at wars with all his neighbours at that time. Almost 100 years later, the shortage of saltpetre for gunpowder in World War I again forced the Germans to invest heavily in the development of a viable technology for ammonia synthesis. The technology of ammonia synthesis and the associated developments in syngas production established the major principles of chemical engineering, high pressure technology and catalysis. It is also significant that the great economic depression in 1928 and the subsequent war efforts led to the invention of several commercial polymers, including polyethylene, and that changed the face of polymer industry dramatically in future.

There is another example how the needs of the society triggered a fundamental development in chemistry *albeit* science as a whole. The coal mining industry in England had its origin in 12th century or so. In 1709 Abraham Darby discovered a process by which ordinary coal could be used for extraction of iron. This triggered a large scale mining of coal and the open cast mining technique had to be replaced by mining in the deep, as coal was no longer available in the surface seams. But this resulted in a severe shortage of coal and an unprecedented industrial crisis as most of the mines were flooded and there was a danger of explosions due to coal gas being accumulated in the mines. No mechanical pumps were available to pump out such huge volume of water on sustained basis. The crisis was solved by the invention of Papin engine, and then Newcomen engine, which could pump out water from the underground mines and make the mining of coal possible.

What was this Papin engine? It was simply a cast iron cylinder with two chambers – top chamber containing some water under a piston and the bottom chamber was a fireplace. On fire, the water turned to steam and the piston was lifted. Then after cold water was sprayed over the steam chamber, the steam condensed to water, creating a vacuum and the piston was pushed down by air pressure. This was the first instance of steam, acting as a driver of piston. The Papin engine did not have any industrial success, but its variant, The Newcomen engine, served in the European coalmines for more than 100 years. It was also the precursor of the steam engine for locomotion, which changed radically the methods of production, and transportation, and finally the trade and commerce. The enhanced market and economic opportunities generated more interest in scientific research. But such a momentous driver of change (use of steam as a mover of piston) had its conceptual roots in the resolution of a simple question: why does water rise only up to a height of about 10 meters in a siphon?

Aristotle had answered this question earlier by saying, ***"Nature abhors vacuum".*** Torricelli answered it by inventing barometer, which proved the existence of vacuum. Blaise Pascal proved further the existence of air pressure by experimenting with barometer at various altitudes, and Guericke demonstrated it dramatically at Magdeburg. Once the existence of vacuum and air pressure was settled, air pumps were invented and exhaustive experimentation was done by using them. The direct and indirect consequences of these concepts of vacuum and air pressure were many – one, the use of steam as a driving force in engines; two, the study of heat engines and birth of thermodynamics, and thermo chemistry – and the formulation of chemical principles guiding the chemical equilibrium; three, the discovery of Boyle's law and other gas laws, leading to the formulation of the first quantitative relationships in chemistry; four, the study of the effect of depleted air or vacuum on life and a burning candle (combustion). The last named study led to the separation of air into oxygen and nitrogen, resulting in the irreversible destruction of the age-old Aristotelian theory of four elements. Conceptually it was a very significant leap, as it recognized the existence of more elements than just air, water, fire and earth.

One indirect consequence of the studies on combustion was the discovery of the Oxygen theory of combustion and the law of conservation of mass by Lavoisier. But both these theories were arrived at on the basis of some very accurate weighing and calculation of mass balance. After Lavoisier's success, the chemical balance became the principal tool of a chemist. A careful application of this tool led to the discovery of some of the most basic laws of chemistry such as the laws of fixed proportion, multiple proportions and reciprocal proportion. Thereafter the Atomic theory of Dalton appeared as the most logical explanation of these laws. And once the Atomic theory was established, there had to be the concepts of atomic weights, molecules, molecular weights, moles, Avogadro number, and so forth – all one after another logically for explaining and reconciling the experimental observations. Thus, in the area of scientific research there is nothing as sudden or out of blue. It is basically an evolutionary process, where the data are gathered for many years by many, the concepts gradually take shape in the minds of many scientists – ultimately someone gets the clinching evidence or gives a definite shape to the idea that conforms to the logic of existing theories, and it is hailed as a new development.

It is not that all ideas are accepted immediately. In the history of chemistry many ideas, which are hailed today as the foundation of modern chemistry, were not accepted at all initially. In fact, there were bitter fights against some of these ideas. For example, Boltzmann's statistical mechanics was criticised severely for years by Ostwald and Mach. Suffering from severe depression Boltzmann committed suicide. van't Hoff's tetrahedral model of carbon atom was called 'nonsense, trivial, devoid of reality and incomprehensible to a clear-minded researcher' by none other than Wilhelm Hermann Kolbe, who is known as the father of organic chemistry. Kolbe did not stop at that. He called van't Hoff a 'pseudo-scientist'. Incidentally, van't Hoff received the first Nobel Prize in Chemistry, not for this tetrahedral model but for his Isochore – the relation between equilibrium constant with temperature, which had many immediate practical applications. Prejudice affected also the acceptance. Mrs Fulhame in Britain was the first to observe the phenomenon of catalysis much before Berzelius, but there is still very little recognition of the same except by a few.

Another classic example is Avogadro's hypothesis. It was not accepted for about 50 years because the leading chemists of the day, Berzelius and Dalton, would not accept it. For Dalton, the acceptance of the hypothesis would mean that many of his atomic weights would be wrong; for Berzelius, the concept of diatomic molecule, which was an important postulate in Avogadro's hypothesis, was against his Dualistic theory. The issue was partially resolved in 1860 during the International Congress at Karlsruhe, when the explosive growth in organic chemistry made it necessary that the atoms and molecules are properly defined and a method is established to determine the molecular weight of organic compounds. This growth in organic chemistry itself was catalysed by a simple discovery by Wöhler – the synthesis of urea in the laboratory, which destroyed the myth of the vital force theory and at the same time, established the concept of geometric isomerism in carbon compounds.

An important lesson of the story of chemistry is the fact that the scientists are essentially human beings and have their pride, prejudice, aspirations and despair. Newton did not like Hooke, and Hooke did not respect Newton either. Johann Bernoulli and his son Daniel Bernoulli – each one was a genius in his own field, but the father's treatment of the son was so harsh that the son had to pronounce later that physics would be served better if there were no mathematicians. Davy was arrogant, treated Faraday almost as a servant, and envied later Faraday's success, but did not patent his landmark invention of safety lamp for any material profit. Boyle could think of the atomistic nature of matter much ahead of his time and wrote 'The Sceptical Chymist' with concepts that were in total variance with those of Aristotle, but in the matter of women's liberty and rights, he was completely traditional. He even supported a bill, which made alchemical research (conversion of base metal to gold) legal. Faraday, who was completely indifferent to money and worldly pleasures, professed his undying love for a young girl, Sarah Bernard, and confessed his work as fancies and stupidity in comparison with his love for Sarah. Mendeleev, a very reputed professor of 42 years of age, threatened to jump into sea, if Anna Ivanovna Popova, an art student of 19, did not marry him, notwithstanding the fact that his first wife was still living and he was forbidden legally to marry for the second time. Scheele, who was one of the most prolific chemists of the 18^{th} century, died at the relatively young age of 44, probably from the effects of chemical poisoning. Two days before his death he married a widow, who was his caretaker for eleven years. Why did he do so? May be, he wanted the widow to inherit his pharmacy without any legal problem. The chemist who had spent his life in looking for elusive gases, acids and poisons, may have become soft and romantic towards the widow. We do not know. There are many such examples illustrating the humane face of these famous chemists. There are also many examples of the queer Fate bestowing her kindness and cruelty on her disciples in the most unexpected and diverse manner. But the starkest lesson is the story of chemicals that act as poisons and destroy our environment and that of Fritz Haber, who changed the face of chemistry and chemical engineering by inventing the ammonia technology, but himself was responsible for the deaths of the millions during Word Wars I & II by the chemical weapons, which too were invented under his guidance.

Editor's footnote:
The reader's attention is drawn to a detailed book by Dr N C Dutta "The Story of Chemistry" University Press, 2005 ISBN 81 7371 530 0. This article is based on this book. The authors email address is ncdatta@hotmail.com