CHEMISTRY

On page 408 of volume 3 of the Encyclopedia, edited by D. Diderot in 1751, one of the main works of the Enlightenment, appears the article dedicated to chemistry. There you can read:

> *Chemistry was little cultivated among us; this science is only very poorly spread, even among the savans, despite the pretension to the universality of knowledge which makes today the dominant taste. Chemists are a distinct people, still very few, with their own language, their laws, their mysteries, and living almost isolated in the midst of a greater people hardly curious of its business and expecting nearly nothing from its industry.*

Since then, the meaning reflected in this text written during the historical period that marks the birth of chemistry as an independent science, many things have changed, others have not.

As we know it today, chemistry is the result of a thousand-year-old multitude of inheritances that, embodied in trades, influenced the daily life of all cultures, helping to build, in all of them, a material culture. It is still surprising that practices as different as that of the blacksmith and metallurgy, the healer and pharmacy, the potter and ceramics, the baker and biotechnology have come together to end up merging, barely three centuries ago, in a common field: chemistry.

It should be noted that there is no disciplinary knowledge absent from a social context of transmission and from a social group (the current chemical community, both academic and industrial) that reproduces itself. For this reason, what we currently call chemistry, as is the case with the other sciences, can only be understood through their historical changes.

Chemical practices: pluralism, theories and models.

Chemistry is thus a relatively young discipline that has integrated a multitude of millenary trades, today transformed into technosciences, a place where it is studied, practiced and transmitted how to manufacture and transform substances in small and very large quantities. Chemistry is mainly about chemical reactions.

Here practice is understood to be the series of coordinated and shared activities (rules, reasons, techniques, purposes, beliefs) that are disciplined through the change of "correct" norms or procedures and that have a stable structure with the ability to reproduce itself through different learning processes. Some of the norms and procedures will change slowly and others quickly.

In the scientific practices of chemistry, the laboratory is the central place, where the chemical experiment is carried out. Chemical practices (analysis and synthesis) are different from other scientific practices, particularly those from physics.By participating in a practice, one knows what to do and what to say, although part of the knowledge about it is tacit knowledge. Chemical practices are related to Kuhn’s 'exemplars', that is, the collection of problems, theoretical and experimental, shared and solved by a specific community at a particular historical moment that are generally found in professional publications, and especially in their own discipline textbooks. It is apprenticeship in the regimented discipline of the chemical community that allows transmission of purposes.Chemical practices do not try to discover what matter is like, what they mainly seek is to build new substances.

By accepting that the history of chemistry can be reconstructed from the practices carried out by different communities, that is, the facts emanating from small research laboratories, greatly amplified through industrial processes and that today have transformed the face of the world, we are talking about pluralism.

Pluralism appeals that there is more than one way to success. The pluralism of purposes in chemical practices, which for some consists in analyze the composition of a certain plant, for others synthesizing a new substance similar to the one found in the plant, for others in producing it in large quantities, for others verifying that it does not pollute the environment, the idea of monism identified with a single scientific method is rejected. Differently from other sciences, particularly physics, a higher and unique goal, like scientific truth', cannot be encountered in chemistry.

The place of theories in the development of chemistry is debatable, particularly because by relying unequivocally on a specific way of experimenting it has theorized differently from the other sciences. The foregoing became clear from the appearance of T. Kuhn *The structure of Scientific Revolutions.* For Kuhn, scientific revolutions are changes that require a reconstruction of the historical commitments of a particular scientific community. The commitments shared by groups or communities are characterized by the use of the word 'paradigm', which means a ''criterion for choosing problems that, while the paradigm is taken for granted, can be assumed to have solutions'' (Kuhn 1970, p. 37). Over the same historical period different scientific communities around the world share the same paradigm and research and teaching based on this paradigm are known as ‘‘normal science’’. When there is a scientific revolution the community changes its paradigm, it means its principal theory, thereby changing the activities related to ‘normal science’. Normal or paradigmatic science is employed by a specific community in its daily activities, based on their previous achievements, and is what is taught in textbooks. Scientific progress in normal science is cumulative or gradual. Revolutionary science develops when a crisis occurs in normal science. The result of a revolutionary process in science is the emergence of a new paradigm, which displaces the previous one, and has traditionally been identified with changing theories.

We have learned through our education that scientists must carry out their research work from a single theory, even among those who, like chemists, do not seek a single truth. In this way theory choice between competing theories appears mandatory but in chemistry it is not and was not the case, because chemistry is not only theoretical, it is also experimental, it is also industrial.

Despite the use that Kuhn gave in his book to the first chemical revolution (the one that marks the birth of this discipline as an independent science) as a clear example of a paradigm shift, the limitations that his proposal throws have been debated since then. Special mention is made of the absence in his discourse of experimental work and the use of instruments, a matter on which philosophers and historians of science have worked intensively in recent years. In a challenge to the Kuhnian picture this means that during those historical periods that have been characterized as revolutionary not all previous concepts are abandoned, and less the experimental procedures, but that they are transformed from within, through shifting the questions being asked and the criteria for acceptable answers. In brief after a major historical chemical transformation takes place a new way of doing chemistry is introduced which largely leaves in place existing experimental methods, and changing one or more theories, thereby changing the way in which chemistry is practiced.

Through the operation of technical-chemical systems, human beings as willing agents obtain objects that were not in the world, such as dynamite, aspirin, nylon, freons and the millions of artificial substances that constitute a supernature, and which are philosophically called artifacts. There are no new substances - or artifacts - without action and without design. They are not only the result of an intentional human action, they also have a meaning embedded in a specific historical context. Since its millennial origin, through the trades, the main way in which chemists today 'know' is 'doing' and this chemical practice characterized by action increases and has increased the complexity of the world. Chemistry professionals (some four million people around the world) make fundamentally new substances. From a few hundred in 1800 to more than 150 million today, most of which are traded. And more than 15,000 new ones are being added every day, that is, one every six seconds. The synthesis of new substances makes chemistry the most productive science. *Chemical Abstracts,* the database that reports on the majority of publications in this discipline, reported practically the same number of publications as all the other sciences combined. This tremendously successful peculiarity of chemical practices, this making artifacts, this beginning to ethically discuss their impact on the world that they technically build, this supernature has gone unnoticed by philosophers of science, and by many educators and practitioners of chemistry. For chemists, reality is found in the entities that explain chemical practices, such as molecular orbitals, not in the underlying physical theories, like quantum mechanics.

Finally it is important to recognize that the theoretical discoveries of chemical communities throughout their history have received different names: theories (Bronsted-Lowry acid base theory), equations (Arrhenius equation), laws (constant proportions law), principles (LeChatelier principle) and models (Lewis atomic model). Beyond the unresolved discussion on scientific theories between different approaches (syntactic, semantic and pragmatic) chemical practices appear to be closed to models. Because models are built contextualizing a certain portion of the world, with a specific goal, generally explain and predict, that relates to a certain chemical practice. Because in chemistry, models are also mediators between the real world and us, it means they function not only as representations but also as means of intervention (for example Berzelian formulas as paper tools in XVIII century organic chemical practice). Because different models for the same field of application can coexist and usefully complement each other (for example in actual acid-base reactions). Because models are a more successful theoretical interpretation of plural chemical practices, they will be used in the rest of this text.

A brief history of chemical practices

The end of alchemy was characterized by the construction of at least three models capable of explaining what we know today as chemistry.The mechanistic model of particles developed by R. Boyle; the compositional model, which considered that chemical reactions, particularly those of combustion, were carried out from the presence of a substance called phlogiston in everything that contained it, developed by G.E. Stahl; finally, the model of affinities that collects the empirical experience by which some substances were more inclined to combine with each other, developed by E.F. Geoffroy.

As we know it today, chemistry began when the highly successful lecturer J. Black improved the analytical balance and, in 1754, isolated carbon dioxide from magnesium carbonate, what can be recognized as the first quantitative chemical reaction. Over a decade later, H. Cavendish improved the hydro-pneumatic tank and isolated a new gaseous substance not contained in natural air. Hydrogen was the first gas recognized as such. A. Lavoisier is still considered a key figure in this period merging two independent and different chemical traditions such as Continental analytical chemistry and British pneumatic chemistry. Through his definition of an element as the last unit of empirical analysis achieved his ambition to ‘‘reform and improve the chemical nomenclature’’. With his development of calorimeter, of the oxygen model to explain combustion and the determination of the law (model) of conservation of matter paved the way of new chemical practices.

At that time N. LeBlanc patented the method for the large-scale production of sodium carbonate, used mainly in the manufacture of soaps, glass and paper. The production of hundreds of tons of this substance per year meant in some way the beginning of industrial chemistry and its impact on the environment.

The invention of A. Volta of the electric battery was followed by a multitude of experiments in which various researchers passed electricity through different objects and substances. H. Davy highlighted in this activity by the isolation of various elements among them Na, Mg, Ca, Sr. The birth of electrochemistry was important, but it was more important J. Dalton's proposal of the atomic model for the structure of substances, an issue that was supported, extended and partially consolidated by J. J. Berzelius, extraordinary experimenter who gathered the greatest amount of atomic (and molecular) weights. Berzelius discovered several elements, driving the electrochemical model of the chemical bond and the nomenclature of the elements that we use today.

Although not everyone accepted the existence of the chemical atoms, as a chemical entity. For instance, stoichiometry and the model of equivalents developed by J. B. Ritcher allowed for many years, particularly in France, to explain chemical reactions (mainly those of neutralization) without having to accept the atomic model.

The synthesis of urea by F. Wöhler in 1828 and the concept of isomerism indicated the beginning of organic chemistry. Since them, not only composition was valuable, structure became very important. Shortly after, Berzelius separated chemistry into inorganic and organic, the latter being interpreted with C.F. Gerhardt' types model, instead of the electrochemical bond model proposed by Berzelius himself. The electrochemical model indicated that the formation of all compounds was due to the attraction between opposite electric charges and was successful with inorganic compounds but a failure with organic compounds. For this reason, many chemists accepted the vitalist model that held that through a vital force, different from the principles of inanimate objects, such as salts and inorganic minerals, complex organic compounds were formed. However, this model collapsed with the synthesis of urea. Thus, for many of the following decades, chemical practices were separated between those who worked with inorganic compounds and those who did so with organic compounds.

The distinction between atoms and molecules was solved in Karlsruhe at the beginning of September of 1860, at the First International Congress of Chemists. The meeting was convened by three renowned personalities of the time who, like Lavoisier, yearned to reform and enhance the language of Chemistry. In the letter through which they summoned 127 people, appeared that the raison d'être of this meeting was to overcome the deep divergences about words and symbols, which damaged communication and discussion, essential mediators for scientific progress. They failed in their original attempt, but after the meeting they shared the exemplars that materialized in textbooks.

Two of those exemplars were related with instruments: the kaliapparat developed by J. Liebig for the determination of the minimum formulas of the organic substances, and the polarimeter used by L. Pasteur to characterize optical isomerism, until then only identified in organic compounds. Chemistry was a European public activity that later on improved its language, by means of other congresses and with the foundation of the IUPAC (1919). Different models were developed to explain new reactions and new chemical properties, like aromaticity. On the other hand, and since the participation of S. Cannizzaro in Karslruhe, molecules were clearly differentiated from atoms and with D. I. Mendeleev, another attendee to the event, valence model and atomic weights occupied a place in his famous periodic table. Until today different models developed around the original concept of valency played a significant role in chemical practices.

In 1874, independently, J.H. vant't Hoff and J. Le Bel explained optical isomerism in molecules from the asymmetry of the carbon atom. Since them the molecule is the most important chemical entity. Many of the theoretical doubts were dispelled, while the industrial advances due to the discovery of the mauve dye by W. H. Perkin accelerated, particularly in Germany, the creation of a transnational chemical industry. Meanwhile, in England, the Alkali Act was published to stop the discharges of hydrochloric acid into the atmosphere. Thus Chemistry, originally

Inorganic, had a subdiscipline greater than itself, Organic Chemistry.

The German university model that closely linked "pure" research with "applied" research was copied by other European countries. Chemistry was the first, among all other sciences, in which experimental work during it’s teaching became obligatory. At that time, compulsory education was installed in many European countries and schools began to be built and managed by local governments. Probably, during the 19th century, Chemistry was the most taught science. Everything that could be synthesized and marketed was produced.

As an example, the respectable Bayer pharmaceutical company did it. In addition to Aspirin, they commercialized cocaine and heroin. In Sweden, A. Nobel invented dynamite, and its controlled explosions changed the surface of the Earth. Some years later, spectroscopy developed by R. Bunsen and G. Kirchhoff allowed the discovery of the He element in the Sun.

Through analysis and synthesis organic chemists could copy molecules that were originally in plants and animals, and then produce entirely new molecules. Substitution models were used to explain specific chemical reactions. European societies first, then the rest of the world, were flooded with new dyes, materials and medicines from the powerful German chemical industries. In Germany the number of colleges and universities with chemistry departments and their teachers, researchers and students grew significantly. Chemists gradually incorporated more instruments in their laboratories and measured more accurately.Thermodynamics were well recognized. Physical chemistry / chemical physics, the new speciality of chemistry and physics was under way. In 1887 W. Ostwald and J. van't Hoff founded the first journal devoted to this subdiscipline, *Zeitschrift für Physikalische Chemie*, which is still being published. In USA chemical engineering emerged around the concept of unit operations.There D. Little recognized that the majority of chemical processes were different combinations of a small number of operations like heating, cooling, distilling, drying etc.

The acceptance that atoms could be divided, a result of the work of J. Thomson with his cathode ray tube, led him to the discovery of electrons. The research and characterization of his colleague F.W Aston on the isotopes identified with his mass spectrograph, together with the discovery of radioactivity, produced a turning point in the practice of chemistry. The recognition of the existence of atomic nuclei and electrons, the new entities of chemistry, gave rise to models that explained the nature of the chemical bond, (G.N. Lewis and W. Kossel) as well as ions and radicals. In chemical practices, a priority of entity-realism over theory-realism can be recognized: long before an appropriate theoretical representation was developed chemists denoted their scientific objects as ions or radicals. With spectroscopy and X-rays, electromagnetic radiation occupied an important place in chemical thought, increasingly influenced by the advances that were taking place in physics. It was clear that beneath the omnipresent materiality of the substances, hitherto practically deprived of the chemicals, there was a reality that only physicists could access under the techniques that were being developed.

On the other hand, in contrast with the ease to commercialize any substance, usual practice at the beginning of XX century in the United States the Food and Drug Administration was established with the intention of controlling the local food and medicine market, which will later become global.

The First World War, in which the United States participated decisively, confirmed that world geopolitic was changing. Although Germany lost the war, the German officer F. Haber who developed the most important techno-scientific process in the history of mankind, the artificial synthesis of urea won the most controversial Nobel Prize at the end of the contest, in 1918.This synthesis gathered knowledge from different chemical, physical and engineering practices. The American atomic model of Lewis, later generalized by I. Langmuir, faced the European model developed by quantum physicists. Both models were the results of their time and the ambitions of their creators.

The first one could explain the chemical bond, fundamental to chemical practices, whereas the second one, spectroscopy, fundamental to physics practice.

In 1945 at the end of the Second World War, the president of the National Science Foundation of the United States, V. Bush, published a report entitled *Science. The endless frontier*, in which he openly requested the federal government to finance science research in American universities, and also to give support to the companies that had supplied materials and equipment to the army. With the adoption of this proposal chemical laboratories changed more than in the previous 300 years. From that moment on, the use of the next instruments became widespread in chemical practices: electrophoresis and ultraviolet visible and infrared spectrometers; X-ray crystallography; mass spectroscopes (particularly since 1956) and later, the most important of all of them, those of nuclear magnetic resonance. On the other hand, chromatographs occupied a place in chemical laboratories' tables. New equipment industries were created following the military logic of the standardization of the parts, which facilitated their consumption. The new sub-discipline of instrumental chemistry appeared. Since them, spin has been incorporated into the daily practice of the chemical community. As evidence, R.W. Woodward took advantage of the arrival of new instruments, such as nuclear magnetic resonance, in his research on synthetic chemistry. That allowed him the preparation and characterization of more complicated products, many of them of great biological and medicinal importance. The synthesis of morphine, cholesterol, cortisone, strychnine, penicillin and chlorophyll shared the onset of tranquilizers (such as Librium and Valium), as well as contraceptives. The total synthesis of vitamin B12 is a milestone in the history of chemistry. To all this must be added the way in which commercial macromolecules changed the way of "constituting" the world. The post- war period marked the beginning of the plastics era. Different research groups around the world undertook the application of thermodynamics and chemical kinetics to the systematic study of these materials.

The new sub-discipline of molecular biology emerged prior to the Second World War by the integration of different disciplines to answer a question: how is genetic information transferred from one organism to another? That question was originally formulated by what was termed the phage group, which was however consolidated at the end of the contest with the so-called protein paradigm. Molecular biology was trying to discover general physicochemical models that govern vital phenomena where macromolecules, especially proteins, became the 'principal focus'. Since its origin, molecular biology depends upon the design, provision and maintenance of complex and expensive instruments.

At this time, computers were incorporated into chemical research practices and with them the programs that allowed “chemical calculations”. Since then many chemists, championed by L. Pauling and R. Mulliken, began to think about the structure of matter in terms of quantum mechanics. They did so considering some of the quantum mechanics principles incorporating broadly empirical information from chemistry practices. Quantum chemistry appeared as a new sub-discipline of chemistry with new educational challenges.

The words ‘plastic’ and ‘flexible’ became commonplace and identified a valuable attitude, even though they also characterized the emerging global consumer society.

At the end of the XX century the size and type of chemical objects (substances), the way in which they must be produced and the time in which they are transformed were distinguished. Many new sub disciplines appear like organometallic chemistry.In one-way or another, chemistry’ limits had been set out. Multinuclear NMR thanks to the work of R. E. Ernst, reached a high level of perfection in sensitivity and resolution and became indispensable for chemistry practices.

In 1974 S. Rowland and M. Molina published the results of their research on the effect of chlorofluoroalkanes in the ozone layer. It was not the first time that chemical companies and governments around the world faced difficulties for its ability to pollute the environment, but this time, unlike all previous, the damage and the risk were unequivocally global. In this sense, a couple of years earlier the use of DDT in the United States was banned as a result of the extensive information coming from a new instrument, “the most sensitive easily portable and inexpensive analytical device in existence”, the Electron Capture Detector (ECD) invented and refined by J. Lovelock. After a strong struggle with the chlorofluoroalkanes chemical industry, where Molina and Rowland played an active role, the political response to ozone layer depletion was the Montreal Protocol. Signed in the eighties by more than 200 countries, it is the first universally ratified treaty in United Nations history. So after the publication of R. Carson’s *Silent Spring* in the sixties the foundation of the US Environmental Protection Agency in the seventies, and the Montreal Protocol, green chemistry with its 12 principles appeared.

At that moment the community learned to make chemical reactions in less extreme conditions (in terms of pressure, temperature and solvents) than hitherto used. The chemical practices approached conditions that allow life and decrease the generation of potential contaminants. The construction and handling of large and different molecular aggregates gave rise to supramolecular chemistry. Close to this subdiscipline is another: nanochemistry. This sub-discipline refers to the possibility of using chemical synthesis knowledge to build molecular aggregates of size, shape, composition or specific surface and it has multiple applications today in medicine, cosmetics and materials. With a long history (particularly in colored glasses) nanoparticles became present in chemical practices. The origin of nanochemistry can be placed at the same time of the discovery of fullerenes in 1984 by R. Curl, H. Kroto and R. W. E. Smalley, and the subsequent synthesis of carbon nanotubes. In the same years, physicists at IBM designed the scanning tunnelling microscope (STM) and Atomic Force Microscope (ATM) instruments that allow "seeing" atoms and manipulating them individually at very low temperatures. In 1999 A. Zewail was awarded with the Nobel Prize in Chemistry ‘‘for his studies of the transition states of chemical reactions using femtosecond spectroscopy’’. In femtochemistry the time scale in chemistry practices is, therefore, the time scale of the motion of atoms. Although there are chemical phenomena that last for billions of years, the most basic processes take place at few femtoseconds (1×10^{-15} s).

Perhaps the biggest change in the chemical industry was in pharmacy. Since the second half of the XIX century, many of the European dye companies have been transforming into pharmaceuticals. At the end of the XX century, more than half of the world's drug research was conducted in the United States and millions of ‘artificial’ substances were commercialized. Some of the most important developments in this short period were the use of recombinant DNA technology and of combinatorial chemistry for the design of medicines. Besides, three Swiss companies (Ciba, Geigy and Sandoz) merged into what was until then the largest global business integration in history creating Novartis.

Contrary to what was indicated at the beginning of this text, in its relatively short history the chemical industry cannot be ignored.

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