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LECTURE

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A schematic overview of the historical evolution of Analytical Chemistry

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Abstract The historical evolution of Analytical Chemistry is briefly discussed as related to the progress of Chemistry within the 16–19th centuries under the leadership of Paracelsus, Boyle, Lavoisier and Dalton. A clear distinction is made between chemical analysis (up to the end of the 19th c.) and today's Analytical Chemistry, paying close attention to a number of aspects and consequences related to the chemical revolution which took place at the overlap of the 18–19th c. which resulted in the quantification of Chemistry, causing increasing development and improvement of the chemical metrology which was an essential factor for Chemistry to acquire a scientific dimension and to become more specialised during the 19th century. A panoramic view of the whole development is presented by resorting to the inclusion of a number of synoptical tables outlining the stepwise progress of Chemistry, chemical analysis and Analytical Chemistry within the five last centuries taking into consideration the main protagonists involved as well as the experimental means, techniques and methodologies used and/or developed.

Introduction

The present communication is a logical continuation of a brief outline on the historical development and trends in Analytical Chemistry [1], interpreting our science with COMTE's three stadia laws, its important experimental heritage based on western European Alchemy to arrive finally at its present status and conceptual meaning which have been the object of an interesting philosophical competition organised by the WPAC [2] which gave an actual definition of our science (Edinburgh, 1993):

"Analytical Chemistry is a scientific discipline which develops and applies methods, instruments and strategies to obtain and evaluate information about the nature and composition of MATTER in space and time".

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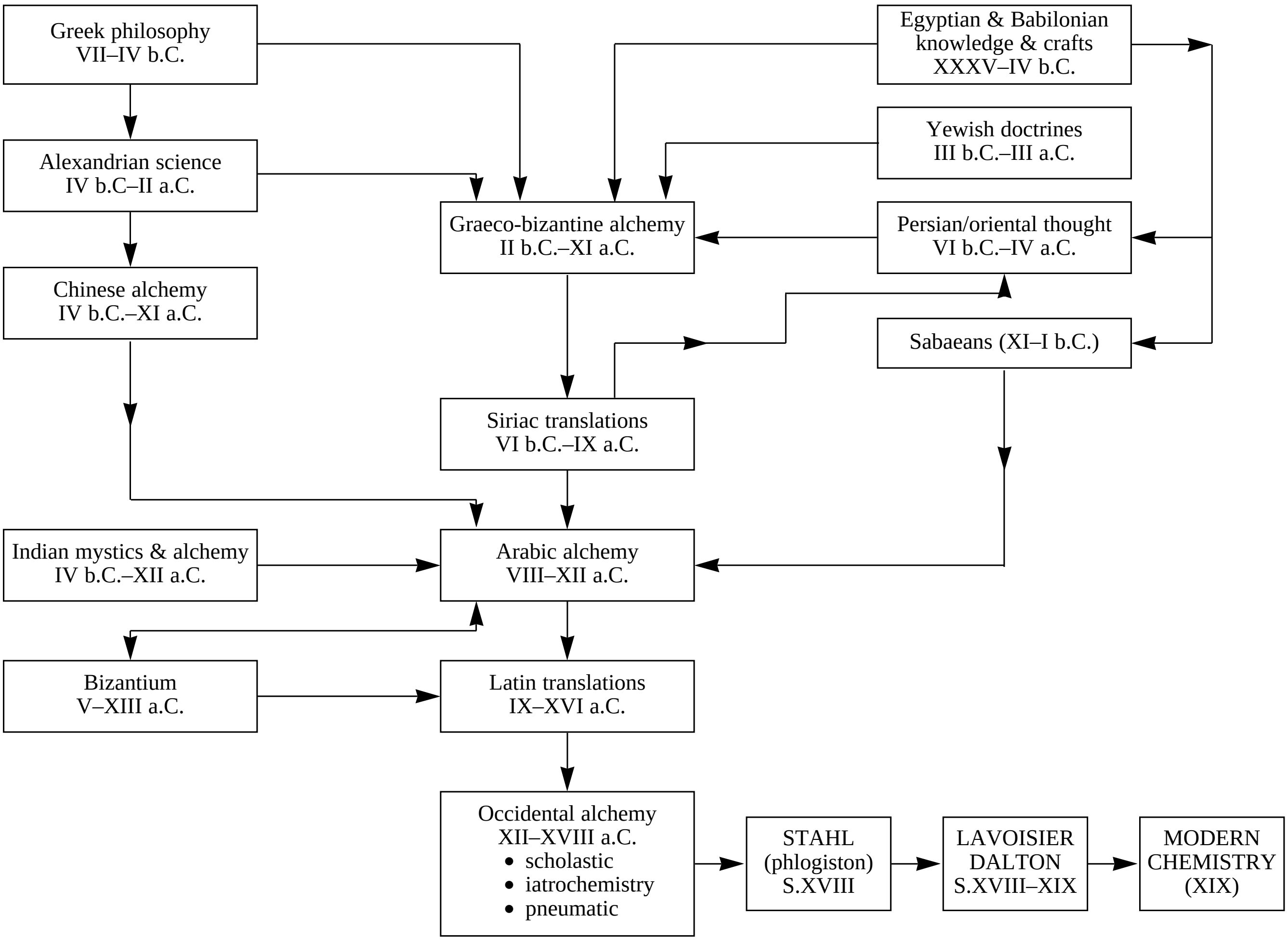
Brief attention has been paid very recently [3] to the chemical aspect of matter which is the object of Analytical Chemistry and which is directly related to the concept of chemical elements.

The present paper aims at completing the previous one [1] by synthesising in tabular form the main aspects involved by the progress of Analytical Chemistry within the 16–20th centuries using a number of condensed outlines by centuries which allow quick and panoramical review of the evolution of our science troughout the centuries. Short sentences, concepts and keywords are used in a suitable tabular form with the purpose of presenting maximal information in a small space.

To begin with, an outline of the historical "pedigree" or genealogic tree of modern Chemistry is presented in Table 1 showing the large amount of cultural influences and interactions which through several millenia have formed stepwise the Science of Chemistry and Analytical Chemistry. The alchemical inheritance of Chemistry is very important as derived from the materialistic or exoteric projection of Alchemy which is but a particular aspect of a vast syncretic polyfaceted "corpus" [4]. Chemistry is a Science of recent emergence but of a very ancient origin as can be seen by the great number of important crafts and technologies developed through the neolithic period. A number of assaying techniques for metals and different products were also progressively introduced to control the quality of manufacture, for trade purposes and to detect forgeries well before our reference age, such as fire analysis, the touchstone analysis, cuppelation, amalgamation, gall-tests etc. which are genuine antecedents of our analytical discipline [4].

In more modern terms Chemistry can be interpreted to be the result of a constant process of development which has passed over revolutionary periods within the 16–20th c. as depicted by Table 2 which centers around a few names of maximum significance, namely; Paracelsus, Boyle, Lavoisier and Dalton, who brought about the transformation of scholastic alchemy, preparative and descriptive chemistry into a Natural Science. Due attention should be paid, however, to the fact that chemical analysis has played a most decisive historical role in the emergence of

Table 1 The genealogic "pedigree" of Alchemy and Chemistry



its mother Science, namely Chemistry, from which it is now but an specific branch.

No attempt will be made herein to enter into biographical details and specific chronological aspects. The aim of the present paper is just to provide a panoramical overview on the subject. Pertinent specifical details on most of the aspects considered here can be easily found in a number of historical monographies [5–10] as well as in a huge amount of specialised bibliography.

Iatrochemistry and chemical analysis

Chemical activities acquired great importance in the 16th c. as derived from the protagonism and improvement of distillation techniques which were used profusely in Medicine and Pharmacy, the development of Metallurgy, the assay of minerals, water analysis etc. thereby making applied and technical chemistry into fields of social importance and economic interest.

However without discounting these aspects, the major factor in the development of Chemistry is related to the "iatrochemical revolution" brought about by Paracelsus, who changed the traditional objectives of Alchemy by bridging it to useful purposes with Medicine. It is impossible here to analyse the immense revisionistic impact of the paracelsian revolution which has been the object of many thousands of publications in the last five centuries and which is now the object of renewed attention and interpretation [11, 12]. However, the meaning of this revolution can be found in the critical and merciless revision of "classical" Medicine and Alchemy which opened the doors towards innovation of methodologies and new objectives for both disciplines. The extent of Paracelsus's "post mortem" impact was so great that from the last third of the 16th c. to the very end of the 17th c. the medical profession was clearly divided between antiparacelsians and pro-paracelsians, the latter being the great majority.

Specific fundamental aspects bound to the 16th c. of chemical interest are summed up in Table 3 as regards to its trends, experimental means, techniques and methodologies, whereby a number of the most outstanding protagonists of this century are mentioned.

Table 2 Essential cornerstones in the secular progress of Chemistry

	XVII: BOYLE	
	* "Chymiatria": academic status * Parallel iatrochemist & mechanocorpuscular progress of chemistry. Gradual independence vs. Medicine. Inital physicalization * PV = k (1 st quantitative law) * Progress of chemical analysis * P: New chemical element (Brand) * "Gas" term coined. Pneumatic chemistry starts (Van Helmont)	
XVI: PARACELSUS	**XX: CHEMISTRY**	XVIII: LAVOISIER
* Iatrochemical revolution * Alchemy-Medicine-Pharmacy association * "Tria Prima": New matter philosophy * Emphasis on: – preparative chemistry (purity, separations isolation of active principles) – chemical metallurgy – materials assay techniques & water analysis. Spagiric alchemy – mineral pharmacotherapy – distillation, sublimation improvements * Publication of many important books	* Scientifically consolidated Experimental Science: – Physical Chemistry – Quantum Chemistry * Huge metrological-instrumental developments * Growing subspecialisation * Multi- interdisciplinar science * Chemometrics: new powerful tool * Holistic social dimension * 30 new elements discovered	* Phlogiston period (STAHL) * Strengthening of chemistry (autonomy) * Emphasis on experimental, descriptive, pneumatic, combustion & calcination chem. * Empirical tables on chemical affinity * Gases acquire chemical identity (BLACK) * Important progress of chemical and mineralogical analysis (blowpipe, wet methods) * 16 new chemical elements discovered * CHEMICAL REVOLUTION: Theories (combustion, acidity), metrology, nomenclature, etc.
	XIX: DALTON	
	* Chemistry becomes a profession * Atomic theory, stoicheiometry, chem. symbology, atomic weights * Essential developments of chemical analysis, organic chemistry and physical chemistry * 1 st specialisation of chemistry * 51 chemical elements discovered * Rationalisation & scientification of chemistry: – Periodic Table – Physical Chemistry	

The overlapping of paracelsism with the Scientific Revolution (S.XVII)

During the 17th c. a most curious coexistence – generally within a context of mutual ignorance – took place, specially about the middle of the century, implying a number of outstanding physicians (Sennert, Van Helmont, Sala, Starkey, etc.) and chemists (Livabius, Glauber, Tachenius, Kunckel, Beguin, Lefevre, Lemery, Homberg, etc.) who were imbued by the paracelsian doctrines to a greater or lesser degree while new trends in Science, specially related to an atomistic or corpuscular revival of the philosophy of matter, took place protagonised by Gassendi, Jungius, Boyle, and Newton among others.

Recent historiography demonstrates clearly that a real doctrinal clash took place in this century between traditional approaches of matter based on elements and principles and the turn to atomistic views. From a chemical point of view brief attention will be paid here to three protagonists of maximum importance: Van Helmont, Newton and Boyle. The reciprocal influence among these figures was very great although there existed fundamental differences between them concerning their chemical views.

Table 3 Chemical synopsis of the 16th century

EXPERIMENTAL MEANS	XVIth c.: FACTS & TRENDS	TECHNIQUES
	PROTAGONISTS	
	* Brunschwygk * PARACELSUS * Ercker * Thurneysser * Agricola * Biringuccio * LIVABIUS	
* Mineral acids, metals and salts * Aqua regia, alcohol * A variety of laboratory equipment: glass & ceramic vessels, balances, ovens, muffles, stills, crucibles, tongues, etc. * BOOKS: A number of important high-qua lity technological ones (assay techni- ques; distillation; applied chemistry. metallurgy; pyrotechnics) – 1 st chemical book in modern sense (LIVABIUS, "Alchymia", 1597)	* Traditional alchemy becomes "Ars spagirica" (separation, isolation, purification) * Assocation of Alchemy and Medicine ("Chymiatria", "Iatrochemistry") * "Triada Prima" as matter philo- sophy * Emphasis on technical chemistry, – metallurgy and mineral pharmacology	* Fire assay * Cuppelation * Touchstone (coupled with mineral acids) * Flame colorations * Organoleptical and topochemical obser- vations, crystal visual examination, etc.
	METHODOLOGY	
	* Distillation (dry & wet) * Sublimation * Maceration, extraction * Crystallisation * Precipitation * Fusions, calcinations * Metallurgical & ore assay * Systematic analysis of mineral waters and urine	

Van Helmont can be considered to be the precursor of "pneumatic chemistry" coining the word "gas" and differentiating the existence of more "airs" than natural or "common" air, while adhering to a monistic qualitative theory of matter reminiscent of Tale's by postulating water to be the prime element. Boyle was greatly influenced by Van Helmont as Newton was by Boyle. However, neither Van Helmont nor Boyle understood the "chemical entity" of gases as chemical substances but just noted their peculiar aggregation state.

The impact of Boyle's work on chemistry and specifically on chemical analysis was extremely important [7, 13] probably the greatest of any scientist of this century. However recent historiography [14–16] has shed a lot of light onto the chemist-alchemist conflict involving his personality which resulted in frequent ambiguities in his writings indicative of the transition period between the alchemical tradition and the scientific tradition begun in this crucial century.

A most interesting fact revealed by the recent study of Newton's inedited work on Alchemy [17–19] indicates his great interest in the subject not from the point of view of an addict but really as a scientist aiming at developing a theory for the chemical reactions in mathematical terms; in short it seems that Newton attempted to develop some kind of atomistic theory accounting for the chemical phenomena in mathematical terms more or less similar to his mechanical theories on macroscopic astronomy based on physical-mathematical laws. For this purpose he was forced to repeat many chemical experiments using a lot of alchemical recipes. The large relative number of alchemical books in Newton's personal library [20] is a clear indication of his interest in the field. However, he did not succeed in his effort to bring alchemy or chemistry into sci-

Table 4 Chemical synopsis of the 17th century

	PROTAGONISTS	
	* Van HELMONT * BOYLE * Hooke * Kunckel * Tachenius * Glauber * Beguin * Lemery * Homberg	
EXPERIMENTAL MEANS	**XVIIth c.: FACTS & TRENDS**	TECHNIQUES
* Purified acids and salts availabe in greater amount and number * Improved laboratory equipment (glass-stoppered vessels; porcelain introduced) * Barometer, vacuum pump, microscope * Burning glasses * BOOKS: Important ones on – chemical philosophy – descriptive chemistry & textbooks – preparative chemistry – chemical analytical tests	* “Chymiatria” enters University * “Alchymia” becomes “Chymia” * Chemistry separates from Medicine as autonomous physical science (mechanical philosophy) * Beginning of phys.-chem. qual. & quant. analytical methodology) * 1 st physicalisation trend of chemistry and chemical analysis * 1 st new element discovered (P)	* Rectification and vacuum distillation * Fractional crystallisation * Fire analysis * Borax fusions * Flame colorations * Introduction of natural dyestuffs as visual indicators * Introduction of SH_2 as separating precipitant
	METHODOLOGIES	
	* Water analysis * Wet analytical separations * Phys.-chem. complementary anal. * Visual & indicator end-point acidimetric neutralisations * Comparative visual quantitative colorimetry * Increased emphasis on weighing * New qualitative analytical tests	

entific terms and left practically all his painstaking long-year work unpublished.

A very interesting opinion is held by Eliade [21] to interpret the clash between the hermetic tradition and the scientific developments of the 17th c. as a last European attempt to develop an ambitious holistic system of knowledge within a Christian religious frame aimed at the attainment of a Christian fusion of hermeticism with the newly developed natural sciences (medicine, astronomy and mechanics). Analysing the mutual influence among Van Helmont, Newton and Boyle specially in connection with the transmutation of water and air, Walton [22] concludes that the authority of Newton and Boyle served to establish the doctrine of transmutation as a plausible explanation of certain chemical processes of importance established by “the wisdom of the great Author of Nature”, a statement which conforms neatly to Eliade’s interpretation.

Such an approach to the situation of philosophical and scientific change typical of the 17th c. can explain many aspects related to a number of apparent paradoxical views exhibited by a number of outstanding scientists of this century which had to face a frontal collision of neo-renaissance Alchemy (Van Helmont), rational philosophy (Descartes), philosophical empiricism (Bacon, Locke) and very successful experimentalism (Galileo, Torricelli, Guericke, Leuwenhoek, Hooke, Boyle) within a frame of revolutionary developments of mathematics (Newton, Leibnitz, Descartes) and a very strong revival of atomism as philosophy of matter (Gassendi, Jungius, Boyle, Newton).

Table 5 Main aspects related to the "chemical revolution"

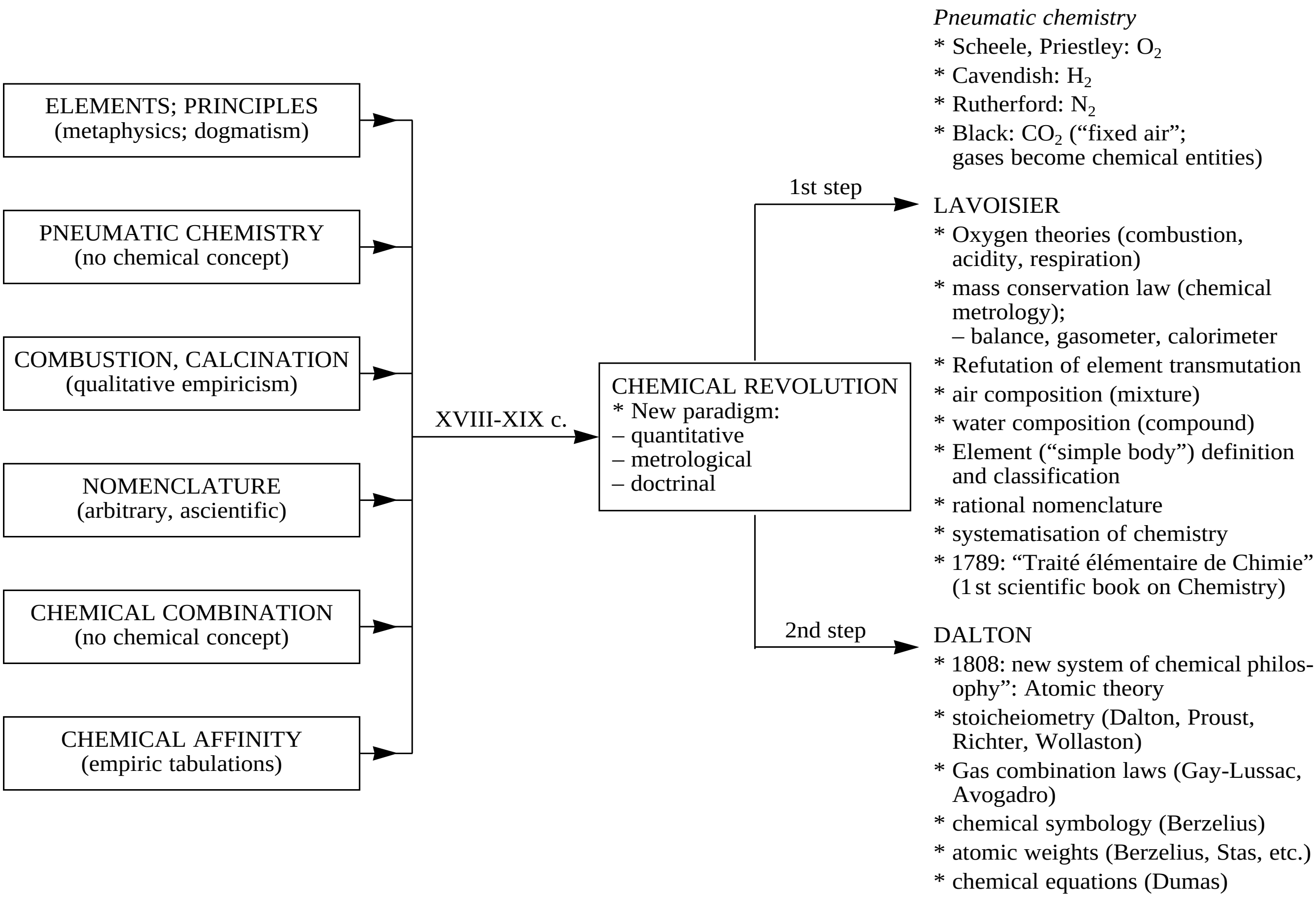


Table 4 sums up the most relevant aspects related to the development of chemistry in the 17th c. which can be considered to be a transition period between renaissance Alchemy in its iatrochemical projection and pneumatic chemistry which flourished in the following century, together with a generally less metaphysical and more pragmatic approach to Chemistry. With a few exceptions (i.e., Lomonosov) the atomistic approach of the 17th c. practically did not transcend into the 18th c.

The last century of Alchemy: Pneumatic chemistry and the "chemical revolution"

The 18th c. means for Chemistry a crucial transition between metaphysics and science, between qualitative blind experimentation and quantitative metrology, between disordered and arbitrary chemical nomenclature, alchemical symbolism and descriptive chemistry vs. rationality, systematisation and scientism.

Nearly the whole century was dominated by Stahl's phlogiston theory centered around combustion and calcination of metals and the discovery of new gases which proved to be essential elements.

The understanding of the oxidation-reduction process bound to the combustion of metals and the establishment of the chemical identity of gases as ordinary chemically reactive substances, the discovery of the true composition of the traditional "elements" air and water, among other factors, gave rise to a true chemical revolution, the main aspects of which are condensed in Table 5 considering the main deficiencies and fundamental problems faced by the new order in Chemistry, clearly distinguishing the two revolutionary steps associated to Lavoisier and Dalton.

From all the problems posed before only one remained unsolved, namely that related to chemical affinity which would have to wait two more centuries to be explained satisfactorily in atomistic terms.

A lot of experimental chemical work was carried out in this century resulting in the discovery of many new chemical substances, both organic and inorganic, among them 16 new chemical elements, the development and improvement of laboratory equipment, and the introduction of new chemical-analytical and physical techniques and methodologies.

Table 6 sums up most of the fundamental aspects related to the achievements in Chemistry made in the 18th century as well as the improvements derived from the availability of new laboratory equipment and the develop-

Table 6 Chemical synopsis of the 18th century

PROTAGONISTS	
* Cronstedt	* Gahn
* Kirwan	* Wenzel
* Geoffroy	* Bergman
* Descroizilles	* Cavendish
* Priestley	* Black
* Klaproth	* LAVOISIER
* Rutherford	* Proust
* Scheele	* Brandt

EQUIPMENT	**XVIIIth. c.: FACTS & TRENDS**	METHODOLOGIES
* Initial titrimetric glassware	* Pneumatic & combustion chemistry	* Blowpipe fundamental development
* Woolfe flasks, gasometer	* Gases attain chemical identity	* Mineralogical analysis
* Hydro- and hydrargiropneumatic trough	* Emphasis on descriptive chem.	* Sea water analysis
* Hydrometer	* Beginning of chemical schools	* Microscopy examination (instrumental improvement)
* Electrostatic machine	* Important development of gravimetric methods	* Gas analysis (qualitative & quantitat.)
* Leyden flask	* 16 new elements discovered	* Increasing emphasis on industrial chemical analysis
* Eudiometer	* Beginning of titrimetry	* Initial application of chemical analysis to archaeology
* Powerful burning glasses and mirrors	* CHEMICAL REVOLUTION: – Modern systematic chemistry – Oxygen-centered sci. chemistry	
* Mercury thermometer		
* Calorimeters		
* Improved balances		

BIBLIOGRAPHY
* Important textbooks on descriptive & applied chemistry
* Monographs appear on: – chemical affinity – blowpipe technique – chemical philosophy – chemical nomenclature – water analysis
* 1st book on modern systematic scientific chemistry (LAVOISIER, 1789)

ment of new methodologies and techniques used in chemical analysis as applied to a great number of minerals and varied materials.

Development of chemical analysis in the 19th century

The important development initiated by chemical analysis in the 18th c. was followed by an explosive protagonism in the 19th c. as derived mainly from the quantification in Chemistry brought about by Dalton's atomic theory and the development of stoichiometry. The first half of the century was led mainly by the extensive development of analytical methodologies of many types related to titrimetric and gravimetric analysis which allowed for the discovery of a great number of new chemical elements. Attention was paid also to the development of the organic elemental analysis essential for the development of organic chemistry which started after Woehler's accidental synthesis of urea.

This period of development of chemical analysis can be considered to be the "backbone" of analytical chemistry which developed very quickly thanks to the careful and toiling work of a great number of outstanding protagonists [3] and concluded with the elaboration of very useful systematic analytical procedures paying special attention to the separation of elements in groups and aiming to guarantee a high degree of reproducibility and accuracy of the analytical results. The names of Berzelius, Rose, Klaproth, Vauquelin, Wollaston and Fresenius, deserve a very special mention in such developments.

Table 7 Chemical synopsis of the 19th century

PROTAGONISTS	
* Klaproth	* Proust
* Gay-Lussac	* Thénard
* Wollaston	* Prout
* Vauquelin	* Dalton
* Berthollet	* Berzelius
* Dumas	* Liebig
* Fresenius	* Wöhler
* Bunsen	* Rose
* Mohr	* Winkler
* Kjeldahl	* Ostwald

EXPERIMENTAL MEANS	**XIXth c.: FACTS & TRENDS**	INSTRUMENTS
* Kipp generator; reflux condensers	* Crucial period for chemical analysis based on: – Atomic theory & stoicheiom. – Rational chemical language – Accurate atomic weights – Consideration of anal. errors	* Electrochemical cells
* Filter paper, Gooch crucibles	* Mineralogical vast development	* Voltameter, conductimeter
* Platinum ware	* 51 new elements discovered	* Spectroscope, colorimeter, photometer
* Callibrated volumetric labware	* Development of organic chem. elemental analysis	* Polarimeter, refractometer
* Bunsen/Teclu burners	* Systematic wet inorganic analysis	* Improved microscopes and balances
* Metallic reductors		* Electroscope, spintariscope
* Synthesis indicators and reagents		* Oxyhydrogen blowpipe
* Gas volumetric glassware		* BOOKS: – Many standard textbooks & monographs – 1st scientific book on Anal. Chem.[1]
* Gasometers		* JOURNALS; Specific ones appear[2]
* Vacuum dessicators		
* Orsat apparatus		
* Chemical slide rules		

METHODOLOGIES
* Huge development of gravimetric, titrimetric and gasometric methods
* Systematic wet separation
* Organic elemental analysis
* Industrial system. gas analysis
* Spectral analysis, colorimetry
* Electrogravimetry
* Organic reagents (introduction)
* Potentiometry (introduction)
* Differential thermal analysis
* Reduction of scale of operation
* Progressive decline of blowpipe

[1] Ostwald, 1894
[2] Fresenius, "Z. Anal. Chem.", 1862

The 19th c. can be considered to be the golden age of wet chemical analysis which demanded a great deal of experimental dexterity and care. The influence of chemical analysis in this period was crucial for the development of Chemistry in general, establishing its laws on a firm experimental basis and opening the way to accurate determinations of the atomic weights of the chemical elements finally leading to the establishment of the periodic system, a cornerstone of systematisation in Chemistry, which Guerlac [23] acknowledges as the final triumph of quantification in the older Chemistry, a metrological achievement which started with the quantitative definition of chemical substances (Dalton).

Only a few of the protagonists of this period implied in the spectacular development of chemical analysis are listed in Table 7 which sums up the most relevant aspects and

Table 8 Main aspects related to the quantification of Chemistry bound to the attainment of scientific status by Chemistry

	XIXth c.	
	* Instrumental introductory stage: (diversified metrology) – calorimetry – electrolysis – electric conductivity – visual colorimetry – emission spectroscopy – electrogravimetry * Analytical chemistry: Systematic qual./quant. wet analysis (inorg. & org.) * Organic chemistry: synthesis, theories * Physical chemistry: theories, models, techniques, instruments. Huge theoretical development.	
XVIII/XIXth c.	**SCIENTIFIC CHEMISTRY**	XXth c.
Metrological introductory stage: * Balance, burette, gasometer, calorimeter, eudiometer – Stoicheiometry (laws) – Atomic weights (tabulation) Chemical analysis (inorganic, elemental & functional organic) – volumetries (gasometry) – titrimetries gravimetries * Discovery of new chemical quantitative laws * Growing quantitative trend of experimental chemistry	* Experimental scientific method * Quantitative matter paradigm * Diversified high-quality metrology * Growing physicalisation & mathematisation * Increasing specialisation: – restricted fields & subfields – interdisciplinarity * Diversification & growth of chemical literature * "Balkanisation" of specialised journals * Holistic social dimension	* Atomistic physicalisation: – Quantum Chemistry, Theoretical basis: Physical Chemistry * Instrumental, electronic, informatic & new materials revolution: – Eclosion of instrumental methods (spectroscopic, electrical, optic) – Miniaturisation, automation, robotisation, microprocessors * CHEMOMETRICS

achievements that this discipline attained in the 19th c, where the impressive experimental means, instruments and methodologies contributed to the solid establishment of chemical analysis as a tool of general applicability in Chemistry.

The final step to transform chemical analysis into a scientific discipline, namely Analytical Chemistry, took place towards the end of the century by incorporating a number of theoretical developments worked out by Physical Chemistry for the study of electrolytes, thermochemistry and reaction kinetics, homogeneous and heterogeneous equilibria.

Metrological and instrumental development of Chemistry

Scientific Chemistry cannot be conceived of without a specific metrological development which implies both the establishment of quantitative theories and laws and requires the introduction of suitable measuring devices and instruments. The specific metrological development in any science brings about the passage from merely qualitative empiricism and description to an Experimental Science, and is therefore bound to a fundamental philosophical categorisation of experimental knowledge.

The fundamental steps and consequences of such metrological development for Chemistry are summed up in Table 8. As stated above one should be aware of the fundamental role played by chemical analysis to enhance scientifically the rank of chemistry especially within the time span between Lavoisier and Mendeleev where chemical analysis was the very marrow of the scientific evolution of Chemistry in its metrological categorisation making this period an unforgettable "heroic stage", a real cornerstone of our actual Analytical Chemistry which nowadays is often overlooked by many outstanding but overspecialised analytical chemists.

The main developments associated with the quantification of Chemistry are succinctly considered in Table 8 summing up the most relevant doctrinal implications, measuring devices and instrumentation used or developed as well as the trends of development from the 18–19th c. to the present time. Some of the most outstanding features are briefly outlined in the central lower part of Table 8.

Table 9 Synopsis of Analytical Chemistry in the 20th century

	PROTAGONISTS	
	* Curie * Roentgen * Fajans * Moseley * Ostwald * Nernst * Sörensen * Bjerrum * Arrhenius * Tiselius * Pregl * Feigl * Heyrovsky * Ringbom * Kolthoff * Sillén * Schwarzenbach * Charlot	
EXPERIMENTAL MEANS	**XXth c.: FACTS & TRENDS**	METHODOLOGIES
* Highly diversified quality lab. equipment (Pt, porcelain, borosilicate, glass, many polymeric new materials, etc.) * A huge amount of organic synthesis reagents (indicators, precipitants, dyestuffs, masking agents, etc.) * A great variety of solvents, ion-exchangers (organic & inorganic), sorbents, etc. * Ultrapure reagents, a great variety of standards and reference materials * Huge chromatographic equipment development (fillings, columns, etc.)	* *1 st half*: Scientific analytical chemistry with special emphasis on ionic equilibria * *2nd half*: Science of measurement – Instrumental development – Separation methods – Automatisation & chemometrics – Superspecialisation * Social protagonism of Anal. Chem * Conceptual revision	* Semimicro, micro & ultramicroanalysis * Trace & ultratrace multielemental anal. * Chelatometry; catalytic-kinetic analysis * Non-aqueous analytical chemistry * Huge emphasis & refinement of instrumental methods: – Optical and spectroscopic (any type) – Electroanalytical (any type) – Chromatographic & other sepn. methods * Hyphenated instrumental increasing trend * Emphasis on performance characteristics
	INSTRUMENTS	
	* *1st half*: pH-meters, colorimeters spectrographs, spectrophotometers micro & ultramicrobalances * *2nd half:* Huge variety of refined instrumentation (any type) * Microprocessors, computers, data bases, preparative automatised stations, etc. * BIBLIOGRAPHY (proliferation). – Standard textbooks & Monograph – Collections, series, encyclopediae – "Balkanisation" of spec. journals	

Analytical Chemistry in the 20th century

The attainment of a scientific dimension by Analytical Chemistry can be essentially traced back to three historical books due to Lavoisier [24], Dalton [25] and Ostwald [26] which together with Boyle's "Sceptical Chymist, 1661" can be considered to be a kind of "Old Testament" of modern Chemistry.

As stated by the author elsewhere [1] two quite different trends of development can be clearly perceived from the examination of Analytical Chemistry in the 20th c.:

- a first half clearly dominated by the impact of "classical" Physical Chemistry
- a second half, following the 2 nd World War, influenced by the electronic, physical and technological revolutions which resulted finally in the consolidation of Analytical Chemistry as a very diversified Science of Chemical Measurement

In the first period special attention was paid to the refining of "classical" wet analytical methods under special consideration of solution equilibria, the introduction and widespread use of organic reagents, the development of microanalysis and of chelatometry or complexometry, spot qualitative and semiquantitative analysis and an important addition – the development of a variety of separation methods based on solvent extraction and ion-exchange. The latter was fostered by the extensive analytical work carried out under the Manhattan Project which also resulted in the new fields of radiochemistry and trace and ultratrace analysis.

With the explosion of instrumental and materials developments following the 2nd World War we enter into a period of increasing physicalisation, instrumentation and specialisation of Analytical Chemistry emphasising the performance characteristics of analytical methodologies. Analytical chemistry acquires new dimensions in aims, applications, horizons and trends resulting finally in identity dilemmas such as: Is Analytical Chemistry a real autonomous Science or just a service discipline for chemical measurements? Ironically such a question has a significant precedent in our discipline at about the last third of the 19th c. when, after having acquired maximum development and having paid a fundamental service to all branches of Chemistry, it became undervalued and was considered only an ancillary tool or instrument of Chemistry, only just a useful technical service discipline. The situation is reminiscent of the role assigned to "Chymiatria" in the 17th c. as only a useful ancillary complement to Medicine.

Such an state of affairs led the WPAC to actualise properly the concept and aims of Analytical Chemistry, [2] crystallising finally in the already mentioned WPAC – definition of the discipline.

The risk of losing identity for chemical analysts actually can be traced to a number of reasons such as:

- the increasing superspecialisation of the discipline
- the actual emphasis on instrumentation and measurements
- the ignorance or disdain for the fundamental chemical background of Analytical Chemistry
- The generalised lack of interest of the analysts as investigators for the Philosophy and History of Science, in general, and of Chemistry specifically.

In conclusion, we are faced with a conceptual problem demonstrative of the large gap established between Culture and Specialisation, between sheer Humanism and Science.

Table 9 condenses briefly the most interesting aspects of Analytical Chemistry in the present century under consideration of a number of outstanding protagonists of special impact, experimental means and techniques developed, methodologies worked out and a simplified overview of the huge instrumental development.

As a consequence, an explosive increase in valuable publications has resulted which can be equally clearly divided into two periods and trends closely paralelled by the two periods previously considered. In the first period the practice and learning of the discipline was based clearly on "classical textbooks" (i.e., Furman, Curtman, Lundell, Charlot, Erdey, Belcher, Kolthoff, Sandell, Gilreath, Treadwell) while in the second one increasing emphasis has been given to instrumental methodologies.

As a result a huge proliferation of all kinds of handbooks, collections, series, and monographies is typical of the second half of the century, including an increasing number and specialisation of journals specifically devoted to the actual broad field of Analytical Chemistry.

As for the future of our discipline, a lot of attention has been paid to the question by a number of authors. In the author's opinion, the actual strong position of Science and of Analytical Chemistry as an interdisciplinary and useful tool of service in any human activity will be a sufficient guarantee not to be afraid about the future of our discipline. On the other hand many of the foreseeable trends and applications of Analytical Chemistry for the coming future have already started with full success.

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