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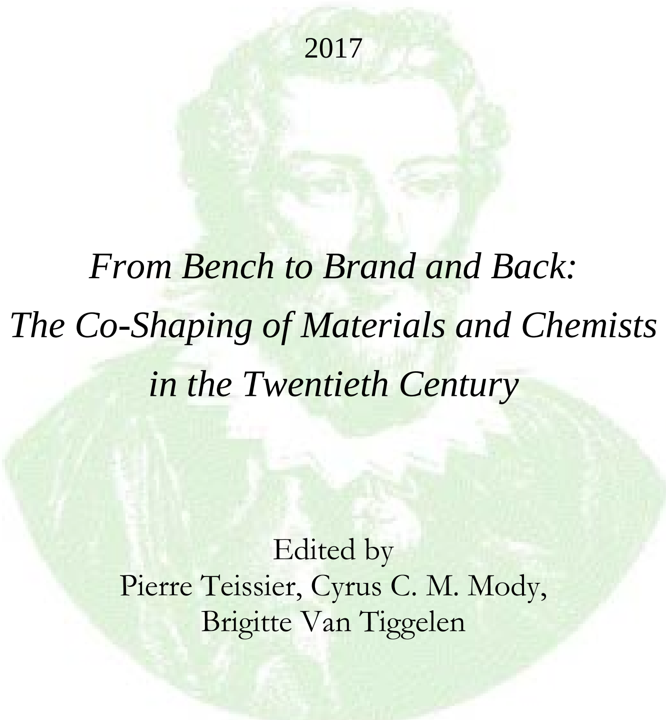

From Bench to Brand and Back:
The Co-Shaping of Materials and Chemists
in the Twentieth Century

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Chromatographs as Epistemic Things: Communities around the Extraction of Material Knowledge

Apostolos Gerontas*

Abstract

Automated chromatography – gas chromatography and later high performance liquid chromatography – played an important role in the transformation of chemical analysis during the 1960s and 1970s. This chapter presents the historical narrative of the production and dissemination of chromatographic technology, and discusses the effects of the automation of separation at the social and epistemic levels. Emphasis is given to materiality, not only of chromatographic technological knowledge, but also of the knowledge produced by application of this technology in research.

Keywords: gas (GC) and high-performance liquid chromatography (HPLC), instrumentation, epistemology of things, research technology, scientific identity.

Résumé

La chromatographie automatisée – chromatographie gazeuse et par la suite liquide à haute performance – a joué un rôle important dans la transformation de la chimie analytique durant les années 1960 et 1970. Ce chapitre présente le récit historique de la fabrication et circulation de la technologie chromatographique et discute les effets de l'automatisation de la séparation aux niveaux sociaux et épistémiques. L'accent est mis sur la matérialité, non seulement de la connaissance de la technologie chromatographique mais encore de la connaissance produite par l'application de cette technologie en recherche.

Mot-clés : chromatographie gazeuse (GC) et chromatographie liquide à haute performance (HPLC), instrumentation, épistémologie des choses, recherche technologique, identité scientifique.

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"Every scientific advance is an advance in method."
Mikhail Tswett (1910)

CHEMISTRY was "revolutionized" during the 20th century by the introduction of a multitude of instrumental techniques of analysis – and by the industrialization of their production, maintenance, and promotion (Baird, 2002). On the one hand, the changes in chemical analytical practices had a stark epistemological and cultural dimension, affecting not only chemical praxis *per se* but also chemical theory, world-view, and sense of meaning and position of chemistry relative to other disciplines and the world. On the other hand, the new analytical methods had a significant effect in the organizational structures of modern chemistry. As Egon Fahr was already observing in the mid-70s, while the pre-automation "classical" analytics before World War II mainly focused on reaction phenomena and chemical properties, the analytical branch that evolved after the war was carried out mainly through the utilization of physical properties of the bodies analyzed (Ettre, 2008).

In the specific case of the professional practice of analytical chemistry, the changes were of a nature and magnitude that can be seen as fundamental. The emergence of instrumental techniques at the fore dramatically shifted the focus – and, therefore, the very meaning – of analytics from "separation" to "identification" of compounds. What had been the analytical chemists' job, as late as 1940 – namely to "separate" and "quantitatively manufacture" compounds utilizing their reaction properties – was downgraded to a job for research technicians, since the new instrumentation made this possible.

The analytical chemist of the post-war decades became a professional manager of sub-professionally educated personnel (a distinction reflected in the academic curricula) that would necessarily free him or her from what was previously seen as the "dull" work of separation. Indeed, the analytical chemist of the 1950s was able to focus on the elemental properties of compounds, in what an external observer could probably describe as a process of chemistry finally becoming a "science" – of the kind that physics was. This closing of the distance between chemistry and physics in practice, focus, and scope not only made chemical practice faster or more effective; it created an "identity crisis" too. This change of nature of course became visible to professional chemists and specialists as early as 1947, and both its "positives" and "negatives" have been commented upon (Baird, 1993).

Thus, although analytical chemistry remains the discipline that focuses on "signal production and interpretation", (Lewenstam & Zytkow, 1987, p. 308)[1] the very nature of the signal read and interpreted changed after the 1940s, and, therefore, the image that each interpretation paints has become increasingly different. Indeed, we witnessed a key event in the general history of chemistry: the shift in the focus of chemical analytics from the purely chemical properties of chemically defined substances to the properties of "molecular species". Today "molecular structures are no longer considered properties of substances; they are now the species whose identity is to be determined and which are subject to chemical classification" (Schummer, 2002, p. 202). On the theoretical-field level this process reflects the transition from "classical" organic chemistry to physical chemistry, to physical organic chemistry, and then to the actual theoretical chemistry of today.

Despite the fact that the bases of the new methods developed and utilized during this period were all set before the war, their domination of analytical praxis was only possible after the means of modern electronics and optics were available, and after a market for those methods existed at a critical level. The rapid development of related industries (pharmaceuticals, biomedicine, and food) offered the necessary market for the commercial viability of these methods from the 1950s on.

By the 1970s the literature reports two different terms that tend to describe what were considered largely different branches: *chemical analysis* (corresponding to "classical" analysis based on reactions), and *instrumental analysis* (corresponding to the "new ways"). From the same decade on, we can register an attempt to cover both terms by the much broader umbrella term "*separation science*", with claims to a separate disciplinary status, under which instrumental analysis is actually the dominant power and classical analytics have been reduced to the status of poor relative.

In the driver's seat in the new era, not coincidentally,[2] we find mostly specialists of the new chromatographic instrumentation. Barry Karger, Lloyd Snyder, and Csaba Horváth (1973) co-authored a hand-book entitled *An introduction to Separation Science*. There, although the significant differences

[1] According to Yuri A. Zolotov (cited in Danzer, 2007, p. 2), the chemical, physico-chemical, and physical methods of analytical chemistry do share a basic common epistemological characteristic: "All of them […] have the same feature: it is the dependence of signal on analyte concentration. The important task of analytical chemistry is therefore the discovery and implantation of these dependencies into analytical procedures."

[2] As E. Lederer and M. Lederer (1955) wrote: "No other discovery has exerted as great an influence and widened the field of investigation of the organic chemist as much as Tswett´s chromatographic adsorption analysis."

between different methods and processes of chemical separation are acknowledged, the authors write in the preface:

> we believe, however, that common underlying principles of separation exist and that the understanding of these fundamentals can result in a fuller appreciation of the advantages and disadvantages of the specific methods. We also believe that these principles lead to the logical establishment of a field of separation science. (Karger *et al.*, 1973, p. 9)

And for building up of the necessary connections in the already-recognized fields, the authors say that

> these [separation process] systems are often, beyond their practical usefulness, excellent examples to illustrate the underlying physico-chemical principles. An introduction to separation science, therefore, is an introduction to thermodynamics and transport phenomena as well. (Karger *et al.*, 1973, p. 11)

This "separation science" was then, and is still today, a term with an ambiguous definition. While it clearly contains chromatography at its current center, its claim of unifying methods based on common "physico-chemical principles", over and through traditional disciplines, is in doubt – and was never fully acknowledged by the broader community of chemists and chemistry-related professionals. Its existence as a term however does represent, as we shall see, an important epistemic shift in modern chemistry, as well as changes of a social nature that modern instrumentation brought to the chemistry-related disciplines. On the one hand, instruments of modern chemistry have an independent epistemic value: they are "epistemic things", as defined by H. J. Rheinberger (1997), embodying phenomena and leading through their manipulation and evolution to the production of new knowledge,. On the other hand, instrumentation reconfigured the position of modern chemists inside their institutions and vis-à-vis their own professional practice.

Chromatography: From Bench Design to Brand Instruments

Chromatography appeared as a technique of separation at the turn of the 20th century, created as a separation tool by Mikhail Semenovich Tswett (1872-1919) to tackle the then-current issue of chlorophyll isolation. It was recognized and canonized, after a latent period, as a chemical tool in the mid-1930s through the research of Richard Kuhn and Edgar Lederer on carotenoids and the subsequent work of other researchers primarily in

Germany (Gerontas, 2014). Both of these were critical periods for the establishment of a series of chemistry-related disciplines and sub-disciplines, the re- distribution of relative disciplinary weights and spaces, and the reformation of older academic milieus. While the "race for *chlorophyll*" was starting on one side of the European continent in 1901, the word *"biochemistry"* was not yet officially introduced, and the discipline that today we identify with physical chemistry had only recently become autonomous from the broader chemical world.

Chromatography, as invented by the physiologist Mikhail Tswett, was a physical-chemical technique built to solve a biological problem – namely, the isolation of chlorophyll, which was considered by chemists of the day to be solvable only through traditional organic analysis. Despite being a separation technique, chromatography was created to serve the needs of the discipline of physiology: separating, but not interfering with or destroying the molecular structure (Gerontas, 2014). Thus, we could consider chromatography's appearance as a bridgebetween two world-views, the strictly mechanistic-constitutional view that organic chemists held about living matter, and the more holistic one, which physiologists had to hold. Functionality of a molecule – and, therefore, its position in a biological cycle – did not need to be destroyed or altered for its separation. This evolutionary step can be considered as of vital importance for the establishment of experimental physiological chemistry and the disciplines which are today perceived as standing on it.

The technology that offered the basis for the automation of the procedure became available in the mid-1950s. The first complete gas chromatograph apparatus was built in 1952 in Austria (Hinshaw, 2003; Bobleter, 1990) and, finding a ready market awaiting, the machine gave birth almost immediately to a vibrant industry that continued expanding during the following decades.

At the 1954 National Meeting of the American Chemical Society, H. W. Patton of Tennessee Eastman Co. presented what is reportedly the first American paper in GC. In it he described a self-constructed system using an adsorption column in the elution chromatography mode, an inert carrier gas, and commercially available thermal conductivity cells that played the role of the detector. Another person present at the meeting, L. V. Guild of Burrell Co., realized the possibility of changing this setup into a full GC apparatus for commercial production. The new instrument was announced next year, under the commercial name Kromo-Tog Model K-1 (Ettre, 2008). The machines that followed shared all the main characteristics that made gas chromatography successful: they were user-friendly and versatile – planned to be useful from the very start. They did not demand deep knowledge of chromatography to produce data, but they could grow together with the experience and practice of their user (and expanded with the purchase of peripherals and applications). Quite importantly, they did not demand the user and the manager of the data and the organizer of the research to be the same person.

By the end of the 1960s gas chromatography was the analytical method most considered as dominant among all the available methods of instrumental analysis. As a method, GC was from the beginning characterized by its protean abilities: capacity of analyzing samples across a broad qualitative range, easy adaptation for preparative work, and the possibility of use on different scales of quantity and precision from the miniscule to the mass industrial. Probably a more important characteristic for our subject, however, was the complexity of the machinery necessary to perform all these functions with minor adaptations. In a single apparatus, by the mid-1950s, micro-column technology was being used for adsorption, while ultra-sensitive sensors of different kinds were combined with pumps, pressure controllers, and micro-furnaces – all coupled to printing machines and the necessary lamps and switches. Apparently, GC was a chemical creature that demanded much more than chemistry to live. All these "externals" to the technique were built upon theoretical constructs that, even if they offered a rather crude description of the phase kinetics in the machines, were effective enough to support the stone-upon-stone creation of functional apparatus. Quite importantly, as figure 1 demonstrates, the particulars of chromatography were decisively hidden from the view of its users and essentially black-boxed.

Figure 1 - F&M Model 700 Dual-Column Gas Chromatograph, ca. 1961
(Source: Courtesy of the Chemical Heritage Foundation)

The fact that the production of the apparatus would have to be delegated outside, away from the chemical laboratory *per se* was only expected. The usefulness of the machine, its potential as a product in a more or less secure market, coupled with the possibilities of variations of technology that would act protectively against patent restrictions were sure to attract companies with a relative know-how in one or more of the technologies involved in the complete apparatus. Meanwhile the delegation of this work to industry at the same time made the machine more available to interested researchers, and afforded a drive towards standardization which could not be reached through the alternative "do-it-yourself" strategy. Although this process is largely familiar to any chemist nowadays – who usually has an inbuilt psychological distance from the instruments that he or she utilizes, formed already from his early years of study – it was a relatively unexplored path in the 1950s,[3] and one that would show some unexpected dimensions.

On the one hand, industrial players not only utilized expertise transferred from academia, they also built significant R&D structures themselves, which were soon to play an important role in the evolution of the instrumental culture of modern chemical research. On the other hand, the "outsourcing" of the construction of GC apparatus to industry turned these tools into commercial objects like any other and created a vibrant market. The companies had the understandable motivation to compete for control of this market, not only through improved technology and products, but also through service structures, advertisement, "lobbying", and "special relations" with the "clients" – in this case, universities, hospitals, public institutions, states, etc.

The first commercial steps resulted in the rapid expansion of available technology, the multiplication of available instruments, and the expansion of available solutions suited to an increasingly larger proportion of research requirements. The second phase had effects which were more pronounced in the long-run. After all, since the primary interest of the

[3] Several of the companies that participated in GC production (especially in its first commercial steps) were companies that had built their technological bases in instrumentation – mostly optics and electromagnetism – and their connections to academia during the World Wars (mostly during the 2nd, but not only) or by interwar momentum and incentives (which included the Great Depression). To offer examples, the Varian brothers built their first klystron at Stanford University with the help of Prof. William H. Hansen, while aiming "to invent a source of strong microwave signals in order to improve air navigation and warn of potential Nazi bombing raids" (Varian Associates Edition, *50 years of Innovative Excellence*), while Burrell Corporation's interest in gas analysis and adsorption originated in the World War I effort concerning gas masks and chemical warfare.

companies was expansion of the available market, the proportion of researchers working with GC instruments had to be raised. This could be achieved only if the "practice" of gas chromatography were disconnected from its theory and the connected understanding of the technique, in a process that history of technology was to observe several times since.

By the end of the 1950s, the industrial editions of guides to "practical" gas chromatography would multiply, soon to be followed by relevant courses too. Industry offered not just "practical" solutions to already existing problems of research, it also "suggested" problems that could be solved by utilization of GC, and tutored young chemists (and not only chemists) in how to "practically" utilize gas chromatography apparatus. Side by side with the manuals of the machines, industrial guides appeared, offering tutoring in their use. Courses were planned and offered on industrial grounds and at universities (but not run by university personnel), while advertisements in specialized journals of analytical chemistry – first in the US, later also in Europe – made a special point of the "simplicity" and the speed of the new machines. The "practical and convenient" character of the technique was aggressively promoted by the interested companies as a strategy of widening their available market and their percentage of control over it (Gerontas, 2013).

This process of disconnection between theory and praxis was of a magnitude (and of a suddenness) that disturbed more traditional chromatographists, not least because it significantly weakened their – then newfound – claims that chromatography was a "*scientific field*", distinct from the other fields of chemistry (Wixom & Gehrke, 2010). While the expansion of the applications of GC through the chosen industrial strategies was indeed rapid, this very expansion had significant effects on the grounding of these very applications in solid theoretical facts. The comprehension level of the newly expanded pool of users of the technique was on average lower – and a significant part of the "science of chromatography" was being transformed into an empirical "craft".

For a concise view of the community's complaints and concerns, itself a compilation of similar concerns over probably one and a half decades, we find for example an editorial in the specialized journal *Chromatographia*, written by L. Szepesy (1970, p. 253) under the title "Software must be developed":

> [T]he instrumentation in gas chromatography and in data processing i.e. the hardware, has made a very fast progress. Will the development of basic knowledge and theory, i.e. the software, keep level with that? I think the answer is no and the gap will be ever wider. In my opinion we can hardly claim at the present time, that chromatography is an exact science. We have

> insufficient basic knowledge for the description of the elemental processes of flow, diffusion and mass transfer taking place in a chromatographic column. […] We are now witnessing a development in liquid chromatography similar to which took place in gas chromatography in the fifties. The hardware for efficient application of liquid chromatography is making fast progress.

In a similar tone, the noted chromatographist V. Heines complained in 1971 that, concerning the theory of chromatography, "there has been no fundamental breakthrough since 1944" (Heines, 1971, p. 280-281). Indeed the "general theory of adsorption" which Tswett (1906a; 1906b, p. 238) imagined for his original chromatography not only had not materialized, it had become somewhat of an impossibility. If in the early 1940s, J. Norton Wilson (1940) and Don Devault (& Libby, 1943) wanted to write a "theory of chromatography", by the end of the 1960s the only interesting aim for researchers was writing surveys concerning the "theories" of chromatography – loosely using the word "theory" to mean a multitude of models describing optimal molecular kinetics. The veteran chromatographists were concerned: not only about the "software" of the already existent and successful gas chromatography, but also about the fact that the then new-born high performance liquid chromatography was following exactly in GC´s steps.

Social and Epistemic Hierarchies: Turning Liquid Chromatography to High Performance

The most persistent shortcoming of GC, and the one most bound to this technique's very nature, was the fact that not all the analyzable substances can be readily vaporized. Even among the ones that can, not all of them can be vaporized without significant losses, damage to their molecular structure, or even production of unwanted by-products. This holds true generally in the chemistry of organic macromolecules; but it becomes crucial in the chemistry of biological substances, where the functionality of a molecule in a process is as important as the isolation of this molecule *per se*.

The new focus on protein structures and their newly comprehended economic significance in the 1950s attracted the attention of several researchers in the chromatographists' community. The then developing ion-exchange chromatography offered the basis for what was in fact the first LC instrument. The amino-acid analyzer of S. Moore, W. H. Stein and D. H. Spackman – a direct result of research funded, organized, and executed at the Rockefeller Institute for Medical Research – was first described in 1958 and entered commercial use one year later (Ettre, 2008;

Moore *et al.*, 1958). Despite the fact that the amino-analyzer was indeed the first instrumental LC, it was still a long way (and almost a decade removed) from the possibility of an actual high-speed liquid chromatograph. It was absolutely specialized, and the technology available at the time gave no possibilities for expansion of its scope. Its creation however occupies a position in this narrative for two main reasons: it was the first instrument utilizing LC that actually worked, thus giving an encouragement to researchers in both academia and industry who were thinking of taking this course; and it managed successfully to enter mass production, proving to the interested industrial players that a market-to-fill indeed existed.

When the actual liquid chromatograph appeared, it was less a result of automating liquid chromatography, and more an adaptation of the gas chromatograph to liquid phases – despite the physical difficulties that such a transformation had. Gas chromatographs were immensely successful. They had set the standard for what should a chromatography apparatus be able to do, and – most importantly – around them there was already a network of specialists, companies, institutions, and journals that had both the interest and the funds to expand. Not surprisingly, as the noted chromatographist Istvan Halász noted in retrospect (Halász in Kirkland, 1971, p. 211): "Most of the workers developing high-speed liquid chromatography were outstanding experts in the field of gas chromatography who tried to 'translate' and to apply their theoretical knowledge and experimental skill to this new field."

By the summer of 1965, Csaba Horváth and Sandy Lipsky at Yale had a full instrument that could actually go to the production line, if not for the fact that its parts – especially the columns of the newly created packing material – were not yet individually in production. The machine was presented at the 6th Symposium for Gas Chromatography (September 1966 in Rome, Italy). However, Horváth and Lipsky decided that since they still had work running concerning the behavior of nucleic acids in the apparatus, they would proceed with the presentation of an interim report – a full paper would have to wait. The final system, as described in a publication of 1967, contained a Hitachi-Perkin-Elmer Model 139 UV-Vis spectrophotometer for detection with a 5μL cell, which was individually constructed by Horváth himself from a Swagelock GC fitting (Ettre, 2008). Csaba Horváth was the godfather of the new apparatus. The "P" in HPLC initially stood for "pressure but was later replaced with the word "performance" – which probably had a better ring in an era quite fascinated by performance.[4] Later,

[4] The reason for the change from "pressure" to "performance" is unclear; and still in several languages the name of the HPLC apparatus is translated from English as

in the 1970s, and due to the initial investment that was necessary for a new HPLC machine, the chromatographists' community started joking that the "P" in HPLC stands in reality for "price". After all, the new machines were significantly more expensive than almost any other piece of equipment that a laboratory could have (Gerontas, 2014).

To Build the Science of Chromatography or the Science of Separation

The networks that gas chromatography initiated were the primary instruments of knowledge transfer and education of the new specialists of the field of instrumental chromatography (and, partially at least, "separation science") – specialists who themselves were no longer definable through the previously acknowledged disciplinary barriers. From the 1950s on, the new group of specialists involved people from almost every field related to chemistry, and some that indeed had nothing to do with chemistry altogether. In the new, growing forest, chemical engineers, mechanical engineers, pharmacologists, physicians, electricians, and mathematicians could all find a niche and, while finding it, re-define their own selves as "chromatographists" and specialists in the new techniques. The borders separating the "natural" categories of knowledge as they were represented by the existing scientific fields of the time proved to be too thin in all cases of chemical instrumentation – and in the case of chromatographic instrumentation too.

Quite importantly, the mechanization of chromatography created for the first time a distinction between the "chromatography-users" and the "chromatography-producers". Not all the new "chromatographists" were in a position to understand the technology involved in the new machines even down to the basic level, and not all of the producers of this technology were actively involved in any kind of research other than the production of the technology. With the appearance and expansion of chromatographic apparatus, an important number of chromatography specialists were now "research-technologists" (Shinn, 2002; 2004). The term "research technologies" should be taken to mean the instrumental-technological means for research which operate in the grey zone between "science" and "technology" without explicitly belonging to one of the two, and – even when specia-

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high *pressure* liquid chromatography. Horváth stated at least once (Ettre, 2008) that the initial name gave the impression that pressure was the only difference that the new apparatus had with traditional column chromatography. Yet there were other factors, such as offering super performance. However, considering the fact that it is indeed high pressure which is the heart of the HPLC machine, it might just be that the word "performance" had a better and more market-oriented sound to it.

lized – they serve academic research equally as well as industry, forensic services, the police, the military, metrology, technical and engineering players, or whoever else might need this service.

Since there was no direct correspondence between the new technologic means for practicing chromatography and an established field of study, while the design and construction of the new machines suggested multi-disciplinarity, automated chromatography failed to find a position in the standardized academic curricula (Gerontas, 2013). It was not purely chemical enough to be taught in a chemistry department, it was useful to biology, medicine, pharmaceutics, and of course, dependent on chemical engineering and all the fields that were connected to it, but it did not directly belong to any of them. Instead, automated chromatography could find a position in the already existing universe of instrumentation and the chromatography specialists could carve a corner of it for the sake of their self-identification. Since the 1930s research-technology had migrated massively from Europe to the United States and circuits, hubs, and networks of instrument specialists and companies had appeared quite quickly. Chemical instrumentation (or more correctly instrumentation for chemistry) had its own and important niche in this environment, visible, but not in any case independent from, the broader instrumentation field which as a whole had its own big field-representative.

The Instrument Society of America – later renamed the International Society of Automation (ISA) – was founded in Pittsburgh in 1945, as an attempt to unify the numerous local organizations of a similar kind in the US. It soon became an increasingly international body with members all around the world (a fact that more than anything signifies the need for such an instrument-specialized society and its lack elsewhere). Being almost from the start the single non-directly-industrial player broadly involved in education and certification of technicians and users of instruments, it played a significant role in forming the scientific "under-class" of laboratory technicians that fueled the rapid expansion of laboratory automation in the US. Designed from its very inception to be interdisciplinary in nature, it soon exceeded by far the subject of instrumentation and came to prominence worldwide in the more general field of industrial automation. The society published (and publishes) several journals – of which the most relevant to chemistry are *American Laboratory* and the *International Laboratory* – as well as books and digests, and provides courses, training and certification to professionals in selected locations all through the US.

The subjects and the organization of the material of the published digests of articles coming from the journals and conferences of ISA offer a picture of the diverse interests and sub-groups inside the society, and, possibly, the different weights that each group held and the positioning of chemistry among all the interest groups. The petroleum-related subjects seem to have been a standard heavy-weight interest of a significant part of the ISA membership especially in the late 1960s and early 1970s (the existence of the annual National Chemical and Petroleum Instrumentation Symposium and the full publication of all its papers from 1960 on indicates that). Analysis instrumentation had its own weight; there were indexes of proceedings from 1956, *American Laboratory* and the *International Laboratory* stably focused there, and there were annual anthologies of papers from these journals. However, not all instrumental techniques carried the same weight.

Many of the users and virtually all of the producers of the technology of gas chromatography were able to find a position in the broad range of people involved with ISA and modeled their own smaller groupings and practices according to the ones that ISA maintained. Chromatographic journals appeared,, and conferences, meetings, and symposia of specialists were often organized. The means that ISA had devised for the promotion of instrumentation and automation among the interested publics became the ways of the chromatography crowd and the involved businesses as well, with the businesses at the steering wheel. Instrument-making companies organized workshops and teaching events, published handbooks, had their own training centers, and participated in the funding of groups and networking activities such as symposia and conferences that did a lot both to strengthen the shared identity of chromatographists and to attract new talents to chromatography. Industrially organized workshops and organized training at the course-centers of the big instrument producers became the primary means of education of the next generation of chromatographists.

Virtually all the big instrument-producing companies had their own course-centers and organized their course material primarily around the models that they were commercially producing. A survey of the material left from the Perkin-Elmer Corporation's[5] division in Germany reveals that the workshops organized and the training offered to new practitioners of

[5] Perkin-Elmer, a company with a deep background in optics, was one of the corporations that entered the gas chromatography sector early, and became almost dominant in it in the 1960s. The background in optics obviously played a significant role in this success story. After the Second World War, the company took over a previously German owned factory at the Bodensee. There, next to the training centers and the production units, the company also operated its own museum of instrumentation. The greatest part of the archive material from this museum and a big part of the instrument collection are currently in the possession of the Chemical Heritage Foundation.

chromatography were rather diverse in character. Slides, demonstrations, short lectures, together with notes about specific issues and applications of the machines constituted these courses and workshops, and the relative weight of each medium often changed. However, all of them did share one basic characteristic: they were explicitly practical. The aim of the training of the courses and the workshops was invariably not to substitute "scientific" training but to create "plug-and-play" (to use the personal computer terminology) users of chromatographic machines as quickly as possible. Thus, in the course-material of Perkin- Elmer surviving from its Bodensee course-center, the material referring to issues concerning chromatographic theory is virtually non-existent. Similarly, the (hand) books that were produced by the company also focused on the practicality of the apparatus and not the underlying principles.

Furthermore, it was through the active advertising of new machines and methodology of these companies that more new chemists and chemistry-related specialists came into contact with the newly available analytical technology. Therefore, despite the absence of any means of formal training of any kind in the new automated chromatography, the dissemination of the technique, the multiplication of its possible applications, and of its practitioners grew in an explosive manner.

As the noted chromatographists Calvin Giddings and Roy Keller (1965) noted in *Advances in Chromatography*, the "explosive growth" of the field had already made it "difficult for any single individual to maintain a coherent view" of its progress. Between 1958 and 1963 the specialized *Journal of Chromatography* "swelled" from 563 pages to 1,698 pages and "the 1964 volumes contained 2,300 pages, an increase of some 300 % over 6 years,', while the 1965 volume was expected to reach 2700 pages. As they continue,

> Hais and Macek in their bibliography of paper chromatography covering the years 1943-1956 report 10.290 references. A continuation, which covers the period 1957-1960, lists 8.300 more. Preston as of October, 1965, published about 11,400 cards reporting papers, books, reviews, meetings, etc. that have appeared since the inception of the method. (Giddings & Keller, p. ix-x)

This "explosive" growth[6] of articles, publications, books concerning the chromatographic techniques reflected the equally explosive magnifica-

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[6] The term "explosive" has been repeatedly used by practitioners of chromatography in personal communications with the author–which may offer us an idea about how they perceived the rapidity of the expansion of their field. Quite interesting is the fact that chromatographists of different decades were each using the term for

tion and generalization of the application of chromatography and the continuous flow of new recruits to the ranks of chromatography specialists. A technique that was initially built for application in the physiological chemistry of the early twentieth century was transformed through mechanization into a broad cluster of techniques that could be applied in a variety of subfields of the analytical plateau: in research or in industry, in pharmaceuticals or radiochemistry.

This was the vibrant reality: the specialists of chromatography (and around them the specialists of all separation techniques) had their conferences, their journals, funding, companies, unions, and institutions. Research on the improvement of automation of research was a more than valid field and "making the fortune for many people",[7] while the chromatography-producers were building up their common identity, narrative, and reproduction mechanisms (Gerontas, 2013). Giving to this identity a disciplinary name however, and demarcating it from other identities active at the chemistry-related plateau was not that easy – and still it is not fully resolved.

One suggestion came in the form of a claim that there was an independent "science of chromatography". According to this claim (explicitly voiced in the title of the *Journal of Chromatographic Science* since 1963 and numerous publications through the decades up to today), chromatography is far more than a technique (or even a cluster of techniques) for chemical separations. Instead, chromatography is a scientific discipline, a phenomenon or a cluster of physical-chemical phenomena with numerous practical applications. As such, chromatographic science has chromatography as its theoretical epistemic object, while chromatographic applications (instrumental or not) have a double function. They are research techniques outside chromatographic science *per se*, and simultaneously the epistemic objects and the experimental procedures inside the field.

A competing suggestion was that chromatography, as a cluster of techniques, shared more with the other analytical techniques used for chemical separation than with anything else. According to this view, as mentioned, there are physical-chemical principles which are common and underlying for all the mixture separation techniques such as chromatography, electrophoresis, distillation, crystallization; etc. Thus, all of these should be included in one, unified "science of separation". This term was

their decade: so, for Ettre, Giddings and Keller there was an explosion in the 1960s, for Molnár in the 1970s, for current chromatographists in the biotechnology era of the 1980s, etc. If nothing else, that signifies that the "explosion" was a durable one.

[7] 2016 private communication of Jack Gill to the author.

significantly more widespread than the "science of chromatography", as it was supported by the existence of a number of journals and academic curricula after the 1980s. The "science of separation" was also easier to fit into the more traditional sense of the discipline. After all, such a separation science would at least be reducible to an accepted physical-chemical "theoretical" basis. Yet, the term never became catchy enough for such a discipline to be fully recognized in the traditional sense.

On the one hand, this instrumentation science could not be fully grounded to theory. A great part of the instrumentation knowledge is never reducible to words and remains strictly "praxical" in nature, at least according to the meaning given by Heidegger (1954; Ihde, 2009). It is only transferable in the form of packets of technology: modules and whole instruments. On the other, the organizational structures of the instrumentation specialists remained at a pre-academic institutional stage, or a pre-disciplinary status (Hacking, 1983).

Instrumental Processing: Knowledge Production and Materials Distribution

As mentioned, the chromatographists were *de facto* separated into two different categories: the chromatography-users, who did not need to have deep knowledge of the technology involved to practice chromatography; and the chromatography-producers, the research-technologists *per se*, who were the main motors of the development of new instruments, applications, and solutions.

For the first category of chromatographists, the technology was effectively black-boxed. This fact made the reproduction and continuous expansion of their class an easy matter. No academic curriculum was necessary, no elaborate scientific handbooks and training. The practical training at the industrial course-centers, apprenticeships with previous users of the machines, coupled with active assistance from the Application Groups of the instrument makers were more than enough for the machines to be immediately useful to their buyers. User-friendliness and fast problem solving were – for the basic and routine users – significantly more important than deep understanding of underlying principles.

The type of knowledge that came to these consumers and which they put to use was largely "praxical" in nature with, however, significant epistemic contributions to the outcome of their researches. Instruments effectively altered the world being observed (and the type of observations possible), creating thus a "different texture of the world" (Baird, 1993, p. 270). Practically speaking, the snapshots of reality offered by instruments could be utilized as reality themselves – a radical and revolutionary identification in its own right. Since modern science cannot function without viewing the world through the technological window, the modern scientist can only perceive as objectively real what is represented as such by his or her equipment. Not surprisingly, this new objective reality built by instrumentation is highly related to the ability of the modern scientist to imagine reality through the instrumentation-generated snapshots of it. That is, the objective of this reality is easily turned into the mathematically supported products of the subjective of the scientist. As Alfred North Whitehead claimed :

> The reason we are on a higher imaginative level is not because we have a finer imagination, but because we have better instruments. […] a fresh instrument serves the same purpose as foreign travel; it shows things in unusual combinations. The gain is more than a mere addition; it is a transformation. (quoted by Ihde, 2009, p. 46)

Returning to the definition of chemical analysis as the discipline which receives and interprets a signal from states of material knowledge, chromatographic apparatus did not only alter the sensitivity or the speed of separation processes; they gave researchers access to new types of material knowledge that could readily be fed onto next-level processes. As we can see in the representation of figure 2, if the original mixture (to be separated) in a physical equilibrium state is the initial material knowledge of the separation process, then the collapse of the equilibrium by the chromatograph could be perceived as producing a new type of material knowledge next to the signal, which can be further used in the next levels of analysis and/or synthesis. Thus, in the analytical process, a chromatograph (of any kind) becomes an essential black box: its input being material knowledge, its output the signal (expressed by a chromatogram) and the separated substances (new material knowledge).

The difference between the two types of material knowledge in this process could be called the "epistemic contribution" or "epistemic content" of the chromatograph – with the chromatograph itself being essentially a black-boxed information-producing automaton for its base user. Since the epistemic contribution of the machine comes from the destruction of a physical equilibrium, it can for any given process be expressed in entropy units and/or information units.

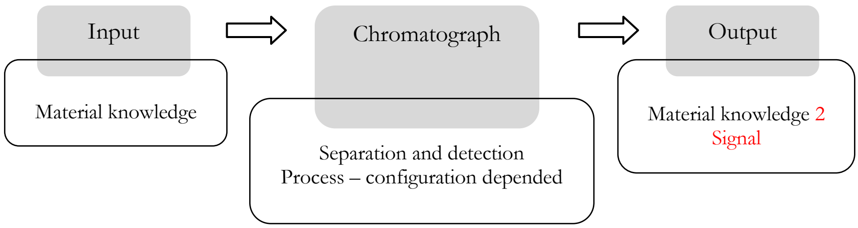

Figure 2 - The chromatographic process, with the apparatus as a black box
(Source: picture processed by the author)

Next to (and "over") the basic routine users of the apparatus, however, was the "higher class" of the producers and the super-users of the machines. This group needed a deeper understanding of both the principles of chromatography and the technological laws which made the machines possible. Since academic pre-graduate training in chromatographic instrumentation remained rudimentary well into the 1980s, the training of this class was also dependent on apprenticeships and seminars – albeit at a significantly higher level. Lineages of research-technology producers appeared, great names of the field being the doctoral supervisors of the next generation of great names and the collaborators both in the academic and industrial sectors of other great names. Quite often, these personal relations would also take an "ethnic" and personal character, with lineages of researchers containing an important number of people of the same nationality, even while extending over different countries or continents. The most notable example of this was the "Hungarian School" of chromatography. The Hungarian sage of gas chromatography Halász was, in Germany, the supervisor of the, also Hungarian, father of HPLC Horváth, who was the childhood friend of the Perkin-Elmer senior scientist Ettre. The latter played an important role in bringing Horváth to Yale, where he constructed the first HPLC. There Horváth and another Hungarian, Molnár (who was sent to Yale from Europe by Halász too), developed the solvophobic theory of chromatography (Gerontas, 2013).

If this setting looks pre-disciplinary or a-disciplinary (or even pre-scientific) in nature, it should be remembered that these are exactly the characteristics often seen in periods of fast "revolutionary" changes as Hacking (1981, 1983) suggests. During these periods traditional institutions are reconfigured, while a number of new groups appear and attempt to carve their niche – most probably starting their organization from the traditional "guild" forms and structures. Specifically in analytical chemistry, the introduction of instrumentation brought with it an identity crisis which made the setting even more fluid (Baird, 2004, p. 99-103).

While the formal structuring and recognition of a field of "separation science" (or "chromatographic science") was lacking, mostly because of its absence in academic institutions and curricula, this class of chromatographic instrument producers was really producing new knowledge in the form of technological packages and modules. Interestingly, in this process chromatographic apparatuses held more than one position, often simultaneously. Chromatographs were quite often the products of the process, but they were also the objects of experimentation; while, also often, the final research products were new applications, physical-chemical parameters, peripherals, and modular adaptations (Gerontas, 2014). What all the products shared was the essentially material nature of the knowledge produced, and the similar materiality of the knowledge transferred and distributed to the consumer class.

Conclusion

Since separation process lies at the basis of any chemical process (being the first essential step), its automation after the 1950s had crucial effects on the overall practice of chemistry. The chromatographic apparatuses – initially GC, afterwards HPLC too – played a significant role in the transformations that are usually described by the term "instrumentation revolution" and stand, even today, at the center of any laboratory (either in their initial forms, or as hybrid apparatuses embodying other processes besides chromatography).

Reforming the practice of separation meant the subsequent reformation of the stratification of the laboratory micro-society and its relation to external players. The new laboratory, after the 1960s, was significantly more dependent on the logistical and technical support of the instrument makers than the laboratory of the past. Furthermore, the distance between managerial chemists and the laboratory technicians and personnel became more pronounced and more significant, socially and economically.

The new chemist does not only have a psychologically inbuilt distance from his or her instruments, but also a practical one: while he or she is responsible for the management of the laboratory in ways which were not necessary in the pre-instrumentation era, there is no longer a need for deeper involvement in the experimental procedures and setup per se. A great part of these procedures is automated; another great part is computer-modeled and simulated. The data is presented to the chemist already translated and ordered, by both machines and human technicians. Finally, a great part of the interpretation of these data can be semi-automated based on databases of accumulated knowledge of the past.

In practice, the introduction of the analytical instrumentation liberated a great amount of "creative force", while at the same time assisting in reinforcing a type of micro-social stratification in the laboratory. As a result, highly qualified chemists take managerial roles, occupied primarily with planning of research and experimentation. On the other hand, a significant part of the work which was once tied to analysis – sample preparation, analysis per se, statistical processes, basic data interpretation and classification – is delegated to computers, students, and technicians.

For this new laboratory to exist, as we have seen, chromatographic apparatus had to be stripped from their theoretical content. Modern analysts utilizing their instruments for their research cannot always be sure about their functions (both in technical principle and in diagnostics). Thus, occasionally the act of collecting and processing the data that these instruments supply can be an act of sheer faith on the part of the scientist involved. Not knowing the details of the technology, heavily dependent on spare parts and technical assistance from "outside," the modern scientist has been trained to use the high-tech equipment of his or her laboratory, but has often not been educated to do so.

In retrospect, this distancing between practice and academic theory had positive effects in the fast innovation, dissemination, and multi-adaptation of analytical technology, which significantly increased the epistemic output of virtually every chemistry-related discipline. Indeed, it could probably be argued that the weaker the "scientific" and theoretical background necessary for the functioning of the chromatographic apparatuses, the more effective and broader their application was. Predictably, this weakening of the cognitive element of the chromatographic machines did bring a strengthening of the cognitive element of the chemistry-related fields – that is, a strengthening of the cognitive element at a higher level of knowledge.

In many ways, chromatography as a case which can be examined next to other cases of technological knowledge and dissemination, some of them more known and notable due to the more generic character of the technology involved (i.e. computer and internet technologies). In these cases, groups of interested technologists (in the case of computers, enthusiasts of the Silicon Valley type) side by side with industrial players were the primary generators of both the knowledge and the translation-transfer processes towards a wider public. In those cases, too, we can observe the separation between the producers of technology and its consumers, accompanied by a weakening of the cognitive element of these technologies at the consumer level.

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