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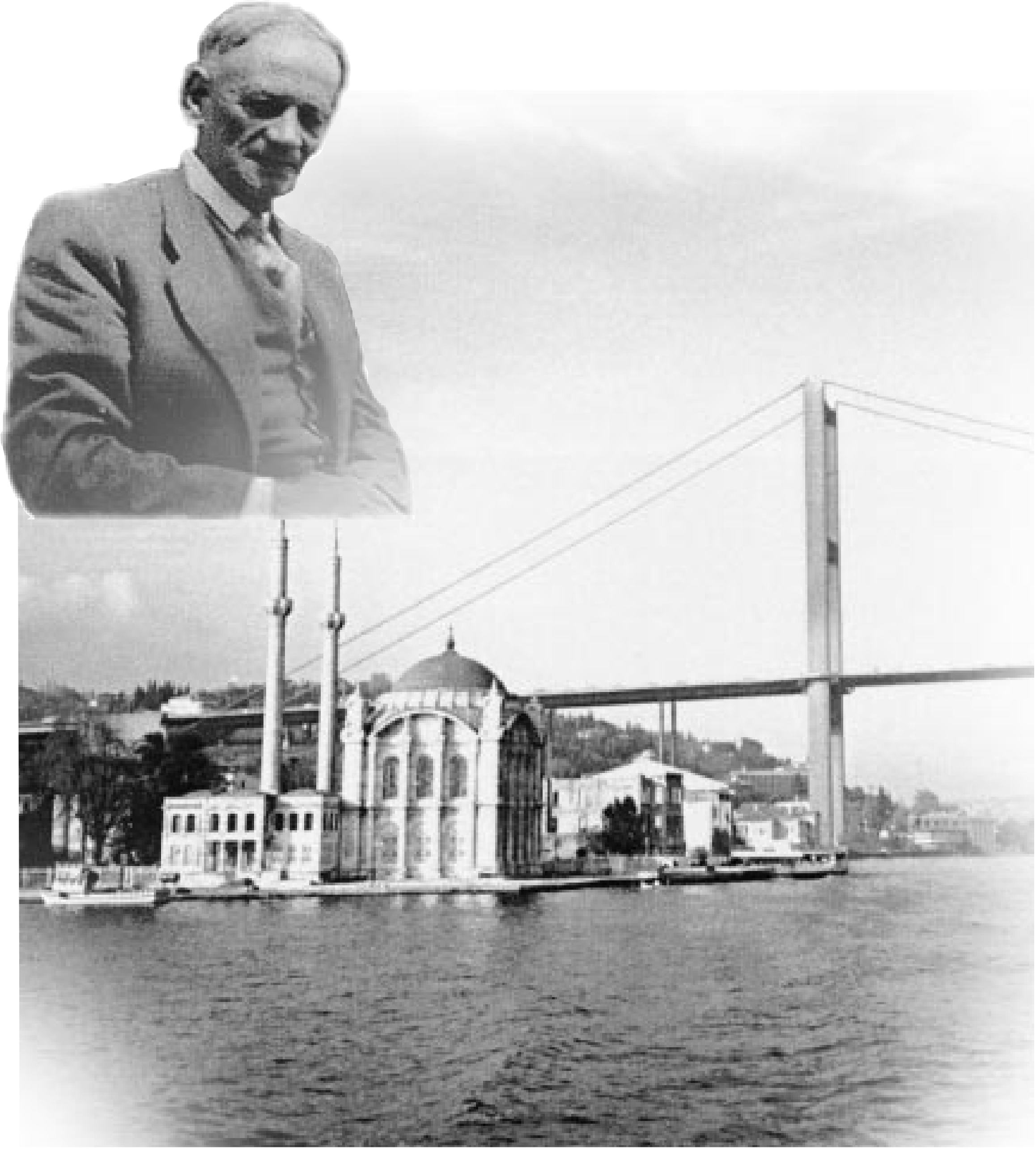

BULLETIN FOR THE HISTORY OF CHEMISTRY

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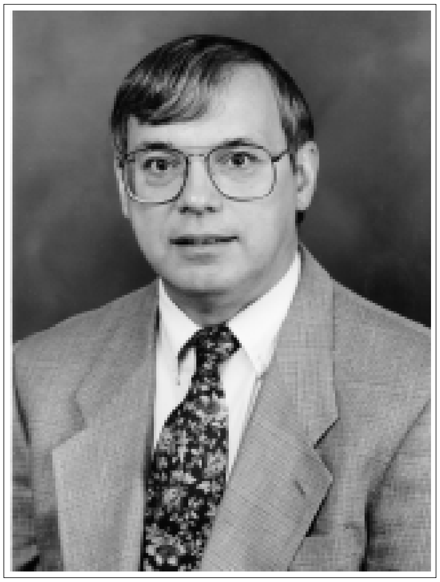
The Cover... F. G. Arndt overlooking Istanbul and bridge spanning Europe and Asia (Arndt photo courtesy of H. W. Arndt)

THE 2002 EDELSTEIN AWARD ADDRESS

TO BOND OR NOT TO BOND: CHEMICAL VERSUS PHYSICAL THEORIES OF DRUG ACTION*

John Parascandola, National Library of Medicine

In 1903, Arthur Cushny, Professor of Materia Medica and Therapeutics at the University of Michigan, published an article in the *Journal of the American Medical Association* entitled "The Pharmacologic Action of Drugs: Is It Determined by Chemical Structure or by Physical Characters(1)?" To a chemist today, this question might seem odd. The physical properties of a drug and its chemical structure are, after all, intimately related, and even if one wants to distinguish between closely integrated physical and chemical properties, surely both are involved in drug action. Physical properties such as solubility and chemical reactivity due to the presence of certain molecular structures can and do both influence pharmacological effects.


John Parascandola

At the turn of the twentieth century, however, the understanding of the nature of chemical bonding and of cellular structure and function was still in its infancy, and many chemists and pharmacologists sought a simplified answer to Cushny's question. There was thus significant controversy over whether the physical or the chemical properties of a substance could best explain its pharmacological action, and over the value of attempts to relate the physiological activity of a drug to its chemical structure.

The fact that drugs may exert a selective action on specific organs of the body had long been recognized empirically and expressed vaguely in the traditional designation of certain remedies as cordials (acting on the heart), hepatics (acting on the liver), etc (2). As early as the seventeenth century, the noted chemist Robert Boyle had tried to explain the specific effects of drugs in terms of the mechanical philosophy by suggesting that since the different parts of the body have different textures, it is not implausible that when the corpuscles of a substance are carried by the body fluids throughout the organism, they may, according to their size, shape and motion, be more fit to be detained by one organ than another (3).

Attempts were also made in the sixteenth and seventeenth centuries, under the influence of Paracelsus and his followers, to explain drug action in more chemical terms. The iatrochemists, for example, tended to attribute most physiological and pathological phenomena (including pharmacological action) to acid-base interactions (4). It was not until the nineteenth century, however, when chemistry had become firmly established as a science, that the chemical approach could be given a clearer and more specific expression. Around mid-century, for example, Jonathan Pereira, who was not himself a confirmed adherent of the chemical theory, explained this viewpoint as follows (5):

> The action of a medicine on one organ rather than on another is accounted for on the chemical hypothesis, by assuming the existence of unequal affinities of the medicinal agent for different tissues. Thus the action of alcohol on the brain is ascribed to the affinity of this liquid for the cerebral substance.

Other scientists were more specific in attributing the action of drugs to chemical interaction. In the early 1870s, for example, British pharmacologists Thomas Lauder Brunton and Thomas Fraser both voiced the view that it seemed likely that the physiological action of drugs is usually due to a chemical reaction between the drug and some constituent of the cell or tissue. At the turn of the twentieth century, German investigator Sigmund Fränkel argued that the selective action of drugs can only be understood by assuming that certain groups in the drug molecule enter into a chemical union with the cell substance of a particular tissue. Once fixed in the cell in this manner, the drug can exert its pharmacological action (6).

The chemical viewpoint was given a boost by a number of studies in the late 19th century on the relationship between pharmacological action and chemical structure. Among the most important of these early structure-activity studies was the work of the aforementioned pharmacologist Thomas Fraser and his chemistry colleague at the University of Edinburgh, Alexander Crum Brown. Their first paper on the subject, published in 1869, began with a declaration of faith: "There can be no reasonable doubt that a relation exists between the physiological action of a substance and its chemical constitution, understanding by the latter the mutual relations of the atoms in the substance (7)."

Brown and Fraser were aware of the need to go beyond relating activity to just chemical composition, i.e., to the presence and proportion of certain elements. It was necessary to attempt to relate activity to the chemical structure of the molecule. Unfortunately, the structure of most organic compounds, the substances of greatest pharmacological interest, was not known in 1869. They refused to allow such considerations to deter them, reasoning that one should still be able to discover the nature of the relationship between structure and constitution in at least an approximate manner.

What one needed to do, Brown and Fraser argued, was to produce a known change in structure which would be the same in a number of different compounds, and then observe the effect on physiological activity. From an examination of the literature, they concluded that physiological activity was often associated with an unsaturated valence, i.e., with the presence of an atom which could undergo further addition. Chemical addition often seemed to remove or diminish physiological activity. For example, carbon monoxide is highly toxic, but addition of another oxygen to produce carbon dioxide results in a much less toxic substance.

Pharmacologist Thomas Fraser collaborated with his University of Edinburg colleague, chemist Alexander Crum Brown, on early studies of the relationship between chemical structure and pharmacological activity (courtesy of National Library of Medicine).

Brown and Fraser decided to work with alkaloids because so many important drugs (e.g., morphine and quinine) fell into this class and because there was some evidence that the addition of methyl iodide to these compounds (*i.e.*, methylation) destroyed or diminished their physiological action. This fact lent support to their theory about the relationship of addition and saturation to activity.

In their first experiments on the subject, they studied the pharmacological activity of six alkaloids, as well as their methylated derivatives. They found that upon methylation the ability of these alkaloids (e.g., strychnine) to produce convulsions disappeared. The narcotic properties of morphine and codeine were also diminished. At the same time, the methylated compounds exhibited a very different toxic effect, although generally only at doses much greater than those required by the alkaloids to produce their usual toxic effects. The methylated derivatives all exhibited a paralyzing, curare-like effect. A relatively small change in structure had thus produced a dramatic change, both quantitative and qualitative, in the pharmacological properties of the alkaloids (8).

Brown and Fraser expanded their studies to other substances, and soon found that in general the compounds now known as quaternary ammonium salts (which included the methylated alkaloids) were associated with a paralyzing action (9). The two Scottish scientists had been quite fortunate in their choice of compounds to study, because such clear-cut relationships between structure and activity are not that common. In fact, some three decades later, in 1901, British biochemist F. Gowland Hopkins declared that the results obtained by Brown and Fraser were still "the most satisfactory instance to hand, of obvious relation between chemical constitution and physiological action (10)." Nevertheless, Hopkins was convinced that such a relationship existed, and that the difficulties involved in investigating the question did not render the study unprofitable. Hopkins went on to list other examples which, while not as definitive and elegant as those brought to light by Brown and Fraser, supported this view. For example, he cited various studies that had demonstrated relationships between certain structural features of molecules and specified pharmacological actions—such as the characteristic intoxicant and narcotic properties of primary alcohols (11).

These early results had led some physicians and scientists to be overly optimistic about the immediate prospects of structural studies on drugs for therapeutics. For example, Thomas Lauder Brunton suggested in the 1870s that the time might not be far off when scientists would be able to synthesize substances that would act on the body in any desired way (12). A decade later, he retained his faith in the advances that would be produced by structure-activity investigations, stating that "the prospects of therapeutics appear to me very bright." He thought it highly probable that before long physicians would have different series of remedies, arranged in order of comparative strength, that would modify various body functions, such as the circulation of the blood, the action of the heart, and the biliary secretion of the liver (13).

The noted biologist Thomas Huxley was also impressed by the advances made in chemical pharmacology during his lifetime, and in 1881 he wrote (14):

> ...there surely can be no ground for doubting that, sooner or later, the pharmacologist will supply the physician with the means of affecting, in any desired sense, the functions of any physiological element of the body. It will, in short, become possible to introduce into the economy a molecular mechanism which, like a very cunningly contrived torpedo, shall find its way to some particular group of living elements, and cause an explosion among them, leaving the rest untouched.

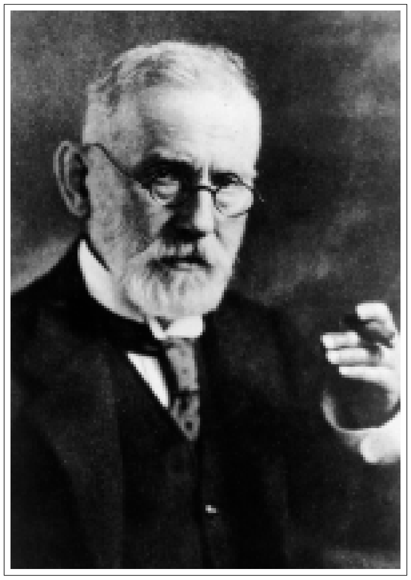
By the turn of the twentieth century, as reflected in the statement by Hopkins previously quoted, this overly optimistic outlook had been tempered by the recognition that the task was more difficult and progress would be slower than originally anticipated. Nevertheless, there was still substantial interest in the field and a number of studies were able to demonstrate a relationship between a particular physiological action and the presence of some functional group within the molecule. To cite several examples, structure-activity studies were carried out on tropeines at the Wellcome Chemical Research Laboratories in London, on organic halogen compounds at St. Andrew's University in Scotland, and on amino alcohols at the Pasteur Institute in Paris (15).

The chemical viewpoint found its clearest expression in the receptor theory of drug action, developed independently by John Newport Langley in England and Paul Ehrlich in Germany around the turn of the twentieth century (16). Langley, a physiologist, had come to his theory largely as a result of the study of the antagonistic action of drugs. As early as 1878, in attempting to explain the antagonism between atropine and pilocarpine in their action on the submaxillary gland, he postulated that "there is a substance or substances in the nerve endings or gland cells with which both atropine and pilocarpine are capable of forming compounds." The combination depended upon the relative mass of the two drugs and their chemical affinity for the cell substance involved (17).

Although this statement contains the germ of the receptor theory, it was not until the first decade of the twentieth century that Langley elaborated on these views. Once again it was a case of antagonism between drugs that prompted him to suggest the idea of a receptive substance in the cells with which the drugs combined. Langley noted that curare antagonizes the ability of nicotine to cause contraction of the muscle. A sufficient dose of curare could completely annul the contraction produced by a small dose of nicotine; further injection of nicotine once again resulted in contraction. Langley concluded that the two drugs must act on the same protoplasmic substance or substances in the muscle cells, and presumably this process involved a combination of the alkaloid with what Langley termed the "receptive substance" of the protoplasm. The two drugs competed with one another for this substance, thus explaining their antagonistic action (18). As result of further studies, Langley concluded that many drugs and poisons act by combining with specific constituents of the cell. He generalized (19):

> I conclude that in all cells two constituents at least must be distinguished, (1) substances concerned with carrying out the chief functions of the cells, such as contraction, secretion, the formation of special metabolic products and (2) receptive substances especially liable to change and capable of setting the chief substances in motion. Further, that nicotine, curare, atropine, pilocarpine, strychnine, and most other alkaloids, as well as the effective material of internal secretions produce their effects by combining with the receptive substance.

By this time, Paul Ehrlich, the founder of modern chemotherapy, had developed his own receptor theory to explain immunological phenomena such as the neutralization of microbial toxins by antitoxins produced in the body. In the late nineteenth century, Ehrlich adopted the then common view that protoplasm can be envisioned as a giant molecule consisting of a nucleus of special structure which is responsible for the specific functions of a particular cell (e.g., a liver cell or a kidney cell), with attached chemical side chains. These side chains are more involved in the vital processes common to all cells, such as oxidation and nutrition.



Paul Ehrlich was one of the founders of the receptor theory of drug action (courtesy of National Library of Medicine).

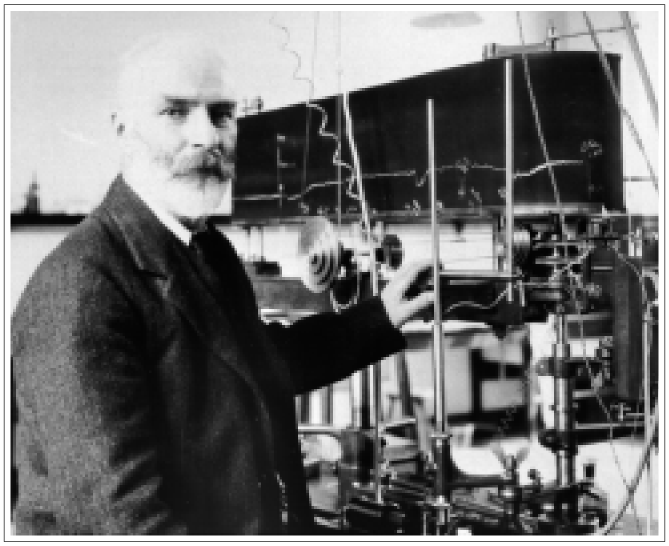
In the 1890s, he applied this concept to immunology. In his view, one of the "receptive side chains" of the cell possesses an atom group with a specific combining property for a particular toxin, such as tetanus toxin. This side chain is normally involved in some ordinary physiological process, such as nutrition, and it is merely coincidental that it has the ability to combine chemically with the toxin. Combination with the toxin, however, renders the side chain incapable of performing its normal physiological function. The cell then produces more of the side chains to make up for the deficiency, but it overcompensates so that excess side chains are produced, break away from the cell and are released into the bloodstream. These excess side chains in the bloodstream are what we call antitoxins or antibodies. They neutralize the toxin in the blood when combining with it, thus preventing it from anchoring to the cell and exerting its poisonous effect (20).

Langley recognized that his theory of receptive substances was similar to Ehrlich's side chain theory of immunity. He even speculated that his receptive substances need not be distinct compounds, but could be side chains on the protoplasmic molecule (21). Interestingly enough, for reasons that will be discussed later in the paper, Ehrlich himself did not immediately extend his receptor theory from immunological agents such as antitoxins to simpler chemical drugs. When he did finally do so, Langley's work was one of the motivating factors.

Meanwhile, however, not all drug researchers were convinced that most drugs exerted their action by forming chemical bonds with constituents of the cell, or that the investigation of structure-activity relationships, largely driven by the field of structural organic chemistry, would lead to great advances in therapeutics. The rise of physical chemistry as a distinct discipline at the end of the nineteenth century provided an alternative model for pharmacologists and others engaged in the study of drug action. These scientists devoted their attention to the influence of physicochemical properties, such as solubility and surface tension, on the physiological activity of drugs and poisons. Although it was recognized by many that one could not always distinguish clearly between physical and chemical factors in drug action, there was a tendency to emphasize either one or the other approach, leading to the chemical and the physical camps (22).

The key issue in the dispute was whether or not drugs formed chemical bonds with cell constituents, the receptive substances or side chains proposed by Langley and Ehrlich. Supporters of the physical view contended that in most cases drugs acted not by combining chemically with cell constituents, but by altering the surface tension, electrolytic balance, osmotic pressure, or other physicochemical properties of the cell. They tended to criticize the structure-activity approach to pharmacology. This challenge was clearly stated by the Scottish-born pharmacologist Arthur Cushny in the 1903 article cited at the beginning of this paper. Cushny analyzed the meaning and value of structural formulas, "...which adorn so many pharmacological treatises but which I fear fail to enlighten as many readers as they repel." The formula, he stated, indicates such things as the origin of the molecule and what compounds it is likely to react with, but it gives no information about the physical properties of the substance. Yet in Cushny's view, these properties (such as volatility and solubility) played a crucial role in determining the action of drugs. One could not therefore expect to predict the physiological effects of a drug accurately from a knowledge of its chemical structure (23).

Critics of the structural chemistry approach pointed out that sometimes compounds of very different structure exhibited similar pharmacological activity. A favorite example was the group of drugs known as general anesthetics, substances that produce narcosis. This pharmacological group includes compounds of widely different structures, such as ether, chloroform, pentane and urethane. This situation was difficult to explain in terms of structure-activity relationships or on the basis of the receptor theory. One could not associate any particular group of atoms in these molecules with the anesthetic activity, and it was not clear how these compounds of rather varied chemical constitution could all combine with the receptive substance responsible for narcosis. This latter point was further emphasized by the fact that the general anesthetics were relatively inert chemically. Moreover, it was shown that the depressant activity of these narcotic agents was directly proportional to their partition coefficients between lipids and water. In other words, lipid solubility, a physical property only indirectly related to chemical structure, played a key role in the action of these compounds (24).



At the turn of the twentieth century, pharmacologist Arthur Cushny favored the view that physical properties of drugs were the major determinants of their physiological action (courtesy of National Library of Medicine).

There were other examples of compounds of widely different structure that exhibited similar pharmacological action, or the reverse, i.e., chemically similar compounds which differed markedly in their pharmacological action. Of these substances, pharmacologist-biochemist Carl Alsberg said: "...we may be sure that their action depends upon their physical rather than their chemical properties (25)."

The most extreme example of compounds with very similar structures that had widely different pharmacological action involved optical isomers, whose structures are mirror images. Today these compounds are used to support the receptor theory and the importance of chemical structure for pharmacological action, because it is believed that they demonstrate that the shape of a drug molecule must be such that it fits a structure complementary to it on the surface of the receptor. One scientist in the 1960s, for example, wrote (26):

> To explain some of the types of structural specificity just referred to is difficult unless we infer that there are 'drug receptors' which bear much the same relationship to certain drugs as do locks to the corresponding keys. Some of the best evidence for the existence of drug receptors has been obtained by comparing the effects of stereoisomers...Since optical isomers have identical properties except insofar as their molecules are mirror images, we are led to suppose that the shape of the drug molecule is important in these cases because part of the drug must fit a structure complementary to it.

Yet the scientist who first provided convincing proof that optical isomers can have very different properties did not explain this phenomenon in terms of the receptor theory. That scientist was the afore-mentioned Arthur Cushny. In 1903, he argued that this difference in action between optical isomers illustrated the relative independence of pharmacological action and chemical structure, "...for nothing can be more nearly related chemically than the two hyoscyamines, yet some of the most characteristic features in the action of one are almost entirely wanting in the other." Since optical isomers have identical physical properties, however, Cushny had to admit that some chemical combination in the cell was probably involved in this phenomenon. But he did not envision this reaction as involving one isomer structurally fitting a receptor surface better than another. Instead, he postulated that the two optical isomers combined with some chemical in the cell to produce compounds that were no longer mirror images, but were now diastereomers. These diastereomers would have different physical properties, and Cushny attributed their different pharmacological activities to this fact (27).

Biochemist-pharmacologist Carl Voegtlin of the Public Health Service's Hygienic Laboratory, the forerunner of the National Institutes of Health, agreed with Cushny that the chemical structure of a drug was important only insofar as it determined the physical properties of a drug. These physical properties in turn determined the retention, distribution, etc. of a drug in the organism, and hence its physiological effects (28).

Other supporters of the physical theory of drug action included the British physiologist William Bayliss, the German pharmacologist Walther Straub, and the German physical chemist Isidor Traube (29). Even Paul Ehrlich, whose receptor theory of immunology was discussed earlier in this paper, was hesitant at first to extend this theory to drugs. Ehrlich did not think it likely that drugs acted by forming a firm combination with the cell, as bacterial toxins did. He pointed out that the action of many drugs is of a transitory nature, and that they can often easily be extracted from tissues by solvents, thus they could not be firmly bound to the protoplasm of the cell. Instead, he thought that drugs were fixed in cells by forming solid solutions involving the lipoid portion of the cell or by combining with certain "non-living" constituents of the cell (and not the protoplasm itself) to form "feeble salt-like formations" (similar to the insoluble, salt-line compounds called "lakes" formed by dyes). Langley's work and Ehrlich's own studies on drug resistance finally convinced Ehrlich that drugs did indeed combine chemically with protoplasm. He then extended his side-chain or receptor theory to cover drugs as well as immunological agents (30).

This controversy over a chemical versus a physical (or physicochemical) approach drug action was part of a wider disagreement in the early twentieth century over the relative value of these two viewpoints. As other historians such as Joseph Fruton, Robert Kohler, and Pauline Mazumdar have shown, a similar debate was taking place in immunology and biochemistry in efforts to explain the actions of antibodies, enzymes, and other biological molecules (31).

The controversy did not result in a resolution in favor of one or the other side, but instead came to lose its meaning and relevance. In a sense, both sides were right, since both the physicochemical properties of molecules and their ability to form chemical combinations play a role in drug action. The borderline between "physical and chemical" has also become blurred as our understanding of molecular interactions has progressed. In a period where relatively little was known about the biochemistry of the cell, and when an understanding of the nature of chemical bonding was just beginning to emerge, it is not difficult to see why a distinction developed between physical and chemical factors which may seem to us to be rigid and artificial. To scientists at the beginning of the twentieth century, a chemical bond implied a firm union, either what we would call a covalent or ionic bond, and the concepts of hydrogen bonds and Van der Waals forces had not yet been developed.

This debate helped to sharpen the focus of questions relating to the mechanism of drug action. Proponents of both views were forced to reexamine their thinking and clarify their views as they responded to critics. Reasonable parties on both sides of the controversy eventually had to admit that both physical and chemical properties were involved in drug action, and that it was not always easy to distinguish between them. It was also generally recognized that pharmacological activity was at least ultimately related to molecular structure, for few would deny that structure determined physical as well as chemical properties.

In 1920, the British physiologist-pharmacologist Henry Dale argued that "we must recognize the improbability that the whole of the widely different types of activity of chemical substances will ever be brought under one principal of interpretation." Whether physical or chemical properties are more important may vary with the substance. Dale also recognized cases where a particular chemical structure not tied specifically to a physical property governs the reaction with the cell, and yet the reaction cannot be regarded as involving a firm chemical combination. Rather, it must involve "some looser type of additive molecular combination." Here, he added, we are "in the borderland between chemical and physical union, the exploration of which holds out such promise for the illumination of biological conceptions (32)."

The exploration of this "borderland" did indeed lead to significant advances in biomedical science. In the paper cited above, Dale was concerned that the attempts by scientists to force all kinds of pharmacological action under one scheme of explanation retarded progress towards a rational conception of drug action. On the other hand, as I have argued, the debate over these questions helped to pave the way for a broader view of drug action, which essentially absorbed both positions and made the controversy no longer meaningful. Today both physical chemistry and structural organic chemistry are utilized in the effort to explain the mechanism of drug action.

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CHEMISTRY AND THE 19TH-CENTURY AMERICAN PHARMACIST*

Gregory J. Higby, American Institute of the History of Pharmacy

In his piece on "The Emergence of Pharmaceutical Science," John Parascandola wrote, "the . . . community pharmacy never played a significant role in this country in the development of the . . . sciences, as it did in Europe where many practicing pharmacists made important scientific discoveries in the backroom laboratories of their pharmacies (1)." It would be difficult to disagree with this well reasoned conclusion; yet anyone who examines the American pharmacy literature of the 1800s will be struck with the vast number of notes and articles on a broad range of scientific subjects. Chemistry was a favorite topic of pharmacy writers and back-of-the-shop investigators. Some of the roots of this interest and activity are explored in this short paper.

The Beginnings of American Pharmacy

Although the pharmacy had origins going back to medieval Europe, what became the American drugstore arose in the early 19th century from four roots: the traditional apothecary's shop; doctor's shops — where physicians prescribed and dispensed; the general store; and the wholesale druggist.

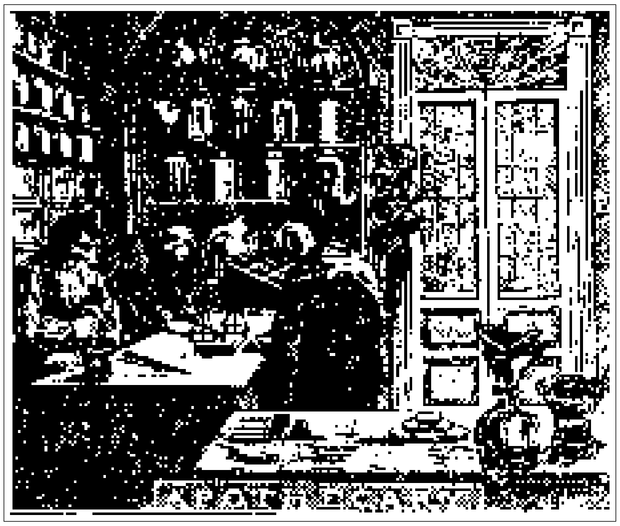
There were few apothecary shops before 1800. Before the expansion of medical education that occurred in the early 19th century, physicians were few and far between and located mainly in cities and towns. These practitioners dispensed their own medicines usually compounded by their apprentices. Apothecary shops and wholesale druggists provided drugs and medicines to these dispensing physicians as well as the general public. Women in the household usually handled most domestic medical chores including administering simple teas or laxative preparations purchased from apothecaries or general stores. To operate successfully, apothecaries needed to understand rule-of-thumb chemistry to manufacture common preparations and popular compounds. They also had expertise in handling related items usually lumped together with drugs, such as dyes, oils, and paints.

Doctor's shops were probably just as prevalent in the early 1800s. Self-styled physicians—there were no effective laws regulating medical or pharmaceutical practice—diagnosed and dispensed medicines in an environment that was not much different from that of an apothecary's shop. In fact, men often went back and forth between the two occupations, depending on their comfort level.

Without regulations in place, general stores were free to sell medicines of all sorts including opiates. Usually they kept their medicine departments simple: packaged herbs and patent medicines. In contrast with apothecaries, these shopkeepers made no claims to special expertise. They did not have a backroom laboratory or the requisite heat, water, and necessary apparatus.

Druggists

Oddly enough, the last and smallest group in number—the druggists—was perhaps the most significant for the development of American pharmacy. The Revolutionary War had forced druggists to learn manufacturing techniques to replace missing chemicals imported from England. "Thus, to be able to detect adulterations and to do their own manufacturing, they became highly interested in a better knowledge of drugs and chemicals (2)." When wholesaler Thomas Atwood in New York City was looking for a partner in 1784, he placed an ad for a "man of abilities. He must understand pharmacy thoroughly, and he should be grounded in chemistry (2)." In Boston in 1795, a druggist put out a pamphlet with the title, "Catalogue of drugs and medicines, instruments and utensils, dyestuffs, groceries, and painters' colours, imported, prepared, and sold by Smith and Bartlett at their druggists store and apothecaries shop (2)." Often businesses that had started out as wholesale drug storehouses opened front ends to the public and moved into retail, calling themselves drug*stores*.



In the middle of the 19th century, American pharmacists commonly placed work areas near the front of their shops to benefit from natural light and to feature the proprietor's professional skills. (Edward Hazen, *Popular Technology: Or Professions and Trades*, Vol. I, 1841, p 236)

These druggists were among the earliest manufacturers of general chemicals in the United States (3). John Harrison of Philadelphia, for example, established the first manufacturing facility for sulfuric acid in the United States in 1793. After the beginning of the 19th century, a significant number of druggists and apothecaries expanded into chemical manufacturing. As Haynes put it, "The 'laboratory' of every apothecary shop was an embryo chemical manufacturing plant (4)." The War of 1812, again cutting off English goods, greatly helped domestic industry. Firms founded by apothecaries, such as Farr and Kunzi, came to dominate the preparation of alkaloids after the isolation of quinine in 1820 by Pelletier and Caventou.

Literature

It is no accident, therefore, that the popular pharmaceutical texts of the young republic placed a premium on chemical knowledge. The first American publication of a pharmaceutical "best seller" was the 1791 edition of the *Edinburgh New Dispensatory*. Thomas Dobson of Philadelphia put this out as a pirated duplication of Andrew Duncan's 1789 book from Scotland. Its first page begins (5):

> Pharmacy is the art of preparing, preserving, and compounding substances for the purposes of medicine. This art has . . . commonly been divided into two branches, *Galenical*, and *Chemical* pharmacy. But for this division there is no just foundation in nature . . . even the most simple pharmaceutical preparations are to a certain extent chemical.

The work then goes into a brief introduction on the principles of chemistry.

The first fully American work with a large impact was *The American New Dispensatory* by James Thacher, published in 1810. Thacher used the *Pharmacopeia of the Massachusetts Medical Society*, published in 1808, as the fundamental compendium for his work (6). Again, this book was aimed at both physicians and apothecaries, and like Duncan it referred to chemistry right away in its first sentence (7):

> Such has been the series of improvements in chemical Science for the last thirty years, that Dispensatories and Pharmacopeias have in constant succession been superseded and rendered obsolete.

Thacher goes on to tell readers what made this chemical knowledge so appealing (7):

> Chemistry . . . enables us, by the use of proper solvents, or by the due application of heat, to separate those proximate principles of vegetables in which their virtues reside, from other inert or noxious matter with which they may be mixed; it ascertains how far these processes are useful, points out those changes in composition by which the virtues of the substances acted on are frequently altered, and the means by which such injuries may be lessened or prevented.

The most important early pharmaceutical work in the young nation was the *Pharmacopoeia of the United States of America* (USP), published in 1820. Two physician-chemists of the era, Samuel Latham Mitchill and Lyman Spalding, were the instigators of this enterprise. The primary list of drugs, numbering 217, included 41 chemicals, such as ferrous sulfate, potassium nitrate, and calcium carbonate. After obtaining these, the apothecary was expected to make up a wide variety of new compounds or preparations according to official recipes for items such as potassium tartrate, calomel (mercurous chloride), and silver nitrate (8).

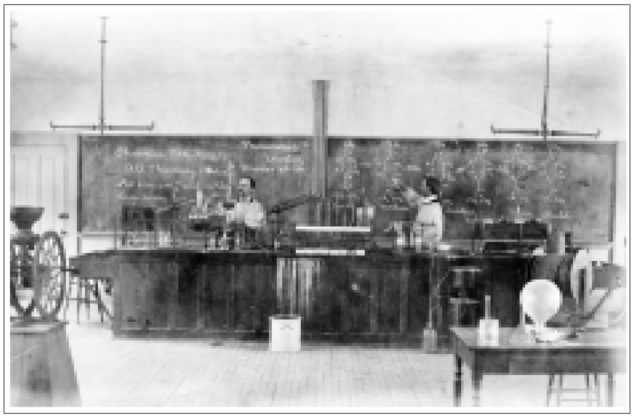
Philadelphia College of Pharmacy

Soon after the USP appeared, a group of druggists and apothecaries, gathered in Philadelphia, founded the Philadelphia College of Pharmacy, the first local pharmacy organization in the United States. The college quickly established a school of pharmacy, with two physician-professors: Samuel Jackson to teach materia medica with pharmacy and Gerard Troost to teach chemistry (9). [Physicians continued to dominate chairs in chemistry at colleges of pharmacy up through the Civil War](10).

The school of pharmacy succeeded in Philadelphia, and other cities established local societies and schools. Yet, most of the other schools never materialized or else died quickly. They did not have the base of support provided by the manufacturing and wholesaling sectors in the Philadelphia area, which dominated the trade. These firms supported the school and encouraged their apprentices to attend night classes primarily to obtain chemical instruction. In sharp contrast, almost all other American pharmacists learned their trade only through apprenticeship.

In 1825 the four-year-old Philadelphia College of Pharmacy started another risky enterprise: a new journal—the *Journal of the Philadelphia College of Pharmacy*. Soon renamed the *American Journal of Pharmacy*, it was the first English-language pharmacy periodical and one of the earliest American specialty journals in science (11).

Leafing through its pages, we see what most of us might expect looking back 177 years: articles on the art of pharmacy, that is, how to take basic ingredients and combine them into dosage forms of medicine. We would not be surprised to find pieces on the topic of materia medica: that is, the sources of drugs, their form and function, and medicinal activities. We would find the first article published was written "On the Preparation of Glauber's and Epsom Salt and Magnesia, from Sea Water (12)." This is straight inorganic chemistry. The issues that followed were filled with similar articles on various mineral salts or the new alkaloidal chemistry (13). A rough count in the early years of the journal shows a division of articles in this proportion: about 1/3 chemistry; 1/3 materia medica; and 1/3 practical pharmacy: This triad of the pharmaceutical field persisted up through the late 1800s.



Teaching laboratory for pharmaceutical chemistry, University of Wisconsin, 1894. (Source: Kremers Reference Files, University of Wisconsin School of Pharmacy)

The early editors of the *American Journal of Pharmacy* were physicians connected with the College who supported the growth of the young profession. They knew well the model of practice on the continent—physicians prescribing and apothecaries compounding—and wished to encourage it in the United States. A well-trained apothecary corps was essential.

For the small pharmaceutical elite, the fostering of chemistry was a key component to advancement. Daniel B. Smith, president of the Philadelphia College of Pharmacy, reflected this attitude when he addressed the graduates in 1837 (14):

> [T]he steady march of improvement which has elevated our profession . . . is mainly due to the ability with which its members, in France and Germany, have cultivated the science of chemistry.

Smith and his colleagues greatly sought recognition from the public and especially from physicians. They began calling themselves "pharmaceutists"—perhaps emulating French pharmaceutical chemists—to distinguish themselves from common apothecaries. They had not yet made any great discoveries but they could claim a professional connection with the likes of Sertuerner, Pelletier, and Caventou. At this time, apothecaries were generally viewed as a special group of shopkeepers, and it frustrated the elite of the American occupation that well trained "pharmaceutists" were not receiving the respect they deserved. They did not deny that they were subservient to physicians, but they wanted an appropriate status for their "professed" expertise, which included chemistry (15). As Smith stated (14):

> In this stage of improvement in the science of organic chemistry, it is . . . of the utmost importance for the members of our profession, to devote their labors to its further advancement and to appropriate to our peculiar department, the rich fruits of the labours of continental Chemists.

Smith concluded (14):

> When this revolution in organic chemistry is effected, our shops, instead of being filled with tinctures [of doubtful] character, . . . will contain certain acids and bases and salts, unalterable by age, and capable of the same extemporaneous use and preparation as the salts and bases in common use. It is to this approaching and inevitable change in the character of Pharmacy that I wish to call your attention and invite your aid.

Smith's challenge to the graduates was typical of the era. The first generation of educated pharmaceutists was asked to go out and prove their profession's worth in their backroom laboratories. Chemical investigation was going to elevate the American profession as it had on the continent.

Smith's address led off the June, 1837 issue of the *American Journal of Pharmacy*, sent to all members of the college and subscribers across the nation. The very next page contained the inaugural essay by recent graduate, William Procter, Jr. The brightest student in the school's history, Procter had followed his teachers' directive and isolated an active proximate principle from *Lobelia inflata*. Unfortunately, Procter did not have the equipment to do a definitive analysis of the alkaloid (16).

Procter's experience illustrates a problem with the idealized vision put forward by Smith and his contemporaries: the few American pharmacists who had the desire and ability to do chemical investigations lacked the time and apparatus to complete their efforts (17). Moreover, pharmaceutical chemistry in Europe was leaving the cramped back rooms of shops for better equipped and staffed laboratories in industry and academe (1).

Drug Quality Concerns

The 1840s brought a new problem to American pharmacy that chemistry seemed ready to solve. As European countries tightened down on drug adulteration within their borders, poor quality crude drugs made their way to the shores of the United States. Some adulterations were simply mechanical such as bullets added to opium cakes; others were more sophisticated such as mixing blue clay in with blue pill mass (18). In addition, alkaloidal chemistry allowed European firms to extract the active constituents from botanicals and export the exhausted remains as whole to foreign markets. As one Congressional committee put it (19):

> This country [has] become the grand mart and receptacle of all the refuse merchandise, . . . not only from European warehouses, but from the whole eastern world.

The *American Journal of Pharmacy* was filled with articles long and short on detecting drug adulterations and sophistications. Pharmacists proudly portrayed themselves as the most reliable monitors on drug quality. The problem came to a head during the Mexican War, when newspapers reported a high number of deaths among soldiers from disease rather than combat. Army physicians blamed poor quality drugs. Congress quickly passed the Drug Importation Act of 1848 after lobbying by the young American Medical Association. The law called for port inspectors, who were soon appointed. They had trouble, however, rejecting crude botanical drugs when few recognized positive standards existed. They had manuals for analysis but the inspectors needed an approved set of concrete minimum percentages of active ingredients. Some authority needed to step forward to provide this (20).

A New York physician who ran an apothecary shop, C. B. Guthrie, turned his attention to the task. He issued a call for a national convention of pharmaceutists and druggists, to take place in New York City on October 15, 1851. The various colleges of pharmacy across the nation were invited to send delegations of three to the convention to draw up standards for inspectors <u>and</u> to consider "the proposal of any measures that might be calculated to elevate the profession, and to promote their interests throughout the country (21)." The pharmacists who gathered drew up a set of standards based on the best contemporary knowledge. For example, opium needed to contain at least 7% morphine by weight. The standards were warmly received by some inspectors, but the system eventually broke down from cronyism and corruption (22). Still, the pharmacy group decided to meet again in Philadelphia the next year to establish a national society, the American Pharmaceutical Association (APhA).

APhA and Chemistry

The young association was dominated by prominent apothecaries and druggists, especially from the Philadelphia area, who wanted to elevate the reputation of their occupation. Concerned about the general quality of apprenticeship training, they sent out a survey across the nation. The committee that reported to the 1853 APhA convention was shocked by the state of affairs (23):

> The larger number of those who deal in drugs and medicines do it solely to make money; they aim at making the most out of the least outlay of capital or trouble; to *sell* medicines is their vocation; and he is the best [apprentice] who can sell the *most*, under whatever circumstances . . . . To avoid the necessity of gaining the requisite knowledge of practical pharmacy, it is no uncommon habit to buy their preparations ready made, except the simpler ones, and at the lowest price, and the business, thus shorn of its most interesting department, the application of chemistry to the conversion of crude drugs into medicines, becomes a mere store keeping, where the [apprentice] is kept putting up and selling parcels and bottles of medicines, the preparation of which, and the beautiful reactions often concerned in their manufacture, he is as complete a stranger to as though they do not exist.

The committee and the year-old association were at a loss for what do. They looked on during the 1850s as the retail pharmacy sector exploded. While the per capita number of physicians stayed steady, the number of drugstores increased by nearly 25%. And many, if not most, of these were run by "mere shopkeepers." For keepers of the professional flame there were different solutions. Some championed laboratory work and the glorious search for alkaloids; others like Edward Parrish called for pulling together the wide gamut of practitioners into a "one [grand] professional fraternity," that is, the APhA and then educating them via the organization (24).

In 1858, William Procter, by then professor of pharmacy at PCP, editor of the *American Journal of Pharmacy*, and a shop owner as well, went before the APhA convention and addressed in his gentle way the dilemma facing the American profession at mid-century. He gave a short paper entitled "Thoughts on Manufacturing Pharmacy (25)." Procter was most concerned with galenical preparations—the traditional tinctures and extracts of plant drugs—but all official drugs were included. If apothecaries bought these preparations ready-made, they were on the road to becoming "mere shopkeepers" who would pass their ignorance to their apprentices (26). Procter was caught in a bind, however, because many of the owners and operators of the Philadelphia firms were his friends, like Daniel B. Smith and William Hodgson. And he could not guess that two of his own students, named Wyeth and Wellcome, would lead the effort to mass produce end dosage forms.

During the 1860s the APhA reacted to the declining level of expertise with a wide variety of programming. A committee on queries assembled scientific topics for volunteers to investigate and describe at future conventions. An annual report on the scientific progress of pharmacy was included in every annual association proceedings. Committees drew up syllabi for preceptors to use when guiding the studies of apprentices. None of these efforts could stem the tide. Wedded to the traditional apprenticeship model of training, the elite could not find a method for guaranteeing adequate scientific instruction, especially in chemistry.

Prescott

In 1871, the University of Michigan College of Pharmacy sent a delegate to the annual APhA convention. His name was Albert B. Prescott, and he was the head of Michigan's three-year-old program. (He was president of the American Chemical Society in 1886.) Although he was a physician-chemist of high repute, Prescott's credentials as a delegate were rejected by the convention; but he was invited to stay on as an individual member. The body of the association argued that the Michigan program was not a true "college of pharmacy" since it did not require apprenticeship experience to receive a diploma. All the other schools required apprenticeship because it was believed that preliminary experience in a shop, wholesaler, or manufacturer was essential before going through the "finishing" of formal instruction.

Not being a shy individual, Prescott returned the next day to the convention with a short paper. Entitled simply "Pharmaceutical Education," this strong attack on the status quo began (27):

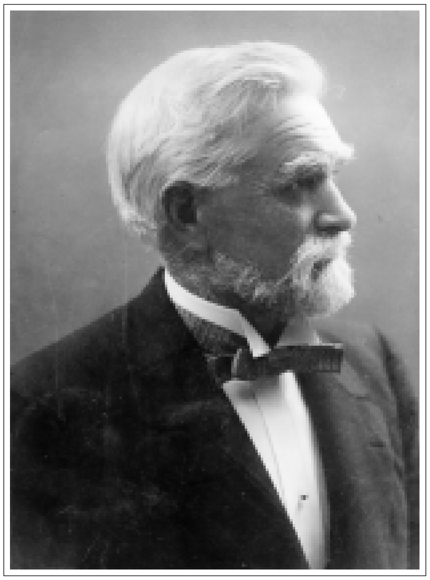
> The conditions of pharmaceutical apprenticeship in this country, constitute a subject of regret to all thoughtful observers. . . . In a large number of instances, the apprentice is led to perform mechanical labor in blind ignorance of the nature of the material with which he deals; he becomes habituated to a feeble and automatic mode of action, and hence, too often, he never afterward breaks through to the light. Elementary text-books on chemistry and botany are not placed in his hands; he learns to refer to official and non-official authorities, and to follow after statements and methods which he does not understand; and, too often, he finally ceases to 'wonder why' he does this or that. The history of processes of prepa-

> ration, and the discussion of physical and chemical ways and means are in a tongue unknown to him.

As an analytical chemist, Prescott was especially discouraged (28):

> From this apprenticeship, the young man emerges into responsible dealing in a trade abounding in adulterations and substitutions, low standards and shrewd deceptions. From this beginning, year after year still leaves him at the mercy of wholesale deceptions, innocent of the wrong done under his hand, if we may term him innocent whose ignorance places human life in daily jeopardy.

As a college professor, Prescott witnessed the growing demand for science instruction in the technological vocations. He argued strongly that it was imperative for pharmacists to receive this education in a college laboratory *before* shop experience. Lastly, Prescott acknowledged the value of requiring practical experience before graduation but he criticized the lack of any requirement for college laboratory training. He recognized the "useful services" the "colleges have performed in keeping pharmacy alive" but could not support their fundamental lack of modern science training (29).



Albert B. Prescott, Dean of the University of Michigan College of Pharmacy. (Source: Kremers Reference Files, University of Wisconsin School of Pharmacy)

The paper elicited a few harsh responses from the APhA convention. John Maisch of the PCP was especially incensed by Prescott remarks. He claimed that nothing was done to prevent students from studying chemistry before entering the shop for apprenticeship. Students may also study chemistry individually in the laboratories of individual instructors. He had to admit, however, that laboratory instruction was not yet required anywhere other than at Michigan. "But Rome was not built in a day," Maisch lamented, "[it] will gradually come (30)." In fact, the alumni association at PCP had just constructed a laboratory for the use of their students with Maisch as its director. It was not yet required, however, and laboratory instruction did not become a significant part of their curriculum until 1878 (31).

At that 1871 APhA convention Prescott later read another paper on "Sulphophenic Acid and its Salts," which was accepted for publication. One must credit the Association for its openness. It published Prescott's scathing critique of pharmacy education even though no one agreed with his position (32).

The open forum and cordial scientific exchange kept Prescott coming to APhA meetings after 1871. He was elected third vice president in 1885 and president of the Association in 1899. In 1900 Prescott was elected the first president of what is today called the American Association of Colleges of Pharmacy. By then his model of laboratory-based pharmacy education had triumphed, helped in large part by forces outside the profession.

Modernization of American Pharmacy

The late 19th century brought considerable change to pharmacy. With most basic preparations now available from drug companies, anyone with enough courage and capital could open up a drugstore. The number of pharmacists grew enormously, and the quality of prescriptions dispensed declined accordingly.

In response to public and professional concern, effective state laws regulating pharmacy were enacted across the nation in the 1870s, 1980s, and 1990s. State boards of pharmacy examined prospective pharmacists to ensure minimum competence, stimulating the growth of educational opportunities. Apprentices sought out chemistry instruction to pass state licensing exams. An influx of new state-affiliated pharmacy schools in the 1880s and 1890s helped to raise the level the practice significantly. Many like the University of Wisconsin combined laboratory science with an experiential requirement for graduation (33).

New and more effective drugs entered the scene in the late 1800s, including synthetics such as antipyrine, acetanilide, phenacetin, and chloral hydrate. Greater uniformity came to galenical preparations, pushed forward by the modernization of the United States Pharmacopeia. Large-scale manufacturers began moving into the production of end dosage forms as well (34).

The new generation of professional leaders like Joseph Remington shifted their emphasis away from the rear guard action of keeping manufacturing in the shop and toward publicizing the skills of pharmacists as master compounders. Only they could put together the "tailor-made" prescriptions written by physicians to meet the special needs of individual patients. Chemical expertise was vital for preventing prescription incompatibilities (35). A few pharmacists branched out into analysis work, and there was a movement to advertise pharmacists as "chemists on the corner," but the previous urgency had died away.

At the APhA annual conventions the scientific enterprise constructed in the 1850s and 1860s progressed slowly. The 1898 APhA Proceedings contained the massive "Report on the Progress of Pharmacy": 500 pages of article abstracts, including 230 pages devoted to inorganic and organic chemistry (36). The Ebert Prize, which the association first awarded in 1874 for the best scientific article in pharmacy, was given to James Knox and Albert Prescott for "The Caffeine Compounds of Kola (37)." Over the years, more than 1,000 queries had been put forward by APhA committees with about 300 of them being chemical in nature. They varied from "Do any of the best samples of sulphuric and other mineral acids of American origin contain appreciable amounts of arsenic (38)?" to "Is there a crystalline active principle in capsicum (39)?" Papers on preparing chemical compounds in shop continued into the 1880s but elicited little discussion (40). As the years went forward to 1900, chemistry queries shifted primarily to assaying. With interest in laboratory work declining, the committee brought forward issues concerning the suppression of quackery and commercial problems. Questions concerning preparations dropped off as large-scale manufacturers took over the making of not only ingredients and preparations but entered the field of end dosage forms. The corner pharmacist could not match the elegance of the modern sugar-coated pills or the low price of the machine-made tablets that appeared at century's end. By 1900, one young woman in a factory could operate a pair of machines punching out 100,000 headache tablets a day. Compounding, the crux of professional practice in the late nineteenth century, started its great decline (41).

Bullock and Crenshaw took over the successful business of Smith and Hodgson in 1849, building it into an ever larger manufacturing and wholesaling concern. (Source: Archives of the American Pharmaceutical Association, Washington, DC)

Drugstore Evolution

Changes in practice and technology altered the face of the drugstore as well. Before the Civil War, pharmacists put their compounding areas near the front of their shops to benefit from the natural light from windows and to demonstrate their professional abilities. By the 1890s, stores were rearranged with the prescription table moved to the back of the shop, pushing out most of the old laboratory area. This opened up the front for more profitable goods such as tobacco products and candy. Above all else, the shift of pharmacy practice to the back of the shop gave the soda fountain front and center position. Ironically, it was the pharmacist's practical chemistry expertise that allowed him to make up flavorings and to handle temperamental carbonated water generators. Some pharmacists turned their inventiveness to developing new soft drinks, including root beer, Dr. Pepper, and Coca Cola. Unfortunately, the public soon came to see pharmacists more as sellers of chocolate sodas than health care professionals (42).

A few retail pharmacists continued their backroom laboratory pursuits well into the 20th century, but the serious work was taken over by a new generation of university trained scientists who staffed the new state-supported colleges of pharmacy. Young men, fascinated by the application of chemistry to pharmaceutical problems, bypassed drugstores to find positions in academe, industry, or government. Those who remained found that scientific discoveries made elsewhere continued to contribute to the stature of pharmacy. The striving for full professional recognition based on educational accomplishments, however, would continue for another half century (43).

Conclusion

In 1821 the Philadelphia College of Pharmacy began training the first generation of professional leaders, inculcating the importance of chemical expertise and the potential glory that awaited the discoverer of the newest active principle. During the middle of the century, these leaders carried the message out to the greater world of pharmacy through the pages of the *American Journal of Pharmacy* and the meetings of the American Pharmaceutical Association. As large-scale manufacturing of preparations increased in mid-century, spurred by the Civil War, pharmacists turned away from making their own compounds. Because of the apprentice-based training model, pharmacy was confronted with a crisis: how would apprentices learn their chemistry when chemicals and compounds were simply bought from wholesalers? Through their journals and societies, the elite of pharmacy tried to battle this trend. Pharmacy was rescued from becoming "mere shopkeeping" by a combination of factors: the rise of the state-supported school of pharmacy, the passage of state licensing laws, and the development of a cadre of academically trained pharmaceutical scientists. The hard fought ascendancy of this latter group made the chemical sciences the centerpiece of American pharmaceutical education for most of the twentieth century.

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THE EARLY DAYS OF CHEMISTRY AT CATHOLIC UNIVERSITY*

Leopold May, The Catholic University of America

In the late nineteenth century, several universities were founded as graduate schools in the United States: for example, Stanford University in the West and Johns Hopkins University in the East. In 1884, the Bishops of the Catholic Church of the United States decided to found a graduate school, which opened in 1889 with 37 students in the sacred sciences (1).

With the advent of graduate schools, no longer would anyone seeking advanced studies in chemistry need to travel to Europe. So, Rev. John J. Griffin went to Johns Hopkins to pursue a doctorate with the organic chemist, Ira Remsen. In 1895 he presented his thesis entitled "On the Reaction of Ethyl and Methyl Alcohol with Paradiazometatoluenesulphonic Acid in the Presence of Certain Substances; and on Metatoluenesulphonic Acid" (2). Griffin, born in Corning, NY, on June 24, 1859, earned an A.B. in 1881 and a M.A. in 1883 from Ottawa College (Canada). After being ordained on May 1, 1885, he served as Instructor in Elementary Physics, Ottawa College, 1885-1886, and then spent 1886 with the Archdiocese of Boston. This year of service yielded important results because years later the priests in Boston contributed funds to purchase chemical journals for the Department of Chemistry at Catholic University. After serving as Instructor in Elementary Physics and Chemistry, Ottawa College, 1887-1890, he started his doctorate studies. During the next five years, during his studies in Baltimore, MD, he taught chemistry at St. Joseph's Seminary and the College of Notre Dame of Maryland (3).

The association with the latter was to last many years. For example (4):

> Reverend John Joseph Griffin of the Catholic University of America" was "instrumental in establishing the chemistry curriculum."…. in 1910. Fr. Griffin flew to purchase state of the art science and laboratory making the new lab '...the finest and most up-to-date in any Catholic college for women.

The chemistry club at the college is named after Griffin. In 1897, a collection of crayon portraits of celebrated chemists was donated by the college to the Department of Chemistry at Catholic University and displayed so that "..the student is constantly reminded of those eminent workers who laid the foundation and aided the development of the science" (5). Unfortunately, these are no longer in the Department. After about a year's illness, Griffin died on November 15, 1921 at the Notre Dame Convent in Baltimore, which is associated with the Notre Dame College.

After receiving his doctorate, he moved 30 miles south from Baltimore to Washington, DC, to organize the chemistry department in the School of Philosophy. In addition to himself as Professor of Chemistry, Drs. Frank Cameron and Thomas M. Chatard were listed as Professors of Chemistry in 1895 (6). The name of the latter never appeared again, and Cameron resigned after two years to take a position at Cornell University (7). The published admission requirements included good moral character and studious habits. For the doctoral degree, facility in reading Latin, French, German, and others, was required before beginning the courses. No religious qualifications were required, and the tuition was one hundred dollars (6).

The Department of Chemistry announcements were introduced with the following statement (8):

> (the course of study was) organized with the general aim of exciting in the student a spirit of inquiry and of training him to the habit of persistent work, and of dealing intelligently and correctly with Nature and its laws. In Chemistry, as in all other experimental sciences, progress consists in the discovery and classification of facts. Hence the student must be made acquainted with the methods of observation, and experiments; facts and the laws of Chemistry. From the very beginning of his course the greatest stress will be laid upon laboratory work; but lectures will be given regularly in General, Organic, Theoretical and Physical Chemistry and from time to time on selected topics.

Rev. Dr. John J. Griffin

The proposed listing of courses for the doctorate is given in the Table. They are similar to the courses offered currently to undergraduates in chemistry with the exception of crystallography and mineralogy, blowpipe and mineralogy, a laboratory course (8). The chemistry laboratories were located in McMahon Building, which contained many of the other departments including the other science departments. The laboratories for gas analysis, general chemistry, analytical chemistry, organic chemistry, balance room, and private laboratory were located in the basement. The lecture room, the apparatus room, the photography room, and the distilled water apparatus were

TABLE

PROPOSED LIST OF COURSES FOR GRADUATE STUDIES IN CHEMISTRY AT THE CATHOLIC UNIVERSITY OF AMERICA IN 1895[a]

No.	**Subject**	**Lec/Lab/week**	**Semester**	**Instructor**
I	General Inorganic Chemistry	3 Lec, 2 Lec 6 Lab, 1 Rec.	1st,2nd year	Griffin
II	Organic Chemistry	2 h, 3 h	1st,2nd	Griffin
III[b]	Physico-Chemical Methods	2 h		Cameron
IV[b]	Crystallography and Mineralogy	Lec & Rec-2	year	Cameron
	Blowpipe and mineralogy	6 Lab	year	
Advanced Work				
V[b]	Advanced Organic Chemistry	2 h	year	Griffin
	Physical Chemistry	2 Lec	year	Cameron
VI[b]	Theory of Chemistry	2 h	year	Cameron
	History of Chemistry	1 h	year	Cameron
	Or VIII - Historical Chemistry[b] Alternating with Special Topics in Chemistry			
VII[b]	Legal Chemistry	10 Lec		
	Laboratory work: quantitative analysis (gravimetric, volumetric, gas & electrolytic)			
	Organic chemistry: study of difficult compounds			
	Journal Club- all members report on current principal articles			
IX[b]	Special Lectures- Advanced students lecture on older literature			

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[a] Ref. 8.

[b] Added in 1896, Ref. 12.

on the 4th floor (9). The courses that were required before doing research for the doctorate were general chemistry, organic chemistry, crystallography and mineralogy, physical chemistry, history of chemistry, and laboratory work in quantitative analysis. The students were also required to attend the Journal Club, which was to meet once a week for examination and discussion of current publications, and special lectures given by students to acquaint their peers with the older literature (8). The Chemical Museum was located on the third floor and contained mineralogical specimens collected by Cameron, products of various refineries, and chemicals prepared by students (10). The library, which was located in the basement, was very important because "the formation of reading habit being an essential factor in the making of a chemist, all of the important chemical journals are kept on file." Friends including priests from the Archdiocese of Boston provided subscriptions to current journals (10). The *CU Bulletin* for 1896 (11) stated that nine students were doing research under Cameron and Griffin. In 1896, a new course (VIII) Legal Chemistry introduced by Griffin involved toxicological investigations. Cameron also introduced new course entitled Theory of Chemistry, (VI) 2 h/yr for which courses I to III and an "ability to follow language of calculus" were required. The topics include chemical equilibrium, theories of solutions, thermo-chemistry, electrochemistry, etc. (12). The laboratory courses (I to IV) were held for six h/wk for the whole year. The laboratory was opened from 2 - 5 P.M. every afternoon and 9 A.M.. to 5 P.M. daily and Saturday, 9 A.M. to 1 P.M. for advanced students (12).

The emphasis in the laboratory work was on analytical and organic chemistry. This is in contrast to the present curriculum, where the laboratory experience in analytical chemistry is minimized. Because of the dominance of Griffin, there was an emphasis on organic chemistry in research and the laboratory courses.

In 1897, Col. Patrick B. O'Brien of New Orleans donated a sum of $150,000 to establish three professorial chairs in chemistry, physics, and sacred science. The Patrick O'Brien Chair of Chemistry was awarded to Griffin and his Department Head successors until 1959 (13).

In 1899, only Chemistry I, General Chemistry; Chemistry II, Organic Chemistry; and Chemistry III, Advanced Work, were offered by Griffin (14).

During summer of 1900, the trolley line of the city and Suburban Railway opened along Michigan Avenue to afford more direct communication with the city; also, it was reported that Michigan Avenue "has been graded and macadamized" (15). In this same year Julius A. Nieuwland, destined to be the first recipient of a Ph.D. in chemistry, entered the university. Born in Hansbeke near Ghent, Belgium, on February 14, 1878, he was brought by his parents to the United States two years later. In 1899, after graduating with a B.A. from Notre Dame in Indiana, he entered Holy Cross College in Washington, DC, where he pursued theological studies at the same time he embarked on his doctoral program. He was ordained in 1903 and completed his thesis, "Some Reactions of Acetylene," earning the Ph.D. degree in 1904 under the direction of Griffin (16).

After receiving his degree, Nieuwland returned to Notre Dame where he spent the rest of his life teaching and doing research in acetylene chemistry. One of his students achieved fame in another field. Knute Rockne, a high school teacher of chemistry, who was studying for a master's degree under Nieuwland, noticed an advertisement for the football coach at Notre Dame. He applied for the position, was accepted, and became a very renowned college football coach. Nieuwland continued his association with the Department of Chemistry at Catholic University, where he died of a heart attack while talking to Prof. Henry P. Ward on June 11, 1936 in Room 218 of the Maloney Chemistry Laboratory. When there were many graduate students doing research in the building, it was rumored that a ghostly figure was seen in the late hours of the night. Perhaps, it was Fr. Nieuwland returning to visit.

During Griffin's lifetime at the University, three additional doctoral dissertations were completed:

Ignatius A. Wagner, "The Condensation Products of Acetone," 1913

A. J. McGrail, "The Reactions of Calcium Carbide with the Vapors of Certain Organic Compounds," 1916

Viictor A. Bast, "The Action of Calcium Carbide on Benzaldehyde and on Some Other Organic Compounds," 1918

Two additional theses were started under the direction of Griffin and completed in 1923 after his death:

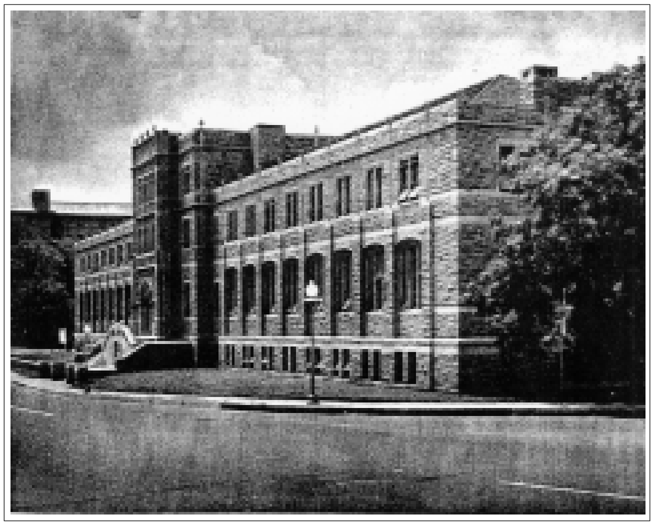
Eugene P. Mullins, "The Catalytic Hydrogenation of the Condensation Products of Acetone"

Henry P. Ward, "The Action of Hot Calcium Car-

> bide on the Vapors of Some Monohydric Aliphatic Alcohols"

None of the results in these dissertations was published in chemical journals, but an abstract of Wagner's dissertation was printed in *Chemical Abstracts* (17).

In 1902, Griffin served also as the Vice-Dean of the Faculty of Philosophy (18), becoming Dean in 1903 and promoted to Very Reverend (19). In the same year that Nieuwland completed his doctoral thesis, the University planned on starting an undergraduate program. On May 18, 1904, the rector, Denis J. O'Connell, wrote to Griffin that the "opening was deferred until (a) full picture of financial status was available" (20). In November of that year, Griffin wrote to the Board of Trustees that there would be "more activity because undergraduates encouraging to all instructors the spirit of work that would have pervaded our halls and inspired professors and students to their best efforts." A few students were admitted (21), and the Board of Trustees endorsed the program. In the fall of 1905, 187 students were enrolled (21). All students were required to take the year of General Chemistry (22). At the present time, those students not concentrating in a science usually take a year of courses specially designed for them: Chemistry in Our Lives, Chemistry in Modern Times, and Science under Oath.



Martin Maloney Chemistry Laboratory

A number of courses were added in 1905: electrochemistry, gas analysis, industrial chemistry, and metallurgy because a program in chemical engineering was offered for undergraduates in the Chemistry Department. Each student was also required to do a bachelor's thesis under Griffin's direction. This arrangement continued until the offerings in chemical engineering were moved to the School of Engineering in 1955 with the Head of the Department of Chemistry serving as the Head until Prof. James Barclay was appointed in 1958. Griffin taught all the courses until 1910, when two assistants were added, Henry B. Froning, in General Chemistry and Clarence E. Baltzley in Metallurgy. Griffin was listed for the other courses as well as serving as Dean, while John W. Rauth was Custodian of Apparatus (23). The next year Charles L. Kelly served as Instructor in Chemistry and William E. Hatcher was the Custodian of Apparatus. Griffin was not listed as Dean (24), but in 1912 he was appointed Vice-Dean of the School of Science. Henry B. Froning was an Instructor, with Clarence J. Johnson serving as Custodian of Apparatus (25). In the following year, 1913, Charles Rascher, who had received a B.S. in Chemical Engineering at the University, and Aloysius J. McGrail served as Instructors in Chemistry, A. O. Mathews as Custodian of Apparatus; Griffin continued as Vice-Dean (26). McGrail remained as an Instructor until 1919 after he had received his doctorate (27). In 1914, Patrick O'Brien was appointed Professor but remained for only one year (28). A new course, municipal chemistry, was added to the undergraduate curriculum, which dealt with water supply, sewage, food, inspections, and sanitation. Griffin gave this course with one lecture and six hours of laboratory (29).

In the summer of 1914, the newly erected east wing of the Martin Maloney Chemical Laboratory, replete with an open laboratory on the roof of the pavilion (30):

> ..was sufficiently completed at the time of the opening of the school year in October to permit transfer of the Department from the restricted quarters in McMahon Hall that it had occupied during the twenty years of its existence. (It is) a granite structure in the Tudor-Gothic style..and consists of a central pavilion and two wings. The pavilion contains four working floors, each having an area of 2,500 square feet and each of the two wings possesses three working floors, having a surface of 5,000 square feet each. The exterior walls are of Port deposit granite with freestone trimmings, and the interior walls are of buff-colored impervious brick. The construction is fireproof throughout. On the ground floor are the laboratories for Metallurgy and Assaying, Industrial Chemistry, Electro-Chemistry, the Lecture Hall, unpacking and storage rooms, gas room and repair

> shop.... The first floor of the pavilion is taken up entirely by a large lobby around which are grouped the show cases of the Chemical Museum. Opening into it is the first year laboratory, that of General Chemistry, which occupies the entire first floor of the east wing of the building....The corresponding floor of the west wing is devoted to the laboratory and supply rooms of Organic Chemistry…The Director's office and laboratory, together with the Chemical Library and Reading Room, occupy the second floor of the pavilion, and the laboratory of Physical Chemistry, that of Quantitative Analysis, balance room, instructors' laboratories, and a small number of rooms devoted to special methods and research take up the second floor of the wings. A smaller Lecture Hall, a Photographic laboratory, the apparatus office and stock room occupy the third floor.

When the building was renovated in the 1960s, there remained little evidence of the Chemical Museum maintained by Griffin. The remains of the mineralogical collection were donated to George Washington University. The Lecture Hall was certainly never built because a separate building connected to the Martin Maloney Chemical Laboratory was constructed in 1923. The furniture in the laboratories on the second floor was donated to the Smithsonian Museum, where some pieces were used in the display of Ira Remsen's Laboratory.

In the 1915 academic year Frederick S. Cosgrove was appointed Instructor and Griffin served as Vice-Dean of the School of Science (31). In the next year two new instructors were appointed: Philip W. Shepard and Daniel F. J. Lynch, who remained until 1919, Griffin continuing as Vice-Dean (32). In 1917 an undergraduate course in the chemistry of photographic processes was to be taught by Griffin (33). The remainder of the building was scheduled to be completed in the fall of 1917 (34).

With the imminence of the declaration of war by the United States, the military subcommittee of the Chemical Committee of the National Research Council accepted the offer of cooperation of the Bureau of Mines "to carry on investigations into noxious gases, generation and antidote for same, for war purposes, also investigations into gas masks" (35). On April 3, 1917 Charles L. Parsons initiated a census of chemists in the United States in February 1917 jointly sponsored by the Bureau of Mines and the American Chemical Society (35). He was then the chief chemist of the Bureau of Mines and Secretary of the American Chemical Society. A listing of research chemists in the United States was prepared for the Chemical Committee of the National Research Council in mid-1917 by Marston T. Bogert, who had been president of the American Chemical Society in 1907-1908 (36). At the end of May, 1917, laboratories in 21 universities, three companies, and three government agencies were involved in this work involving a total of 118 chemists (37). The head of Chemical Warfare Research at the Bureau, George A. Burrell, selected American University as a research center on April 30, 1917 (37). The chemists, some of whom were in the Army, arrived in September to occupy uncompleted laboratories (37). The operation was financed by the War and Navy Departments and operated by the Bureau of Mines (38). By January of the next year there were about 200 officers and 500 enlisted men at the American University Experiment Station (39).

In 1917 the Rector of the Catholic University of America wrote to U.S. President Woodrow Wilson (40):

CATHOLIC UNIVERSITY OF AMERICA
WASHINGTON, D. C.
OFFICE OF THE RECTOR

March 28, 1917

Your Excellency:

In view of the present emergency, the Catholic University of America has the honor to offer itself to you for such services as the Government of the United States may desire from it.

With sentiments of profound respect, I have the honor to remain,

Very faithfully yours.

THOMAS J. SHAHAN,
Rector

His Excellency Woodrow Wilson
President of the United States
The White House
Washington. D. C.

The President responded as follows:

> THE WHITE HOUSE
> WASHINGTON
>
> *March* 30, 1917
>
> MY DEAR BISHOP SHAHAN
>
> Let me thank you warmly for your generous letter of March 28. I am very grateful to you for your pledge of cooperation and support.
>
> Cordially and sincerely yours
>
> WOODROW WILSON
>
> RIGHT REVEREND THOMAS J. SHAHAN
> Rector
> Catholic University of America
> Washington, D. C.

About January 15, 1918, Dr. W. Lee Lewis, Associate Professor of Chemistry at Northwestern University and Captain in the U.S. Army, was sent to establish a new unit (Organic Unit No. 3) of the Offense Research Section of the Experiment Station in the Martin Maloney Chemistry Laboratory. This was a result of the Shahan-Wilson correspondence and the association between Griffin and Col. J. F. Norris, who had done graduate work together at Johns Hopkins University (40). Norris was the commander of the American University Experiment Station. The site was also selected because of the "adequate laboratory space" given to the unit, "the excellent library, one of the finest in the country, and the superior appointments of the building together with the cordial attitude of the staff" (40). The mission was the discovery and development of new offense weapons. Another segment of the Offense Research established at this time was the Research Analytical Unit, which was concerned with the development of analytical methods for new compounds and analysis of materials that could be done with ordinary procedures. The Catalytic Unit was concerned with preparing fluorine and fluorinated derivatives, ethylene tetrachloride, acetic acid, and chlorinated and brominated ethers. The Dispersoid Section worked on the dispersion of toxic solids. From June 17, 1918 to January 1, 1919, a unit of the Defense Research Section, concerned with the preparation of clothing for protection against war gases, was stationed in the building. As the number of personnel grew, a Safety Department was established. This service unit included a nurse, a driver, a telephone operator, an orderly, and a policeman in addition to safety engineers. The unit was closed on January 1, 1919 (40). On June 25, 1918, the Experiment Station was transferred from the Bureau of Mines to the War Department. Three days later, the Chemical Warfare Service was founded as part of the National Army (41).

The principal project of Organic Unit No.3 was initially concerned with the production of mustard gas. This work was done at American University because the hood ventilation at the Martin Maloney Chemical Laboratory was poor (42). Dr. R. R. Williams, previously with the Bureau of Mines, worked with the unit for two months in 1918 to isolate ricin from castor beans. This extract, highly toxic to animals, had been isolated in 1905 (43). It was presumably prepared to be used on the enemies' horses, which were used in transportation of guns, etc.

About April 13, 1918, a quantitative study of the reaction of acetylene with arsenic trichloride, which had been described by Nieuwland in his thesis, was initiated. The observation appeared in Nieuwland's thesis as follows (44):

Arsenic Trichloride ($AsCl_3$)

> Pure arsenic trichloride free from oxide did not show any reaction with perfectly dry acetylene. When aluminum chloride was added the absorption of the gas was effected with the evolution of considerable heat. The contents of the flask turned black. When decomposed by pouring the substance into cold water, a black gummy mass separated out, and on standing for some time crystals appeared in the aqueous solution. The tarry substance possessed a most nauseating and penetrating odor, and was nauseating and penetrating odor, and was extremely poisonous. Inhalation of the fumes, even in small quantity cause nervous depression. No chlorine derivatives of acetylene were noted. Owing to the poisonous nature of the compounds formed, their thorough investigation was postponed.

The reaction involves the synthesis of dichloro (*trans*-2-chlorovinyl)arsine with aluminum chloride as the catalyst. The product, a potent blister agent with a geranium-like odor, was named lewisite. It was designated Agent L and manufactured in Willoughby, OH. Mustard gas ($[(ClCH_2CH_2)_2S$ is also a blister agent with a weak, sweet, and agreeable odor. A eutectic mixture of lewisite and mustard designated HL was used also a blister agent. A shipment of lewisite was on the high seas to Europe when the armistice was signed. The U.S. Navy sank the vessel at sea (45). Although its existence was kept secret during the war, several papers describing the reactions were published in the 1920s (46). Most of the chemists left at the Organic Unit No.3 by December 15, 1918, and the unit was formally closed on January 1, 1919 (40).

Cpl. Henry P. Ward was one of the chemists working on these projects. After he was discharged from the U.S. Army, he entered the graduate program in chemistry at Catholic University. His forty-four year association terminated when he retired as an Ordinary Professor in 1962. When there was construction of new buildings near the Maloney Chemistry Laboratory during the 1960s, he was concerned that lewisite might still be present in containers buried behind the building after World War II. These fears were unfounded, as no evidence of these containers was unearthed. However, the paint on the ceilings in some of the rooms in the building continually peeled because of to the hydrolysis of the absorbed lewisite. The ceilings are now hidden by the false ceilings installed during the renovation of the building in the 1960s.

In 1919, Lynch and McGrail were replaced as instructors by Thomas F. Power and Ward, with Griffin serving as Vice-Dean of the School of Sciences (47). Eugene P. Mullins replaced Power in 1921 (48). Griffin (48) was no longer Vice-Dean but served as a delegate from the School of Sciences to the Academic Senate of the University. The next year after Griffin died, Dr. Hardee Chambliss replaced Griffin as Patrick O'Brien Professor of Chemistry and Head of the Department of Chemistry (49). There were twelve candidates for advanced degrees listed in 1921(50). This number is considerably higher than in previous years where the number was about three to five.

The early years of the Chemistry Department from 1895 to 1921 were dominated by Griffin. Initially the department was established as a graduate program and in 1905, undergraduate studies in chemistry and chemical engineering were introduced. Throughout the period of 1897 to 1921, Griffin was the only professor, assisted in many years by one or two instructors. He was the sole research supervisor for the chemistry graduates and the chemical engineering undergraduates. During this period, he supervised four doctoral and about twenty Master dissertations. All of the research was in the area of organic chemistry, which was the major interest of Griffin.

ACKNOWLEDGMENT

I thank the Department of Archives, Manuscripts, and Museum Collection of The Catholic University of America for the photograph of the Rev. Dr. J. J. Griffin and their assistance during the research for this paper. I appreciate the assistance of Mr. Thomas E. Murrell of the U. S. Corps of Engineers, in obtaining the Archives Search Report on Catholic University, March 1995, which contained some of the reports cited here.

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M. CAREY LEA, THE FATHER OF MECHANOCHEMISTRY

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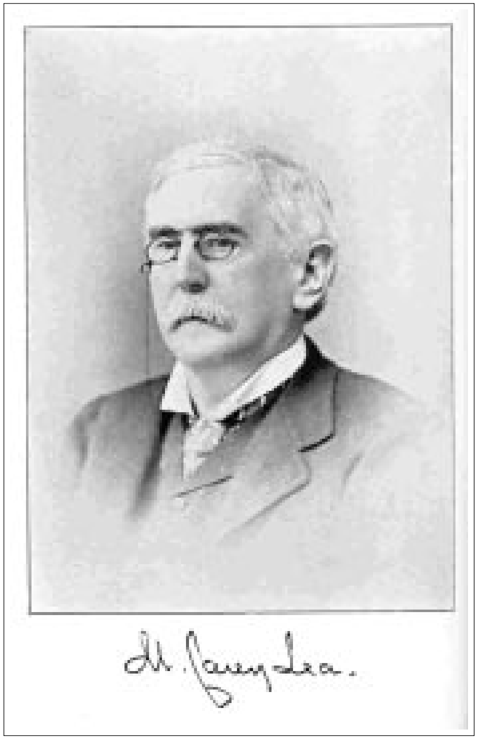
Introduction

Most historical reviews of mechanochemistry mention the papers of Matthew Carey Lea as the first systematic investigations on the chemical effects of mechanical action. Yet, very little is known about the person, his motivation and the details of his results. The original literature is not easily accessible and the two existing biographies (1, 2) focus on his results in photochemistry and the study of "allotropic silver," but overlook the importance of his mechanochemical experiments. The objective of this paper is to address these shortcomings through examination of Lea's work in mechanochemistry, by exploring how his ideas developed from observing the pressure sensitivity of photographic plates to the systematic investigations on the mechanochemical decomposition of compounds 26 years later.



M. Carey Lea.

Mechanochemistry is the study of chemical changes induced by pressure, shear, impact or friction (3). Some mechanochemical effects, such as the use of impact to initiate explosives and the grinding of salts to accelerate dissolution, are considered common knowledge, while others, like the reduction of carbon dioxide by gold under mechanical action, are quite unexpected (4). Mechanochemical reactions are often induced in ball mills, where the compression and shear between the colliding milling balls are used to drive chemical transformations in a mixture of reactant powders. Combination reactions, such as the formation of metal sulfides from a mixture of metal and sulfur powders, displacement reactions between a metal oxide and a more reactive metal and a variety of other inorganic and organic reactions have been induced by ball milling (5). Mechanochemical methods can be utilized in the processing of silicates (6) and minerals (7) and mechanical alloying is basically mechanochemical processing applied to metallurgical systems (8).

Most chemical reactions follow the same path whether induced by mechanical action or heat. For example, if CuO is ball milled with an appropriate amount of Fe powder, Cu metal and Fe_3O_4 are obtained. The same reaction can be induced by heating the powder mixture to high temperature. One could argue that the only direct result of the mechanical action is the generation of heat and if any chemical change is observed, it is due to a secondary thermochemical process. This phenomenon was questioned by Lea, however, with his recognition of the first indications that mechanochemical reactions can be fundamentally different from thermochemical ones, which he reported at the end of the 19th century (9-12). His most important observation was that silver halides decompose by trituration in a mortar, although they melt when heated. This is the result that established mechanochemistry as a separate branch of chemistry.

Carey Lea was about seventy years old when he performed these famous experiments on the mechanochemical decomposition of compounds. That work, however, was not without precedent. He discovered the effect of mechanical pressure on photographic plates already in 1866 and used it shortly thereafter to produce developable images that resembled the images produced by light (13). The similarity between the effects of pressure and light was extended into a parallelism relating the chemical effects of different energy forms, including heat, light, and chemical and mechanical energy. This parallelism provided the framework for Lea's systematic studies on the chemical changes of silver halides and "allotropic silver" (14-16). He found that the application of a small amount of energy always produced an impression that could be brought out with a photographic developer, while a larger amount of energy usually resulted in an immediately visible color change. He found only one exception, namely that mechanical energy generated by the rounded end of a glass rod was not capable of reducing silver halides without the aid of a developer. Lea suspected that more intense mechanical action was needed and decided to use grinding in a mortar as the source of mechanical energy. The results were positive, providing the motivation for the systematic investigation of mechanochemical decomposition (9-12).

The Life of M. Carey Lea (1823-1897)

Matthew Carey Lea was born in Philadelphia, August 18, 1823, to a family of considerable privilege and exceptional intellectual background. His father, Isaac Lea (1792-1886), was a distinguished naturalist, an expert on contemporary and fossil shells; his collected works fill thirteen large volumes. Isaac Lea was the descendant of an influential Quaker family, the great-great-grandson of John Lea, who emigrated to America with William Penn in 1699. Carey Lea's mother was Frances Anne Carey (1799-1873), a strong and intellectual woman, who gave ample attention to the education of her children. She was the daughter of Matthew Carey (1759-1839), an Irish patriot, who fled to America from political persecution in 1784 and became an eminent writer and the founder of a major publishing house. After marrying Frances Anne Carey in 1821, Isaac Lea joined the publishing business and became a partner. The other partner at the time was his brother-in-law, Henry Charles Carey (1793-1879), who was also a reputable economist.

Matthew Carey Lea was the second son of the family, the eldest son (also called Matthew) having died in infancy. His younger brother and best friend, Henry Charles Lea, (1825-1909) continued the family's publishing business. He was also an eminent writer on philosophical and historical subjects and an expert on the history of inquisition. Early in his life, he also published a few papers on chemistry in the *American Journal of Science*. The youngest child of the family was Frances Lea (1834-1894), who dedicated much of her life to caring for her ill mother.

Because Carey Lea suffered from weak health from his early childhood, he was not sent to boarding school but received his education at home from a private tutor. He and his brother formed the "class" of Eugenius Nulty, a teacher with broad background in both the sciences and the humanities. After a short excursion into law—he was admitted to the Philadelphia bar in 1847—Lea studied chemistry at the consulting laboratory of Prof. James C. Booth. His later experiments were performed in the private laboratory of his home in the Chestnut Hill district of Philadelphia.

Few chemists knew Lea personally. His weak health and a laboratory accident that damaged one of his eyes made him an elusive figure. He worked quietly and independently in his laboratory, keeping contact with the rest of the scientific community through publications. The breadth of his scientific achievements is clearly shown by the list of the more important papers included in his Biographical Memoirs (1). It contains more than 100 titles, published mainly in the *American Journal of Science*. In addition to his scientific papers, he published close to 300 technical articles and correspondences in the *British Journal of Photography*. He wrote his only book on photography, a comprehensive manual that includes chapters on optics and practical picture-taking techniques, as well as photochemistry, laboratory techniques, and safety (18). Lea was thoroughly familiar with the results of others and read and quoted the scientific literature published in English, French, and German.

For someone so active and eminent in science, he belonged to few scientific institutions. He was not associated with any university department. As a member of the Franklin Institute from 1846, he used its library collection extensively but never participated actively in the work of the Institute. In 1895* he was elected a member of the National Academy of Sciences.

In 1852 Lea married his cousin, Elizabeth Lea Jaudon, with whom he had his only son, George Henry Lea. After the death of Elizabeth in 1881, he married Eva Lovering, the daughter of Harvard professor Joseph Lovering.

Matthew Carey Lea died on March 15, 1897, in the seventy-fourth year of his life, from complications related to a prostate operation. Unfortunately, his notebooks were destroyed in accordance with his desire (2), seriously limiting the information available about his work. His scientific books and apparatus were donated to the Franklin Institute, together with a substantial fund in perpetuity for the purchase of books and journals.

The Observation of Mechanochemical Effects in Photochemistry

Although Carey Lea's most lasting contributions are in mechanochemistry, during his lifetime he was primarily known as an expert on the chemistry of photography. In the list of his most important scientific papers, the first photography-related article is dated 1864 (1). The following five years of his life brought incredible activity on the subject: Besides eight scientific works published mostly in the *American Journal of Science*, Lea wrote extensively for the technical magazines of photography. In 1865-66 alone he published 140 papers and correspondences in *The British Journal of Photography*. They cover every subject related to photography from optics, laboratory techniques, and practical hints to applications, legal matters and even a few related anecdotes. Some papers describe scientific experiments related to the chemical foundations of photography.

The most important, yet the most evasive and controversial question of photographic chemistry during this period regards the nature of the latent image. According to modern theory, its formation involves photoionization, defects acting as traps, local electric fields, diffusion, nucleation, etc. (19). Some details of the theory are still ambiguous today. In the 1860s anything beyond empirical studies and speculation was beyond the power of science. Two theories, "chemical" and "physical," competed with each other. The proponents of the chemical theory believed that the exposure of a silver halide to light resulted in an incipient reduction to a subhalide or even metallic silver and that the reduction of the remaining silver halide was catalyzed by the minute reduced fraction during development. Lea fiercely opposed this view, at least in the case of pure silver iodide. In 1866 he wrote (20):

> Does chemical decomposition necessarily accompany the production of an impression upon iodid of silver? In my opinion *it does not*. I hold that: When perfectly pure iodid of silver, isolated, is exposed to light, it receives a physical impression only.

Lea based his opinion partly on chemical evidence (20):

> ...even when the action of light is prolonged to many thousand times the period sufficient for the production of a developable image, still no chemical alteration can be detected in the exposed iodid.

Generalizing this observation to photographic plates based on other silver halides, supporting the "physical" theory of the latent image, he insisted that, although some sort of chemical change during exposure of a photographic plate was possible, it was not necessary. A physical impression was perfectly sufficient to carry the latent image.

Although Lea considered such chemical evidence a decisive proof of the physical theory, he offered an even more conclusive one, through an argument based on mechanical action (13):

> ...no confirmation of the physical theory could be more striking than that which would result, if it could plainly be shown that a purely physical cause, independently of light, was competent to control development; and that if this cause was not merely physical as distinguished from chemical, but also purely mechanical in its nature, there would result an inference which the advocates of the chemical theory would find it extraordinarily hard to countervail.

The language of the statement clearly reflects his excitement over this idea. Curiously enough, Lea, who later performed the first systematic studies on mechanochemistry, considered the production of a developable latent image by pure mechanical force a very strong argument for the physical theory, because—as he stated very explicitly—a *mechanical* cause certainly could not produce any *chemical* impression. As he wrote in the same paper (13), "Here is no possibility of reduction, no possible production of metallic silver, or of subiodid, no possible elimination of iodine ..." In order to test his idea, he selected a ruler with carved-out letters and an embossed card with raised lettering, pressed them against sensitized photographic plates in the dark, and brought out an image of the lettering by developing the plates. Clearly, the image originated from the different pressures under the carved-out or raised letters and the rest of the surface. Of course, there is another possible explanation: pressure may actually produce a chemical change that is amplified by development; but in 1866 Carey Lea did not even consider this possibility.

Photographic chemistry remained the main topic of Lea's research for the next two decades, although his work on the topic was not as intense as it was during 1864-66 (1). As his objection to the chemical theory of the latent image faded, he began to attribute the latent image to the formation of "photosalts," combinations of a silver halide and a small amount of sub-halide. His last paper on photographic chemistry was published in 1889. Dry plates and films were produced on an industrial scale by then, and Lea in his small private laboratory could not compete with the resources of the emerging photographic industry.

Transformations of Allotropic Silver

Probably Lea's best-known discovery is that of "allotropic silver" (21). He took up the study of the reduction products of silver in connection with the investigation of the photosalts in 1886. The reduction of silver citrate by ferrous citrate provided several new forms of silver in a reproducible manner. Depending on the proportions of the reactants and on the method of purification, three forms of allotropic silver were found: A, soluble; B, insoluble, derived from A; and C, gold-colored. All these forms of silver were sensitive to light (22). Some allotropic silver samples prepared by Lea are preserved in the Library of the Franklin Institute, (23). What Lea considered solutions of allotropic silver were in fact colloids, and the dried forms would be classified as porous nanocrystalline materials today. Nevertheless, his recipe is still useful to make silver sols for physical investigation (24).

Allotropic silver, however, was particularly interesting to Lea because of its light sensitivity. Exposure to light for an extended amount of time converted gold-colored silver into an intermediate form and finally to ordinary white silver. Lea also made an observation that was directly related to mechanochemistry (25):

> I brought with me to my summer home a number of specimens in tubes... On opening the box no tubes of gold colored silver were to be found, all had changed to white. But the same box contained pieces of paper and of glass on which the same material had been extended; these were wholly unchanged and had preserved the gold color perfectly. Apparently, the explanation was this, the mere vibration caused by the jarring of a journey of 600 miles by rail and steamboat had had no effect in changing the molecular form, but the material contained in the partly filled tubes had been also subjected to *friction* of pieces moved over each other, and this had caused the change.

To confirm this interpretation, he sent a tube, partly filled with gold-colored silver but rendered motionless by being tightly packed with cotton wool, on a 2,400-mile train trip. The sample arrived back unaltered, while the control samples that were left loose in partially filled tubes became white.

Lea investigated the properties and transformations of allotropic silver in significant detail over the next two years. Some properties, such as light sensitivity and the formation of allotropic silver from partially reduced halides or oxides, suggested structural similarities between the subsalts of silver and allotropic silver (26). This question was discussed systematically in a series of three articles published in 1891 (14-16). In the first paper Lea described the properties and reactions of gold-colored allotropic silver (14). He also attempted "to prove that all forms of energy act upon allotropic silver, converting it either into ordinary silver or into the intermediate form. Mechanical force (sheering stress) ... converts it directly into ordinary silver." When allotropic silver is converted into a more stable form, it becomes less dispersed, as indicated by the lower reactivity and larger density. This observation led to the "working hypothesis" on the nature of allotropic, intermediate, and ordinary silver "that they may represent the three possible molecular forms of silver, viz: *atomic, molecular and polymerized* (15)." If taken literally, this statement is naive, but one can focus on the logic of Lea's reasoning. He claimed that silver in its compounds must exist in the atomic form. Consequently, a parallelism is anticipated between the transformations of allotropic silver and the reduction of silver halides. Experiments confirm the existence of such a parallelism. The application of a small amount of energy—heat, light, mechanical force, electricity (high tension spark), and chemism—produces a latent change that can be brought out by the application of a developer. A larger amount of energy usually brings about full decomposition, as indicated by color change.

There was only one exception to the above parallelism between allotropic silver and silver halides. Mechanical stress, namely sheering and pressure applied with the rounded end of a glass rod, was capable of fully transforming allotropic silver into regular silver, but it only produced a developable impression in halides. No visible reduction could be effected this way. Lea decided to investigate whether this asymmetry was indeed valid, expecting the contrary. The resulting investigation is his first systematic study on the chemical effect of mechanical action (9).

The Four Papers on Mechanochemistry

In 1892 Lea proved conclusively that any form of energy, including mechanical, was indeed capable of disrupting silver halide molecules (9). The paper presenting the results was read before the National Academy by George F. Barker. This is a very important work, rich in ideas and ground-breaking results. The chloride, bromide, and iodide of silver were investigated, and to all were applied both static pressure and shearing stress. He applied 100,000 pounds to the square inch (about 6,900 times atmospheric pressure) to halide powders wrapped in platinum foil, the pressure being maintained for 24 hours. The coloration of the powders clearly indicated that some decomposition of the halide had taken place. The decomposition of the iodide was surprising for Lea, because it did not decompose upon exposure to light.

Lea next used trituration in a porcelain mortar to deliver large amounts of shear. Initially he was skeptical about decomposing the silver halides by the relatively weak forces during trituration. Therefore, he added tannin as a weak reducing agent to the silver chloride before grinding it in a mortar. The reaction was so quick that he decided to use an additive, namely sodium carbonate, which was capable of taking up acid but lacked reducing power of its own. The characteristic coloration was observed again, indicating that reduction took place. Finally, he repeated the experiment without any additive, to explore whether silver chloride could not be disrupted by stress alone (9):

> For some time no effect was visible. After about ten minutes' action dark streaks began to appear and after about five minutes' more work a considerable portion of the chloride was darkened.

Based on its color and reactivity, he identified the darkened portion as silver photochloride, i.e. a molecular combination of a chloride and a hemichloride. He obtained similar results with silver bromide.

For Lea, the main objective of this series of experiments was to prove that "..every form of energy is not only capable of producing an invisible image, that is, of loosening the bonds which unite the atoms, but is also capable, if applied more strongly, of totally disrupting the molecule." For today's mechanochemists, the relevance of the experiments is much broader. Even the abandoned trials and the decomposition experiments in the presence of other reactants are quite interesting, although they are never mentioned in later references to Lea's works. In a discussion on the role of heat, he noted that it could be important when generated by friction, but "in the case of simple pressure heat certainly plays no part (9)." This is not quite so. Although the mechanical work done by the press on the powder is indeed negligible, the experiment is carried out under isothermic rather than adiabatic conditions. Nevertheless, the role of heat, if any, is certainly different in the cases of static pressure and trituration; yet the halides were decomposed by both.

The paper described above (9) is the prelude to the purely mechanochemical investigations published in a series of three articles during 1893-94 (10-12). The main theme of these papers is the initiation of *endothermic reactions*, specifically the decomposition of compounds with negative heat of formation, by the application of mechanical force.

The effect of static pressure was investigated in the first paper (10). In an examination of the possible decomposition of 15 materials, strong darkening was observed in silver salicylate, potassium platinobromide, and mercuric oxychloride. Mercuric iodide showed considerable darkening, although no free iodine was detected. Other materials showed less pronounced effects or no darkening at all.

The second part of the series is the most important of Lea's writings on mechanochemistry (11). He begins with a review of the existing literature, concluding that, "Of the relations which exist between two forms of energy, mechanical and chemical, very little if anything is known." He quotes Ostwald (27), who introduced the term "mechanochemistry" by analogy to thermochemistry and photochemistry, but stated that "almost nothing" was known about it. A lengthy quotation from Horstmann exemplifies the general view of chemists at the end of the 19th century. It concludes by stating that "...it cannot be admitted that actual chemical changes can be brought about by mechanical impulse." Carey Lea set out to prove the contrary.

Although static pressure was capable of inducing chemical decomposition (10), the actual decomposed fraction was quite small. Lea recalled from his investigation of silver halides that shearing stress could initiate reactions much more efficiently than static pressure (9). Therefore, he performed decomposition experiments on at least 17 materials with a mortar and pestle. The most important examples are sodium chloroaurate and the chlorides of mercury and silver (11).

The decomposition of sodium chloroaurate was studied, as the reaction product, metallic gold could be separated easily and weighed, making the quantitative measurement of the reduced fraction possible. In one experiment, the trituration of 0.5 g of chloroaurate for half an hour yielded 10.5 mg of pure gold - a sizable quantity. Using reaction heat data from the literature, Lea estimated that the decomposition of the appropriate amount of chloroaurate required 518 gram-meters (about 5 Joules) of energy. This energy had to originate from the mechanical work of the trituration.

Mercuric chloride is a very important example for two reasons: For one, it was not decomposed by static pressure, but easily acted upon by trituration. More importantly, it sublimes rather than decomposes upon the action of heat. This is one of Lea's frequently cited results, the first example of a mechanochemical reaction that brings about an outcome different from the effect of heat. Incidentally, silver chloride melts undecomposed when heated, but decomposes by trituration, providing another example where the effects of heat and mechanical energy are distinctly different.

Shearing stress was also applied in a different, less energetic way. A piece of strong paper was treated with the material to be investigated, laid upon a piece of plate glass, and marked with the rounded end of a glass rod (11). The appearance of darkened lines was regarded an indication of decomposition. The idea was adapted from earlier studies in photochemistry (13). As Lea wrote, "More than twenty years ago I was able to show that marks made in this way on a sensitive photographic film could be developed, as an invisible image had been impressed. That, however, is a somewhat different matter from actual and visible decomposition following each stroke of the rod..." He also used the same method to apply shearing stress to allotropic silver, spread over boards of paper (14). In the current experiment, he applied the method to about a dozen silver, platinum, and mercury compounds. Usually positive results were obtained on the same materials that could be decomposed by trituration. Silver chloride was an exception that did not show distinct marks from the pressure of the glass rod, although it did respond to trituration.

Some quantitative examples are given in the last paper of the series (12). Silver oxide is soluble in ammonia but silver is not. Using this difference in solubility, Lea could separate the two substances after trituration in order to weigh the decomposed fraction. He also studied mercuric oxide. It could be separated from its decomposition products because mercuric oxide dissolves in dilute hydrochloric acid, but mercury does not. Consequently, quantitative measurements of the decomposed fraction were possible. Similar experiments were performed on silver carbonate and sulphite, auric oxide, and potassium permanganate. The iron in potassium ferricyanide and ferric ammonia alum could be reduced to the ferrous state by trituration.

Lea himself considered the difference between the effects of heat and stress a very significant finding. After a failed attempt at reducing cupric chloride by trituration, he wrote (12):

> This reaction taken with the preceding shows how distinct is the action of mechanical energy from that of heat. For cupric chloride is reduced by heat to cuprous chloride, but shearing stress has no such action. On the other hand shearing stress reduces ferric sulphate which heat does not.

His understanding of the clear difference between the effects of heat and mechanical action justifies identifying Carey Lea as the true founder of mechanochemistry. Not only did he show that mechanical action was capable of inducing chemical changes, even endothermic ones, but he also proved that these changes were sometimes different from those produced by heat.

Choosing the most suitable mechanochemical reactor and processing conditions is an important problem for today's mechanochemists. Besides his important fundamental observations, Lea also investigated the practical question regarding benefits and problems associated with the choice of different mortars and pestles. Unglazed porcelain had the disadvantage that "a very appreciable amount of material is removed from the mortar and pestle. (12)." Minimizing contamination from the milling bodies is still an important issue in mechanochemistry. Lea also stated that a metal mortar was not appropriate for his experiments because of the possibility of chemical interaction (11). He tried to use an agate mortar, but the amount of chemical change was "only one fifth to one-tenth of a porcelain mortar of the same size." Quantitative comparisons on the decomposition of silver oxide were performed to establish this fact. Lea blamed "the high polish which is very unnecessarily given to the inside of agate mortars" for the difference. He favored porcelain mortars, but the abraded material had to be separated from the product (12). Lea also mentioned that the quantity of the processed material should be small, only about a few tenths of a gram (11). The analogous problem is well known to modern mechanochemists, who usually limit the mass of the powder to less than one fifth of the total mass of the balls. Selecting the proper type of mechanochemical reactor is another important practical problem, because different combinations of compression and shear may result in different reaction products, just like mercuric chloride and silver tartrate responded to trituration but not to static pressure in Lea's experiments (11).

Questions on Priority

As Barker describes, Carey Lea "was naturally retiring in his disposition and, owing, no doubt, to his continued ill health, lived the life almost of a recluse (1)." Yet, he was aware of the value of his work and made sure that his achievements would become widely known. He published his most important findings in more than one journal, first in both *The British Journal of Photography* and *The Philadelphia Photographer* (13) and later in the *American Journal of Science* and the *Philosophical Magazine* (9-12, 14-16). Papers 10-12 on mechanochemistry (and a few articles on other subjects) were also published in German translation in the *Zeitschrift für Anorganische Chemie*. The papers make reference to earlier publications in the same journal but not to the parallel versions in other periodicals. This is sometimes confusing, as references to two papers published at about the same time in two different journals may refer to the same article; but, given the large number of publications, that is not necessarily the case. The list of references at the end of this paper is grouped together according to different versions of the same paper as a means of clarification. Summaries and full copies of Carey Lea's papers appeared regularly in other journals, such as the *Chemical News* and the *Journal of the Franklin Institute*.

Lea's experiments in 1892-94 are usually cited as the first systematic investigations related to mechanochemistry (9-12). They certainly provide an overwhelming array of new ideas and conclusive experiments, far beyond anything published earlier by others. However, some attempts to investigate the chemical effects of mechanical action preceded the works of Lea.

The earliest known mention of a mechanochemical process is that by Theophrastus of Eresus on the preparation of mercury from cinnabar by trituration (28). Although that remark extends the history of mechanochemistry into antiquity, it is only a single sentence on a single reaction, far from a systematic study.

Lea himself made reference to two earlier investigations, those of Spring in Ref. 15 and 10 and of Hallock in Ref. 10. He wrote (10):

> In Prof. Spring's well known investigation, combination was brought about between substances whose tendency to combine was restrained by their being in the solid form. ... The same remark applies to some of the interesting experiments of Dr. Hallock.

Therefore, Lea not only knew about earlier investigations but acknowledged them in his own papers.

In spite of these references, Professor Walter Spring at the University of Liége made a strongly worded claim of priority. This, together with the response from Carey Lea, can be found in *Zeitschrift für Anorganische Chemie* (29-31). Whether the claim of Spring is well founded or not is open to question. It is certainly true that his investigations were published about 10 years before Lea's interest turned to mechanochemistry (32, 33). It is also true that Spring's experiments covered several reactions and involved both pressure and shearing stress, but he studied only exothermic reactions. Lea never claimed that his had been the first observation of a chemical effect by mechanical action, only that he was the first to induce endothermic reactions by mechanical energy. Also, the early studies of Lea on the effect of pressure on sensitized photographic plates were performed in 1866, pre-dating Spring's investigations by another 15 years. In any case, it is worth taking a careful look at Spring's papers and giving them proper credit in the history of mechanochemistry.

The other person mentioned by Lea was William Hallock, a researcher with the U. S. Geological Survey. His primary interest was the possible liquefaction of solids under pressure and the possibility that liquefaction may also result in chemical reactions (34, 35). This question is of utmost importance for the geologist, but it is somewhat farther from the main issues of mechanochemistry.

Epilogue

In this study the scientific achievements of Carey Lea have been analyzed from the point of view of mechanochemistry. His well-known experiments were performed when he was already seventy years of age, but they followed logically from his earlier investigations. Hints on the chemical effects of mechanical stress were already observed during his work in photochemistry, and the methods and materials of the later studies reflect that experience. His desire to develop a consistent theoretical framework for the action of different forms of energy gave him the direct motivation to study mechanochemical reactions.

While Lea investigated the effect of pressure and shearing stress on dozens of materials, some of his results stand out as the clearest demonstrations of the difference between the action of heat and mechanical energy. These most important findings are:

- Silver halides decompose by trituration, but melt when heated.
- Mercuric chloride decomposes with trituration but not with pressure or heat.
- Cupric chloride is reduced to cuprous when heated, but does not respond to trituration.
- Ferric ammonia alum is reduced to ferrous by trituration but not by heat.

During his life, Carey Lea was known as a pioneer in photographic chemistry, and later his discoveries on allotropic silver were praised widely. These are the two achievements mentioned in the obituary published in the *American Journal of Science* (36). New instrumental methods and intense development brought tremendous advances in photographic chemistry, few statements of Lea are considered strictly valid today. The allotropic forms of silver were shown to be silver colloids instead. These results were important steps in the development of chemistry, but they were superseded by new ideas. However, Lea's results on the decomposition of some compounds by mechanical action are still the clearest demonstrations of the fact that the chemical changes produced by mechanical action are distinctly different from those effected by heat. These results secure for Matthew Carey Lea a place among the great chemists whose contributions are valid and important more than one hundred years after their publication.

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ANDRÉS del RÍO, ALEXANDER von HUMBOLDT, AND THE TWICE-DISCOVERED ELEMENT

Lyman R. Caswell, Seattle WA

The Spanish-Mexican mineralogist Andrés del Río is today acknowledged as the discoverer of Element 23, although its accepted name, *vanadium*, was given to it by Swedish chemist Nils Sefström some 30 years after del Río's discovery. The initial failure to recognize del Río's work, and to assign his name, *erythronium*, to the element, was the result of poor communications, reliance on a friend, German naturalist Alexander von Humboldt, and, possibly, to prejudice. In this paper these effects will be examined, along with a misinterpreted analysis that also contributed to that failure.

Andrés Manuel del Río y Fernández was born in Madrid, Spain on November 10, 1764 (1). His early education, in classical subjects, resulted in a bachelor's degree at the age of 15 from the University of Alcalá de Henares. His scientific education began two years later with private instruction in physics. Thereafter, he concentrated his studies on mineral chemistry, analytical chemistry, and, especially, mineralogy.

In June 1782 Del Río enrolled in the Royal Academy of Mines at Almadén, Spain, with a scholarship from the Spanish Crown. At Almadén he studied chemistry, geology, mineralogy, and mining engineering. In 1783 the Spanish Ministry of Mines provided him with a grant for travel and advanced study elsewhere in Europe. He went to Paris, where he spent four years studying mineral chemistry with Jean d'Arcet, professor of chemistry at the Collège de France and director of the porcelain factory at Sèvres.

In 1789 Del Río enrolled in the Mining Academy at Freiberg in Saxony. The director of the Freiberg Academy, Abraham Gottlob Werner, was an outstanding mineralogist and one of Europe's most influential geologists. The academy was a leading institution for instruction in geology and mining engineering, as well as in *oryctognosy*, Werner's cumbersome term for "practical" mineralogy as applied to the needs of the mining technologist. Werner was a leading proponent of the *Neptunian hypothesis*, which held that most geological structures were deposited from materials dispersed or dissolved in water, and which minimized the importance of volcanic activity (2).

While Del Río was at Freiberg, Alexander von Humboldt enrolled in the mining academy. Baron Friedrich Wilhelm Karl Alexander von Humboldt was born in Berlin on September 14, 1769, the son of a retired Prussian army officer and an heiress (3). A brilliant but restless young man, Humboldt had attended several institutions without taking a degree, until he found inspiration from Werner's instruction at Freiberg. Del Río and Humboldt went in separate directions after graduation from Freiberg, to meet again several years later in Mexico.

After leaving Freiberg, Del Río went to the Austrian Imperial-Royal Mining Academy at Schemnitz (4) in Hungary to study analytical chemistry. The director of the Schemnitz academy, Anton von Rupprecht, had made the academy a leading center for instruction in the chemical analysis of minerals (5). From Schemnitz, Del Río went to England to study new developments in iron metallurgy. Late in 1791 he returned to France to become an assistant to Lavoisier. When Lavoisier was arrested during the Reign of Terror, November 8, 1793, Del Río returned to England. It is said that Del Río, fearing that he might also be arrested, fled from Paris disguised as a water-carrier (6).

In February, 1793 Fausto Delhuyar offered Del Río the chair of chemistry at the newly organized Royal College of Mines in Mexico City. Delhuyar, the co-discoverer of tungsten, had come to Mexico in 1788 as the Director-General of Mines of New Spain. Under his direction, the College of Mines, the first technical college in the Western Hemisphere, was organized on the model of the Freiberg mining academy and inaugurated on January 1, 1792 (7).

Andrés del Río

Del Río declined the offer of the chair of chemistry and requested the chair of mineralogy, which Delhuyar granted. He arrived in Mexico City in December, 1794, bringing a supply of laboratory equipment and accompanied by a servant. He initiated his course in oryctognosy on April 27, 1795, with a class of ten students. In order to provide his students with a text in their native language, Del Río published the *Elementos de Orictognosía*, "organized according to the principles of A. G. Werner." The first volume of the *Elementos*, "comprising earths, stones and salts," was printed in Mexico City in 1795, and the second volume, "comprising combustibles, metals and rocks," was published in 1805 (8).

The Twice-Discovered Element

In addition to his teaching duties, Del Río had the tasks of organizing the large mineral collection that had already been accumulated at the College of Mines and of carrying out chemical analyses of newly discovered minerals. In 1801 with two assistants, he analyzed the "brown lead" (*plomo pardo*) from the Purísima del Cardonal mine near Zimapán in the present state of Hidalgo, initially following the procedure for analyzing lead ores that he had learned at Schemnitz. The only surviving complete description of these experiments is a lengthy footnote in Del Río's Spanish translation of the *Tables of Karsten* (9). Treatment of a half ounce of the pulverized ore with hot, dilute sulfuric acid yielded a precipitate of lead sulfate and a green solution, which was neutralized with ammonia. White crystals were deposited from this solution in the course of a few days. Acidification of the ammoniacal solution with nitric acid yielded "aurora red" crystals, which formed a yellow salt with potash. Thermal decomposition of the white crystals gave "an opaque mass of color between the brown of liver and the gray of lead." A portion of this residue was dissolved in hot, concentrated nitric acid. The nitric acid was evaporated from this solution and the residue was diluted with cold water, giving an emulsion which gradually cleared. This solution gave yellow precipitates with silver, mercury and lead nitrates. The borax bead test on the residue that settled from the emulsion gave a green glass. An attempt to reduce a portion of the "opaque mass" with charcoal was unsuccessful.

The observed chemistry was unlike that of any element known to Del Río. Deciding that he had discovered a new element (9):

> I called it 'panchromium' (*pancromo*, from the Greek, "all colors") for the universality of colors of its oxides, solutions, salts, and precipitates, and then 'erythronium' (*eritrono*, from the Greek, "red") on account of the red color formed by its salts with the alkalis and the earths, on treatment with heat and with acids.

The first published notice of the new element appeared in a Spanish journal in 1802 (10):

> Panchromium. New metallic substance announced by Don Manuel del Río in a report sent from Mexico to Sr. Don Antonio Cavanilles, dated September 26, 1802.

Del Río's first complete paper describing his experiments and their conclusions was addressed to French chemist Jean-Antoine Chaptal. It was lost when the ship carrying it wrecked off Pernambuco, Brazil.

Alexander von Humboldt arrived in Mexico City in April, 1803. After graduating from the Freiberg Mining Academy in 1792, Humboldt had been certified an inspector of mines. He rose rapidly in the Prussian mining bureaucracy, partly through his ability and partly through influence. Upon the death of his mother in 1796, he inherited a large fortune and resigned from all of his official positions, hoping to fulfill an ambition to be a scientific explorer, inspired by the model of Captain James Cook. Frustrated in his attempt to follow Napoleon to Egypt, he went to Spain, where King Charles IV granted him permission to explore and evaluate the resources of the Spanish possessions in the Americas, provided Humboldt paid all the expenses of the expedition. Humboldt and French botanist Aimé Bonpland arrived in South America in July, 1799. Mexico was the last Spanish colony that they visited.

Humboldt and his companions remained in Mexico from March, 1803 until March, 1804. In Mexico City he visited the Royal College of Mines several times, giving lectures, participating in oral examinations, and ultimately selling his scientific instruments to the college. In addition, he spent nearly six months in the mining districts of Mexico, inspecting the mines, mining technology then in use, and the methods for processing silver ores. He reported all this information and much more concerning Mexico, its resources, its products, and its people, in his comprehensive *Political Essay on the Kingdom of New Spain* (11). He renewed his friendship with Del Río, whom he praised as a "distinguished chemist" in the *Political Essay*. Humboldt wrote an "Introducción a la Pasigrafía Geológica," which was included in the second volume of the *Elementos de Orictognosía.*

Del Río told Humboldt about his newly discovered element. Humboldt was skeptical, noting that the behavior of the element sounded like that of chromium, which had been discovered by Vauquelin in 1797, or uranium, discovered by Klaproth in 1789. In those times of slow communication, a detailed description of chromium did not reach Mexico until after Humboldt's arrival, when the College of Mines received Volume V of Fourcroy's *Système des Connaissances Chimiques* at the end of 1803 (12). The new information convinced Del Río that his discovery was actually chromium. A lecture on mineral veins published in Mexico by Del Río in 1802 (13), which briefly described the brown lead of Zimapán, but made no mention of its analysis, was republished in lengthened form in Spain in 1804 with an added footnote, which read, in part (14):

> From this brown lead I obtained 14.80% of a metal that appeared new to me...but having seen in Fourcroy that chromic acid also gives red and yellow salts on evaporation, I believe that the brown lead is a chromate of lead with an excess of base in the state of yellow oxide.

A similar statement was appended to Del Río's description of the analysis of the brown lead in his translation of the *Tables of Karsten,* which was also published in 1804. The latter reference gave his full analysis, "...80.72% yellow lead oxide, 14.80% of 'this new substance,' the rest being a little arsenic, iron oxide, and muriatic acid."

Humboldt had agreed to take Del Río's new paper, describing the discovery of erythronium in more detail than the one lost at sea, on his return to Europe, as well as samples of the brown lead. In a communication to the Museum of Natural History in Paris, Humboldt described the contents of 19 boxes of rocks and mineral samples that he had shipped. Box No. 14 contained (15):

> [B]rown lead of Zimapán...It is in this lead mine...that Mr. Delrio...has discovered a metallic substance very different from chromium and from uranium...Mr. Delrio believes it to be new, and the name erythronium has been proposed for it because the erythronate salts take a beautiful red color on heating and with acids. The ore contains 80.72% yellow lead oxide, 14.80% erythronium, a little arsenic and iron oxide.

Since Humboldt, although skeptical ("Mr. Delrio *believes*..."), nevertheless allowed for the possibility of a new element in this description, it is probable that his note was written and the samples shipped before Del Río discovered the description of chromium in Fourcroy's text and decided that his conclusions were in error.


Alexander von Humboldt

Following his arrival in Paris in August 1804, Humboldt gave a sample of the brown lead to Hippolyte-Victor Collet-Descotils at the Institut de France. Collet-Descotils (16) began his analysis by treating 25 decigrams of the pulverized ore with hot, dilute nitric acid, obtaining a greenish-yellow solution and a red precipitate, "...that I afterward recognized as iron oxide." He acidified the solution with concentrated sulfuric acid, precipitating lead sulfate. The filtrate was evaporated to dryness and the residue dissolved completely in an ammonia solution. After boiling off the excess ammonia, he added lead nitrate, obtaining a yellow precipitate. Silver nitrate gave a "magnificent orange" precipitate, but mercury nitrate gave a "yellowish" precipitate instead of the expected red one (17). To Collet-Descotils, these observations confirmed the presence of chromium. His completed analysis reported 69% metallic lead, 5.2% "presumed oxygen," 3.5% iron oxide insoluble in nitric acid, 1.5% "dry muriatic acid", 16% chromic acid, and a loss of 4.8%. At the conclusion of his report, Collet-Descotils' wrote (16):

> The experiments that I have reported appear to me sufficient to prove that this ore contains nothing of new metal.

Many of the chromates and vanadates of metals are known today to have similar, but not identical colors. Collet-Descotils may have been influenced by Humboldt's expectation that erythronium was actually chromium, leading him to conclude that he had proven this element, even though the color of at least one of the precipitates was not quite right. Humboldt had not shown him Del Río's paper to provide a basis for comparison of results. It is also possible that Collet-Descotils' initial red precipitate was misidentified. Ferric oxide, vanadium pentoxide, and vanadic acid are similar in color; and all three of these compounds have low solubility in dilute nitric acid. Collet-Descotils did not explain how he "afterward recognized" that the initial red precipitate was iron oxide.

Humboldt accepted Collet-Descotils' conclusion that erythronium was chromium, and Del Río's paper was never published. Humboldt forwarded Collet-Descotils' paper on the analysis, published in 1805, to Del Río; but it was apparently several years before it was received in Mexico, a result, no doubt, of the tight British blockade on Napoleonic France at the time. The paper produced an annoyed response from Del Río (18), published in 1811, in which he pointed out that he had already, in 1804, published his conclusion that the element in the brown lead was chromium (9,15). "[T]hese foreigners," he said, "do not deign to read even our most celebrated periodicals."

Del Río's annoyance at the lack of recognition for his priority in the conclusion that the brown lead contained chromium festered into bitterness as time went on. In 1817 he addressed a letter to Humboldt that was published in 1819 (19), in which he protested against Humboldt's turning over to Collet-Descotils for analysis not only the brown lead, but a number of other mineral specimens as well, all of which Del Río had already analyzed to his own satisfaction, and whose results he had published. Referring to the brown lead, he said (19):

> [You] saw fit to give it to your friend doubtless for the reason that we Spaniards should not make any discovery, no matter how small, either in chemistry or mineralogy, these being a foreign monopoly.

After reviewing in detail the history of his and Collet-Descotils' analyses, and emphasizing his priority, he asked (19):

> [D]id I lose all credit for it for not having known in 1802 all the properties of chromium in a country so lacking in books, where for the same reason the sciences are so little cultivated?

In a final slightly conciliatory note, he added:

> I believe that in compensation for your injuries to me, you have showered me with praise in your *Political Essay*, most of it excessive, and some of it qualified... Speaking frankly, I would have appreciated less praise and more accuracy.

Swedish chemist Nils Gabriel Sefström in 1831 found a new element in a sample of cast iron prepared from an ore mined at Taberg, Småland, Sweden. He gave the element the name *vanadium*, after Vanadis, one of the names of Freya, the Norse goddess of love and beauty. Friedrich Wöhler simultaneously was reinvestigating the composition of the brown lead of Zimapán, working with a sample that Humboldt had given him. Sefström gave some vanadium pentoxide to J. J. Berzelius, who demonstrated that the new element was not uranium. Berzelius sent some of the vanadium pentoxide to Wöhler, who conclusively showed that vanadium was identical to Del Río's erythronium, not to chromium. In a communication to *Poggendorffs Annalen* Berzelius described these developments (20):

> This metal, recently discovered by Professor Sefström...has also been found in a mineral of Zimapán, in Mexico...Del Río had already analyzed this mineral in the year 1801, and had at first claimed to have discovered in it a new metal, called by him "erythronium"; but later the chemist Collet-Descotils analyzed the same mineral, affirming that the supposed metal was not new but only chromium. Del Río became convinced that he had believed in something that was an error...until Sefström had the luck to discover it again in a surprising fashion. The recognition that the mineral of Zimapán is a vanadate and not a chromate was made by Professor Dr. Fr. Wöhler in Berlin.

Wöhler, who was on the track of the same metal, was disappointed, first by Sefström's prior announcement of the new element, and because (21):

> ..[e]ven if I had charmed her out of the lead mineral, I would have had only half the honor of discovery, because of the earlier results of Del Río on erythronium.

Although Wöhler recognized Del Río's earlier work, he supported Sefström's priority in the discovery, "because he succeeded by an entirely different method (21)."

Vanadinite

Humboldt described the discovery of vanadium, giving equal credit to Sefström, Wöhler, and Del Río, at the session of the French Academy of Science on February 28, 1831 (20). He also sent a copy of Berzelius' report to Del Río. Del Río remained unmollified. In the second edition of the *Elementos de Orictognosía*, published in 1832, he wrote (22):

> When [Humboldt] left Mexico, I gave him...a copy in French of my experiments in order that he might publish them. If he had judged them worthy of public attention...*the discovery of a new metal would not have been delayed for thirty years*, which is the objection now unjustly made against me.

The brown lead of Zimapán now bears the mineralogical name *vanadinite*. Chemically it is lead chlorovanadate, $Pb_5Cl(VO_4)_3$. Vanadinite is found not only in Mexico, but also in South Africa, where it is mined commercially as a source of vanadium.

Two Personalities: Analysis and Conclusions

After his return to Europe, Humboldt lived first in Paris, and then, after his expedition to Russia and Siberia in 1829, in his native Berlin, punctuated by frequent trips to Paris. He died in Berlin in 1859. Del Río remained in Mexico after that country became independent in 1821, unlike his Spanish-born colleagues at the College of Mines, who returned to Spain. He had married a Mexican woman and adopted Mexico as his home. Except for a sojourn in the United States in 1829-1833, Del Río remained in Mexico for the rest of his life, teaching at the College of Mines and ultimately becoming its director. He died in Mexico City in 1849.

Andrés del Río and Alexander von Humboldt lived in an era of rapid change in the style in which science advanced. Humboldt was a polymath, one of the last of the scientific amateurs who supported their investigations either with inherited wealth or by employment in one of the traditional professions. By the time of his death, Humboldt was probably the last such scientist on the European continent, although a few, notably Charles Darwin, remained in England. Del Río, on the other hand, was one of the new, more specialized breed of scientists who made their living as professors of their sciences in academic institutions. The French scientists with whom Humboldt associated upon his return to Europe in 1804 were already mostly of this new kind. This trend, beginning in the technical schools like those of Freiberg and Schemnitz, and amplified by the École Polytechnique in Paris, spread with the introduction of science departments or institutes into the traditional universities in the first half of the nineteenth century (5, 23). Although Humboldt had a general knowledge of chemistry and kept himself up-to-date on the latest advances, his knowledge was not sufficiently specialized for him to critique the analyses of Del Río or of Collet-Descotils.

The education and personalities of Humboldt and Del Río may also be contrasted. Humboldt, educated in the broad outlook of the eighteenth-century Enlightenment, retained the social and political views of a man of the Enlightenment throughout his life. On the other hand, Del Río moved from a purely classical education in languages and literature, mathematics and philosophy, to the narrow specialization of the mining academies. Whatever social and political views he may have had he kept to himself, which, realistically, may have been the safest thing to do in colonial Mexico. We know him mostly through his works in mineralogy and chemistry.

Del Río and Humboldt differed in their ability to accept new theoretical developments in the sciences. Humboldt was quick to accept the "new chemistry" of Lavoisier and Fourcroy, seeing the advantages of the oxygen theory of combustion and the binomial nomenclature. Del Río, more conservative, gave up the older nomenclature and the phlogiston theory only after his chemist colleagues, Fausto Delhuyar and Luis Lindner, had adopted their Spanish translation of Lavoisier's *Traité Élémentaire de Chimie* as the chemistry text for use at the College of Mines (24). Humboldt's study of volcanoes in South America and Mexico led him to abandon Werner's Neptunian hypothesis of geology; but Del Río clung to it despite the evidence around him in Mexico.

Both men were diligent workers with a capacity for long, detailed and enthusiastic activity. Humboldt was a compulsive collector of data and specimens and a prolific writer. Humboldt was also a brilliant speaker, a very social person, whose company was enjoyed by most of the leading intellectuals of the Americas and of Europe (25) and who had a talent for being accepted into their society in each country he visited. Much less is known about Del Río's personality, since there are no contemporary accounts; and Ramírez' biography of Del Río (1) is more laudatory than objective. We know that Del Río was an effective teacher, dedicated to the College of Mines and to its students. He was probably less out-going than Humboldt. He did have an Iberian sensitivity to a perceived slight, as shown by his responses to Collet-Descotils' analyses; but he was likely right in his accusation of prejudice on the part of the European scientific establishment.

There is no evidence that Del Río ever forgave Humboldt, or was willing to accept the name that another gave to the element he had originally discovered. Humboldt was occasionally sharp in expressing his opinion of persons whose intellectual abilities did not, in his opinion, match their pretensions; but Del Río was not one of those persons. He was always friendly toward Del Río and kind in his responses to him; and if he took offense at Del Río's complaints, he kept it to himself. Indeed, Humboldt may never have been fully convinced of Collet-Descotils' conclusion that the element in the brown lead was chromium. If he had been, why would he have given a sample of the brown lead to Wöhler to re-analyze? Wöhler could have learned of Del Río's erythronium only from Humboldt, who may even have shown him Del Río's unpublished paper.

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25. For example, the poet Johann Wolfgang von Goethe was a life-long friend of Humboldt, and greatly admired his intellect. On the other hand, Goethe's neighbor in Weimar, the poet Friedrich von Schiller, said about Humboldt that "There is a little too much vanity in all his doings...I experience through him, with all due respect for the wealth of his subject matter, a poverty of meaning..." (Ref. 3, p 74).

ABOUT THE AUTHOR

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FRITZ ARNDT AND HIS CHEMISTRY BOOKS IN THE TURKISH LANGUAGE

Lâle Aka Burk, Smith College

Fritz Georg Arndt (1885-1969) possibly is best recognized for his contributions to synthetic methodology. The Arndt-Eistert synthesis, a well-known reaction in organic chemistry included in many textbooks has been used over the years by numerous chemists to prepare carboxylic acids from their lower homologues (1). Perhaps less well recognized is Arndt's pioneering work in the development of resonance theory (2). Arndt also contributed greatly to chemistry in Turkey, where he played a leadership role in the modernization of the science (3). A detailed commemorative article by W. Walter and B. Eistert on Arndt's life and works was published in German in 1975 (4). Other sources in English on Fritz Arndt and his contributions to chemistry, specifically discussions of his work in Turkey, are limited. Arndt spent over two decades of his professional life at Istanbul University in two distinct periods: between 1915 and 1918 during the reign of the Ottoman Empire, and between 1934 and 1955 during the Turkish Republic. Among Arndt's major contributions while there are his books. These valuable historic sources provide insights into changes that occurred during Arndt's lifetime in the science of chemistry and in politics worldwide. They perhaps are most usefully considered within the time frame of Arndt's life and the development of Turkey as a modern nation (Table I).

Fritz Arndt was born in Hamburg on July 6, 1885. Education, music and science played an important role in his prosperous enlightened family. His paternal Uncle Adolf was a chemist, and perhaps an inspiration for young Fritz's interest in the subject. Music remained his "other great love, and Brahms unquestionably his favorite composer (5)."

After graduating from the Matthias-Claudius Gymnasium in Wansbek in greater Hamburg, Arndt began his university education in 1903 at the University of Geneva, where he studied chemistry and French. Following the practice at the time of attending several institutions, he went from Geneva to Freiburg, where he studied with Ludwig Gattermann and completed his doctoral examinations. He spent a semester in Berlin attending lectures by Emil Fischer and Walther Nernst, then returned to Freiburg and worked with Johann Howitz and received his doctorate, *summa cum laude*, in 1908. Arndt remained for a time in Freiburg as a research assistant with Gattermann and from there went to Griefswald, where he worked for a year with Karl von Auwers. He then became an assistant in Kiel to Heinrich Biltz, whom he accompanied in the autumn of 1911 to Breslau, now Wroclaw in Poland (4, 5a).

In 1915 Arndt, who had become a docent in Breslau, was offered a five-year teaching position in Turkey. The university in Istanbul (called the *Darülfünun* during the Ottoman Empire) was undergoing reforms; and, at the request of Şükrü Bey, the Ottoman Minister of Education, Germany agreed to provide an educational assistance mission consisting of twenty academics to help upgrade the institution. A specific request for chemistry faculty was forwarded to Emil Fischer in Berlin. Fischer sent the request along to Alfred Stock, who had gone to Berlin from Breslau. Stock had known Arndt in

Breslau and contacted him in the summer of 1915. As a result of these negotiations Arndt, having received an official offer from the German Ministry of Culture in Berlin in October 1915, accepted a five-year position with the title *Müderris* (Professor), as did two other chemists, Gustav Fester and Kurt Hoesch, assistants at the time at Frankfurt am Main and Berlin, respectively (4, 6, 7).

Arndt arrived in Istanbul in November, 1915. Within the year a new Chemistry Institute (*Yerebatan Kimya Enstitüsü*) housing the first academic department of chemistry in Turkey was founded under his leadership. For the first time, chemistry was taught as an independent discipline separate from medicine and biology (8). Arndt was convinced chemistry could not be taught without laboratory instruction and, finding the existing facilities at the university inadequate, he spent much of his first year planning a building in the Yerebatan district of Istanbul to house the new institute (9). Supplies and chemicals arrived from Germany in spring 1917 and classes started in fall 1918 (10). The facilities were modern for the times, and the curriculum was based on the German model. During lectures, according to Islamic Ottoman tradition, a partition separated the female students from the males. The female students also had their own laboratory. Arndt directed the institute and taught inorganic chemistry (11).

Professors at the Darülfünun wearing the required head gear (fez), Istanbul 1916. Arndt is seated in the front row, fourth from the left. (Courtesy of H. W. Arndt)

Linguistically gifted, Arndt was sensitive to the use of language and throughout his career stressed clarity of expression. In addition to German he spoke English, French, and Italian and had translated into German one of Bohr's books from Danish (5a). He worked closely with the students, learning to speak Turkish in one year and teaching in that language throughout his career at Istanbul University (12). His students recalled, with affection, his thorough command of the Turkish language including local colloquialisms and puns and the German accent which he never lost.

One of the major challenges Arndt and the Turkish students faced was the lack of chemistry textbooks containing current information and a consistent use of language. At the time of Arndt's arrival in Istanbul in 1915, texts were written in Arabic, then the official alphabet of the Ottoman State. For chemical notation, an ongoing debate over using Arabic script as opposed to the Latin alphabet resulted in numerous inconsistencies. Some authors used Latin letters for the names of the elements or their symbols and a combination of Latin letters and Arabic numbers for chemical formulae and for equations. Others preferred to maintain Ottoman tradition and used Arabic script (which reads from right to left) for all these purposes. Moreover, some authors followed the notational style of using superscripts for the number of atoms contained in a formula, while other authors used subscripts. Hence even the simplest substances might be written differently in different texts. For example, "water" might appear in Arabic script written out as a word or as a formula. Alternatively, it could be written with the Latin symbols as H^2O or H_2O. Reading from right to left, it might also be written as O^2H or O_2H depending on the author. The notations of more complex structures, such as organic ring systems, included even further inconsistencies.

In 1916, on Arndt's suggestion, Heinrich Biltz's manual *Qualitative Analyse* was translated from German into Ottoman Turkish by the Turkish chemist Suzi Osman Bey, who had been assigned to Gustav Fester as an assistant teacher. In the same year, *Praktikum der Quantitativen Anorganischen Analyse* by Alfred Stock and Arthur Stähler was translated from German into

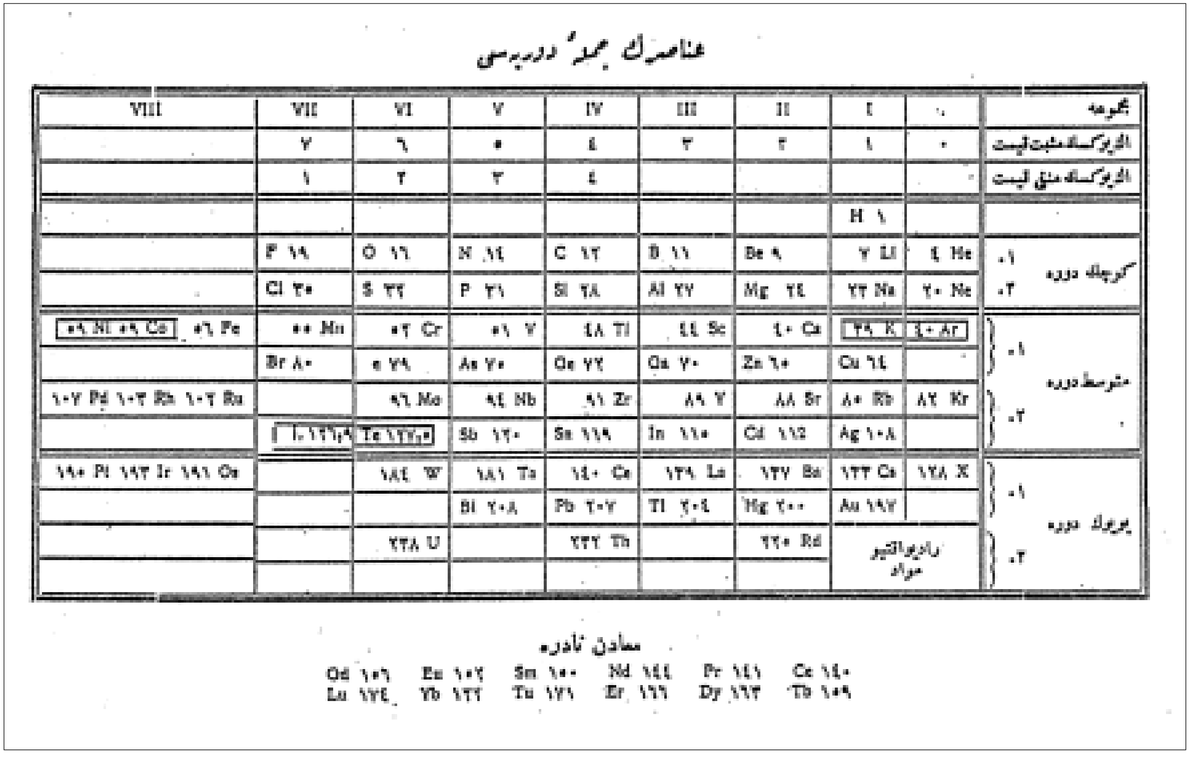
Ottoman "with the assistance of Professor Arndt" by Fazlı Faik, Arndt's German-educated assistant teacher (13). Arndt's own *Kurzes Chemisches Praktikum für Mediziner und Landwirte*, published originally in German in 1912, and a new as yet unpublished laboratory manual by Arndt on inorganic chemistry were both translated from German by Fazlı Faik and published as *Muhtasar Tatbikat-ı Kimyeviye* (brief chemistry experiments) in 1916 and *Kimyayı Gayrı Uzvîden İlk Tatbikat* (first experiments in inorganic chemistry) in 1917 (14, 15). These books provide important documentation for the modernization of Turkish chemistry (16).

The German influence in Turkish textbooks was reflected in the use of the Latin alphabet for the names and symbols of the elements and for writing equations; Arabic letters were no longer used for these purposes. Subscripts for the number of atoms in chemical formulae were used consistently. The numbering system and representation of organic substances including ring structures became more consistent. German (and sometimes Latin) names were given for compounds in addition to the traditional French and Ottoman names. The French symbols for iodine (I for iode) and nitrogen (Az for azot) were replaced by the German symbols, J for Jod and N for nitrogen, or Stickstoff (17).

The periodic table included in Arndt's *Muhtasar Tatbikat-ı Kimyeviye* and *Kimyayı Gayrı Uzvîden İlk Tatbikat* is the second published in Turkey and the first in which chemical symbols are given with the Latin alphabet (18, 19). The table reads from right to left, consistent with Arabic tradition. The elements are organized according to their atomic weights, which are given in Arabic script. Explanatory text fragments, including the title ("the periodic classification of the elements"), properties of the periods and groups ("maximum positive value," "maximum negative value," "small period," "medium period," "large period," "radioactive materials," "rare earth metals") are also written with Arabic script. Elements are represented with Latin alphabet symbols and Roman numerals are used for the groups.

Arndt was to describe later the challenges involved in the printing of these books as follows (20, 21):

> These books were printed with Arabic letters but with Latin formulae. The difficulties are hard to imagine in Europe, and even in Turkey of today. The printing took place at the Imperial Press where chemistry books had been printed previously, but without additional attention at the time, to careful editing or the correction of errors. Numerous corrections were necessary on my part, and even when these were com-



عناصرك جدول دوريسی

مجموعه	٠	I	II	III	IV	V	VI	VII	VIII
اك بيوك [illegible] مثبت قيمت	٠	١	٢	٣	٤	٥	٦	٧	
اك بيوك [illegible] منفی قيمت					٤	٣	٢	١	
		H ١							
كوچك دوره ١.	٤ He	٧ Li	Be ٩	B ١١	C ١٢	N ١٤	O ١٦	F ١٩	
٢.	٢٠ Ne	٢٣ Na	Mg ٢٤	Al ٢٧	Si ٢٨	P ٣١	S ٣٢	Cl ٣٥	
متوسط دوره ١.	٤٠ Ar	٣٩ K	٤٠ Ca	٤٤ Sc	٤٨ Ti	٥١ V	٥٢ Cr	٥٥ Mn	٥٩ Ni ٥٩ Co ٥٦ Fe
		Cu ٦٤	Zn ٦٥	Ga ٧٠	Ge ٧٢	As ٧٥	Se ٧٩	Br ٨٠	
٢.	٨٢ Kr	٨٥ Rb	٨٨ Sr	٨٩ Y	٩١ Zr	٩٤ Nb	٩٦ Mo		١٠٧ Pd ١٠٣ Rh ١٠٢ Ru
		Ag ١٠٨	Cd ١١٢	In ١١٥	Sn ١١٩	Sb ١٢٠	Te ١٢٧٫٥	I ١٢٦٫٩	
بيوك دوره ١.	١٢٨ X	١٣٣ Cs	١٣٧ Ba	١٣٩ La	١٤٠ Ce	١٨١ Ta	١٨٤ W		١٩٥ Pt ١٩٣ Ir ١٩١ Os
		Au ١٩٧	Hg ٢٠٠	Tl ٢٠٤	Pb ٢٠٧	Bi ٢٠٨			
٢.	راديو اكتيو مواد		٢٢٥ Rd		٢٣٢ Th		٢٣٨ U		

معادن نادره

Gd ١٥٦ Eu ١٥٢ Sm ١٥٠ Nd ١٤٤ Pr ١٤١ Ce ١٤٠
Lu ١٧٤ Yb ١٧٣ Tu ١٧١ Er ١٦٦ Dy ١٦٣ Tb ١٥٩

The periodic table from Arndt's *Muhtasar Tatbikat-ı Kimyeviye* (1916) From E. Dölen, *Osmanlılarda Kimyasal Semboller ve Formuller (1834-1928)* (Ref. 6, p109)

> pleted, with each corrected page, new errors in Arabic appeared which needed further correcting. This lasted until roughly 1918, when I was nearly finished. Then Turkey fell. The first Turkish student who used these books with me was not in Istanbul, but in Breslau. Naci Bekir, my student there, later completed his doctorate with me. In the Turkish Republic, these books were used until the Arabic script was banned.

TABLE I. Chronology of Fritz Georg Arndt's Life

YEAR	F. G. ARNDT	TURKISH HISTORY
1885	Hamburg, Born July 6	Ottoman Empire Reign of Abdülhamid II (1876-1909)
1908	PhD, Freiburg	Young Turk Revolution
1911-1915	Breslau	Reign of Mehmed V (1909-1918)
1915-1918	Istanbul	World War I (1914-1918)
1918-1933	Breslau	Reign of Mehmed VI (1918-1922) War of Independence (1919-1922) Abolution of the Sultanate (1922) Turkish Republic Founded (1923)
1933	Oxford, England	Atatürk's University Reforms (1933)
1934-1955	Istanbul	Death of Atatürk (1938) World War II (1939-1945) Turkey joins NATO (1952)
1955-1969	Hamburg (Died Dec 8, 1969)	Turkey a multiparty republic

At the end of World War I, the Ottoman Empire, then aligned with Germany, was defeated. The activities of the German professors in Istanbul were terminated, and German nationals were forced to leave. Returning to Breslau in January 1919, Arndt joined his family who had left Istanbul earlier. In Breslau, Arndt resumed a successful teaching and research career until 1933, making contributions to synthetic methodology and also to the development of resonance theory and to the emerging field of physical organic chemistry (22). The idea of the resonance hybrid or *Zwischenstufe* (intermediate state) was introduced by Arndt and his co-workers in 1924 (23). This notion was confirmed following the developments in quantum chemistry, and independently by Christopher Ingold and his co-workers. In 1934 Ingold used the term "mesomerism" for resonance and his terminology was adopted widely and eventually by Arndt (24). Why Arndt's pioneering work in this area did not gain wider international recognition is discussed in Ernest Campaigne's revealing article, which focuses on this question, and in a more generalized article published recently by Ute Deichmann (25, 26).

Post World War I years had been especially challenging for Turkey. At the end of the war, the internal structure of the Ottoman Empire collapsed, and British, French, Italian, and Greek forces occupied much of its territory. From the following War of Liberation led by Mustafa Kemal Atatürk, Turkish forces emerged victorious. The sultanate was abolished in 1922, and a new state, the Republic of Turkey, was founded in 1923 with Atatürk as its president. Major reforms were undertaken in the young republic to rejuvenate and modernize the nation. A new civil code granting women social rights was adopted in 1926, and Turkey was officially declared a secular state in 1928. Other reforms included the adoption of the Latin alphabet in 1928 and the metric system in 1931. Reform initiatives in language were formalized with the founding in 1932 of the Turkish Language Foundation (*Türk Dil Kurumu*), the major function of which was to oversee changes in the language from Ottoman to Turkish (27). Reforms in higher education were also initiated to upgrade the university in Istanbul, which had suffered severely during and after World War I, and to raise its level to that of major European institutions. Plans for these reforms, drawn up in 1932, included the hiring of foreign faculty in a variety of fields. The persecution and displacement of academics in Germany provided a unique opportunity for the Turkish government to implement the university reforms and to hire a large number of outstanding faculty members (28). These reform initiatives together with the events taking place in Germany at that time were responsible for Arndt's return to Turkey.

As a result of the Aryan policies of the National Socialists soon after the Nazi takeover in January 1933, German academics started losing their positions (26, 29). Arndt was dismissed from his chair at Breslau in April of 1933, apparently because his father was Jewish. He received an invitation from Nevil Sidgwick and Robert Robinson to go to England through the intermediacy of the Academic Assistance Council, the English rescue organization later renamed the Society for the Protection of Science and Learning, in which Ernest Rutherford played an active role. Arndt accepted a research appointment in the Department of Organic Chemistry at Oxford University and soon joined his British colleagues. Meanwhile in Turkey, the Swiss rescue operation, *Notgemeinschaft Deuscher Wissenschaftler im Ausland* (Emergency Society of German Scholars Abroad) was helping many dismissed German scholars find positions at Istanbul University.

In 1934 the Turkish Ministry of Education invited Arndt, who was in England at the time, to come to Istanbul University. He did so, and returned to the institute he had founded two decades earlier. The name of the university had been changed from *Darülfünun* to Istanbul University in August 1933. Students were now using the Latin alphabet. The traditional headgear for males, the fez, had disappeared, as had the partition in the classroom separating the female students. In the new Chemistry Institute, Arndt held a chair in general chemistry (*Genel Kimya Kürsüsü*) and headed this division, which included the fields of inorganic and organic chemistry (30). He served in this capacity until his retirement in 1955 (31).

Among Arndt's most pressing activities in 1934 was the revision for publication of new editions of *Muhtasar Tatbikat-ı Kimyeviye* and *Kimyayı Gayrı Uzvîden İlk Tatbikat.* These texts were reprinted in the Latin alphabet. They were written in what was essentially a modern language, new Turkish or *yeni Türkçe*, which in 1934 was in an early state of development. The new Turkish translation from German of *Kurzes Chemiches Prakticum fur Mediziner und Landwirte* (*Muhtasar Tatbikat-ı Kimyeviye*) was printed with the Latin alphabet in 1934; updated versions followed in 1937, 1942, and 1946 (32). The new version of *Kimyayı Gayrı Uzvîden İlk Tatbikat* under the name *Gayrı Uzvî Kimyadan İlk Tatbikat* was printed with the Latin alphabet in 1935; updated editions of the latter followed in 1946 and 1950 (33).

In addition to these, Arndt published two major works during his second period in Turkey. These were comprehensive texts, both experimental in approach, in the areas of inorganic and organic chemistry. His inorganic textbook was first published in 1938 under the title *Genel Kimya Dersleri I – Gayrıuzvî Kimya* (General Chemistry Lessons I – Inorganic Chemistry). Updated editions were printed in 1944, 1949, and 1953 (34). Arndt's organic textbook, also published in 1938 as lecture notes under the title *Profesör F. Arndt'ın Genel Kimya Dersleri II – Uzvî Kısım* (Professor F. Arndt's General Chemistry Lessons II – Organic Section), appeared with updated editions in 1947 and 1950 (35). The different editions of Arndt's four books are summarized in Tables IIa and IIb. Arndt wrote in his forewords about the profound changes in chemistry that were occurring during his lifetime, mentioning specifically developments in the areas of quantum chemistry, nuclear chemistry, fluoride chemistry, the chemistry of silicon compounds, and theoretical organic chemistry. Incorporating these and other changes into books presented a challenge worldwide for chemists in his generation. In Turkish there was the additional challenge of using a language that was constantly changing (36).

Arndt contributed significantly to Turkish language reforms and worked closely with the Turkish government in the adoption of new scientific terminology (37). He was one of the few non-native speakers who served on the government's official commission on terminology (*Terim Komisyonu*) and in this context, dealt personally with Atatürk, whom he admired deeply. Arndt was, nevertheless, concerned about several aspects of these reforms, such as the constant changing of word usage, which he believed generated difficulties in com-

TABLE IIa. Arndt's Laboratory Manuals Published in Turkey between 1916 and 1950 [I.1 and II.1 are printed in Arabic script and in the Ottoman language, the rest are printed with the Latin alphabet and in the new Turkish language]

I. Laboratory Manual for Physics, Chemistry and Biology students [Kurzes Chemisches Praktikum, or Brief Chemistry Experiments]

1. Muhtasar Tatbikat-ı Kimyeviye (1916) Author: F. Arndt, Professor (Müderris) of Inorganic Chemistry at the Istanbul Darülfünun (translated from German into Ottoman by Fazlı Faik)
2. Kısa Kimya Tatbikatı (1934) Author:Ord. Prof. Dr. F. Arndt (translated from German into new Turkish by Dr. Abdurrahmanlı and Selâhattin Mustafa)
3. Kısa Kimya Tatbikatı (1937) Author: Ord. Prof. Dr. F. Arndt (translated from Ottoman into new Turkish by Dr. Abdurrahmanlı and Selâhattin Mustafa)
4. Kısa Kimya Lâboratuarı (1942) Author: Ord. Prof. Dr. F. Arndt
5. Kısa Kimya Lâboratuarı (1946) Author: Ord. Prof. Dr. F. Arndt

II. Laboratory Manual for Chemistry, Chemistry-Physics and Chemistry License Students [First Experiments in Inorganic Chemistry]

1. Kimyayı Gayrı Uzvîden İlk Tatbikat (1917) Author: F. Arndt, Professor (Müderris) of Inorganic Chemistry at the Istanbul Darülfünun (translated from German into Ottoman by Fazlı Faik)
2. Gayrı Uzvî Kimyadan İlk Tatbikat (1935) Author: Ord. Prof. Dr. F. Arndt
3. Anorganik Kimyaya Başlangıç Laboratuarı – İlk Tatbikat (1946) Authors: Ord. Prof. Dr. F. Arndt, "with the assistance of " Dr. Lütfi Ergener and Melika Ergener
4. Anorganik Kimyaya Başlangıç Laboratuarı – İlk Tatbikat (1950) Authors: Ord. Prof. Dr. F. Arndt and Doç. Dr. Lütfi Ergener

TABLE IIb. Arndt's Textbooks Published in Turkey between 1938 and 1953 [All are printed with the Latin alphabet and in the new Turkish language]

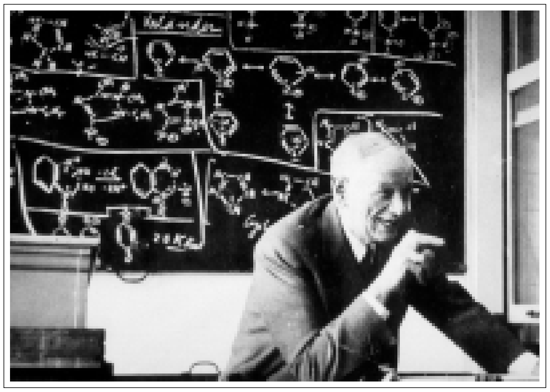
I. Textbook in Inorganic Chemistry

1. Genel Kimya Dersleri I - Gayrıuzvî Kimya (1938) [General Chemistry Lessons I – Inorganic Chemistry] Author: Ord. Prof. Dr. F. Arndt
2. Denel Kimya Dersleri I - Umumî ve Anorganik Kısım (1944) [Experimental Chemistry Lessons I – General and Inorganic Section] Author: Ord. Prof. Dr. F. Arndt
3. Denel Anorganik Kimya (1949) [Experimental Inorganic Chemistry] Authors: Ord. Prof. Dr. F. Arndt and Dr. Lütfi Ergener
4. Denel Anorganik Kimya (1953) [Experimental Inorganic Chemistry] Authors: Ord. Prof. Dr. F. Arndt and Doç. Dr. Lütfi Ergener

II. Textbook in Organic Chemistry

1. Profesör F. Arndt'ın Genel Kimya Dersleri II – Uzvî Kısım (1938) [Professor F. Arndt's General Chemistry Lessons II – Organic Section] Author: None indicated; lecture notes
2. Denel Organik Kimya (1947) [Experimental Organic Chemistry] Authors: Ord. Prof. Dr. F. Arndt and Doç. Dr. Lütfi Ergener
3. Yeni Denel Organik Kimya (1950) [New Experimental Organic Chemistry] Authors:Ord. Prof. Dr. F. Arndt and Doç. Dr. Lütfi Ergener

municating with the students. He felt that these changes were especially challenging for chemistry students who needed to acquire, in addition to a new language, a scientific vocabulary unique to the field. Arndt discussed problems related to the changing language in detail in the forewords of several of his textbooks (38).



Arndt lecturing. Note double-headed arrows on the board and his characteristic warm,witty style. (Courtesy of H. W. Arndt)

Arndt's students must have found the dictionary (*lügatçe*) included in the 1949 and 1953 editions of *Denel Anorganik Kimya* particularly helpful (39). In this dictionary, the equivalents in four languages (Turkish, Ottoman, German, and English) of 137 chemical terms are given in tabular form (selected examples are shown in Table III). Also of interest in the 1953 edition is a biographical footnote on Ernest Rutherford, which includes the following statement, quite atypical for a chemistry text (40):

> Lord Rutherford founded, during the reign of the darkest dictatorship in Europe, a worldwide committee, the Society for the Protection of Science and Learning, to protect the freedom of science and of ideas.

Arndt's expertise in resonance theory is clearly apparent from the organic text published in 1938. In this book, the differentiation between tautomerism and resonance (which he called *tautomeri* and *mesomeri* in Turkish) is clearly made, both in the wording of the text and in his early use of the presently accepted conventions in notation. By 1938 Arndt was using the presently accepted convention of representing tautomers with reversible arrows, and resonance hybrids with double-headed arrows (41). Many authors who were writing at this time were using reversible arrows to indicate resonance, or were showing different resonance structures without the use of arrows. Arndt may be, in fact, one of the first authors to include the double-headed arrow in a textbook. In an interview in Istanbul with the author during summer 1993, Professor Enis Kadıoğlu, who was a former student of Arndt at Istanbul University, stated that Arndt was masterful in the classroom in making these concepts perfectly clear. His Turkish students who called him *Arndt Hoca* (pronounced hodja in English, the Turkish manner of addressing a teacher with respect) fully appreciated the significance of their teacher's pioneering work in this area and valued learning from the "*eksper*" or expert (42).

Group photo of Arndt at Istanbul University with his Turkish students, c. 1950. (Courtesy of H. W. Arndt)

Several factors contributed to Arndt's success as a teacher and an author. Arndt taught both inorganic and organic chemistry and was skillful in communicating and integrating information. He discouraged memorization and emphasized recognizing underlying principles. In his lectures and books, he bridged the areas of inorganic and organic chemistry. His texts in these fields complement each other, and contain many interconnections. For instance, the organic text of 1947 includes over fifteen references to the inorganic text in the first eighty pages (43).

Arndt was also masterful in integrating theory with experiment and constantly stressed the significance of the latter. Of his four books, two are manuals for the laboratory; and the updated editions of both his inorganic and organic texts contain the word "*Denel*" (experimental) in their titles. Included throughout the text in these latter works are short experiments (or lecture demonstrations), which help to illustrate the chemistry or concepts being discussed. In the classroom, an assistant would typically carry out the demonstrations as Arndt lectured. Arndt's texts are rich in visual and sensual information. Descriptions of color (or lack of), physical state, appearance of a solid (*e.g.*, as beautiful crystals), and smell (*e.g.*, as having a pleasing fragrance, or a fragrance that is familiar to everyone) reflect his intimate acquaintance with these materials and depict him as a practicing experimentalist. In one example, which is most likely based on personal experience, he cautions against exposure to hydrogen cyanide, or *siyanür asiti* (44). This very dangerous volatile material, he writes, has a subtle fragrance, experienced more typically as a strange feeling in the tonsils. Risk of exposure is high for those who cannot sense this. For detecting the elusive toxin, he suggests smoking a cigar or pipe in the area since the presence of trace amounts characteristically will ruin the taste of tobacco (45, 46).

In his inorganic and organic texts, Arndt frequently illustrates his points by using local examples relevant to the Turkish students. Examples from his organic textbook of 1947 include (49):

> under the subject of hydrocarbons, the properties of the oil (*petrol*) harvested from the Caucasus and Lake Baykal regions; under the subject of alcohols, the preparation of ethanol from corn in Turkey rather than from potatoes in Europe; under the subject of fats and oils, the similarity of the appearance of aqueous mixtures of these materials to the mixture obtained "when water is added to rakı" (the Turkish drink which turns cloudy when mixed with water); under the subject of polyenes, the cultivation near Istanbul of the native *kök sakızı otu*, a plant used as a source for rubber; under the subject of sugars, the economic significance in Turkey of the production of beet sugar and the properties the latter (47). In another example in this text relevant but not unique to Turkey, Arndt writes about coal mine explosions in a discussion of properties of hydrocarbons. Here he discusses Sir Humphry Davy's safety lantern (which, the text indicates, is shown to the class.) The safety principle is demonstrated in lecture by igniting ether in a crucible and pouring the burning mixture through a wire mesh: the vapor above the mesh continues to burn, but what goes through does not. The use of a similar mesh in Davy's lantern separating the flame and the outside atmosphere, Arndt points out, has prevented numerous mine disasters from the buildup of explosive methane-oxygen mixtures, or *grizu*. Arndt makes a connection here to inorganic chemistry and refers to pages in the inorganic text that describe the chemistry of hydrogen and its potential explosion hazards, which in the presence of air or oxygen, Arndt points out, are similar to those of methane (48). The addendum to the 1947 organic text is of historic interest: here are mentioned as current significant developments in chemistry the structure elucidation of penicillin through X-ray analysis by Dorothy Crowfoot Hodgkin and a paper by R. B. Woodward and C. H. Schramm on a novel preparation of a synthetic fibrous protein analogue, which Arndt deems a noteworthy accomplishment in polymer as well as in protein chemistry.

Arndt's comprehensive textbooks for inorganic and organic chemistry are written in a warm, conversational style, perhaps because they were initially based on lecture notes (50). They include many phrases such as "as we saw before," "as you see in the organic (inorganic) book," and "now that we know that." These phrases also add to the continuity and interconnection of the topics. Inclusion of the experimental component and examples relevant to the reader make the material engaging, interesting, and easy to read.

Many generations of chemistry students in Turkey used these books, which were highly valued, in constant demand, and commonly out of print. These works reflect, in addition to the author's chemical expertise, his teaching philosophy and unique talents as a sensitive pedagogue and a linguist.

ACKNOWLEDGMENTS

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2. (a) E. Campaigne, "The Contributions of Fritz Arndt to Resonance Theory," *J. Chem. Educ.*, **1959**, *36*, 336-339; (b) See also G. W. Wheland, *Resonance in Organic Chemistry*, John Wiley and Sons, Inc., New York, 1955, 2; O. T. Benfey, *From Vital Force to Structural Formulas*, The Beckman Center for the History of Chemistry, Publication No.10, Philadelphia, 1992, 109; J. Hudson, *The History of Chemistry*, Routledge, Chapman and Hall, New York, 1992, 182-183; W. H. Brock, *The Fontana History of Chemistry*, Fontana Press, London,1992, 486.
3. Y. Akçamur, "Modern Kimya, Fritz Arndt ve İlk Araştırma," in *Türk Dünyasında Kimya Bilimi ve Eğitim Tarihi*, A. H. Köker, Ed., Erciyes Üniversitesi Gevher Nesibe Tıp Tarihi Enstitüsü Yayını, Erciyes Üniversitesi Matbaası, Kayseri, 1993, 45-53.
4. W. Walter and B. Eistert, "Fritz Arndt, 1885-1969," *Chem. Ber.*, **1975**, *108*, I-XLIV.
5. (a) H. W. Arndt, Australian National University, Personal Communication; (b) H. W. Arndt, "Ils Aimaient Brahms," *Quadrant*, August **1985**, 81-2.
6. E. Dölen, *Osmanlılarda Kimyasal Semboller ve Formüller (1834-1928)*, Çetin Matbaacılık, Istanbul, 1996, 104.
7. H. Widmann, *Atatürk Üniversite Reformu: Almanca konuşan ülkelerden 1933 yılından sonra Türkiyeye gelen öğretim üyeleri—Hayat Hikayeleri—Çalışmaları—Etkileri*. Istanbul Üniversitesi Cerrahpaşa Tıp Fakültesi Atatürk'ün Yüzüncü Doğum Yılını Kutlama Yayınları, Istanbul, 1981, 25-26 [Turkish translation by A. Kazancıgil and S. Bozkurt of H. Widman, *Exil und Bildungshilfe: Die deutschsprachige akademische Emigration in die Turkei nach 1933*, Herbert Lang, Bern, 1973; Peter Lang, Frankfurt am Mein, 1973.]
8. (a) A. R. Berkem, *Türkiyede Son Yetmiş Yılda Kimya Alanındaki Gelişmeler*, Türkiye Kimya Derneği Yayınları: No. 8, Istanbul, 1988, 3-19; (b) A. R. Berkem, *Üniversitelerimizde Kimya Öğretimi*, Türkiye Kimya Derneği Yayınları: No. 10, Istanbul, 1990, 5-8; (c) A. R. Berkem, *Kimya Tarihine Toplu Bir Bakış*, Türkiye Kimya Derneği Yayınları: No. 12, Istanbul, 1996, 163-170.
9. The Turkish word *yerebatan* means sunken, or underground; the district is named for the Byzantine cisterns located in the historic Sultanahmet section of Istanbul, near the university and in the vicinity of the Aya Sofya museum, the Topkapı Palace, and the Imperial Printing House where Arndt's first books were printed.
10. In 1918, three transfer students (all male) from biology were admitted to the Chemistry Institute as second-year students. These were the first graduates who received in 1920 the first chemistry diplomas granted in Turkey. Of the eight students who made up the first year class in 1918, four were female. Seven members of this class (including the four females) graduated in 1921 making up the second group of Turkish chemists to receive diplomas in the profession. (Ref. 8a, p 6)
11. K. Hoesch taught organic chemistry and G. Fester industrial chemistry. Other courses in the new chemistry program were taught by Turkish faculty with the exception of geology, which was taught by Dr. Penck, formerly a docent at Leipzig. These courses included analytical chemistry, biochemistry, dyeing materials and techniques, nutrition chemistry, topics in industrial chemistry, mathematics, physics and geology. Physical chemistry was not incorporated into the chemistry curriculum in Turkey until the French chemist Michel Faillebin joined the faculty at the Chemistry Institute as the head of the physical chemistry division in 1926.
12. Arndt refused to use a translator in his Turkish classes. For this he gave the following reasons: the presence of a translator in the classroom interfered with the personal interactions between the teacher and the students. The required synchrony in the classroom between the lecture and the chemical demonstrations was disrupted during translations, and translations that lagged in time were not useful. In addition, the correctness of the information conveyed to the students by the translator could not be checked. (Ref. 7, p 235)
13. E. İhsanoğlu, *Açıklamalı Türk Kimya Eserleri Bibliografyası (Basmalar/1830-1923) ve Modern Kimya Biliminin Türkiye Cumhuriyetinin Kuruluşuna Kadar Olan Durumu ve Gelişmesi*, İlim Tarihi Kaynaklar ve Araştırmalar Serisi No.2, Istanbul, 1985, 96-97; see also Ref. 6, pp 106-107.
14. E. Dölen, "Ord. Prof. Dr. Fritz Arndt'in Türkçe Yayınlanmış Yapıtları," *Doğa ve Bilim*, Sayı 11 (Haziran 1982), 68-76; See also Ref. 13, pp 99-100.
15. In the foreword of the 1935 edition of *Kimyayı Gayrı Uzvîden İlk Tatbikat*, Arndt states that this book is based

for the most part, on *Experimentelle Einführung in die Unorganische Chemie* by "Professör H. Biltz" and on *Anorganisches Practikum* by "Professör E. Riesenfeld."

16. Ref. 13, pp 26-27 and Ref. 6, p 106.
17. By the early twentieth century, the number of Turkish students who were receiving their degrees and training at Germany had increased substantially. Turkish-German cultural relationships were gradually replacing Turkish-French relationships of the previous centuries, and German influences in education were replacing French traditions.
18. The first periodic table in Turkey was published in 1894, in *İlmi Kimyayı Gayrı Uzvî-i Tıbbî* (medicinal inorganic chemistry) by Vasil Naum. Naum's table is titled "the classification of elements according to the system of the chemist by the name of Mendeleyef" (translation from Ottoman Turkish by the author.) The names of the elements are given in full, and all of the text and numbers are written in Arabic script. The table reads, in Arabic tradition, from right to left. In contrast, the periodic table included in the 1907 memorial article for his teacher Mendeleyev, by Ali Bey Hüseyinzade Turan from Azerbeycan, is also written with Arabic letters and numbers. However, this latter table does not follow the Arabic tradition of reading from right to left, instead, it reads from left to right. This convergence of Arabic and Western tradition in the history of the development and adoption of the periodic table is quite interesting. See Ref. 6, pp 69, 108-111 and Ref. 14, pp 70-72.
19. The periodic table in the two books is the same, with one exception: The atomic mass of Cd (112) in *Muhtasar Tatkibat-ı Kimyeviye* (Ref. 6, p 109) is written as ``2 (only the first two digits are in Arabic script) and as ``` (all three digits are in Arabic script) in *Kimyayı Gayrı Uzvîden İlk Tatkibat* (Ref. 14, p 72). This is possibly due to an editorial correction by Arndt himself.
20. The printing house, Matbaa-ı Amire, is located in the first courtyard of the Topkapı Palace, near the building of the Yerebatan Chemistry Institute. It presently houses the conservation laboratories of the Istanbul Archaeological Museum.
21. Ref. 7, p 237-8, translated into English from the Turkish by the author.
22. For the development of this field in England and in the United States see M. Saltzman, "The Development of Physical Organic Chemistry in the US and in the UK," *J. Chem. Educ.*, **1986**, *63*, 588-593.
23. F. Arndt, E. Scholz, and P. Nachtwey, "Über Dipyrylene und über die Bindungsverhältniss in Pyron-Ringsystemen," *Ber. Dtsch. Chem. Ges.*, **1924**, *57*, 1903-11.
24. C. K. Ingold, "Mesomerism and Tautomerism," *Nature*, **1934**, *133*, 946-7; see also M. Saltzman, "C. K. Ingold's Development of the Concept of Mesomerism," *Bull. Hist. Chem.* **1996,** *19*, 25-32.
25. Ref. 2a, pp 337-338.
26. U. Deichmann, " Chemists and Biochemists during the National Socialist Era," *Angew. Chem. Int. Ed. Engl.*, **2002**, *41*, 1310-1328.
27. Over the centuries, the court language of the Ottomans had incorporated many Arabic and Persian terms, and this official language was not easily accessible to the majority of the Turks, especially to those who were not educated. In the new Turkish republic, the language reforms addressed these issues. In an effort for improved communication nationwide, and with the outside world, words with Turkish roots (*öz Türkçe*, or pure Turkish) were substituted for Arabic and Persian equivalents; internationally accepted terms were adopted for words which did not exist in pure Turkish. For the Hungarian parallel of "the language problem" see G. Palló, "Roles and Goals of Chemical Textbooks on the Periphery, The Hungarian Case," in *Communicating Chemistry - Textbooks and Their Audiences, 1789-1939*, A. Lundgren and B. Bensaude, Eds., Watson Publishing International, Canton, MA, 367-395.
28. In the summer of 1933, the Turkish government offered positions at Istanbul University in a variety of disciplines to over thirty displaced German professors who arrived with their families and assistants. These individuals were well established in their fields, and they, and others who arrived in the following years, helped design the modern Turkish higher education system. In addition, serving as consultants to the Turkish government in many areas, they helped build the new nation.
29. S. Friedlander, *Nazi Germany and the Jews. Vol 1: The Years of Persecution, 1933-1939*, Harper Collins, New York, 1997.
30. The other two divisions in the new Chemistry Institute at Istanbul University were Industrial Chemistry headed by Reginald Herzog, who was displaced from his position as second director of the Kaiser Wilhelm Institute in Berlin, and Physical Chemistry, headed by Gabriel Valensi. Prof. Ali Rıza Berkem who was a former assistant of Professor Valensi eventually became head of the division of Physical Chemistry and served in this position until his retirement. Professor Berkem continues his contributions to chemistry as the president of the Turkish Chemical Society, and as a prolific historian of chemistry.
31. After he retired from Istanbul University Arndt returned to Hamburg and remained professionally active. He received numerous awards and lectured and traveled widely until his death in 1969.
32. (a) F. Arndt, *Muhtasar Tatbikat-ı Kimyeviye*, çeviren Fazlı Faik, Matbaa-ı Amire, Istanbul 1332 [1916]; (b) Ord. Prof. Dr. F. Arndt, *Kısa Kimya Tatbikatı*, çevirenler Dr. Abdurrahmanlı ve Selâhattin Mustafa, Fen Fakültesi Neşriyatından, Arkadaş Matbaası, Istanbul, 1934; (c) Ord. Prof. Dr. F. Arndt, *Kısa Kimya Tatbikatı*, çevirenler Dr. Abdurrahmanlı ve Selâhattin Mustafa, Fen Fakültesi Yayınlarından, Arkadaş Matbaası, Istanbul, 1937; (d)

Ord. Prof. Dr. F. Arndt, *Kısa Kimya Lâboratuarı*, Üniversite Kitabevi, Istanbul, 1942; (e) Ord. Prof. Dr. F. Arndt, *Kısa Kimya Lâboratuarı*, Ankara Üniversitesi Fen Fakültesi Yayınları, Um.: No. 35, Kim.: No 5, Marifet Basımevi, Istanbul 1946.

33. (a) F. Arndt**,** *Kimyayı Gayrı Uzvîden* **İ***lk Tatbikat***,** çeviren Fazlı Faik, Matbaa-ı Amire, Istanbul 1333-1917; (b) Ord. Prof. Dr. F. Arndt, *Gayrı Uzvî Kimyadan* **İ***lk Tatbikat,* Fen Fakültesi Ne**ş**riyatından, Arkada**ş** Basımevi, Istanbul, 1935; (c) Ord. Prof. Dr. F. Arndt, yardım edenler Dr. Lütfi Ergener ve Melika Ergener, *Anorganik Kimyaya Ba***ş***langıç Laboratuarı –* **İ***lk Tatbikat,* Istanbul Üniversitesi Yayınları: No. 269, **Ş**irketi Mürettebiye Basımevi, Istanbul 1946; (d) Ord. Prof. Dr. F. Arndt ve Doç. Dr. Lütfi Ergener, *Anorganik Kimyaya Ba***ş***langıç Laboratuarı –* **İ***lk Tatbikat,* Istanbul Üniversitesi Yayınları: No. 269, Kutulmu**ş** Basımevi, Istanbul, 1950.
34. (a) Ord. Prof. Dr. F. Arndt, *Genel Kimya Dersleri I - Gayrıuzvî Kimya*, Kimya Talebe Yurdu Ne**ş**riyatı, Istanbul 1938; (b) Ord. Prof. Dr. F. Arndt, Denel Kimya Dersleri I - Umumî ve Anorganik Kısım, Üniversite Kitabevi, Istanbul, 1944; (c) Ord. Prof. Dr. F. Arndt ve Dr. Lütfi Ergener, *Denel Anorganik Kimya*, Istanbul Üniversitesi Yayınları: No. 406, **Ş**irketi Mürettebiye Basımevi, Istanbul, 1949; (d) Ord. Prof. Dr. F. Arndt ve Doç. Dr. Lütfi Ergener, *Denel Anorganik Kimya,* Istanbul Üniversitesi Yayınları: No. 406, Fen Fakültesi Yayınları: No. 6, Kutulmu**ş** Basımevi, Istanbul, 1953.
35. (a) *Profesör F. Arndt'ın Genel Kimya Dersleri II – Uzvî Kısım,* Kimya Talebe Yurdu Yayınlarından, Arkada**ş** Basımevi, Istanbul, 1938; (b) Ord. Prof. Dr. F. Arndt ve Doç. Dr. Lütfi Ergener, *Denel Organik Kimya,* Istanbul Üniversitesi Yayınları: No. 329, Kutulmu**ş** Basımevi, Istanbul, 1947; (c) Ord. Prof. Dr. F. Arndt ve Doç. Dr. Lütfi Ergener, *Yeni Denel Organik Kimya*, Istanbul Üniversitesi Yayınları: No. 329, Kutulmu**ş** Basımevi, Istanbul, 1950.
36. The changes in the Turkish language, which started in the 1920s, continue to this day.
37. Other German professors who contributed to the Turkish language reforms and the adoption of terminology in their fields include Wolfgang Gleissberg in astronomy, Fritz Neumark in economics, and Ernst Hirsch in law.
38. See for instance the forewords of Ref. 33 (b) and (c).
39. Ref. 34 (c), pp 607-612 and 34 (d), pp 607-610.
40. In this book, Arndt's admiration for Ernest Rutherford's chemical achievements is obvious. The statement regarding Rutherford's leadership in the Society for the Protection of Science and Learning, which was instrumental in Arndt's going to England in 1933, may be a reflection of Arndt's debt to the great chemist. See Ref. 34 (d), p 356.
41. For examples of Arndt's early use of double headed arrows, see Ref. 35 (a), pp 75, 119, 174, 251, 260, and 356.
42. Conversation at Istanbul Technical University (Istanbul Teknik Üniversitesi) with the late Professor Enis Kadıo**ğ**lu, May 12, 1993.
43. Ref. 35 (b), pp 1-80.
44. Ref. 35 (b), p 153.
45. This method of detecting the presence of hydrogen cyanide is attributed to Gattermann. See J. R. Partington, *A History of Chemistry*, Macmillan, London, 1964, Vol.4, 834.
46. Arndt was fond of smoking cigars and pipes. The Arndt family lived in Ortaköy, on the Bosphorus during Arndt's second period in Turkey. In a conversation with the author in May 1993, Cemil Güyümcüo**ğ**lu, the proprietor of the tabacco store in Ortaköy, remembered "Arndt Bey" (Mr. Arndt) as the "Professor with the pipe" (author's translation from Turkish.)
47. Ref. 35 (b), pp 55, 81-82, 129, 211, 341.
48. Ref. 35 (b), p 61.
49. Ref. 35 (b), pp 501, 523. For the publications of these works, see D. Crowfoot, C. W. Bunn, B. W. Rodgers-Low and A. Turner-Jones, "X-ray Crystallographic Investigation of the Structure of Penicillin," in *Chemistry of Penicillin*, H. T. Clarke, J. R. Johnson and R. Robinson, Eds. Princeton University Press, Princeton, NJ 1949; R. B. Woodward and C. H. Schramm, "Synthesis of Protein Analogs," *J. Am. Chem Soc.,* **1947**, *69*, 1551-2.
50. For another example of a successful textbook which was developed from lecture notes, see M. J. Nye, "From Student to Teacher – Linus Pauling and the Reformulation of the Principles of Chemistry" in A. Lundgren and B. Bensaude, Ed., *Communicating Chemistry - Textbooks and Their Audiences, 1789-1939,* Watson Publishing International, Canton, MA, 2000, 397-414.

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Lâle Aka Burk is a Senior Lecturer in Chemistry at Smith College. A native of Turkey, she completed her undergraduate education at the American College in Istanbul and pursued her doctoral work in natural products chemistry in the United States. Her research interests outside of her field in bio-organic chemistry lie in the area of the history of chemistry in Turkey, the cultural transformations in the Ottoman Empire and the Turkish Republic, and Turkish influences on Western culture.

TABLE III. Selected terminology in four languages (Turkish, Ottoman, German and English) from the dictionary (*lügatçe*) included in the 1947 and 1953 editions of *Denel Anorganik Kimya* (Experimental Inorganic Chemistry)

TÜRKÇE	OSMANLICA	ALMANCA	INGILIZCE
[Turkish]	[Ottoman]	[German]	[English]
ametal	sibihmaden	Nichtmetal	nonmetal
anorganik	gayrı uzvî	anorganisch	inorganic
bilesik	mürekkep	Verbindung	compound
çözünemez	gayrı kabili inhilâl	unloslich	nsoluble
denel	tecrübî	experimentell	experimental
esnek	elâstikî	elastisch	elastic
hat	hat	Linie	line
ısık	ziya	Licht	light
organik	uzvî	organisch	organic
saydam	seffaf	durchsichtig	transparent
teori	nazariye	Theorie	theory
ultra-mor, ultra-violet	—	Ultraviolett	ultra-violet

FUTURE ACS MEETINGS

March 23-27, **2003**—New Orleans, LA
September 7-11, **2003**—New York, NY
March 28-April 1, **2004**—Anaheim, CA
August 22-26, **2004**—Philadelphia, PA
March 13-17, **2005**—San Diego, CA
August 28-September 1, **2005**—Washington, DC
March 26-30, **2006**—Atlanta, GA
September 10-14, 2006—San Francisco, CA
March 25-29, **2007**—Chicago, IL
August 19-23, **2007**—Boston, MA
April 6-10, **2008**—San Antonio, TX
August 17-22, **2008**—Philadelphia, PA
March 22-26, **2009**—Salt Lake City, UT
August 16-21, **2009**—Washington, DC
March 21-26, **2010**—San Francisco, CA
August 22-27, **2010**—New York, NY
March 27-31, **2011**—Anaheim, CA
August 28-September 1, **2011**—Chicago, IL
March 25-29, **2012**—San Diego, CA
August 19-23, **2012**—Boston, MA

BOOK REVIEWS

Methods and Styles in the Development of Chemistry. Joseph S. Fruton, American Philosophical Society, Philadelphia, PA, 2002; xviii + 332 pp, Cloth, ISBN 0-87169-245-7; $40.

Winner of the 1993 Dexter Award in the History of Chemistry, Dr. Fruton is best known for his work on the history of biochemistry and, more recently, for his essays and autobiography. This small, attractive volume represents his first venture into the general history of chemistry and is very much in the tradition of the well-known short histories of chemistry by Partington and Leicester, both of which are still available as quality Dover paperbacks. Like its predecessors, the book tends to emphasize the lives of famous chemists and, like them, its coverage of 20th-century developments after 1925 is minimal at best. However, Dr. Fruton has a lighter, more discursive writing style, which makes his book a much better read, and has availed himself of much of the recent secondary literature in the history of chemistry, as is apparent from the excellent notes appended to the end of the book.

The book is divided into ten chapters which are thematic in content but also roughly chronological in terms of when the topics in question became historically important. Protochemistry is covered in the first chapter under the title “The Greek Inheritance and Alchemy,” followed by two chapters dealing with the 17th and 18th centuries (“Chemical Composition and Phlogiston” and “Antoine Lavoisier”), five dealing with 19th-century developments (“Atoms, Equivalents, and Elements;” “Radicals and Types;” “Valence and Molecular Structure;” “Stereochemistry and Organic Synthesis;” and “Forces, Equilibria, and Rates”), one dealing with the 20th century (“Electrons, Reaction Mechanisms, and Organic Synthesis”), and a final “Conclusion.” I would strongly recommend this book as a possible text for a one-quarter or one-semester history of chemistry course directed at chemistry majors. That said, however, there are also some caveats to that recommendation, though I am loath to place the responsibility for these solely on Dr. Fruton and suspect that many of them are due to the publisher and editors since they apply equally well to much of the recent literature in the field.

The first deals with the book’s title. There was a time when academic books had honest titles which succinctly summarized their contents and intended use, such as “A Short History of Chemistry”, “An Introductory History of Chemistry”, etc., but starting in the 1970s it became fashionable to base titles either on catchy “in the know” phrases (e.g., “Atoms and Powers”) or grandiose higher historical or cultural themes (e.g., “Enlightenment Science in the Romantic Era”) with only the subtitles following the colon giving any real concrete information about the book’s actual contents. Though Dr. Fruton has been a keen critic of much of this historical silliness, as witnessed by his essays and the conclusion to the book under review, he nevertheless appears to have fallen into this trap himself. The title “Methods and Styles in the History of Chemistry” surely suggests a special emphasis on instrumental and procedural innovations (methods) and a detailed study of each scientist’s published works in order to identify philosophical choices, favored approaches to problem solving, preferences for certain types of experimental or theoretical argument, etc. (style). But nothing of this sort is apparent in this book beyond a general discussion of this topic in the forward. As already pointed out, the special emphasis, if any, is biographical; and Fruton appears to use the term “style” in a highly idiosyncratic manner to denote what is, in reality, nothing more than a summary of a given chemist’s research accomplishments.

A second criticism deals with the illustrations. In scientific writing illustrations are highly integrated with the text and serve to clarify difficult points. In contrast to histories of chemistry written by chemists, those written by historians are notable for their lack of illustrations. Though this has improved somewhat in recent years, one receives the impression that many of the illustrations used in their books have been added as a decorative afterthought; and the same appears to be the case with some of the illustrations in this book, few of which are discussed in any substantive manner within the body of the text or in the captions. Thus, though an entire chapter is devoted to chemical types, not a single type formula is illustrated, while an entire page is consumed in showing Faraday's apparatus for the measurement of electromagnetic rotation, a topic of little relevance to the history of chemistry.

A third criticism has to do with equations and formulas. According to historians, chemists who write about history of chemistry are usually guilty of two sins: whiggism and writing for other chemists. Though common sense would dictate that chemists are the most logical audience for books dealing with the history of chemistry, said historians have managed to delude themselves and their publishers into believing that there is a vast nonchemical audience for books of this type. Two unforeseen consequences of this delusion appear to be the assumptions that the use of chemical formulas and mathematical equations must be kept to an absolute minimum (and preferably banished to an appendix if possible) and that it is unnecessary to have a qualified chemist read the manuscript before publication. The result has been a proliferation of an embarrassing number of elementary chemical errors in recent history of chemistry publications. Examples include John Servos' definition of a reaction rate, in his otherwise excellent history of American physical chemistry community, as the change in concentration with respect to temperature (instead of time), and Elisabeth Crawford's painful page-long attempt, in her otherwise outstanding biography of Arrhenius, to verbally describe the factors involved in measuring the conductivity of an electrolyte solution, when reproduction of the appropriate equation would have made all instantaneously obvious.

The appearance of similar errors in Dr. Fruton's book is more puzzling since he is both an outstanding chemist and historian and, to judge from his acknowledgments, had various chemists review at least some portions of his manuscript. But they are there in abundance, especially in the chapter on "Forces, Equilibria and Rates," where the publisher has chosen to set the equations within the body of written text, rather than setting each on a separate line for proper emphasis, as is universally done in the technical and mathematical literature. Thus van't Hoff's isochore is incorrectly given (p. 176) as:

$$\mathrm{dlnK/dT} = \Delta\mathrm{lnU/RT}^2 \text{ instead of } \mathrm{dlnK/dT} = \Delta\mathrm{H/RT}^2$$

The Arrhenius equation is incorrectly given (p. 176) as:

$$\mathrm{lnk} = \mathrm{Ae}^{-E/RT} \text{ instead of } \mathrm{k} = \mathrm{Ae}^{-E/RT}$$

and the Nernst equation (written for some reason for a concentration cell rather than for a redox couple) is incorrectly given (p. 183) as

$$\mathrm{E} = (\mathrm{RT/N})\mathit{F}\ln(\mathrm{C}_1/\mathrm{C}_2) \text{ instead of } \mathrm{E} = (\mathrm{RT/N}\mathit{F})\ln(\mathrm{C}_1/\mathrm{C}_2)$$

Likewise on pages 173-174, Gibbs' equation from his 1873 memoir on graphical methods for the thermodynamics of fluids:

$$d\varepsilon = t d\mu - p dv$$

is both incorrectly reproduced (Gibbs used η rather than μ for entropy) and incorrectly identified with his later free-energy equation:

$$\Delta G = \Delta H - T\Delta S$$

when in fact it is Gibbs' expansion of the equation for the first law of thermodynamics:

$$\Delta U = \Delta Q + \Delta W = T\Delta S - P\Delta V$$

and the free-energy equation does not appear until Gibbs' later memoir on the equilibrium of heterogeneous substances, where it is given in his notation as:

$$\zeta = \varepsilon - t\eta + pv$$

Finally, free-energy is represented as both ΔG and ΔF at various points in the chapter without explicit mention of the change in notation and E is used to symbolize both activation energy and electrochemical potential, also without comment.

A final criticism involves the coverage of 20th-century chemistry. As noted earlier, the short histories by Partington and Leicester have little to say about 20th-century events beyond the establishment of Bohr's model of the atom and early radiochemistry. Fruton does slightly better as he not only discusses these events, but also early electronic bonding models and the rise of physical organic chemistry to about 1966. However, nothing is said about colloid and surface chemistry, modern solid-state and inorganic chemistry, quantum statistical mechanics, or developments in the field of analytical chemistry.

Nevertheless, once these criticisms and limitations are apparent, it is easy enough for a teacher to provide the necessary corrections and supplements, and I stand by my earlier recommendation of this book. Indeed, I would rate it, along with Bill Brock's 1992 history, as one of the best short histories to appear in the last 40 years. *William B. Jensen, Department of Chemistry, University of Cincinnati, Cincinnati, OH 45221-0173.*

The German Chemical Industry in the Twentieth Century. John E. Lesch, Ed., Kluwer Academic Publishers, Dordrecht, Boston, London, 2000, viii + 449 pp. Hardcover. ISBN 0-7923-6487-2. Euro 163.50; $176.

This book, Volume 18 in the "Chemists and Chemistry" series from Kluwer, is a collection of 14 papers from a conference held at Berkeley, CA in March 1997. In the introduction by the editor, Department of History at Berkeley, the three themes of the volume are enumerated: research and development, impact abroad, and an account of the German chemical industry since 1945. Except for a short chapter on "I.G. Farben Revisited," the chapters are presented in Parts I-III according to the three themes. The first two papers in Part I—"Research and Technological Innovation"—by J. A. Johnson and D. Stoltzenberg (the recent Haber biographer) provide insightful descriptions of the effective research programs in the German chemical industry, with emphasis on the academic-industrial symbiosis in the period 1903-1939 and the particular roles played by Emil Fischer and Carl Duisberg. The impact of World War I is described here and also in the following paper by M. Szöllöse-Janze, "Losing the War but Gaining Ground: The German Chemical Industry during World War I." In the following chapter by P. Löhnert and M. Gill, the handling of Jewish scientists and those married to Jews at I.G. Farben's Agfa Filmfabrik Wolfen in the 1930s is documented. A. N. Stranges describes Germany's synthetic fuel industry, 1930-1945, in the last paper in Part I.

The four papers in Part II deal with the interaction of Germany chemical industry with Great Britain, Japan, and the United States. U. Marsch makes a case for the development of a strong British chemical industry, with the German's as model. This included formation of British Dyestuffs Ltd., founding of numerous research associations (modeled after the Kaiser-Wilhelm Institutes), and initiation of governmental financial support for industry. A. Kudo describes the opening in Japan of operations in dyestuffs, ammonia, and synthetic oil by I. G. Farben in the 1920s and 1930s. For this reviewer, one of the most revealing accounts is found in the paper by M. Wilkins, "German Chemical Firms in the United States from the late Nineteenth Century to the post-World Ware II Period." Here the reader can follow the fate of German firms established in the U.S. before World War I, their demise, and rejuvenation after 1945. The Bayer aspirin saga is an especially dramatic example. These international negotiations between the two world wars are further explored by K. Steen from the political point of view in the final paper in Part II.

Part III, "The Industry since 1945," is made up of four papers by social scientists. In the first, the legacy of anti-Semitism is treated by means of the Richard Willstätter controversy. The second covers the often short-sighted and selfish handling by the Soviets of chemical industry in East Germany after 1945. Next comes an overview of developments in chemical industry in the 1980s in the U.S., Japan, and Western Europe (not limited to Germany). The final chapter by R. Stokes provides an overview of the conference and poses the question as to what additional research remains for historians of the German chemical industry in the 20th century.

The authors have consistently substantiated their presentations with documentation in the form of lists and tables. While this strengthens the narrative, it makes for heavy reading. (This reviewer managed to get through the book over the period of a year.) Yet the volume is a valuable resource for anyone who seeks an overview of the evolution of the Germany chemical industry. Chemists will probably find less compelling those papers dealing with social, economic, and political impact. This reader was gratified by the straightforward account of Emil Fischer's suicide (p 87), so often overlooked or even denied. Inevitably one finds overlap and repetition of some aspects of the subject from chapter to chapter: background settings, the Jewish dilemma, impact of wars, the reaction to the economic depression, the Kaiser-Wilhelm Institutes (later Max-Planck Institutes). Although errata appear throughout the book, some of them can be attributed to oversights in translation ("trinitrotoluol," e.g.). *Paul R. Jones, University of Michigan*.

The Philosophy of Robert Boyle. Peter R. Anstey, Routledge, London, 2000. xv + 231 pp. $90.

The last fifteen years have seen a wave of new scholarship on Robert Boyle that has recast the old image of him as the "father" of modern chemistry, to a mechanical philosopher firmly embedded in the world and thought of seventeenth-century natural philosophy. We now know more, for example, about Boyle's development as a natural philosopher and theologian and his intense interest and participation in the alchemical tradition. Boyle has long been regarded as one of the founders of the mechanical philosophy in the seventeenth century, and historians have also recently articulated more precisely the specific influences on Boyle's corpuscularianism. Yet Boyle's style as a writer, and his known public disdain for proclaiming and creating explicit overarching "systems" of nature, have precluded an efficient systematic analysis of Boyle's mechanical philosophy. In *The Philosophy of Robert Boyle*, Anstey attempts to reconstruct the fundamental assumptions underlying Boyle's mechanical philosophy, including the primary qualities of matter, the nature of causation, natural law, motion and place, and the interaction of the corporeal realm of brute matter with the incorporeal realm of spirit and God.

The first part of the book treats Boyle's theory of the qualities. It is well known that Boyle considered size, shape, motion, and texture of atoms to be the primary qualities of bodies. Yet as Anstey points out, Boyle was not explicit as to why he chose these properties as primary and not others such as extension, indivisibility, or impenetrability. From a close reading of Boyle's *On the Origin of Forms and Qualities*, Anstey offers a classification of qualities according to Boyle and suggests two reasons for Boyle's choice of primary qualities. The first involved reasoning from the corpuscles themselves towards the sensible qualities, termed by Anstey the "bottom-up approach." The second mode of reasoning moved in the opposite direction, from Boyle's general reductive principles (termed the "top-down approach" by Anstey), by which all sensible qualities are reduced to increasingly smaller concretions of corpuscles until reaching the individual atoms. Anstey concludes that Boyle ultimately remained agnostic about the primacy of properties such as infinite indivisibility and impenetrability of matter, but matter without the properties of size, shape, and texture was inconceivable to him. Having discussed the nature of Boyle's primary qualities, Anstey then moves on to unravel Boyle's complex ontology of the sensible (nonmechanical) qualities and their relation to the mechanical qualities. Such an understanding is important for uncovering Boyle's stance on the sensible qualities, a central issue in the mechanical philosophy, and more precisely, his influence on Isaac Newton's form of corpuscularianism and John Locke's well known differentiation of the primary and secondary qualities.

In the second half of the book Anstey turns to Boyle's concept of motion and the nature of Boyle's "mechanism" in the mechanical philosophy. Boyle did not offer a comprehensive mathematical theory of motion that departed from or elaborated on Descartes' or Galileo's detailed treatment of motion; but it does seem clear that Boyle thought a great deal about motion and its importance in understanding the nature of causation and natural law in the mechanical philosophy. For example, like many of his contemporaries, Boyle clearly rejected the scholastic distinction between "natural" and "violent" motions. Because he was primarily concerned with explicating the qualities of bodies and not their motion or place, Boyle usually discussed the concept of "place" as in his theological and epistemological works, and not in his discussions of the mechanical philosophy proper. An understanding of motion was also central to Boyle's concept of natural law, God's relationship to his creation, and the interaction of mind and body. After extensively examining each of these issues in Boyle's works, Anstey suggests that Boyle was a "nomic occasionalist," meaning that the causal interaction of bodies required that God intervene in a law-like way. Boyle's recourse to this nomic occasionalism allowed him to avoid the deistic implications of the mechanical philosophy, while recognizing that nature itself could have a hand in causing phenomena.

Anstey is well versed in the Boyle corpus, relying on well known works such as *A Free Inquiry into the Vulgarly Received Notion of Nature*, *The Origin of Forms and Qualities*, and *The Christian Virtuoso* as well as lesser known works. His analysis also relies on a good knowledge of the current historiography on Boyle; with some exceptions he fits his own conclusions within that framework rather than offering an entirely new picture of Boyle. For example, Anstey notes that Boyle's alchemy fits well with his nomic occasionalism, as his attempt to locate the philosopher's stone was also a search for a tangible link between the material and spiritual realms. *The Philosophy of Robert Boyle* can be heavy reading at times for the author assumes a basic knowledge of seventeenth-century philosophical categories such as voluntarism, occasionalism, and concurrence; but it is worth a close examination for understanding the nature of Boyle's natural philosophy. *Peter J. Ramberg, Division of Science, Truman State University, Kirksville, MO 63501.*

Mendeleyev's Dream: The Quest for the Elements. P. Strathern, Berkley Books, New York, NY, 2000, 309 pp., ISBN 0-425-18467-6. $14.

Paul Strathern has written a very readable, brief popular history of the foundations of the chemical sciences. To those casual readers who want to understand the development of the chemical sciences Strathern has performed a marvelous service. A brief description of how Mendeleyev produced his periodic law in 1869 including the dream scenario ala Kekulé forms the prologue and setting for the rest of the book. Combining a background in chemistry, physics, mathematics and philosophy, this prolific author has produced a book that is both enjoyable to read and also provides delightful anecdotes in each chapter that teachers at all levels will find particularly useful.

The text is divided into 14 chapters arranged in chronological format. The first chapter deals with aspects of Greek natural philosophy concerning the structure of matter. In a concise manner the major ideas concerning the elements of Empedocles, Aristotle, and Plato are discussed. The second chapter deals with the foundations of alchemy in Alexandria, where the Greek philosophical tradition was blended with Egyptian technology to produce alchemy. Following the decline of Alexandria, alchemy had a rebirth in the new Arab civilization, which spread across the Middle East, North Africa, and parts of Europe. The contributions of the Arab alchemists Jabir, Al-Razzi, and Avicenna are discussed in detail.

The third chapter deals with Europe in the Middle Ages and the emergence of scientific thought and the conflict with the Roman church. The ideas of Roger Bacon are discussed to illustrate this point. The works of the Arab alchemists, having now been translated, were disseminated in Europe; and new discoveries of a practical nature were being made in the context of the age old attempt to find the mythical philosopher's stone. New laboratory techniques were invented and old ones improved upon by the European alchemists. The discovery of new substances is also found in this chapter.

A whole chapter is devoted to Paracelsus, whose life, accomplishments, and influence are reviewed in great detail. Many anecdotes about this remarkable person are given and to this reviewer this was one of the better chapters in the book. Paracelsus died two years prior to the publication of Copernicus's *Revolutions of the Heavenly Spheres* and the next two chapters are devoted to a brief but very readable analysis of the scientific revolution. Particularly interesting are the discussions of Nicolas of Cusa (1401-1464), who anticipated in many ways Copernicus and Giordano Bruno, whose radical ideas included the revival of the atomism of Lucretius. Galileo, Descartes, Gilbert, and Francis Bacon receive ample attention for their philosophical perspectives on the methodology of science.

In the next chapter, "A Born-Again Science," the important discoveries of van Helmont concerning the gaseous state and the use of quantitative methods are stressed. Strathern credits van Helmont as the founder of biochemistry and discusses the experiments that he performed that led to this appellation. Franciscus Sylvius , a pupil of van Helmont, continued his work and saw digestion as a chemical process involving acids and bases. He was able to extend these ideas to a description of the process of neutralization and the origin of salts. Through his experiments Sylvius was leading the way to the distinction between elements and compounds. An interesting anecdote in this chapter, typical of many found in the text, is the origin of the name for the drink gin. As Strathern relates, Sylvius developed a cure for kidney ailments by mixing distilled grain spirit flavored with juniper berries, called in Dutch *genever*. Although it failed as a cure-all, it became a popular drink and in English was abbreviated to gin.

The ideas of Robert Boyle on the composition of matter are also treated in this chapter. Boyle is shown to be typical of many of the scientific elite of his time in terms of their interest in theological matters and their self-deprecation of their scientific contributions. Boyle, fascinated by the work of Otto von Guericke, had Robert Hooke build an effective laboratory vacuum pump. This led to his law and the demystification of air as an element. Boyle's most significant practical chemical contribution was the development of an indicator for acids and bases prepared from an extract of the violet plant.

In Chapter 8 the discovery of several new elements, phosphorus by Brand in 1669, chlorine by Scheele in 1770, nickel by Cronstedt (1751), and platinum accidentally in 1735, make for fascinating reading. The material on Scheele was particularly enlightening given the short shrift he is accorded in most texts. "The Great Phlogiston Mystery" is discussed in the next chapter. The development of this theory of chemical transformations as developed first by Becher and extended by Stahl is given in detail. In the context of the phlogiston theory the work of the great English eccentric Henry Cavendish and the Unitarian minister-turned-chemist Joseph Priestley are found in this chapter. The discussion of their lives as presented will be useful as background for any general discussion of this period in the history of chemistry.

The last four chapters are the most disappointing. In a scant 70 pages the author takes up the Chemical Revolution, Dalton and the atomic theory, the work of Berzelius and Davy, as well the early attempts at the periodic classification of the elements. In the last chapter he returns to Mendeleyev in more detail. For the casual reader there is sufficient material to give a flavor of this crucial era in these four chapters.

This being a popular history, there are no footnotes in the text, although there are suggested further readings for each of the chapters at the end of the text. These include reference works, monographs, and journal articles. There is a seven-page index that will be helpful for finding specific points.

This reasonably priced book is not in the same category as Ihde's *The Development of Modern Chemistry* or Brock's *Norton History of Chemistry* but is aimed at a general audience. For practicing chemists and students of the discipline with little knowledge of the development of their field of study this book is an ideal first step. Along with the more scholarly recently published work of Trevor Levere *Transforming Matter* these make a good pair. *Martin D. Saltzman, Providence College, Providence, RI, 02918.*

Heinrich Caro and the Creation of Modern Chemical Industry. C. Reinhardt and A. S. Travis, Kluwer Academic Publishers, Dordrecht, Boston, London, 2000, *xxii* + 453 pp. ISBN 0-7923-6602-6. $189.

If William Henry Perkin (1838-1907) was responsible for the beginnings of the synthetic organic chemical industry, then, as this book makes clear, it was Heinrich Caro who made it possible for the industry to reach its full potential in the nineteenth century. Carsten Reinhardt and Anthony Travis have not only produced the first complete biography of Caro, but have also addressed questions as to what factors enabled the organic chemical industry to grow and prosper in Germany during Caro's lifetime. By following the growth of Caro's employer BASF, they have also given us an insight into what led Germany to become the preeminent chemical manufacturing power in the world.

This is a masterfully researched work, based upon a wealth of material deposited at the Deutsches Museum in Munich by Caro's daughter Amalie, as well as upon other primary and secondary sources. The authors' presentation is written on two levels, so that those without any knowledge of organic chemistry can follow the narrative with little difficulty, while those familiar with elementary organic chemistry will be better able to appreciate the key developments in the chemistry of synthetic dyes.

The text is divided into twelve chapters; the first two deal with Caro from his birth in 1834 until 1859 when he finished his apprenticeship as a calico printer. The next three chapters cover the years 1859-1866 which he spent in England, where he took part in the synthetic dye revolution. Chapters 6-9 are devoted to Caro's career at BASF, which lasted from 1868-1890. Chapters 10 and 11 summarize his life in terms of his accomplishments and failings, as well as the years from 1890 until his death in 1910, during which time he remained a member of the supervisory board of BASF and an observer of the dye industry. Finally in the last chapter the authors discuss the myth and history associated with Caro. The text includes 64 pages of notes, a twelve-page bibliography, and indexes according to dye type, name, and companies. There are numerous photographs and other illustrations.

Heinrich Caro was born in the town of Posen, East Prussia (Poznan, Poland), the son of Simon and Amalie Caro. His Jewish ancestry would play an important role in the shaping of his future career. In 1842 Caro's father decided to move to Berlin, where he felt the business opportunities and educational environment would be better for his sons. Caro's parents are best described as secular, but still rooted in Jewish tradition.

In Berlin, Caro attended the Kölnische Realgymnasium where he proved to be an indifferent student at first. He was very taken with literature and music and wrote rather bad poetry, we are told. Caro became interested in liberal politics and was an observer of the failed Revolution of March, 1848 in Berlin. Caro's opportunity to work in the chemical laboratory of the Realgymnasium in 1850 changed his life. He now became totally fascinated with chemistry. Despite some misgivings on the part of his father, but with the encouragement of his mother, Caro decided that chemistry would be his field of study.

In 1852 Caro completed his secondary school education and sought admission to Berlin's Königliches Gewerbeinstitut, the leading technical college in Prussia. Caro was very aware that even a secular Jew had very limited opportunities in the Prussian academic world. Therefore he did not seek a university degree but opted for the practical training of the trade school. Caro, "[d]riven by a combination of natural ability and the sure knowledge that in the future he would have to support himself, … spared no efforts with his studies." (p. 25). Caro's teachers were Karl Friedrich Rammelsberg and Gustav Magnus, also of Jewish descent. As pointed out by the authors, it was this lack of entry into the academic world which led men such as Caro—and other future graduates of the Gewerbeinstitut (from 1866 known as Gewerbeacademie) in the 1850s and 1860s, such as August Leonhardt, Ivan Levenstein, and Carl Liebermann—into the world of practical chemistry. This in turn would set the agenda for much academic research in the nineteenth century.

His teachers suggested that Caro consider a career in calico (cotton) printing as a textile colorist. Well paid employees, colorists were responsible for preparing and fixing dyes as well as creating designs. This required an apprenticeship, the posts for which were difficult to obtain. Caro was able to secure one at the C. & F. Troost printing factory in Mülheim in May, 1855. Only natural or semi-synthetic dyes were used. The authors present concise descriptions of the most important dyes of the time, particularly madder (the basis of Turkey Red) and its refined form known as garancine, as well as the role chemists played in their preparation and application.

Caro's apprenticeship was to last for three years; most of his salary going to pay for the instructions from the resident colorist at Troost, Achille Steinbach. Caro was willing to put up with long hours and miserable living conditions since he knew that, when his apprenticeship was completed, he would be qualified to teach the trade himself or obtain lucrative employment in the German textile industry. "Calico printing consumed his entire being. His perseverance and rapid progress, drawing on his chemical education and a philosophy of self-help, were to become the hallmarks of a man who would change the course of the history of dye technology." (p. 38). The authors provide an excellent description of the problems of using madder colors and include pictures and drawings of equipment used in the calico printing industry. In 1857, Caro's employer sent him to Manchester, England, where he was able to see for the first time the large-scale application of organic chemistry in the textile industry. Contacts were made with manufacturers and colorists that would lead, in the autumn of 1859, to his return to Manchester after completing his apprenticeship.

The authors devote three chapters to the Manchester years, 1859-1866, which were critical for Caro's later major contributions to the dye industry. In the autumn of 1859, armed with letters of introduction, Caro came to Manchester, which with Huddersfield, were the dye manufacturing centers in Great Britain. The industry was undergoing a major change from natural and semisynthetic dyes to the new synthetic aniline dyes discovered in 1856 by William Henry Perkin. Caro was hired by the firm of Roberts, Dale & Co., a leading Manchester manufacturer of textile chemicals.

During this period, Caro, as well as many other German trained chemists, worked for British dye manufacturers. The knowledge they obtained of experimental techniques and the manufacturing processes would be crucial to the future rise of the German chemical industry. The need for efficient marketing as well as a system of customer service was also an outgrowth of the experiences of these German visitors. The authors explain in great detail the invention of the whole range of aniline dyes during the 1860s.

Caro invented a new process for mauve and discovered an aniline black dye in 1862. This aniline black was superior to the natural black dyes derived from logwood and madder in calico printing. By 1864 dyers had a range of aniline dyes consisting of purple, red, blue, black, green, and violet. Other coal-tar dyes provided brown and yellow colorants.

Caro began to appreciate the value of the connection between the academic research laboratory and the synthetic dye industry. Key examples were the contract work performed by the German chemists Carl Schorlemmer (Owens College, Manchester) for Roberts, Dale & Co. and A. W. Hofmann (Royal College Chemistry, London) for firms in London. Carl Martius, an assistant to Hofmann in London, was induced by Caro to join Roberts, Dale & Co. in August, 1863. Martius would be instrumental in developing the first azo dyes. Shortly after his return to Germany in 1867 he and Paul Mendelssohn-Bartholdy co-founded a predecessor of AGFA.

As the authors make clear: "Liberality, tolerance, diversity, and mechanized textile production in Manchester wove together science and technology in ways that were not possible elsewhere in Europe." (p. 88). The seven years that Caro spent in Manchester were the most critical in his life, as he was to wed his training in the art of calico printing with the newly emerging synthetic dye industry.

The synthetic dye industry in the 1860s was a cutthroat business with scheming, double-dealing, and industrial espionage the norms. Alliances were formed and broken all in the name of improving profits and status of individual chemists and their employers. Caro seemed to have been able to acquit himself well in this environment and became one of the most important individuals in the British dye industry. He was constantly called upon for advice and developed skills as an expert witness in cases of litigation.

In late 1866 Caro decided to return to Germany. The aniline-based dyes had reached a stage of final development, and Caro's health was suffering from the foul, polluted air in Manchester that caused severe respiratory problems. The Germany that Caro returned to in 1866 was much different from the one he had left in 1859. As the authors state (p 127):

> Most significant to Caro's future, and the futures of many of his colleagues, was the tremendous social and economical transformations of the country, the increasing influence of the well-educated upper middle class, the emancipation of the Jews, and the take-off of the much-delayed industrial revolution in the German states.

Much of the rest of the book addresses the question of the relationship between pure and applied chemistry, corporate structure, and innovation, as illustrated in the career of Caro. These are the types of questions that the new generation of historians have been dealing with. Earlier works such as J. J. Beer's *Emergence of the German Dye Industry* (1959) and George Meyer-Thurow's 1982 paper in *Isis*, "The Industrialization of Invention: A Case Study From the German Chemical Industry," tended to stress the importance of the advances in structural and other areas of chemistry and did not address many of the points that Reinhardt and Travis raise. The life of Heinrich Caro to them illustrates their thesis concerning the importance of these other factors.

When Caro returned to Germany, he first settled in Berlin but then moved to Heidelberg for reasons of health and was admitted to the laboratory of Robert Bunsen. Caro, at this point, entertained the idea of an academic career while perhaps acting as a consultant to the emerging German dye industry. At Heidelberg he pursued his investigations into rosolic acid, which he had begun in Manchester. This research would later lead to a synthesis of alizarin, the red dye derived from the madder plant.

Caro was invited in 1867 by the founders of BASF to act as an external inventor and consultant for their new plant at Ludwigshafen in Bavaria. BASF manufactured both inorganic bulk chemicals and aniline dyes at Ludwigshafen, where the "wide, fast-flowing Rhine was used for water disposal, particularly the mixture of aromatic and arsenic compounds employed in the production of aniline dyes." (p 112).

Before Caro's association with BASF, the German dye industry had relied on pirating the products of other manufacturers. Patents were virtually worthless in the various parts of the still fragmented Germany. Basic research to produce new inventions was not done, and this would be the greatest impact that Caro would have. He negotiated a profit sharing arrangement with BASF for the recipes to make three of the dyes he had invented. In contrast to other consultants who moved from one job to another, Caro stayed with BASF and in November, 1868 became the joint managing technical director. The authors cite the terms of the contract to show that here is the first example of a technical director who also had a research function.

Mr. H. Caro is to undertake, in particular, tasks in the laboratory that are necessary from both a theoretical and practical point of view. (p. 138). With this document, science-based industry had been formalized.

Caro's first major achievement at BASF was the production of synthetic alizarin by using the laboratory process developed by the academic chemists Carl Graebe and Carl Lieberman, assistants to Adolf Baeyer at the Gewerbeakademie in Berlin. Caro made significant contributions to the transfer of this laboratory synthesis to a commercial product. The difficulties encountered in the scaling up are discussed in great detail as well as the contributions made by William Henry Perkin, who shared alizarin production with BASF. Perkin had developed a process similar to that of Caro, Graebe, and Lieberman; but theirs had been patented in London first. The industrial alizarin synthesis marked the beginning of the application of the structure of organic molecules as a means of rational synthesis, and the collaboration between academics and industrialists. From this time on, Caro was to make the fullest use of academic-industrial connections for the benefit of BASF.

After 1877 azo dyes became increasingly important, and by 1900 the greatest number of dyes were members of this class. The diazotization and coupling reaction was first discovered by Peter Griess, one of Hofmann's assistants in London in 1858. The authors discuss the various types of azo dyes as well as the contributions made by Caro, Griess, Martius, Witt, and Hofmann.

A single chapter is devoted to one of Caro's major achievements, the fostering of the academic–industrial collaboration. The BASF model would be replicated by many of the other German dye companies; in many ways it was the industrial research that drove the academic research agenda in the nineteenth century. The close collaboration between Caro and Adolf von Baeyer is discussed in great detail as a means of showing the growing partnership of academia and industry. Baeyer worked closely with Caro from 1873-1883 when BASF, deciding to establish its own central research laboratory, greatly reduced its dependence on external contract consultants. Caro supplied Baeyer with technical and patent information as well as organic chemicals. Baeyer in turn reported his discoveries to Caro and undertook the analysis and structural elucidation of industrial products and intermediates. They published jointly and each greatly admired the other's type of work. The most important product of this collaboration was synthetic indigo, which was not marketed until 1897. Without the encouragement of Caro the authors contend that synthetic indigo would not have been produced. At least ten other academic chemists, including Emil Fischer and Victor Meyer, acted as consultants on a continuous basis for BASF in this period of time.

By 1885 the BASF management had decided to centralize its discovery of new products in house and it was Caro who created the model of the industrial research laboratory. "The modern, dedicated, industrial research laboratory, and in particular the central research laboratory was an organizational innovation in its own right and by 1900 an important component of all leading science-based dye firms."(p 220). The German model was not duplicated in France or Britain. This has often been cited as one of the reasons for the failure of the chemical industries in these countries and their dependence on German imports.

The historical development of the BASF central laboratory under the direction of Caro is discussed in great detail. The authors meticulously describe the organization and the types of research conducted. When Caro retired from BASF in 1890, the circumstances were a subject of much speculation. Caro felt that he had not been able to accomplish all he had set out to do. He advised his close friend Ivan Levinstein, "I am starting on a new way of life, because the former one has led me on to fruitless and desolate fields of work." (p 306). Caro continued to consult for BASF but did not produce any new marketable products.

In retirement Caro became a chemical celebrity and was much admired, particularly in England, for his pioneering industrial research. He began writing a history of the dye industry soon after his retirement, which was published in the *Berichte der Deutschen Chemischen Gesellschaft* in 1892. Caro became chairman of the *Verein Deutscher Chemiker* in 1897 and held the post until 1901. His management of the society led to a doubling of its membership, and it became the most important chemical society in Germany. Caro was also responsible for improving the society's journal, *Zeitschrift fur Angewandte Chemie*. He was the German coordinator for the 50th anniversary celebrations of the discovery of mauve held during July, 1906 in London. He greatly enjoyed seeing his old friends from the beginnings of the synthetic dye industry again. Caro, who had suffered from poor health his whole life, finally succumbed on September 11, 1910, at age 76.

In a final chapter the authors discuss the myths that developed concerning Heinrich Caro after his death. In Great Britain, which had been the birthplace of the dye industry, the departure of Caro, Hofmann, and other German chemists in the 1860s was given as one reason, in the early part of the 20th century, when attempts were being made to rationalize the failure of the British dye industry. This was not the only reason, but when included with the lack of investment in research by the British dye industry, the fundamental lack of appreciation of the theoretical developments in aromatic chemistry, and an antiquated educational system, they all contributed to the collapse of the British dye manufacture.

Caro, it is pointed out by the authors, had his faults, particularly a quarrelsome nature with his colleagues, which made him less than the most successful of leaders. However, being first in the introduction of so many new dyes and cultivating a system of close and fruitful contacts with academic chemists, he attained a nearly mythic status.

Through the story of Heinrich Caro, Reinhardt and Travis have produced the definitive work on the early years of the synthetic organic chemical industry. The foundations that Caro laid down flourished and endured, evolving smoothly from dyestuffs to pharmaceuticals and explosives, then to high-pressure chemistry, synthetic polymers, and, finally, the life sciences. My only regret is that the price of this book will discourage its wide distribution. *Martin D. Saltzman, Providence College, Providence, RI 02918.*

***Erratum*:**

Volume 27, Number 2, p 108:

Legend under the photograph should read:
"Francis Home, courtesy the Wellcome Trust"

INSTRUCTIONS FOR AUTHORS

Articles of 4-12 pages, typed, double-spaced (excluding references) should be submitted as hard copy (2 copies) and also on diskette, preferably formatted in Word or Wordperfect, to **Editor, Bulletin for the History of Chemistry**, at the University of Michigan. Chemical formulas, to be kept to a minimum, should be computer-generated and printed on separate sheets, with a clear indication of their location in the ms. Authors are encouraged to provide photographs (black and white glossy prints) and drawings (black ink) to enhance the publication. Include a legend for photos, drawings, graphs and credits if appropriate. Diskettes, photographs, and drawings will be returned at the authors' request.

The title of the article should be of reasonable length (up to 15 words); a subtitle may be included if appropriate. Authors should strive to make the title descriptive of the specific scope and content of the paper, bearing in mind that the title will determine entries in the subject index. Subheadings within the paper may be used if authors feel their inclusion will enhance clarity.

Format as found in recent issues of the **Bulletin** should serve as a guide. Authors should consult J. S. Dodd, Ed., *The ACS Style Guide*, American Chemical Society, Washington, DC, 2nd ed., 1997. Format the document throughout with standard 1" left and right margins. Direct quotations, which in the journal will be indented, will be repositioned by the graphic artist.

REFERENCES AND NOTES should appear at the end as part of the main document and NOT buried as footnotes. References should conform to the format as illustrated below. Standard **Chem. Abstr.** abbreviations are to be used (see CASSI); title of the article is in quotes. Books and journals are italicized, as are volume numbers. The year of publication of periodicals (not books) is boldfaced. Inclusive page numbers are given for an article or partial section of a book. Note the placement of commas and periods. It is imperative to recheck the accuracy of references before submitting the ms. In the text references are identified by Arabic numbers within parentheses—no superscripts.

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William B. Jensen, Founding Editor

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