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Important Figures of Analytical Chemistry from Germany in Brief Biographies

From the Middle Ages to the Twentieth Century

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Acknowledgments

This volume arises from the wish to fulfil the ideals set out by the Working Party on Analytical Chemistry of the Federation of European Chemical Societies after EUROANALYSIS I in 1972 and continued to the present by the Division of Analytical Chemistry of the European Association for Chemical and Molecular Sciences for the organisation of EUROANALYSIS conferences.

That there should always be an opening ceremony where the host country makes a contribution describing the history and development of Analytical Chemistry in the respective country.

A listing of the publications of such lectures and other materials on the history of analytical chemistry in Europe resulting from the activities of the Study Group History is available via the DAC-EuCheMS website.

Germany has been the host country on two occasions for EUROANALYSIS I, Heidelberg, 1972 and for EUROANALYSIS XII, Dortmund, 2002. However due to the nearly impossible task to provide the historical review lectures for Germany, within the time frame of an opening ceremony, no such lectures were presented. The present work seeks to complete series of these accounts by dealing with the previous gap, that for Germany.

The authors wish to record their thanks and appreciation to their wives, Cecilia Mary Burns, Ursula Hanni Müller, Gloria Salzer and Sigrid Werner, for their tolerance and support during the many years of research and preparation of this text.

Contents

Chapter 1
Introduction and Overview

D. Thorburn Burns, R. Klaus Müller, Reiner Salzer and Gerhard Werner

The contributions of chemists of and who worked in Germany are vast and any account must deal with three main problems: define what specifically is analytical chemistry within the whole corpus of chemistry, determine the geographical area to be designated as Germany from the variable areas occupied by the German speaking states and the country as unified over the ages and selection of the system for the periodization of developments in chemistry and their subdivisions over time.

The formulation of an agreed definition of analytical chemistry was first considered by the Working Party on Analytical Chemistry (WPAC) of the Federation of European Chemical Societies (FECS) in 1975. Following an international competition and further debate, the WPAC agreed in 1993 the definition to be:

> Analytical chemistry is a scientific discipline which develops and applies methods, instruments and strategies to obtain information on the composition and nature of matter in space and time [1].

This definition could with advantage, at the present time, be further refined by replacing *analytical chemistry* by *analytical science.* An "Inventory of Definitions in Analytical Chemistry" is available to provide assistance with the categorization of topics within the diverse subdivisions of the subject that have arisen particularly from the development of instrumental methods [2].

An additional essential problem was the logical choice of the persons to be included, who had to be dealt with not only based on their services for analytical chemistry, but also by their national background. Our survey aimed not to boast the importance of the country, but to express the feeling of obligation towards essential contributions to our scientific area by persons correlated with Germany, as it had been done similarly for other countries. But who is a German chemist? Birthplace alone may mislead, for example, when somebody was born abroad, but studied, lived or worked mainly in Germany. The place of the most relevant analytical studies might be considered as a criterion, or the language of their most relevant publications (although then hardly any German researchers would remain on this criterion). In a political sense, the changing borders between Germany and

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neighbouring countries such as Sweden, Poland, Czech Republic, Austria and France let some chemists commonly considered as Germans become Foreigners (or vice versa), and depending on personal points of view on their nationality.

The selection of the included scientists has been decided by best intention and knowledge of the authors, but is certainly incomplete. Nevertheless, it provides examples for a broad development, which was one of the preconditions for our current state of the art. The articles are intentionally focused onto the analytical contributions of the authors. Some of the articles on especially well-known people are certainly rather short, but this is often more balanced by the high number of available biographical publications about them.

For a number of reasons, we chose 1920 as the final year of birth for important analytical scientists to be included in this compilation. None of the scientists appreciated in this book is living anymore. Data Protection Acts prevent archives from permitting access to non-published personal information. This could lead to severe imbalances between biographies of those who died earlier and whose documents are available, those who died more recently and whose documents are not accessible, and those still alive and grant all information about their personal data.

During the period of existence of the "Iron Curtain", the role of the IUPAC via its commissions and many of its members acting individually and their National Societies was important in developing and maintaining close relationships between numbers of analytical chemists across the divide. Assistance was also given by analytical chemists on either side, which ensured scientific contacts at least on a minimal level. Of the figures mentioned in this book, Wilhelm Fresenius, played an outstanding role also in this respect.

Hufbauer in his scholarly monograph, *The Formation of the German Chemical Community* took a reasonably broad geographical view of the extent of the community but used a relatively narrow time frame, 1720–1795 [3]. He discussed in detail, the role of Lorenz Crell (1745–1816), the chemical journalist, in the formation of the community, the various differences of opinions between the German and French chemists during the period of the demise of the phlogiston theory and the "notorious reduction experiment" that of mercury(II) oxide. The book concludes with three most useful appendices, which deal with biographical profiles, institutional histories and a list of Crell's subscribers.

Interestingly, Partington in his monumental *History of Chemistry* [4], following a historical time sequence, dealt with the subject primarily by persons, then by locations and to a lesser extent by theories. Many German contributions were described within broad topics, such as iatrochemistry, however, a specific chapter on *Chemistry in Germany* [4a], covering the contributions from Johann Christian Wiegleb (1732–1800) to those of Johann Wolfgang von Goethe (1749–1832), a time span from the mid-1700s to 1840 which includes Crell's activities, by the end of the which German community was quite well developed. In Volume 4, accounts were given of the history of the subdivisions of chemistry, physical, organic, inorganic, radioactivity and atomic structure of atoms but not that of analytical chemistry.

Thomas Thomson in his *History of Chemistry* gives considerable details under the heading *Progress of Analytical Chemistry* of the period of the development what are now called that of classical methods. From the progress made in the late eighteenth century by Martin Heinrich Klaproth (1743–1814) by his substitution of silver crucibles for the iron crucibles used by Bergmann to that made in the early nineteenth century by William Hyde Wollaston (1767–1829) by his introduction of platinum crucibles [5]. This account was followed by von Meyer in his now classic, *A History of Chemistry: From the Earliest times to the Current Day* [6] who divided his account of analytical chemistry as follows: qualitative analysis of inorganic substances, quantitative analysis of inorganic substances, volumetric analysis, methods of gas analysis and finally, the analysis of organic substances [6a]. He reviewed the chemical literature, the manuals, textbooks and journals. Concerning the most recent textbooks of technico-chemical methods, he noted, in particular, the development of methods for the analysis of articles of food and drink, the importance of which is shown by the increasing provision for instruction in it [6b]. The significant contributions to the growth of chemical instruction in the nineteenth century by German chemical institutions and their influence abroad were well recognized by the end of the nineteenth century [6c].

The first comprehensive free-standing account of the history of analytical chemistry as such is that due to Szabadváry [7, 8] in 1966. Starting with the earliest knowledge of analysis in antiquity, followed by those in the middle ages, the periods of iatrochemistry and of phlogiston, he continues to the establishment of the fundamental laws of chemistry, qualitative and gravimetric analysis and volumetric analysis. The material in the modern period focussed on instrumental methods of organic analysis, of electrochemical and of optical methods and briefly on radiochemical and chromatographic methods. This seminal account was followed by Laitinen and Ewing's monograph in which the editors chose to de-emphasize the early work covered in the general histories of chemistry and focus on the more modern period [9]. The topics covered are developments in chemical methods of analysis, analytical spectroscopy, electrochemical chemistry, separations and lastly the common features of instruments and signal processing instrumentation. Overall this is an excellent, well-illustrated account but suffers from the serious omission of all biographical data, which was made available at the time of publication via a set of microfiche cards, but which now cannot be acquired. The development of chemical instrumentation in the twentieth century was the subject of a conference in 2000 which resulted in an interesting multi-authored volume *From Classical to Modern Chemistry: The Instrumental Revolution* [10]. In addition to describing the development of specific techniques and many of the personalities involved, this volume places the techniques in their social, economic and political contexts. Furthermore, the impact of instrumentation on all branches of chemistry and on the biomedical and environmental sciences is outlined. Since these three accounts, Hudson has listed the reviews of the development of analytical chemistry in specific countries and further expanded the number and variety of instrumental methods to include thermal methods [11].

Homburg has recently discussed *The rise of analytical chemistry and its consequences for the development of the German chemical profession* [12], focusing on the changes in the chemical laboratory rather than the changes over time in the theoretical basis of chemistry. Particular attention was paid to social developments in Germany which led to the separation of practical chemistry from the arts, the distinction perceived between chemists trained at the Universities and Polytechnics and those "empirically trained", and to the emergence of courses in practical analytical chemistry and a new profession. However, academic analytical chemistry and industrial analysis went their separate ways in Germany until the 1840s. This division is described more detail in the article *Two factions, one profession: the chemical profession in German society 1780–1870* [13]. Wetzel in outlining the social effects of the revolution in Germany 1848 on the "*Origins of and education and career opportunities for the profession of 'chemists' in the second half of the nineteenth century in Germany*", expands further on the dualism that existed within the German formal and professional education systems [14].

Vershinin and Zolotov have drawn attention to the problems that exist in the periodization of developments of the history of chemical analysis [15] which have arisen from the semi-independent developments of analytical chemistry in industry and in academic science. Both moved apart as different people worked in these two fields. However, as the problems they solved were closely related, the historical development of academic analytical chemistry and industrial chemical analysis shows considerable synchronicity and similarity in periodization. They proposed four periods, namely: (1) before the middle of the seventeenth century; (2) late seventeenth century to second half of the nineteenth century; (3) late nineteenth century to second half of the twentieth century; (4) from the 1979–1980s till the present time. This classification broadly fits with the approach taken herein, where we have split the earlier period's alchemy and assay, iatrochemistry and analysis in solution, the phlogiston period, the demise of phlogiston and rise of stoichiometry and lastly the period of the development of text books of chemical analysis. Our subsequent Chapter is termed *The growth into a scientific discipline* and covers the period of 1800–1920 (birth of the personalities 1800–1870). The book is concluded by the Chapter *The development of instrumental techniques* that includes scientists born between 1870 and 1920.

There is no comprehensive account of analytical chemistry in Germany, from the precursors of science in the early middle ages to the present era, either before or to follow on from Szabadváry and Chalmers' brief overview produced to celebrate the centenary of Carl Friedrich Mohr's death in 1879 [16]. Merely a few specialized areas have been reviewed such as that on metallurgical analysis in Habashi's *Chemistry and metallurgy in the German Empire 1740–1918* [17] and Possehl on the development of analytical and quality control laboratories in the German pharmaceutical industry [18].

Improvements on the simple classical chemical methods of analysis were the extensions and systematization of "wet analysis" by Kühn [19], Erdmann [20] and Fresenius (separation schemes, mineral waters, [21]), Reinsch [22] and Behrens (microchemical analysis) [23]; the invention of volumetry or titrimetry, extended and improved by Anton Friedrich Robert Behrend, Fritz Förster, Walther Hempel, Justus Liebig, Mohr [24], Schwarz [25], Volhard [26], Winkler [27]; and the development of chromogenic reagents with selectivity and other broad applicability by Otto [28], Fehling [29], Nessler [30], Dragendorff [31], Griess and Leibius [32] and Ehrlich [33].

The measurement of physical parameters for analytical purposes was introduced by Ernst Otto Beckmann (ebulliometric and cryoscopic determination of relative molecular masses, [34]), and the application of optical phenomena from the Lambert-Beer Law [35] to spectral analysis (Kirchhoff and Bunsen [36, 37]), to the use of electrochemical principles such as electrolytic separations (Classen [38]) through contributions of Förster [39] and LeBlanc [40] to Robert Bunsen, Walter Hermann Nernst and Ostwald [41].

Implementation of chemical analysis from mainly metals, minerals and mineral waters to categories of other analytes and other economical areas led to significant advances. For example, Justus Liebig's extensive analyses of biological samples [42] led to a significant increase of agricultural productivity, and Julius Nessler's and Stöckardt's [43] work in agricultural and forestry chemistry has had similar impacts. The forensic-toxicological procedures and analytical systems of Erdmann [44], Mohr [45], Otto [28], Sonnenschein [46], Autenrieth [47] and Gadamer [48] produced substantial advances in poison and other crime detection, and Hoppe-Seyler [49] opened up the extremely wide new field of clinical chemistry, which has included many of the aforementioned methods initiated in the outlined time frame.

Theoretical advances such as the Lambert-Beer Law [35], the Nernst Equation for ionic equilibria or his Partition Law [50] had general importance for analytics as well as for technical processes and in the interpretation of biological phenomena. The detection of new elements has been more or less a side effect of the analytical advances, equally to the sometimes surprising technological applicability and success of—originally more academic or purely analytical—results such as the invention of azo dyes by Griess and Leibius [32] or the separation of rare earth elements.

When what became known as chemistry was still in its basic evolution stages and comprised all its later branches in the centuries before 1800, special chemical fields of activity developed more and more from the turn to the twentieth century and created experts focusing onto smaller sectors of chemistry including that of analytical chemistry. In the nineteenth century, one could contribute essentially to analytics even from neighbouring disciplines such as medicine, pharmacy and biology (e.g. work of Autenrieth [47], Dragendorff [31], Ehrlich [33], Hoppe-Seyler [49], Otto [28], Sonnenschein [46], Gadamer [48]). Considering chemical analytics in a broad sense, it seems appropriate to also include aspects on those steps forward, which finally contributed to the present tremendous knowledge and methodologies in biochemistry, biology and medicine and to the fascinating improvements of our insight into nature.

The image of analytical chemistry at the outgoing nineteenth century is still dominated by wet-chemical methods (Fig. 1.1), but the measurement of physical

Fig. 1.1 Grand lecture hall of the Chemical Laboratory at Universität Leipzig, opened in 1868. *Photo* Archive Faculty Chemistry and Mineralogy, Universität Leipzig, with permission

parameters and the application of physico-chemical techniques start to complement the picture. The vast development of analytical chemistry as a sub-discipline is illustrated by the progress shown by Remigius Fresenius' *Anleitung zur qualitativen chemischen Analyse* (Instruction for qualitative chemical analysis) [51], which grew from the little booklet of the first edition in 1841 to a volume of considerable size by the 16th edition in 1895 [52].

Around the same time, Wilhelm Ostwald published his book *Die wissenschaftlichen Grundlagen der analytischen Chemie* [53] (The scientific foundations of analytical chemistry treated in an elementary manner [54]). One sentence of the author's preface is still quoted today:

> Analytical chemistry thus fills the subordinate but at the same time indispensable position of handmaid to the other branches of our science.

Commonly neglected is Ostwald's sequel remark:

> While we everywhere find the liveliest activity with regard to the theoretical arrangement of scientific material, and observe that questions of this kind always arouse far more interest than purely experimental problems, analytical chemistry is content with fashions of theory which have long been discarded elsewhere, and sees no harm in presenting its results in a shape which has really been antiquated for the last half century.

The young generation of analytical chemists at the time eagerly obeyed Ostwald's demands to combine advanced analytical techniques with the theoretical foundation of their data. Due to Ostwald's worldwide reputation, these developments were adopted in all developed countries (e.g. [55]). The improved understanding of the chemical mechanisms behind the analytical determinations permitted an increasing accuracy of quantitative determinations. Initial steps were based on electrochemical titrations (e.g. Erich Müller, Wilhelm Böttger) and extended to the anticipation of fuel cells (e.g. Kurt Schwabe). The developments were supported by the early miniaturization of the analytical equipment, which provided not only access to low concentrations but also to smaller sample sizes (e.g. Georg Lockemann, Max Boëtius).

Another area of impressive developments was in the separation and determination of elements (e.g. Otto Hönigschmidt, Robert Grießbach, Wilhelm Geilmann, and Werner Fischer). Here, it was not only the access to advanced technical equipment but also the need for painstakingly executed chemical operations that limited progress. Progress was facilitated by early radiochemical trace analyses (e.g. Ida Noddack-Tacke, Otto Hahn, Fritz Straßmann), the progenitors of modern environmental analyses and even cosmochemistry. In due course, the capability for trace analysis needed to be complemented by fast chemical determinations for the detection of short-lived species.

Many important industrial processes and new chemical products required innovative approaches in analytical research (e.g. Hermann Staudinger, Karl Fischer). In the production processes, more and more analytical controls were used (e.g. Erwin Lehrer, Hermann Kienitz). Of great impact to process control were the developments in spectroscopy (e.g. Josef Goubeau, Erwin Lehrer, Arthur Simon, Reinhard Mecke, Kurt Laqua, and Hans Massmann). From about 1965, chromatographic techniques became popular (e.g. Robert Grießbach, Reinhard Mecke, and in particular Gerhard Hesse). The large amount of data available from analytical instruments that became available then required the careful consideration of the data quality (e.g. Heinrich Kaiser and Wilhelm Fresenius).

The top advances in analytical chemistry between 1935 and 1985 have been summarized in a list of the 500 most-cited papers [56]. Of these, 133 papers (27 %) belong to analytical chemistry, clear evidence for the growing importance of the sub-discipline. By 1980, the overwhelming majority of these papers dealt with bioanalytical tasks. The dominating techniques used in the research are spectroscopy and spectrometry (45 %), chromatography (37 %) and immunoanalysis (13 %), whereas nuclear analysis (3 %) and electroanalysis (1 %) lost much ground compared to the beginning of the century [56]. The lives and contributions of the major contributors in Germany to this period of progress are summarized in Chap. 4.

Some ideas that were prophetic at their time and have since been shown to have prognostic value, so suggests a paper of Fresenius and Babo [57], to compare several published analytical procedures for the same purpose for effectivity prior to their application, because authors often claim imaginary advantages for their proposal. Only a late understanding, a few decades ago, lead to the obligation of today to state and justify the improvements claimed and to validate an analytical procedure. The change happened during the ambitious publication practices, e.g. in the early years of chromatography, with the publication of new proposals regardless of the legion of already existing ones, and of their real performance.

In the present account are included several people, for the sake of comprehensive cover of the history of analytical chemistry, who whilst they did not personally make any original direct contributions but assisted in the development and or the dissemination of techniques or theoretical concepts within the broad area of analytical science by their recording and/or publication of relevant material.

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Chapter 2
Important Figures in Analytical Chemistry from Germany: From the Middle Ages to the Nineteenth Century

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The Period of Alchemy and Assay Analysis

The earliest recorded analytical methods are those for the precious metals of gold and silver. Of major importance for later assayers are the detailed and beautifully illustrated accounts of fire assay by Agricola and by Ercker in the sixteenth century.

Albertus Magnus Saint, was Albert von Bollstädt, commonly known as Albertus Magnus (the English translation of which is Albert the Great,) (born ca. 1200 Lauingen, died 15 November 1280, Cologne) [1a, 2, 3, 4] (for portrait see Fig. 2.1). Albert's principal importance derives from the role he played in bringing Aristotle back to preeminence by making his writings readily accessible with detailed discussions and explanations and introducing Greek and Arab science into the universities of the Middle Ages. He studied liberal arts at Padua and in 1223 joined the Dominican Order, became bishop of Regensburg in 1260 but relinquished this post in 1262 to be able to devote more time to study. The latter part of his life was spent in preaching and teaching mainly in Cologne. He was canonized in 1931 and declared patron of all who cultivate the natural sciences in 1941. Thomas Aquinas was one of his most important students [1b]. Albert wrote a large number of works dealing with theology, minerals and natural history, which in time appeared in printed form and now are conveniently available in various editions of *Opera Omnia* [5, 6]. He included sections on chemical practices and alchemy in *De Mineralibus* [5a, 7] and was aware of the frauds of alchemists. Albert was interested in alchemical theories, but was not convinced of the alchemist's claims to make gold as he had not observed it being carried out and realized that chemical explanations were needed for many natural phenomena. Albert was probably the first to use the term "affinity" in the sense of chemical relation or attraction; sulphur burns metals because of its affinity. He knew how to carry out the cupellation procedure and the cementation process for the separation of silver and gold. When having some alchemical gold, which had come into his possession, tested it was found that after several firings, it was reduced to dross. Despite

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Liber ſecretorum Alberti magni de virtutibus herbarum: ⁊ ani
malium quorundam. Eiuſdemq; liber de mirabilibus mundi:
⁊ etiam de quibuſdam effectibus cauſatis a quibuſdam anima
libus ⁊c.

Fig. 2.1 Title page to *liber secretorum* (1502) [10] showing a portrait of Albertus Magnus with his students

the lack of evidence of Albert's direct participation in alchemical procedures, not long after his death, he acquired fame and repute as a skilled alchemist and his name has been attached to numerous Latin [4a] and English tracts on alchemy [8]. Most of his genuine works were republished numerous times prior to the collected editions. In his "Book of Secrets" [9–12], in the section on stones he described the physical properties, mythical (occult) attributes and sources of minerals such as asbestos, magnetite and onyx [4b]. On his travels, he made frequent side trips to mines and excavations to learn by observation the nature of metals and also to collect samples and was also aware of much contemporary chemical technology [4c].

Georgius Agricola latinized from his German name Georg Bauer, (born 24 March 1494, Glauchau; died 21 November 1555, Chemnitz) was probably the most important and influential technical writer of the sixteenth century [13, 14]. He was educated in classical languages at the Universität Leipzig and became a lecturer there (1522–1524). For the next 4 years, he studied at the universities of Bologna, Venice and, probably, Padua and obtained a medical degree. In 1527, he settled as town physician at Joachimsthal in Bohemia (now Jáchymov/Czech Republic). He spent his free time visiting mines and smelters and reading Greek

Fig. 2.2 Agricola's illustration of the acid parting of gold and silver [16]. A—Ampullae arranged in the vessels. B—An ampulla standing upright between iron rods. C—Ampullae placed in the sand which is contained in a box, the sprouts of which reach from the opercula into ampullae placed under them. D—Ampullae likewise placed in sand which is contained in a box, of which the sprout from the opercula extends crosswise into ampullae placed under them. E—Other ampullae receiving the distilled aqua and likewise arranged in sand contained in the lower boxes. F—Iron tripod, in which the ampulla is usually placed when there are not many particles of gold to be parted from the silver. G—Vessel

and Latin authors referring to mining. He resigned in 1530 and spent the next 2–3 years in study and travel. About 1533, he became town physician of Chemnitz in Saxony, where he remained until his death in 1555.

Agricola was the author of several books beginning with *Bermannus* in 1530 [15] and culminating in his famous *De Re Metallica* in 1556 [16–18]; the book was finished in 1550 but delayed in publication due to the slow preparations of the wood-block illustrations for which the book is justly famous. The Seventh Book describes in detail the method of assaying ores by cupellation and acid parting (see Fig. 2.2 for illustration of the process), the preparation and purification of reagents and cupels, and how to test if coins are good or debased using a touchstone [19]. Detailed procedures were given for preparing the touch needles and of the balances and weights in common use at the time. The descriptions of mining and the extraction and assay methods were based on the *Bergbüchlein* and *Probierbüchlein*, the earliest known was by Ulrich Rülein von Calw, Augsburg, 1505, (most editions are anonymous), on mining and assaying, respectively, published in the early sixteenth century [20].

Lazarus Ercker also known as Erckner or Erckel, (born ca. 1530 Annaberg; died 7 January 1594, Prague) was born in the Saxony mining town of Annaberg and educated at the Universität Wittenberg [21–23, 24I]. He became an assay master at an early age, about 25, and then became warden of the mint at Goslar in 1558. After his wife's death in 1567, he returned to Dresden but failed to find a post. He then went to Prague and with his brother-in-law's support was appointed control tester at Kuttenberg in Bohemia (now Kutná Hora/Czech Republic). In 1574, he published his now famous and well-illustrated text, *Beschreibung der allerfürnemisten Mineralischen Ertzt und Bergwerksarten* [25], which made use of material from Agricola's *De Re Metallica* omitting the discussion on mining, but giving much more precise, detailed and practical assaying methods. It included laboratory equipment and procedures, how to prepare cupels, constructing furnaces, making and adjusting assay balances and described only procedures he himself had tested. His contemporaries praised his work and Emperor Rudolf II knighted him in 1586, with grant of a coat of arms bearing a most appropriate device, *Erst prob's, dann lob's* ("Test it first, then praise it"). It appeared in eight editions in German, one in Dutch and two in English [26, 27]. The first English edition was that translated by Sir John Pettus, published with the title, *Fleta Minor* [26], a punning reference to the Fleet Prison where Pettus was incarcerated for the final years of his life and where he did the final writing. Pettus was imprisoned "through the accusations of an unscrupulous woman", his wife [27a, 28]. The early German editions all used the original blocks, gradual and slight deteriorations are evident in the later editions [29, 30], and however, for the Pettus edition, the 44 illustrations were redrawn, with the men in English dress of the period.

The Period of Iatrochemistry and Early Examples of Analyses in Solution

Basil Valentine or Basilius Valentinus, supposedly was a German Benedictine monk of Erfurt, born in Mainz in 1394 (for portrait see Fig. 2.3). The many publications attributed to him misled and perplexed chemists for many years until the position was clarified by Partington [31, 32]; the attributions must be false as the works refer to events that took place after his death. The real identity of Valentinus is now thought to rest with Johann Thölde, a chemist and owner of a salt works who first published the Valentine treatises during the period 1602–1604 [33]. The actual author(s) was very familiar with laboratory preparation, assay and some precipitation procedures, mining techniques, the then known metals, and in particular with the preparation of many compounds of antimony and the mineral acids. His most famous book, *Triumph Wagen Antimonii* (The Triumphal Chariot of Antimony) [34] is important as it contains a wealth of information on antimony and its ores. This book was the primary source for the many antimonial compounds used by seventeenth century Paracelsian or chemical physicians.

Fig. 2.3 Portrait of Basil Valentine

Andreas Libavius his given name was Andreas Libau but he is more well known under the Latinized Libavius (born ca. 1560 Halle/Saale; died 25 July 1616, Coburg) studied first at the Universität Wittenberg [24I] and then at Jena [24II] where he was graduated in medicine [35–37]. He occupied several teaching posts and was town physician in Rothenburg ob der Tauber, 1591–1607, before becoming director of the *Gymnasium* (academic high school) at Coburg in 1607, where he died in 1616. He was an enthusiastic chemical practitioner and author of numerous works on chymistry, religious matters and on education. He was not blind follower of Paracelsus and carried on controversies with both Paracelsists and Galenists. Libavius was an exponent of the iatrochemical trend in medicine; as a result, the application of chemicals was stressed in his writings. He was among the first to describe chemicals and their reactions in clear plain language. His most famous work, *Alchemia* (1597), is clear and systematic and has been described as the first systematic textbook of chemistry [38]. The enlarged edition, *Alchymia* (1606), in folio format [39], is beautifully illustrated, with 200 woodcuts, showing various sorts of chemical glassware, vessels, furnaces as well as architectural plans for the building of a *domus chymici*, a complete chemical institute containing numerous laboratories, store rooms, a library, study rooms and living quarters which was never built. Although sceptical of alchemy as a practical art, Libavius was knowledgeable of alchemical lore and symbolism such as the "Vase of Hermes", shown in *Alchymia* (1606).

Libavius is one of the founders of chemical analysis. He paid special attention to the analysis of mineral waters [38a], investigating those at Rothenburg ob der Tauber [40] and at Coburg [41]. He described many analytical reactions in solution, including that of iron with infusion of galls, the darkening of the blue of copper vitriol by addition of *spiritus urinae* (ammonia), and the darkening of solutions of lead, silver or copper salts with sulphur vapours (H_2S). He was aware of a volatile acid present in acidulous waters. He determined the quantities of dissolved salts by evaporation and examined the shapes of the crystals obtained, to identify alum, vitriol or saltpetre. He also dealt with the tastes, specific gravity, colours and odours of mineral waters and their medicinal uses, both internally and as baths.

Although Libavius travelled very little, he maintained contacts with many natural philosophers and read a great deal. In *Alchemia* (1597), he listed Edward Jorden first among certain friends, including Tycho Brache, who offered him information for his book, they met, whilst Jorden was a student on the continent. Jorden was the first to use acid–base indicators when examining mineral waters [42]. In his text on mineral waters, *Discovrse of Natvrall Bathes and Minerall Waters* [43], Jorden leaned on Libavius and cited him at least 17 times; a typical example of how Libavius' books were in use and cited by chemical practitioners throughout most of the seventeenth century.

Johann Rudolph Glauber (born 10 March 1604, Karlstadt; died 16 March 1670, Amsterdam) was a self-educated practical chemist [44, 45] (see Fig. 2.4 for portrait). He read, travelled and worked in Germany, Austria and Switzerland and obtained an extensive knowledge of chemistry, alchemy, pharmacy, mineralogy and their associated technologies. Glauber went to Holland in 1646 and settled in Amsterdam in 1648 where he had a large laboratory and prepared materials for sale. In his writings, he often extols his preparations in an exaggerated manner. In 1649, he returned to Germany, and in 1651, he set up a laboratory in Kissingen. He returned to Amsterdam around 1655 and set up another large laboratory. Over the years, Glauber prepared and described a vast range of inorganic and organic compounds, and was expert in the manufacture of the mineral acids and improved and invented numerous kinds of furnaces and stills. He was influenced by Paracelsus in his theoretical views and believed in alchemy as seen in the some titles and passages in his works [46]. Glauber wrote his works in German but with titles in Latin, most of his numerous works were published in Holland; many were regarded as important at the time as the various Latin, English and French translations of individual book and of compilations demonstrate. His most important

Fig. 2.4 Portrait of Johann Rudolf Glauber (1604–1670) by Anthonius Santvoort (1654 AS). The inscription round the portrait reads (translated), “True portrait of the honoured and highly esteemed Johannis Rudolphi Glauberi Noble chemist and experimenter at Kitzingen in Franconia”

work is *Furni novi philosopici.* (New Philosophical Furnaces) [47, 48], a book, written with clarity, which established his reputation, as a master of laboratory skills. In the Preface to the English translation of collected works [49], Packe said the Latin works were then very scarce and expensive in London. He purchased the copperplates in Amsterdam with the legends in German. Packe knew no German so he translated the Latin works. His list of subscribers included Robert Boyle and William Penn.

Glauber made significant contributions to dry and wet tests for qualitative analysis. He described the characteristic colours given by metals when fused with fusible Venice glass (a precursor to the borax bead test), the coloured precipitates given by solution of salts of metals with ammonia and with salt of tartar (potassium carbonate), paid attention to crystal forms, he also dealt with assaying.

Fig. 2.5 Portrait of Johann Kunckel (1638–1703), from *Ars vitaria* [49]

Johann Kunckel (born ca. 1630 Hütten, Schleswig; died 20 March 1703, Stockholm), was awarded Swedish nobility in 1693 under the name **Johann von Löwenstern-Kunckel** [24a, 50, 51] (see Fig. 2.5 for portrait). He was the son of an alchemist and had no university education and learned chemistry from his father and practical chemistry from pharmacists and glassworkers. He eventually became pharmacist to the Duke of Saxe-Lauenburg, later to the Elector of Saxony; he lost this post and then taught at the Universität Wittenberg [24I]. In 1679, he went to the court of Friedrich Wilhelm, Elector of Brandenburg. On the elector's death in 1688, he entered the service of King Charles XI of Sweden as Minister of Mines and was ennobled in 1693 as Baron von Löwenstern.

Kunckel's chemical views derived from alchemy crossed with rational philosophy. Whilst he despised alchemists for their mysticism, he inclined to regard their aims as rational. He was a very able practical chemist who made, in his times, significant contributions to chemical analysis, including dry and wet reactions via blowpipe analysis and early gravimetric methods. His interest in the use of a blowpipe came from his studies of glass manufacture. He described how metal oxides may be reduced on charcoal with a flame. He carried out many quantitative experiments and described in his most important work *Laboratorium Chymicum* [52] some were remarkably accurate, for example, he says when 12 parts of silver were dissolved and precipitated with common salt or *sal ammoniac* (NH_4Cl), this gave exactly 16 parts of silver chloride, which is close to the theoretical value of 15.95 [52a].

Although Kunckel knew some Latin, he wrote his works in German, giving many of them Latin titles as was then customary. Partington lists his numerous works, their various editions and translations [50a]. Best known, and read for the next century, was a series of essays on aspects of glass making, *Ars vetraria experimentalis* [53]. This was a translation into German of Christopher Merret's Latin edition of Antonio Neri's *L'arte vetraria* of 1612 [54a]. Kunckel kept Merret's notes and added further notes as well as a section on the making of coloured glass. Its translation into French in the mid-eighteenth century added considerably to his reputation [55]. Kunckel perfected the art of making ruby glass [52, 53], by suspension of gold, the nature of which still excites scientific interest [56].

Kunkel was also important in the history of the discovery of phosphorus and shares with Robert Boyle the honour of discovering the secret of the process by which Hennig Brand of Hamburg had prepared phosphorus. Having obtained a hint from Brand during a visit to Hamburg in 1675 that it was made from urine, he returned to Wittenberg and by July 1676 had prepared half an ounce of solid white phosphorus. He published an account of his phosphorus and its medical properties, but not its method of preparation [52, 57–59], and this was first published by Boyle [60].

Both Davis and Partington regarded Kunckel as one of the most competent chemists of the seventeenth century, an able experimenter and an acute observer with great patience and stubborn application—the qualities found in a great chemist.

Otto Tachenius also called Tachen and Tackenius (born ca. 1620 Herford, Westphalia; died ca. 1680 Venice), details of his life are obscure and mainly come from statements by his protagonists such as Helwig Dietrich (over a letter on the alkahest) and Johann Zwelfer (over the invention of the viperine salt) [61–63]. He is said to be the son of a miller and a former abbess, and he was apprenticed to a pharmacist at Lemgo but dismissed for theft, then acted as assistant to pharmacists in Kiel, Danzig (now Gdańsk/Poland) and Königsberg (now Kaliningrad/Russia). In 1644, he went to Italy and in 1652 obtained an M.D. from Padua and then settled in Venice. He was a passionate and provocative man and involved in many scientific polemics and in disputes with authorities. His works were published in Venice from 1655, the most important being *Hippocrates Chimicus*, *Per ignum et aquam Methodoinaudita Novissimi Salis Viperini…* [64, 65] and *Antiquissimæ Hippocraticæ Medicinæ Clavis Manuali experientia in Naturæ fontibus elaborate* [66]. Tachenius was introduced into Italy the hypothesis of acid and alkali as the basis of physiology and pathology. He was a good chemist with a clear understanding of reactions and a wide knowledge of substances and their preparation, for example, when discussing the manufacture of soap, he noted that fats contain a hidden ("occult") acid [65a].

Of the many extant analytical notes of Tachenius, one of the most interesting is that of his systematic examination of the effect gall-nut extract on metal salt solutions, given by Nierenstein from the 1677 English translation of *Hippocrates*

Chimicus [65b] in *Incunabula of Tannin Chemistry* [67] and discussed later by Szabadváry [68] who regarded Tachenius as, “a somewhat neglected figure in the history of chemistry”. Tachenius recorded the colour formed by various metals and established that iron was not removed from the human body via the urine as previously supposed, as no colour was obtained when urine was treated with gall-nut extract. An early, if not the first, example of analysis applied to biochemistry.

Another interesting applied analysis is Tachenius’ examination of samples of rose water, used at the time to prevent ascarides [65c]. It was found that certain samples taken internally for this purpose caused the patients to vomit. Tachenius examined the problem and found that it was not due to the rose water *per se*, but due to copper contamination which came from the copper flasks used in its preparation. If a few drops of alkali are added to the rose water, a green precipitate forms; after filtering, the rose water did not cause vomiting. When the green precipitate was fused with borax, it showed the presence of copper.

Friedrich Hoffmann (born 19 February 1660, Halle/Saale; died 12 November 1742, Halle/Saale) was the son of a physician of the same name [24b, 69–71] (for portrait see Fig. 2.6). From 1678, he studied medicine at Jena under Wolfgang Wedel, and chemistry with Caspar Cramer in Erfurt [24III] and graduated M.D.

Fig. 2.6 Portrait of Friedrich Hoffmann (1660–1742) from his *Opera Omnia Physico-Medico* (1740)

at Jena in 1681. He then travelled extensively, and whilst in England, 1684–1685 became acquainted with Robert Boyle [72]. In 1685, he commenced medical practice and his reputation grew rapidly. In 1693, he was appointed the first Professor of Medicine at the new Friedrichs-Universität Halle/Saale [24IV]. His lectures on physics, chemistry, anatomy, surgery and medicine attracted great numbers of students from all over the world. He worked at the university for 48 years. From 1709 to 1712, he was personal physician to Friedrich I, King of Prussia, but as he preferred the scientific to court life and returned to his professorship, but returned to court in 1734 for about 8 months. He received numerous honours and academy memberships including Fellowship of the Royal Society of London. Although his main contributions were to medicine, he maintained a lifelong interest in chemistry. Hoffmann made major contributions to the investigation of mineral waters, specifically by significantly improving on the contemporary analytical methods and by distinguishing essential components. Hoffman studied carbon dioxide (called *spiritus mineralis*), which he described as a weak acid intermixed with several salts. He noted the presence of sulphates in certain waters, detected rock salt with *lunar caustic* (silver nitrate), copper by precipitation with iron, separated magnesia from lime and described the manufacture of artificial mineral waters. Essays on the examination of mineral waters are included in several of his medical works and were discussed in detail in *De method examinandi aquas salubres* [73]. This text was followed by numerous accounts of specific mineral waters sources and their contents. Hoffmann's numerous contributions were collated and translated, by Shaw [74].

The Phlogiston Period

Georg Ernst Stahl (born 22 October 1659, Ansbach; died 14 May 1734, Berlin) studied medicine at the Universität Jena, which was at the time a stronghold of iatrochemistry, stressing the unity of chemistry and medicine and the application of chemistry in medicine, and graduated in 1684 [75–77] (for portrait see Fig. 2.7). He taught chemistry for awhile at Jena, in 1687 was appointed court physician to the Duke of Saxe-Weimar and in 1684 moved to the new Friedrichs-Universität Halle/Saale. He left Halle in 1715 to be court physician in Berlin to Friedrich Wilhelm I of Prussia. As noted by Partington, Stahl was a prolific author [76]. He is principally remembered for his part in the development of the phlogiston theory following on from the earlier work of J. J. Becher about the combustible component or principle of bodies *terra pinguis* (oily earth), which Stahl called phlogiston. The phlogiston theory [78] was the first systemizing chemical theory and lasted most of the eighteenth century until experimental evidence mounted against it, culminating in the chemical revolution, and Lavoisier's explanation of the role of oxygen in combustion. Stahl also made considerable progress on the properties of salts and the concept of an affinity series for metals, fractional crystallization and concentration of solutions by freezing.

Fig. 2.7 Portrait of Georg Ernst Stahl (1660–1734)

Andreas Sigismund Marggraf (born 3 March 1709, Berlin; died 7 August 1782, Berlin) was one of the most famous and experimentally adept chemists of the phlogiston period; his interest in chemistry for its own sake, his refinement of analytical tools and his use of the balance anticipated some facets of the chemical revolution and the demise of the phlogiston theory [24c, 79–81], (see Fig. 2.8 for his portrait).

He was the son of a court apothecary; from 1725 to 1730, he was a pupil of Caspar Neumann at the court pharmacy. He later studied at the universities of Straßburg (now Strasbourg/France) [24V] and Halle/Saale [24IV]. In 1734, he travelled to Freiberg to the Mining Academy [24VI] to study chemistry with Henckel and assaying with Süssmilch. In the spring of 1735, he returned to Berlin to work with his father in the Berlin court pharmacy. In 1738, he became a member of the Kurfürstlich Brandenburgische Sozietät der Wissenschaften (Electoral Brandenburg Society of Sciences, now Berlin Brandenburgische Akademie der Wissenschaften) [24VII]; in 1753, he became Director of the Academy's

Fig. 2.8 Portrait of Andreas Sigismund Marggraf (1709–1782)

new chemical laboratory and from 1760 Director of its Class of Experimental Philosophy. Many of his papers were published in the journals of the Berlin Academy and are available as collected works in German [82] and in French [83].

Marggraf's earliest publications are on phosphorus and its compounds. He recorded that 1 oz increased in weight by 3½ drahms when burnt. He made numerous advances in inorganic analysis, by purifying reagents, examining the effects of alkalis on metals and their salts, using a microscope he could distinguish between "cubic nitre" (sodium nitrate) and "prismatic nitre" (potassium nitrate) and that they could also be distinguished by a flame test using a blowpipe. He designated sodium salts as "mineral fixed alkali" and potassium salts as "fixed vegetable alkali". He pioneered the use of the reagent potassium hexacyanoferrate (formed from cattle blood ignited with alkali) as a sensitive reagent for iron in a variety of samples. Many of his tests were used systematically as, for example, in his essay on the chemical examination of water.

He also published several memoirs on plant and animal chemistry, for example, characterizing the acid extracted from ants (formic acid), examining the "essential oil” from cedar wood, the most important was his discovery using microscopy, that beet sugar was identical to cane sugar [84].

Marggraf worked with quite small amounts of materials, compared to his contemporaries. His papers are models of concise, rigorous and systematic experimentation with little speculation beyond the conclusions which the observations seemed directly to establish.

Johann Andreas Cramer (born 14 December 1710, Quedlinburg; died 6 December 1777, Berggieshübel near Dresden) was the son of the leaseholder of the state ironworks in Quedlinburg who introduced him to metallurgy [24d, 85–87]. After secondary school, Cramer at first studied law at Hamburg, then medicine at Halle/Saale [24IV], which he abandoned as anatomy made him sick. He returned to law, but continued to study chemistry. In 1729, he proceeded to Academia Julia (Julius-Universität) Helmstedt [24VIII], where he spent about 1 year. He then started to practise law in the mining town of Blankenburg (then Principality of the Empire, now in Saxony-Anhalt). In his spare time, he pursued chemistry and metallurgy to an extent that he was described as “black Cramer”. In 1734, he returned to Helmstedt and then to Leiden to study medicine where he also taught analytical chemistry. Whilst at Leiden, Cramer worked on a textbook, the first of its kind, *Elementa artis docimasticae*, published in 1737 [88]. This text appeared in several editions and was translated into several languages including English [89, 90]. Both editions were produced by the printers to the Royal Society and over the years and brought him international recognition. In his book, Cramer described all the instruments and apparatus of contemporary analytical chemistry, explaining in detail the construction of an accurate and sensitive balance. Although Cramer’s book was designed as an introduction to the trade of assaying, he believed that assaying could contribute to the pursuit of natural knowledge. Cramer classified minerals by the use of blowpipe tests on a charcoal block and by borax bead tests.

He visited England in 1738 and 1739 to learn more about metallurgy and assaying and lectured on the subject in London. After further travels, he returned home and was appointed director of the Brunswick Mining and Metallurgy administration, a post he lost in 1773 by the actions of his enemies. In 1774, he accepted a new post in Saxony, and he was consultant to the Habsburg Mining Administration in Hungary from 1775–1776. He returned to Germany in 1777 as consultant to the Saxon Mining Administration, but died later that year. Although barely mentioned by Szabadváry, Partington states he was the best assayer of his time. Recently, Cramer’s contributions to assaying in the eighteenth century have been reassessed [91, 92].

Heinrich Johann Lambert (born 26 August 1728, Mülhausen/Elsass, now Mulhouse/France; died 25 September 1777, Berlin) grew up in impoverished circumstances and by self-education became a noted mathematician and physicist [93] (for portrait see Fig. 2.9). Although not a chemist, his name is well known to analytical chemists by his name being associated with the law that governs the absorption of radiation by matter, commonly called the Beer–Lambert (in Germany: Lambert–Beer) law [94].

Fig. 2.9 Portrait of Johann Heinrich Lambert (ca. 1728–1777)

Lambert's book, *Photometria* [95], that deals with optical measurements was published in 1760. In it, he stated:

> If a light beam with an intensity I passes through a layer [in his experiments, of glass] of width l, its intensity will decrease to $I \times 1/n$ of its original intensity while if it passes through a further similar layer its intensity will decrease to $I \times 1/n \times 1/n$ of its original value. For m layers the intensity of the exiting light will be $I' = I/n^m$.

He also noted:

> The amount of captured light is the greater, the greater the number of particles within a given volume and the larger the surface area of a given particle.

Later, in 1852, Beer pointed out that the Lambert law also applied to solutions and defined the absorption coefficient [96].

The Beer–Lambert law could equally be described as the Bouguer–Bernard law. Bouguer's research predated but was unknown to Lambert, his *Essai* [97] was published in 1729. Bernard also defined the absorption coefficient, a few months after Beer [98].

The Demise of Phlogiston and the Rise of Stoichiometry and Quantitation

Carl Wilhelm Scheele (born 19 December 1742, Stralsund; died 21 May 1786, Köping, Sweden) is normally listed as a Swedish chemist but is included herein because Stralsund is in Western Pomerania, then a Province of Prussia, although

Fig. 2.10 Portrait of Carl Wilhelm Scheele (1742–1786)

at the time, it was temporarily under Swedish rule [99–102]. He began his career at the age of fourteen by a pharmacy apprenticeship with B.A. Brauch in Gothenburg (for portrait see Fig. 2.10). He occupied positions in pharmacies in Malmö, Stockholm, Uppsala and Köping. Scheele was a man of great modesty, often in poor circumstances, who was more interested in doing research on chemicals rather than producing them for sale. In Uppsala, he became acquainted with T.O. Bergman, from whom he received advice and encouragement. Scheele made a great number of important chemical discoveries including those of the elements chlorine, fluorine, manganese, molybdenum, tungsten and oxygen. Those on air and combustion, he published in …*Luft und dem Feur*…(1777) [103], which not only brought him to the attention of Priestly and Kirwan in London [104] but that of Frederick the Great as well. The latter wanted him as successor of the diseased Andreas Sigismund Marggraf at the Kurfürstlich Brandenburgische Sozietät der Wissenschaften (Electoral Brandenburg Society of Sciences, now Berlin Brandenburgische Akademie der Wissenschaften), but his plenipotentiary was not able to find him [105].

Most of Scheele's other studies were published in the proceedings of the Royal Academy of Sciences in Stockholm [106] of which he became a full member in 1775. Due to his significant achievements in inorganic chemistry, those in organic chemistry are often overlooked. He was the first to isolate and characterize a large number of organic acids such as tartaric, lactic, uric, citric, gallic, pyrogallic and malic acids. In 1776, he was able to establish his own pharmacy in Köping, which he purchased from the widow of the previous owner H. Pohl. On his death bed, Scheele married the widow Pohl, but passed away 48 hours later at the early age of 43, probably due to the toxic effects of the chemicals he had worked with.

Martin Heinrich Klaproth (born 1 December 1743, Wernigerode; died 1 January 1817, Berlin) was the son of a tailor, after leaving school at 15 became an apprentice pharmacist in Quedlinburg [24e, 107–109] (for portrait see Fig. 2.11). He later became an assistant pharmacist in Hanover, Berlin and Danzig (now Gdańsk/Poland). In 1771, he went to work in Valentin Rose's pharmacy in Berlin. Rose died 4 weeks after Klaproth had joined him. Klaproth continued to run the pharmacy and see to the education of Rose's two sons, one of them Valentin Rose Jr. became a chemist of note and in due time collaborated with him. In 1780, he married a wealthy niece of A.S. Marggraf and purchased his own pharmacy. Previously, he had carried out some research in addition to pharmacy; he then devoted himself almost entirely to research mainly on the analysis of minerals from all parts of the world.

Klaproth discovered or co-discovered zirconium, uranium, titanium, strontium, chromium and cerium and confirmed the prior discoveries of tellurium and beryllium. After confirming several of Lavoisier's experiments, he abandoned the phlogiston theory and was the first important German chemist to openly accept the

Fig. 2.11 Portrait of Martin Heinrich Klaproth (1743–1817)

views of Lavoisier. Klaproth introduced new techniques, fusion of finely ground insoluble mineral in alkali carbonates, decomposition of silicates by fusion with barium nitrate. He constantly drew attention to the necessity of avoiding or making allowances for contamination from apparatus and reagents. Most significantly he broke with the tradition of ignoring small losses and gains in weight in analytical work. He used the discrepancies, over a few percentage points as a means of detecting faulty and incomplete analyses. Once satisfied with his procedure for analysing a mineral, he reported his procedures in detail, with the final results including any remaining discrepancy.

Most of his numerous publications are in his *Beiträge* [110] and listed in the Royal Society Catalogue [111]. The first two volumes of *Beiträge* were translated into English [112] and the first three into French [113]. The advertisement to the English translation of volume I of his collected works neatly expressed Klaproth's reputation as follows:

> The merits of KLAPROTH, in Chemical Analysis, are so eminently established with men of science throughout Europe, that it would seem improper to enlarge on the most consummate skill and accuracy with which he performed his experiments, as well as on his laudable candour in stating their results.

The notice in volume II was equally fulsome in its praises. In addition to *Beiträge*, Klaproth wrote *Observations relative to the Mineralogical and Chemical History of the Fossils of Cornwall* [114] and with Benjamin Wolff, a good Dictionary of Chemistry [115].

Over the years, Klaproth moved up in the Prussian medical bureaucracy and in the Berlin Academy [24e, VII]. He received numerous honours at home and abroad, for example, in 1795 by election as a Fellow of the Royal Society of London. In 1800, Klaproth was appointed leader of the chemistry laboratory of Berlin's Academy (Königlich Preußische Sozietät der Wissenschaften). In 1803, he sold his pharmacy at a great profit and moved into the academy's new laboratory residence, where he worked until his death in 1817. After the founding of the Friedrich-Wilhelm-Universität (now Humboldt-Universität), Berlin he was appointed in 1810 to be the first Professor of Chemistry.

Lorenz Florenz Friedrich von Crell (born 21 January 1744, Helmstedt; died 7 June 1816, Göttingen) was the son of Johann Friedrich Crell, Professor of Medicine in the Academia Julia (Julius-Universität) of Helmstedt [24VIII], who died in 1747 [24f, 116, 117]. His early education was supervised by his maternal grandfather, Lorenz Heister who was also a Professor of Medicine in the University of Helmstedt. In 1759, Crell entered the local university, studied the philosophical sciences for 6 years and the medicine (see Fig. 2.12 for his portrait). During his medical studies, he was introduced to chemistry by G.C. Beireis. He was graduated M.D. in 1768. He then spent the next two and a half years on a study tour to Strasbourg, Paris and Edinburgh. During this trip, the men that influenced him most were William Cullen and Joseph Black, both in Edinburgh. Crell remained in contact and correspondence with Black [118], some letters were published [119] and he translated Black's *Lectures on the Elements of Chemistry* [120].

Fig. 2.12 Portrait of Lorenz Florenz Friedrich von Crell (1745–1816)

Soon after his return to Germany, he was appointed to the new chair of chemistry in the Collegium Carolinum (now Technische Universität) Brunswick in 1771 [24IX]. He was Professor of Philosophy and Medicine at the Universität Helmstedt from 1773 until its closure in 1810 by the Napoleonic regime, when he transferred to Göttingen [24X]. He is primarily remembered for his literary activity although he carried a number of original researches on inorganic materials and on natural products [121].

Over the years, Crell produced and edited a large number of journals [24f(i), 122], some were short lived such as his first, *Chemisches Journal* (1778–1781), translated into English as *Chemical Journal* [123], this was important as it was the first journal to be exclusively devoted to chemistry [124]. Some of his other journals such as *Chemische Annalen* (1784–1804) were more long-lasting. Crell published work by many distinguished analytical chemists such as Klaproth, Lowitz and Richter. Through his position as a successful journal editor, Crell was enabled to exert a strong influence on the German reception of the various theories being developed to deal with the then new area of pneumatic chemistry [24f(ii)]. At first, he supported Richard Kirwan's view that phlogiston was inflammable air (hydrogen) and continued to do so against the tide of opinion in the rest of the German chemical community. Interestingly, it was Crell who published Kirwan's conversion in 1791 to Lavoisier's views [125] nonetheless Crell remained a phlogistonist. Crell received numerous honours and awards from the major European scientific societies including in 1783 Fellowship of the Royal Society of Edinburgh, and in 1788, Fellowship of the Royal Society of London.

Johann Tobias Lowitz (born 25 April 1757, Göttingen; died 7 December 1804, St. Petersburg/Russia) was the son of Georg Moritz Lowitz who from 1762 was Professor of Mathematics in the Georg-August-Universität Göttingen [126–128] (see Fig. 2.13 for silhouette portrait). In 1767, his father was called to St. Petersburg as Professor and Member of the Imperial Academy of Sciences. In 1774, he and his father went on an Academy expedition to the shores of the Caspian Sea. They were captured by a band of rebels and his father was hanged, Tobias escaped and returned to St. Petersburg and was placed at the Academy Gymnasium. In 1776, he became apprentice to the Court Pharmacy. He then studied at universities in Germany. In 1787, he was appointed Court Apothecary. In the course of his work, he was called upon to prepare and purify many chemicals, and he became a talented and innovative chemist. One of his important discoveries was the use of charcoal to absorb visible impurities from many substances and gases [129]. Among his many analytical innovations [127] were the study of crystal

Fig. 2.13 Portrait of Johann Tobias Lowitz (1757–1804) drawn in St. Petersburg in 1799

form of salts under a microscope as a basis for their identification, the separation of calcium from barium based on the relative solubility of their chlorides in absolute alcohol, the colours alkaline earth metals impart to flames, the dissolution of silicates in hot caustic alkali solutions, an alternative to fusion, and a series of novel titrations of acetic and sulphuric acid [130]. His publications were mainly published in Crell's *Annalen* and *Nova Acta* of the St. Petersburg Academy [131] of which was elected an adjunct in 1790 and a full member in 1793.

Jeremias Benjamin Richter (born 10 March 1762, Hirschberg, now Jelenia Góra/Poland; died 14 April 1807, Berlin) after graduation from Hirschberg Gymnasium, he joined the engineering corps of the Prussian army in 1778 [24g, 132–135] (see Fig. 2.14 for his portrait). He devoted his spare time to studying chemistry. He left the army after 7 years and studied mathematics in the Königliche Albertus-Universität zu Königsberg in Preußen (now Kaliningrad/Russia) [24XI] and graduated as doctor in 1789, with a dissertation *De usu matheseos in chymia*, a clear indication of his future interests. He worked for a while near Glogau (now Głogów/Poland) and then in 1795 as assayer as secretary of the mining office at Breslau (now Wrocław/Poland), finally from 1798 as "second Arcanist" (chemist) at the Königliche Porzellan-Manufaktur (Royal Porcelain Factory) Berlin. Richter carried out research in his own time, mainly at night, and shaped by his firm conviction that all chemical processes are based on mathematical laws. His terminology is difficult to understand as he uses his own peculiar symbols instead of names for chemical substances and writes in a verbose style. Richter's results and their publication are clearly set out and explained by Partington [132].

Richter was the first to recognize the significance of the law of neutrality and establishes the basic rules of stoichiometry. The word stoichiometry originates from Richter, in his major work, *Anfangsgründe der Stöchyometrie oder Messkunst chymischer Elemente* [136]. In his series of experiments published between 1792 and 1802, he determined that the weights of various bases (lime, soda, baryta, potash and magnesia) which neutralized a given quantity of an acid was characteristic of the particular base. Likewise, the weights of different acids neutralized by a given weight of a certain base were characteristic of the particular acids. Richter's work was almost unknown and not appreciated until in 1802 E.G. Fischer, in a note to his translation into German of Berthollet's *Recherches sur les lois de l'affinite* [137] put Richter's results in tabular form, the weight equivalents of various bases that would neutralize 1,000 parts of sulphuric acid. The numbers assigned to the various acids show the weights of acids necessary to neutralize the same amount of any base as could be neutralized by 1,000 parts of sulphuric acid. This publication of the first table of equivalent weights made Richter's results widely and generally available. Richter made significant contributions to various areas of preparative chemistry [133], and it was not until the acceptance of Dalton's atomic theory that the significance of his studies in stoichiometry became fully recognized.

Fig. 2.14 Portrait of Jeremias Benjamin Richter (1762–1807)

The First Analytical Textbooks

Many guide books to assaying, such as those by Agricola, Ercker and the booklets, *Bergbüchlein* and *Probierbüchlein* [20], were published in the sixteenth century, although these were compiled for artisans rather than scientists. These were followed in the next century by texts dealing with the characterization of mineral waters. By the end of the seventeenth century, scientific textbooks of chemistry became available, however, they contained little specific analytical material. At the end of the eighteenth and early nineteenth century, the first books devoted to analytical chemistry appeared. Important examples are those by Lampadius, Pfaff and Rose.

Wilhelm August Lampadius (born 8 August 1772, Hehlen, now part of the district Holzminden; died 13 April 1842, Freiberg) after leaving school at the age of 13 he became apprenticed in Göttingen's Rats-Apotheke [24h, 138–142] (see Fig. 2.15 for his portrait). During his apprenticeship, he studied languages and natural sciences on his own, then began attending lectures at Georg-August-Universität Göttingen [24X] and meet J.F. Gmelin. In 1791, he finished his training as a pharmacist and began scientific studies in earnest. He worked closely

Fig. 2.15 Portrait of Wilhelm August Lampadius (1772–1842)

with G.C. Lichtenberg and J.F. Gmelin, serving as experimental assistant in their courses. Lichtenberg introduced him to his future employer, Count J. von Sternberg.

In 1792, Sternberg employed him as a travelling companion for an expedition through Russia to China. En route to Russia, he met M.H. Klaproth in Berlin. On arriving in St. Petersburg, he learnt that the Russian Government had denied permission for the expedition. He stayed awhile and met T. Lowitz, then accompanied Sternberg back to his Bohemian estates. Lampadius then established a new ironworks for Sternberg at Radnitz (now Radnice) near Pilsen. During this time, when A.G. Werner was seeking a successor to C.E. Gellert in the Kurfürstlich-Sächsische Bergakademie (Mining Academy) Freiberg [24VI], he interviewed him on Klaproth's recommendation. Favourably impressed, Werner recommended the appointment. Lampadius held the chair with great distinction from 1794 until 1842. In 1801, Lampadius published the *Handbuch zur chemischen Analyse der Mineralkörper* [143].

His methods were similar to those of Klaproth but parts of the book are in the style of textbooks of a much latter period. For example, it gives lists of equipment and apparatus required for analysis and instructions for their use. The introductory part deals with the preparation and purification of various reagents. These descriptions are the earliest record of standard methods used for the testing of the purity of analytical grade reagents, in many cases are very similar to current methods. The purity of distilled water was tested as follows:

1. Neither lead acetate nor heavy earth (barium) acetate should cause turbidity.
2. It must remain clear after the addition of silver solution.
3. It should show similar effect with potassium carbonate.
4. Similarly with potassium cyanide, and
5. Similarly with lime water.

Lampadius described the tests for the more important salts, and he did not realize that it was necessary to examine for metal ions and anions, this only became apparent after Berzelius's dualistic theory. In addition to gravimetric methods, he used titrimetric methods. His method for sodium carbonate with sulphuric acid using curcumin paper as indicator was absolute as he determined the amount of pure sodium carbonate equivalent to the acid consumed [141, 142b]. He made many discoveries in technical chemistry [144] and published major texts in this area in addition to those on the examinations of minerals. For example, he investigated the commercial production of sugar from beets and introduced gas lighting to Germany at the amalgamation works Halsbrücke (now part of Freiberg).

Christoph Heinrich Pfaff (born 2 March 1773, Stuttgart; died 23 April 1852, Kiel) came from a well off family his father being the General Treasurer of Württemberg [24i, 145] (see Fig. 2.16 for his portrait). He was tutored at

Fig. 2.16 Portrait of Christoph Heinrich Pfaff (1773–1852)

home, then he entered Hohe Karlsschule (Duke Carl's Academy) in Stuttgart in 1782, after 4 years of pre-university study. From 1786–1788, he studied in the Academy's philosophical section and from 1788–1793 in its medical section. From the mid-1780's, natural history was his chief enthusiasm.

It has been said that once introduced to chemistry, it became his favourite science. His MD thesis in 1793 was on animal electricity. He then went to Georg-August-Universität Göttingen to study obstetrics and also worked in J.F. Gmelin's laboratory. From 1795, he spent 2 years as personal physician to Count F. Reventlow, later his patron as Curator at the Universität Kiel. After a year in private practice in Heidenheim, he was then appointed as Assistant Professor in the Medical Faculty at Universität Kiel. In 1801, he went to Paris at government expense to prepare for the chair of chemistry, whilst in Paris, he met the leading French chemists of the day. From 1802–1846, he held the chair of chemistry and physics in the medical faculty. He was an extremely productive scientist dealing with topics in voltaic electricity, physics, botany and pharmacy, general and preparative chemistry, but above all, in analytical chemistry [146]. In addition to his numerous research papers and textbooks, Pfaff made a major and influential contribution to analytical chemistry by writing the first general and comprehensive two volume textbook, *Handbuch der analytischen Chemie für Staatsärzte, Apotheker, Oekonomen und Bergwerks Kundige* [147]. Szabadváry describes the contents and their significance in some detail, noting in particular, the lengthy section on the preparation of reagents, tests for their purity, detailed discussion of qualitative and quantitative gravimetric reactions of metals, and the book concludes with the analysis of gases and organic substances [148]. In view of Pfaff's considerable contributions, it is surprising that he only merited *en-passant* mentions by Partington and in the Dictionary of Scientific Biography.

Friedrich Stromeyer (born 2 August 1776, Göttingen; died 18 August 1835, Göttingen) was the son of J.F. Stromeyer, Professor of Medicine at the Georg-August-Universität Göttingen [149, 150]. He studied pharmacy at the university and so was influenced by J.F. Gmelin. He continued his studies in Paris with L.N. Vauquelin who was an exceptionally able analyst. Returning to Göttingen [24X], he graduated in medicine in 1800 (see Fig. 2.17 for his portrait). He then made a scientific tour and met many distinguished chemists; their accomplishments decided him to turn from medicine to chemistry. In 1802, he habilitated as *Privatdozent* (Assistant Professor) in pharmacy and chemistry. He made such progress that after Gmelin's death he was named extraordinary professor in 1805, the next year, the director of the chemical laboratory and in 1810 full professor. He wrote several textbooks on chemistry and published a considerable number of important investigations [151] most of which were analytical in nature, including the analysis of minerals and the use of starch to detect free iodine. In 1817, he discovered cadmium. Importantly, Stromeyer predated Liebig in the establishment, in 1805, of laboratory instruction for undergraduate students in chemistry [149].

Joseph Fraunhofer (born 6 March 1787, Straubing, Lower Bavaria; died 7 June 1826, Munich) although not a chemist, is worthy of mention herein, as exemplifying

Fig. 2.17 Portrait of Friedrich Stromeyer (1776–1835)

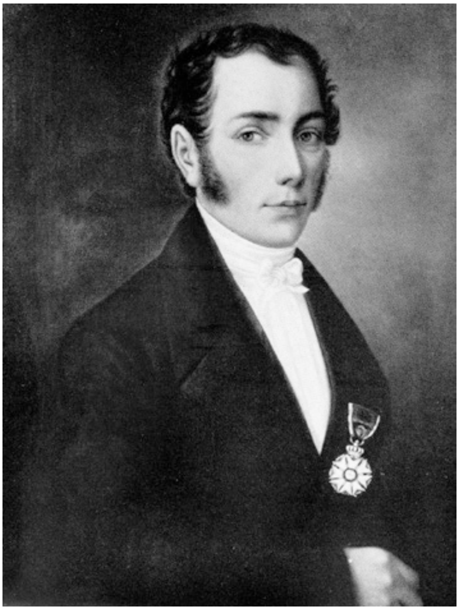

Fig. 2.18 Portrait of Joseph Fraunhofer (1787–1826)

the highest level of union between a craftsman and a theoretician (see Fig. 2.18 for his portrait). His activities permitted major progress in analytical chemistry via spectroscopy and his improvements to optical components, namely to glass for prisms, achromatic lenses and in the manufacture of diffraction gratings. He came from a poor family and received limited schooling, after the death of his father in 1798 became apprenticed to a glass polisher [152]. When the workshop house collapsed, he was buried under the ruins. Elector Maximillian Joseph heard of the accident was present at his extrication and presented him with sufficient money for release from his apprenticeship, purchase of a glass polishing machine and books on optics. After working as a journeyman, he then entered the firm of Utzschneider, Reichenbach and Liebner and continued to improve his knowledge of mathematics and optics. In 1814, he examined the dark lines in the solar spectrum, discovered earlier by Wallaston, in great detail for the purpose of measuring the homogeneity and optical constants of glass. From 1821, he researched into the manufacture and equations of transmission and reflecting diffraction gratings. Under Fraunhofer's guidance, the workshop designed and produced the finest possible optical and mechanical instruments which permitted others to develop spectroscopy for analytical purposes [153].

Friedlieb Ferdinand Runge (born 8 February 1794, Billwärder (now part of Hamburg); died 25 March 1867, Oranienburg) at the age of fifteen was apprenticed to an apothecary in Lübeck (see Fig. 2.19 for his portrait). He then studied medicine in Berlin, Göttingen and graduated for the Universität Jena in 1819 [154, 155]. His dissertation dealt with the physiological effects of belladonna. Runge was asked to demonstrate the dilation experiment on his cat for Goethe who was so impressed he gave him some rare coffee beans and suggested him to try to determine what compound in the beans gave them their physiological effect [156]. Runge accepted the challenge and within months isolated caffeine from them. Runge then returned to Berlin and received a doctorate in chemistry in 1822.

Fig. 2.19 Portrait of Friedlieb Ferdinand Runge (1794–1867)

Then, after 3 years travelling in Europe visiting chemical factories and laboratories became *Privatdozent* (Assistant Professor) at the Schlesische Friedrich-Wilhelms-Universität Breslau (now Wrocław/Poland) becoming Extraordinary Professor in 1828. Finding conditions were unfavourable to the development of his experimental researches moved to Berlin in 1831 and put an end to his academic career. In 1832, he took a position with a chemical works, *Chemische Produkten-Fabrik zu Oranienburg* (near Berlin). Given almost a free hand, in this industrial laboratory, Runge began the most fruitful period of his life carrying out his important study of analytical reagents, synthetic dyes and the discovery of coal–tar products [157]. The history of chromatography begins with the work of Runge when he observed that certain coloured substances when spotted onto a filter paper spread out into concentric rings [158, 159], and these he recorded in two books [160, 161]. He retired from the firm in 1852 but worked as a consultant until his death.

Heinrich Rose (born 6 August 1795, Berlin; died 27 January 1864, Berlin) was born into a family of scientists, his father and grandfather, both named Valentin Rose, were pharmacists who wrote on pharmaceutical and chemical topics [162, 163] (see Fig. 2.20 for his portrait). Rose first trained as a pharmacist in Danzig (now Gdańsk/Poland) but war against Napoleon intervened. He was in Paris with the occupying army in 1815, whilst there he met the leading French scientists including Berthollet. On his return to Berlin, he worked with Klaproth, long associated with the Rose family. He continued with his pharmaceutical apprenticeship in Mitau (now Jelgava/Latvia), near Riga. In 1819, he travelled via St. Petersburg and Finland to Stockholm to work with Berzelius on mica and then on the properties of titanium. Rose left Stockholm in 1821 and went to Kiel [24XII] and submitted his doctoral thesis on compounds of titanium and then returned to Berlin. In 1822, he became

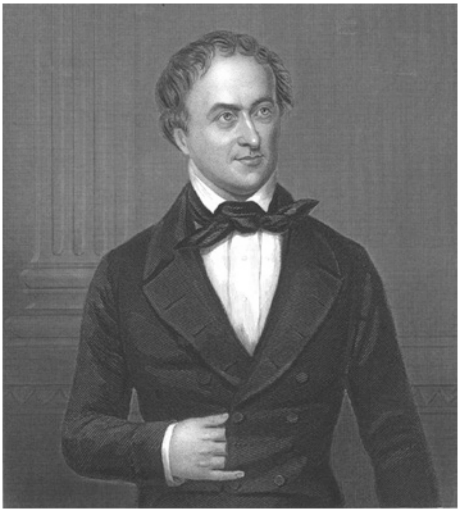

Fig. 2.20 Portrait of Heinrich Rose (1795–1864)

Privatdozent in chemistry at the Friedrich-Wilhelms-Universität Berlin, a year later *Extraordinarius* and in 1835, *Ordinarius*, i.e. as a full professor.

Rose's contributions to chemistry were twofold, firstly by the training, he gave directly at the Friedrich-Wilhelms-Universität Berlin and indirectly through his great textbook of analytical chemistry, *Handbuch der analytischen Chemie* [164–166]. His second contribution was by his vast number research papers, mainly on analyses of inorganic materials and minerals [167]. His textbook was first published in German in 1829 and in translation, English (1831); French (1832); Italian (1835–1838). The text is divided into two parts, qualitative and quantitative. In the qualitative section, Rose dealt with soluble as well as insoluble materials, reagents and the detailed behaviour of elements and their most important compounds. The quantitative section gave details of the determination of elements and necessary modifications required if other elements that can interfere were present. The calculations were carried out using the tables published by Berzelius. The text went through several editions and translations, being in their time, the standard reference works on the subject. Its importance can be judged from the translator's preface to the English edition:

> The high repute in which the Author of the following Work is held as an Analyst, renders it altogether unnecessary for me to offer any apology for the publication of this translation. As the English chemist possesses at present no competent literary instructor to guide him in his analytical researches, it may be assumed that a Work, emanating from the Berlin School, and sanctioned by the name of Rose, will not be looked upon with indifference.

The sixth and last German edition was prepared by Finkener after Rose's death [165].

Friedrich Wöhler [born 31 July 1800, Eschersheim (now part of Frankfurt/Main); died 23 September 1882, Göttingen] after early education in Frankfurt, he studied medicine at the Philipps-Universität Marburg [24XIII] and then at Heidelberg [24XIV] where he was graduated in 1823 [168–170] (see Fig. 2.21 for his portrait). At Heidelberg, Gmelin facilitated Wöhler's interest in chemistry and encouraged him to go abroad for further training and recommended him to Berzelius in Stockholm. Here, he received rigorous training in mineral analysis and formed a firm and long-lasting friendship with Berzelius. He was appointed in 1836 to the chair of chemistry in Göttingen to succeed Stromeyer. Wöhler is best known for his contributions to organic chemistry, starting with synthesis of urea from inorganic sources, and collaboration with Liebig. He met Liebig in 1825 over a minor squabble concerning the interpretation of analytical results of silver fulminate and silver cyanate, a classic example of isomerism. Wöhler's success in organic chemistry owed much to his analytical skills. In addition, he retained a lifelong interest in the analyses of minerals, and particularly of meteorites, and published extensively on these topics [171]. He also wrote three analytical texts, *Beispiele zur Übung in der analytischen Chemie* [172], *Praktische Übungen in der chemischen Analyse* [173] and *Die Mineral-Analyse in Beispielen* [174].

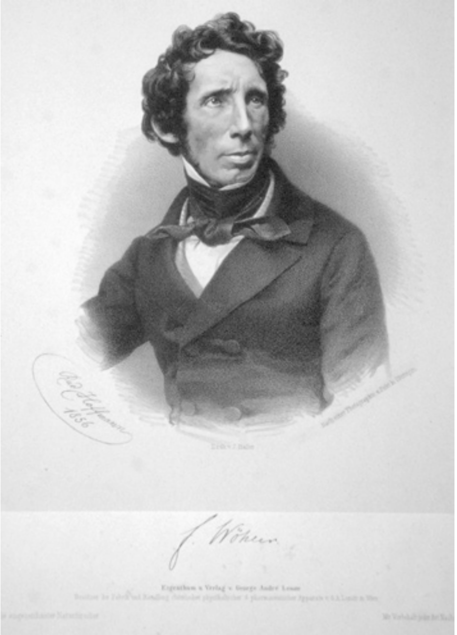

Fig. 2.21 Portrait of Friedrich Wöhler (1800–1882)

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Chapter 3
Growth into a Scientific Discipline: The Nineteenth Century

R. Klaus Müller

The personalities mentioned in this chapter were born between 1800 and 1870. They dealt in the early years with the systematization of wet analysis, then invented and improved volumetric analysis, measured physical parameters and began to imply instrumental methods for analytical purposes, analysed biological samples and extended analytical science into neighbouring areas such as medicine, pharmacy and biology.

Otto Bernhard KÜHN (born 6 May 1800, Leipzig; died 5 December 1863, Leipzig)

After attending the famous Fürstenschule (Princes High School) Grimma and studying Medicine in Leipzig and Göttingen, he was graduated to Dr.med. at the Universität Leipzig with the thesis *De cholestearine, eique similibus pinguedinis corpore humani formis* in 1827 and was appointed there to Privatdozent in 1828. Already in 1829, he became Ordinary Professor of Chemistry at the Medical Faculty of the Universität Leipzig, where at this time chemistry was exclusively attached.

Kühn (for portrait, see Fig. 3.1) contributed to analytical and biological chemistry mainly by several books: *Anleitung zu qualitativen chemischen Untersuchungen*, *Lehrbuch der Stöchiometrie*, *Practische Chemie für Staatsärzte* and *Versuch einer Anthropochemie* [1–4]. He edited the Journal *Practische Chemie für Staatsärzte* (Leipzig 1829). He played an active role in general academic matters (Dean of his faculty 1854–1855, 1857–1858 and 1861–1868) and might have been a model later for his contemporary colleague Erdmann (see there).

Justus LIEBIG (since 1845 Freiherr von Liebig, born 12 May 1803, Darmstadt; died 18 April 1873, Munich)

Liebig was born the son of a druggist and dye merchant and became fond of chemistry in his childhood. During high school and in an apprenticeship in apothecary, he obtained only little estimation of his tutors, but improved his knowledge by practising with his father and by reading. He began to study chemistry in 1819 in Bonn, where Professor Wilhelm Gottlob Kastner recognized his talent and hired him as an assistant. After his appointment at the Friedrich-Alexander-Universität Erlangen, Kastner took the promising student with him. Liebig was graduated to

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Fig. 3.1 Portrait of Otto Bernhard Kühn (1800–1863). *Photo* Universitätsarchiv Leipzig, with permission

PhD, and Kastner recommended him for a study at the Sorbonne in Paris with Gay-Lussac, Thénard and Vauquelin. Another recommendation by Alexander von Humboldt led to the appointment of Justus Liebig (then 21!) as Professor at the Ludwigs-Universität (now Justus-Liebig-Universität) Giessen in 1824. Poor support by his university led him to the establishment of a private Institute for Pharmacy and Technical Craftmanship (together with several colleagues). He became internationally famous for his teaching, his experimental results and his publications, already during his activities in Giessen. There he became friends with Friedrich Wöhler (1826) for lifetime, and in 1845, he was awarded the nobility title *Freiherr von Liebig* (equivalent to baron). After he had declined offered positions at various universities, he finally accepted that of Max von Pettenkofer and King Maximilian II of Bavaria and changed 1852 to the Chair at Ludwig-Maximilians-Universität München.

Liebig was an important promoter of organic chemistry, and his role in analytical chemistry is also very fundamental. He invented the system of elementary organic analysis, developed adequate apparatus ("five-globe-apparatus") and created the experimental basis for the structural elucidation of organic compounds [5, 6]. His extensive analyses of biological samples of plants and animals [7] brought improvements in agricultural chemistry, with the introduction of mineral fertilizers, mainly with superphosphate. After many objections in the beginning, this gained much popularity. His books *Anleitung zur Analyse organischer Körper* [8], *Die organische Chemie in ihrer Anwendung auf Agrikultur und Physiologie* [9], as well as his *Chemische Briefe* (Chemical letters, periodic papers for the public [10]) with his suggestion of fertilization with superphosphate contributed to a significant increase of agricultural productivity.

He published a handbook of organic chemistry together with Geiger [11], a handbook of pure and applied chemistry, together with Poggendorff and Wöhler (3 vol. 1842–1848) [12] and founded the journal *Annalen der Chemie und Pharmacie*.

Several industrial companies (some still existing) base their existence on Liebig's initiatives. Liebig was—besides his undisputable appreciation in science—one of the most popular chemists ever, but this is probably mainly due to his invention of *Liebigs Fleischextrakt* (meat extract). Not often regarded is the fact that he worked at almost the whole range of chemistry. His most relevant widespread analyses of biological samples (vegetable and animal) lead to new knowledge about the composition of living organisms, enabling him to contribute to the victory over the starvation disasters in the nineteenth century. This had been caused partly by the ineffective agriculture of field crops [13]. He is considered the father of artificial fertilization, whose positive impact on the increase of agricultural yields and the overcome of starvation disasters in the nineteenth century nevertheless has not impeded the "modern" objections towards mineral fertilizers and the narrow-minded "bio"-ideology, the "organic farming" amidst the generalized discredit of chemistry.

Despite much poor understanding, Liebig (for portrait, see Fig. 3.2) was highly esteemed at his time: he received numerous honours, orders and awards, he was

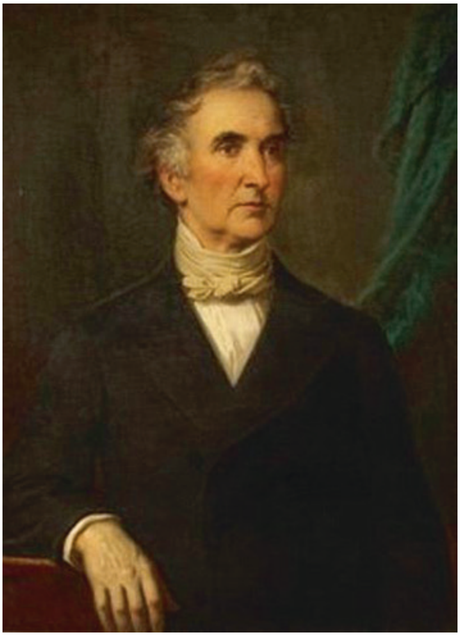


Fig. 3.2 Portrait of Justus von Liebig (1803–1873)

the President of the Bayerische Akademie der Wissenschaften (Bavarian Academy of Sciences), and his books went through many editions and translations into 34 languages.

Liebig and his work are dealt with in numerous books and articles.

Otto Linné Erdmann (born 11 April 1804, Dresden; died 9 October 1869, Leipzig).

After an early start as an apprentice in pharmacy, he finished his education in a gymnasium in Leipzig and studied medicine and sciences in Dresden from 1820 and in Leipzig 1823–1824, where he was graduated to Dr. phil. in 1824. Then, he worked for one year as director of the *Blaufarbenwerk* (Blue Color Works) Hasserode (now part of Wernigerode/Saxony-Anhalt), returned back to Leipzig and habilitated at the university 1825 (thesis *De natura affinitatis chemicae*), where he was appointed Professor of Technical Chemistry in 1827 (Extraordinary Professor) and 1830 (Ordinary Professor).

Erdmann performed many analyses of ores, stones and slags, worked on indigo and other dyes, together with Marchand on coal gas, determined atomic weights (relative atomic masses) and suggested the *Schwimmer-Burette* for the parallax-free reading of volumes in volumetric analysis. He became well known by several textbooks [14, 15] and for the initiation of scientific journals: he founded the *Journal für technische und ökonomische Chemie* (Leipzig 1828–1833) and the *Journal für praktische Chemie* (Leipzig 1833, in continuation *Journal für technische und ökonomische Chemie,* together with RF Marchand, FW Schweigger-Seidel and G Werther).

He was also active in forensic chemistry with analyses and expertises, and he even corresponded with Liebig on these matters. In a letter (dated Nov. 12, 1861 [16]), he explained his examination of suspicious blood stains in a murder case, which he could identify as caused by red algae. He emphasized therefore that the detection of blood in forensic cases can only be ascertained by the combination of microscopical and chemical investigation, while the optical appearance alone can be seriously misleading [17].

Besides his scientific work and academical teaching [18], Erdmann (for portrait, see Fig. 3.3) developed several public and social activities and connections: Rector of the Universität Leipzig 1849, 1854–1856 and 1862–1863, member of the *Eisenbahndirektorium* (railway board)—because he had developed a procedure to remove the sulphur content of the domestic coal, which then could be used instead of the more expensive imported coals, Member of Parliament of Saxony 1839–1840, Member of the Free Masons Lodge Apollo in Leipzig since 1827 and Member of the Sächsische Akademie der Wissenschaften (Saxonian Academy of Sciences). In 1843, he initiated the building of the Chemical Laboratory of the Universität Leipzig. For further details, see [19–24].

Carl Friedrich Mohr (born 4 November 1806, Koblenz; died 26 September 1879, Bonn).

Born as the son of a pharmacist, Mohr studied botany, chemistry and mineralogy at the Rheinische Friedrich-Wilhelms-Universität Bonn, worked in his father's pharmacy and began to study pharmacy at the Ruprecht-Karls-Universität

Fig. 3.3 Portrait of Otto Linné Erdmann (1804–1869)

Heidelberg in 1828. After a short time in Berlin (at Heinrich Rose), he went back and graduated with a PhD in Heidelberg in 1832. Again, he came back to the paternal pharmacy in Bonn, which he took over after his father died.

Mohr then entered a chemical factory, but habilitated in Berlin and subsequently in Bonn, and was appointed Professor of Pharmacy at the Rheinische Friedrich-Wilhelms-Universität Bonn in 1867.

He made essential contributions to volumetric analysis and inaugurated the argentometric titration of chlorides with silver nitrate or vice versa. He wrote a textbook on volumetry *Lehrbuch der chemisch-analytischen Titrirmethode* (Textbook of the chemical-analytical titration method) [25], and published the books *Lehrbuch der pharmaceutischen Technik* [26] and *Chemische Toxicologie, Anleitung zur chemischen Ermittlung der Gifte* (Chemical Toxicology. Guide to the chemical detection of poisons) [27]. Another book on geology reflects the wide scope of his scientific activity [28].

Mohr (for portrait see Fig. 3.4) has introduced various tools into the analytical laboratory, e.g. the Mohr balances, the cork drill, the scaled burette and the squeeze tap.

He was also very active in public life as member of several associations, of the City Council and of committees and as elected delegate to the Prussian parliament in Berlin.

The impact of Carl Friedrich Mohr on volumetric analysis has been discussed in two doctoral theses [29, 30].

Eduard Hugo Reinsch (born 1809, died 1884)

He was the Professor of Chemistry at the Agrikulturschule (agricultural school) Erlangen. Reinsch is renowned mainly by his wet chemical test for arsenic and

Fig. 3.4 Portrait of Karl Friedrich Mohr (1806–1879)

some other heavy metals in (biological) fluids for the detection of poisonings and his contributions to chemical microscopy [31]: “Application of the microscope to the testing of minerals and chemical compounds makes greater progress from day to day, and the microscope approximates the spectroscope with regard to the recognition of smallest amounts of oxides, superseding the latter in so far, that it provides hints to the present amounts of a constituent.”

Although Szabadváry [32] criticizes these remarks of Reinsch as being exaggerated, it can certainly be accepted at least for some minerals, when, e.g. for granite, the relative content of microscopical constituents can eventually even be estimated by counting areas.

On the other hand, microscopical identification of components—also of residues of isolation procedures from biological specimens and at least after purification and sublimation—has come in use in the nineteenth century and remained in common use for several decades after 1900. In toxicological laboratories, microsublimation, microscopic melting point determination and microcrystal reactions have remained in daily practice before chromatography and later hyphenated instrumental principles entered the detection of poisons isolated from biological samples.

Julius Adolf STÖCKHARDT (born 4 January 1809, Röhrsdorf near Meissen; died 1 June 1886, Tharandt near Dresden)

Stöckhardt was the son of a priest. After his apprenticeship in a pharmacy, he studied pharmacy and chemistry in Berlin (1833 *Staatsprüfung*/State Examination), worked afterwards in Koblenz and then—after visiting chemical factories and institutes in Belgium, England, France, Switzerland and Dresden—went to work in a factory for mineral water (Struve, Dresden). After his graduation at the Universität Leipzig (thesis on methods of scientific education) in 1836, he became a Professor at the Staatsgewerbeschule Chemnitz (State College of

Technology and Business, now Technische Universität Chemnitz) in 1838, and then, in 1847, he became a Professor for Agricultural Chemistry and Technology at the Forestry College Tharandt (now department of the Technische Universität Dresden). Representant of Liebig's views of agricultural chemistry, he succeeded on the background of his research in initiating the foundation of numerous agricultural research institutions in several countries, e.g. 1852 of the still existing Landwirtschaftliche Versuchsstation (Agricultural Research Station) in Leipzig-Möckern.

His publications reach from 1844 *Zusammensetzung, Erkennung und Benutzung der Farben* (composition, detection and use of colours/paints) [33], *Schule der Chemie* (School of chemistry) [34], to the field of his main activities *Guanobüchlein* (Guano booklet) [35], and *Chemische Feldpredigten für deutsche Landwirthe* (Field sermons for farmers) [36]. With investigations on the effects of coal combustion fumes onto the growth of plants (especially spruces), he pioneered research on "acid rain", a key topic in the twentieth century [37, 38]. From 1847 to 1849, he was the coeditor of the German Abstract Journal *Chemisches Zentralblatt*, from 1850 to 1859, he was the coeditor of *Zeitschrift für Landwirthe* (Journal for farmers), and in 1855, he was the founder of the journal *Der chemische Ackersmann* (The chemical-acre man or farmer) [39].

The work of Stöckhardt (for portrait, see Fig. 3.5) was reflected and honoured by numerous authors [40–47]. Wienhaus emphasizes his engagement for interdisciplinary cooperation and the popularization of scientific results.

Fig. 3.5 Portrait of Julius Adolph Stöckhardt (1809–1886)

Friedrich Julius Otto (born 8 January 1809, Grossenhain/Saxony; died 12 January 1870, Braunschweig)

Son of a merchant, Otto attended the Bürgerschule (town school) and then became an apprentice in the pharmacy of his native town (1823–1828), where he was given opportunity to gain scientific, especially chemical knowledge and enthusiasm. In 1829, he began his study of pharmacy and chemistry at the Universität Jena at Wackenröder and Döbereiner. He left the university in 1830 for financial reasons and worked as a chemist for the chemical entrepreneur Johann Gottlieb Nathusius (1756–1835) in Althaldensleben near Magdeburg. There, he was responsible for a variety of commercial productions: spirit and liqueurs, vinegar, a beer brewery, a mill (cereals and oil), factories for bricks, ceramics and porcelain.

In 1832, he graduated Dr. phil. at the Universität Jena with a thesis on the production of vinegar (for which he had introduced a new express procedure as well as a new quantification method) [37, p. 16]. After his promotion, he began to work at the newly founded College and Research Institute for Agriculture and Forestry in Braunschweig, which became his lifetime appointment.

Besides his impressive experimental work, teaching, publishing and public initiatives for agriculture and pharmacy [48], he became renowned as analytical chemist mainly by his book on toxicological analysis and by his improvement of the extraction procedure of Jean Servais Stas for alkaloids.

Based on his forensic expertises, he wrote the *Anleitung zur Ausmittelung der Gifte* (Guide for the detection of poisons) and published it first in 1856 (Verlag Vieweg/Braunschweig [49]). It covered the relevant poisons of that time, a comparatively small number and dominated by arsenic, which, despite the analytical markstone of Marsh’s detection method of 1836 [50], still caused the majority of poisonings. Their chemical detection had become possible not before the late eighteenth to the first decades of the nineteenth century.

At that time, there were no reliable tests for organic poisons. These increased in relevance following numerous isolations of the “active principles” (mostly alkaloids) of plants (and animals) after the identification and purification of morphine as the main constituent of opium by Friedrich Wilhelm Adam Sertürner (1783–1841) since 1803–1804 [51–53]. Only in 1851, the Belgian chemist Jean Servais Stas (1813–1893) developed a procedure for the isolation of alkaloids from biological samples. He succeeded in isolating nicotine from stomach content and organ tissues after deproteinization by tartaric acid and ethanol, evaporation of the alcohol, alkalinization and extraction with diethyl ether [54, 55]. Otto improved this procedure by adding additional extraction steps for acidic and neutral compounds. This *Stas–Otto procedure* remained in use with minor variations until today, especially when “general”, undirected toxicological analyses in so-called “general unknown cases” were aimed to detect and identify unknown or unsuspected toxic compounds in a systematic way [systematic toxicological analysis (STA)].

Otto's book was written with the background of his experience from expertise in forensic cases. He expressed in the foreword to the third edition of his book his intention to present only self-proven methods:

> ….ich habe mich…gehütet, denen, welche nach dem Buch arbeiten, die Wahl unter verschiedenen Methoden zu überlassen. Wer es besser weiß als ich, bedarf des Buches nicht, wer es nicht besser weiß, den bringt die Wahl in Verlegenheit […I have avoided to give the users of the book the choice between several methods. Who knows it better than me, does not need the book, and who knows not better, will become embarrassed by the choice.]

By the way, this might not have been too difficult in the nineteenth century, but was doubtless a positive model. Later, it was exaggerated to the saying that a forensic toxicologist would rather use a colleague's tooth brush than his analytical procedure.

The book was reissued again already in 1857 and 1867, followed by editions by his son Robert in 1870, 1875 and 1884.

Besides a number of other textbooks, Friedrich Julius Otto contributed also to Liebig's *Handwörterbuch der Chemie* (Pocket dictionary of Chemistry [12]).

A comprehensive survey about the life and work of Friedrich Julius Otto is given by Ursula Pohl in a book based on her doctoral thesis [48].

Robert Wilhelm Bunsen (born 30 March 1811, Göttingen; died 16 August 1899, Heidelberg)

Bunsen was the son of a Professor of literature and studied natural sciences (mainly chemistry) at the Georg-August-Universität Göttingen, graduated there to PhD with a thesis on hygrometry [56, 57]. After an informational round trip through Western Europe (during which he met Runge, Liebig and Mitscherlich), he habilitated in Göttingen and did experimental work as well as temporary teaching for the vacant position of Friedrich Stromeyer (afterwards appointed to Friedrich Wöhler). Through appointments to Kassel (successor of Wöhler at the Höhere Gewerbeschule (Polytechnic), now Universität Kassel), Philipps-Universität Marburg and Breslau (now Wroclaw/Poland), he became Ordinarius at the Ruprecht-Karls-Universität Heidelberg as a successor of Leopold Gmelin.

Bunsens experimental activities reached from inorganic to physical and technical, even to organic topics, and several had analytical impact: gas analyses in the control of metallurgical processes [58], dicyan [Bunsen Pogg Ann 34] and cacodyl (tetramethyl diarsan), analyses of minerals and gases in Iceland (effluents of the Geysir and of the volcanic eruption of Mount Hekla in 1845) [59], development of a gas burner (*Bunsen burner*) based on a draft of Faraday, analysis of mineral waters, a calorimeter based on ice) and mainly the spectral analysis together with Robert Kirchhoff (whom he met first in Breslau). He developed iodometry to quantitative measurements, reduced the elements aluminium, calcium, lithium and magnesium from their chlorides [60–62] and detected the new elements caesium and rubidium. The book on gasometry (1857 [63]) was a comprehensive survey about the state of the art, to which Bunsen had essentially contributed, e.g. with his investigations on the exhaust of blast furnaces, resulting in major savings of coal by avoiding incomplete combustion.

His perhaps most popular invention was the electrochemical zinc–carbon battery, derived from the previous zinc–platinum pair [64, 65]. He was very much directed and skilled in practical operations and introduced various new tools and techniques.

Bunsen's most important contribution to analytical chemistry—based on his cooperation with Gustav Kirchhoff (see there)—was besides his contributions to gas analysis, undoubtedly spectral analysis: although predecessors like Alter, Swan and Talbot had suggested basic elements of spectroscopy, Bunsen and Kirchhoff can be considered as the founders of this broad sector of analytical chemistry. They recognized not only the information value and certainty of spectroscopic/spectrometric measurements, but also the widespread range of applications, e.g. for astronomic research [32] and introduced the term extinction coefficient.

Bunsen (for portrait, see Fig. 3.6) was given numerous awards and honours, e.g. memberships in the Deutsche Akademie der Naturforscher Leopoldina (now Germany's national academy of science in Halle, Saale) (1851), Accademia dei lincei (Rome 1875) and Order Pour le Mérite (France 1864). A moon crater was named after him (1964), and a bronze statue by Hermann Volz and a bronze plate

Fig. 3.6 Portrait of Robert Bunsen (1811–1899). *Photo* University Archive TU Dresden, photo collection, with permission

to his memory (one of the "Historic sites of chemistry" of the German Chemical Society GDCh) were posed in Heidelberg at his former laboratory.

The German Society for Physical Chemistry is named after Bunsen (Deutsche Bunsen-Gesellschaft für Physikalische Chemie), honouring his importance for physical chemistry.

Robert Bunsen never married, and despite his many honours and worldwide estimation, he complained after his retirement feeling lonely [32].

For more details to his life and work, see [66–71].

Hermann Fehling (born 6 June 1811, Lübeck; died 1 July 1885, Stuttgart)

Son of a merchant, he began with an apprenticeship for pharmacy in Lübeck and Bremen, followed by a study of natural sciences (mainly chemistry) at the Ruprecht-Karls-Universität Heidelberg from 1835 to 1837. As an assistant of Gmelin, he graduated with a PhD in 1837 in Heidelberg and became the assistant of Liebig in Giessen. After working some time with Dumas in Paris, he became the Professor for technical chemistry at the *Vereinigte Kunst-*, *Real- und Gewerbeschule* (Polytechnic College) Stuttgart, where he took over responsibilities in numerous academic and public commissions. His scientific activities aimed mainly to the development of volumetric methods for technical purposes (analysis of foodstuffs, materials and mineral waters).

The Fehling reagent (aqueous solution of copper sulphate, sodium carbonate, tartaric acid and potassium hydroxide) for the detection of glucose was only a slight modification of an earlier proposal of A.C. Becquerel [32, 72], who published it for the qualitative detection of sugar. Fehling (for portrait, see Fig. 3.7) found the relation of 1 molecule glucose to 1 atom copper, and by his publication [73], he became well known for this reagent.

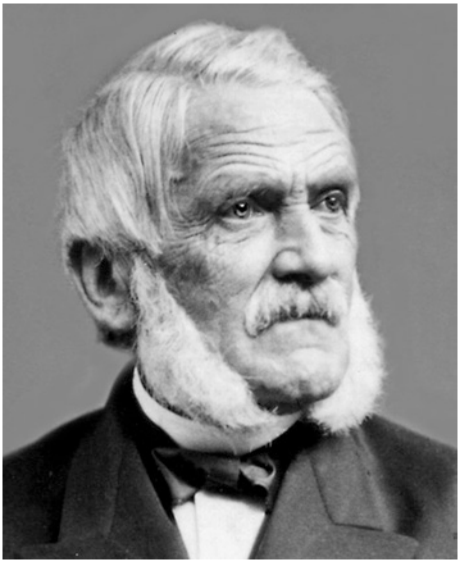


Fig. 3.7 Portrait of Hermann Fehling (1811–1885)

Franz Leopold Sonnenschein (born 13 July 1817, Cologne; died 26 February 1879, Berlin)

As an apprentice in pharmacy, Sonnenschein established his own laboratory in Berlin and worked together with a physician as tutor for students of pharmacy, preparing them for their final examination. After studying chemistry at the Friedrich-Wilhelms-Universität Berlin, he habilitated in 1851 [74]. As *Privatdozent* (Assistant Professor), he was active in practicing especially analytical chemistry and in technical endeavours, for which he earned much appreciation. He was appointed Professor at the Friedrich-Wilhelms-Universität Berlin in 1869, where he remained until his death.

Sonnenschein's analytical results were applied widely in forensic chemistry. He invented the phosphomolybdenic acid as reagent for nitrogen bases and alkaloids. He published several books, e.g. *Anleitung zur chemischen Analyse* (Guide to chemical analysis) 1858 [75], *Handbuch der analytischen Chemie* (Manual of analytical chemistry [76]), *Anleitung zur quantitativen chemischen Analyse* (Guide to quantitative chemical analysis [77]), as well as *Handbuch der gerichtlichen Chemie* (Manual of forensic chemistry [78]).

Further details can be found at [79].

Carl Remigius Fresenius (born 28 December 1818, Frankfurt/Main; died 11 June 1897, Wiesbaden)

Fresenius started his career as an apprentice in a pharmacy, visiting in parallel scientific lectures and performing chemical experiments in his own laboratory in his father's garden shed. He began study in 1840 at the Rheinische Friedrich-Wilhelms-Universität Bonn and worked in the private laboratory of a pharmacist. He finished his study at the Ludwigs Universität (now Justus-Liebig-Universität) Giessen, graduated in 1842 on the quantitative analysis of arsenic and became *Privatdozent* (Assistant Professor) in 1843, working for a short time as assistant of Liebig. Appointed as Professor for chemistry, physics and technology at the *Herzoglich-Nassauisches Landwirtschaftsinstitut Hof* (Agricultural Institute of the Duchy of Nassau) at Geisberg (now part of Wiesbaden), he established a laboratory there in 1848. He developed and enlarged this laboratory during five decades, founding a division for the education of food chemists, and a research institute for agricultural chemistry.

Fresenius (for portrait, see Fig. 3.8) worked very successfully in various areas of analytical chemistry, so on the separation and detection of arsenic and antimony, on soda and metal alloys and on the composition of mineral waters. He suggested a series of methods for the determination of the contents of mineral waters and applied them to the systematic investigation of mineral wells of his home country Nassau. His fundamental work, the book *Anleitung zur qualitativen chemischen Analyse oder systematisches Verfahren zur Auffindung der in der Pharmazie, den Künsten und Gewerben häufiger vorkommenden Körper für Anfänger* (Guide to qualitative chemical analysis or systematic procedure to the detection of substances frequently appearing in pharmacy, the arts or trades for beginners) was first issued 1841 [80] and experienced 16 (!) editions until 1895.

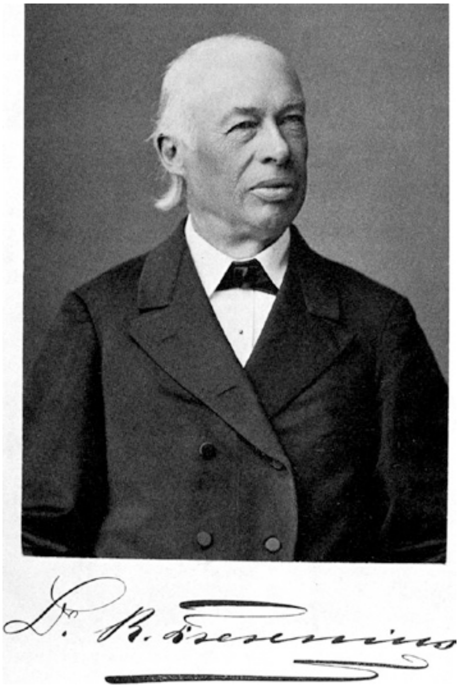


Fig. 3.8 Portrait of Carl Remigius Fresenius (1818–1897)

Its systematic structure and mainly the separation procedure with H_2S have been well accepted and influenced the development of analytical chemistry in general. The book was translated into several languages; the first English edition—printed simultaneously with the German one—experienced eight editions, the French one five editions.

Other books—issued in 1843 and 1847 [81, 82]—provided procedures for the analysis of commercial products. In a paper by Fresenius and von Babo [83], he anticipated an idea of the late twentieth century in suggesting the validation of analytical procedures by objective criteria of their performance.

His *Anleitung zur quantitativen Analyse* was published in 1846 [84]. He founded the *Zeitschrift für Analytische Chemie* in 1861. His sons Heinrich and Wilhelm continued to run the Fresenius Laboratory as well as the Journal.

Additional information to Remigius Fresenius can be found at [85–92].

Karl-Heinrich Schwarz (born 27 January 1823, Eisleben/Saxony-Anhalt; died 15 September 1890, Eberswalde near Berlin)

He studied chemistry at universities in Halle/Saale, Gießen (at Justus von Liebig) and Berlin. He earned his PhD 1846 in Halle/Saale and worked subsequently in Paris with Pelouze (successor of Gay-Lussac) at the École polytechnique, where he became acquainted with titrimetry.

He changed to the Schlesische Friedrich-Wilhelms-Universität zu Breslau (now University Wroclaw, Poland) to complete his habilitation in 1849 and worked there as *Privatdozent*. In Breslau, Schwarz wrote *Praktische Anleitung zu Maaßanalysen—Titrier-Methode* (Practical guide to volumetric analysis or titration method) [93], important as being the first book on volumetric analysis. After working in chemical industry in Austria, he became Extraordinary Professor in Breslau in 1863, and finally, in 1865, he became Ordinary Professor at the Steiermärkische landschaftliche Technische Hochschule (Styrian Technical College) am Joanneum (now Technische Universität) Graz.

Schwarz expressed his hope to the acceptance of the new analytical technique in the introduction [32, p. 246]:

> By means of these measuring methods it was possible to introduce quantitative analyses into practical life. I would feel sufficiently appreciated, if I should succeed in contributing at least a bit to broaden also in Germany the path, on which science implies onto the intensive activities of industry and technique.

He suggested as early as 1853 the use of sodium thiosulfate instead of the instable H_2SO_3 (used by Bunsen and others) for iodometric titrations.

Gustav Robert Kirchhoff [born 12 March 1824, Königsberg/Eastern Prussia (now Kaliningrad/Russia); died 17 October 1887, Berlin]

Kirchhoff studied mathematics and physics at the Albertus-Universität Königsberg 1842–1847, worked 1850–1854 in Breslau (now Wroclaw/Poland) together with Bunsen, then went to Heidelberg and finally became a Professor of theoretical physics in Berlin.

Besides numerous other experimental and fundamental theoretical findings, he found the rules for the mutual dependence of potential difference, current and resistance (Kirchhoff rules for the branching of electric currents, basic for electric networks) as a young man. As his most important analytical contribution, he developed together with Robert Bunsen the spectral analysis [94], which he at first applied to the sun and other astronomic objects [95]. They also detected two new elements (rubidium and caesium) by their spectra [95].

Kirchhoff (for portrait, see Fig. 3.9) became a member of the Royal Netherlands and the Hungarian Academies of Science and was awarded with the Order Pour le Mérite. The moon crater Kirchhoff was named after him.

Further information can be found at the article on Robert Wilhelm Bunsen and at [96–103].

August Beer (born 31 July 1825, Trier; died 18 November 1863, Bonn)

August Beer studied mathematics and natural sciences at the Rheinische Friedrich-Wilhelms-Universität Bonn and became coworker of Julius Plücker; graduation 1848 and habilitated 1850 in Bonn; there he became Professor from 1855 to 1857. Among his physical and mathematical publications (papers and books), those about optics and capillarity are most important for analytical chemistry, mainly by the part of Beer in the inauguration of the Lambert–Beer law ($\log I_0/I = k\ c\ d$; I_0 and I light intensities before and after passage of light, k constant, c concentration of solute, d distance, the constant k became the absorption coefficient) for the dependence of light absorption from concentration and the absorption coefficient. Beer found the dependence of

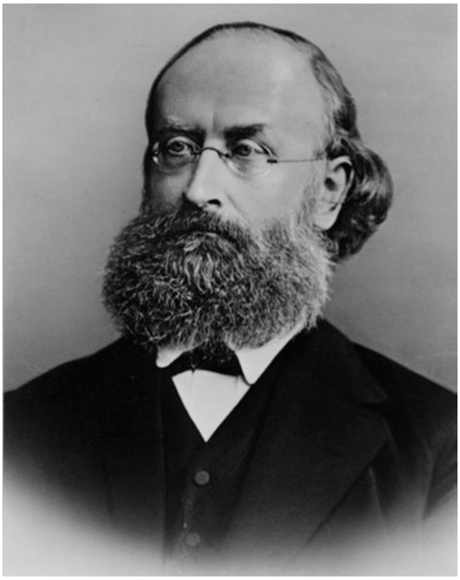


Fig. 3.9 Portrait of Gustav Robert Kirchhoff (1824–1887)

the transmitted light portion on the concentration of absorbing solutes (1852 [104]), while Lambert described in 1760 the dependence on the layer diameter and published the book *Photometria*. At almost the same time, Pierre Bouguer (1698–1758) and F. Bernard have found the same effects and laws [32, p. 337f, 105–107].

Beer published in 1848 *De situ axium opticorum in crystallis biaxibus* and in 1854 *Einführung in die höhere Optik* (Introduction into the higher optics [108]), besides other papers on electrostatics, electromechanics, capillarity and refraction indices. A planned textbook summarizing mathematical physics was not finished due to his early death and was issued posthume in parts *Einleitung in die Lehre vom Magnetismus und die Elektrodynamik* (Introduction into the knowledge of magnetism and electrodynamics, 1865 [109]) and *Einleitung in die mathematische Theorie der Elastizität und Kapillarität* (Introduction in the mathematical theory of elasticity and capillarity, 1869 [110]).

Further details can be found at [111, 112].

Felix Imanuel Hoppe-Seyler (born 26 December 1825, Freyburg/Unstrut; died 10 August 1895 Wasserburg/Bodensee)

Born as Felix Hoppe, he renamed himself Hoppe-Seyler in appreciation for his growing up at the home of his relative Seyler. He studied medicine at the universities Halle, Leipzig, Berlin, Prague and Vienna, and graduated with a PhD in 1850 at the Friedrich-Wilhelms-Universität Berlin.

After practising as a physician for 2 years beginning in 1852 (*Arbeitshaus Berlin*), he worked as *Prosektor* (pathologist) at Königliche Universität zu Greifswald (now Ernst-Moritz-Arndt-Universität Greifswald), researched on topics in physiological chemistry and medicine and habilitated there in 1854. Subsequently, he became

Fig. 3.10 Portrait of Felix Hoppe-Seyler (1825–1895)

assistant to Rudolf Virchow in Berlin (1856) and was appointed there Extraordinary Professor in 1860, afterwards Professor of Applied Chemistry in Tübingen and finally (1872) Professor of Physiological Chemistry at the Kaiser-Wilhelms-Universität Straßburg (now Strasbourg, France), where he remained for the rest of his life.

Based on his research activities, Felix Hoppe-Seyler (for portrait, see Fig. 3.10) is considered to be one of the founders—if not *the founder*—of biochemistry or physiological chemistry. He revealed and named the haemoglobin. His student Friedrich Miesche identified the deoxyribonucleic acid (DNA) in Hoppe-Seyler's laboratory in Tübingen (1869).

His foundation (1877) of the journal *Zeitschrift für physiologische Chemie* (from 1921 Biological Chemistry) was certainly an essential step to the establishment of this discipline, which has since grown to one of the most expanding branches of chemical analytics. The same can be said about his comprehensive textbooks *Handbuch der physiologisch- und pathologisch-chemischen Analyse* (1858 [113]) and *Physiologische Chemie* (4 volumes 1877–1881 [114]) with their series of re-editions. Many of his students contributed to the growth of physiological chemistry and to clinical chemistry. A considerable part of his pupils became scholars and professors themselves.

The Deutsche Gesellschaft für Klinische Chemie und Laboratoriumsmedizin (German Society for Clinical Chemistry and Laboratory Medicine) confers the Felix-Hoppe-Seyler Award for scientific achievements in this area. Additional information can be found at [115–119].

Julius Nessler (born 6 June 1827, Kehl am Rhein; died 19 March 1905, Karlsruhe)

After studying chemistry at the Albert-Ludwigs-Universität Freiburg from 1853, he was graduated in 1856 with the thesis *Über ein neues Reagenz auf*

Fig. 3.11 Portrait of Julius Nessler (1827–1905)

Ammoniak… where he described the tetraiodomercurate reagent, which later was named after him.

He worked with Lambert, Heinrich von Babo and Robert Wilhelm Bunsen and from 1857 in a chemical plant in Karlsruhe. In 1859, he founded in Karlsruhe an agricultural research station, which in 1863 became the state-owned *Agricultur-chemische Versuchsstation*. This he headed until 1901 (when he was pensioned aged 74).

Nessler (for portrait see Fig. 3.11) was appointed Professor in 1870, *Hofrat* (Privy Councilor) in 1879 and *Geheimer Hofrat* in 1889. He earned numerous awards and honorary memberships of agricultural associations—among others of the *Deutscher Weinbauverein* (German Association of Winery) in 1901. His publications have been directed mainly to agriculture (cultivation of wine [120] and tobacco, two textbooks for agricultural colleges [121]), but he became most well-known by the Nessler's Reagent [122, 123]: potassium tetraiodomercurate(II), $K_2[HgI_4]$, which forms with NH_3 the red-brown precipitating dye $[Hg_2N]I$, the iodide of the cation of Millon's base [124].

$$NH_4^+ + 2K_2\left[HgI_4\right] + 3NaOH + OH^- \rightarrow \left[Hg_2N\right]I\downarrow + 4KI + 3NaI + 4H_2O$$

For further information see [125–127].

Johann Peter Griess (born 6 September, 1829 Kirchhosbach near Kassel, died 30 August, 1888, Bournemouth/England)

Peter Griess' education and studies were uncommonly widespread. He visited an agricultural private school and a high school of trade and craftsmanship (*Höhere Gewerbeschule*) in Kassel, and after a short time in military (*Husarenregiment in Hessen*) he began to study chemistry among a whole variety of other subjects (philology, psychology, botany, medicine) in Hofgeismar, Kassel, Jena, Marburg, Munich. At first he enrolled at the Universität Jena in 1850, soon changing to Marburg (1851–1853). Disciplinary difficulties required him to move to Munich (Ludwig-Maximilian-Universität) in 1853, where he visited Liebig's lectures. He returned to Marburg (Hermann Kolbe) in 1854 and studied solely chemistry. He left the university, without a final examination, for employment at a chemical factory in Offenbach/Main, but returned soon back to the Philipps-Universität Marburg to work with Kolbe.

In Marburg, Griess discovered the diazotization of aromatic amines by nitrous acid (at first by infusion of nitrous gases into an aqueous solution of picraminic acid) [128, 129]. This reaction in its generalized version—the diazotization by nitrous acid and aromatic amines—achieved his main scientific interest for lifetime together with the production of azo dyes by coupling the diazonium compounds. His detection reaction for nitrites based on alpha-naphthylamine and sulfanilic acid (1879) obtained analytical relevance as the first organic reagent at all. (Nevertheless, this reagent is also cited *Lunge's reagent* after the famous Professor of Chemical Technology Georg Lunge (1839–1923); see [124]).

Hermann Kolbe recommended Peter Griess to August Wilhelm von Hofmann in London (Laboratory of the Royal College of Chemistry), who—although at first somewhat disappointed by his first encounter with the young man—invited him to work in London. There he was asked at first to contradict rumours about strychnine causing the bitter taste of English beers at this time, and Griess continued the association with beer brewing until his death.

Although the structure of the new class of organic compounds remained still unknown, Griess synthesized several azo dyes and communicated with other chemists opening the era of synthetic dyestuffs (e.g. Heinrich Caro, Carl Alexander von Martius, Otto Nikolaus Witt), as well as with the *Badische Anilin-und Soda-Fabrik* BASF [130]). He obtained no benefits from his inventions, except by selling several patents for azo dyes.

Griess (for portrait see Fig. 3.12) was hired as a chemist by the brewery Samuel Allsopp and sons in Burton-upon Trent, but found opportunity to continue his research on azo compounds.

Azo dyes also found analytical use for the detection of aromatic amines in paper and thin layer chromatography, mainly by the *Bratton-Marshall reagent*, N-(1-naphthyl)-ethylenediamine dihydrochloride [131]. Although this reagent probably was an incidental finding, it was certainly one of the most widely used and cited organic reagents at all, although numerous other compounds had been equally suitable and found efficient, if there had ever been a systematical research and comparative evaluation (own observation [132]).

Fig. 3.12 Portrait of Peter Griess (1829–1888)

The Ludwig-Maximilian-Universität München honoured Peter Griess in 1877 with the honorary doctorate.

Further information is given by [130, 133–139].

Jacob Volhard (born June 4, 1834 Darmstadt, died January 14, 1910 Halle/Saale)

Son of a wealthy attorney, Volhard visited the Gewerbeschule in Darmstadt (1851/1852) and intended to study history, but was forced by his father to study chemistry at the Ludwigs-Universität (now Justus-Liebig-Universität) Gießen (1852–1855): at this time, many parents in Hesse had been ambitious to make their sons followers of Liebig. After his promotion in 1855, Volhard worked until 1856 in Heidelberg, and afterwards, for two years, he worked as an assistant to Liebig in Munich. There he was criticized for his lack in ambition and working intensity; it appears he intended to become an artist. Nevertheless, he worked with A.W. von Hofmann in London 1860/1861, went to Marburg in 1862, and habilitated in Munich in 1863, where he became Assistant Professor and obtained his own laboratory with support of his father. In 1865, he became *Adjunkt* (assistant without teaching duties) at the Institute for Plant Physiology of the Bayerische Akademie der Wissenschaften (Royal Academy of Science) München, holding this position until 1876, in parallel to his office at the Ludwig-Maximilians-Universität München. There he took over the Inorganic Laboratory in 1875. In 1879, he was appointed Professor of organic chemistry at the Friedrich-Alexander-Universität Erlangen. Finally, he changed to the Friedrichs-Universität Halle (now Martin-Luther-Universität Halle-Wittenberg) in 1882 as Ordinary Professor, where he became Emeritus in 1908.

Fig. 3.13 Portrait of Jacob Volhard (1834–1910)

Volhard (for portrait, see Fig. 3.13) belongs to the fathers of volumetric analysis, although some of the titrations named after him were described earlier by others and were only re-evaluated by him [32]. He wrote a whole series of analytical textbooks [140–147], published on general and theoretical topics [141, 147, 148] and even on the history of chemistry [148–150].

Further information can be found at [151–154].

Johann Georg Noel Dragendorff (born 8 April 1836, Rostock; died 7 April 1898, Rostock)

After studying pharmacy in Rostock and his graduation 1861 with a PhD, he became Ordinarius of Pharmacy in Dorpat/Livland (now Tartu/Estonia) and worked there for three decades.

In 1868, he published his book *Die gerichtlich-chemische Ermittlung von Giften…* (The forensic-chemical detection of poisons), which was issued again in 1876 [155, 156]. Due to political pressures he changed back to his hometown, remaining scientifically active. He worked on biological, forensic and toxicological analytics and became renowned both by his books and by his colour reagent (bismuth iodide/potassium iodide) for the detection of tertiary aromatic amines. Producing intensive orange spots, it is still extensively used in thin-layer chromatography. In 1876, Dragendorff (for portrait see Fig. 3.14) initiated the first toxicological journal *Jahresberichte Fortschritte…*, after he had edited the *Pharmazeutische Zeitung für Russland* in

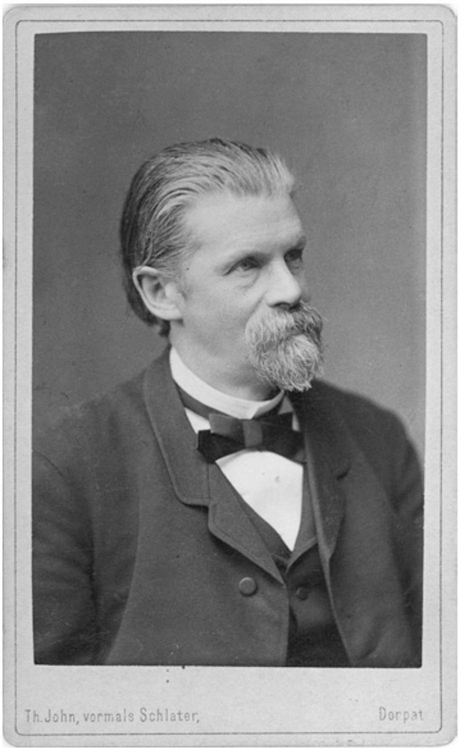


Fig. 3.14 Portrait of Johann Georg Noel Dragendorff (1836–1898)

St. Petersburg. His book *Die qualitative und quantitative Analyse von Pflanzen…* (Qualitative and quantitative analysis of plants…) [157] was written in Dorpat and published in Göttingen, and his last one *Die Heilpflanzen der verschiedenen Völker und Zeiten* (Medicinal plants of various people and times) [158] was finished just before his death in 1898. Further information is given by [159–166].

Friedrich Konrad Beilstein [born 5 February (February 17 Gregorian) 1838, St. Petersburg; died 5 October (October 18 Gregorian) 1906, St. Petersburg]

Although born (the first of seven children of German parents) and died in Russia, Friedrich Konrad Beilstein lived from the age of 15 in Germany and studied in Heidelberg (Bunsen, Kekulé), Munich (Liebig) and Göttingen (Wöhler), so that he generally is considered a German chemist.

He was graduated in Göttingen with his thesis *Über das Murexid* in 1858. Subsequently he studied in Paris at Charles Friedel and Adolphe Wurtz as well as in Breslau with Carl Löwig, and became *Dozent* (Lecturer) in 1860 and Extraordinary Professor in Göttingen (1865). Finally he was appointed successor of Dimitri Mendelejew at the Technological Institute in St. Petersburg (1866). He was elected Member of the St. Petersburg Academy of Sciences, and retired from the institute in 1896.

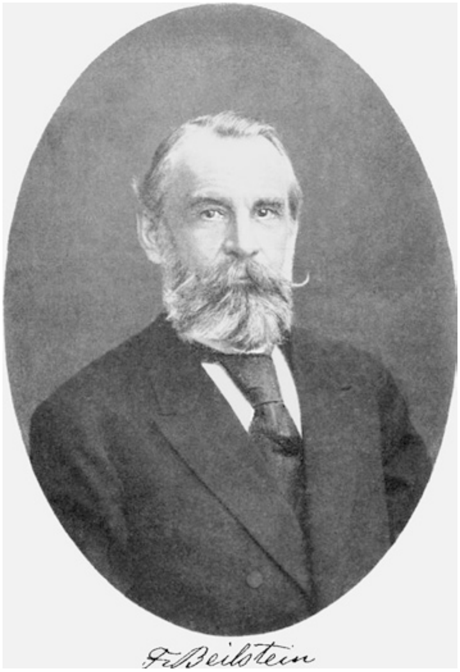


Fig. 3.15 Portrait of Friedrich Konrad Beilstein (1838–1906)

Beilstein (for portrait see Fig. 3.15) was certainly an organic chemist, but he created with founding and editing his *Handbuch der Organischen Chemie* [167] a tremendous data collection, which was and remains a fundamental tool for the analysis of organic compounds.

Nevertheless, he is perhaps even more widely known for his *Beilstein test*—the green flame coloration by a copper wire moistened with the substance to be tested, indicating chlorine (or another halogen) as a substituent. Compared with that, his second memorable single finding, the *Beilstein rule*, is of more narrow relevance for preparative organic chemistry, stating that halogenation of alkylbenzenes occurs preferably at the side chain in the heat, but preferably at the ring in the cold [168].

More information is given by [169–171].

Clemens Winkler (born 26 December 1838, Freiberg/Saxony; died 8 October 1904, Dresden)

As son of a metallurgist he visited the *Gewerbeschule* (vocational school) Chemnitz. He studied chemistry at the Bergakademie (Mining Academy) Freiberg until 1859 and worked at the *Blaufarbenwerk* (Blue Colour Works) Niederpfannenstiel near Aue/Saxony, as Master. He was graduated with PhD at the Universität Leipzig with a thesis on silica compounds. In 1873, he was appointed Professor of Inorganic Chemistry at the Bergakademie Freiberg.

His most important and wellknown technical development was the catalytic process for sulphuric acid (1875, further improved by Rudolf Knietsch

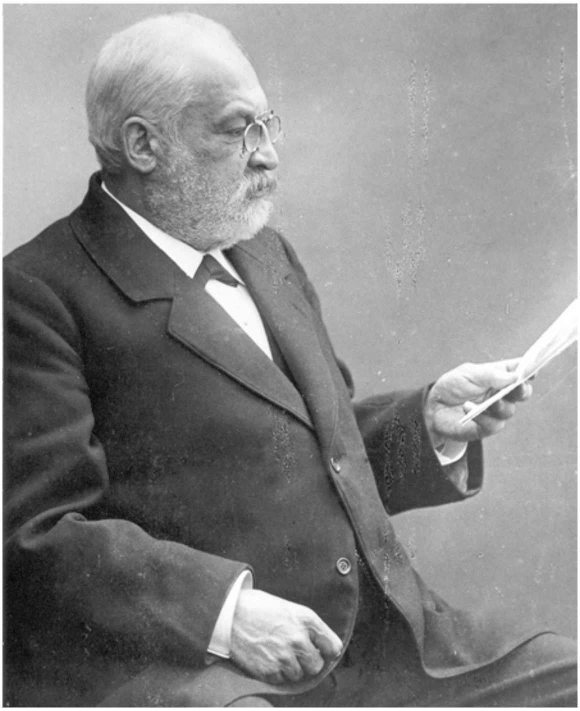


Fig. 3.16 Portrait of Clemens Winkler (1838–1904)

in Ludwigshafen at BASF). Winkler (for portrait see Fig. 3.16) improved Bunsen's gas analysis together with Walter Hempel [172–177], designed an apparatus for the provision of H_2S in the analytical laboratory [178], built the first industrial flue-gas desulfurization system and published on titrimetry [179–183].

Without a doubt, his most significant result was the detection of the new element germanium in 1886, as proof of both his analytical accuracy and consistence, as well as of the prophecy of Mendeleev. Winkler experienced a difference of 7 % in his analyses of the mineral argyrodite, and he searched until he detected a new element. He named it germanium (indium and gallium had been revealed and named before). The properties of this element fulfilled very satisfyingly the expectations of Mendeleev for his *ekasilicium* at the presumed gap in the fourth (now 14th) group between silicium and tin [184, 185].

His publications reflect broad interests and activities of Winkler [186, 187], most of them belonging or related to analytical chemistry [188–193].

More details are to befound at [194–197].

Theodor Heinrich Behrens (born 1843 Büsum/Holstein, died 1905)

Behrens studied physics and chemistry at the Christian-Albrechts-Universität zu Kiel, where he was graduated with a meteorological dissertation (1866) and became *Privatdozent* (Assistant Professor) in 1871. From 1874, he was Professor of mineralogy, geology and mining at the School of Polytechnics Delft, where he founded the first microchemical laboratory (1897). In 1898, he was appointed Professor of microchemistry at Amsterdam.

With his publications *Mikrochemische Methoden zur Mineral-Analyse* (Microchemical methods of the analysis of minerals) and *Beiträge zur mikrochemischen Analyse—Methoden und Reaktionen der einzelnen Elemente* (Contributions to microchemical analysis—methods and reactions of the single elements) as well as with several editions of the two volumes *Anleitung zur mikrochemischen Analyse* 1894 and 1895–1898, he is regarded as one of the founders of microchemical analysis [198].

Alexander CLASSEN (born 13 April 1843, Aachen; died 28 January 1934, Aachen)

Classen studied from 1861 at the universities Giessen and Berlin, where he graduated with a PhD and worked as assistant in Berlin for two years. Based in his private laboratory in Aachen (established in 1866), he gave lectures on analytical chemistry, became *Dozent* (Lecturer) in 1870 and Professor for organic and analytical chemistry (1878/1882) and was Director of the Institute of Electrochemistry of the Königlich Rheinisch-Westphälische Polytechnische Schule (Technical College, now Rheinisch-Westfälische Technische Hochschule/RWTH) Aachen until 1914. In 1923, he became honorary doctor of the RWTH Aachen.

Classen is one of the founders of electrochemical analysis [199] with his studies on the influences of voltage and current density on the deposition of metals, and he e.g., recognized the advantages of higher temperatures and of stirring, and recommended in 1897 express methods with rotating anode [200]. His institute became internationally known as a centre of electrochemistry.

He described the formation of sugar and alcohol from cellulose [201] and published (together with Roscoe) a textbook on inorganic and analytical chemistry, a handbook, selected methods, quantitative electrochemical analysis, and volumetric analysis [202–204]. Classen was also editor of the last issue of Mohr's textbook on titrimetry in 1914 [32].

Walther HEMPEL (born 5 May 1851, Pulsnitz/Saxony; died 1 December 1916, Dresden)

Hempel studied from 1867 at the Königlich Sächsische Polytechnische Schule (Royal Polytechnic, now Technische Universität) Dresden, 1871/1872 at the Friedrich-Wilhelms-Universität Berlin (at August Wilhelm von Hofmann and Adolf von Baeyer), and 1872 in Heidelberg (Robert Bunsen), where he graduated with a PhD. In 1873, he went to Dresden (*Zentralstelle für öffentliche Gesundheitspflege*, Center for Public Health) and became soon assistant of Schmitt at the Chemical Laboratory of the Polytechnic, where he habilitated in 1878 and was appointed Extraordinary Professor in 1879. In 1880, he became Professor for Technical Chemistry, and in 1893, he became Professor for inorganic experimental chemistry and for inorganic technical chemistry (both until 1912). He was Rector of the Polytechnic 1902–1903.

He invented several instruments (Hempel pipette, Hempel burette, a calorimetric bomb for the estimation of combustion heat, and Hempel oven for volumetry

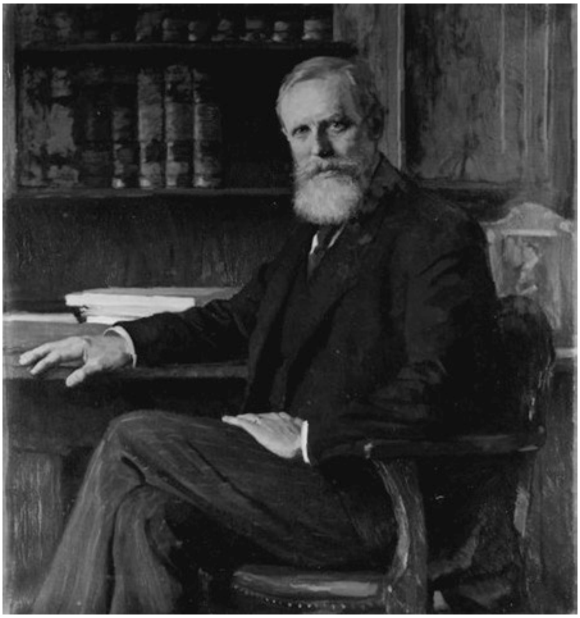


Fig. 3.17 Portrait of Walther Hempel (1851–1916). *Photo* University Archive TU Dresden, photo collection, with permission

and for gas analysis [205–207]). Hempel (for portrait see Fig. 3.17) introduced sodium peroxide into analytical techniques and demonstrated the possibility of chlorine production by electrolysis of sodium chloride (1889). He worked together with Crétier on attempts to determine the oxygen content of compounds [32, p. 303] and investigated the possibilities for the avoidance of injuries and damages by gaseous exhausts of combustions. Together with Clemens Winkler he is regarded as founder of technical gas analysis [202]. Additional information can be found at [208–213].

Ernst Otto Beckmann (born 4 July 1853, Solingen; died 13 July 1923, Berlin)

Beckmann was the son of a fabricant. After high school (Koblenz and Leipzig) he worked as a pharmacy assistant at several places (the last being in Wiesbaden at Remigius Fresenius). He then studied pharmacy and chemistry in Leipzig. After graduation with a PhD in 1878 he went to Braunschweig (Robert Otto), where he habilitated in 1882 for chemistry and pharmacy.

In 1884, he returned to Leipzig to Hermann Kolbe and became Professor, changed to Erlangen in 1892 and back to Leipzig as Ordinarius of applied chemistry in 1897. Finally, he became the director of the newly founded Kaiser Wilhelm Institute in Berlin (where Richard Willstätter, Lise Meitner and Otto Hahn worked with him).

Beckmann (for portrait see Fig. 3.18) worked mainly on organic, nutritional and physical chemistry, contributing to analytical aspects in all these three areas. Most well-known became his invention of a special thermometer type and of devices for ebullioscopic and cryoscopic determination of molecular weights [214, 215]. His

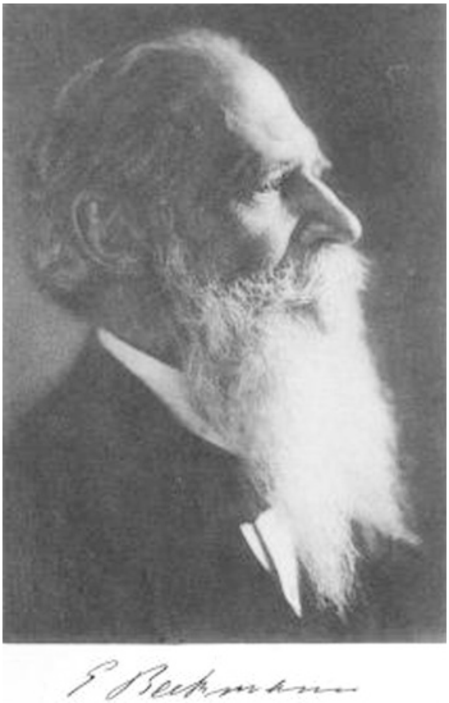


Fig. 3.18 Portrait of Ernst Beckmann (1853–1923)

apparatus for the photometry of *coloured flames* [216] also found great interest at his time.

In Leipzig he managed the building of the new *Laboratorium für Angewandte Chemie* (Laboratory for Applied Chemistry) [217], which still exists and became confirmed by the German Chemical Society (Gesellschaft deutscher Chemiker GDCh) as one of the *Historische Stätten der Chemie* (Historical Sites of Chemistry) [218]. In 1905 he wrote the obituary on Wislicenus [219].

Additional information see [220–223].

Wilhelm Ostwald [born 21 August (September 2 Gregorian calendar) 1853, Riga/Latvia; died 4 April 1932, Leipzig]

Ostwald began to study chemistry after high school in Dorpat (now Tartu/Estonia) and was graduated in 1878 at the Kaiserliche Universität (Royal University) Dorpat and worked there at first as an assistant (physics and chemistry) of Karl Schmidt and Arthur von Öttingen and then worked as a school teacher. In 1881, he was appointed Professor at Riga Polytechnic, teaching chemistry and philosophy, before he changed to Leipzig in 1887. Besides his impressive, extraordinary range of experimental and theoretical work, Ostwald had hundreds of students trained as assistants, and 70 of his pupils became Professors.

If not *the founder* of physical chemistry, he was (together with van't Hoff, Arrhenius and Nernst) an essential cofounder of this new discipline. He also made important contributions to analytical chemistry in various ways. In his book *Wissenschaftliche Grundlagen der analytischen Chemie* (Scientific Foundations of Analytical Chemistry [224, 225]), he introduced the expressions dissociation constants, solubility product, ion product, H ion concentration and indicator equilibrium into the discipline.

Wilhelm Ostwald's main scientific topics comprise the combustion of ammonia to nitric acid, the dilution law and the *Ostwaldsche Stufenregel* (Ostwald's rule), elucidation of electrolytic dissociation, fundamental principles of catalysis, his *Farbenlehre* (Colour Theory and System [226]), design of a *Pyknometer* (specific gravity bottle) and a thermostat and a rheostat to the prognosis of combustion cells and solar energy. He founded (together with van't Hoff 1887) the *Zeitschrift für physikalische Chemie, Stöchiometrie und Verwandtschaftslehre* (editor until 1921 for 100 volumes! - from 1928 Zeitschrift für physikalische Chemie) and cooperated in the determination of atomic weights in the respective international commissions. In addition, he wrote numerous books and articles and worked on philosophical topics. He wrote a whole series of textbooks on analytical [224, 225], general [227, 228], inorganic [229], physical chemistry [230], electrochemistry [231] and several introductions to chemistry for the public [232–238]. With proposals to the organisation of sciences and of scientific literature as well as to a rational use of energy has he extended his activities beyond chemistry to philosophical confessions, e.g. [239, 240].

352 scientists from 30 nations worked with Wilhelm Ostwald between 1887 and 1906 in Leipzig, and 148 doctoral theses were produced under his direction—in addition ten habilitations. A small collection of renamed scholars might submit an impression of Ostwalds influence onto the further development of physical chemistry: Ernst Otto Beckmann, Robert Behrend, Georg Bredig, Walther Nernst, Max Le Blanc, Theodore William Richards (1868–1928, Nobel Prize 1914), Robert Luther (1868–1945), Alwin Mittasch (1869–1953), Fritz Pregl (1869–1930, Nobel Prize 1923), Frederick George Donnan (1870–1956), Max Bodenstein (1871–1942), Eugene C. Sullivan (1872–1962, Corning–Glass Works, inventor of PYREX glass), Niels Bjerrum (1879–1958).

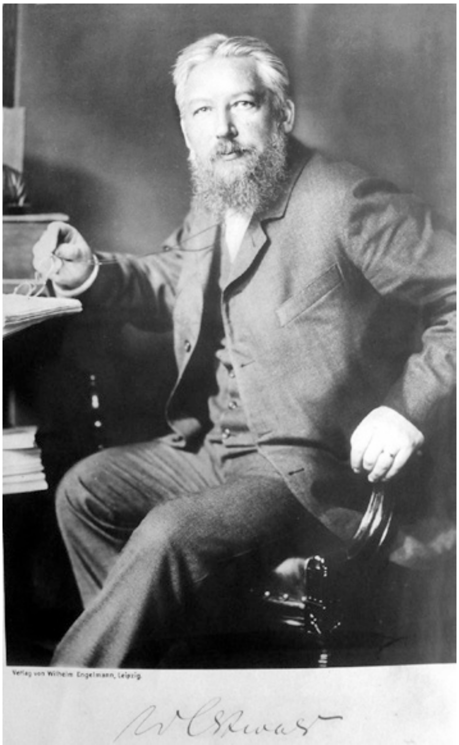
In 1889, Ostwald (for portrait see Fig. 3.19) founded the series *Ostwalds Klassiker der exakten Wissenschaften* (Ostwalds Classics of Exact Sciences) with reprints of memorable scientific papers, and edited himself 16 (in total there are meanwhile almost 300 of those booklets, e.g. [55]). Another historic series was initiated 1911: *Große Männer—Studien zur Biologie des Genies* (Great men—studies on the biology of the genius) with 11 volumes until 1932.

He obtained the Nobel Prize in 1909 for his research on catalysis and the principles of chemical reaction kinetics and equilibria, and he became elected to numerous scientific academies.

Differences with the officials of the Universität Leipzig, starting in 1905, led him (after a guest professorship in the USA) to resign 1906 and to withdraw to his big estate and newly built *Haus Energie* in Grossbothen near Grimma (in the Leipzig region), where he lived with his family until his death in 1932.

Additional information is given by [241–250].

Fig. 3.19 Portrait of Wilhelm Ostwald 1901 (1853–1932)



Paul Ehrlich [born 14 March 1854, Strehlen (now Strzelin near Wroclaw/Poland); died 20 August 1915, Bad Homburg vor der Höhe near Frankfurt]

Paul Ehrlich visited the high school *Maria Magdalenen-Gymnasium* in Breslau (1864–1879) and studied medicine at the universities Breslau, Straßburg (now Strasbourg, France) and Freiburg; he graduated Dr.med. at the Universität Leipzig (Julius Cohnheim) with the thesis *Beiträge zu Theorie und Praxis der histologischen Färbung* (Contributions to the theory and practice of histological staining), which already announced his interest in diagnostic methodology. He worked afterwards at the Charité Berlin as assistant of Theodor von Frerichs, the founder of experimental clinical medicine, dealing with topics of histology, hematology and dye chemistry. In 1882, he obtained the title Professor of Friedrich-Wilhelms-Universität (now Humboldt-Universität) Berlin. His habilitation thesis *Das Sauerstoff-Bedürfnis des Organismus. Eine farbenanalytische Studie* (The oxygen need of the organism—an analytical study of dyes) was issued as a monograph in 1885.

Due to a longer disease and animosities with Carl Gerhardt—the successor of von Frerich, Ehrlich established a private laboratory in Berlin in 1889. After he was appointed Außerplanmässiger Professor (Extraordinary Professor) of the Friedrich-Wilhelm-Universität Berlin in 1890, Robert Koch employed him at his institute for infectional diseases (1891), and in 1896 Paul Ehrlich became director of the newly founded *Institut für Serumforschung und Serumprüfung* (Institute for Serum Research and Testing, now Paul-Ehrlich-Institut), obtaining simultaneously the title *Geheimer Medizinalrat*. This institution was transferred to Frankfurt/Main as *Institut für experimentelle Therapie* (where Ehrlich cooperated with Max Neisser). Entitled Honorary Professor at the Georg-August-Universität Göttingen (1894), he became director of the Georg Speyer Haus in Frankfurt/Main in 1906, the basis of his activities towards chemotherapy and the development of his syphilis remedy, *Salvarsan*.

In 1908, Ehrlich was awarded the Nobel Prize (together with his former opponent Ilja Metschnikow), and in 1914 he was appointed Ordinary Professor of Pharmacology at the newly founded Johann Wolfgang Goethe-Universität Frankfurt am Main.

Ehrlich married Hedwig Pinkus (14 August 1883, in the Synagoge of Neustadt, now Prudnik, Poland), the daughter of an entrepreneur (textile factory), and so obtained financial independence.

Ehrlich's (for portrait see Fig. 3.20) activities and results, mainly in histology, hematology and chemotherapy, show that chemical reactions with biological entities from cells to the human body, have strong diagnostic impact.

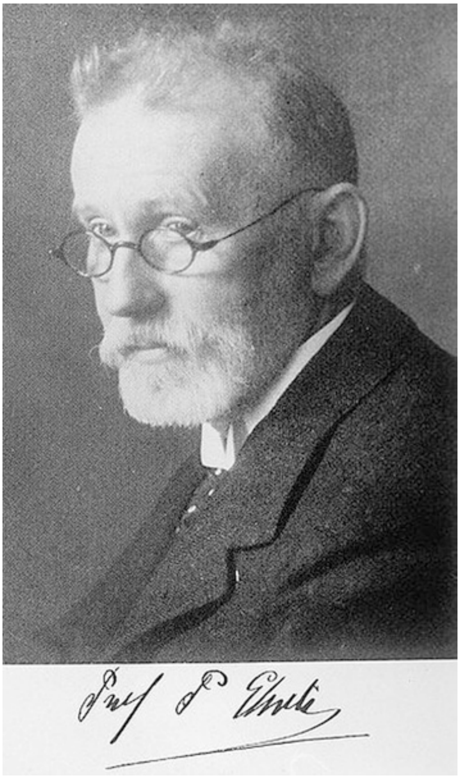


Fig. 3.20 Portrait of Paul Ehrlich (1854–1915)

By his methods for the staining of blood cells (possibly triggered by his cousin Carl Weigert, who in the 1870s initiated the staining of bacteria with *aniline dyes*), he revealed new categories of those and created a systematic testing schedule for blood diagnosis. This comprised the leucocytes (he detected the granulocytes already in his doctoral thesis), the differentiation of leucocytes and lymphocytes, as well as the erythrocytes and their predecessors, and the invention of dry blood tests. For urine he developed his diazo test for the differentiation of abdominal diseases (*Ehrlich reagent*).

Chemical reactions as the mechanism of the staining of tissues and microorganisms obviously have been the conceptual basis of Ehrlich's search for substances for the chemotherapeutic treatment of infections [251].

Also in the other fields of Ehrlich's activity, one recognizes his at this time uncommon conviction of the prevalence of chemical affinities in the mechanisms of biological processes and phenomena—immunity, infections, antisera and their standardization, cancer research.

Although the target of disagreements with his theories, priority claims, antisemitic defamations, Ehrlich earned many honours during and after his lifetime, e.g. *Geheimrat*, *Geheimer Obermedizinalrat* (1907), *Grosse Goldene Medaille für Wissenschaften*. Many streets, institutions, schools, pharmacies and even a moon crater have been named after him. Ehrlich is portrayed on a German post stamp 1954 and on the 200 DM banknote.

Additional information can be found at [252–257].

Anton Friedrich Robert Behrend (born 17 December 1856, Hamburg-Harburg; died 15 September 1926, Hanover)

After study of the first law year in Heidelberg, he stepped over in 1877 to natural sciences and then to chemistry in Leipzig and graduated there Dr. phil. (thesis *Über substituierte Sulfamide und Amidosulfonchloride*). Afterwards, he became assistant at Ostwald's Institute of Physical Chemistry, obtaining habilitation in 1885, *Privatdozent* (Assistant Professor) at the Universität Leipzig 1885–1889. He became then Professor of organic and physical chemistry at the Königliche Technische Hochschule (Royal Technical College) Hannover (1894–1924).

Behrend (for portrait see Fig. 3.21) first worked on potentiometric titration in Leipzig at Ostwald's institute and published the method as *Elektrometrische Analyse* in 1893: titration of mercury-II-nitrate with potassium halogenides KCl, KBr, KJ [258]. Later he invented a mercury electrode. Potentiometry was further developed and published in 1897 by his coworker Wilhelm Böttger (born 1871, see Chap.4 of this book).

Behrend published the synthesis of uric acid and its derivatives [259], proved the purine structure of uric acid—contradicting Emil Fischer—and demonstrated the rotational isomeric forms alpha and beta of glucose and its ring structure.

For further information see [32, 260–262].

Wilhelm Autenrieth (born 1 April 1863, Langensteinbach/Baden; died 25 January 1926, Freiburg im Breisgau).

Autenrieth studied chemistry and pharmacy (Berlin and Freiburg) and graduated in Erlangen in 1888, habilitated in Freiburg in 1895 and was there appointed

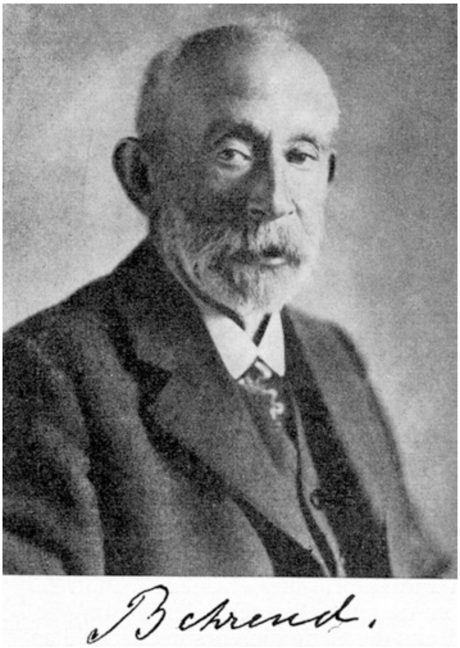


Fig. 3.21 Portrait of Robert Behrend (1856–1926)

extraordinary Professor of Medical and Pharmaceutical Chemistry in 1900. In 1921, he became director of the pharmaceutic-medical division of the Chemical Institute of the Albert-Ludwigs-Universität Freiburg. He developed a colorimeter [263] and wrote *Qualitative chemische Analyse: ein Leitfaden zum Gebrauche in chemischen Laboratorien* (Qualitative analysis—a guide for use in chemical laboratories) in 1897 [264] and *Die Auffindung der Gifte und stark wirkenden Arzneistoffe* (The detection of poisons and strong acting pharmacological agents) in 1892 [265]. The latter became a standard textbook, following in the tradition of Friedrich Julius Otto. It experienced 6 editions until 1941—unique among books on toxicological analysis.

Further information at [266].

Walther Hermann Nernst [born 25 June 1864, Briesen (now Wąbrzeżno/Poland); died 18 November 1941, Zibelle (now Niwica/Poland)].

Son of a judge, Nernst studied (after high school in Graudenz, now Grudziądz/Poland) at the universities of Zurich, Berlin and Graz, graduating at the Julius-Maximilians-Universität Würzburg in1883 (Kohlrausch) and habilitated in Leipzig (Wilhelm Ostwald) in 1887. Afterwards, he went as assistant to Eduard Rieche to Göttingen and became *Privatdozent* (Assistant Professor). In 1905, he moved to Berlin, where he worked as Professor at the university (1922–1924), as Rector of the Friedrich-Wilhelms-Universität Berlin (1920/1921) and 1922–1924 as President of the *Physikalisch-Technische Reichsanstalt* (Physical and Technical Institute of the German Reich, now Physikalisch-Technische Bundesanstalt).

As an admirer of automobiles, he had purchased the first motorcar in Göttingen in 1899 and made suggestions for the improvement of fuel combustion in car engines. After he bought a farm estate (*Rittergut*, Knight's Estate) in Zibelle near Muskau/Lusatia), the family moved there from Berlin.

Primarily experimenting in physics, the range of his work is fairly widespread: phenomena of phase borders and in electrolysis, dielectric constants, reaction kinetics (among others combustion in the automobile engine), liquid crystals, heterogenic gas equilibria, influence of light on chemical reactions, invention of the *Nernst lamp* and definition of the *Nernst theorem of thermodynamics* [267–269]. He started his main activities with Ostwald in Leipzig in physical chemistry: concentration chains of electrolytic solutions, galvanic cells and the *Nernst equation*. His *Partition Law* [270–272]—fundamental for the relation of concentrations in two-phase systems of immiscible liquids—became basic for extractive separations, as well as for chromatography in general.

Numerous renamed chemists have been promoted under Nernst's guidance (e.g. Leonid Andrussow, Karl Baedeker, Karl Friedrich Bonhöffer, Ernst Bürgin, Friedrich Dolezalek, Erich Fischer, Karl Fredenhagen, Fritz Lange, Irving Langmuir, Frederick Lindemann, Margaret Maltby, Kurt Peters, Matthias Pier, Emil Podszus, Hans Schimank, Franz Eugen Simon) and Max Bodenstein and Arnold Eucken habilitated under his direction. Nernst (for portrait see Fig. 3.22) was cofounder of the *Deutsche Elektrochemische Gesellschaft* (now Deutsche Bunsen-Gesellschaft für

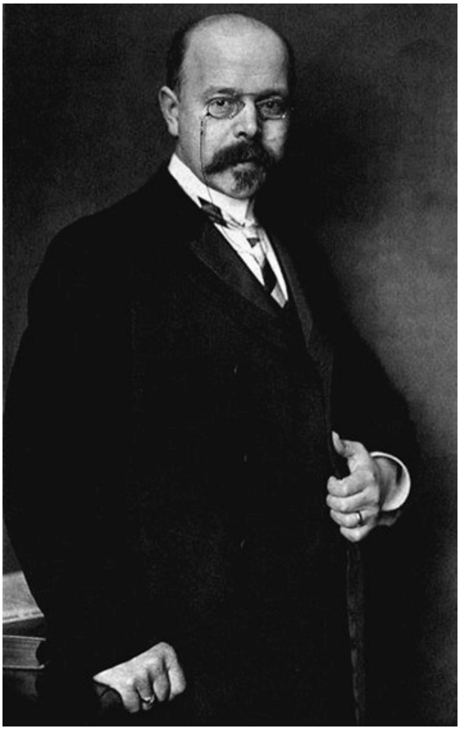


Fig. 3.22 Portrait of Walter Nernst (1864–1941)

Physikalische Chemie) in 1884. He received the Nobel Prize in 1920, earned several honorary doctoral degrees, was elected as member of 12 scientific academies and of the Royal Society, and was conferred with the order Pour le mérite (France).

As an activity outside chemistry he contributed to the construction of a new musical instrument in 1930, the electronic *Bechstein/Siemens/Nernst-Flügel* (grandpiano) [273].

It has to be mentioned—although an activity outside analytical chemistry—that Walther Nernst was among the promoters of chemical warfare during World War I, when he invented, recommended and tested chemical weapons (besides suitable poisons mainly possible ways of transport, distribution and applications onto the sites of the enemies) [274, 275].

See also at [276–280].

Max Julius LeBlanc [born May 26, 1865 Barten (now Barciany, Poland), died July 31, 1943 Leipzig].

Studied chemistry at the universities Tübingen, Munich and Berlin, in 1883–1886, and then became private assistant of August Wilhelm von Hofmann in Berlin, where he graduated with a PhD in 1888. Afterwards, he worked at Wilhelm Ostwald in Leipzig as an assistant (1890–1893) and after his habilitation as *Privatdozent* (Assistant Professor). In 1896, he changed to *Farbwerke vorm. Meister Lucius & Brüning AG* (colloquially Farbwerke Hoechst, now Hoechst AG Frankfurt am Main) and directed the electrochemical division. In 1901, he was appointed to the Ordinariate for physical chemistry at the Technische Hochschule Karlsruhe (now Karlsruher Institut für Technologie), where he founded the first Institute for Electrochemistry. In 1906, he became Director of the Institute for Physical Chemistry of the Universität Leipzig (until his retirement in 1934). He was also Rector of the Universität Leipzig and member of the Königlich Sächsische Gesellschaft der Wissenschaften (Royal Saxonian Academy of Sciences, now Sächsische Akademie der Wissenschaften) Leipzig and of the Deutsche Akademie der Naturforscher (German Academy of Sciences) Leopoldina Halle.

LeBlanc (for portrait see Fig. 3.23) worked mainly on electrochemistry, both directed to analytical and technical applications. He found out, that the decomposition potential in electrolytic solutions is ion specific (1889 [281]) and introduced the pH determination by the hydrogen electrode (1893 [282]) and oscillographes for the measurement of fast potential changes [32]. From 1918–1926 he experimented on natural rubber (caoutchouc). Attempts were directed to the electrolysis by alternating currents. He developed acid-resistant diaphragms (1900) and succeeded in the electrolytic production of chromium (1902). He could demonstrate that minor deviations from stoichometric compositions of metal oxides enhance the electric conductivity considerably. He published his *Lehrbuch der Elektrochemie* in 1922.

Further information can be found at [283, 284].

Jeremias Siegismund Karl Friedrich (Fritz) Förster [born 22 February 1866, Grünberg/Silesia (now Zielona Góra, Poland); died 14 September 1931, Dresden].

Förster was interested in chemistry since his childhood. While experimenting, he lost his left eye. He studied at the Königlich Technische Hochschule (Royal

Fig. 3.23 Portrait of Max LeBlanc (1865–1943)

Technical College) Berlin-Charlottenburg from 1884, graduated with a PhD at August Wilhelm von Hofmann 1888, and then worked as assistant of Franz Mylius at the Physikalisch-Technische Reichsanstalt (Physical-Technical Imperial Institute, now Physikalisch-Technische Bundesanstalt) in Berlin.

In recognition of his research and fundamental publications about the behaviour of glasses and their resistance towards chemicals, he was awarded habilitation by the Technical College and obtained an appointment to the Technische Hochschule (Technical College, now Technische Universität) Dresden, where he taught electrochemistry and physical chemistry. He became Professor 1898 (Extraordinary, 2 years later Ordinarius for Physical Chemistry and Electrochemistry). In 1912, he took over the Chair for inorganic and inorganic–technical chemistry and was elected Rector for the years 1917/1918. He became a Member of Königlich Sächsische Gesellschaft der Wissenschaften (Royal Saxonian Academy of Sciences, now Sächsische Akademie der Wissenschaften) Leipzig in 1912, of the Akademie der Wissenschaften zu Göttingen (Academy of Sciences) in 1921.

Mylius and Förster were the first titrating acids and bases with 0.001 n solutions and iodine–eosin as indicator (1891; publications see [32, p. 275]). They produced also iron carbide and pure platinum.

Förster (for portrait see Fig. 3.24) worked on tautomery, on electrolysis of copper and alkali chlorides and on passivity during electrolysis, developed electroanalytical methods for metal separations [282, 285–287], investigated the Edison accumulator, sulphur/oxygen compounds and Wackenroder's liquid as a means for desulphurization and always also directed towards technical applications. Publications on Saxonian coal (anthracite) have been directed to its behaviour

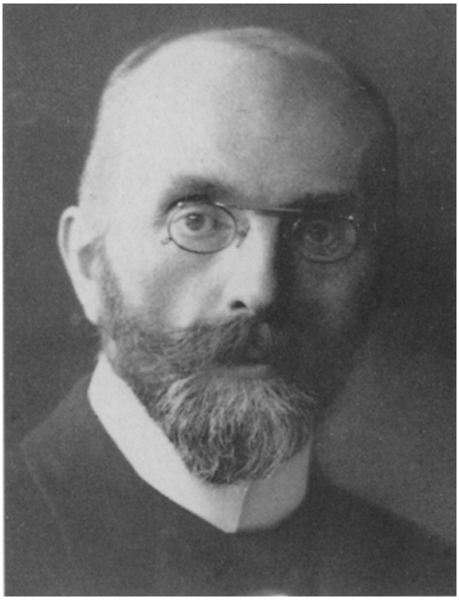


Fig. 3.24 Portrait of Fritz Förster (1866–1931). *Photo* University Archive TU Dresden, photo collection, with permission

during distillation, the estimation of its heating capacity, sulphur and nitrogen content and the low-temperature gasification (*Tieftemperaturverkokung*).

Förster was honoured with the title *Geheimer Hofrat*, with the honorary doctorate of Stuttgart University and as member of the scientific academies Göttingen and Saxony. The Technische Universität Dresden named one of its main buildings after him [288], as did the City Council of Dresden with a public square.

See for further details [288–292].

Johannes Gadamer [born 1 April 1867, Waldenburg (now Walbrzych/Poland); died 25 April 1928, Marburg].

Gadamer concluded his study of pharmacy at the Philipps-Universität Marburg with the final examination (*Staatsexamen*) in 1893 and graduated Dr. phil. with a thesis about thiosinamine (at Ernst Schmidt) in 1895. After his habilitation (1897 Marburg) he was appointed Professor of Pharmaceutical Chemistry at the Schlesische Friedrich-Wilhelms-Universität zu Breslau (now Wroclaw, Polen) in 1902, where he remained until 1919, when he became successor of Ernst Schmidt in Marburg.

Gadamer worked on the structural elucidation of natural compounds (alkaloids, glykosides) and elucidated the structure of the glykosid sinigrin $C_{10}H_{16}O_9NS_2K$ [293].

He became renown by his book *Lehrbuch der chemischen Toxikologie und Anleitung zur Ausmittelung der Gifte* (Textbook of chemical toxicology and Guide to the detection of poisons). The analytical part shows a remarkably systematic structure and had two editions at lifetime of the author (1909 and 1924 [294]). A completely new, enlarged reedition (3 volumes 1966–1979) was produced by Friedrich Rolf Preuss and Engelbert Graf.

Gadamer was Rector of Marburg University, and Dean of the Philosophical Faculty of the Schlesische Friedrich-Wilhelms-Universität Breslau 1913–1915. He was appointed to the *Reichsgesundheitsamt* (Imperial Health Authority) in 1915, was honoured by the title *Geheimer Regierungsrat* (Secret governmental counselor) in 1916 and was awarded with the honorary Dr.med.h.c. at the Schlesische Friedrich-Wilhelms-University Breslau Medical School in 1921.

See also [295, 296].

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Chapter 4
Development of Instrumental Techniques: The Twentieth Century

Reiner Salzer and Gerhard Werner

This chapter is devoted to scientists who were born between 1870 and 1920. The time of their working careers is characterized by the better understanding of the chemical mechanisms behind the analytical determinations, of spectroscopic and separation techniques which led to enhanced selectivity and accuracy of the measurements, remarkable miniaturization of equipment and to the extension of the application areas towards low concentrations and small sample sizes.

Erich Max Müller (born 17 February 1870, Chemnitz, died 16 November 1948, Dresden)

Erich Müller (for portrait see Fig. 4.1) was son of a factory owner. After high school in Görlitz, he studied chemistry in Straßburg (now Strasbourg/France) and Berlin. After completing his PhD at Landolt's institute in Berlin in 1895, he made study trips to France, the USA and worked in industry in England [1]. After a short period of work in his father's factory in Seidenberg, Schlesien (now Zawidów/Poland), he moved to the Technische Hochschule (TH) Dresden and worked for 1 year on electrochemistry in Fritz Förster's group in the institute of Walter Hempel. After a study stay at Nernst's institute in Göttingen, he returned to Dresden and there completed his habilitation thesis (to qualify him as university teacher) *Kathodische Polarisation und Depolarisation* in 1900 and joined the *Institut für Elektrochemie und physikalische Chemie* of the TH (now Technische Universität) Dresden founded in the same year. In 1904, he became Extraordinary Professor (which corresponds to Associate Professor in UK or USA terms) at the TH Braunschweig, in 1906, he became Full Professor at the TH Stuttgart. In 1912, he served as Rector of the TH Stuttgart but returned in the same year to Dresden as Head of the *Institut für Elektrochemie und physikalische Chemie*, which he directed until he retired in 1935. Between 1914 and 1916, his work was interrupted by his service in the First World War. Müller served as Rector of the TH Dresden in 1930. He continued his research until 1944.

Müller designed and implemented a course in practical electrochemistry in 1900 [2]. This led to his famous book *Elektrochemisches Praktikum* in 1912,

D.T. Burns et al., *Important Figures of Analytical Chemistry from Germany in Brief Biographies*, SpringerBriefs in History of Chemistry,
DOI 10.1007/978-3-319-12151-2_4

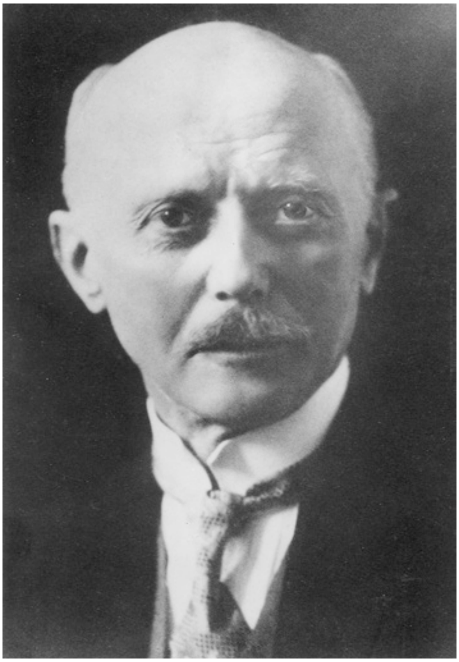

Fig. 4.1 Portrait of Erich Müller (1870–1948). *Photo* University Archive TU Dresden, photograph collection, with permission

printed in 9 editions up to 1953 and in many translations. Müller's research was always based both on thorough theoretical studies and on practical applicability. His main interest was the electrolysis of sodium chloride. Very early, he used current-potential curves to investigate electrode processes [3]. He studied the electrochemical formation of inorganic and organic compounds, some of them later of technical importance. His main scientific achievement was in the understanding of the mechanism of chrome plating. Very early, he recognized the importance of titration curves for quantitative determinations, conducting simultaneous analyses and making contributions to the development of the field of volumetric analysis. Many of the common potentiometric determination procedures were developed in his group and were described in his textbook *Die elektrochemische* (*potentiometrische*) *Maßanalyse*, produced in 7 editions between 1921 and 1944 [4].

Wilhelm Carl Böttger (born 2 October 1871, Leisnig, died 23 October 1949, Hanover)

Wilhelm Böttger was the son of a cloth factory owner. After practical education in Chemnitz, Berlin and Switzerland, he studied pharmacy from 1893 to 1895. After passing the *Staatsexamen* (government licensing examination) in 1895, he then turned to chemistry at the Universität Leipzig, with a focus on electrochemistry. In his first semester, he was fascinated by Ostwald's book

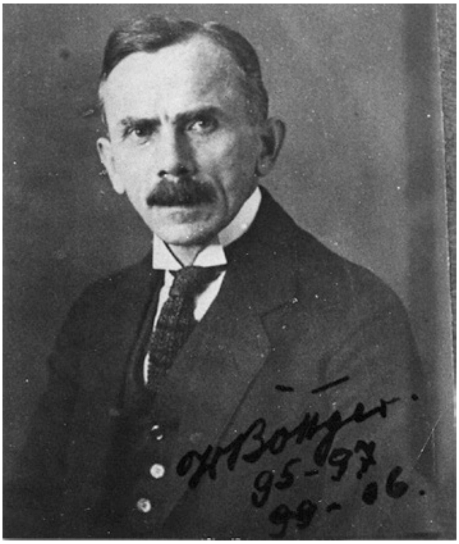

Fig. 4.2 Portrait of Wilhelm Böttger (1871–1949). *Photo* Archive Faculty Chemistry and Mineralogy, Universität Leipzig, with permission

Die wissenschaftlichen Grundlagen der analytischen Chemie (The scientific foundations of analytical chemistry) [5], which is an early review of applications of physico-chemical principle to the solution of analytical problems. From then on, Böttger considered the liberation of analytical chemistry from empiricism to be his task for life [6]. He completed his PhD in Ostwald's group in 1897 on the application of the electrometer as indicator for the determination of acids and bases. After being assistant of Otto Wallach in Göttingen, he moved back to Leipzig to work with Wilhelm Ostwald and Max LeBlanc (1903) in the Institute of Physical Chemistry at Universität Leipzig, where he habilitated in 1903 in analytical and physical chemistry [7]. In 1904/1905, he worked as research associate of A.A. Noyes at the Institute of Technology in Boston and became Extraordinary Professor in Leipzig in 1910. In 1922, he became Extraordinary Honorary Professor at the same university (for portrait see Fig. 4.2). His focus was again on the development of a scientific foundation of analytical chemistry, which at that time still mainly had an empirical background. Böttger developed the technique of potentiometric titration, which he learnt from its inventor, Robert Behrend, whilst working in Ostwald's institute. He introduced liquid mercury electrodes into analytical practice and studied the applicability of dyestuffs for the determination of endpoints in acid–base titrations. Böttger introduced standard solutions for titrations (FIXANAL®) and controlled their commercial manufacture by J.D. Riedel-E. de Haën AG from 1922. His book *Qualitative Analyse vom Standpunkt der Ionenlehre* (Qualitative analysis from the point of view of ion theory) was widely used for over two decades [8]. His book series *Physikalische Methoden der analytischen Chemie* (Physical methods of analytical chemistry) was also very well accepted [9–12]. After his retirement in 1938, Böttger moved to Hanover and continued his research there.

Georg Lockemann (born 17 October 1871, Hollenstedt, Lower Saxony, died 4 December 1959, Hollenstedt)

Lockemann started his chemical education in 1891 at the Technische Hochschule Hannover, changing in 1894 to the Universität Heidelberg, where in 1896 he graduated with a thesis about azobenzene derivatives. After a short employment in the Sülbeck saltworks [13], he became an assistant of E. Beckmann in the Universität Leipzig. For his habilitation in 1904, he worked in the theory of the Beckmann rearrangement [14]. His reputation was so well established that in 1907 he became head of the chemical division of the Robert-Koch-Institut in Berlin. A second habilitation at the Friedrich-Wilhelms-Universität Berlin in 1909 dealt with the improvement of the Marsh test. In 1910, he was appointed Professor in the Robert-Koch-Institut and got the title *Geheimer Regierungsrat* (official title for senior civil servants). In 1926, he was commissioned to teach history of chemistry and pharmacy at Berlin (for portrait see Fig. 4.3). He retired in 1937, but was called back to his previous position from 1939 to 1945. Then, he went home to his native province and lectured for three semesters in the Georg-August-Universität Göttingen on history of chemistry.

His main contributions to analytical chemistry were the improvements of the methods of detecting arsenic following on from the work by Marsh, Gutzeit and Liebig [15]. The Lockemann procedure allowed the detection of amounts down to 10^{-7} g, which is an extremely high sensitivity for a non-spectroscopic method [16]. This required the preparation of arsenic-free reagents and glassware. Among his other contributions to analytical chemistry are a method of detecting cyanogens in mixtures [17] and an apparatus for formaldehyde determination [18].

Fig. 4.3 Portrait of Georg Lockemann (1871–1959). *Photo* J Chem Educ 27 (1950) 236, with permission

Particularly, noteworthy are his articles and books on the history of chemistry (e.g. on Goethe's relation to chemistry [19]) and the biographies of eminent chemists as reviewed and listed by Neumann [20].

Otto Hönigschmid [born 13 March 1878, Horowitz, Bohemia (now Hořovice/Czech Republic), died 14 October 1945, (suicide) Munich]

After his high school examination in Prague, he studied chemistry at the German Carl-Ferdinand-Universität Prag and graduated 1902 with a PhD under G. Goldschmiedt in organic chemistry. He became a teaching assistant, but asked frequently for leave to work abroad. From 1904 to 1906, he worked with H. Moissan in Paris, where he started to work on carbides and silicides, which were the subject of his habilitation in 1908 [21]. He left Prague again to become a Research Fellow of Th.W. Richards at Harvard University. When he came back, he was appointed to the Radium-Institut in Vienna. In 1911, he became Professor at the Deutsche Technische Hochschule Prag and 1918 at Ludwig-Maximilians-Universität München (for portrait see Fig. 4.4).

Hönigschmid's most important work was in the precise determination of atomic weights. He learned the necessary techniques during his stay with Richards, where he redetermined and corrected the atomic weight of calcium and this value is still valid [22, 23]. In 1910, he was the first to determine the atomic weight of radium. He combined the knowledge obtained at Harvard with great practical skills, devising and masterly design and self-production of devices, and not least with his idiosyncratic way of thinking [24]. Otherwise it would have been impossible for him to determine the atomic weight of nearly 50 elements, each of which had to be treated as a special case. He developed methods for the preparation of extremely pure and well-defined compounds, mainly halides, which could be distilled or

Fig. 4.4 Portrait of Otto Hönigschmid (1878–1945). *Photo* Chem in uns Zeit 15 (1981) 164, with permission

sublimed. Of special importance was the accuracy of the atomic weights of key elements silver, chlorine, bromine, sodium, potassium and sulphur. The relative precision for the atomic weight of silver (107.880) was 1:100 000 which was and is considered to be high-performance analytical chemistry. Particular importance was given to the atomic weight determination with the study of radioactivity and for the evidence of existing isotopes. Hönigschmid was able to determine the atomic weights of ^{35}Cl and ^{37}Cl after their separation by Clusius and Dickel in 1938 [25]. With the new technique of mass spectroscopy by Aston, there was a fruitful exchange of information and complementary support. For many years, Hönigschmid was the head of the German Atomic Weights Commission and from 1930 also active in the corresponding international committee of IUPAC. Hönigschmid was member of several academies. He received the *Goethe-Medaille für Kunst und Wissenschaft* (Goethe Medal for Arts and Science) [26] and 1940 the *Liebig-Medaille* of the German Chemical Society.

Otto Hahn (born 8 March 1879, Frankfurt, Main, died 28 July 1968, Göttingen)

Otto Hahn was the son of an innovative factory owner [27]. After high school in Frankfurt, Main, he intended to become an industrial chemist and matriculated 1897 in Marburg. Before completion of his PhD in Marburg in 1901, he spent two semesters with Adolf von Baeyer in München. After 1 year military service, he worked for 2 years as assistant at the Universität Marburg. In 1904, Hahn moved to the University College London and had his first experience in radiochemistry with Sir William Ramsay. In 1905, he discovered radiothorium, then considered a new chemical element, now known as ^{228}Th. Later that year, Hahn went to Sir Ernest Rutherford at McGill University, Montreal, Canada. There he discovered the radioactive elements thorium C (now ^{222}Bi), radium D (now ^{220}Pb), and radioactinium (now ^{227}Th) [28]. In 1906, Hahn returned to Germany to work with Emil Fischer, Friedrich-Wilhelms-Universität (now Humboldt-Universität) Berlin, and discovered within a few months mesothorium I, mesothorium II and the mother substance of radium–ionium. Mesothorium I (now ^{228}Ra) had a high potential for medical radiation therapy [29]. For the discovery of mesothorium I, Hahn was for the first time proposed for the Nobel Prize in Chemistry (in 1914 by Adolf von Baeyer). In 1907, Hahn qualified as university lecturer (habilitation thesis) at the Friedrich-Wilhelms-Universität Berlin.

In 1907, Lise Meitner came to Berlin from Vienna. They cooperated for more than 30 years and established a lifelong close friendship (see Fig. 4.5). In 1908, Hahn succeeded in demonstrating the radioactive recoil incident to alpha particle emission and thus interpreting it correctly [30]. In 1910, Hahn was appointed Professor, and in 1912, he became Head of the Radiochemistry Department of the newly founded Kaiser-Wilhelm-Institut für Chemie in Berlin [31].

During the First World War, Hahn was conscripted into the army, where he was assigned, together with James Franck and Gustav Hertz, to the special unit for chemical warfare under the direction of Fritz Haber. Hahn resumed his research with Lise Meitner in 1918 and discovered protactinium, the long-lived mother substance of the actinium series. Hahn published the first report on his discovery of

Fig. 4.5 Otto Hahn and Lise Meitner in their laboratory, 1908. *Photo* Archive of the Max Planck Society, Berlin-Dahlem, with permission

uranium Z (now ^{234}Pa) in 1921, the first example of nuclear isomerism [32]. For this discovery, Hahn was again nominated for the Nobel Prize in Chemistry (in 1923 by Max Planck and others).

In 1924, Hahn was elected to full membership of the Prussian Academy of Sciences in Berlin (proposed by Einstein, Planck, Haber, Schlenk and von Laue). In this time, Hahn founded the new field of "Applied Radiochemistry", based on his recently developed "emanation method". In 1933, he published a book in English (and later in Russian) entitled *Applied Radiochemistry* [33]. It contains his lectures given as Visiting Professor at Cornell University in Ithaca, New York in 1933.

Hahn was Director of the Kaiser-Wilhelm-Institute für Chemie in Berlin from 1928 to 1946. In 1934, Hahn resigned from the Friedrich-Wilhelms-Universität Berlin to protest about the dismissal of Jewish colleagues and those with Jewish ancestry, notably Lise Meitner, Fritz Haber and James Franck. In 1938, with the support of Hahn, Lise Meitner emigrated illegally to Stockholm, Sweden. Hahn continued to work with Straßmann. In December 1938, they found barium in a uranium sample irradiated by neutrons. This was the discovery of nuclear fission. Until 1944, Hahn continued investigation on the proof and separation of many elements and kinds of atoms which arise through fission [34]. In 1945, Hahn was awarded the 1944 Nobel Prize in Chemistry for the discovery of nuclear fission [35].

From 1948 to 1960, Otto Hahn was the founding President of the newly formed *Max-Planck-Gesellschaft zur Förderung der Wissenschaften* (Society for the Advancement of Science). He initiated the Mainau Declaration of 1955, in which a large number of Nobel Prize winners drew attention to the dangers of nuclear weapons. Up to his death, he warned persistently of the dangers of the nuclear arms race and of the radioactive contamination of the planet [36]. From 1957, Hahn was repeatedly nominated for the Nobel Peace Prize.

Hahn was member or honorary member of 45 Academies and scientific societies. He received 37 of the highest national and international orders and medals. He declined both the invitation to become honorary citizen of Magdeburg, German Democratic Republic (1957) and an honorary membership of the Soviet Academy of Science in Moscow (1958).

Hermann Staudinger (born 23 March 1881, Worms, died 18 September 1965, Freiburg im Breisgau)

Hermann Staudinger was son of a high school teacher with socialist and pacifist leanings, to whom he owed much of his political outlook. He was educated in Worms, matriculated in 1899 and continued his studies first at the Vereinigte Friedrichs-Universität Halle-Wittenberg, later at Darmstadt and München [37]. He graduated with a PhD in Halle in 1903, supervisor: Jakob Volhard, and qualified for inauguration as academic lecturer at the Universität Straßburg (now Strasbourg/France) in 1907. In the same year, he was appointed Professor of Organic Chemistry at the Institute of Chemistry of the Technische Hochschule Karlsruhe (now Karlsruher Institut für Technologie). Between 1912 and 1926, he was lecturer at the Eidgenössische Technische Hochschule in Zurich, Switzerland. From there, he openly criticized Germany's involvement in the war, and he directly challenged Fritz Haber about his role in gas warfare [38]. In 1926, Staudinger became Lecturer of Chemistry at the Albert-Ludwigs-Universität Freiburg. There he remained for the rest of his career. From 1940 onwards, he held an additional appointment as Principal of the Research Institute for Macromolecular Chemistry (for portrait see Fig. 4.6). Staudinger resigned from his post as Principal of the Chemical Laboratories of the university in April 1951 and accepted the honorary appointment as Head of the State Research Institute for Macromolecular Chemistry, which he held until April 1956.

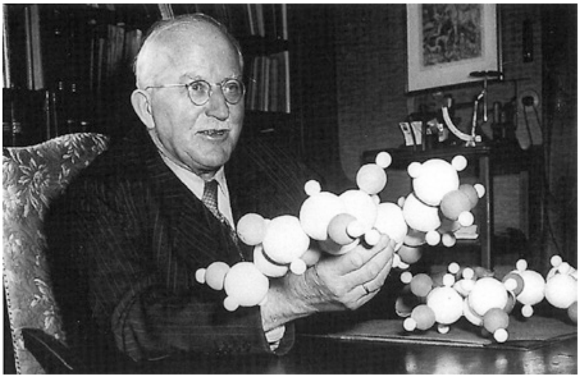

Fig. 4.6 Portrait of Hermann Staudinger (1881–1965). *Photo* Archive of the Gesellschaft Deutscher Chemiker (GDCh), with permission

Staudinger began his research on natural and synthetic polymers in Zurich. In the early 1920s, he published a series of papers on his new theory that polymers were actually covalently bonded molecules of high-molecular weight formed by the linking together of smaller molecules [39, 40]. Whilst Staudinger worked as a synthetic organic chemist, he is also considered the founder of the area of polymer analytics [41]. Before Staudinger's studies, nothing was known about the analytical identification and structure of macromolecular substances. Staudinger demonstrated that macromolecular substances are composed of several thousand of molecular segments, but they are neither aggregates nor colloids. He proved his findings in 1927 by synthesizing polyoxymethylene and by determining molecular masses of the macromolecules [42]. Staudinger coined the terms *macromolecules* and *polystyrol*. Staudinger compared molecular masses of polymers measured viscosimetrically and osmometrically, respectively, and deduced a dependency of their ratio upon the polymerization temperature ("branching of filamentous molecules" [43]). During World War II, Staudinger chose to stay, but he was debarred from professional organizations and denied research funds. After World War II, Staudinger turned to the study of biological macromolecules [44].

For his work, Staudinger received the *Emil-Fischer-Medaille* of the German Chemical Society in 1930, the Cannizzarro Prize of the Reale Accademia Nazionale dei Lincei in Roma in 1933. Many universities around the world honoured his scientific achievements by honorary doctorates. In 1952, he was awarded the *Bundesverdienstkreuz* (Order of Merit) of the Federal Republic of Germany. Staudinger received in 1953 the Nobel Prize in Chemistry for his discoveries in the field of macromolecular chemistry [45]. He was a member and honorary member of many Chemical Societies and the Society of Macromolecular Chemistry in Tokyo. Since 1971, the German Chemical Society (GDCh) regularly awards the *Hermann-Staudinger-Preis* for achievements in the field of polymer chemistry.

Paul Robert Albert Grießbach (born 3 April 1886, Dresden, died 25 December 1970, Wolfen)

Robert Grießbach grew up in a teacher's family. He started his university education in mathematics and science in Leipzig in 1909. After interruption by World War I, he completed in 1920 his dissertation on precipitation equilibria, supervised by Wilhelm Böttger. His industrial carrier began in a laboratory rich in tradition, namely the *Ammoniaklaboratorium* of BASF in Ludwigshafen headed by A. Mittasch. In 1929, he became head of the Inorganic Laboratory in the Farbenfabrik Wolfen, a position he held up to retirement in 1955 [46]. In 1953, he became a part-time Professor at Universität Leipzig, which was changed into a Full Professorship from 1955 up to 1966 (for portrait see Fig. 4.7).

Grießbach is considered the father of commercially available ion exchange resins, which were produced since 1936 under the name "Wofatit" [47]. Extensive research led to a great number of different types of cation and anion exchangers. The results of his basic research of the acid–base behaviour, swelling, porous structure and the thermodynamics and kinetics of the exchange process are summarized in his book *Ionenaustauscher in Theorie und Praxis* (1957) [48]. This

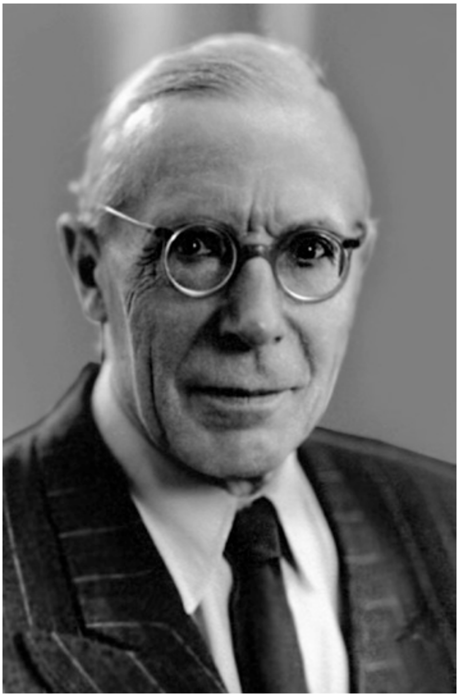

Fig. 4.7 Portrait of Robert Grießbach (1886–1970). *Photo* Ekkehard Grießbach, with permission

book was followed by two specialized volumes, the first on ion exchange chromatography by Dorfner [49] and the second on chelate forming ion exchangers by Hering [50]. Grießbach's results are the fundamental basis for numerous analytical separations, preconcentration and purification processes. He received several governmental prizes and orders and the *Clemens*-*Winkler*-*Medaille* of the East German Chemical Society [51].

Max Boëtius [born 7 December 1889, Tetschen (now Dečin/Czech Republic), died 3 July 1972, Dresden]

After high school in Tetschen, he studied chemistry in Dresden, completed his PhD there in 1922 and worked as assistant in the Institute for Organic Chemistry. His scientific interest was in the microanalytical determinations of carbon and hydrogen. He visited Fritz Pregl in Graz, Austria (Nobel Prize in chemistry in 1923) in order to specialize in quantitative organic microanalysis. Boëtius defended his habilitation thesis in Dresden on the sources of error in microanalysis in 1929 and thus introduced microchemistry as special topic at a German university (for portrait see Fig. 4.8). His book about error sources in the microanalytical determination of carbon and hydrogen became a reference book in the field [52]. His device for the determination of the melting point (*Boëtius*-*Mikroheiztisch*, micro heating stage) was used until recently and kept his name well known.

Boëtius became Supernumerary Extraordinary Professor (corresponds to Assistant Professor) for organic chemistry in 1937, and Extraordinary Professor

Fig. 4.8 Portrait of Max Boëtius (1889–1972). *Photo* University Archive TU Dresden, photograph collection, with permission

(corresponds to Associate Professor) for special areas of organic chemistry—in particular microchemistry in 1941. He became Full Professor of organic chemistry in 1945 and was Head of the institute until his retirement in 1956 [53].

Ludwig August Wilhelm Geilmann [born 16 May 1891, Unterrieden (now part of Witzenhausen/Hesse), died 25 May 1967, Mainz]

After his high school examination in 1911, Wilhelm Geilmann studied chemistry in Göttingen and completed his PhD there in 1914 with a dissertation under supervision of Mannich on the detection of methyl alcohol. Subsequently, but interrupted by World War I, he worked as assistant in the Institute for Agricultural Chemistry. In 1923, he moved to the Institute of Inorganic Chemistry in Hanover and started teaching mineral analysis and soil chemistry after his habilitation in 1924. In 1929, he became Assistant Professor and 1939 Associate Professor. In 1942, he was elected a member of the *Deutsche Akademie der Naturforscher Leopoldina* (now German National Academy of Sciences Leopoldina [54]) in Halle. In 1950, he received a call from Fritz Straßmann, who was a former student of Geilmann, to be Extraordinary Professor for analytical chemistry at the Johannes Gutenberg-Universität Mainz, which was changed into a Personal Full Professorship in 1955 (for portrait see Fig. 4.9). He was retired in 1959 [55]. Geilmann was the first awardee of the Fresenius Medal of the German Chemical Society (1962).

In some twenty publications, Geilmann laid the foundation for the analytical chemistry of rhenium (overview [56]). He introduced sublimation into analytical chemistry [57]. His strong interest in history was expressed in a series of papers extending from *Chemistry in service of cultural history* [58–60] to *Analytical chemistry from the beginning of human culture up to present time* [61]. He dealt

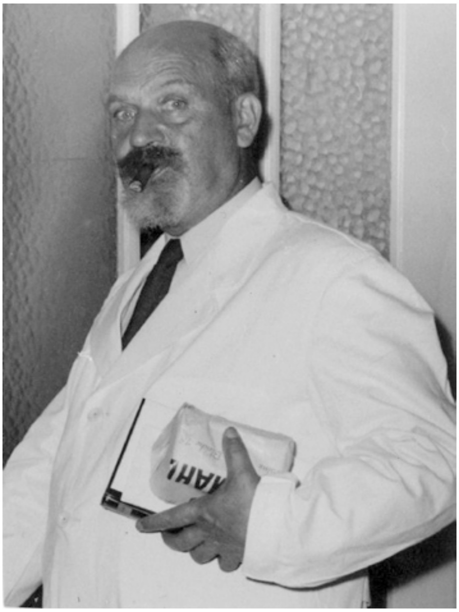

Fig. 4.9 Wilhelm Geilmann on his way to the lecture hall, around 1960. *Photo* Günther Tölg, Dortmund, with permission

with the investigation of historic glasses and other evidence of human technical activities. He tried to answer two questions:

1. What kind of changes was experienced by objects during centuries or even millennia exposed to different soils and atmospheric constituents?
2. Which materials were used by the old craftsmen and how were they handled? [62].

Johann Peter Caspar Arthur Simon [born 25 February 1893, Barmen (now part of Wuppertal), died 5 May 1962, Dresden]

Arthur Simon grew up as son of a merchant. In 1913, he matriculated in chemistry at the Ludwig-Maximilians-Universität München. 1 year later, he was conscripted as an officer into the army. After a slow recovery from a battle injury, he resumed his study at the Georg-August-Universität Göttingen. Under the guidance of Richard Zsigmondy, he completed his PhD on the quantitative determination of antimony (1922). The determination of antimony according to Simon and Neth's method became for many years a standard analytical procedure [63]. Simon worked as assistant in Göttingen, Clausthal and Stuttgart. In Stuttgart, he completed his habilitation thesis in 1927 on oxides and oxide hydrates and became Extraordinary Professor there in 1930. He developed the Simon Müller furnace, which extended the accessible temperature range for thermal analyses to above 2,000 K, and the Simon cryostat (1927 patented). He extended his scientific interest to structural analysis and—together with Josef Goubeau—introduced Raman spectroscopy to German chemistry [64].

Fig. 4.10 Arthur Simon (*left*) celebrating with his disciples Eberhard Steger (*mid*) and Heinrich Kriegsmann (*right*) around 1970. *Photo* Private

Simon declined appointments at the Deutsche Technische Hochschule Prag (1931) and the TH Graz (1932) but accepted the invitation to become the successor of Fritz Förster at the TH (now Technische Universität) Dresden (1932). There he continued his investigations on the constitution of compounds of groups 15–17 of the periodic system. He often found practical application for the results of his investigations.

Simon developed new components for Raman spectrometers to facilitate the use in analytical laboratories (Hg arc, optical filters) [65]. He understood the necessity to use both Raman and IR spectroscopy in structural investigations even before such spectrometers became commercially available. He established one of the best-equipped laboratories for vibrational spectroscopy in Germany, operated by his former students Eberhard Steger and Heinrich Kriegsmann (see Fig. 4.10) [66].

In 1945, when 80 % of the TH Dresden laid in ruins, Simon devoted all his energies and power to the renewal of the educational system. He took offices in the Saxonian government and in the TH Dresden. Simon was member or honorary member of 5 academies and scientific societies. He received orders and medals. In 1958, he was awarded an honorary doctorate (Dr.-Ing. E.h.) by the TH Darmstadt [67] and in 1959, was elected Vice-President of the Saxonian Academy of Sciences [68].

Reinhard MECKE [born 14 July 1895, Stettin (now Szczecin/Poland), died 5 May 1969, Freiburg im Breisgau]

Reinhard Mecke was the son of a chemist. He spent three of his last school years (from 1909 to 1912) in Chicago. Afterwards, he studied physics and mathematics at the universities in Freiburg, Bern and Marburg. He obtained his PhD in

Fig. 4.11 Portrait of Reinhard Mecke (1895–1969). *Photo* Institute for Physical Chemistry, Universität Freiburg, with permission

physics on the topic *Light Scattering Phenomena in Homogeneous Fog*. He joined the physical institute at the Rheinische Friedrich-Wilhelms-Universität Bonn and proceeded to study the field of molecular spectroscopy. Initially, he analysed electron band spectra of diatomic molecules and in 1923 he completed his habilitation thesis. In 1927, he married one of his lady students. Their eight children in due course have continued the scientific tradition of their parents. Mecke was the very first person who accomplished the full analysis of the rotation-vibration spectrum of an asymmetric top molecule [69]. Later, between 1930 and 1950, Mecke developed the concept of valence and deformation vibrations and the basic theoretical concepts for analysing localized CH oscillators (for portrait see Fig. 4.11).

Mecke accepted the position of Extraordinary Professor at the Ruprecht-Karls-Universität Heidelberg (1932). His laboratory was located in the house in which Bunsen and Kirchhoff had discovered spectral analysis in about 1860. In 1937, Mecke became Professor of Theoretical Physics at the Albert-Ludwigs-Universität Freiburg, subsequently in 1942 Ordinarius of Physical Chemistry and director of the Institute for Physical Chemistry. He turned to the field of quantitative spectroscopy and studied the association equilibria of hydroxylic compounds; he determined the CH and OH bond dipole moments, and he tackled problems of quantitative analysis and purity testing. In 1944, the institute was severely damaged by bombs. Mecke continued research work to a limited extent in a small village at the side of Lake Constance. The very first precursor meeting of the later series of EUCMOS congresses (European Congress on Molecular Spectroscopy) took place in Konstanz in 1947.

Mecke was one of the pioneers of molecular spectroscopy. He was apparently the first to introduce a kind of two-dimensional spectroscopy and its analytical application [70]. In addition, he contributed to other fields including measurements of the dielectric constants of compounds forming hydrogen bonds, the formation of ozone in the atmosphere, infrared photography, development and use of an analog computer for the calculation of molecular vibrations and his early gas chromatographic analyses of wines and liquors [71].

In 1958, Mecke established the *Institut für Elektrowerkstoffe* [72] (now Institut für Angewandte Festkörperphysik/Institute for Applied Solid State Physics [73]) of the Fraunhofer Society for Applied Research and promoted research in microwave region and in NMR spectroscopy as well as in solid-state physics.

Mecke retired from his university chair in 1963, and from the directorship of the Fraunhofer-Institut in 1968 [69]. He was a member of the *Deutsche Akademie der Naturforscher Leopoldina*, *Halle* (now German National Academy of Sciences Leopoldina [54]) and was awarded the *Bunsen-Denkmünze* (Bunsen Medal) by the *Deutsche Bunsen-Gesellschaft für Physikalische Chemie*.

Ida Noddack-Tacke [nèe Ida Tacke, born 25 February 1896, Lackhausen (now part of Wesel/North Rhine-Westphalia), died 24 September 1978, Bad Neuenahr, Rhineland-Palatinate]

Ida Tacke grew up as a daughter of a factory owner [74]. In 1915, she matriculated for chemistry at the TH Charlottenburg (now Technische Universität Berlin). She was one of the first women in Germany to study chemistry at university level. After completion of her PhD in Berlin in 1921, she worked for 2 years being the first graduated woman in the German chemical industry. She then obtained a position at the *Physikalisch-Technische Reichsanstalt* (Physical and Technical Institute of the German Reich, now Physikalisch-Technische Bundesanstalt—PTB [75]) in Berlin together with the chemist Walter Noddack, whom she married in 1926 (see Fig. 4.12). They looked for the then unknown elements 43 and 75 of the periodic system. In 1925, they claimed the discovery of the two elements and called them rhenium and masurium (in honour of their respective home regions). Only the discovery of rhenium was confirmed [76].

In 1934, she criticized Fermi's postulation of a production of transuranium elements [77] and for the first time suggested the possibility that "it is conceivable that the nucleus breaks up into several large fragments, which would of course be isotopes of known elements but would not be neighbors of the irradiated element". A few years later this would become known as nuclear fission. In 1939, Otto Hahn and Fritz Straßmann provided the chemical proof for nuclear fission.

Ida Noddack and her husband also investigated the ubiquitous presence of the numerous trace elements in a variety of materials. They identified traces of rare elements in the aquatic fauna and in meteorites. Their postulation of the omnipresence of the chemical elements laid the foundation of trace element chemistry and of cosmochemistry [78]. Between 1932 and 1937, the Noddacks were proposed 10 times for the Nobel Prize but never received it because of the historic situation.

Fig. 4.12 Ida Noddack-Tacke together with her husband Walter Noddack around 1930. *Photo* Archive city of Wesel N 33, photograph 75, with permission

Karl Albert Otto Franz Fischer [born 24 March 1901, Pasing (near Munich), died 16 April 1958, Hamburg]

Karl Fischer's father was a Royal Bavarian artillery officer, who moved to Leipzig after his retirement before the beginning of World War I. Karl Fischer started his chemical education in Leipzig under the supervision of the head of the Analytical Division of the Institute of Physical Chemistry, Wilhelm Böttger, in what was a hard school of qualitative and especially quantitative analysis where an exponentially increasing number of repetitions were required in case of wrong results. Because of his ability to produce exact work, Fischer was employed as a student co-worker in Böttger's private laboratory, where the FIXANAL® reagents for Riedel-de Haën [79] were produced and tested. Fischer intended to start a dissertation in analytical chemistry, but after a personal dispute with Böttger Fischer dealt in his dissertation with the chemistry of rubber under the supervision of Kröger (PhD 1925). In time, Fischer became reconciled with Böttger and worked as university assistant in Leipzig up to 1927 (for portrait see Fig. 4.13). Afterwards, he joined the Edeleanu Company [80] and was worldwide involved in the installation of petrol refining plants, and in 1935, he became the leader of its research laboratories. After World War II, he was for 5 years Professor for Petroleum Chemistry at the University of Maryland, USA. Later, he returned back to Germany to work as head of the DEA Research in Hamburg. In 1958, he died of a heart attack.

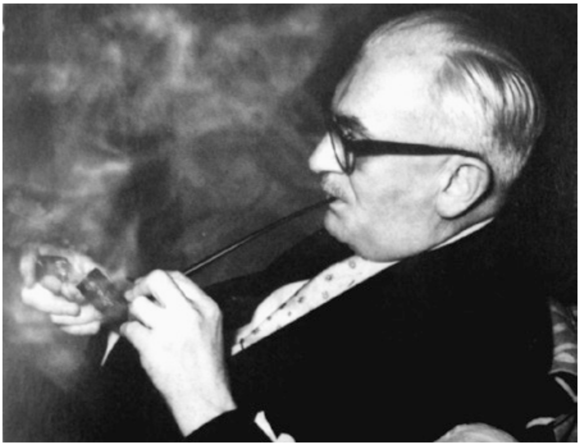

Fig. 4.13 Portrait of Karl Fischer (1901–1958). *Photo* Eugen Scholz, "Karl-Fischer-Titration", Springer-Verlag, Berlin–Heidelberg–New York–Tokio, 1984

His research activities were focused on petrol technology and paraffin analysis. There is only one single publication from him, that on water determination [81], which is now performed half a million times a day worldwide. Fischer had to find a fast method to determine water in liquid sulphur dioxide which was the reason for corrosion during the Edeleanu process. The Karl Fischer Titration is based on the Bunsen reaction between iodine and sulphur dioxide in water. Karl Fischer used this reaction in a non-aqueous solvent containing an excess of sulphur dioxide. Pyridine was used for neutralization of the acid formed in this reaction, because "it was by chance on the shelf" [82]. The titration was originally performed manually but has since been automated. It remains the primary method of water content determination used worldwide by governments, academia and industrial laboratories, including all major chemical manufacturers and petroleum refiners [83]. The method is now in all pharmacopoeias. Fischer held many patents, but none about his titration.

Josef Goubeau (born 31 March 1901, Augsburg, died 18 October 1990, Stuttgart)

Josef Goubeau was son of a pharmacist. After high school in Augsburg, he studied chemistry in Munich and earned his PhD (supervisor: Otto Hönigschmid) in 1926 on the atomic weight of potassium. After 2 years as assistant in Munich, Goubeau moved to Freiburg and worked on Zintl phases. In 1929, he became an assistant at the *Bergakademie* (Academy of Mining, now TU) Clausthal and worked on pseudohalogens. From 1930 on, he used Raman spectroscopy to study bond properties of various inorganic and organic molecules. In 1932, Goubeau first described analytical applications of Raman spectroscopy (isomeric impurity of xylols [84]). In 1935, he accomplished his habilitation thesis on analytical applications of Raman spectroscopy. He became known as pioneer in the application of vibrational spectroscopy in chemistry (for portrait see Fig. 4.14). Soon he was invited to work at the Georg-August-Universität Göttingen as staff assistant (1937), Assistant Professor (1940) and Associate Professor (1943) [85]. In addition to various molecular structures, he especially investigated the analytical

Fig. 4.14 Portrait of Josef Goubeau (1901–1990). *Photo* Otto Mundt, University Stuttgart, Institute of Inorganic Chemistry, with permission

application of the Raman effect and established its usefulness by a wide variety of both qualitative and quantitative examples [86]. He also studied the chemistry of boron, beryllium and silicon, particularly from the standpoint of molecular structure. Goubeau contributed the chapter *Raman spectral analysis* in Böttger's *Physikalische Methoden der analytischen Chemie* [12].

In 1951, Goubeau became Ordinarius Professor and Head of the Laboratory for Inorganic Chemistry at the TH (now Universität) Stuttgart. His important achievements were the calculation of force constants of chemical bonds from their molecular vibrations and the interpretation of force constants with respect to bond orders and the electronegativities of binding partners. The research on the theoretical foundation of bond properties and force constants led to the prediction of compounds with multiple bonds between heavy elements, the synthesis of which was only achieved many years later.

Goubeau retired from his university chair in 1969. He was a member of academies and received the *Alfred-Stock-Gedächtnispreis* by the German Chemical Society (1953). In 1966, he was awarded an honorary PhD by the *Bergakademie* Clausthal (1966) and the Ludwig-Maximilians-Universität München (1986) [87].

Friedrich (Fritz) Wilhelm STRAßMANN (born 22 February 1902, Boppard, died 22 April 1980, Mainz)

Fritz Straßmann was the son of a court official. After school in Düsseldorf (1920), he studied chemistry at the TH (now Gottfried Wilhelm Leibniz Universität) Hannover and earned his PhD (Dr.-Ing.) there in 1929. His PhD work was on the solubility of I_2 in CO_2. After a short time as assistant in Hanover, he accepted a post at the Kaiser-Wilhelm-Institut (KWI) für Chemie in Berlin (1929). Straßmann's expertise in analytical chemistry was employed for working with radioactive isotopes and their application for structure elucidation and for age determination of minerals and stones. His paid post expired at the end of 1932, but he continued his work, unsalaried, at the KWI [88]. In 1934, he declined a job in industry because he did not want to register with the Nazi-controlled German Chemical Society. Otto Hahn and Lise Meitner found an assistantship for him at the KWI at half pay (1934), and from 1935 on a full assistant position. The Friedrich-Wilhelms-Universität (now Humboldt-Universität) Berlin denied him habilitation, which was a prerequisite for academic career, because of his opposition to the Nazi system.

Straßmann's task was the investigations of the products of uranium bombarded by neutrons [89]. Enrico Fermi reported the generation of transuranium elements by neutron bombardment but was unable to identify such elements by chemical means. Hahn and Straßmann succeeded at the end of 1938 in the detection of an artificial radioactive Ba isotope, i.e. they discovered nuclear fission. Lise Meitner and her nephew Otto Frisch provided the physical interpretation of the analytical results (1939). Straßmann continued his investigations of fission products of thorium and uranium as well as on the element 93 until 1946 (for portrait see Fig. 4.15). All his results were continuously published in publicly accessible journals Naturwissenschaften, Zeitschrift für Physik and Abhandlungen der preussischen Akademie der Wissenschaften. After major destruction during bombardment of Berlin, the KWI was relocated in 1944 to Tailfingen (now part of

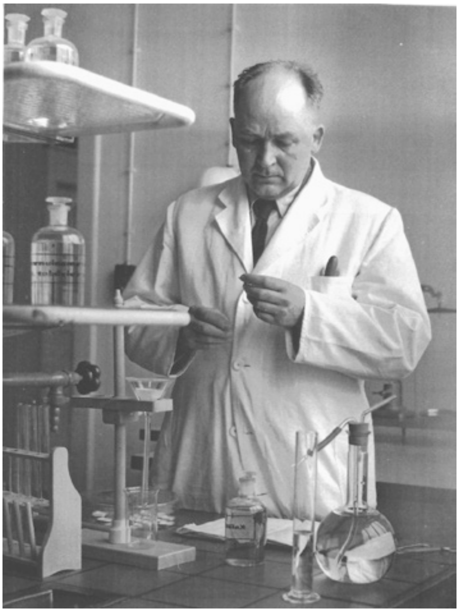

Fig. 4.15 Fritz Straßmann in the Institute for Inorganic and Analytical Chemistry Johann Gutenberg-Universität Mainz, around 1960. *Photo* Chronicle, Universität Mainz, Institute for Nuclear Chemistry, with permission

Albstadt/Baden-Württemberg), which after the defeat of Germany became part of the French zone. Straßmann was assigned the management of the radiochemical department of the remains of KWI. Frédéric Joliot-Curie proposed Mainz as the new site for the radiochemical department of KWI. Straßmann took over most of the responsibilities for the new institute [from 1949: Max-Planck-Institut (MPI) für Chemie]. In addition, from 1946, he held the Chair of the new Institute of Inorganic Chemistry of the Johann Gutenberg-Universität Mainz, without habilitation, which was a great exception at that time. In 1953, Straßmann left the MPI and devoted all his power to the development of the university institute. Straßmann was one of the signatories of the Göttingen Eighteen, a group of leading nuclear researchers who protested against armament with tactical nuclear weapons (1957). Together with Hahn and Meitner he was honoured by President Johnson with the Enrico Fermi Award (1966).

Straßmann acquired a special nuclear reactor for the institute. This reactor was inaugurated in 1967 [90]. It permitted fast chemical determinations, a trademark for Straßmann's institute. In 1972, this institute was split into two, the Institute for Inorganic and Analytical Chemistry and the Institute for Nuclear Chemistry, 2 years after Straßmann's retirement. Straßmann was recognized by the Yad Vashem Holocaust Memorial in 1985, as a Righteous Among the Nations [91].

Werner Reinhold Lothar Fischer [born 21 August 1902, Elberfeld (now part of Wuppertal), died 16 August 2001, Freiburg im Breisgau]

Werner Fischer grew up in an environment dominated by chemistry as son of an engineer at Bayer AG. After school in Cologne, he studied at the Technische Hochschule (now Gottfried Wilhelm Leibniz Universität) Hannover. Under the direction of Wilhelm Biltz, Professor of Inorganic Chemistry, he got the diploma in 1925, the dissertation (1927) on *Affinity of Chlorine and other Halogens to Gold* and his habilitation in 1932. In 1933, he became Extraordinary Professor for Inorganic and Analytical Chemistry at the Albert-Ludwigs-Universität Freiburg [92]. In 1944, he succeeded Biltz as head of the Institute for Inorganic Chemistry in Hanover which he retained until retirement in 1968 (for portrait see Fig. 4.16).

In about 1932, Fischer suggested the term *chalcogens* ("ore formers" from chalcos old Greek for "ore") for the elements O, S, Se and Te [93]. The new term was soon used in publications and so the Committee for the Reform of Inorganic Chemical Nomenclature recommended in 1941 that "the elements oxygen, sulphur, selenium and tellurium may be called chalcogens and their compounds chalcogenides". Fischer took care of the revision of the textbooks by Biltz and Fischer [94], which he edited for several years and improved by own researches [95]. He investigated the elements from the 3rd and 4th analytical group of cations in the classical systematic separation scheme with respect to co-precipitation and introduced new separation steps. He studied the extractability of halides by ethers, ketones and other solvents. Besides the analytical applications, he used this technique for the purification of rare metals such as hafnium and zirconium. In 1937, Werner Fischer was the first author, who published the effective separation of rare earths by liquid–liquid extraction [96]. After World War II, he had to rebuild

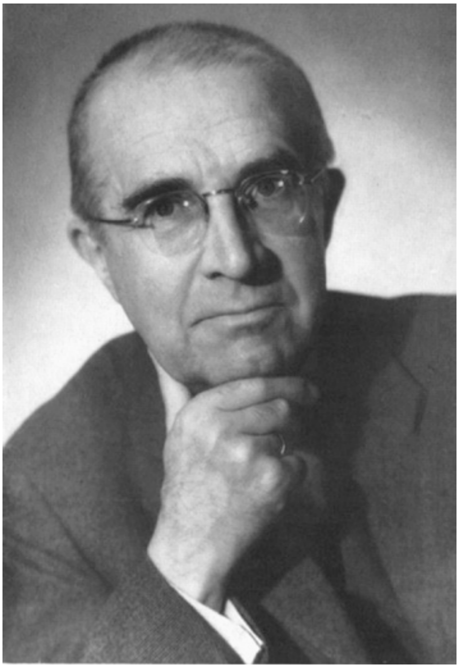

Fig. 4.16 Portrait of Werner Fischer (1902–2001). *Photo* Fresenius Z. Anal. Chem. 190 (1962) 1, with permission

the institute and soon continued his research on rare earth separations by solvent extraction and started in new fields, the fundamentals of chromatography and determination of rare elements [97].

Erwin Lehrer (born 5 July 1904, Reutlingen, died 10 October 1997)

After high school in Reutlingen, he studied physics in Tübingen and completed his PhD there in 1926 and worked as assistant. In 1927, he joined the *I.G. Farbenindustrie AG*, *Werk Oppau* [now *Badische Anilin-und Sodafabrik* (*BASF*) *Ludwigshafen*]. He pioneered the development of analytical recording instruments for chemical processes including data treatment (for portrait see Fig. 4.17). Initially, he worked on ferromagnetism [98] before he developed a sensitive bolometer detector for infrared (IR) radiation [99]. In 1936, he introduced a light chopper to the design of the IR spectrometer [100] and in 1939 the double-beam technique, resulting in the construction of the first fully automated IR double-beam spectrometer [101]. This instrument marks the beginning of systematic spectral analysis, i.e. structural and constitutional analysis [102]. After World War II, this instrument was confiscated by British forces and shipped to the UK, where it disappeared. The double-beam design became standard for all optical spectrometers until the advent of Fourier transform instruments.

The first design of automated IR double-beam spectrometer was not sufficiently rugged for online continuous process analysis. For this reason, Erwin Lehrer together with Karl Friedrich Luft developed in 1938 a non-dispersive instrument

Fig. 4.17 Portrait of Erwin Lehrer (1904–1997). *Photo* BASF Corporate Archive, Ludwigshafen, Rhein, with permission

for chemical process control, the *Ultrarotabsorptionsschreiber* (URAS, infrared absorption recorder) [103]. This instrument was the first online continuous process gas analyzer [104], now known as non-dispersive infrared (NDIR) gas analyzer. Many thousands of this type of analyzers have since been produced and used in the fields of combustion, pollution, medical, automotive, chemical, refining, and more than 100 different gases from ppm to per cent ranges have been measured.

Lehrer also developed an analyzer called Magnos (*Magnetischer* O_2-*Schreiber*, an magnetic O_2 recorder instrument) for the determination of paramagnetic gases (as O_2 or NO) in magnetically inert gases [105]. This principle is used, even today, to survey explosive gas mixtures and combustion processes [106].

In the 1950s, Lehrer developed complete chemical production lines (acetylene process) as well as programmed control and safety systems (high-pressure polyethylene). From 1962 until his retirement in 1969, he was in charge of the production of magnetic tapes. In 1972, he was awarded the *Fresenius-Preis* of the German Chemical Society (GDCh).

Kurt Schwabe (born 29 May 1905, Reichenbach, Vogtland, Saxony, died 4 December 1983, Meinsberg, Saxony)

Kurt Schwabe was the son of a town clerk. After school in Reichenbach in 1924, he studied chemistry at the TH (now Technische Universität) Dresden and earned his PhD (Dr.-Ing.) there in 1928 (supervisor: Erich Müller). After short employment at I.G. Farben, he returned to Dresden and completed his habilitation in 1933. He refused to join the Nationalsozialistischer Deutscher Dozentenbund

Fig. 4.18 Portrait of Kurt Schwabe (1905–1983). *Photo* University Archive TU Dresden, Photograph Collection, with permission

(National Socialist University Teachers' League) and had to leave university. In 1934, he accepted the position as senior chemist in the paper mill of Kübler and Niethammer in Kriebstein, Saxony [107]. In 1939, he became Supernumerary Professor at the TH Dresden. At the same time, he was appointed state advisor for pulp and paper industry. In 1945, he founded the *Forschungsinstitut für chemische Technologie* (Research Institute for Chemical Technology) in Meinsberg [108]. Schwabe was appointed Full Professor for Electrochemistry and Physical Chemistry (for portrait see Fig. 4.18). He headed this institute until his retirement in 1970. Between 1959 and 1969, in addition Schwabe was head of the Institute for Radiochemistry at the *Kernforschungszentrum Rossendorf* (Central Institute for Nuclear Research, now *Helmholtz-Zentrum Dresden-Rossendorf* [109]). After the transformation of the Technische Hochschule (TH) Dresden to the Technische Universität (TU) Dresden in 1961, Schwabe became the first Rector (1961–1965). In 1965, he founded the *Zentralstelle für Korrosionsschutz Dresden* (Central Institute for Corrosion Inhibition) and headed this institute until 1971 [110].

Schwabe pioneered electrochemical sensing. His broad interests in electrochemistry include corrosion and corrosion inhibition, theory of electrolytes, electroanalytical chemistry, in particular in pH measurement [111] and polarography [112]. Already in the 1960s, he investigated the potential of fuel cells [113].

After retirement, Schwabe continued his work at the Meinsberg research institute, at that time an official research laboratory of the TU Dresden. The institute became an independent body in 1980 and is nowadays called *Kurt-Schwabe-Institut für Mess- und Sensortechnik Meinsberg* [108].

Schwabe was President of the Sächsische Akademie der Wissenschaften (Saxonian Academy of Sciences) (1965–1980). In 1971, he was appointed Vice-President of the Academy of Sciences of the GDR. Between 1980 and his death, he was Vice-President of the International Society of Electrochemistry. He received many orders and medals and was awarded four honorary doctorates.

Heinrich Kaiser (born 5 February 1907, Bochum, died 23 August 1976, Dortmund)

He studied physics, mathematics and chemistry in Münster, Freiburg and Cologne and completed his PhD in Cologne in 1932 on the oscillation frequencies in undamped electrical circuits. This provided the background for his later studies on spark-generator excitation in emission spectroscopy [114]. Kaiser worked as assistant to Karl Försterling at the Universität zu Köln and was introduced to spectroscopy [115]. Between 1934 and 1946, he directed the spectrographic laboratories of the Carl Zeiss Company in Jena and Dresden. Together with important parts of the company, Kaiser moved to Oberkochen by forced resettlement before regions of eastern Germany were handed over from USA to Soviet troops. Kaiser soon came to specialize in optical emission spectrochemical analysis, working on the accuracy of spectral analysis. In 1947, he completed his habilitation at Rheinische Friedrich-Wilhelms-Universität Bonn and was appointed to the staff of the newly founded State Institute for Testing Materials in Dortmund (for portrait see Fig. 4.19). He advocated and founded in 1952 the independent *Institut für Spektrochemie und Angewandte Spektroskopie* (Institute for Spectrochemistry and Applied Spectroscopy, now *Leibniz—Institut für*

Fig. 4.19 Portrait of Heinrich Kaiser (1907–1976). *Photo* Leibniz—Institut für Analytische Wissenschaften—ISAS—e.V., with permission

Analytische Wissenschaften—ISAS—e.V. [116]) in Dortmund. Lines of work included atomic spectroscopy, atomic absorption, inorganic analysis, molecular spectroscopy, electronics and general physics, X-ray fluorescence and mass spectrometry. His own particular interests were focused on the theory of errors in quantitative spectrochemical analysis, limits of detection and evaluation of analytical procedures [117, 118]. From 1954, he was an Associate Professor of the Westfälische Wilhelms-Universität Münster until, in 1968, he was nominated a Professor at the newly founded Universität (now TU) Dortmund. He retired from the Directorship of ISAS in 1975, shortly before his death.

Heinrich Kaiser was the Chairman of the IUPAC Commission V.4 on Spectrochemical and other Optical Procedures for Analysis (1965–1969). Under his guidance, it made very notable contributions, particularly in spectrochemical nomenclature [119]. As a member of UNISIST, which was set up by ICSU and UNESCO, he studied the feasibility of a world system of scientific information. He was a member of the Spanish Academy of Sciences (1970), an Honorary Member of GAMS (Paris) as well as of the Society for Analytical Chemistry. Kaiser had received the Hasler Award of the Society for Applied Spectroscopy (1974) [120].

Gerhard Edmund Hesse (born 21 July 1908, Tübingen, died 7 June 1997, Erlangen)

Gerhard Hesse was the son of a Professor of Zoology. He studied at the universities in Bonn and then Munich where he received in 1932 his doctoral degree for a thesis on toad toxins (supervisor Heinrich Wieland [121]) and in 1937, his habilitation on African arrow poisons. In Munich, he also worked as assistant for Otto Hönigschmidt [122]. In 1938, he joined the Philipps-Universität Marburg as a reader and in 1944 became Extraordinary Professor in Freiburg. In 1952, he received a call as Full Professor of Organic Chemistry and director of Institute of Organic Chemistry at the Friedrich-Alexander-Universität Erlangen/Nürnberg. He retired in 1973 but continued for 2 years more till his successor was in post (for portrait see Fig. 4.20).

Gerhard Hesse considered himself primarily to be an organic chemist, who utilized chromatography for solving problems in that field [123]. He was not only a user but contributed many essentials to chromatographic theory and practice. As an early pioneer, he has been said to be the "grandfather of gas chromatography" [124]. In 1942, he was the first who applied an inert carrier gas as mobile phase [125, 126]. He called this method "adsorptive distillation" [127]. The system he described is still valid: an adsorbent in a heated column, a carrier drives the molecules, which will be adsorbed and desorbed many times, a separation occurs because of differences in adsorption, followed by detection of the separated species. About one decade later for this technique, the name gas chromatography was introduced by E. Cremer. Hesse used chromatographic methods in all his investigations. He dealt especially with acid–base properties of the adsorbents and with the water content of eluents in liquid chromatography. With the use of cellulose derivatives, he showed new possibilities for the separation of enantiomers

Fig. 4.20 Portrait of Gerhard Hesse (1908–1997). *Photo* Chromatographia, 46 (1997) 233, with permission

[128, 129]. Gerhard Hesse was very active in popularization of chromatography, writing several books [130–133] and organizing many training courses for large numbers of chemists [134]. In 1972, he received the *Fresenius-Preis* of the German Chemical Society and two different Tswett medals, one in 1975 from the University of Houston and another in 1978 from the Academy of Sciences of the USSR.

Hermann Friedrich Karl Kienitz (born 4 May 1913, Aachen, died 10 October 1979, Weisenheim am Berg)

Hermann Kienitz finished high school in Breslau (now Wrocław/Poland) in 1933 and matriculated in physics and mathematics. After 4 semesters study, he changed to chemistry at the Schlesische Friedrich-Wilhelms-Universität Breslau (now University of Wrocław) and the TH Breslau (now TU Wrocław). He completed his PhD in 1938 at Breslau on complex halogen salts of three-valent rhodium. Between 1939 and 1940, Kienitz worked as assistant at the TH Breslau and began his research for a habilitation on the structure and absorption spectra (UV and VIS) of salts of metal complexes. The work was stopped by his conscription to army service at the end of 1940. In 1942, he was obliged to work as scientific assistant at the IG Farben plant Ludwigshafen to participate in the development of catalysts for the dehydration of gaseous hydrocarbons. In 1944, he became employee of the BASF AG and worked in the oil pyrolysis plant Heydebreck (now Kędzierzyn/Poland). As refugee, he found a position at the Martin-Luther-Universität Halle-Wittenberg but returned to Ludwigshafen shortly before regions of eastern Germany were handed over from USA to Soviet troops (for portrait see Fig. 4.21).

In the *Ammoniaklaboratorium* (Ammonia Laboratory, large unit in the central research of BASF), Kienitz turned to the application of physical and

Fig. 4.21 Portrait of Hermann Kienitz (1913–1979). *Photo* Archive of the Gesellschaft Deutscher Chemiker (GDCh), with permission

physico-chemical techniques in analytical chemistry. He was in charge of the development and the implementation of all gas-analytical tasks in the company. He developed the purity testing of compounds based on precise measurement of their cooling curves. From 1953 on, he headed a group for instrumental analytical chemistry, whose tasks extended from quantitative multicomponent analysis to trace analysis and environmental issues [135]. His interests extended to structure elucidation of organic compounds [136]. He was early in understanding the opportunities of electronic data processing [137], automation in chemical analysis [138] and pointed out the importance of error analysis when examining analytical data [139]. In 1970, he advanced to being the Department Head in the central research board of BASF. He retired in 1977.

Earlier, Kienitz became Honorary Professor for Industrial Analytical Science at the TU München (1969). He always stressed the development of analytical chemistry into an independent chemical sub-discipline with own research and education [140]. He received the *Fresenius-Preis* of the German Chemical Society (1975). He worked as Chairman of the IUPAC Commission “Physico-chemical Measurements and Standards” and many other commissions at national and European levels.

Wilhelm Friedrich Nils Remigius FRESENIUS (born 17 July 1913, Berlin, died 31 July 2004, Wiesbaden)

Wilhelm Fresenius was the great grandson of Carl Remigius Fresenius. After school in Wiesbaden and a short internship at the *Chemisches Laboratorium Fresenius* Wiesbaden (Chemical Laboratories Fresenius Wiesbaden), he studied

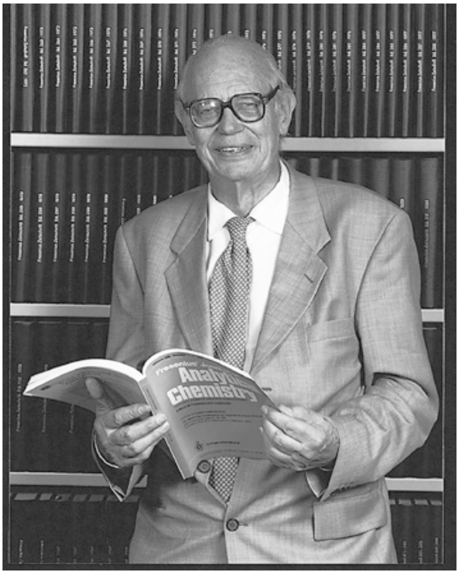

Fig. 4.22 Wilhelm Fresenius in his office in the *Institut Fresenius*. *Photo* Archive of the European University of Applied Sciences Fresenius, with permission

chemistry as had his father, grandfather and great grandfather. His academic training took place in Frankfurt/Main, Munich, and Heidelberg and subsequently in Göttingen, where he obtained his doctorate in 1939 working with A. Eucken on infrared spectroscopy. Following specialization in food chemistry, he obtained his State Examination in Frankfurt/Main in 1943 [141]. In 1945, he became director of the Laboratories on the death of his uncle Remigius Fresenius [142]. He was also Editor-in-Chief of the Fresenius' Zeitschrift für Analytische Chemie [143] (for portrait see Fig. 4.22). The Laboratories needed to be restored after severe war damage, and a new beginning had to be made with the journal after 4 years compulsory suspension and the establishment of a new competitor namely, Analytica Chimica Acta [144]. Following a successful development in 1962, the Laboratories needed to be split into the test laboratory (later: Institut Fresenius) and the chemistry school (later: *Europa Hochschule Fresenius*—European University of Applied Sciences Fresenius—and Vocational Training School) [145], both headed by Wilhelm Fresenius. At the same time, he committed himself to university and science, the church, local politics and business and justice [146].

A particular focus within the broad analytical research of Wilhelm Fresenius was on water, food, air, soil and consumer products. He did not restrict himself to selected groups of organic and inorganic compounds but aimed at the complete characterization from the analyte to the microbiological quality of the complete sample [147]. He developed many procedures for quality improvement, e.g. of food, commodities, drinking and mineral water [148].

Wilhelm Fresenius has been honoured in many ways by medals, memberships and honorary memberships at national and international levels. He served as President or Director for several societies and their divisions.

Kurt Laqua [born 11 May 1919, Trachenberg near Militsch, Silesia (now Żmigród near Milicz/Poland), died 10 April 2013, Munich]

Kurt Laqua was the son of a legal court official. After high school in Neiße, Silesia (now: Nysa/Poland), he served in the military (1937–1945). In 1941, he was allowed to study physics for one semester at the TH Breslau (now TU Wrocław/Poland). After war time captivity, he studied physics in Bonn. He completed his diploma thesis in 1948 (supervisor: Walter Gerlach) and accepted a salaried position at the State Institute for Material Testing in Dortmund. After completion of his PhD on spectral properties of spark discharge (1951, supervisor Heinrich Kaiser), he went for 7 years to the National Physical Research Laboratory of the Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa, finally as Senior Research Officer. In 1958, he returned to become Head of the Department Atomic Spectroscopy at the *Institut für Spektrochemie und Angewandte Spektroskopie* (Institute for Spectrochemistry and Applied Spectroscopy, now Leibniz—Institut für Analytische Wissenschaften—ISAS—e.V.) Dortmund [116] (for portrait see Fig. 4.23). He continued in this office until his retirement in 1984 [149].

Laqua completed his habilitation on the local vaporization from solid surfaces by laser pulses in 1973 and became Supernumerary Professor of Experimental Physics at the Universität Düsseldorf in 1978.

Laqua was one of the most respected atomic spectroscopists worldwide [150]. He made many essential contributions, often at the very start of their development. Initially, his main interests were radiation sources for atomic spectroscopy and multi-element analysis, but he investigated all techniques to be considered for analysis of chemical elements [151]. He thoroughly studied the analytical properties of various sparks and arcs as excitation sources and judged them in terms of sensitivity, limit of detection and precision of the results [152]. He succeeded to use lasers both as sampling tool for elemental analysis and as primary source for atomic absorption measurements. Later, he demonstrated the advantage of employing instruments of high spectral resolution to improve the detection limits

Fig. 4.23 Kurt Laqua as Chairman of the XXIV Colloquium Spectroscopicum Internationale in Garmisch-Partenkirchen in 1985. *Photo* Spectrochimica Acta 64B (2009) 361–362, with permission

even of complex analytes. Laqua successfully combined theoretical developments with practical applications in process control and quality assessments [153].

Laqua was member of editorial boards of the most important international journals of atomic spectroscopy, and he was Vice Chairman of the IUPAC Commission V.4—Spectrochemical and other Optical Procedures for Analysis. In 1985, he was awarded the *Fresenius-Preis* of the German Chemical Society (GDCh) and in 1992 the *Bunsen-Kirchhoff-Preis* of the Division Analytical Chemistry of the GDCh [154].

Hans Paul Josef Massmann (born 11 November 1920, Essen, died 3 December 1982, Essen)

Hans Massmann completed high school in Essen (1939) and matriculated at the Georg-August-Universität Göttingen for physics. He was in 1939 conscripted to army service. After 8 years as prisoner of war (1940–1949), he studied physics in Cologne and completed his PhD there in 1958, working mainly in the field of semiconductor physics. In the same year, he joined the *Institut für Spektrochemie und Angewandte Spektroskopie* (Institute for Spectrochemistry and Applied Spectroscopy, now *Leibniz—Institut für Analytische Wissenschaften—ISAS—e.V.*) Dortmund [116] (for portrait see Fig. 4.24). Until his death, he worked there together with Kurt Laqua in the Department Atomic Spectroscopy. After retirement of Kurt Laqua, he became Head of this group. His research interests covered many aspects of spectrochemical emission analysis, including X-ray spectroscopy, hollow-cathode lamps, spectroscopic techniques for atomic absorption, atomic fluorescence and flame emission [155]. Of particular importance are his contributions to the technique of electrothermal atomization (ETA) in atomic absorption

Fig. 4.24 Portrait of Hans Massmann (1920–1982). *Photo* B. Welz, Florianopolis, Brazil, with permission

spectroscopy [156], inspired by a publication of Boris Vladimirovich L'vov [157]. ETA permitted distinct improvements in ultratrace analysis of clinical, biological and environmental samples. It was his version of electrothermal atomizers, known as the Massmann cuvette which, in its simple, straightforward design revolutionized elemental trace analysis (1965). For these achievements, he received the award *Biochemische Analytik* (1974) and was elected Corresponding Member of the German Society for Clinical Chemistry [155]. In his later work, Hans Massmann investigated the nature and structure of the spectral background within the spectral band pass of the spectrometer in order to improve the accuracy of electrothermal atomization procedures.

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