CHRISTLIEB EHREGOTT GELLERT AND HIS METALLURGIC CHYMISTRY

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Introduction

Christlieb Ehregott Gellert (1713-1795) (Fig. 1) was the first professor of metallurgical chemistry at the Mining Academy in Freiberg on its foundation in 1765. His book *Metallurgic Chymistry* was first published in German in 1751 as *Anfangsgründe der metallurgischen Chemie* (Fig. 2). The book is a little known work although it is of special importance because it was written towards the end of the Age of Alchemy. It was also the first and last book combining chemistry and metallurgy, a course Gellert was giving at the Academy. His successor Wilhelm Lampadius (1772-1842) separated this course into two sections: one for chemistry and one for metallurgy (1). The book, therefore, provides a glimpse at a critical period in the history of chemistry and metallurgy, with use of the alchemist symbols and adherence to the phlogiston theory.

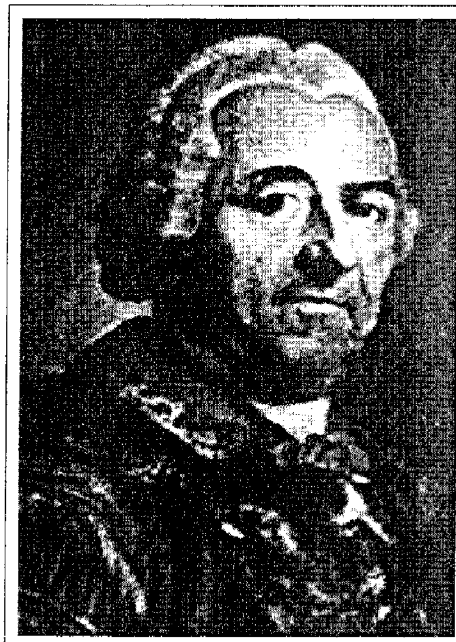

Figure 1. Christlieb Ehregott Gellert (1713-1795)

Gellert was born on August 11, 1713 in Hainichen, a suburb of Freiberg, as the son of the town pastor, and he died May 18, 1795 in Freiberg; he never married (2-5). He studied at Meissen and Leipzig. From 1735 to 1747 he was professor in a secondary school in St. Petersburg (6) and at the same time became associated with the Russian Academy of Sciences. On his return to Freiberg he worked in private metallurgical practice as a consultant to the local smelters. A few years later he started private teaching of metallurgical chemistry at his home to fill the gap created by the death of Johann Friedrich Henckel (1679-1744), who was the first to found in 1735 in Freiberg a private School of Mines (7). Gellert restored to Freiberg its precious fame as a center for teaching metallurgical chemistry, and it became the goal of the local and foreign students. For example, because of his fame as the best metallurgical chemist of his time, the King of Sardinia sent him five students. In 1753 he was appointed Inspector of Mines and Smelters in Saxony, and in 1762 he became Chief Administrator of Foundries and Forges of Freiberg before accepting the teaching position at the newly founded Mining Academy.

In 1746 while in St. Petersburg he translated Cramer's book (8) *Elementa Artis Docimastica* into German as *Anfangsgründe der Probierkunst* (682 pages) and in 1750 wrote his own work *Anfangsgründe der metallurgischen Chemie* and in 1755 another work *Anfangsgründe zur Probierkunst*, both published in Leipzig. Both were translated in 1758 into French by the philosopher Baron Paul-Henri Dietrich d'Holbach (1723-1789) and published in Paris under the title *Chimie métallurgique* in two volumes. Italian translations appeared in 1758 and 1790. Gellert is credited with being the first to realize that the melting point of a mixture of two oxides is lower than that of either oxide taken separately. This is, of course, important in the formation of slags during a smelting process. He also measured the density of alloys and concluded that this was mostly greater than that calculated by the mixture rule.

The metallurgy of gold and silver played an important role in the development of chemistry before the Industrial Revolution. While the action of mercury on gold and the formation of amalgams were known to the Romans, this knowledge was applied for the first time on an industrial scale to recover silver from its ores in Mexico and the Spanish South American colonies in the middle of the sixteenth century. In Europe silver was mainly recovered from sulfide ores by smelting. Interest in the Spanish practice was aroused in Europe as a possibly cheaper technology. The Austrian mineralogist Ignaz von Born (1742-1791) tested this possibility by what became known later as the "chloridizing roasting process (9)." The silver sulfide ore, which is not amenable to direct amalgamation, was first roasted with salt and then slurried with water and mercury to make silver amalgam from which silver could be recovered. The process was improved by Gellert and applied on an industrial scale in a plant near Freiberg, which operated from 1790 to 1857 and produced more than 300 tons of silver.

Gellert's Main Work

Gellert broke the tradition of his time by writing in German instead of Latin. His first book was translated into English in 1766 as *Metallurgic Chymistry* by John Seiferth, apparently at the request of the Royal Society in London (10). The English translation, however, was not printed until ten years later. This is deduced from the first few pages of the book which carry a message "To the President and Members of the Royal Society," dated August 20, 1766, followed by another message "To the Reader," dated June 4, 1776; both messages were signed by the translator. In the introduction, Gellert refers to the sources he used. Although he quotes the names of Becher, Stahl, Henckel, Pott, Marggraf, and Cramer, he does not cite the titles of their works nor any other details. Also in the text (p 375) he refers to Agricola and Schlütter without citing their works (11).

The book is composed of two nearly equal parts: Part I. Theoretical, divided into three sections: The Nature and Objects of Metallurgical Chemistry, Chemical Agents and Instruments, and Chemical Operations. Part II. Practical, containing 97 experiments.

The first division of the Theoretical Part can be compared to modern mineralogy, ore deposits, and properties of metals (very briefly). The second division is a discussion of the four chemical agents: fire, air, water, and earth which are usually and erroneously described in history of chemistry books as the "Four Elements." Gellert clearly states that "fire is the principal agent in the art of chemistry; without its assistance no chemical operation can be performed." Concerning air, he argues


Anfangsgründe
zur
Metallurgischen
Chimie
In einem
theoretischen und practischen Theile
nach einer
in der Natur gegründeten Ordnung
abgefasset
von
C. E. Gellert,
der Kayserl. Academie der Wissenschaften zu St. Petersburg
Mitgliede.
Mit Kupfern.
Leipzig,
bey Johann Wendler, 1751.

Figure 2. Gellert's *Anfangsgründe der metallurgischen Chemie* (1751)

that, "Since no chemical operation may be done without fire, it follows that they can neither be performed without air." He emphasises further that no fire can exist without air, and nobody known could live and grow without air. Gellert states that "Water has that peculiar property of uniting with other bodies and to constitute

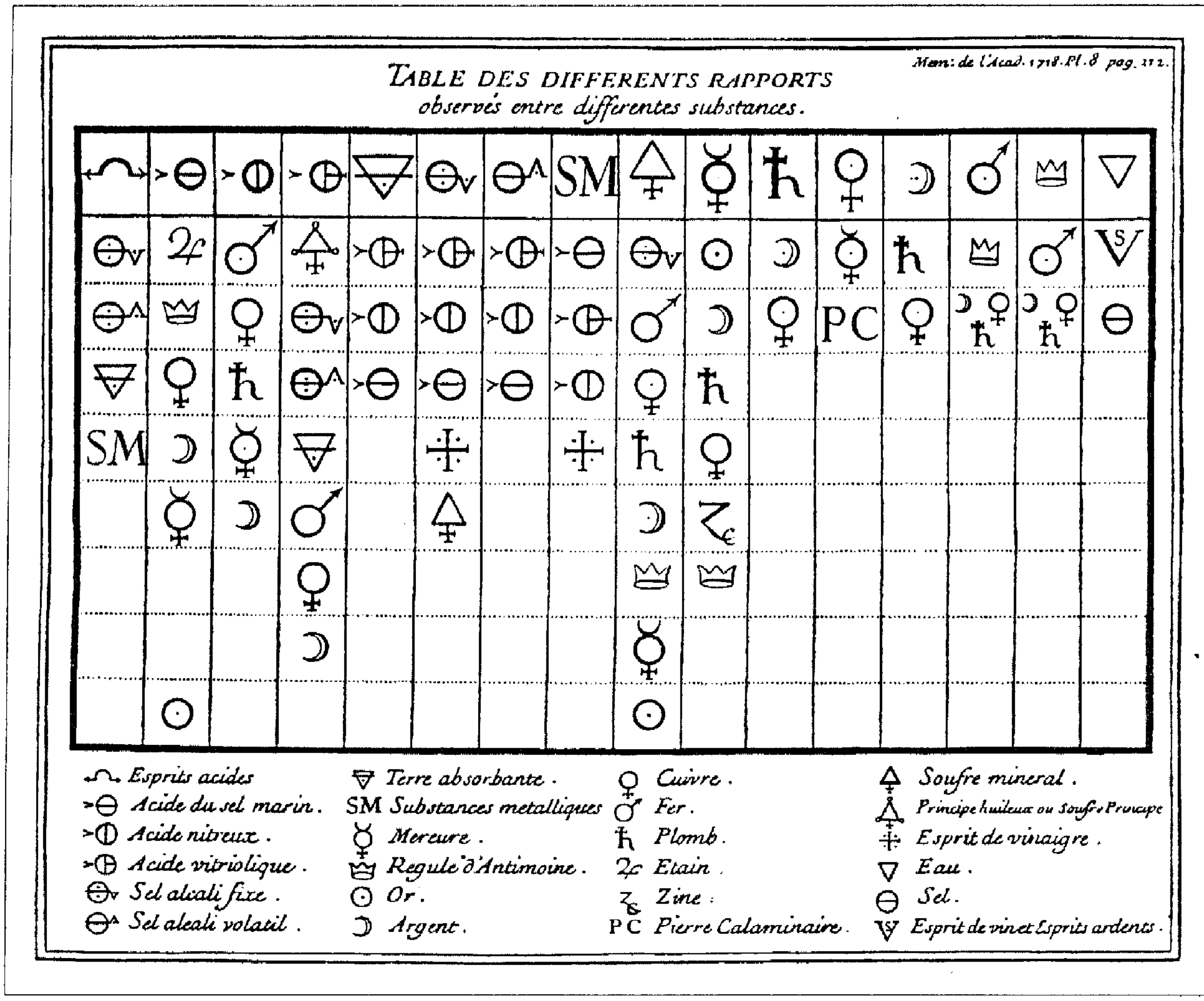

Figure 3. Geoffroy's Affinity Table (1718)

therefore so perfect a mixture…." Further, he defines earth as "a simple, hard, fixed, friable body, not fluxing in the fire, and neither soluble in air nor water, nor spirits of wine, nor in any oil." With these statements Gellert makes sense of the so-called four elements which are usually ascribed to Aristotle but in reality were known earlier to the Persian prophet Zoroaster (660-583 B.C.?) as the four sacred elements (12).

In addition to the four agents, Gellert devotes an appreciable space to "Dissolvent Menstrua." This is a general term which in modern terminology could be equivalent to fluxes, to acids forming aqueous solutions, and to metals forming alloys. Gellert then devotes a chapter to chemical apparatus, mainly furnaces. Here he refers to books by Boerhaave, Cramer, and Ludolph, but without citing the exact works (13). The chapter contains numerous illustrations combined in four charts, one being devoted to laboratory utensils such as the alembic (a distillation flask), and tongs, the other three to furnaces.

Chemical operations discussed in the third division are classified according to the four agents. Thus, operations performed by fire include fusion, roasting, calcination, sublimation, distillation, and evaporation. Those performed by air, are described, such as "solution of metals by the air" (oxidation ?), fermentation, putrefaction, and others. Those performed by water, are washing, elixiviation (leaching), and edulcoration (purification by washing). An operation performed by earth is fixation. In addition, Gellert cites chemical operations performed by means of "Dissolvent Menstrua," which include amalgamation, solution in the dry way like glass making, making of brass, soldering, scorification (formation of slag), reduction of "metalline calces into metal," and "solution in the liquid way." For these operations, Gellert modifies Geoffroy's Affinity Table constructed in 1718 without any reference to his predecessor. Both Tables are shown in Fig. 3 and 4 for comparison. Gellert's Table, with 28 columns and 18 rows, was more elaborate than that of Geoffroy, which was constructed of 16 columns and 9 rows. Gellert placed substances having the least affinity with the substance at the head of a column at the top, the reverse of Geoffroy's order. He included a list of "Chemical Figures", i.e., symbols for fire, air, water, earth, acid, alum, metals, etc. He used few letter symbols in the table: cobalt = K, bismuth = W (for Wismut in German), zinc = X. A calx (oxide) is shown by prefixing C, e.g. CX (calx of zinc), CW (calx of bismuth).

The experiments mentioned in the second part of the book were apparently supposed to be conducted by students. Each experiment has a number, a title, and is divided into two parts: Method and Observation. Sometimes more than one method is described for the same experiment. Although they are written in a systematic way, there was no attempt to group related experiments together. Most of the experiments are inorganic in nature; that is, related to metals, salts, and stones. Among the very few are organic experiments is the preparation of soaps from an oil. The modern reader would classify these experiments approximately as follows: preparation of salts, e.g., ferrous sulfate from pyrite, alum from alum ore, saltpeter from a nitrous earth, etc.; preparation of acids, e.g., sulfuric acid by distillation of ferrous sulfate, nitric acid from saltpeter, hydrochloric acid from common salt, aqua regia, etc.; preparation of alloys; melting of two oxides; dissolving metals in a variety of solutions; dissolving minerals in a variety of solutions; and precipitation of a variety of compounds from aqueous solution.

Chemistry, Metallurgy, and Metallurgical Chemistry

Freiberg, an important mining town, is located 40 km southwest of Dresden. It was the capital of the mining

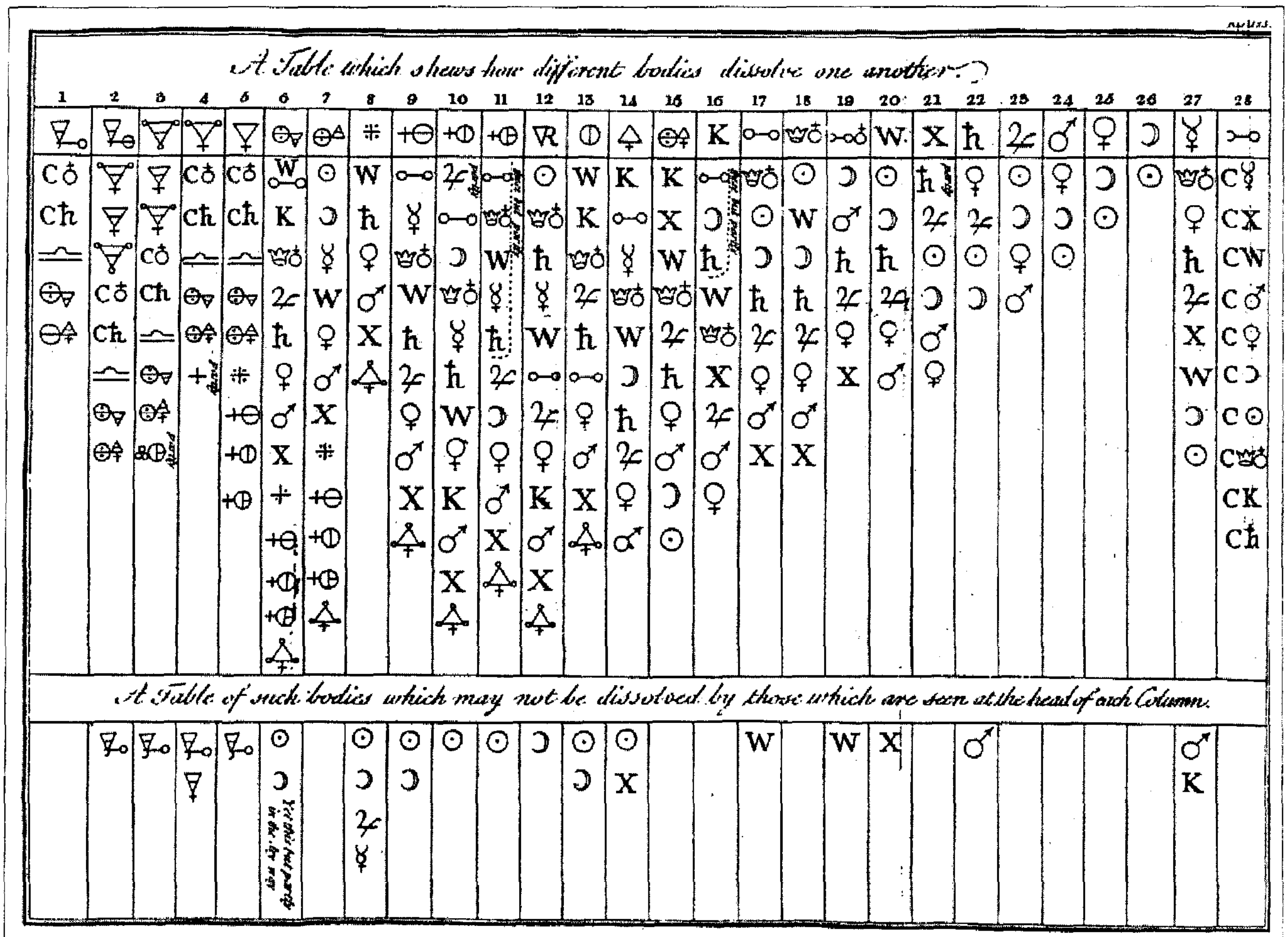

Figure 4. Gellert's Affinity Table (1776)

district of Saxony and the seat of the Mining Academy, which is the oldest school of mines that is still functioning in its original location. It is an ancient imperial city that owes its origin to the discovery of silver mines in its vicinity in the twelfth century. The mining district is known as Erzgebirge or Ore Mountains, the mountain chain that separates the present Czech Republic from Germany. These mining schools played an important role in the advancement of chemistry and metallurgy. Chemistry was taught in mining schools much earlier than in Philosophical Faculties. The Mining School of Potosi in the Spanish colony of Peru already had a chair in chemistry in 1757 (14). Customarily in Europe, chemistry was taught in medical schools, and it was Wolfgang von Goethe, while education adviser to the Grand Duke Carl August the Elector of Jena, who created the first chair of chemistry in the Philosophical Faculty of the University of Jena in 1810. Goethe supplied Johann Friedrich Göttling (1755-1809) with a professorship in chemistry and pharmacy at the University of Jena in 1789 with salary, i.e., before the full chair was founded (15). As early as 1764, pyrometallurgy and fire assaying were taught systematically at the Mining Academy in Schemnitz (16). Pyrometallurgy was known in German as Metallhüttenkunde while fire assaying as Probierkunde, and both were known collectively as Metallurgical Chemistry. Vocational schools for teaching mining, known as Bergschule, were created in the Austrian Empire as early as 1735. With the growing demand for supervisors and government officials, it became necessary to train persons not only in practical arts but in natural sciences, such as chemistry, and general education. As a result, the mining academies were founded in order to equip individuals for higher tasks and larger responsibilities.

Mining and metallurgy were among the most profitable undertakings of the period. This was true especially at Freiberg in Saxony. The silver-bearing lead deposits in the Erzgebirge, discovered about the end of the twelfth century, proved so much richer in silver than the similar ores of the Harz Mountain district, that a mining rush to the Erzgebirge took place. The outcome

Year published	Author	Title	Contents
1530	Agricola	Bermannus	Conversation with a miner and mineralogist
1533	Agricola	De Mensuris et Ponderibus	Greek and Roman weights and measures with some correlation to those used in Saxony
1546	Agricola	De Natura Fossilium	A treatise on minerals
1546	Agricola	De Veteribus et Novis Metallis	Historical and geographical references to the occurrence of metals and mines, and history of mines in Central Europe
1546	Agricola	Retum Metallicarum interpretatio	A collection of about 500 Latin terms in mineralogy and metallurgy with their German equivalent
1546	Agricola	De Orlu et Causis Subterraneorum	Views on geological phenomena
1546	Agricola	De Natura eorum quae Effluunt ex Terra	A short account on substances which flow from the earth, e.g., water, gases, and bitumen
1549	Agricola	De Animantibus Subterraneis	A short work on animals that spent a portion of their life underground (serpents, lizards, etc.)
1550	Agricola	De Precio Metallorum et Monetis	Description of mining, comparison of different coins and their value
1556	Agricola	De Re Metallica	A treatise on prospecting, mining, assaying, beneficiation, smelting, and other topics
1556	Ercker	Probierbüchlein	Assaying
1574	Ercker	Beschreiburg aller-fürnemisten mineralischen Ertz - und Berckwercks - arten	Treatise on mining, ores, and assaying

Table 1. First major books published in Central Europe related to geology, mining, and metallurgy

of this was that by the end of the sixteenth century it was the most highly developed mining district of Europe. The production of metals, especially of gold and silver, was usually a source of important income to the ruling sovereign, no matter upon whose land they were discovered. The practical procedure under this system was to grant to a discoverer the right to work the deposit on payment of a "royalty" to the legal owner of the land. This, in turn, made it necessary for the owner to exercise some supervision over the producer, to ensure he was not being cheated of his rightful dues, either through dishonesty or inefficiency, in the actual operation of the enterprise. Such supervision required a thorough knowledge of mineral technology.

The basic writings or mining, metallurgy, and geology, appearing in Central Europe in the beginning of the sixteenth century, were responsible for transmitting this knowledge for future generations. Among the most important of these books are those by Georgius Agricola (1440-1555) and Lazarus Ercker (1530-1593) (Table 1). Agricola, a medical doctor in Saxony who practiced medicine in the mining district of Joachimsthal, became interested in ores and smelting operations. Ercker, also from Saxony, was the assay master at Dresden and later director of the mint in Kutna Hora in Bohemia. It is no wonder then that many small vocational mining schools were created in Central Europe to teach this art.

There was scarcely any systematic education in other branches of chemistry before 1800. They were generally an adjunct to medicine if they were taught at all at a university. Chemistry was best learned, not in a university but in a pharmacist's shop. Fire assaying, the predecessor of analytical chemistry of today, was taught at the Mining Academy from both a theoretical and experimental standpoint. This method of teaching in Schemnitz was adopted in 1794 in the École des Travaux Publics, later the École Polytechnique in Paris by Antoine François de Fourcroy (1755-1809), who wrote (17):

> La physique et la chimie n'ont été montrées qu'en théorie en France. L'École des mines de Schemnitz en Hongrie nous fournit un exemple frappant de l'utilité de faire exercer ou pratiquer par les élèves les opértions qui font la base de ces sciences utiles. Des laboratoires y sont ouverts et munis des ustensiles et des matériaux nécessaires pour que tous les élèves y répètent dans leurs unions. Le Comité du salut public a pensé qu'il fallait introduire dans l'École des travaux publics cette méthode.

When Justus von Liebig (1803-1873) became Professor of Chemistry at Giessen in 1824, he immediately took steps to offer laboratory instruction in the science in the same way as he himself had received instruction in Paris. Students were first trained in qualitative and quantitative analysis; then prepared organic compounds, and finally carried out a special investigation on a problem suggested by Liebig. The laboratory at Giessen received a great deal of attention and attracted students from many parts of the world.

The teaching staff at the first school of mines contributed greatly to the advancement of mining and geology as well as chemistry and metallurgy. They analyzed and discovered many new minerals, discovered eight metals (Table 2), and created the basic literature in chemistry, metallurgy, mining, and geology. The German and

Year	Metal	Discoverer	School
1783	Tungsten	D' Elhuyar	Vergara, Spain
1797	Beryllium	Vauquelin	Paris
1797	Chromium	Vauquelin	Paris
1789	Uranium	Klaproth	Berlin
1789	Zirconium	Klaproth	Berlin
1801	Vanadium*	del Rio	Mexico City
1863	Indium	Reich and Richter	Freiberg, Saxony
1886	Germanium	Winkler	Freiberg, Saxony

* Independently discovered by Sofstrom at Falun, Sweden in 1830.

Table 2. Metals discovered by teaching staff at the first schools of mines

Austrian professors were particularly prolific. Their writings were influential up to World War I; a serious student must learn German to be able to make use of this vast heritage.

Epilogue

Metallurgical chemistry is the oldest branch of chemistry. Gellert mentioned the seven ancient metals: gold, silver, copper, iron, tin, lead, and mercury, the two new metals, zinc and cobalt, as well as the three metalloids: arsenic, antimony, and bismuth. But, he did not mention platinum although this metal should have already become known in Europe. Metallurgical chemistry became the basis of the emerging branch of metallurgy known today as extractive metallurgy, i.e. the extraction of metals from their ores which can be conveniently divided into three sectors:

Thermal methods: pyrometallurgy, e.g., oxidation, reduction, melting, chlorination, fluorination, etc.

Wet methods: hydrometallurgy, e.g., leaching, filtration, solution purification, ion exchange, solvent extraction, precipitation, etc.

Electrolytic methods: electrometallurgy, e.g., electrowinning and electrorefining, from aqueous solutions and fused salts.

Metallurgical chemistry requires a thorough knowledge of inorganic chemistry, mineralogy, and chemical engineering. The challenge facing extractive metallurgists today is the fact that ores are becoming poorer and poorer while the need is increasing to prepare purer and purer metals. Furthermore, the necessity of avoiding pollution of the environment and of incurring the minimum expenditure of energy during these operations is essential. Hence new chemical reactions are continuously being examined to uncover the most efficient process. Metallurgic Chymistry was the starting point in this direction.

REFERENCES AND NOTES

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2. H-G. Schäfer, in *Neue Deutsche Biographie*, Duncker & Humblot, Berlin, 1964, Vol. 6, 175-176.
3. J. C. Poggendorff, *Biographisch-Literarisches Handwörterbuch zur Geschichte der Exakten Wissenschaften*, Leipzig, 1863.
4. J. A. Partington, *History of Chemistry*, Macmillan, London, 1961. Vol. 2, 709-710.
5. C. Schiffner, *Männer des Metallhüttenwesens*, Verlagsanstalt Ernst Mauckisch, Freiberg, 1942.
6. Saint Petersburg was founded in 1703 by Peter the Great as the capital of Russia. Moscow replaced it as the capital in 1918. Its German name was changed to the Russian Petrograd when Russia entered the war with Germany in 1914. It was named Leningrad in 1924 when Lenin died. Its original name was restored after the fall of the Communist Party in 1991. The Academy of Sciences was founded in 1724 and attracted many foreign scientists, for example the Swiss mathematician Leonhard Euler (1707-1783) with whom Gellert became associated.
7. Henckel was born on August 11, 1679 in Merseburg in Saxony, studied medicine in Leipzig, and practiced his profession in Freiberg for a short time when he became interested in mineralogy, chemistry, and metallurgy. He gave up medical practice in 1732 when he received a contract from the state to look for and evaluate the mineral deposits of Saxony. He published Pyritologia in 1735 in which he discussed smelting processes. In the same year he was given another contract to found a chemical laboratory to teach mineralogy and metallurgy. The laboratory became famous and well attended by many students who came from Sweden, Norway, and Switzerland, as well as from other parts of Germany. He wrote a textbook for his students which was published after his death. It was translated into French in 1756 under the title Introduction à la Minéralogie. It was composed of two parts: the first dealing with minerals and the second with metallurgical chemistry. He died in Freiberg on January 26, 1744.
8. Johann Andreas Cramer (1710-1777) was born in Quedlinburg, studied medicine and chemistry, then turned his attention to assaying. He gave lectures in London and Leyden. In 1739 he published his book Elementa artis docimasticae (second edition, 1744) which was translated into several languages. From 1743-1773 he served as Mining and Smelting Adviser in Braunschweig. During this period he published his three-volume work Anfangsgründe der Metallurgie (1744-1747). He was considered the best assayer of his time and his books were widely used.
9. F. Habashi, "The First International Mineral Processing Congress in 1786," *Bull. Can. Inst. Min. & Met.*, **1996**, *89* (1005), 105-109.
10. Full title: *Metallurgic Chymistry. Being a System of Mineralogy In General, and of all the Arts arising from this Science. To the great Improvement of Manufactures, and the most capital Branches of Trade and Commerce.* Theoretical and Practical Translated from the original

German by J[John] S[eiferth]. A facsimile edition was published in 1998 by Métallurgie Extractive Québec, 800 rue Alain #504, Sainte-Foy, Québec, Canada, G1X 4E7 (ISBN 2-9803247-3-6), with an introduction by Fathi Habashi, available from Laval University Bookstore. Fax (418) 656-2665.

11. The names cited by Gellert are famous chemists who published numerous books on chemistry. Their full names, years of birth and death are only given here: Johann Joachim Becher (1635-1682), Georg Ernst Stahl (1660-1734), Johann Friedrich Henckel (1679-1744), Johann Heinrich Pott (1692-1777), Andreas Sigismund Marggraf (1709-1782), Georgius Agricola (1494-1555), Christopher Andreas Schlütter (?).
12. F. Habashi, "Zoroaster and the Four Elements," *Bull. Hist. Chem.*, in press.
13. Other famous chemists and their books cited by Gellert: Hermann Boerhaave (1668-1738) professor in Leyden, who wrote *Elementa Chemiae* in 1732. His equipment and works are preserved at a museum bearing his name in his home town. Nothing could be found about a chemist named Ludolph. However, Ludolph Ceulen (1539-1610) is cited in Poggendorff as professor of mathematics in Amsterdam and Leyden. For Cramer, see Ref. 8.
14. F. Habashi, "The First Schools of Mines and Their Role in Developing the Mineral and Metallurgical Industries." *Bull. Can. Inst. Min. & Met.*, **1997**, *90* (1015), 103-114; *ibid.*, **1998**, *91* (1016), 96-102; *ibid.*, **1998**, *91* (1017), 96-106.
15. H. Döbling, *Die Chemie in Jena zur Goethezeit*, Jena, 1928, quoted in G. Bugge, *Das Buch der Grossen Chemiker*, Verlag Chemie, Weinheim, Germany, 1961, Vol. 2, 23.
16. The Mining Academy in Schemnitz was founded by Maria Theresa in 1762, at that time a part of the Austrian Empire. The school was closed after the dismantlement of the Empire following the end of World War I. Schemnitz is now known by its Slovak name Banska Stiavnitce.
17. "Physics and chemistry have formerly only been taught from a theoretical basis. The Schemnitz Mining School has illustrated the usefulness of teaching the practical operations which are, after all, the basis of our science. By providing the students with apparatus and chemicals, they are able to reproduce for themselves the phenomena of chemical combination. The Committee for Public Welfare is of the opinion that these methods should be introduced at the École polytechnique." Journal de l'École Polytechnique (1795); Gazette nationale ou Moniteur universal No. 8 Oktidi 8, Vendemiaire; quoted by F. Szabadvary, *History of Analytical* Chemistry, Pergamon Press, Oxford, 1966, 45.

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