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WHAT CAN THE MODERN CHEMIST LEARN FROM THE OLD ALCHEMY?[1]

IT was with very sincere pleasure that I accepted appointment to the non-resident lectureship in chemistry at Cornell for the coming term. I keenly appreciate the honor of the invitation, not only because it gives me opportunity of being a teacher in this famed university, but also, and even more, because of what I can here learn, for it is with us men of science from Europe as it was in the early days with the philosophers of old Greece, a Plato, or a Pythagoras: they journeyed as wise men to Egypt and returned as students of the wisdom of the Egyptian priests.

Indeed, to learn and to work in such an ideal laboratory as the Baker Laboratory of Chemistry is for every chemist, whether old or young, an actual joy. This monumental Temple of Science not only has the best equipment, but a master of the art, the head of the department of chemistry, has furnished it with light and air. A German once has said of the Chemical Laboratory in Munich: "In diesem Hause stinkt es sehr, Dies kommt von Adolf Baeyer her." The Baker Laboratory of Chemistry is exceptional in this regard, it is the most odorless laboratory of the world; it has *no* smell.

The subject which I have chosen for this introductory lecture is, "What can the modern chemist learn from the old alchemy?"

By some this question may be received with astonishment, while others may raise energetic protest. What? We modern chemists, the witnesses and workers of this "Age of Chemistry," can learn something from the old alchemy, full as it was of errors and fantasies! The daily press is constantly announcing the startling results of scientific research: "The riddles of the world are solved!" . . . "The proton has been isolated!" . . . "Atoms have been decomposed!" . . . "The chemical elements have been changed one into another!" . . . "The philosopher's stone has finally been found!" . . . "The transmutation of cheap elements into gold has been accomplished and patented," etc., etc. It almost seems as if we chemists were on the direct road to become God-like and all-powerful, but if we actually were so all-powerful, what would there be left for us to learn, and how could we control the enormous forces which we had developed?

[1] Introductory public lecture by Professor Paul Walden, of the University of Rostock, non-resident lecturer in chemistry at Cornell University.

In the days of the old alchemy there flourished in Italy a poet, Augurelli, who presented in 1518, in hexameter, to Pope Leo X, a work upon the "*Chrysopoeia,*" or the true art of making gold. As a reward the pope presented to this possessor of the Philosopher's Stone an empty purse, since to a man who possesses the secret, nothing is lacking except a purse in which to place and keep the artificially prepared metal. The Past and the Present!

Let the past furnish us a warning against too much phantasy in modern chemistry.

Let us examine with the magnifying glass of time the development of chemistry through separate characteristic periods of the past, in an attempt to see more clearly the relationship between the science of to-day and that of the "good old times" which have largely been forgotten. In this glance backward, we will consider first the old chemists as men and as the so-called "Fathers of Chemistry." Second, the methods of work of the old chemists, experiment or sophistry. Third, the problems and the goal of the old chemistry, and fourth, the purification of matter then and to-day—the purity of matter as a fundamental problem of the chemistry of the future.

I. *The Old Chemists as Men, and as the so-called "Fathers of Chemistry"*

Seven cities once claimed to be the birthplace of the renowned Homer. But while place and time of this gifted poet's birth are veiled in obscurity, his name and writings endure. And so is it with the origin and the name of chemistry. Think of the many terms which were applied to the science—Egyptian, Holy, Hermetic Art, Poiesis, Scientia Alchimiae, etc. And yet the name *Chymia* means nothing further than cast metal, and Chymie, the art of casting metals.[2]

Where was the birthplace of this Chymie? Who were its founders? Some ascribe its origin to Egypt, others to India and China, others, more recently, to Babylon and Assyria. A fourth group of historians find the beginnings of the *science* in classic Hellas, while still others give to the Arabians the credit for the *practical* development of chemistry. And thus we see the mythical Hermes Trismegistos hailed as the seer of magic and chemistry, Empedocles as the father of the theory of the elements, Democritus as the originator of the atomic theory, Geber as the father of alchemy. Paracelsus is honored as the father of iatrochemistry and Masson has recently bestowed upon Robert Boyle the comprehensive title, "The Father of Chemistry."[3] Some of you are also acquainted with the judgment of Wurtz[4]—"La chimie est une science française, elle fut constituée par Lavoisier," and toward the end of the nineteenth century Grimaux[5] stated, "Toute la science moderne n'est que le developpement de l'oeuvre de Lavoisier."

We will not seek to decide which of these pioneers is entitled to the greater credit or whether the striking advances in the beginning of our science are due jointly to Boyle with Becher and Glauber, or to Lavoisier with Stahl, or to Priestley, or Scheele, or to Cavendish. Nor can the development of "toute la chimie moderne" be ascribed to a Dalton or an Avogadro, a Davy, a Berzelius or a Faraday. No single man is entitled to be called the "father of chemistry." And to those who seek to give this title to any single man the terse instruction in the Civil Code of Napoleon might be quoted, "La recherche de la paternité est interdite!" Let us not be so narrow-minded as to attempt to proclaim any one single man as the "father of chemistry," but rather let us regard the development of the science as the product of the combined intellects of the men of all times and of a universal search for the truth.

Let us go back to the time of a Paracelsus and the beginning of iatro-chemistry. Chemistry which up to that time had been primarily directed along metallurgical lines underwent decided change in character: *Man* himself, and his diseases, became the chief subject of chemistry. The physician becomes chemist, and accordingly a benefactor of mankind. The knowledge of the iatro-chemist is sought in all countries and at all of the higher institutions of learning, such as Padua, Bologna, Paris and Montpellier, or Leyden, Basle, Prague, Wittenberg and Leipzig. Many incidents in the history of chemistry witness the noblest sort of competition, the highest degree of internationalism and political tolerance, as well as recognition of individual merit. Take the case of the famous French chemist, the demonstrator of chemistry at the *Jardin des Plantes* in Paris, Nicholas Lefebvre, who in 1664 was called to London to take charge of the laboratory of St. James; or that of Wilhelm Homberg (died 1715), successively German lawyer in Magdeburg, medical student in Padua and student of chemistry under Boyle in London, then doctor of medicine at Wittenberg, personal physician to the Duke of Orleans in Paris, finally becoming a noted chemist and a member of the Paris Academy; or Becher, who was successively professor of medicine at Mayence (1666), then director of the laboratory in Munich, member of the Chamber of Commerce in Vienna, in practice at Haarlem and at last in 1680 in England where he examined the Scottish lead mines and smelting works

[2] Diels, "Antike Technik," 2nd ed, 1920, page 124.

[3] Masson, "Three Centuries of Chemistry," London, 1925, page 574.

[4] Wurtz, Histoire des doctrines chimiques, 1868.

[5] Grimaux, Lavoisier, Paris, 1896, page 128.

and in 1681–1682 visited Cornwall and studied the mines and smelting works . . . "here he suggested several improvements and ameliorations." (Thomson, *History of Chemistry,* Vol. I, p. 247, 1830.)

In the olden times a certain privileged freedom prevailed in the practice of the chemical and medicochemical callings. Knowledge opened the doors to all classes of European culture of that time. This knowledge flowed through the whole world like a liquid. It created a spiritual unity among scholars and paved the way for mutual understanding among the nations and a joint cultural development. Consequently the practical chemist and medical chemist of whatever nation became an international carrier of culture and an apostle of peace.

What about to-day? Must it be so altogether different? If I may be permitted to express my opinion with reference to the creation of the Non-Resident Lectureship here at Cornell, it is this. The value of such an arrangement lies not alone in the scientific and pedagogic activity of the temporary incumbents in their special fields, but further than that, it serves to renew these old and highly ethical forms of reciprocal contacts between scientists in order to create a mutual spiritual atmosphere, and to pave the way for a peaceful cultural development of mankind. From this point of view the step taken by Cornell University may be regarded as historically significant. By this action the great traditions of science become alive again, and we are all moved by the spirit which led Humphry Davy to state publicly one hundred years ago, "Science, like that nature to which it belongs, is neither limited by time nor space; it belongs to the world and is of no country and no age."

II. *The Working Principles of the Old Chemists. Experiment or Sophistry?*

> Thou, youthful seeker after knowledge, investigate and experiment and never desist therefrom, for thou willst harvest fruits a thousand-fold. (Geber)

These were the words of the famous Arabic encyclopedist of the old chemistry, the mythical Geber, some seven hundred years ago. "Labora, Ora et—invenies" . . . did the "adepts" in the monastic cells call out in the middle ages. From among the ranks of the iatro-chemists, we are cautioned at the beginning of the seventeenth century (Crollius, *Basilica Chymica,* 1629), "Alchemy is not attained without work" (that is, experiment).

It is a fact that this uninterrupted work, this indefatigable research has broadened and deepened chemical knowledge. "Desist not therefrom, for thou willst harvest fruits a thousand-fold," so spoke the experienced practician Geber. Are we not struck with awe upon consideration of this old experimental art, which after centuries of endeavor finally succeeded in preparing hydrochloric acid from salt and clay, nitric acid from saltpeter and clay, sulphuric acid from calcined vitriol or alum, and were able with these acids to obtain the key to analysis and synthesis? Think how long these experimental methods took, as compared with the methods of preparation employed in our modern procedure. Only experiment brought the thousand-fold fruits. Very often the latter were not even anticipated by the investigator. They came accidentally. We can, therefore, understand the lesson which Liebig, famous both as a discoverer and experimental artist, gave a hundred years ago. "If one works, one is pretty certain to make discoveries, it makes no difference where one begins."

Any scientific work may lead to a discovery. A pregnant thought. More remarkable, however, are oftentimes the conditions, in particular the mental conditions, under which such a task proceeds. Let us take, for instance, such a divinely gifted discoverer as Sir Humphry Davy (1778–1829). After he had attained world fame, in 1807, by his discovery of alkali electrolysis, it was necessary for him to appear in society more often than he wished. Despite this, he always went to his laboratory after he had returned to his home, where he continued to work until three or four o'clock in the morning. His biography states . . . "His greatest lack was that of time. He was forced to hurry . . . he would put on clean clothes without removing the soiled ones . . . . at times he would have on as many as five shirts and several pairs of socks over one another. He would often arouse astonishment among his friends with the speed at which his corpulence increased and decreased" (Paris). One has often said jokingly that Davy's greatest discovery was Faraday. Faraday, a man who was seldom congenial, wrote of his works (1845), "I am so engrossed in discoveries that I have barely time enough to eat."

There is another, in whom literature and science in unique combination led to great results. Goethe, the famous poet, creator of Faust, was also a great natural scientist. After he had discovered the middle jaw bone in man, *Os intermaxillare,* in 1784, he wrote in a letter, "It has become a delightful avocation for me; I have made an important and pretty anatomical discovery, and I am so happy that my internal organs dance."

Here Goethe has succinctly revealed the psychological principles of work and discovery. It is the joy in the progress in the work which raises one to a high emotional pitch, a rare feeling of happiness; his spiritual exaltation stimulates his physical power, and causes the investigator-discoverer to forget all the usual necessities of the body. This joyful feeling has been experienced by everyone after he has recognized or made certain of a new scientific truth as the result of experiment. It is not the momentary practical value that calls forth the feeling of happiness, but the knowledge that the great Creator and Ruler of the world has revealed to us something which has heretofore been hidden.

One often hears the question: Has this or that scientific observation or discovery any value or use? The history of the development of science and culture has invariably shown that value or use are only relative terms, and are in only partial dependence upon time, place and culture. The answer which the great Benjamin Franklin once gave still holds good to-day. One asked concerning the value of discovery. His answer, as you know, was: "What is the use of a child? It may become a man!"

Thus far I have depicted experiment as the basis for chemical knowledge and advances in chemistry. It is indeed an enlightening fact, perhaps decidedly so at present, to note how in the olden times words of caution were continually expressed condemning the metaphysical and philosophical method in chemistry.

Even Geber about the year 1200 deemed it necessary to advise warningly: "The beginner in science should not despair. If he is looking for knowledge he will find it, however not by the study of books but by investigation of nature" (Geber, *Summa perfectionis,* Chap. 100). Not the study of the works of the Greek and Alexandrian philosophers and pseudo-alchemists, but a direct experimental study of nature itself.

Does it not strike us as somewhat peculiar when in the year 1600 Crollius (*Basilica Chymica*) again differentiates between two types of chemistry and again speaks with words of warning.

"Alchemy is of two kinds, namely, the natural, greatly honored by the children of the art, and, on the other hand, the sophistica or false, greatly despised by these. . . . Consequently, in this subject no one should believe more than that which experience teaches."

Hundreds of years sank away in the sea of eternity. Then did the great Berzelius say at the beginning of the nineteenth century, "chemistry is 99 per cent. manual labor and practice (that is, an art attained by work) and only 1 per cent. theory." Despite this statement, Justus Liebig, then a student, was obliged to listen to a chemical natural philosophy rather than chemistry. About 1840, Liebig criticized this metaphysical era in natural sciences and chemistry by the statement: "The activity and influence of the natural philosophers up to this time was the scourge, the black death of the century," and especially was this true in chemistry. Does not such a statement as that of the natural philosopher, Carus, to the effect that, "the diamond is a pebble which has come to consciousness," sound somewhat strange to our ears? It was the opinion of K. W. G. Kastner (1806) "that iron in combination with hydrogen goes over to carbon," or conversely that "carbon appears as iron upon loss of all hydrogen."

To-day we should regard these chemical definitions as absurd. That these were even acceptable one hundred years ago gives us food for thought, particularly if we examine with a critical eye some of our own modern views. For scientific fads and errors are seen to recur periodically in the development of the science.

The very fact that leading investigators and naturalists had found it necessary to issue warnings from time to time demonstrates the recurrent ascendency of the metaphysical line of thought. We can, therefore, understand why, toward the end of the nineteenth century, Helmholtz recommended to those pursuing the natural sciences "the strict discipline of the inductive method, a faithful adherence to the facts which made the natural sciences great"; why he praised those who were attempting to "remove from the natural sciences all metaphysical frauds and arbitrary hypothesis," and those who were attempting to "make the natural science a more definite and exact expression of the laws governing the facts."

III. *Aims and Tasks of the Old Chemistry*

In medieval times one spoke of chemistry as a "divine" or wonderful *art.* Divine—"because the works of God are of two kinds: The work or course of nature comprises Philosophia; The works and ways of Christ, Theology. In the practice of both of these should all mortals spend their earthly existence." (O. Crollius, *Basilica Chymica,* 1629, p. 71). Paracelsus taught that "Alchemy is the completion of all nature—and that the stomach is the true alchemist," and, that "medicine rested on four pillars, Philosophia, Alchymia, Astronomia and Physica." Without these one could not begin the work of "preparation, separation and true analysis" or "the solution of natural things" (*l.c.,* p. 58). One sees therefore that a great philosophical *Art,* a wide and diversified *knowledge* including all of nature, and a thorough practical *ability* which must be acquired by constant practice, are required.

How and for what purpose shall this divine art be used? Crollius (*l.c.,* p. 247) gives the following answer, "With heartfelt invocation of God and thankful soul this art is to be used for the glory and praise of their Creator, for the benefit of their needy fellowmen, and for the honor of this art, Amen."

We can learn much from this three-century old characterization of chemistry. The purposes and activities of chemistry were not in those days limited to mere technical knowledge. Chemistry was altogether a study and knowledge of nature; its application was service to mankind, in the name and to the glory of God, as the Creator and guide of nature and of the world. The old chemists were imbued with the idea of a kind of divine service or *idyllic* research, and a feeling of security with God.

I made the remark just now that an idealistic searching imbued the old chemists. Many fundamental writings were credited to the old monk, Basilius Valentinus. Is it not remarkable and characteristic of the sixteenth century and the people living at that time, that this monk never lived, and consequently did not himself write these volumes, but that the actual learned author has hidden his identity under this pseudonym?

Does it not make us modern chemists and narrow specialists somewhat retrospective when these, so often misunderstood and ridiculed chemists, so-called alchemists and iatro-chemists, are depicted as veritable romanticists, idealists and moralists. Should we not glean some teachings for our own spiritual guidance from these far past times? Has it not unfortunately become a fact that in our research we have practically lost all connection with nature: that our chemistry is no longer a "natural science"; that it no longer represents a knowledge of nature as a whole, but that it threatens to resolve itself into a host of individual sciences?

Even to-day, looking back but a few years, we can hardly conceive how Joseph Black (1728–1799) could be at the same time a physician, physicist and a great chemist; or how the romanticist of science, Joseph Priestley (1733–1804) could be a theologian, linguist, physicist and a chemical discoverer *par excellence;* or how Jacob Berzelius (1779–1848), physician, could at the same time be a pioneer in mineralogy and a world leader in chemistry; how he could master the applied, analytical, physiological, inorganic, organic and theoretical branches of chemistry in classical style, and how he could unify chemically dead and living nature in its connections and behavior . . . Is it not true that we have become rich, yes very rich, in details, but poorer in "natural science"? Have we not cause for serious concern over the future development of a chemistry, so productive in individual facts, but so unsatisfactory from the point of view of the great ideas in a world of dead and living matter?

Biochemical Aims of the Old Chemists

"La chymie est imitatrice et rivale de la nature, son objet est presque aussi étendu que celui de la nature même; cette partie de la physique est entre les autres ce que la Poësie est entre les autres genres de littérature." Diderot. (Chemistry is the imitator and rival of nature. Its field is almost as wide as that of nature itself; its relation to physics is as that of poetry to the other forms of literature.)

This proud and frequently quoted passage originated amongst the French encyclopedists at the time when the mechanistic view of life in De la Mettrie's "L'homme machine" and in Holbachs' "Système de la Nature" (1770) found its expression.

However, this goal was recognized as that of chemistry many centuries before! Let me quote from several places in an old book.[6]

In order to imitate natural processes "Time, mass and weight . . . are necessary." The alchemists say that they "reverse the orderly processes of nature with their highly developed art, and that they can revert all matter to the *materia prima.*" They, the goldmakers, boasted still further that they, by their art, excel nature, for not only can they restore to life things which have died, but they can also give life and soul to the inanimate, something which nature had not done either because she was not able or did not wish to do so." (p. 38.) Again they claim that "human beings and other living animals can be created in the laboratory with flesh, bone and senses, and can be given a soul," and that they "can generate trees and plants without their natural seeds" (p. 44), that "burned or carbonized wood as well as metallic ashes, which have gone through the smelting fire, can be made to grow, foliate and bear fruit." (p. 43.) This "divine and supernatural art can create power and riches at will. It restores health to the sickly." Concerning those who have reached the senile age, "it transforms the old man into a youth, stronger and more handsome than he originally was." Finally, those who have almost passed into the beyond can, by its power, again regain the strength to live. The preparation in question is called by the alchemists sometimes "quintessence," again "Philosopher's stone," or "potable gold."

Biringuccio thus portrayed the supreme aim of chemistry or alchemy. At what time was the omnipotence of chemistry so heralded? When did this earlier "Age of Chemistry" exist? In the year 1540! Even then the fundamental premises of chemical work were:—time, mass and weight, as well as reversibility

[6] Biringuccio, *Pirotechnia.* Vannoccio Biringuccio (1480–1538) was a famous builder and metal worker of his time in Rome and Florence. His book "Pirotechnia" is a classical text-book of industrial chemistry. It appeared in Venice in 1540 and recently has been translated by Dr. O. Johannsen, 1925, Braunschweig, Vieweg and Son.

of chemical reactions. How similar are the ideals of the past and our present! The *generatio aequivoca* or spontaneous generation, the palingenesis or the regeneration of the dead matter, the question of Homunculus and the rejuvenation of mankind, etc., are these not problems of our own times?

Truly does not Biringuccio speak concerning these problems of the alchemists when he says, "if the claims were really justified, they should not have given their art the name, alchemy, which it now bears, for they could have said that they have God, the creator of all things, locked in a flask."

May I now be permitted to make an excursion into the field of modern medicinal remedies? You all know the meaning of sunlight therapy. You also know the part played in medicine by mineral salts as foods, and as blood and nerve tonics. You have surely heard of the recent curative methods involving the use of acids (acid therapy) some inorganic, others organic. Diseases of the respiratory system, etc., are cured by them. But even dermatology, neurology, ophthalmology, etc., employ substances of this sort. All of these are important problems of modern medicinal science. But why do I mention these things here? Simply to show that for such cases the old chemists, alchemists and iatro-chemists could well be our teachers, were we to study the past of chemistry more thoroughly. Consider the times three centuries ago. It is a proud maxim which held sway at that time

> "In sale et sole existunt omnia."
> (Life depends on salts and sunshine.)

Oswald Crollius,[7] in Wittenberg, recognized as the most influential disciple of Paracelsus, writes in his book *"Basilica Chymica"* (Frankfurt, 1629):

"Not without cause do the ancients say that everything is contained in the sun and in salts" (*l.c.*, p. 184). From this quotation it naturally follows that special powers were ascribed to those acids obtained from sodium chloride or other salts by distillation with clay. Among these were spiritus salis (hydrochloric acid), spiritus salis nitri (red nitric acid containing oxides of nitrogen). On the basis of the experience of Paracelsus, Crollius (*l.c.*, p. 145) recommends the spiritus salis for about twenty diseases both internal and external. Rudolf Glauber, known as an industrial chemist, greatly extended (1650) the list, requiring some five large pages to enumerate all the diseases for which hydrochloric acid in various doses acted as a curative. That was three centuries ago. To-day we state it in another manner and say that the hydrogen ions are vital. "All living nature is regulated by the hydrogen ion concentration. Health and sickness, life and death, are ruled by it," says Arrhenius ("Chemistry and Modern Life," Leipzig (1922, p. 280)).

[7] Oswald Crollius (died 1609) was an outstanding physician (iatro-chemist) who knew what fulminating gold was. He introduced the preparation and the terminology "hornsilver" (luna cornea) for silver chloride, and first prepared tartarus vitriolatus, potassium sulphate, from potassium carbonate and sulphuric acid.

The Transmutation of Metals

Even though Geber, in the 12th and 13th centuries, describes and praises the refinement of metals (Liber de investigatione perfectionis), he differentiates between *imperfection* and *perfection*. The way to go from the first to the second is the "praeparatio." He says "Preparation involves the removal of the superfluous, and the addition of whatever is lacking to bring perfection to an imperfect body" (*l.c.*, Chapt. 2). . . . "This can only be accomplished by application of specially adapted methods and the use of purifying agents." . . . "Experience has guided us to various working processes, such as calcination, sublimation, descension, solution, distillation, coagulation and fixation." (*l.c.*, Chapt. III.) The substances which have been found to be useful in this preparative work include "all sorts of salts, alums, vitriols, as well as glass, borax and related substances, very sharp vinegar and fire" (*l.c.*, Chapt. IV). These are the experimental principles of alchemy. Are these not also the principles which have contributed to the origin and development of our present-day chemical knowledge? Are not the old working methods of seven hundred years ago still employed to-day? And is not the purpose of these operations, these preparative methods, namely, that of the purification of materials, scientifically *correct?* Are not both Analysis and Synthesis represented in this ancient methodology? Are we then not heirs, imitators and developers of these past ages?

We have too often ridiculed and misunderstood the alchemists. Justus von Liebig,[8] was right when he said, "Alchemy has never been anything else than chemistry. It has been done a great injustice by confusing it so constantly with the gold-making arts of the 16th and 17th centuries. Alchemy was *a science*, and it included also all branches of the technical-chemical industry."

Besides the old rules for the refinement of metals by purification, which I have just given, the important chapter on the *transformation of metals* is still intact in the old chemistry. Let me point out incidentally that the theoretical or metaphysical basis for the

[8] Chemische Briefe, 3rd letter.

"possibility" of such a transmutation is founded in Aristotle's philosophy, namely, in the original substance, *prima materia*. We are, however, primarily interested in another side of this subject "transmutation." Were there any facts which would have led then in olden times to conclude that in chemical operations with the metals lead, copper, mercury, silver and gold, such a transformation had taken place? Or, to put it differently, was it not necessary to assume from certain very definite facts that a complete transformation of most metals into gold had taken place, when one considers the status of the chemical methods for separation and preparation of that time?

Again, did the experienced metallurgists and practical chemists of that day really believe in transmutation? The latter question is truly important, the more so, since it has usually been disregarded altogether in passing judgment on the idea of transmutation.

Let me answer immediately and in the *negative*. The real authorities on metallurgical chemistry gave no credence to the possibility of artificial preparation of gold. Two practical chemists may be quoted as witnesses. One is Biringuccio. In his classical work "Pirotechnia," written at the beginning of the 16th century, he not only disavows all possibility of artificial preparation of gold, but he adds, "I would have to regard people as very clever, a sort of terrestrial angels, were I to believe that they could accomplish this." Even though the other witness, the outstanding practitioner, Rudolf Glauber, defended the transmutation idea, he nevertheless writes: "I will not seek to prove, nor could I do so, that he (Paracelsus) made gold and silver in large quantities. . . . I wish only to indicate that it might be possible to do so. How to do so on a large scale I do not know at present, nor am I particularly interested to know." (*Opera Chymica,* I, p. 369, 1658). From this indirect statement we can plainly see that to him transmutation was regarded as *hypothetically* possible, but that practically he had never actually accomplished it and did not regard it as important. For he says in evident disdain of his theoretical proofs, "nor am I particularly interested to know."

But to return to the other question. Were there any reasons which, to a slight degree at least, made it necessary to assume that a transformation to gold had taken place? This question can be answered in the affirmative. We may regard among such facts the finding of *smaller* or *larger traces* of gold during the course of the ordinary metallurgical processes, a fact which was emphasized again and again. Even the great alchemistical scientist, Albertus Magnus (1193–1280) teaches that gold is found in all minerals. Three hundred years later Biringuccio, whom we have already quoted, writes: "there are few metals which do not contain a trace of gold, some more, some less." Glauber even suggests the *reagents themselves* as a source of gold in chemical processes. He obtained gold as a residue after he had dissolved fine silver in aqua fortis, precipitated it with salt water, washed, melted and reduced it to silver, remelted it and then dissolved it again in aqua fortis. Then he inquires, "Where did this gold come from? From the silver, the aqua fortis, or the salt water, the three substances which were used in the reaction?" It was his belief "that the spiritus nitri had carried over some gold which was present in the iron or copper vitriol used in the distillation." (Glauber, *Opera Chymica, I,* p. 112, 1658.) Is not the negative attitude with reference to the sudden appearance of gold in pure silver a remarkable thing about this argument? What could be more logical than for Glauber to assume that a transmutation had taken place, that is, that gold had come into existence? Glauber regards this question or the "possibility" as so improbable that he does not even mention it, but proceeds in a critical experimental way to examine the reagents used in solution and precipitation to ascertain whether they contained gold. The crude nitric acid, prepared by the distillation of saltpeter and vitriol, he regarded as the probable source of the traces of gold found later in the silver, the particles of gold being carried over from the vitriol during the process of distillation.

Two things can be learned from that which has just been presented, first, that the occurrence of small traces of gold in minerals was recognized many hundreds of years ago, secondly, that the elimination and separation of these minute quantities of gold is accomplished with great difficulty, so that gold that was found in the product of a chemical reaction might be mistakenly thought to have been formed in the process. Glauber's insight must be regarded as truly remarkable, and his statement shows that the clever investigators of long ago knew that the gold was not created in the experiment.

Even if these men, learned in their art and in the knowledge of minerals, did not regard the sudden appearance of traces of gold as transmutation, and did not ascribe its origin to other metals, but traced back its source in classical nineteenth century style to minute quantities present in the reagents or apparatus, the theorists were of an altogether different opinion. Their greatest authority, Aristotle, held that metals were formed from the "original substance" and believed in the growth of metals in the earth and from vapors. The alchemists therefore argued that gold could come into existence during chemical processes. For, they added, did not one actually find it in all metals and minerals?

We must admit that we have come to a critical point in our chemical philosophy. Two opposing views are here met with. As long as we adhere to the conception of an element and regard its stability as a law, the transmutation idea will have no place in chemistry. Conversely, as soon as this conception of an element begins to totter, the idea of transmutation will gain in strength. It has been so in the past and is so to-day. Let me speak briefly concerning the future.

What is our attitude and our scientific belief with regard to the transformation of base metals into gold? How long ago was it when, on the basis of our modern theories, the prophecy was made: "If by some agency or other we could only cause mercury to expel an alpha particle (that is, a positively charged helium atom) and a beta particle (a negative electron), the product would be an isotope of gold" (F. Soddy, 1913). Since then (1913) this statement has been often repeated, unfortunately too often, not only by scientists, but also by the press. As a dogma it has already brought confusion in the minds of the laity, and as a new principle it has served the group of contemporary alchemists and pseudo-chemists to resurrect the old idea of transmutation. Are not statements such as the following often made in popular magazines? "The philosopher's stone has been found"—"The dream of the ancient alchemists has been made a reality by modern science." As you know, this idea has reacted upon modern science, but certainly not to the benefit of modern exact research. The much-disputed question concerning the transmutation of mercury into gold, which Miethe claims to have accomplished, has involved, since 1924, not only a whole group of chemists, both theoretical and experimental, but also business-like speculators. And what has been the result? Unfortunately the witty chemist is right in saying, "the gold of Miethe will probably be found to be the gold of the myth." As before, the old way of making gold (earning money) will be the simpler, less expensive and most dependable.

This suggestion by Soddy gives us a picture of how gold might be formed by the degradation of an element of higher atomic number and greater atomic weight. If mercury, which has an atomic weight of 201, can be robbed of an alpha particle which has a weight of 4, the remaining substance would have a weight of 197 and this is the weight of gold. To-day such a suggestion seems scientific to us. But was not the suggestion of Boerhaave brought forward two hundred years ago just as scientific? Silver in his day was represented by the symbol ◡, a corrosive (an acid) by +, gold by ○, and mercury by the symbol ☿. An old English statement (Boerhaave, *New Method of Chemistry,* 1727) runs as follows: "Quicksilver evidently shows gold in the middle or body of it, silver at the top or in the face and a corrosive at the bottom, accordingly all adepts say of mercury that it is gold at heart, whence its heaviness, that its outside is silver, whence its color. . . . And hence that maxim upon mercury: Strip me of my clothes, and turn me inside out, and all the secrets of the world will come forth." There is much food for thought in these words. Is it not peculiar that, just as to-day, mercury played the rôle of mother substance for the artificial preparation of gold? Does not this old symbol of transmutation greatly resemble the modern one? There "the heaviness at heart," here the atomic mass at the center; there the visible properties ("white color") on the outside, here the outer electrons. Does not the one say "Strip me of my clothes," while the other says "remove an alpha and a beta particle"? And do not the two symbols resemble each other furthermore in view of the fact that they have remained nothing but symbols in spite of all experimental efforts? The mode of expression of Boerhaave might well here be used. Not the "clothes" but the "whole skin" would have to be removed!

Let us forget for a few minutes our modern views as scientific aids of a given era. Let us regard as analytical chemists, without any theory, the observations during the bombardment of mercury by electrons and the varying traces of gold coming to light during this treatment. Would it not be more logical to assume that mercury, despite all purification, was still contaminated with minute quantities of gold? If the old chemists were able to detect weighable quantities of impurities, such as a grain of gold by purely chemical means, may not the charge of the electrons be the physical aid, assisting in the separation of the last traces of gold in mercury, and the isolation of quantities to the order of 10^{-8} to 10^{-9} grams? It seems to me that the difference between the past and present lies in the order of magnitude of the applied energy and amount of the impurities which have been separated.

That brings us to the problem of the "*purity of our materials.*" It is a peculiar and striking characteristic of the older alchemists that they seemed to show no curiosity concerning many substances which they observed in the course of their experiments, and made no attempts to investigate them. Thus we find that these old chemists had seen and described the oxides of nitrogen more than seven hundred years ago, had used chlorine in their aqua regia, had obtained sulphur dioxide directly by burning sulphur in air, knew of the formation of hydrogen from iron and sulphuric acid and of its explosibility—yet all these things had to be discovered, that is, identified, recognized and differentiated chemically at the end of the eighteenth century!

IV. *The Problem of "Pure Substances"*

A Berlin physicist, Peter Riess (died in 1883), known for his work in frictional electricity, defines chemistry as the "impure part of physics." Let us assume that such was the relationship between chemistry and physics 75 years ago. The question naturally follows whether the methods or the materials could correctly have been labelled "impure." If we frankly investigate this question, we will find that his charge is justified. Indeed, the problems of purity and methods of purification are of fundamental importance to both pure and applied chemistry. The gradual progressive expansion of qualitative reactions and methods of separation of the individual metallic and gaseous substances did not reach its development until the eighteenth century. Particularly well worked out were the wet analytical methods which soon caused the enrichment of chemistry by 15 new elements. Further differentiation of substances which had heretofore been regarded as homogeneous, by electrochemical and spectroscopic methods in the nineteenth century, is generally known. It is probably not known how many countless substances, now recognized as elemental by every beginner, were regarded as compounds, or how substances later proven to be compounds were considered to be elements. Take the case of uranium, and its oxide, which for fifty years was thought to be the element, or that of titanium nitride, TiN, which was thought to be the free metal.

According to Davy the diamond contained oxygen; phosphorus and sulphur were compounds containing these elements together with oxygen and hydrogen. Berzelius defended the opinion that chlorine contained an element "murium." Nitrogen was a compound according to Davy, and even as late as 1825 Berzelius contended that nitrogen was the suboxide of an element "nitricum." The metals potassium and sodium discovered by Davy were considered by Gay-Lussac and Thenard as compounds of the metal with hydrogen (1808).

If we inquire as to the causes of these erroneous conceptions, the answer is not difficult to find: the undeveloped state of the methods for separation and purification; in other words, the presence of impurities.

If we survey the present, and examine carefully the modern views concerning the nature of the various elements, we will find much in common between the newer and older ideas. The compound nature of the elements was even then a subject for speculation and one which had been repeatedly tested by experiment. The old idea of hydrogen, as a component of all matter, is again accepted in the form of the proton.

Many of our other most modern conceptions find their predecessors in the past. We have already mentioned the fact that Berzelius regarded nitrogen as a compound substance and defended his views very skillfully. That it should be nitrogen, which after just one hundred years should have partially been broken down by Rutherford by bombardment with alpha rays, is a unique phenomenon in the progressive development of our views.

According to Einstein's theory of relativity, a transformation of mass into energy is possible. It has often been said that such a change, as in the case of one atom of nitrogen, would be accompanied by the evolution of an immense quantity of heat which could become economically valuable. According to the well-known Einstein equation, $E = mc^2$ (where E = energy, m = mass, c = speed of light), a quantity of heat equivalent to that obtained by the combustion of 3,000 tons of coal would be obtained by the destruction of one gram of any substance.

More than one hundred years ago Lichtenberg, professor of physics at the University of Göttingen, made the following statement: "If one could only invent some suitable substance to decompose the nitrogen of the air in order to set free its heat, it would be one of the greatest discoveries of economic importance." The reversal of the Einstein equation permits the transformation of energy into mass ($m = E/c^2$). The modern successors of the old alchemists, the hyperchemists and Theosophists, could well maintain from their point of view that this transformation or materialization of energy has long been known to them. It is reported in all earnestness that in the year 1666, at The Hague, in presence of the physician Helvetius, gold made artificially from lead actually gained in weight. Another report concerning an incident in Vienna (1716) states that in the transmutation of copper pennies to silver, there was obtained 125 pounds of silver from 100 pounds of copper.

Concerning the question of the transformation of energy back into matter we can also quote Glauber from his treatise on *"De Auro Potabili."*[9] "It is believable that if we knew a suitable container, we could catch and coagulate in it the rays of the sun as well as the heat from ordinary fire, and thus metals could just as easily be generated on the earth as in the earth." But let us return to our consideration of the historical rôle played in chemistry by "traces" or "impurities." A special volume might be written concerning this influence in the development of chemistry. Think of the part played by catalysts in chemical industry. Consider the vitamins and the most recent experiments of Windaus in physiological chemistry. We will limit ourselves to a few such examples.

Material perception and abstract classification fol-

[9] *Opera Chymica,* II, 328, 1659.

low each other only after long periods of time. Besides the kind of matter the quantity of matter is important in the history of this development. With advanced analytical-chemical procedure, the smallest traces such as accidental, subordinate and minute quantities of a foreign body become sources for the discovery of new elements. Modern industry has learned to value and accumulate these "traces," and to transform them into appreciable quantities. Take the case of tungsten, titanium, selenium, thorium, uranium, radium, helium, germanium, etc. At the same time, this change in practical value of what were once impurities has served to develop the method and sensitivity of their detection and recognition. Thus gold can now be detected in quantities as small as $10^{-8} - 10^{-9}$ grams; helium in amounts as small as 10^{-9} cc (Paneth, 1926); one part of mercury in $1\frac{1}{2}$ million parts of coal tar (Kirby, 1927) and iodine in amounts as minute as 10^{-6} grams can be discovered if present in the soil, plants, meteorites and iron ore, yes, even in steel itself (Fellenberg and Lunde, 1927).

We become contemplative when we find, on the other hand, that even in our purest preparations, using the utmost precautions, such "traces" are still detectable. Let us recall the gold from mercury (Miethe) and the formation of helium from tungsten (Wendt and Irion, 1922). Let us not forget the discovery that quartz vessels hold gases very tenaciously, even after heating for many hours above 1000° C. and being thoroughly exhausted with a pump (W. Biltz and H. Müller, 1927). You all know of the remarkable observations of F. Paneth and his coworkers in 1926–1927, which seemed to indicate the transmutation of hydrogen into helium, with the aid of finely divided palladium. More thorough investigation showed, however, that the asbestos which was used in the apparatus contained helium. Countless other examples could be cited.

We thus see how experimental difficulties which are barely surmountable confront us in the case of such simple and stable substances as the elements. The term "purity" can be applied only to an ideal state, in that this condition is approached asymptotically with our experimental technique as it is at present. What then are we to expect in regard to the purity of compounds, organic and inorganic substances of highly complex nature and by no means stable? How simple—*sit venia verbo*—rather how primitive, are still our customary qualitative tests for purity in this field! One could almost say that we of to-day are scarcely further advanced in the testing of the purity or individuality of complicated compounds than were the old chemists in the testing of the purity of metals. However, the problem of pure, or we may say "ultra-pure" substances has yet other important phases.

As long as we are satisfied to be able to detect the presence of these previously mentioned "traces" of foreign substances in our purest materials, we stand on the firm ground of experimental analytical chemistry. Berzelius held that chemistry consisted of 99 per cent. experiment and one per cent. theory. And we have reason to be proud of being able to detect such a small amount of a gas as 10^{-9} cc, which, in simple illustration, would mean that if this laboratory were a single large box full of air, and we liberated a thimbleful of a rare gas in the building and mixed it thoroughly with the air, we could then detect that gas in a sample of air taken anywhere in the building. But in some cases our modern methods of reasoning suggest an "explanation" for the presence of these minute quantities of matter: we say that they have come into existence by transelementation. Is it not peculiar and psychologically interesting that we, with all our logic and weighty experience, should capitulate so quickly to this new idea? In what other branch of chemistry would we so readily accept so radical a theory? Have we not returned to the reasoning and evidence of the alchemists and those who believed in transmutation, and who believed in transmutation because they wished it?

We are witnesses to-day of a tendency in research against which warnings were once issued. It was Crollius (1629) who three centuries ago pointed out the danger of the *"Sophistica"* or false chemical art. Helmholtz earnestly recommended thirty years ago a cleansing of the natural sciences of all metaphysical, fraudulent deductions. The scientific study of minutest quantities is actually just as characteristic of the present day as is our development of large scale processes in the industries. If we consider the lessons of the past, and take as our guide the natural causes for the occurrence of these minute quantities, are we not justified in asking this question:—Has the so-called destruction of the atom into unweighable quantities of protons and traces of helium, with total exclusion of impurities from the materials and the apparatus, been realized and can it be realized?

In addition to these metaphysical deductions and theoretical conclusions, whose greatest importance is inversely proportional to the smallest traces, there are other questions for the experimental chemist. For example—What are the chemical properties of the "ultra-pure" elements and compounds? In what physical state and in what chemical combination do traces of substances exist, such as gold in mercury, iodine in steel, gas on the surface of quartz, etc? So we pass from the past with its teachings to the future when we say—In addition to our present chemistry a future chemistry or "ultra-pure" substances must arise: not only the physical condition but also the reactions of these "ultra-pure" substances must be investigated. How do these substances react on one another and also in great dilution when present only in traces? Is it not peculiar that matter in the "ultra-pure" state behaves very much like the so-called "unsaturated compounds" as is shown in the behavior of ultra-pure water, the Baker extremely dry bodies, etc.?

And this brings us to the end of our discussion. Can we and should we learn something from the old chemistry, from its masters, its methodology and its aims? I think the answer is "Yes." An individualistic rhythm controls the development of chemistry. People and times change, yet certain ideas and ideals persist forever. True enough they undergo a change in form and value with the course of time, but they live on from generation to generation and act as guides for chemical reasoning and research.

Pascal's words will ever remain true:—"La suite des hommes pendant le cours de tant des siècles doit être considéré comme un même homme qui subsiste toujours et qui apprend continuellement." (The succession of men during the course of many centuries should be considered as one and the same man who exists always and learns continuously.)

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SARAH FRANCES WHITING

AFTER a life characterized by devotion to high ideals and filled with unusual activities, Sarah Frances Whiting, professor emeritus of physics and astronomy at Wellesley College, died on September 12, 1927, at her home in Wilbraham, Massachusetts. She retired in 1916 after forty years of service at Wellesley.

She was born at Wyoming, New York, in 1846. Through her paternal grandmother she was a direct descendant in the ninth generation from Elder Brewster of the *Mayflower*. Her father, the principal of a series of academies which preceded the New York public schools, was not only an excellent classical scholar, but was also well versed in the science of his day. After graduating from Ingham University in Le Roy, New York, Miss Whiting was a teacher there and in Brooklyn for about ten years.

In 1875, when Wellesley College opened its doors to students, Edward C. Pickering, then professor of physics at the Massachusetts Institute of Technology, had established the first students' physical laboratory in America. Mr. Durant, the brilliant founder of Wellesley College, ever alert for new methods of teaching, was greatly attracted by the reports of the students' experiments. He conceived the idea of duplicating the method at his college, but was seriously handicapped because his faculty was to be composed entirely of women. No woman trained in physical experiments could be found, and in no college was such training offered.

Mr. Durant then inquired of Professor Pickering whether it would be possible for him to allow such an appointee to sit as a guest in his classes, since women were not then admitted as regular students. With his wonted courtesy, Professor Pickering agreed and offered to assist in any way towards establishing such a department at Wellesley.

Mr. Durant's quest for the holder of his chair of physics ended when he found Miss Whiting at the Brooklyn Heights Seminary, where, although teaching mathematics and the classics, she had already become fascinated, as she said, with physics and the revelations of the spectroscope.

She went to Wellesley in 1876 to plan and equip the new department of physics. Four times a week in that busy year she sat as a guest in Professor Pickering's classes, and learned from him of his "physical manipulation." Not only did she have to acquire facility in using the instruments, but it rested with her to decide upon those to be purchased for Wellesley, a perplexing problem in those days when all such instruments were made abroad by firms who did not issue catalogues.

She was therefore obliged to visit the physical laboratories of various colleges and institutes, such as Harvard, Yale, Amherst, Bowdoin, Pennsylvania, and see the instruments before ordering. She was always courteously received, although in those early days when the whole idea of a woman's college was so new, there must have been among the staid professors many a "doubting Thomas" who pondered over the question later asked of her by Sir William Crookes in England, "If all the ladies should know so much about spectroscopes, who would attend to the buttons and the breakfasts?"

Her work was varied and onerous during these early years—deciding upon the instruments and putting them together when they came from Germany carefully packed in many detached pieces; lecturing before large classes, for physics was required of all candidates for a degree until 1893; demonstrating and making the experiments go off successfully without assistants until 1885.

But the very novelty of the whole undertaking was most exhilarating. Something was continually being done for the first time.

In the early eighties, Wellesley's good friend, Professor Horsford, of Harvard, offered to install incandescent electric lights in the college library. Alarm was felt among the trustees lest such lights might be