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PROGRESS OF CHEMISTRY AS DEPICTED IN APPARATUS AND LABORATORIES.

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(Abstract.)

From the very earliest times many arts were practiced involving chemical operations, such as working in metals, purification of natural salts for pharmacy, etc., dyeing of cloths and the preparation of pigments, brewing of fermented liquors, etc.; hence we find that long before chemistry became a science, even before it became inoculated with the virus of alchemy, furnaces and apparatus of earthenware, metal and glass, adapted to special work, were in common use.

The important adjuncts to laboratory utensils for the mechanical operations of pulverizing, grinding, sifting, etc., and the use of scales in a general way, date from the very beginnings of human industry; these we disregard in the main and confine our study to apparatus more strictly adapted to chemical operations.

In tracing the progress of chemistry by reviewing the forms and variety of apparatus used at different periods, we do not attempt to establish definitely the date of introduction of a given instrument except in a few instances to be noted in their places. To assign dates to the origin of apparatus that was universally employed before being specifically described is obviously impossible, especially since we shall depend upon drawings to illustrate the subject, and these drawings are commonly far more recent than the apparatus portrayed.

The Egyptians attained great skill in industrial arts at a remote period, and have left records of a most enduring character, pictures cut in their granite tombs and temples. There we see the processes of gold-washing and smelting; the use of blowpipes and of double bellows for intensifying heat, various forms of furnaces, and crucibles having a shape quite similar to those used to-day. Some of these crucibles preserved in the Berlin Museum date from the fifteenth century B. C.

Glass-blowing is a mechanical operation, but the preparation of the glass itself is a chemical process. The skill of the Egyptians in manufacturing glass is depicted on monuments of Thebes and Beni Hassan, and dates at least as far back as 2500 B. C.

Siphons for decanting wine, and on a large scale for draining land, were in use in the fifteenth century B. C. (Wilkinson).

The earliest chemical laboratories of which we have any knowledge are those that were connected with the Egyptian temples. Each temple had its library and its laboratory commonly situated in a definite part of the huge structure; at Edfoo the laboratory leads out of the Prosecus-halls. In these laboratories the priests prepared the incense, oils, and other substances used in the temple services, and on the granite walls were carved the recipes and processes; these are still to be seen by the archæologist.

The Israelites driven out of Egypt carried with them to the promised land knowledge of the technical and artistic skill of their contemporaries, and the Holy Bible contains frequent allusions to industrials arts. Cupellation is plainly described by Jeremiah, metallurgical operations by Job, Ezekiel, and others, and bellows by Jeremiah. This subject, however, I discussed in a paper read to the Academy April 12, 1892.

Geber, the Arabian physician and chemist of the eighth century, wrote very plainly of chemical processes, describing minutely solution, filtration, crystallization, fusion, sublimation, distillation, cupellation, and various kinds of furnaces and apparatus employed in these operations. Geber's works first appeared in a Latin translation from the Arabic at Strassburg, 1529; since then many editions in modern languages have appeared, but the drawings in all those I have seen are obviously of comparatively recent date.

Geber describes in detail the aludel (or sublimatory of glass), the descensory, apparatus for filtration, and the water-bath. This latter instrument, however, is said to have a more remote origin, having been invented by an alchemist named Mary, who is identified with Miriam the sister of Moses ; and the French name *bain-marie* is advanced as proof of this claim.

Perhaps the earliest drawings of strictly chemical apparatus are those in the so-called manuscript of St. Mark, which is a Greek papyrus on the "sacred art," preserved in Venice and recently edited by Berthelot. This embraces among other treatises the *Chrysopoeia of Cleopatra*, which dates from the beginning of the eleventh century. It contains, besides magical symbols, figures of distilling apparatus, the chief being an alembic with two beaks, resting on a furnace.

In manuscript No. 2327 of the Bibliothèque nationale, Paris, which bears the date 1478, are interesting drawings of furnaces, alembics, matrasses, receivers, etc., of glass, earthenware and metal. Some of them are copied from the manuscript of St. Mark. Professor Maspero, the Egyptian explorer reports the discovery by natives of the subterranean laboratory of an alchemist of the sixth or seventh century, at a point not far from Siout. This concealed laboratory contained a bronze furnace, the bronze door of another larger furnace, about fifty vases of bronze provided with beaks, some conical vessels resembling modern sandbaths, vases of alabaster, and gold foil of a low grade valued at over $350. In a corner of the dark chamber lay a heap of black, fatty earth that the workmen seized upon and carried off, saying they would use it to transmute copper ; "whiten" was their expression, but they evidenced a belief that this material was the "powder of projection" capable of changing copper to silver. This was in 1885. The substance on examination proved to be impregnated with some compound of arsenic, which would of course "whiten" copper.

The balance as an instrument of precision reached a high development under the Arabians as early as the twelfth century. The "Book of the Balance of Wisdom," written in the year 515 of the Hegira (1121–1122 A. D.) by al-Khazini describes minutely a water-balance of great ingenuity, and the specific gravity determinations of solids and liquids made by its aid are marvellously accurate. The author also describes a specific gravity flask of a practical make which he calls the "conical instrument of Abu-r-Raihan." This treatise, with its illustrations of the balances and the flask, I analysed in a paper read to the Academy in 1876. (*Am. Chem.*, May, 1876.)

In an interior view of a laboratory of the fifteenth century, by Vriese, very sumptuous appointments are seen ; a lofty room with tiled floor, furnaces on the right under an overhanging hood, an altar on the left before which the alchemist prays on his knees, in the centre a table covered with apparatus, books, and musical instruments, in the foreground an alembic, overhead a lamp swinging from a ceiled roof. The whole indicates wealth and luxury contrasting strongly with later pictures of the laboratories of impoverished alchemists.

The interior of workshops of alchemists of the sixteenth century have been artistically painted by the celebrated Flemish artist David Teniers. Of these interiors I am acquainted with six different styles, having, however, many features in common.

The alchemists, influenced by the atmosphere of mystical associations prevailing in astrology and the black art, affected fanciful names for pieces of apparatus bearing accidental resemblance to objects in nature ; the body of an alembic was a "cucurbit" or gourd ; an alembic-head without a beak was a "blind alembic"; if the beak was joined to the body so as to make a circulatory apparatus, it was a "pelican," owing to its outline resemblance to this bird ; two alembics joined by beaks were "twins"; a flask with a very long neck was a "bolt-head"; a flask with its neck closed before the blowpipe was a "philosophic egg." Again, the cucurbit surmounted by the alembic-head was symbolically called "homo galeatus," a man wearing a helmet.

A special form of furnace much extolled for alchemical operations was an "athanor," deathless, because the fire could be maintained indefinitely. The residuum of any distillation was a "caput mortuum," death's head. A cone-shaped bag for filtering was early known as "Hippocrates' sleeve"; the operating of closing a flask by fusing the neck was applying the "seal of Hermes"; fusing of two metals was their "marriage." A still more extravagant nomenclature was applied to chemical substances themselves, but of these and of the characters employed to designate them I have already addressed the Academy (December 11, 1882, and March 12, 1883). A single example will suffice. Basil Valentine wrote : "The greater the quantity of the eagle opposed to the lion the shorter the combat ; torment the lion until he is weary and desires death. Make as much of eagle until it weeps, collect the tears and the blood of the lion and mix them in the philosophical vase." That is to say : "Dissolve the substance and volatilize it."

In Iheronimus Brunschwick's *Liber de arte distillandi compositis*

(1500) are many coarse woodcuts representing distillations conducted under different planetary aspects ; also a noteworthy interior of a pharmacy of the fifteenth century, the apothecary's assistant busy with a pestle, gallipots on shelves, scales on a hook, and the licence and certificates of the master conspicuously displayed.

The remarkable and abundant illustrations of the operations of mining, treatment of ores by washing and smelting, in George Agricola's *De re metallica* (1556), are too well known to need mention.

The *Alchymia* of Andreas Libau (or Libavius), published at Frankfort in 1595, is conspicuous for accuracy of description and systematic arrangement of topics. He treats in this work of the *Encheria*, or manual operations, and of the *Chymia*, or substances, in separate books. The former he divides into two sections, one dealing with laboratory apparatus, and one with the construction and management of furnaces. He describes and figures an ideal laboratory provided not only with every requisite for chemical experimentation, but also the means of entertaining visitors, including such luxuries as baths, enclosed corridors for exercise in inclement weather, and a well stocked wine-cellar. This work, sometimes called the "First Text-book of Chemistry," contains woodcuts of a great variety of alembics having peculiar forms for special uses ; also a distilling apparatus fitted with an ingenious system of condensers for very volatile liquids. Besides the usual funnels for filtering Libavius describes the now neglected method of filtering by capillary fibres of wool or asbestus ; a process which, however, was known as early as 400 B. C., as I have shown in a paper read to the Academy, October 13, 1879. Filtration was often styled "destillatio per filtrum," and the method just named was known as "destillatio per lacinias ;" it is practically capillary siphoning.

Libavius' sumptuous plans were never realized, but towards the close of the seventeenth century the first public laboratory was opened at Altdorf (near Nuremburg) under Prof. John Moritz Hoffman. In the same year (1683), the first government laboratory was established by Karl XI. at Stockholm; of this the first director was Urban Hjärne.

A woodcut in a work published in 1570 depicts in a very interesting way all the steps in the manufacture of sugar, men chopping the cane, others grinding and pressing it, large cauldrons for boiling the juice, conical moulds in a frame, and the completed sugar-loafs.

Distilling apparatus in great variety is figured in the *Elixir vitæ* of the Italian author Donato d' Eremita, published in

1624. This pharmaceutical work contain nineteen full-page plates engraved with delicate skill.

In Kircher's *Mundus Subterraneus* (1665) are engraved numerous forms of furnaces and stillatories, largely copied from Donato d' Eremita's work.

J. J. Becher, in his account of a "Portable laboratory" (1719), exhibits on a single plate sixty-four different articles, including the following: Crucibles, muffles, cupels or tests, moulds for making cupels and for casting metals, mortars, mills for grinding, bellows, tongs, forceps, a tripod for supporting dishes, a rabbits-foot for brushing powders, a hand screen to protect the face from heat, various vessels of wood, copper, and iron, scales for weighing (three styles), retorts, phials, funnels, bladders, besides an apron, a towel, a linen jacket, an hour-glass, candles and tobacco-pipes!

Straw-rings for supporting round-bottomed vessels are pictured in Lefevre's *Traité* (1669).

The interior of the University laboratory at Utrecht, under the direction of Johann Conrad Barchusen, Professor of Medicine and Chemistry, is neatly figured in his *Pyrosophia*, published 1698. In this, as in others of the period, the prominence given to furnaces reflects the importance attributed to operations by fire.

Physical instruments of chemical application were slower in developing; thermoscopes appeared early in the seventeenth century and thermometers somewhat later.* Torricelli discovered the barometer in 1643, and Pascal tested its utility on the Puy-de-Dôme five years later.

Otto de Guericke's air-pump and frictional electric machine, together with the interesting experiments conducted with the Magdeburg hemispheres are handsomely depicted in his celebrated treatise *De vacuo spatio*, published in 1672. This air-pump and the hemispheres are preserved in the Royal Library, Berlin. The Hon. Robert Boyle improved Guericke's air-pump in 1659, and used it in laying the foundations of pneumatic chemistry, a field that from this time occupies our attention almost exclusively. Boyle's air-pump and accessory apparatus are figured in plates accompanying the several editions of his works.

As is well known the earlier chemists paid little or no attention to gases though they were familiar with processes which

*Geber remarks that "Fire is not a thing which can be measured, therefore it happens that error is often committed in it." He evidently felt the need of thermometers.

generated them ; perhaps the study of gases was retarded by lack of inventive skill in handling them. Dr. Beddoes writing of Mayow, and reflecting on this point, uses the following language : "To be sensible of the merit of these contrivances of Mayow, we have only to recollect how difficult it must have appeared to confine, divide, remove from vessel to vessel, examine and manage at pleasure fugitive, incoercible and impalpable fluids like that which we breathe."

In 1672 Boyle obtained hydrogen gas by the action of acids on iron filings, and showed its combustibility, but seems to have made no attempt to collect and examine the gas.

The first scientific experiments in pneumatic chemistry were made by John Mayow, an Oxford physician, born in 1645 and died at the age of 34 years. In 1669 he published a work entitled *De sal-nitro et spiritu nitro-aëreo*, in which he figures his apparatus and describes his methods. To confine and study any gas, the air, for example, he inverted a cucurbit in a pan of water, used a siphon to establish the level of the water within and without, and introduced a shelf into the wider part of the cucurbit, from which he hung substances whose action he examined. He used a burning glass to ignite substances, camphor for example, placed in the cucurbit ; he also introduced a mouse in a cage supported on a tripod under the cucurbit. He adopted an ingenious plan for transfering gases from one vessel to another, shown in the engraving that accompanies his rare treatises. Mayow failed to distinguish different gases, but was the pioneer in the method of manipulating them. Of his anticipating later theories of combustion we make mere mention, as our theme excludes theory.

Mayow's contrivances were somewhat improved by the eminent English botanist, Rev. Dr. Stephen Hales. In his "Vegetable Statics" (1727) he describes an attempt to analyse the air with many ingenious devices. Hales heated substances in a retort communicating by means of a siphon with a receiver consisting of a flask inverted in a vessel of water, the flask being supported by a cord from above. He heated nitre in this way, and especially noted the permancy of the air obtained, but failed to examine the properties of the air ; and he failed to differentiate the several gases obtained by his methods.

Even before Hales, however, an obscure physician in France, Moitrel d'Élément, had invented improved methods of handling gases. In 1719 he published a little pamphlet containing lucid instructions for measuring and collecting gases ; especially noteworthy is the separation of generator and receiver first suggested by him. The poor physician's skill was unnoticed by his contemporaries. In his old age a benevolent person took him to America where he died unhonored and unsung.

In 1757 Professor Joseph Black, of Scotland, determined the true characteristics of "fixed air," but seems to have made no important addition to the apparatus for studying gases.

In 1767 Mr. Peter Woulfe published a paper in the Philos. Trans. describing an improved apparatus for condensing vapors without loss and applied it to hydrochloric acid, ammonia, nitric acid, and other substances obtained by distillation. The apparatus still bears his name.

The prodigious advance made by Dr. Joseph Priestley in the manipulation of gases won for him the appellation: "Father of Pneumatic Chemistry." His prime invention was the insertion of a shelf into the vessel containing water, and the perforation of this shelf so as to admit of the gases ascending into receivers standing thereupon. This pneumatic trough is not mentioned by Priestley in his first chemical paper, published in 1772, entitled "Directions for Impregnating Water with Fixed Air." In this tract the accompanying figures illustrate his method of collecting the gases. A bottle for generating the carbonic acid, to the mouth of which is attached a bladder, and this in turn communicates with an inverted jar by a flexible "leather pipe sewn with waxed thread" and having quills thrust in both ends to keep them open. This simple apparatus was the forerunner of the modern soda-water machines.

In the first edition of Vol. I. of Priestley's "Experiments and Observations on Different Kind of Air," published two years later than the little treatise above noticed, the author modestly says "my apparatus for experiments on air is in fact nothing more than the apparatus of Dr. Hales, Dr. Brownrigg, and Mr. Cavendish, diversified and made a little more simple." He then describes the pneumatic trough, both for water and for quicksilver, the method of pouring air upward under water, the process of generating gases by heating substances in a gunbarrel, by aid of a burning glass in thin phials filled with quicksilver, and the way to pass an electric spark through gases in a jar over water or over quicksilver. This introductory chapter clearly shows the greatest progress in the manipulation of gases, and the way in which Priestley energetically applied his skill by the discovery of nine gases is well known to every student.

After the disastrous riots in Birmingham, July, 1791, in which Priestley's house and laboratory were wholly destroyed by an angry mob, an inventory was taken of Priestley's laboratory as a basis for damages. This inventory has been preserved and affords detailed knowledge of the material resources of the chemists of the period. It is divided into groups, philosophical instruments, electrical, optical, mathematical and chemical apparatus, with a small stock of substances, the whole footing up to the value of £605. The imperfections of some of the apparatus used by Priestley are shown by the fact that he experimented from December, 1782, to May, 1783, on the direct conversion of water into air by distillation only without the intervention of any other substance, to discover after all that this astonishing result was due solely to leaks in the porous earthen retorts employed in the process. The retorts, as well as other articles had been supplied gratis by Joseph Wedgwood; and Priestley, writing for more, desired to have them glazed within and without. (Scientific Correspondence of Priestley. New York, 1892.)

Scheele, the poor apothecary in a little village of remote Sweden, had to contend with obstacles sufficient to crush any but the bravest heart. With a few bottles, bladders, common dishes, and the simple appliances of a primitive pharmacy, this man of expedients accomplished wonders. Scheele's apparatus for generating oxygen was a simple retort, to the neck of which he tied a bladder. He was not acquainted with the pneumatic trough at the time of his chief discoveries. (Scheele's "Air and Fire," London, 1780.)

In 1796 James Watt, the English engineer, published an account of a simplified "Pneumatic Apparatus for Preparing Factitious Airs." In this is figured an "air-holder" made of tin-plate japanned inside and out, into which gas is conducted from the generating retort in a furnace, by means of a metallic tube bent at an angle of 45°, and terminating in the air-holder. Watt lays great stress on the advantages of inclining the "lower pipe," as stated, through Hales certainly anticipated him in this point. This pneumatic apparatus was manufactured by Boulton and Watt, at Soho, in two forms ; a large size sold for £10 2s. 6d, including auxiliary articles, and a portable apparatus for £3 15s. The pamphlet states that this apparatus are especially adapted for procuring "hydrocarbonate and oxygen air."

Meanwhile, across the Channel, in Paris, the opulent physicist and chemist, the unfortunate Lavoisier, enjoyed the advantages of highly specialized and admirably constructed apparatus of every description. An inspection of the plates in the *Traité élémentaire de chimie*" (1798) shows what a wealth of excellent utensils he had at his command. Two sketches by the pencil of Mme. Lavoisier introduce us into his laboratory while he is conducting experiments in the respiration of a man at work, and of a man in repose. After Lavoisier's legalized murder, an inventory of his laboratory was made by a government commission, among whom was the distinguished Nicholas Leblanc.

Accurate balances now became most important adjuncts to chemical laboratories.

Towards the close of the last century Italy contributed to chemical research two inventions of marvellous power—the Galvanic trough and the Voltaic pile, destined to electrify material human progress.

To sketch the development of chemical apparatus in this century would prolong this superficial review unnecessarily; modern appliances are distinguished by careful adaptation of the means to the end, and are improved by the introduction of coal-gas for heating purposes, by the use of india-rubber tubing and platinum vessels, and by the delicate products of the glass blowers' skill. To these features may be added novel contrivances for analytical chemistry, a field too recent to require elucidation.

[The paper was illustrated with 80 lantern views of the apparatus and laboratories described, including also exterior and interior views of the following institutions: Laboratories of the Museum in Paris, of Strassburg University, Bonn University, College of New Jersey, Kent Laboratory of Yale University, University of Michigan, Lehigh University, Cornell University, College of the City of New York, Woman's Medical College of the New York Infirmary, and School of Mines, Columbia College.