AN ILLUSTRATED HISTORY OF ALCHEMY AND EARLY CHEMISTRY

SPLENDOR SOLIS

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I. Prehistoric Times

To tell the story of chemistry, it is best to start in prehistoric times with primitive humans. In his quest for survival, and endowed with a natural curiosity, primitive man learned much about his environment. He was aware of physical properties of substances such as color, shape or form, hardness, taste, weight, density in the form of relative weight, and odor. And he was most probably aware of natural physical changes such as water to ice (and vice versa), lava to rock, certain rocks to dust, etc.

It is also safe to assume that primitive man, although he had no knowledge of chemistry, was aware of chemical change in the forms of decaying organic matter, natural production of ozone from lightning (by noting the odor of the ozone), wood burning into charcoal and ash, etc.

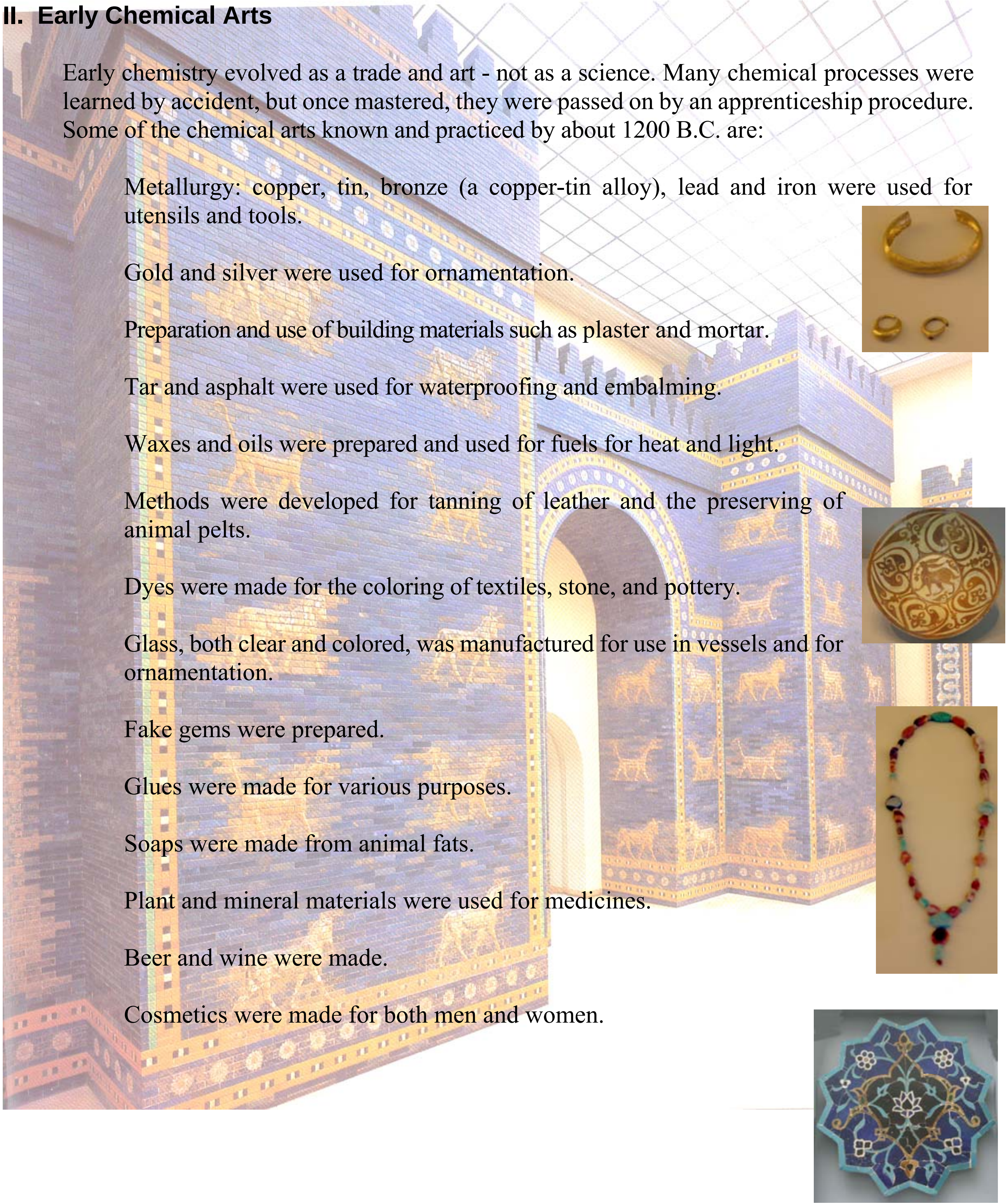
But primitive man was by no means any sort of scientist and he made no logical or organized study of natural phenomena. The information he gathered about the world was passed from generation to generation by memory, demonstration, or by observation without explanation or any understanding of the true reasons for these phenomena. Most probably, much of these happenings were attributed to higher powers, thus laying the early foundations of religion and superstition.

Early cave drawing. From the Hitite Museum, Cappadoccia, Turkey

Primitive man's early encounters with fire were probably through atmospheric (lightning) or volcanic (fiery eruptions and/or lava) sources. Initially, in these first encounters, man was probably afraid and reacted as such, but, later, he learned to tend fire and to use it to keep warm, cook meat, and probably perform some physical and chemical changes with common materials.

Eventually, primitive man learned how build different types of fires and to use fire as a tool to produce many chemical changes deliberately. Over time, through trial and error, he learned how to make pottery from clay, make building materials, make glass, and to separate metals from their ores. First men worked with the less active metals: copper, tin, bronze (an alloy of copper and tin), and lead. Eventually, they learned to work with iron.

II. Early Chemical Arts



Early chemistry evolved as a trade and art - not as a science. Many chemical processes were learned by accident, but once mastered, they were passed on by an apprenticeship procedure. Some of the chemical arts known and practiced by about 1200 B.C. are:

Metallurgy: copper, tin, bronze (a copper-tin alloy), lead and iron were used for utensils and tools.

Gold and silver were used for ornamentation.

Preparation and use of building materials such as plaster and mortar.

Tar and asphalt were used for waterproofing and embalming.

Waxes and oils were prepared and used for fuels for heat and light.

Methods were developed for tanning of leather and the preserving of animal pelts.

Dyes were made for the coloring of textiles, stone, and pottery.

Glass, both clear and colored, was manufactured for use in vessels and for ornamentation.

Fake gems were prepared.

Glues were made for various purposes.

Soaps were made from animal fats.

Plant and mineral materials were used for medicines.

Beer and wine were made.

Cosmetics were made for both men and women.

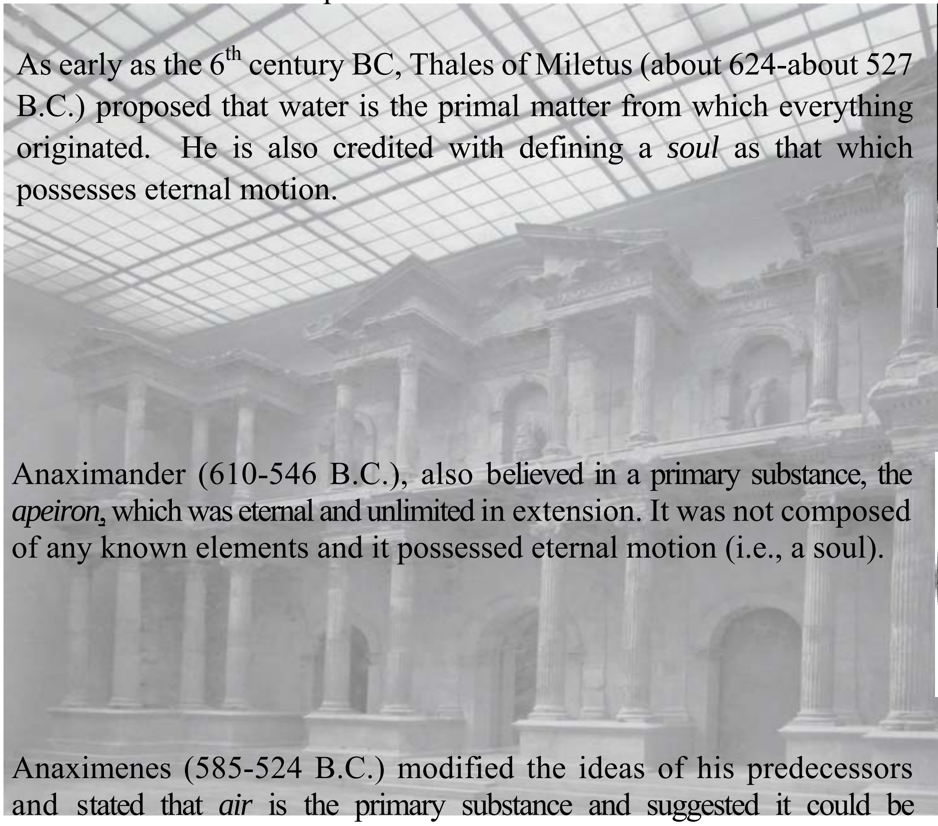
Photos from the Pergamon Museum, Berlin, Germany:
Background: The Istar Gate, Babylon, c. 600 BC
Ancient gold, pottery, necklace, and tilework.

III. Theories of Matter

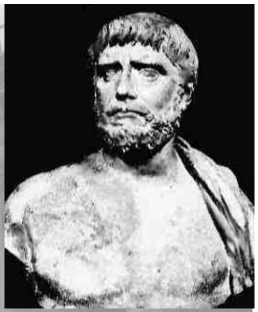
The Greeks and Hindus appear to have developed theories on matter, however, most of the philosophical writings are attributed to the Greeks due to the amount of recorded information that has survived to the present.

Greek writings tell us that they thought substances could be converted or transformed into other forms. They observed the changing of states due to heat and equated it with biological processes. For example, it was believed that an animal digested its food by “cooking” it in its stomach.

The Greeks were philosophers and thinkers, not experimentalists, so they did not conduct experiments to verify their ideas. They believed that a sphere was perfection, so no substance on Earth was perfect.



As early as the 6th century BC, Thales of Miletus (about 624-about 527 B.C.) proposed that water is the primal matter from which everything originated. He is also credited with defining a *soul* as that which possesses eternal motion.



Bust of Thales,
Capitoline Museum,
Rome. Italy

Anaximander (610-546 B.C.), also believed in a primary substance, the *apeiron*, which was eternal and unlimited in extension. It was not composed of any known elements and it possessed eternal motion (i.e., a soul).

Anaximander,
Landesmuseum,
Trier, Germany

Anaximenes (585-524 B.C.) modified the ideas of his predecessors and stated that *air* is the primary substance and suggested it could be transformed into other substances by thinning (fire) or thickening (wind, clouds, rain, hail, earth, rock).

Heraclitus of Ephesus (544-484 B.C.) said that *fire* is the primeval substance and that change is the only reality.

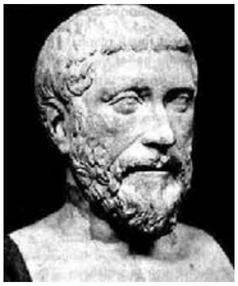
Background photo: The Market Gate of Miletus, The Pergamon Museum, Berlin, Germany

Anaximenes

Heraclitus

The Pythagoreans (Pythagoras (570-490 B.C.)) attempted to reduce the theory of matter to a mathematical and geometric basis by using geometric solids to represent the basic elements: (Refer to Plato, later in this section)

cube = earth
tetrahedron = fire
octahedron = air
icosahedron = water
dodecahedron = ether



Pythagoras

Empedocles of Agrigentum (492-432 B.C.) is credited with the first announcement of the concept of four elements: *earth, air, fire,* and *water*, which were capable of combining to form all other substances. The way in which the elements combined was due to specific attractions or repulsions which were typified as *love* and *hate*.
(NOTE: This 4 element theory dominated science for approximately 2000 years.)

Empedocles

Anaxagoras of Klazomenae (c. 500-428 B.C.) considered the universe to be composed of an infinite variety of small particles called *seeds*. These seeds were infinitely divisible and possessed a quality which allowed "like to attract like" to form substances such a flesh, bone, gold, etc.

Anaxagoras

Leucippus (5th century B.C.) and Democritus (460-370 B.C.) set forth the first atomic theory. They believed that all material things were consisted of small indivisible particles, or *atoms*, which were all qualitatively alike, differing only in size, shape, position and mass.

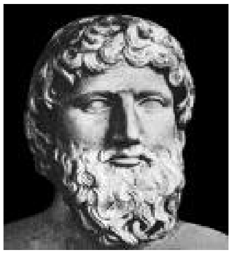
These atoms, they stated, exist in a vacuous space which separates them and, because of this space, they are capable of movement. (This can be considered at the first kinetic theory.)

Leucippus

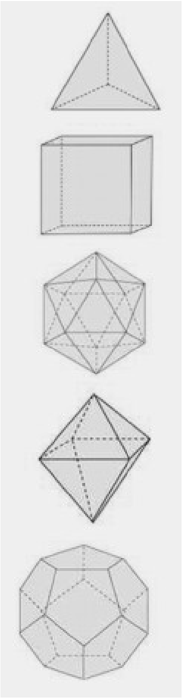
Democritus

Plato (427-347 B.C.) adopted the four element theory *earth, air, fire* and *water* and hinted at a fifth element, an *ether*, which eventually became associated with the heavens.

Using the ideas of the Pythagoreans, Plato associated the four elements with four regular solids:



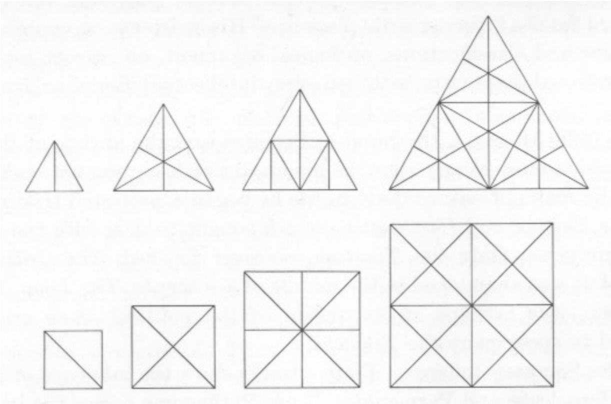
Plato



1. Fire: composed of tetrahedral atoms
2. Earth: composed of cubic atoms
3. Water: icosahedral atoms (20 faces)
4. Air: octahedral atoms

The heavenly element, or *ether*, was represented by the dodecahedron (12 faces). This was the foundation of the universe with a shape closely approximating a sphere.

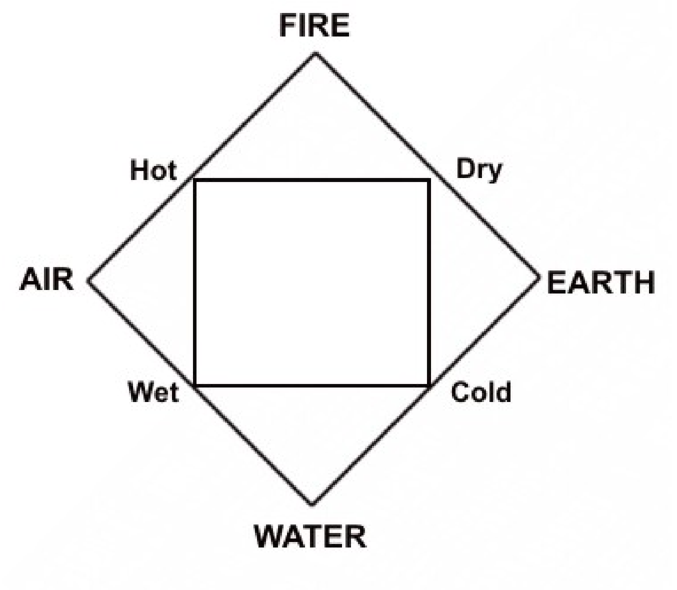
Plato believed in transformations of substances. He said the sides of the four regular solids could be resolved into triangles which could be interconnected to form any substance.



Plato's use of triangles. From Ihde, Aaron J., *The Development of Modern Chemistry*

Aristotle (384-322 B.C.) discounted the geometric forms of the elements used by his teacher Plato, but he retained the fifth element, the *ether*, which he believed formed the heavenly bodies and filled space.

Aristotle attributed matter with four qualities - hot, cold, wet, and dry - which combined in making up matter. These qualities were probably symbolic of the properties of matter rather than the fundamental building blocks as was later thought.

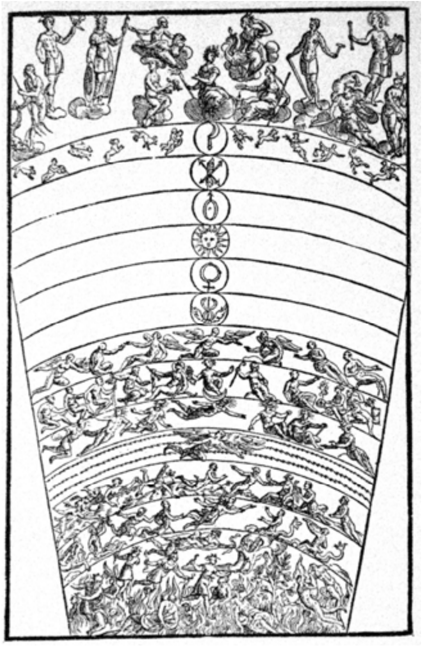


Relation of the four elements and the four qualities.
(This diagram is known as an Aristotelian square.)

The four qualities can form six possible pairs, but since opposites cannot be coupled together, as hot with cold or as wet and dry, there remained only four pairs:

Hot + Dry = Fire
Hot + Wet = Air
Cold + Wet = Water
Cold + Dry = Earth

The qualities were blended in various amounts and were not perceptible when the atoms were combined to form substances.



The scheme of the universe according to the Greeks and Romans.

One ascends successively from the sphere of Hades, through the spheres of water, earth, and air to the heavens of the moon and the plane of Mercury. Above Mercury are the planes of Venus, the Sun, Mars, Jupiter and Saturn. Above Saturn is the dwelling place of the powers that rule, the Supreme Council of the Gods.

IV. Origins of Alchemy

Aristotle's death marked the end of the Greek influence upon the development of the theories concerning the nature of matter and its changes.

Aristotles' student, Alexander went on conquer much of the known world.

Alexander located his city, Alexandria in the middle of the known world, in Egypt. Here, he established a great library collecting writings from the world. All visitors to the city were required to surrender all books, scrolls, and any form of written media, in any language, in their possession which were copied by official scribes and then returned to their owner.

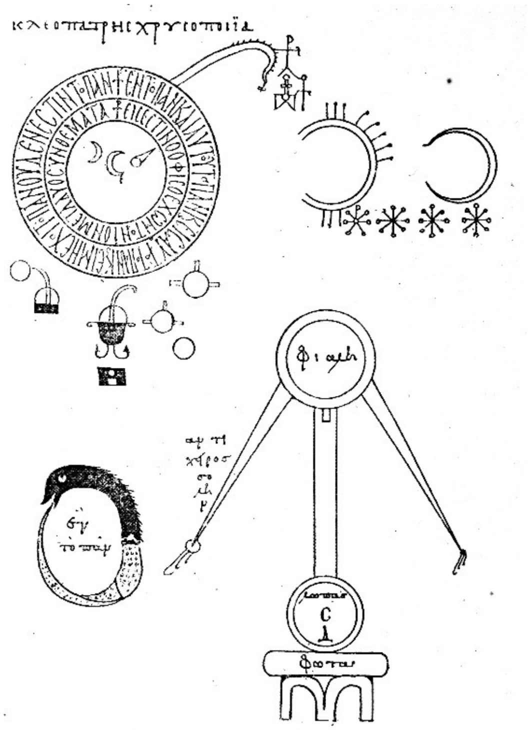
Alexander the Great

The ancient library in Alexandria

Scientific leadership passed from Athens to Alexandria (in Egypt). Here, Greek philosophy plus practical oriental technology plus oriental religious mysticism combined to lead to the birth of alchemy.

Early alchemists were artisans who were especially skillful with metals. They prepared gold and silver vessels and ornaments for nobles and made cheap imitations or substitutes for the poorer people. Aristotle's ideas of interconversion of elements led them to believe that they could convert base metals into gold as easily as they manufactured substitutes. Through many chemical operations, they produced many color changes to make metals resemble gold. In these processes, they developed greatly improved chemical apparatus and learned many new chemical reactions.

Drawing of metal-workers' workshop in Egypt
Eric John Holmyard, *Makers of Chemistry*



From Kleopatra Chrisopoeia: The Gold-making of Cleopatra
From C. A. Burland, *The Arts of the Alchemists*

Transmutation

In order to transmute a substance into gold or silver, the alchemist, in order to insure success, wanted to begin with a substance which was unidentifiable by particular qualities and to impress upon it the pure qualities which, one-after-another, would gradually rise in the scale of metallic virtue toward perfection. (This is based on Plato’s ideas in the *Timeaus*.)

Since individual metals were “too far removed” from gold, the alchemist must begin with **earth** (an unidentifiable solid) and impose on it the desired properties of gold: **water**, or fusibility; **air**, or brilliancy; the color of **fire** and resistance to fire (i.e., not oxidized by heat).

The first step in the transmutation was called **Melanosis,** it consisted of forming the *earth substance.* This was accomplished by alloying metals such as lead, tin, copper and iron. Thus, all the individual properties of the metals were lost or submerged in the *all*.

This alloy of the four metals was known as the *tetrasomy* or *metal of magnesia*. Later, other alloys were used, such as lead and copper with sulfur, or black copper(II) sulfide, or other sulfides.

The only property of this alloy was fusibility. The possession of this property was considered to be, by the alchemist, the first advance step raising the alloy from the condition of earth to water.

Also of importance was the color of the alloy, which was black (due to oxidation). To the alchemist, black symbolized the absence of color and the production of this black earth grew to be a major criterion of the first step of transmutation. So widely was the production of this black color known in Egypt, that it has been suggested that it may have been the cause of the alchemical process being known as the *Black Art* and possibly the origin of the name *alchemy* from *chem.* – meaning black – to which was affixed the Arabic article *al* (the).

This, however, is not the only proposed derivation for the name alchemy. Other possible origins are:

1. Black also refers to the black soil of the rich cultivated land of the Nile valley which was a name for Egypt.
2. Black refers to the *oxidized silver* for which the Egyptian artisans were famous.
3. The word *chem* is derived from the Greek word “to pour” or “mix”, referring to the “mixing of fire and water” in preparing red mercury(II) sulfide.
4. *Chem* is derived from the Hebrew word “from God”: *kem* and *yah.*
5. *Chem* was also the name of the black powder produced by quicksilver (mercury).
6. *Chem* comes from the Greek word meaning *cunning.*
7. *Al Chymia* may have come from a changed form of *al-temam*, meaning perfection.

The second step, after the blackening, was **Leukosis** or whitening. This was accomplished by dipping the metal (alloy) into some coloring which may have been derived from plants or, more often, from other metals. Silver was used in small or considerable amounts, as was mercury, arsenic, antimony, or mixtures of these. As a result, the outside of the metal was whitened and the inside was yellow (usually due to the copper in the alloy).

The third step, **Xanthosis**, was yellowing using a yellowing material such as a dye or sulfur or sulfur based material. Often, small amounts of gold was used as a ferment (based on the “like attracts like” principle). Sulfur was the most popular due to its yellow color. As a result of this third step, the outside of the substance matched the inside of it in color.

Over a period of time, the alchemist became influenced by oriental mysticism and eventually believed that the perfection of metals into gold was merely a symbol of the perfection of the human soul. (See Note 1, below.) Thus, came a fourth step, **Iosis**, which involved changing the gold into a violet or purple color to obtain a sort of super-gold. Since purple was associated with royalty, it was believed to be the highest color that could be attained. (See Note 2, below.) The action of such a gold would be so powerful, it could convert materials by a yeast-like action.

It is quite possible that the alchemists did attain these colors if the correct percentage of copper and, perhaps gold, was present in the alloy. After the fourth step, the work could have resulted in a beautiful violet bronze that may have had iridescent qualities.

Other methods were used for transmutation, all producing similar results.

Later, the sequence of colors changed to black – white - red and the **Ios** became known as the **Elixir** to the Islamic Alchemists in the 9th century. Eventually, the color changes took many forms for the European alchemists. In some cases they followed the Arabic series, in some the Islamic series, and even extensions of these. An example is:

> black – white - iridescence of the peacock's tail – yellow –
> orange – purple -red

The elixir also became known as the Philosopher's Stone or Tincture.

(Note: The term Elixir or Elixir of Life comes from the Chinese belief in a magical drug that would produce immortality. It also became known as drinkable gold or potable gold.)

The writings of the alchemists became more secretive with time to protect their processes as well as to protect themselves from prosecution. The rulers of the time were afraid that their gold would become worthless if the alchemists were successful. Thus, the alchemists used strange names of substances, and, later, as the mystical influence on their work became greater, incantations in their writings to keep others from understanding their notes and recipes.

In the diagram on the right, the hand represents secret societies of alchemists, the circle represents the colors of the alchemical process, and the figures represent the steps to the purification of the soul.

Figures representing the Alchemical process.

(Note 1: A belief that came from the Chinese was that gold was an immortal metal (i.e., it could not be oxidized or reacted with any other substance) and that eating off of gold plates would make one immortal.)

(Note 2: Royal purple, also known as Tyrian purple, is a purple-red (or scarlet) dye which was mentioned in texts surviving from 1600 B.C. and was used to color robes worn by the ancient Phoenicians rulers in the city of Tyre. The dye was collected from a fresh mucus secretion from the spiny dye-murex sea snail (modern name *Bolinus brandaris*). Because the harvesting had to be done by hand and it took some 12,000 snails to extract 1.5 grams of the pure dye, it was very expensive and could only be afforded by nobles. The dye was fast and non-fading and it is believed that the intensity of the color improved, rather than faded over time.)

The following recipe is a process to give copper or bronze a superficial silver or gold color.

> " I also come to bring to Egypt the doctrine of the things of nature, so that you may be raised above the curiosity of the vulgar and the confusion of matter.
> "Take mercury, fix it with the (metallic) body of magnesia or with the (metallic) body of stimmi from Italy, or with sulphur apyre (native sulphur), or with aphreselinon (selenite), or burned limestone, or alum of Melos, or with arsenicon or what you will. Place the white earth (so prepared) upon copper (χαλκος, copper or bronze), and you will have copper without shadow (brilliant). Add yellow electron and you will have gold, with gold you will have chropocolla reduced to metallic body. The same result will be obtained if you use yellow arsenicon or sandarach properly treated, and cinnabar wholly transformed. But mercury alone produces the copper without shadow. Nature triumphs over nature."

stimmi = native sulfide of antimony

arsenicon = arsenic

electron = a gold-silver alloy

cinnabar = mercury sulfide

The writings of the alchemists became more secretive with time to protect their processes from the uninitiated public. The following recipe is more obscure probably for this reason.

> "Whiten according to usage cadmia of Cyprus. I refer to that which has been refined. Then make it yellow. You may make it yellow with the bile of the calf, or turpentine, or ricinus oil or radish, or with the yolk of eggs, all sub-stances which turn it yellow. Then apply the mixture to the gold. For gold is obtained by means of gold and the liquor of gold. Nature triumphs over Nature."

cadmia = crude zinc oxide

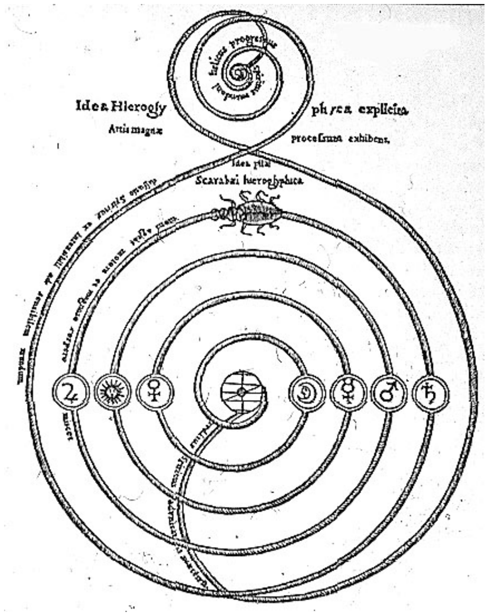
The metal of magnesia, a formed from the four metals shown, by the author. Note that the metal of Magnesia is black on the outside and gold in the inside.

Eventually, the alchemical writings became influenced by mystical ideas and contained incantations and other information meant to impress the reader with the importance of the knowledge possessed by the writer.

> " O Nature, producer of Natures, O Nature which charms Natures in marvellous ways. Such are the things which concern great Nature. There are no other natures superior to those in the tinctures; there are none equal nor inferior. All these things are effected in solution. O my colleagues in prophecy, I know that you have not been inclined to unbelief, but to admiration, for you know the powers of matter, whereas the young people are confused and place no faith in what is written because they are dominated by their ignorance of matter, not knowing that the children of medicine when they wish to prepare a medicament proper for a cure do not attempt to make it in thoughtless baste, but first try what substance is warm, what other substance is cold or moist, and in what condition it should be to favor a mean mixture. This is the way that they prepare the medicine destined for the cure. But those who propose to care for the soul and the deliverance from all pains do not perceive that they will be hindered by proceeding with a haste void of discrimination or reason. Indeed, believing that we are employing fabulous and not symbolic language they make no test of different kinds of substances to find out for example if such a kind is useful for cleaning; such another as accessory; such a one for coloring; such a one to effect complete combination; or if such a kind is good to give brilliancy. They do not ascertain if such a substance will resist the action of fire, and if such another by its addition will render a body more resistant to fire; thus, for instance, how salt cleanses the surface of the copper and even its internal parts, and how it corrodes the external parts when scraped, and even its internal parts. And finally, how mercury whitens the surface of brass (aurichalchum) and cleans it, and how it whitens the internal parts (i. e. when alloyed); how it is eliminated from the surface and how it can be eliminated from the internal part. If the young people were trained in these matters they would not go astray in the preparations they undertake. They do not know that one kind of substance alone can be transformed into as many as ten kinds of contrary natures. Indeed one drop of oil may make disappear a great quantity of purple, and a little sulphur can consume many substances."

As the mystical influences increased, the laboratory work of the alchemists decreased and their writings became more allegorical and mystical in nature. These incantations and strange writings were cause for alchemy to be associated with magic.

By the time of the Byzantine Empire during the 4th and 5th centuries A.D., laboratory work and chemical discoveries nearly ceased.



The Egyptian-Greek key to alchemy

Chinese Alchemy:

It is interesting to note that a similar path to that of the Egyptian-Alexandrian alchemists was followed by the Chinese alchemists, however, they ended up completely mystical and never returned to lab work of any extent. Their idea of a universal "medicine" to aid in transmutation of metals into gold did persist into European alchemy.

Wei Po-Yang, Father of Chinese Alchemy

V. Islamic Alchemy

With the rise of the Arab Empire (8th to 11th centuries, A.D.), the Alexandrian-Greek Alchemy was revived.

The alchemical arts now included numerology and astrology along with many of the mystical ideas from the Alexandrians. One of the works which appeared in this period was the Emerald Table ascribed to Hermes Trismegistus, the Egyptian God Thoth, god of science and mathematics:

> True it is, without falsehood, certain most true. That which is above is like to that which is below, and that which is below is like to that which is above, to accomplish the miracles of one thing. And as in all things whereby contemplation of one, so in all things arose from this one thing by a single act of adoption.
>
> The father thereof is the Sun, the mother the Moon.
>
> The wind carried it in its womb, the earth is the source thereof. It is the father of all works of wonder throughout the world.
>
> The power thereof is perfect.
>
> If it be cast on to earth, it will separate the element of earth from that of fire, the subtle from the gross.
>
> With great sagacity it doth ascend gently from earth to heaven. Again it doth descend to earth and uniteth in itself the force from things superior and things inferior.
>
> Thus thou wilt possess the brightness of the world, and all obscurity will fly far from thee.
>
> This thing is the strong fortitude of all strength, for it overcometh every subtle thing and doth penetrate every solid substance.
>
> Thus was this world created.
>
> Hence will there be marvellous adaptations achieved of which the manner is this.
>
> For this reason I am called Hermes Trismegistus because I hold three parts of the wisdom of the whole world.
>
> That which I had to say about the operation of Sol is completed.

The Egyptian God Thoth, also known as Hermes Trismegistus

The Sun and Moon in the table may have represented gold and silver, but there seems to have been a trend to sometimes use them to represent sulfur and mercury, two principles now included in the composition of metals.

> Sulfur was believed to give metals the qualities of earthiness and combustibility.

Mercury imparted the qualities of lustre and fluidity.

Note: It is believed that sulfur and mercury were not the elements we know today, but hypothetical substances.

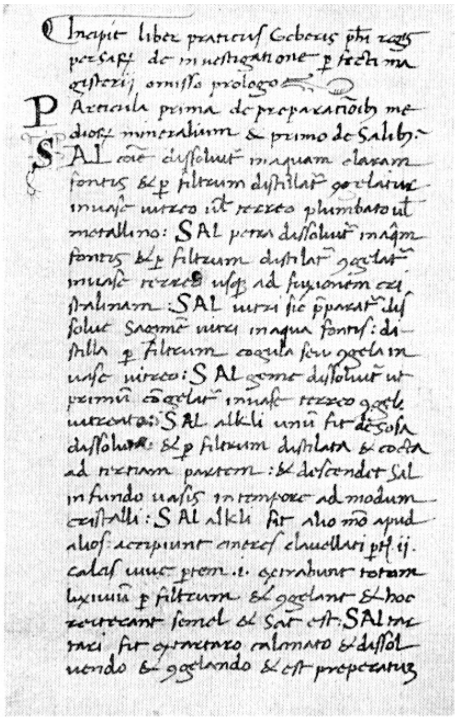
During the Arabic period, the process of distillation was refined and the caustic alkalis (NaOH, KOH) and the ammonium salts (e.g. NH_4C1, etc..) were discovered.

Perhaps the greatest chemist of Islam was **Jabir ibn Hayyan** (Latin: Geber) (c. 721-817 A.D.) Jabir was a physician in Baghdad and is thought to have been the first writer in Arabic to become interested in alchemy. Approximately 500 works have been attributed to him.

Imaginative portrait of Jabir

Jabir's writings reflect his beliefs in mystical powers, influence of the stars, the potency of talismans, etc. In spite of his leanings toward mysticism, he more clearly recognized the importance of experiment than any other early chemist and he made noteworthy advances in both theory and practice of chemistry. He stated:

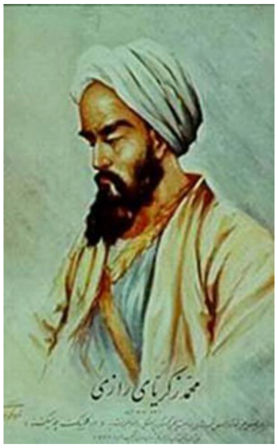
> The first essential in chemistry is that thou shouldest perform practical work and conduct experiments, for he who performs not practical work nor makes experiments will never attain to the least degree of mastery. But thou, O my son, do thou experiment, so that thou mayest acquire knowledge.
>
> Scientists delight not in abundance of material; they rejoice only in the excellence of their experimental methods.



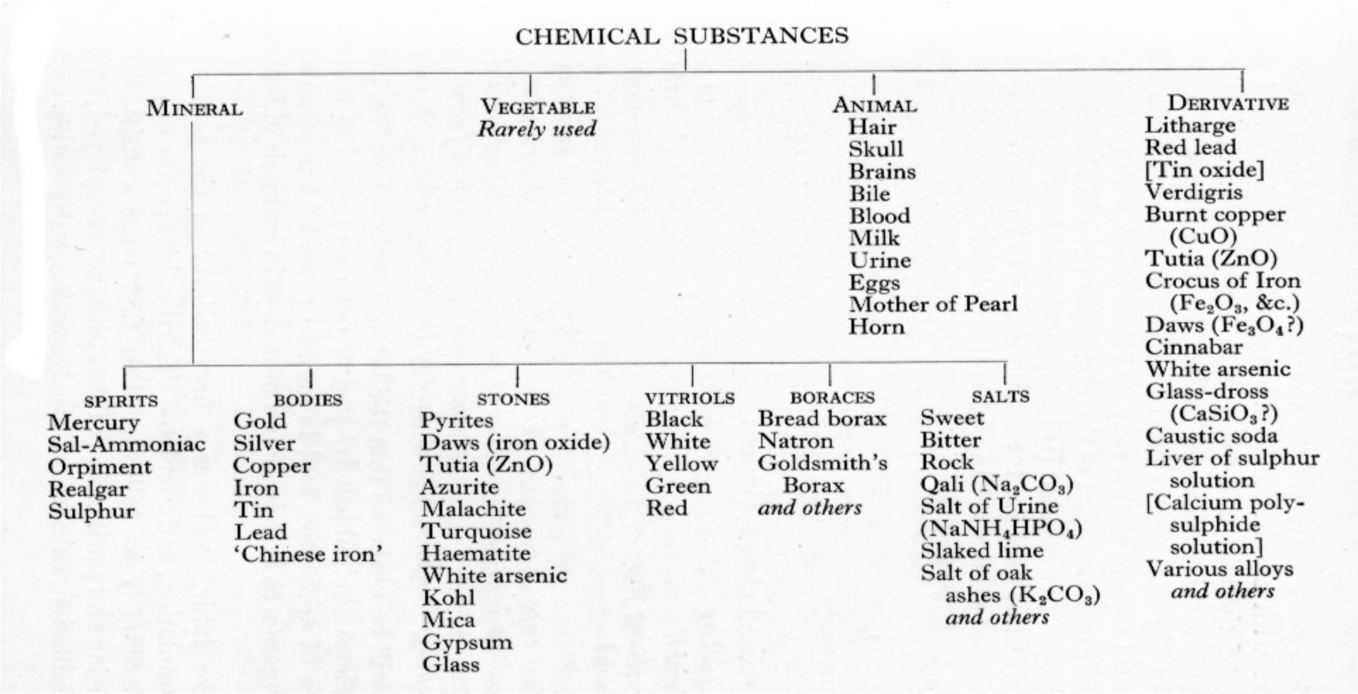
Early manuscript of Jabir's *Investigation of Perfection*

Jabir believed in transmutation but he gave only specific recipes and irections and did not claim that transmutation was coomplished. Practicel applications of chemistry he described were preparation of steel and refinement of other metals, processes for dying cloth and leather, processes for making varnishes to waterproof cloth or to protect iron, the preparation of hair dye, and more. Probably his most useful discovery was that of nitric acid (HNO_3).

Another of the great Arabic chemists was Abu Bakr Muhammad ibn Zakariyya al-Razi, known in the West as Rhazes or Razi (c. 866-925 A.D.). Mostly noted for his systematic classification of carefully observed and verified facts regarding chemical substances, reactions and apparatus described in language entirely free from mysticism and ambiguity. He classified substances as mineral, vegetable, animal or derivative:



Razi



Razi also gave a list of the apparatus used in chemistry. This consists of two classes: (i) instruments used for melting metals, and (ii) those used for the manipulation of substances generally. In the first class were included the following:

Blacksmith's hearth
Bellows
Crucible
Descensory
Ladle
Tongs
Shears
Hammer or Pestle
File
Semi-cylindrical iron mould

The second class included:

Cucurbite
Alembic
Receiving flask
Aludel
Beakers
Glass cups
Shallow iron pan
Sieve
Heating-lamps
Flasks
Phials
jars
Cauldron
Sand-bath
Water-bath
Large oven
Hair-cloth
Filter of linen
Cylindrical stove
Potter's Kiln
Chafing-dish
Mortar
Flat stone mortar
Stone roller
Round mould
Glass funnel
Dish

It appears that the list was comprehensive, but Razi completed the subject by giving details of making composite pieces of apparatus, and in general provides the same kind of information as is to be found nowadays in manuals of laboratory arts.

The alchemical laboratory exhibit at the Deutsches Museum, Munich, Germany

Photos from the alchemical laboratory exhibit at the Deutsches Museum, Munich, Germany

Abu All ibn Sina (c. 980-1036 A.D.), known as Avicenna in Europe, was a Persian born scholar who is sometimes called the "Aristotle of the Arabians"

Although he was extremely well versed in medicine, Avicenna wrote on many subjects including minerals, the formation of rocks and stones and other geological phenomena. He classified minerals as stones, fusible substances, sulphurs, and salts based on the amount of substance and the strength of their composition.

Avicenna adhered to Jabir's works and the mercury and sulfur composition of metals. He refuted the alchemists and stated that the process of transmutation was not possible and only imitations could be made. The nature of metals used would remain unchanged in the process.

Avicenna

Popular literature about alchemists, in Avicenna's time, usually contained stories such as the one below:

> A Persian charlatan [says Carra de Vaux], having arrived at Damascus, took 1,000 dinars of good Egyptian gold, filed them up and mixed the filings with charcoal, various drugs and ordinary flour. To this mixture he added fish-glue, made the whole into a paste, and moulded the latter into small pellets which he allowed to dry. He then clothed himself in the habit of a darwish, and, taking the pellets to a druggist sold them for a few dirhams under the name of Tabarmaq of Khurasan. After which, having assumed a rich cloak, he engaged a slave and went to the mosque, where he scraped acquaintance with several notable persons. He told them that he was an expert in alchemical science, able to make untold wealth in a single day. The

vizier, hearing of this alchemist, ordered him to attend and presented him to the Sultan, who ex-pressed his desire to witness a transmutation. The charlatan produced a recipe in which, among a large variety of drugs, Tabarmaq of Khurasan was indicated, to the extent of roo mithqals. All the rest of the drugs were easily obtained, but at first no trace of Tabarmaq could he discovered. The man insisted upon its necessity, however, and when the druggists' shops had been well searched the discovery was at length made—of course in the shop of the druggist to whom the Tabarmaq had been sold a few days previously, and who stated that he had obtained it from a darwish. The pellets were bought, and the Persian ordered the ingredients to be placed in a crucible and strongly heated. When all was sufficiently hot: `Take out the crucible,' he said. It was taken out and turned upside down, when a fine ingot of gold rolled out.

The Sultan, struck with amazement, ordered the Persian to be rewarded. It was now merely a question of finding more Tabarmaq. Search failed to reveal any more in Damascus. `I know a cavern', said the charlatan, 'in a certain mountain in Khurasan, where a large quantity is to be found. Send some one to dig it out and bring back a thousand camel-loads.' `Go thyself', said the Sultan. The man, after judicious reluctance, allowed himself to be persuaded, and accepted the mission. He was furnished with everything needful for the journey: a tent, a travelling kitchen, sugar, carpets, stuffs and silks, manufactured objects from Alexandria, and, in addition, a large sum of money. Thus equipped, he set out and—as might have been expected—that was the last that was seen of him.

VI. European Alchemy

Until the 12th century, almost the sole contact between Islam and Christian Europe was through the Crusades. Soon, after 1100, European scholars began to discover that the Saracens were possessed of much knowledge and wisdom and many began to wander in Muslim lands in search of learning and enlightenment. Sicily, an appendage of Islam was captured by the Normans in 1091 and, thus, became a center of diffusion of Arabic learning. It was in Spain, however, still under Moorish control, that the greatest activity prevailed. Students were welcomed to the colleges and libraries at Toledo, Barcelona, Segovia, Pamplona, and other Spanish towns. Study was followed by translation.

One of the earliest of the translators was the Englishman **Robert of Chester**. In 1141, he and his friend Hermann the Dalmatian were persuaded to translate the Koran into Latin, a task they completed in 1143. Upon completion of that work, Robert translated the Arabic alchemical book, the “Book of the Composition of Alchemy" completing it on February 11, 1144. This was the first book on alchemy to appear in Latin Europe.

Alchemy, as Robert of Chester observed, was a new science for the West, and one of the difficulties of the transalators was that there were no Latin equivalents of many iof its technical terms. They chose the easiest way of surmounting this obstacle by simply transliteration of the Arabic words into Roman letters. Some of these words are:

Arabic words transliterated into Latin:
(format: Latin, Arabic, English)

Abicum, Arabic, al-anbiq, alembic.
Abric, A. al-kibrit, sulphur.
Alcalai, A. al-qali, alkali. *Alcazdir, A.* al-qasdir, tin.
Alchitram, A. al-qitran, pitch.
Alchohol, A. al-kuhl, kohl (stibium, Sb_2S_3, or galena, PbS).
Aliocab, A. al-'uqab, `the eagle' (sal-ammoniac).
Almizadir, A. al-nushadhir, sal-ammoniac.
Anticar, A. al-tinkar, borax.
Appebriock, A. al-kibrit, sulphur.
Asabon, A. al-sabun, soap.
Ased, A. asad, lion.
Athanor, A. al-tannur, furnace.
Azarnet, A. al-zarnikh, arsenic [sulphides].
Baul, A. baul, urine.
Bayda, A. al-baida, egg [name of a piece of apparatus].
Daeb, A. dhahab, gold.
Danic, A. daniq, a certain weight.
Dem, A. damm, blood.
Faulex, A. fulad, steel.
Fom, A. fum, month. *Hadid, A.* hadid, iron.
Hager, A. hajar, stone.
Kald, A. khall, vinegar.
Kamar, A. qamar, silver moon.
Khatnir, A. khamir, ferment.

Luban, A. luban, gum, resin.
Luban jawa, gum of Java, was corrupted into Benjawin, or benzoin, whence our `benzene'.
Malek, A. milh, salt.
Martach, A. martak, litharge or massicot.
Merdasingi, A. mardasanj, litharge.
Misadir, A. nushadhir, sal-ammoniac.
Nar, A. nar, fire.
Noas, A. nuhas, copper.
Nora, A. nura, lime.
Obelchera, A. abu'l-qar'a, large cucurbite.
Ocob, A. uqab, eagle [sal-ammoniac].
Rusatagi, A. rusakhtaj, black oxide of copper.
Tain, A. tin, clay.
Usifur, A. zanjifar, cinnabar.
Zaibar, A. zaibaq, mercury.
Zaibuch, A. zaibaq, mercury.
Ziniar, A. zinjar, verdigris.

The first results of the abundant influx of knowledge from Islam were to be seen in the sorting out of new material and its arrangement for general use. This was done by several compilers or encyclopedists:

Bartholomew the Englishman, a Franciscan monk, wrote his encyclopedia, *De proprietatibus rerum* (On the Nature of Things, or On the Properties of Things), some time before 1260 (probably between 1242 and 1247). The work, in nineteen books, covered all the sciences as known at that time, including theology, philosophy, medicine, astronomy, chronology, zoology, botany, geography, and mineralogy. The work was to serve as instruction for his fellow Franciscans, who were expected to be educated but did not have the time or means to study each discipline individually. He quoted extensively from a wide variety of authors, referring to the works of Greek, Arabian, and Jewish naturalists and medical writers, which had been translated into Latin shortly before. He cites such authorities as Aristotle, Hippocrates, Pliny, Augustine, Boethius, Rabanus Maurus, Solinus, and Isidore of Seville among many others. The *De proprietatibus rerum* was an immediate success, and continued to be popular for centuries. It was translated into several languages, including Spanish, French, Dutch, and English.

Incipit ꝓhemiū de ꝓprietatib⁹ reꝝ fratris
Bartholomei anglici de ordiue fratꝝ minoꝝ

Cum ꝓprietates reꝝ ſequant̄
ſubſtantias ſm diſtinctionem et ordinem ſub
ſtantiaꝝ erit ordo et diſtinctio ꝓprietatum de
quib⁹ adiutorio diuino eſt pn̄s opuſculū com
pilatū. vtile michi et forſitan aliis qui naturas
reꝝ et ꝓprietates p ſanctoꝝ libros necnon et
pħoꝝ diſperſas nō cognouerūt ad intelligen
da enigmata ſcpturaꝝ que ſub ſimbolis et fi/
guris ꝓprietatū reꝝ naturaliū et artificialium
a ſpirituſancto ſūt tradite et velate queadmodū oñdit beat⁹ Dyoniſius
in iherarchia angelica circa pncipiū dicens. Nō eſt aliter nobis poſſibi/
le lucere diuinū radiū niſi varietate ſacroꝝ velaminū anagogice circūue
latū. qm̄ impoſſibile eſt animo nr̄o ad immaterialē celeſtiū iherarchiarū
aſcendere ꝯtēplationē niſi ea que ſm ipm̄ eſt materiali manuductiōe vta
tur et cetera que dicit. Nō pōt anim⁹ noſter ad inuiſibiliū ꝯtēplationem
aſcendere niſi p viſibiliū ꝯſiderationē dirigat̄. Inuiſibilia eñ dei p ea q̄
facta ſūt intellecta ꝯſpiciunt̄ vt dicit aplus. Et ideo theologia ꝓuide ſa
cris et poeticis informationib⁹ vſa eſt. vt et reꝝ viſibiliū ſimilitudinib⁹ al
legorice locutiōes et miſtici intellect⁹ tranſūptiones forment̄ et ſic carna
lib⁹ et viſibilib⁹ ſpūalia ꝛ inuiſibilia coaptent̄ ¶ Cui⁹ rei gr̄a pn̄s officio
opuſculū ad edificationē dom⁹ dn̄i qui ē deus glorioſus ſublimis et bn̄
dict⁹ in ſecula ſeculoꝝ In quo agit̄ de quibuſdaꝫ ꝓprietatib⁹ reꝝ natura
liū quaꝝ alia eſt incorporea alia corporea. Et pmo de ꝓprietatib⁹ ſubſtā
cie incorporee ſm ſui differētias quaꝝ alia eſt corpori vnibilis vt aia ra
tionalis ſenſibilis et vegetabilis. alia nō vnibilis corpi vt angel⁹. Et an/
geloꝝ alii ſunt boni. alii mali. In bonis vero angelis eſt ordo ſm trinaꝫ
multiplicationē trinitatis. vn̄ a beato Dyoniſio diſtinguūtur tres ierar/
chie celeſtes quaꝝ quelibet triū ordinū ꝯtinet diſpoſitōes. ¶ Nouēdecim
itaqꝫ ſūt de quib⁹ in hoc opuſculo adiuuāte deo p ordinē eſt agendū. et
hoc tā in ꝯmuni qꝫ in ſpeciali ¶ Primo igit̄ agit̄ de deo et nōib⁹ diuinis.
que dicunt̄ de deo vel quo ad eſſentiā vel pſonā ſiue quo ad effectū ſiue
appropatiōeꝫ Scdo de ꝓprietatib⁹ angeloꝝ tā bonoꝝ qꝫ maloꝝ in ge
nerali

Incipit page of a 15th century edition of On the Nature of Things.

Vincent of Beauvais (c. 1190-1264), a Dominican Friar, wrote the *Speculum Majus* or *Great Mirror* (c. 1250), a compendium, of all the knowledge of the Middle Ages. The work consisted of three parts, the *Speculum Naturale*, *Speculum Doctrinale* and *Speculum Historiale*. The *Speculum Naturale,* divided into thirty-two books and 3,718 chapters, is a summary of all the science and natural history known to western Europe towards the middle of the 13th century, a mosaic of quotations from Latin, Greek, Arabic, and Hebrew authors, with the sources given. The section on alchemy is found in the *Speculum Naturale*.

Incipit page of an edition of the *Speculum Naturale*

Albertus Magnus (1193-1280), a Dominican friar and priest, achieved fame for his comprehensive knowledge of and advocacy for the peaceful coexistence of science and religion. He is considered to be the greatest German philosopher and theologian of the Middle Ages. He was the first among medieval scholars to apply Aritotle's philosophy to Christian thought.

His book, *De Rebus Metallicis et Mineralibus*, presented a knowledge of metals and minerals and his beliefs that stones had occult properties.

Two later works, such as the *Secreta Alberti* or the *Experimenta Alberti*, were falsely attributed to Albertus by their authors in order to increase their prestige. There is scant evidence that he personally performed alchemical experiments, but according to legend, Albertus Magnus is said to have discovered the philosopher's stone and passed it to his pupil Thomas Aquinas, shortly before his death. Magnus did record that he witnessed the creation of gold by transmutation.

Albertus Magnus

Roger Bacon (1214-1292), one of the most famous Franciscan friars of his time, was an English philosopher who placed considerable emphasis on empiricism. He was one of the earliest European advocates of the modern scientific method.

The most important of all his writings are the "Opus Majus" (1268), the "Opus Minus", and the "Opus Tertium", along with some attributed books on alchemy. His importance in the development of modern science is a reason he is attributed with a greater input into chemistry and alchemy than his writings suggest.

Roger Bacon

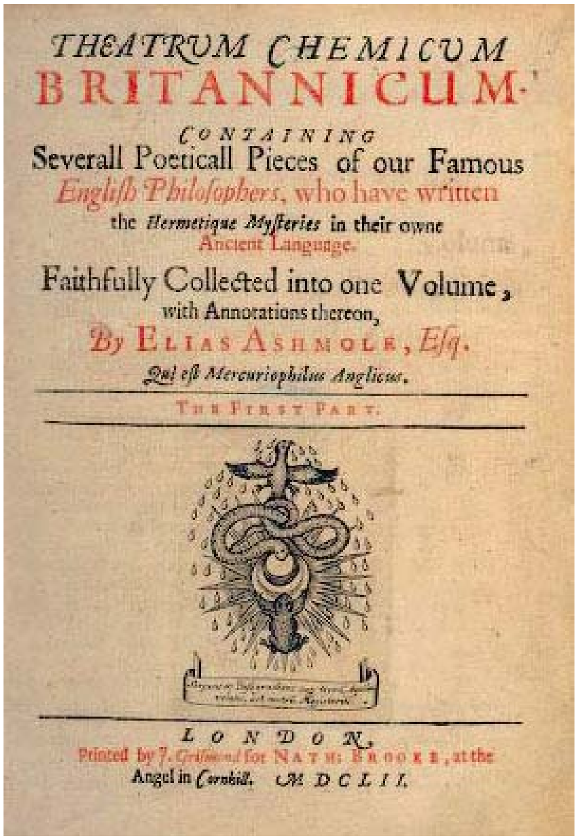
Arnold of Villanova (1235-1311) was an alchemist, astrologer, and physician who studied chemistry, medicine, physics, and Arabic philosophy. His major work was the "Opera Omnia". His translations and commentaries on the works of Galen, Avicenna, AI-Kindi, and Hippocrates helped lift European medical practice out of the realm of folk art and connect it with classical Greek and Arabic medicine. Although he is said to have practiced alchemy, and is rumored to have discovered carbon monoxide and pure alcohol, his works are directed mostly to medicine and chemistry was dealt with only incidentally.

Arnold of Villanova

With the exception of Arnold of Villanova, who performed alchemical experiments, the encyclopedists contributed little of their own. Nearly all the information from the Greeks and Arabs they received was accepted as true and the authenticity of some fantastic stories was not questioned.

The encyclopedists aroused interest in science through systematic propaganda of education and by their enthusiasm. Their main result on chemistry was to initiate a mad rush to make gold, an endeavor that persisted for three centuries. The European alchemists, no longer followed the sequence of the Arabic alchemists with their main goal to produce gold as their final product.

Practical alchemy developed first with textbooks attributed to Jabir under the Latin name of Geber. These Latin works were too clear and systematic in style and contained information that was inconsistent with that of Jabir's time. It is believed that much of these were written by a European scholar, most probably an unnamed Spanish alchemist of the 14th century. Regardless, Geber's works became the principal authorities in Western alchemy for the next two to three centuries.



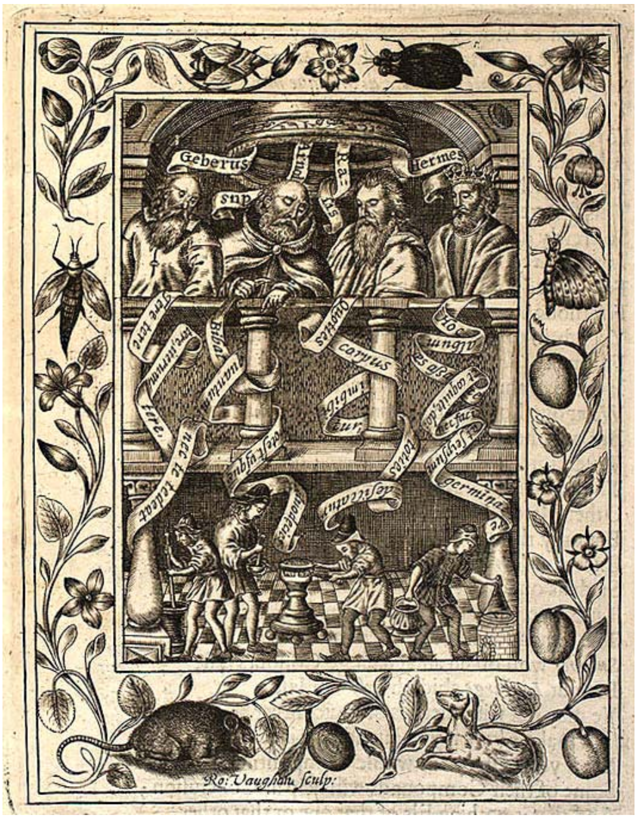
THEATRUM CHEMICUM
BRITANNICUM.
CONTAINING
Severall Poeticall Pieces of our Famous
Engliſh Philoſophers, who have written
the Hermetique Myſteries in their owne
Ancient Language.
Faithfully Collected into one Volume,
with Annotations thereon,
By ELIAS ASHMOLE, Eſq.
Qui eſt Mercuriophilus Anglicus.

THE FIRST PART.

LONDON,
Printed by J. Griſmond for NATH: BROOKE, at the
Angel in Cornhill. MDCLII.

Title page from Ashmole's*Theatrum Chemicum Britannicum,*a collection of English works on alchemy published in 1652.

Since the rebirth of alchemy produced many charlatans who were trying to get rich quick by strange schemes and by circulating large amounts of counterfeit gold, Pope John XXII issued a decree in 1317 prohibiting the practice of alchemy. In an attempt to persuade the Pope to change his mind, John Dastin, a foremost English alchemist of the time, wrote letters to the Pope defending the practice of alchemy. The results of Dastin's efforts are not known, however, both clerical and civil authorities tried to suppress the alchemists continually through the 14th century. As a result, the alchemical writings of the mid-14th to late 15th century became more philosophical and mystical in nature. During this time, very little new alchemical information was published.



The process in the laboratory inspired by the sages of the past—Geber, Arnold of Villanova, Razi and Hermes Trismegistus. From Norton's *The Ordinall of Alchimy*, in Ashmole's *Theatrum Chemicum Britannicum*.

The secret of the alchemical process is a gift from God which is passed down from master to pupil. From Norton's *The Ordinall of Alchimy*, in Ashmole's *Theatrum Chemicum Britannicum*.

An alchemical laboratory. From Norton's *The Ordinall of Alchimy*, in Ashmole's *Theatrum Chemicum Britannicum*.

The English Alchemists

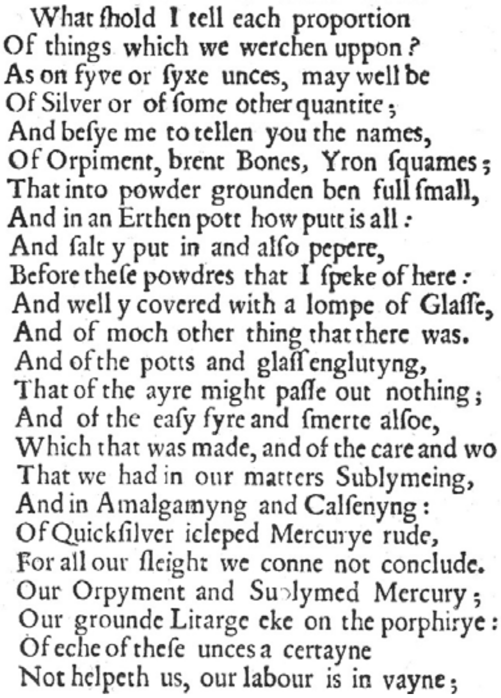
How widespread the practice of alchemy had become is England in the second half of the 14th century can be gauged by the account **Geoffrey Chaucer** (1340-1400) gives of it in “The Canon's Yeoman's Tale" in the *Canterbury Tales* (written from about 1386 to 1400). It is believed, by some, that Chaucer wrote “The Canon’s Yeoman’s Tale” as a personal revenge upon some alchemist who duped him. In the tale, Chaucer shows a more than casual knowledge of the alchemical art.

Geoffrey Chaucer

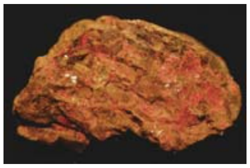
The Canon’s Yeoman’s Tale, from the Nevill Coghill translation

As for proportions, why should I rattle on
About the substances we worked upon,
The six or seven ounces it may be
Of silver, or some other quantity,
Or bother to name the things that we were piling
Like orpiment,* burnt bones and iron filing
Ground into finest powder, all the lot,
Or how we poured them in an earthen pot?
(You put in salt and paper, be it stated,
Before these powders I enumerated,
Securely covered by a sheet of glass,
And plenty of other things, but let them pass.)
And how the pot and glass were daubed with clay
For fear the gases might escape away,
And then the fire, whether slow or brisk,
We had to make, the trouble and the risk
We took to sublimate the preparation
Or in the arnalgaming and calcination
Of quicksilver, crude mercury that is?
We always failed, for all those tricks of his.
Our orpiment, our mercury sublimate,
Our lead protoxide ground on a porphyry plate
And measured out in ounces, grain by grain,
Gave us no help.
Our labour was in vain.

The Tale of The Chanons Yeoman, from Ashmole, *Theatrum Chemicum Britannicum*



What ſhold I tell each proportion
Of things which we werchen uppon?
As on fyve or ſyxe unces, may well be
Of Silver or of ſome other quantite;
And beſye me to tellen you the names,
Of Orpiment, brent Bones, Yron ſquames;
That into powder grounden ben full ſmall,
And in an Erthen pott how putt is all:
And ſalt y put in and alſo pepere,
Before theſe powdres that I ſpeke of here:
And well y covered with a lompe of Glaſſe,
And of moch other thing that there was.
And of the potts and glaſſ englutyng,
That of the ayre might paſſe out nothing;
And of the eaſy fyre and ſmerte alſoe,
Which that was made, and of the care and wo
That we had in our matters Sublymeing,
And in Amalgamyng and Calſenyng:
Of Quickſilver icleped Mercurye rude,
For all our ſleight we conne not conclude.
Our Orpyment and Sublymed Mercury;
Our grounde Litarge eke on the porphirye:
Of eche of theſe unces a certayne
Not helpeth us, our labour is in vayne;



*orpiment
As_2S_3

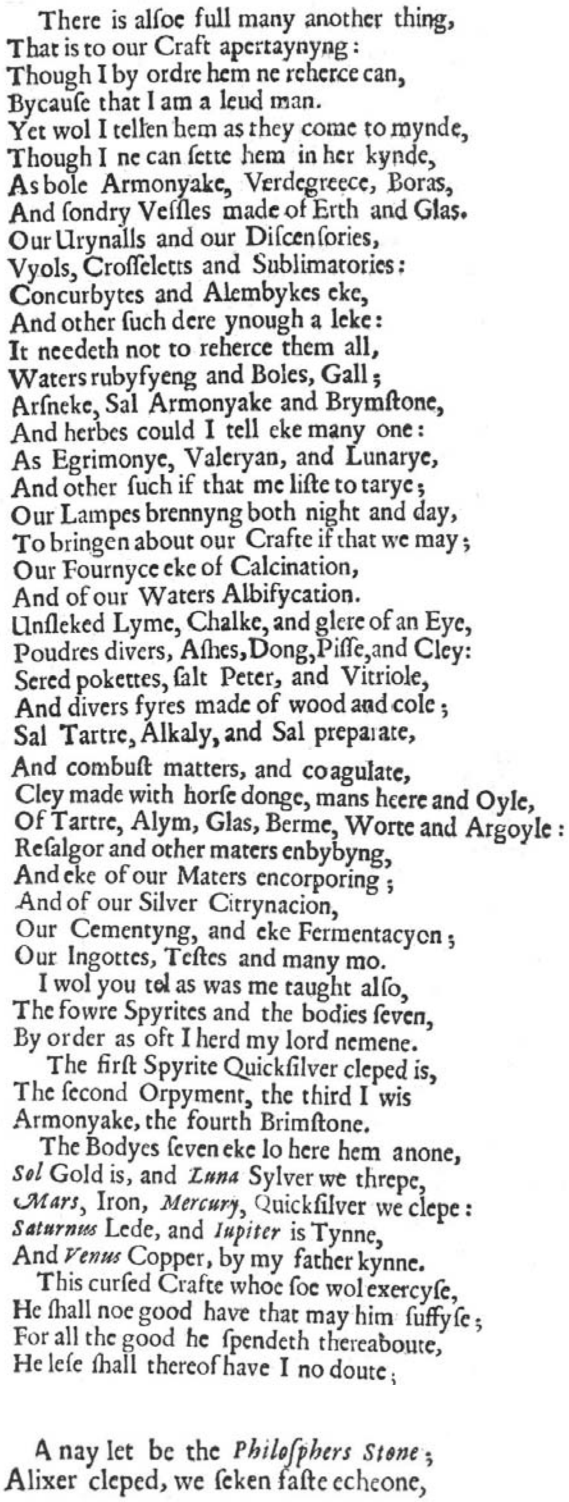
realgar
AsS

arsenic
As

sulfur
S

And there was also many another thing Pertaining
to the trade we had to bring,
Though I can't name them in an ordered plan Because
I'm an uneducated man;
Yet I will list them as they come to mind,
Though not distinguishing their class and kind:
Armenian clay, borax and verdigris,
Earthen and glass-ware vessels piece by piece,
Our urinals, our pots for oil-extraction,
Crucibles, pots for sublimative action,
Phial, alembic, beaker, gourd-retort,
And other useless nonsense of the sort
Not worth a leek, needless to name them all;
Water in rubefaction,* bullock's gall,
Arsenic, brimstone, sal ammoniac,
And herbs that I could mention by the sack,
Moonwort, valerian, agrimony and such,
Which I could number if it mattered much.
Our lamps — we had them burning day and night
To help us to succeed, if we but might!
Our furnace too for calcifying action,
Our waters in a state of albefaction,
Chalk, quicklime, ashes and the white of eggs,
Various powders, clay, piss, dung and dregs,
Waxed bags, saltpetre, vitriol and a whole
Variety of fires of wood and coal;
Alkali, tartar, salt in preparation,
Matters combust or in coagulation,
Clay mixed with horse-hair, sometimes with my own,
Crystallized alum, oil of tartar thrown
With tartar crude and unfermented beer,
Yeast and a dozen more than you shall hear,
Realgar,* various absorbent batters
And, I may add, incorporative matters;
Our silver in a state of citrination,*
Things sealed in wax and things in fermentation,
Our moulds, our vessels for assaying metal
And many other things I learnt to settle
I'll tell as I was taught, if you want more.
There were the bodies seven and spirits four
Which my instructor frequently rehearsed; Among
the spirits quicksilver came first
And orpiment came second, then he passed
To sal ammoniac and brimstone last.
As for the seven bodies that I mention
Here they all are, if they are worth attention:
Gold for the sun and silver for the moon,
Iron for Mars and quicksilver in tune
With Mercury, lead which prefigures Saturn
And tin for Jupiter. Copper takes the pattern
Of Venus if you please! This cursed trade
Robs one of all the money one has made,
And all one spends on it or round about it
Will certainly be lost, I cannot doubt it.

Ah no, let be! For the Philosopher's Stone,
Called the Elixir, never can be known.


There is alſoe full many another thing,
That is to our Craft apertaynyng:
Though I by ordre hem ne reherce can,
Bycauſe that I am a leud man.
Yet wol I tellen hem as they come to mynde,
Though I ne can ſette hem in her kynde,
As bole Armonyake, Verdegreece, Boras,
And ſondry Veſſles made of Erth and Glas.
Our Urynalls and our Diſcenſories,
Vyols, Croſſeletts and Sublimatories:
Concurbytes and Alembykes eke,
And other ſuch dere ynough a leke:
It needeth not to reherce them all,
Waters rubyfyeng and Boles, Gall;
Arſneke, Sal Armonyake and Brymſtone,
And herbes could I tell eke many one:
As Egrimonye, Valeryan, and Lunarye,
And other ſuch if that me liſte to tarye;
Our Lampes brennyng both night and day,
To bringen about our Crafte if that we may;
Our Fournyce eke of Calcination,
And of our Waters Albifycation.
Unſleked Lyme, Chalke, and glere of an Eye,
Poudres divers, Aſhes, Dong, Piſſe, and Cley:
Sered pokettes, ſalt Peter, and Vitriole,
And divers fyres made of wood and cole;
Sal Tartre, Alkaly, and Sal preparate,
And combuſt matters, and coagulate,
Cley made with horſe donge, mans heere and Oyle,
Of Tartre, Alym, Glas, Berme, Worte and Argoyle:
Reſalgor and other maters enbybyng,
And eke of our Maters encorporing;
And of our Silver Citrynacion,
Our Cementyng, and eke Fermentacyon;
Our Ingottes, Teſtes and many mo.
I wol you tel as was me taught alſo,
The fowre Spyrites and the bodies ſeven,
By order as oft I herd my lord nemene.
The firſt Spyrite Quickſilver cleped is,
The ſecond Orpyment, the third I wis
Armonyake, the fourth Brimſtone.
The Bodyes ſeven eke lo here hem anone,
Sol Gold is, and *Luna* Sylver we threpe,
Mars, Iron, *Mercury*, Quickſilver we clepe:
Saturnus Lede, and *Iupiter* is Tynne,
And *Venus* Copper, by my father kynne.
This curſed Crafte whoe ſoe wol exercyſe,
He ſhall noe good have that may him ſuffyſe;
For all the good he ſpendeth thereaboute,
He leſe ſhall thereof have I no doute;

A nay let be the *Philoſphers Stone*;
Alixer cleped, we ſeken faſte echeone,

Chemical Laboratory of Pieter Bruegel the Elder, 1558. This shows what happens when one tries to get rich from alchemy. The alchemist, on the left, is seeding his mixture with a gold coin while his wife shows her empty purse and the children rummage in the empty cupboard. His clerk, on the right is reading the recipe and his puffer is fanning the fire with bellows. Through the window is a foreshadowing of the alchemist and his family being lead to the poorhouse.

George Ripley (1415?-1490) was one of the most important of English alchemists. Little is known about him, but it is supposed that he was a Canon at the Priory of St Augustine at Bridlington in Yorkshire during the latter part of the 15th century, where he devoted himself to the study of the physical sciences and especially alchemy. He studied for twenty years in Italy where he became a great favorite of Pope Innocent VIII. He returned to England in the year of 1478, reputedly in possession of the secret of transmutation. (Being particularly rich, he gave the general public some cause to believe in his ability to change base metal into gold.)

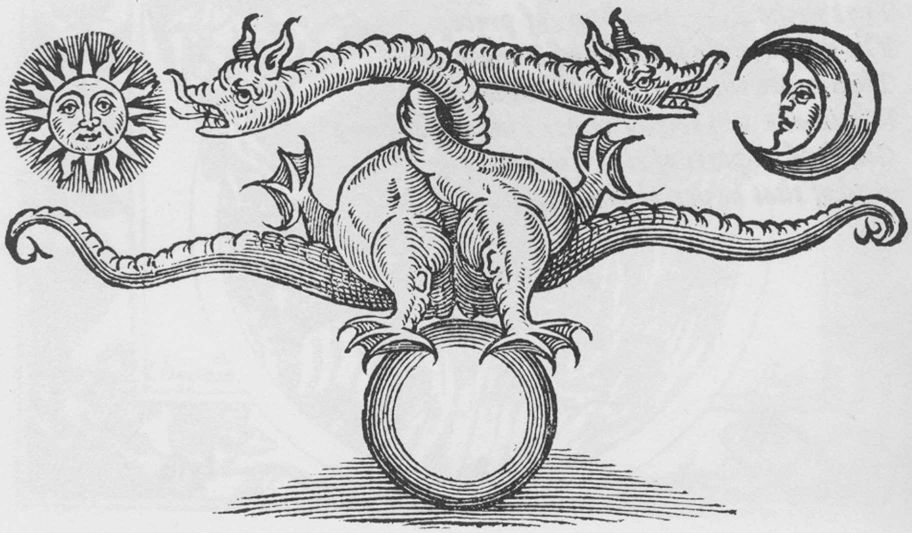
Ripley adopted an allegorical approach to alchemy and his name is attached to as many as five and twenty (25) different works, most of which remain in manuscript. Whether or not they are all by him may be doubted. His most popular work "The Compound of Alchymie; or, the Twelve Gates leading to the Discovery of the Philosopher's Stone", was dedicated to King Edward IV and highly appreciated by him. His twenty-five volume work upon Alchemy, of which the *Liber Duodecem Portarum* was the most important, brought him considerable fame. His emblematic 'Ripley Scrowle' is also quite well know..

Ripley agrees with the majority of alchemists that the progress of the Work can be followed by observing the succession of colours occurring in it. This, he says, in *The Compound of Alchymie*, should be as follows :

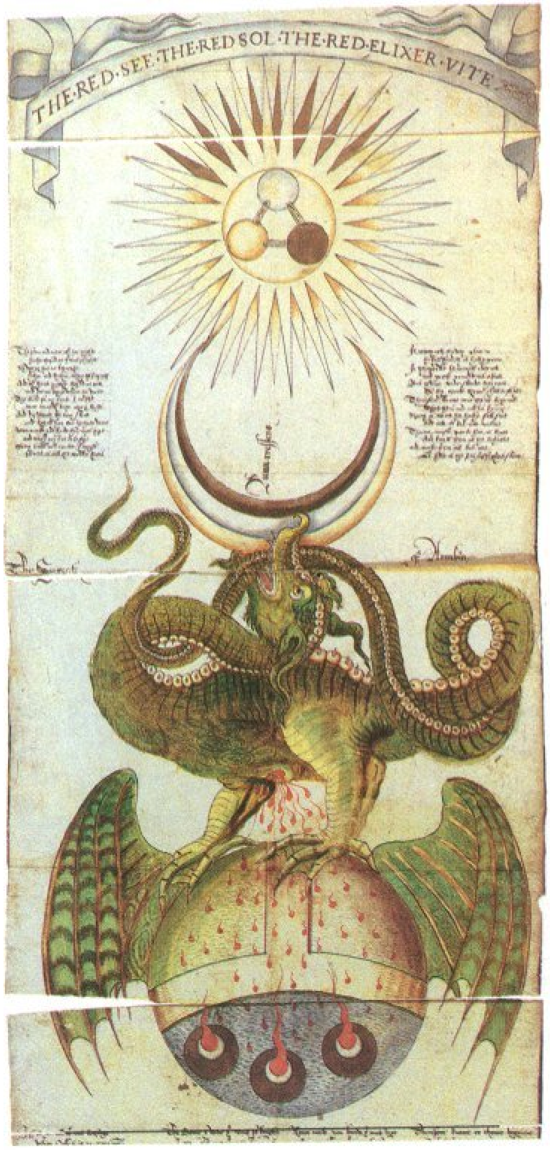
> Pale, and Black, wyth falce Citryne, unparfayt White & Red,
> Pekoks fethers in color gay, the Raynbow whych shall overgoe
> The Spottyd Panther wyth the Lyon greene, the Crowys byll bloc as lede;
> These shall appere before the parfyt Whyte, & many other moe
> Colours, and after the parfayt Whyt, Grey, and falce Citrine also:
> And after all thys shall appere the blod Red invaryable,
> Then hast thou a Medcyn of the thyrd order of hys owne kynde Multyplycable.

In the following passage, the final page and vignette of *Liber Patris Sapientiae*, Ripley tells the qualities one must have to succeed in the Work, showing the dragon arising from the massa confuse.

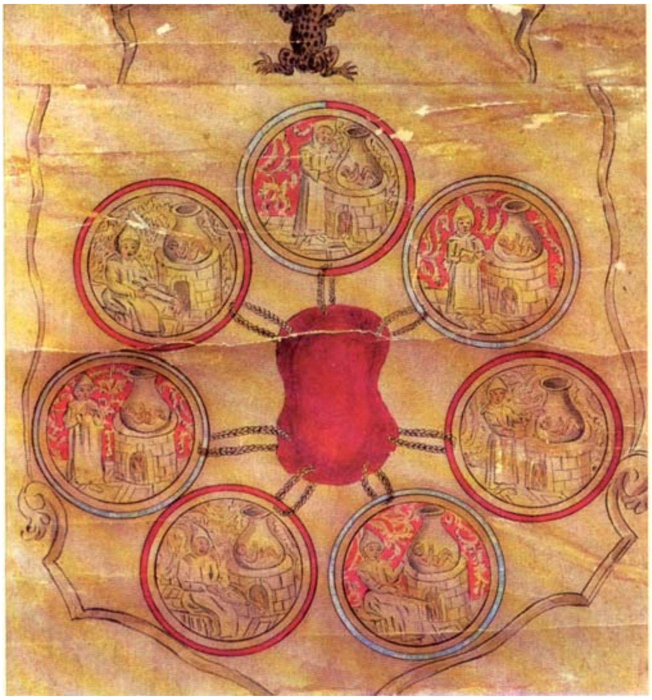
I*Yfe thow wilt thys warke begyn,*
Than ſchrevy the clene of alle thy **Seyne** *:*
Contryte in hert wyth alle thy thowght,
And ever thenke on hym that the der bewght.
Satisfaction thow make wyth alle thy myght,
Than thre fayre flowers thow haſt in ſyght ;
Yet nedeth the mor to thy concleſyon,
Take thow good hede nowe to thys leſſen;
Thow muſt have Graſe, Nature, *and* Reſen,
Spekelatif, *and* Coning, *wyth good* **Condition** *:*
Yet thow muſt have more now herto,
Experience, *wyth* Pracktik, Prudent *alſo ;*
Patient *that thow be, and* Holi in Lyſyngs,
Thenke thow on thys in thy beginings ;
Thes fowrtyn Heſtys as I the ſaye,
Ever kepe thow man both nyght and day,
Of thy deſyres thow mayſt not myſſe,
And alleſo of heven that ſweZt bleß.



The dragon with its wings fixed to the chaotic material orb gives its blood for the making of the red and white stones and the elixir, the triple goal of alchemy. From George Ripley's *Scrowles*



The seven processes of the alchemist. From George Ripley's *Scrowles*



The Melusina decending on the tree of life to bring wisdom to Man and Woman. From George Ripley's *Scrowles*

HERMES BIRD.

Problemis of olde likenes and fuguris,
Wych proved byn fructuos of ſentens;
And have auctorite grounded in Scripture,
By reſemblaunce of notabil apperence;
Wych moralites concludyng on prudence:
Lyke as the Bibel reherſeth be wryting,
How Trees ſum tyme cheſe hemſelfe a Kyng.

First page of Raymond Lully's *Hermes Bird.* The dragon inspirited from above becomes the tree of the philosophers.

VII. Alchemy in the Italian Renaissance (1453-1530)

With the Italian Renaissance (from the fall of Constantinople in 1453 to the fall of Rome in 1530) came the awakening of interests in art, science, and literature. Movable type was used in 1455 to print the Guttenberg Bible and this paved the way for the mass production of books.

All the sciences advanced, except for alchemy which remained mediaeval since it was based on mistakes in interpretation and translation and because it had been exploited by tricksters and charlatans.

Rather than striving for the perfection sought by the early alchemists of the Arabic and Islamic empires, the objectives of the “pseudo-alchemists” of Europe had become:

1. The Philosophers’ Stone or elixir
2. The Alkahest or universal solvent
3. Palingensis – the resurrection of a tree or plant from its ashes
   (also, rebirth or reincarnation)
4. The fountain of perpetual youth
5. The quintessence (a fifth element capable of extraction)
6. Potable gold or universal medicine

The alchemical microcosm and macrocosm

Paracelsus

One of the most forceful men of the Renaissance was **(Philip) Theophrastus Bombastus von Hohenheim** who later called himself Paracelsus (1493-1541). He was the founder of the school of iatrochemistry (medical chemistry or chemotherapy), which turned away from alchemy and held sway throughout the 16th and 17th centuries.

In iatrochemistry, Paracelsus manufactured metallic medicines to cure ills which the physicians of the day could not deal with. His hermetical views were that sickness and health in the body relied on the harmony of man, the microcosm, and Nature, the macrocosm. He took an approach different from those before him, using this analogy not in the manner of soul-purification but in the manner that humans must have certain balances of minerals in their bodies, and that certain illnesses of the body had chemical remedies that could cure them.

He initiated a vigorous onslaught on orthodox medicine and he called upon alchemists to prepare drugs in the laboratory rather than waste their time trying to transmute metals into gold (although he did believe in transmutation). He summarized his own views: "Many have said of Alchemy, that it is for the making of gold and silver. For me such is not the aim, but to consider only what virtue and power may lie in medicines."

To alchemy, Paracelsus contributed the *tria prima* theory which was based on the Greek-Arabic theory:

> All matter is composed of three primal substances: salt, sulfur, and mercury.
>
> **Salt c**omprised the body of matter imparting the qualities of nonvolatility and noncombustibility.
>
> **Sulfur** was the spirit of matter causing the body to possess the combustible principle,.
>
> **Mercury** was the soul of matter imparting fusibility, liquidity and volatility

Paracelsus was responsible for giving the name *alcohol* to spirits of wine. This name was derived from *al-kuhl* or *al-kohol* which had come to mean the *best or finest part of a substance.*

Because of his doctrines which opposed Galen and Avicenna, and his arrogant, boastful manner, Paracelsus remained in few places for long and was not extremely popular. He did, however, provide a much needed stimulus to get alchemists back into the laboratory to carry out serious testing and experimentation.

After his death, the movement of Paracelsianism was seized upon by many wishing to subvert the traditional Galenic physick and, thus, did his therapies become more widely known and used. Some of his followers, however, were too unrestrained in their enthusiasm and admonished many extraordinary and even dangerous poisonous drugs to their patients:

> Cinnabar (HgS) was given to "scatter those black clouds arising from the horrid spectrum of the appoplexie or epilepsie" to introduce a brightness and splendor in the spirit.
>
> Zinc sulphate for the eyes to cause "the species of objects to be seen more plain".
>
> Mercury to destroy "all sorts of worms".
>
> Lead acetate to "clarifie the spleen".
>
> Iron sulphide to cure diabetes.

Such cures were vigorously opposed by several chemists of the time, notably **Andreas Libavius** (1540-1616), a teacher and physician of the later iatrochemical school. Libavius was not a disciple of Paracelsus and denounced many of his doctrines.

Libavius contributed little original material to chemical theory, but the practical approach he used in his book *Alchymia* (published 1595) was an innovation. This book, considered to be the first chemistry textbook, was a comprehensive survey of the contemporary chemical knowledge of the time, written in clear language with no attempt at obscurity.

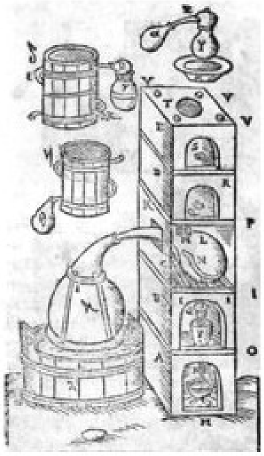
Andreas Libavius

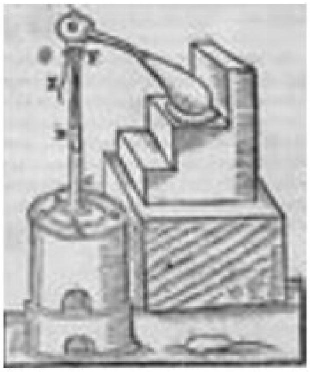
He showed that sulfuric acid could be prepared from sulfur and saltpeter (KNO_3), the preparation of hydrochloric acid, ammonium sulfate, zinc, lead nitrate, and anhydrous stannic chloride. (Because anhydrous stannic chloride gives off fumes when it is exposed to the water vapor in air, alchemists named it "fuming liquor of Libavius.") He was the first to describe the blue color produced by reaction of ammonia with copper salts, and he developed a rudimentary system of chemical analysis.

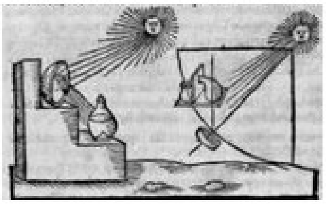
In addition, Libavius is credited with having designed the first true chemistry laboratory and his description of chemical apparatus is the most complete of its time.

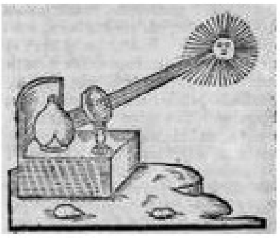
ALCHYMIA
ANDREÆ
LIBAVII, RECOGNITA, EMENDATA, ET
aucta, tum dogmatibus &
experimentis nonnullis;
TVM COMMENTARIO
Medico Physico Chymico:
QVI EXORNATVS EST VAriis Instrumentorum Chymicorum picturis;
partim aliunde translatis, partim
plane novis:
In gratiam eorum,
QVI ARCANORVM NATVRALIVM
cupidi, an absq; involucris elementariorum &
aenigmaticorum sordium, intueri
gaudent.
PRÆMISSA DEFENSIONE ARTIS,
opposita censurae Parisiensi:
Cum Gratia & Privilegio Caesareo speciali ad decennium.

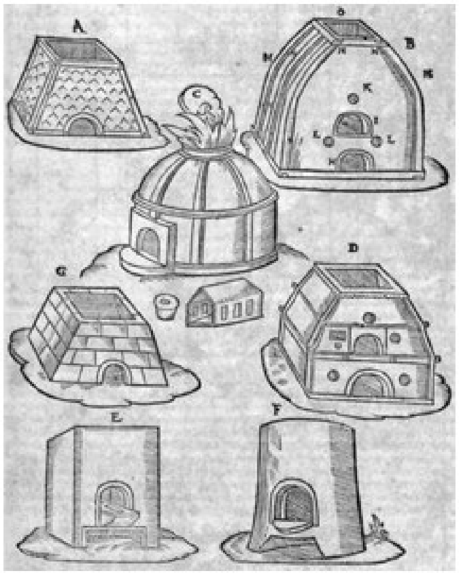
FRANCOFVRTI,
Excudebat Joannes Saurius, impensis Petri Kopffii.
Anno cIↄ. Iↄ. VI.











Illustrations from Libavius' *Alchymia*, 1606 edition.
Upper left: Title page

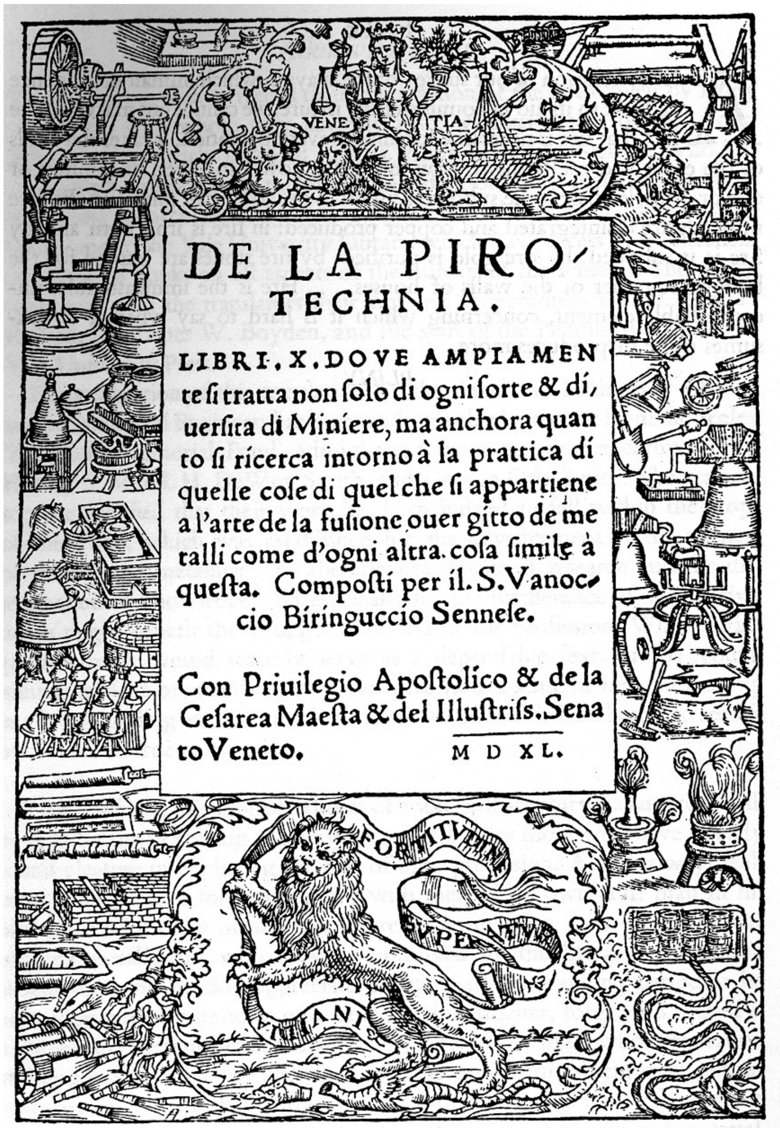
Above: Apparatus for heating and reactions.

Left: Heating with sunlight and furnaces

An interesting alchemical manuscript, produced in 1532-1535, is the *Splendor Solis*, attributed to **Solomon Trismosin**. Little is known of Trismosin's life, he traveled in Italy, and, later, to Constantinople, where he met Paracelsus and instructed him there. The Splendor Solis contains twenty-two allegorical pictures of the alchemical work. The selected pictures below are from a 1582 edition.

VIII. Chemistry in the 16th Century

In addition to iatrochemistry and Libavius' contributions to chemistry, the mining of metals became of great importance. The first book on metallurgy was "De la Pirotechnia" by **Vannuccio Biringuccio**, printed in Venice in 1540 two years after the author's death. The Pirotechnia was written in Italian, rather than "scholarly" Latin, but was illustrated with many woodcuts of the mining and metallurgical practice.

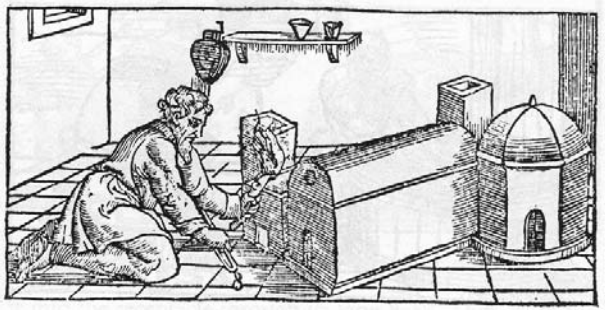


DE LA PIRO-
TECHNIA.
LIBRI. X. DOVE AMPIAMEN
te ſi tratta non ſolo di ogni ſorte & di,
uerſita di Miniere, ma anchora quan
to ſi ricerca intorno à la prattica di
quelle coſe di quel che ſi appartiene
a l'arte de la fuſione ouer gitto de me
talli come d'ogni altra coſa ſimile à
queſta. Compoſti per il. S. Vanoc-
cio Biringuccio Senneſe.

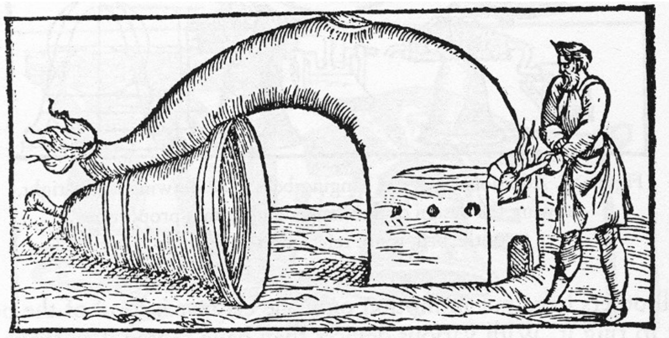
Con Priuilegio Apoſtolico & de la
Ceſarea Maeſta & del Illuſtriſ. Sena
to Veneto. M D XL.

Title page from the 1540 edition

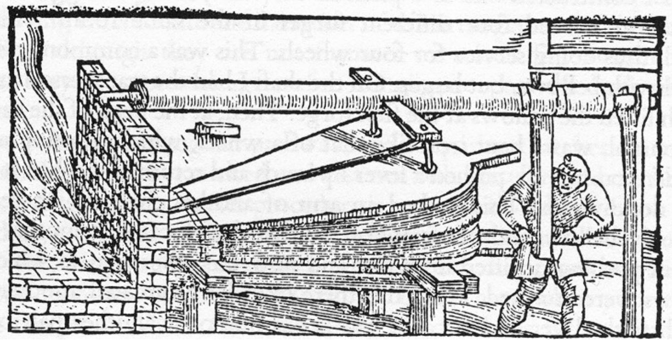
Furnace for melting, working, and annealing glass



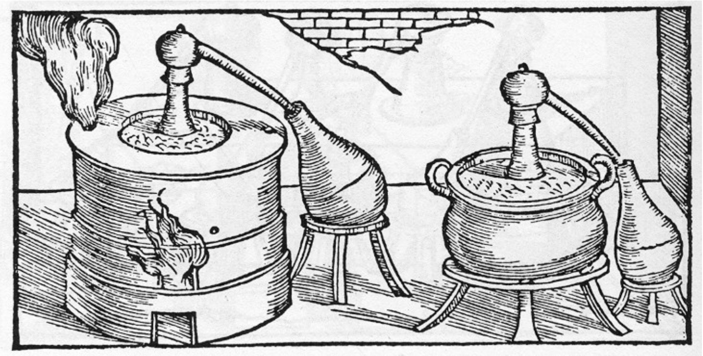
Chambers for the condensation of mercury vapor distilled from the ore.



Furnace for welding a cracked bell



Operation of a bellows with a rocking bar



Distillation with a cucurbit and alembic in a water bath.

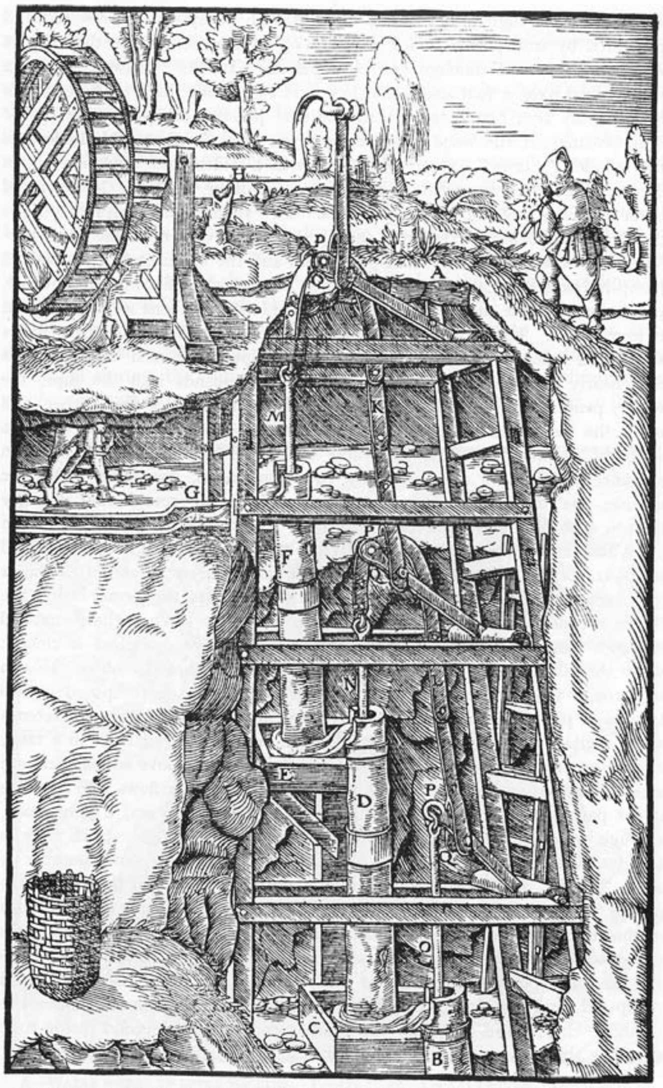
Georgius Agricola

"De Re Metallica" by **Georgius Agricola** (1494-1555), printed in 1556 is considered to be the greatest treatise upon a chemical industry known up to or during the 16th century. Although it did not contain anything new in the way of chemical discoveries or ideas, it was the most clear and complete account of the profession of mining, metallurgy, and accessory arts and sciences ever published. De Re Metallica overshadowed De La Pirotechnia, but did copy pictures and text directly from it along with information from other books at the time.

Born in Glauchau, in the province of Saxony in what is now Germany, Agricola studied classics at Leipzig University, taught Latin and Greek for a few years, and then in 1522 began to study medicine, first at Leipzig and then at Bologna and Padua in Italy. He took his degree in 1526 and doctor began practicing medicine at Joachimsthal (now Jáchymov) in 1527. Joachimsthal was an important mining center of the time, in particular for silver mining. Agricola's geological writings reflect an immense amount of study and first-hand observation, not just of rocks and minerals, but of every aspect of mining technology and practice of the time. Agricola moved in 1536 to the city of Chemnitz, also an important center of the mining industry, and was elected Burgomaster there in 1546. He not only continued his medical practice and his geological studies there, but was appointed to several public and diplomatic posts by Duke Maurice of Saxony, to whom he dedicated his book *De Natura Fossilium*.

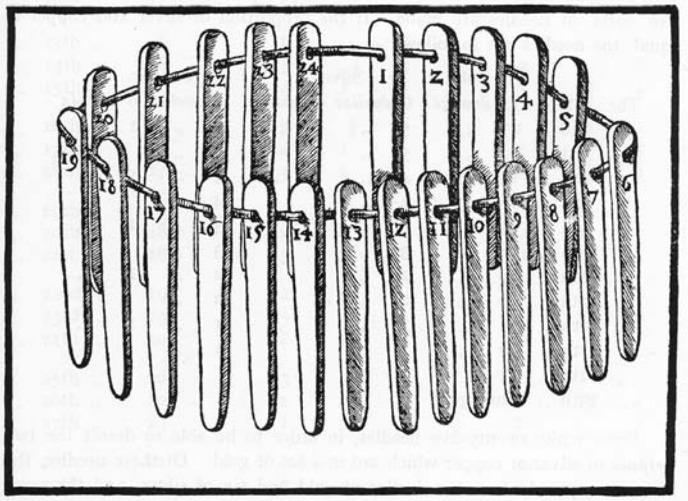
Notes on Jachymov: At the beginning of the 16th century, silver was found in the area of Joachimsthal. The exploitation of this valuable resource caused the place to grow rapidly, and coincidentally made the Counts von Schlick, whose possessions included the town, one of the richest noble families in Bohemia. The Schlicks had coins minted, which were called *Joachimsthaler*. They gave their name to the Thaler and eventually the dollar and similar named currency like tolar.

After the discovery of uranium in 1789 by Martin Klaproth, pitchblende was then mined, primarily at Jachymov. (See photo, next page) This pitchblende may have contained about 1% uranium. The uranium was at that time used for coloring wood, leather, pottery glazes and glass. The miners of these very early years paid a heavy price for their labors. A quote from Agricola's publication De Re Metallica gives us a feel for the conditions in the mines and the miners fate, “the dust has corrosive qualities, it eats away the lungs and implants consumption in the body… Women are found who have married seven husbands, all of whom have this terrible consumption has carried off to a premature death.” The miners themselves called this disease “Bergsucht” or “Mountain Sickness.” The miners attributed it to sub-terranean dwarfs. Others attributed it to metallic vapors. It would not be until 1879 that malignant tumors of the lung were found to be the cause of death. It is from pitchblende from this mine that Marie Curie discovered radium in 1898. It was not until the 1920’s and 30’s when radioactivity in the mines was believed to be the cause of the tumors. (Extracted from *A History of Radon- 1470 to 1984* by Robert K. Lewis.)

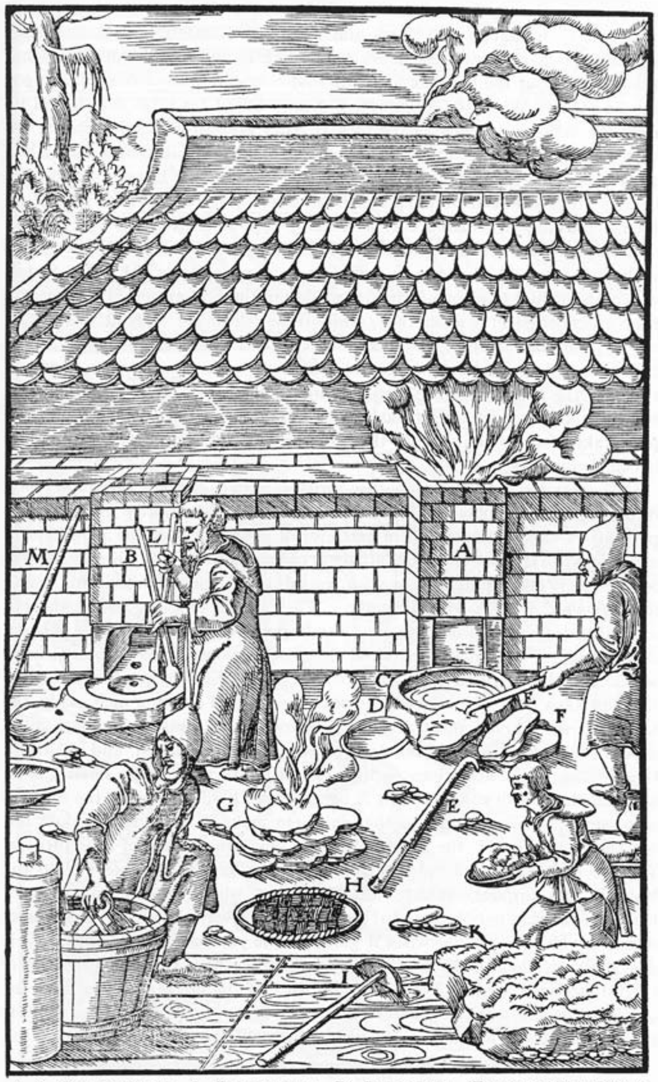


A—Shaft. B—Bottom pump. C—First tank. D—Second pump. E—Second tank. F—Third pump. G—Trough. H—The iron set in the axle. I—First pump rod. K—Second pump rod. L—Third pump rod. M—First piston rod. N—Second piston rod. O—Third piston rod. P—Little axles. Q—“Claws.”

A series of pumps to remove water from a mine. Each pump can only raise water 12 feet.

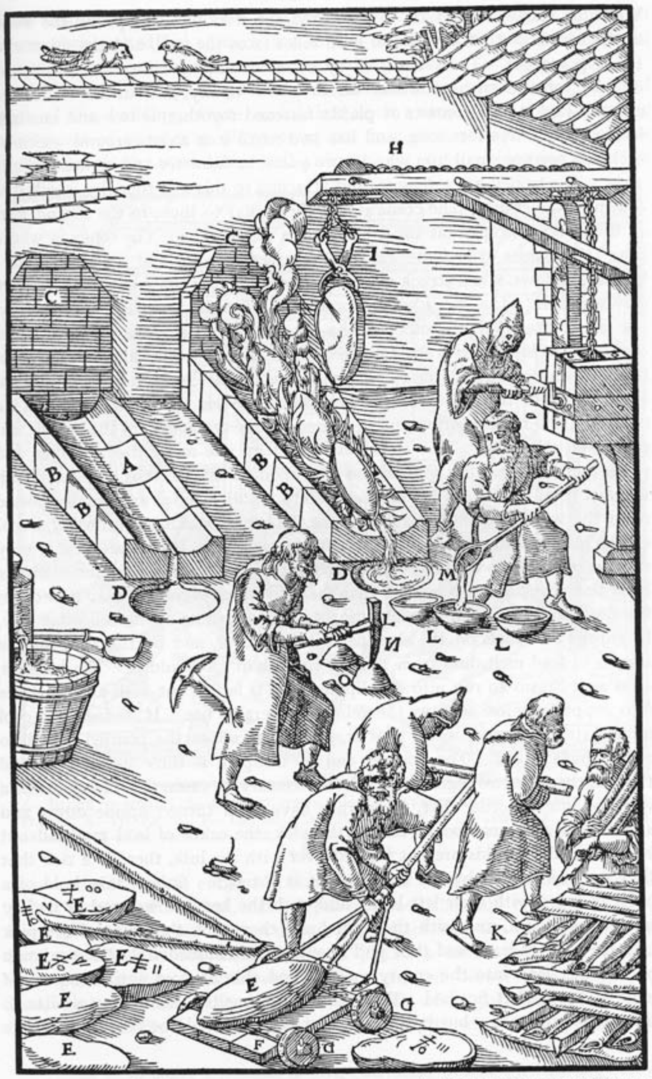


Assaying of gold: 24 needles composed of gold and silver for the analysis of gold. The number on the needle tells what part is composed of gold. When rubbed on a touchstone, the color is compared to a gold sample. (This is the origin of 24-carat gold.)



A, B—Two furnaces. C—Forehearths. D—Dipping-pot. The smelter standing by the first furnace draws off the slags with a hooked bar. E—Hooked bar. F—Slags. G—The assistant drawing a bucket of water which he pours over the glowing slags to quench them. H—Basket made of twigs of wood intertwined. I—Rabble. K—Ore to be smelted. The master stands at the other furnace and prepares the forehearth by ramming it with two rammers. M—Crowbar.

Smelting ores.



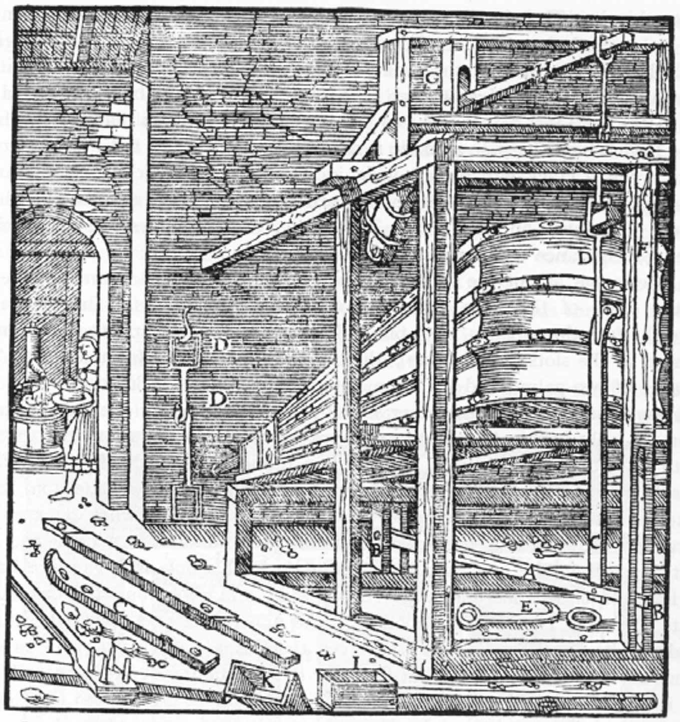
A—Hearth. B—Rocks sunk into the ground. C—Walls which protect the fourth long wall from damage by fire. D—Dipping-pot. E—Masses of lead. F—Trolley. G—Its wheels. H—Crane. I—Tongs. K—Wood. L—Moulds. M—Ladle. N—Pick. O—Cakes.

Separating silver from copper with lead. The lead-silver mixture is cast into moulds.

A—Sea. B—Pool. C—Gate. D—Trenches. E—Salt basins. F—Rake.
G—Shovel.

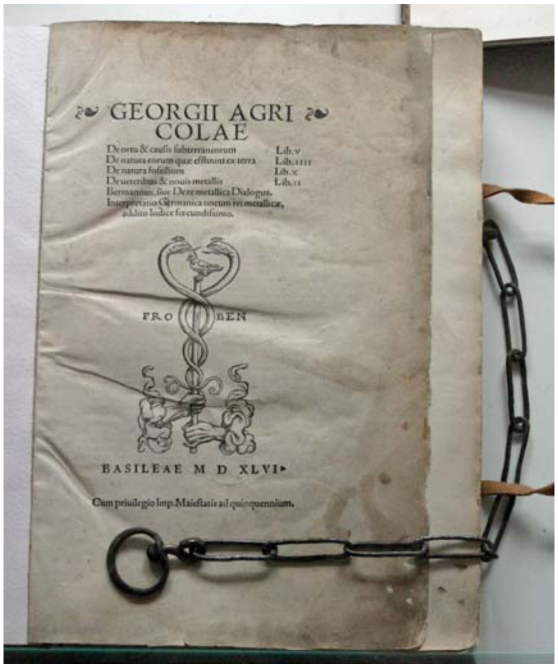
Extracting salt from sea water by evaporation.

A composite photo of the model of the mine
in the Mining Museum in Jachymov



A—Lever which when depressed by means of a cam compresses the bellows. B—Slots through the posts. C—Bar. D—Iron implement with a rectangular link. E—Iron instrument with round ring. F—Handle of bellows. G—Upper post. H—Upper lever. I—Box with equal sides. K—Box narrow at the bottom. L—Pegs driven into the upper lever.

Bellows from De Re Metallica and photographs of models from the Mining Museum in Jachymov.

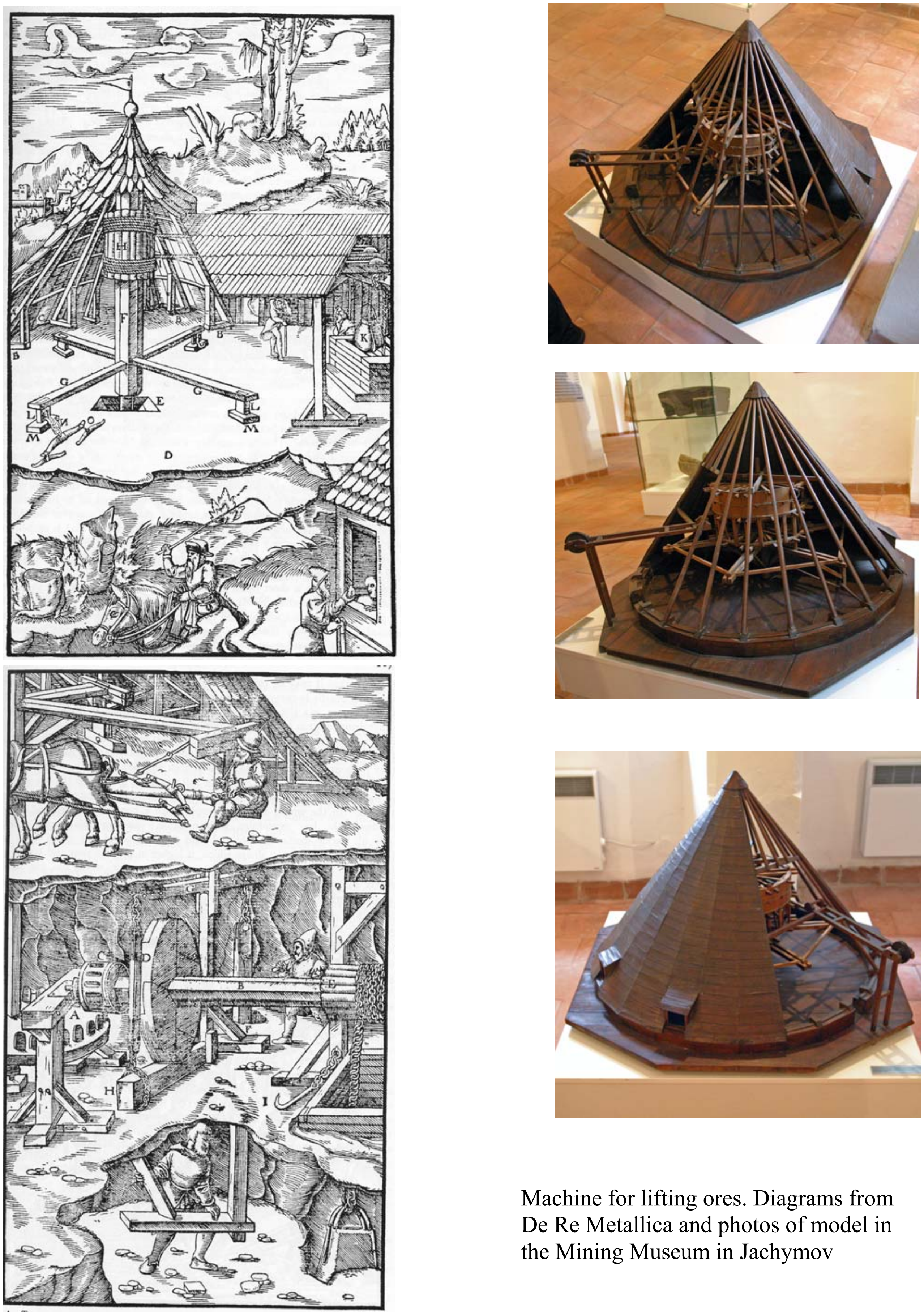


GEORGII AGRI
COLAE

De ortu & cauſis ſubterraneorum Lib. v
De natura eorum quæ effluunt ex terra Lib. iiii
De natura foſſilium Lib. x
De ueteribus & nouis metallis Lib. ii
Bermannus, ſiue De re metallica Dialogus.
Interpretatio Germanica uocum rei metallicæ,
addito Indice fœcundiſſimo.

BASILEAE M D XLVI.

Cum priuilegio Imp. Maieſtatis ad quinquennium.



Machine for lifting ores. Diagrams from De Re Metallica and photos of model in the Mining Museum in Jachymov

IX. Chemistry in the 17th Century

The 17th century was marked by the vitality of traditional alchemical activity and a great independence of thought. Acids and bases were studied in greater detail, treatises on distillation and laboratory work appeared, and the use of the balance marked the beginning of the quantitative study of chemical reactions.

Johann Baptista van Helmont (1577-1644), one of the last, and probably the greatest of the iatrochemists, was the most prominent chemist of the first half of the century.

Johann Baptista
van Helmont

He assumed that there are only two primitive elements: *air* and *water*. Water was the true principle of all things because it was a product from almost all substances, organic and inorganic, when strongly heated. He used the following experiment to illustrate this:

> He took zoo pounds of earth dried in an oven, and having put it into an earthen vessel and moistened it with rain water, he planted in it the trunk of a willow tree of five pounds weight; this he watered, as need required, with rain or distilled water; and to keep the neighbouring earth from getting into the vessel, he employed a plate of iron tinned over and perforated with many holes. Five years having elapsed, he took out the tree and weighed it, and (including the weight of the leaves that fell during the four autumns) he found it to weigh 169 pounds 3 ounces. And having again dried the earth it grew in, he found it only about 2 ounces short of its former weight of 200 pounds; so that 164 pounds of the roots, leaves, wood, and bark, which constituted the tree appeared to have sprung from the water alone.

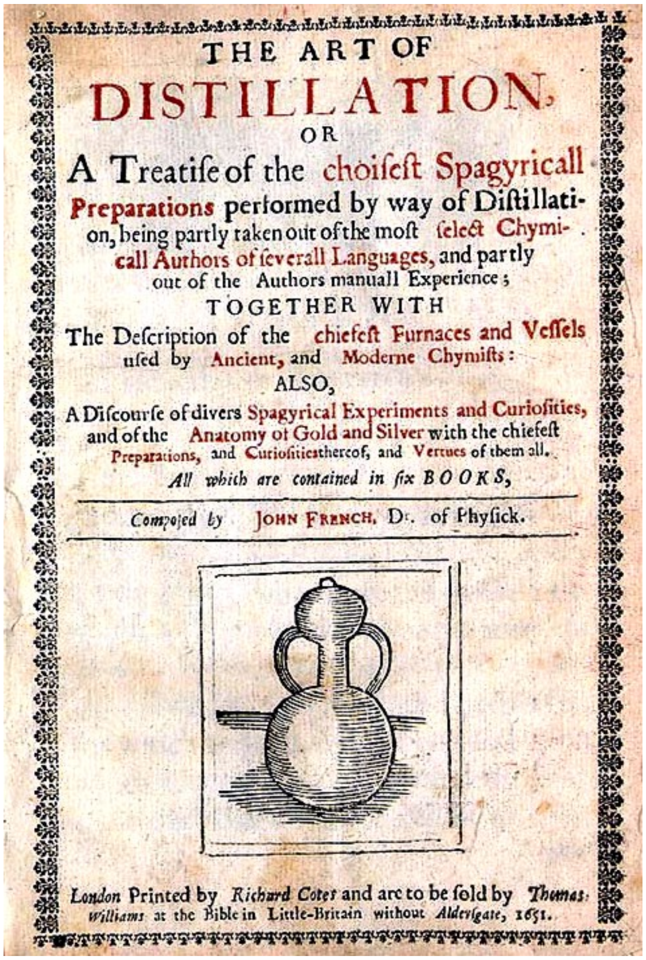
Van Helmont was the first to realize that there was a new and important class of substances which he called *gas* (from the Greek "chaos") to designate them. Although he tried many attempts to collect gases, he remained unsuccessful, but his efforts earned him the title of *founder of pneumatic chemistry.*

He discovered carbon dioxide, which he called *gas silvestre*, a non-flammable gas formed when charcoal was burned or when beer and wine was fermented. This gas was present in mineral waters and he found he could prepare it by reacting acetic acid with a carbonate compound. Unfortunately, he could only demonstrate that this gas would extinguish a flame and that the gas itself would not burn.

Van Helmont also discovered the flammable gas, *gas pingue*, obtained from the intestines or by the fermentation of dung. (This gas is most probably methane with impurities such as hydrogen sulfide, ammonia, and possibly hydrogen.)

Van Helmont placed great emphasis on the use of the balance and, using it, he demonstrated the indestructibility of matter in chemical changes and was the first to use quantitative methods in chemical experiments.

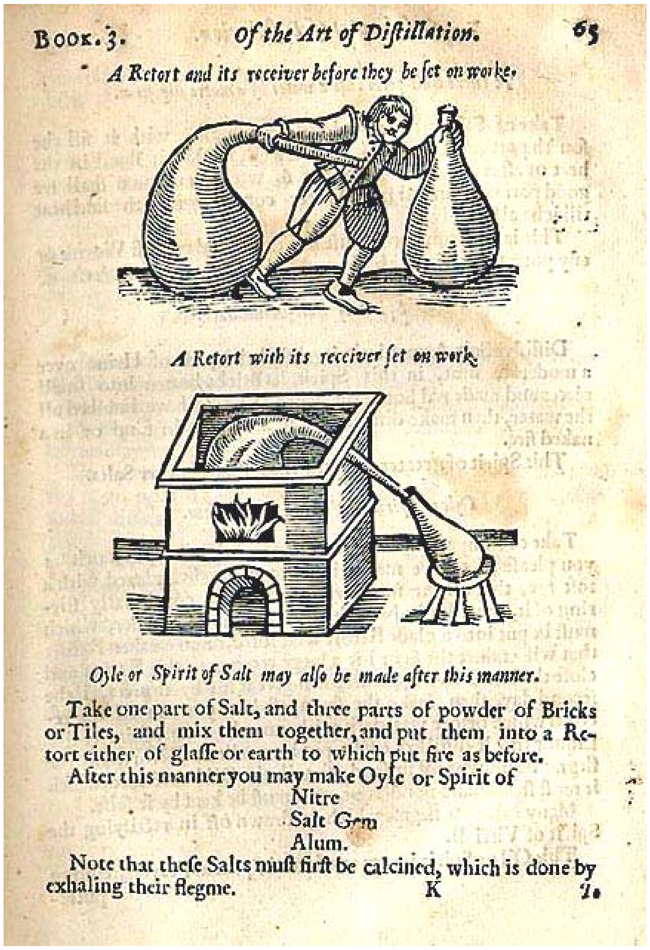
John French (1616-1657), an English physician, is known for his contributions to chemistry and, in particular, for his 1651 book *The Art of Distillation*, a detailed handbook of the art.



THE ART OF
DISTILLATION,
OR
A Treatiſe of the choiceſt Spagyricall
Preparations performed by way of Diſtillati-
on, being partly taken out of the moſt ſelect Chymi-
call Authors of ſeverall Languages, and partly
out of the Authors manuall Experience;
TOGETHER WITH
The Deſcription of the chiefeſt Furnaces and Veſſels
uſed by Ancient, and Moderne Chymiſts:
ALSO,
A Diſcourſe of divers Spagyrical Experiments and Curioſities,
and of the Anatomy of Gold and Silver with the chiefeſt
Preparations, and Curioſities thereof, and Vertues of them all.
All which are contained in ſix BOOKS,

Compoſed by JOHN FRENCH, Dr. of Phyſick.

London Printed by *Richard Cotes* and are to be ſold by *Thomas*
Williams at the Bible in Little-Britain without *Alderſgate*, 1651.



BOOK. 3. *Of the Art of Diſtillation.* 63

A Retort and its receiver before they be ſet on worke.

A Retort with its receiver ſet on work.

Oyle or Spirit of Salt may alſo be made after this manner.

Take one part of Salt, and three parts of powder of Bricks or Tiles, and mix them together, and put them into a Retort either of glaſſe or earth to which put fire as before.

After this manner you may make Oyle or Spirit of
Nitre
Salt Gem
Alum.

Note that theſe Salts muſt firſt be calcined, which is done by exhaling their flegme.

K I.

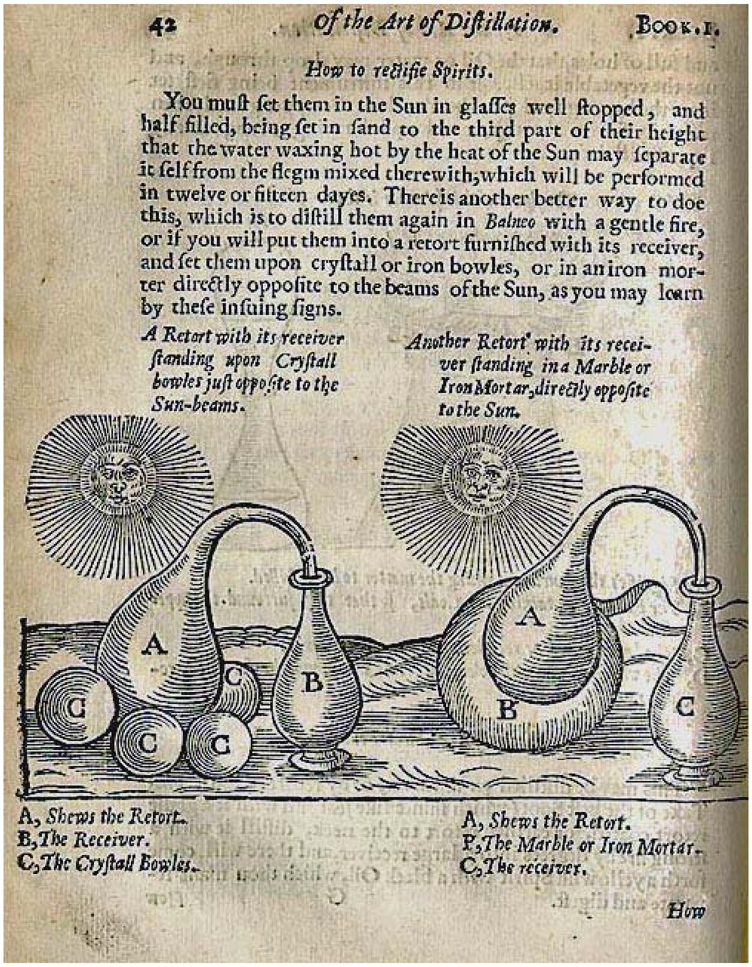
Book. 3. *Of the Art of Diſtillation.* 77

How to diſtill Spirits, and Oils out of Minerals, Vegetables, Bones, Horns, and faſter, and in a greater quantity in one houre then in the common way in twenty four.

This muſt be done in ſuch a Furnace as this.

A, Signifies the Furnace with its iron, or earthen diſtilling veſſell walled in, to which a very large recipient is joined. B, the Diſtiller, who with his left hand taketh off the cover, and with his right caſteth in his prepared matter with an iron ladle. C, the form of the diſtilling veſſell. D, the ſame, as it appeareth inward. E, the form of the veſſell not walled in but ſtanding on the coals for other uſes.

L 3 This,



42 *Of the Art of Diſtillation.* Book. I.

How to rectifie Spirits.

You muſt ſet them in the Sun in glaſſes well ſtopped, and half filled, being ſet in ſand to the third part of their height that the water waxing hot by the heat of the Sun may ſeparate it ſelf from the flegm mixed therewith; which will be performed in twelve or fifteen dayes. There is another better way to doe this, which is to diſtill them again in *Balneo* with a gentle fire, or if you will put them into a retort furniſhed with its receiver, and ſet them upon cryſtall or iron bowles, or in an iron morter directly oppoſite to the beams of the Sun, as you may learn by theſe inſuing ſigns.

A Retort with its receiver ſtanding upon Cryſtall bowles juſt oppoſite to the Sun-beams.

Another Retort with its receiver ſtanding in a Marble or Iron Mortar, directly oppoſite to the Sun.

A, *Shews the Retort.*
B, *The Receiver.*
C, *The Cryſtall Bowles.*

A, *Shews the Retort.*
B, *The Marble or Iron Mortar.*
C, *The receiver.*

How

Johann Rudolf Glauber

Johann Rudolf Glauber (1604-1670), a younger contemporary of van Helmont, was a practical chemist, best known for his treatise on furnaces, the various methods of distillation, and the types of distillates obtained. For this reason, he is sometimes referred to as one of the first chemical engineers.

Glauber acquired extensive knowledge about acids and salts and their interrealtionships as well as the preparations for sulfuric, nitric, acetic, and hydrochloric acids. He was the first to prepare sodium sulfate, a substance to which he claimed wonderful and absurd properties as a sort of miracle salt (called *sal-mirable*). Today, sodium sulfate is known in medicine as Glauber's salt.

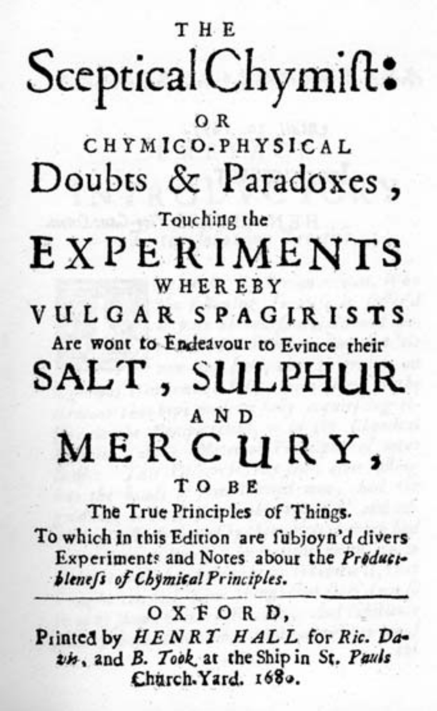
Otto Tachenius (c. 1620-1690), a former student of Sylvius, a well known physician, experienced chemist, and scientist of the day, recognized that "salts are composed of an acid and an alkali". His use of spot tests, such as nutgall extract for detecting iron compounds, helped lay the foundations of qualitative analysis.

The one chemist of the 17th century who exerted a profound influence upon the development of chemistry was **Robert Boyle** (1627-1691). He was the first chemist who employed his efforts to investigate nature, but, more important, was his attitude toward the *solution* of the problems he studied rather than reporting of facts and observations.

Robert Boyle

In his book, *The Sceptical Chymist* (published 1661), Boyle attempted to separate the occult from chemistry and he disclaimed the Aristotelian theory of the elements, the tria prima theory, and the ideas that matter can be separated into its basic elements by distillation. Instead, Boyle hypothesized a universal matter, the concept of atoms of different shapes and sizes, and the possibility of the existence of substances that might properly be called elements. He states:

> And, to prevent mistakes, I must advertise You, that I now mean by Elements, as those Chymists that speak plainest do by their Principles, certain Primitive and Simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the Ingredients of which all those call'd perfectly mixt Bodies are immediately compounded, and into which they are ultimately resolved.



THE
Sceptical Chymiſt:
OR
CHYMICO-PHYSICAL
Doubts & Paradoxes,
Touching the
EXPERIMENTS
WHEREBY
VULGAR SPAGIRISTS
Are wont to Endeavour to Evince their
SALT, SULPHUR
AND
MERCURY,
TO BE
The True Principles of Things.
To which in this Edition are ſubjoyn'd divers
Experiments and Notes about the *Producibleneſs of Chymical Principles.*

OXFORD,
Printed by *HENRY HALL* for *Ric. Davis*, and *B. Took* at the Ship in St. *Pauls* Church-Yard. 1680.

Although Boyle questioned substances that were called *elements* in his time, he could not give any examples of elements that fit his definition. (Elements, were still considered to be substances obtained from the earth or by heating ores until stable products [usually metal oxides] resulted. The fact that something such as carbon had to be mixed with these stable products to get pure metals, the metals were believed to be compounds, not elements.) Thus Boyle left a void in the explanation of matter and what happened in the process of combustion.

Boyle, along with Otto Tachenius, helped to lay the foundations of qualitative analysis using flame colors, spot tests, fumes, precipitates, specific gravity, and solvent action as analytical tools. His use of indicators led to the association of various acidic and alkaline substances.

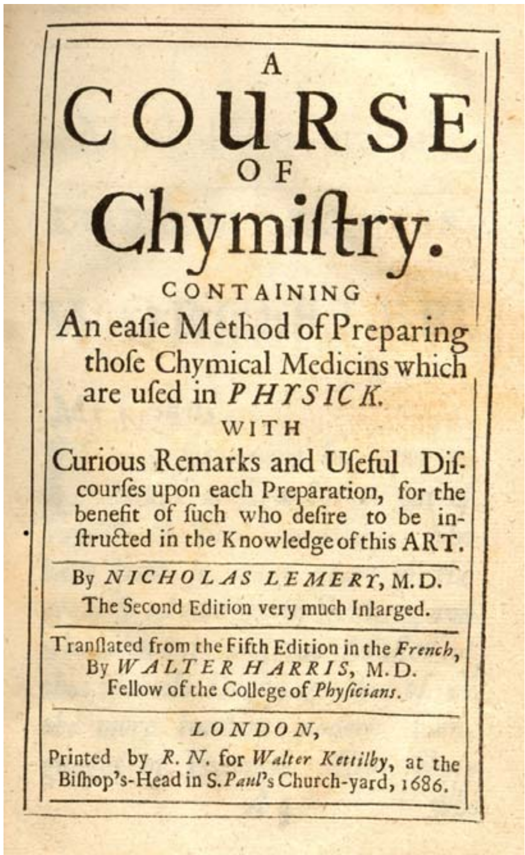
With the aid of Robert Hooke (1635-1703), he carried out experiments with the air pump which led to recognition of the pressure-volume relationship in gases known today as Boyle's Law.

Hooke and Boyle also studied the behavior of combustible substances under various conditions, including evacuated vessels, and observed that combustion stops when air was withdrawn. They realized that air was involved in the combustion of most substances, but, with their inability to isolate and collect gases, their explanations were considered too speculative.

Nicolas Lémery (1645-1715), was a French chemist and pharmacist. Lemery did not concern himself much with theoretical speculations, but holding chemistry to be a demonstrative science, confined himself to the straightforward exposition of facts and experiments. His book *Cours de chymie* (1675) became a standard textbook and went through many editions, and was translated in all the European languages. The importance of his book lies not in its originality or its thoroughness, but rather in its attractive presentation of chemical ideas in corpuscular-mechanist terms. A *Course of Chymistry* sold "like a work of romance or satire".

Nicolas Lemery

Lemery introduced his explanations of chemical reactions in terms of particle shape and movement explaining the nature of salts to their shapes. He said acid salts must have sharp pointed particles because of their sharp taste and because they solidify in the form of sharp pointed crystals. Alkalis, he said were composed of earthy solid particles with pores so shaped as to admit entry of the spike particles of acid. Lemery postulated that, for reaction to take place between a particular acid and alkali, there must be an appropriate relationship between the size of the acid spikes and alkaline pores.



A
COURSE
OF
Chymiſtry.
CONTAINING
An eaſie Method of Preparing
thoſe Chymical Medicins which
are uſed in *PHYSICK.*
WITH
Curious Remarks and Uſeful Diſcourſes
upon each Preparation, for the
benefit of ſuch who deſire to be inſtructed
in the Knowledge of this ART.
By *NICHOLAS LEMERY*, M.D.
The Second Edition very much Inlarged.
Tranſlated from the Fifth Edition in the *French*,
By *WALTER HARRIS*, M.D.
Fellow of the College of *Phyſicians.*
LONDON,
Printed by *R. N.* for *Walter Kettilby*, at the
Biſhop's-Head in S. *Paul*'s Church-yard, 1686.

The title page from *Lemery's Course of Chymistry*

Lemery's tables of apparatus (next page)

The SECOND TABLE.

aa A Moveable Furnace for fuſions.
b Regiſters, or holes to let the air in to the fire.
c A Dome divided in two.
d A little Chimny, and the flame paſſing through it.
e An Iron trevet to ſupport the furnace.
f A glaß Mortar, with its Peſtle.
gh A pot with a coffin of paper over it, for receiving the Flowers of Benjamin.
ikl A Matraß, or Bolt-head, and its blind-head, for ſublimations.
mn A great earthen pan, with a little Cup turned upſide downwards. A Crucible containing the lighted Sulphur. A great glaß Tunnel, to draw Spirit of Sulphur.
o A Mould.
p A copper Body.
q Its Refrigeratory.
r The Receiver.
s A Circulating veſſel.
t A Pot with a hole in the middle of its height, and the ſtopple of the hole lying by.
u Three Aludels, or Pots upon one another.
x The glaß head.
y A Mould to make the balls of Regulus of Antimony, which are called perpetual Pills.
z The Mould wherewith to form the lapis infernalis.
aa A little furnace, and its pan with ſand in it, and an earthen pan filled with liquor to be evaporated.
bb A Coppel.
cc A little Coppel to make trials with.

The

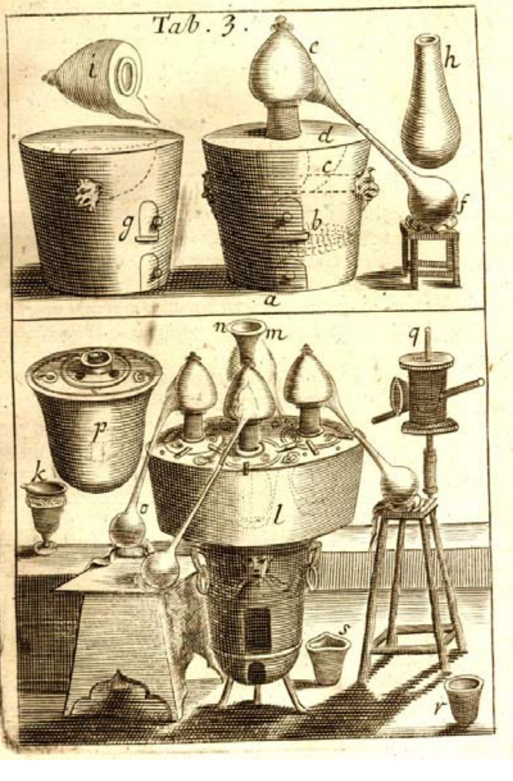
The SECOND TABLE.

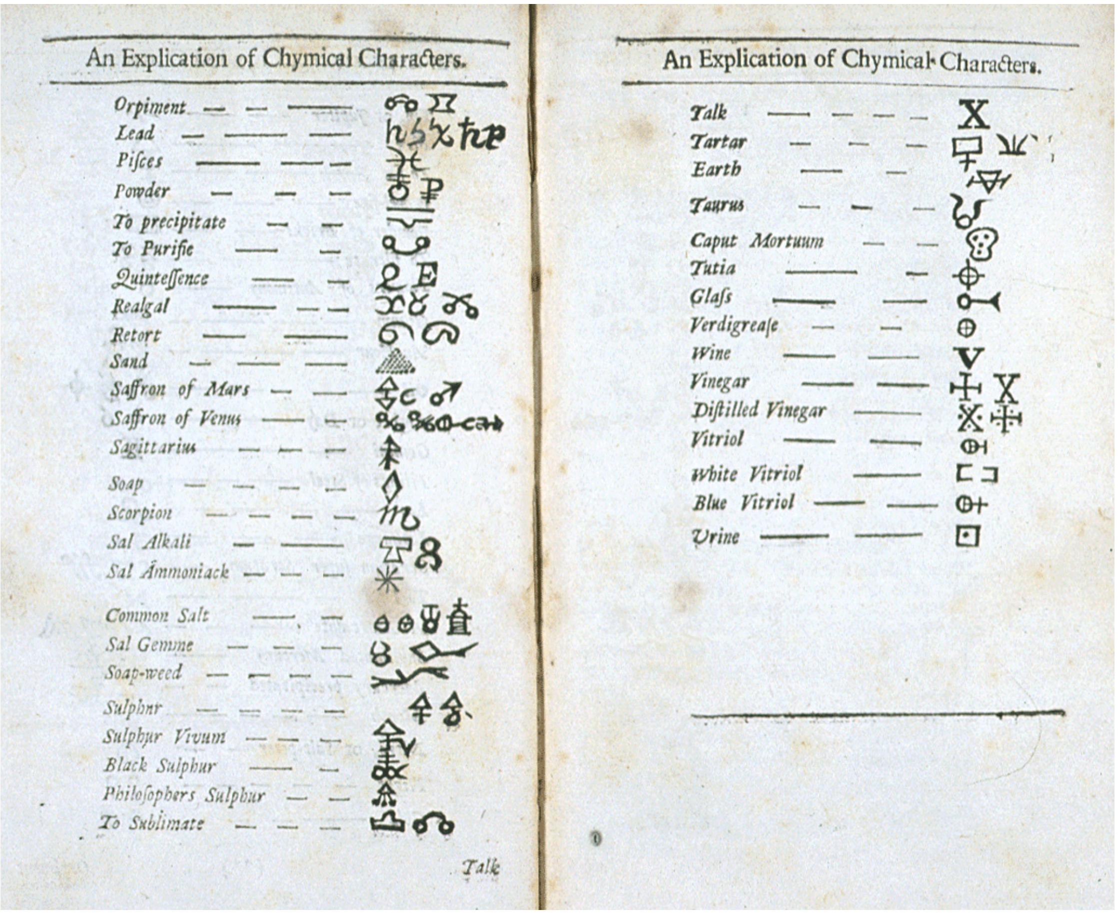
The THIRD TABLE.

A Moveable Furnace to diſtil in Sand.
a The Aſh hole, and its door.
b The Fire-place, and its door.
c The Cucurbite, or Body.
d The Sand, wherein the Body is placed.
e The Head.
f The Receiver.
g The ſame Furnace empty.
h A Body.
i A Head.
k A glaß in which Oil of Cloves is made.
l A Copper Balneum to contain, and diſtil with four Alembicks.
mn A Pipe through which the hot water is poured into the Balneum, according as it evaporates.
o The Receiver.
p A Balneum to diſtil with one Alembick.
q A Mold to make Cups of Regulus of Antimony.
r A French Crucible.
s A German Crucible.

The

The THIRD TABLE.





An Explication of Chymical Characters.

Orpiment
Lead
Piſces
Powder
To precipitate
To Purifie
Quinteſſence
Realgal
Retort
Sand
Saffron of Mars
Saffron of Venus
Sagittarius
Soap
Scorpion
Sal Alkali
Sal Ammoniack
Common Salt
Sal Gemme
Soap-weed
Sulphur
Sulphur Vivum
Black Sulphur
Philoſophers Sulphur
To Sublimate

Talk

An Explication of Chymical Characters.

Talk
Tartar
Earth
Taurus
Caput Mortuum
Tutia
Glaſs
Verdigreaſe
Wine
Vinegar
Diſtilled Vinegar
Vitriol
White Vitriol
Blue Vitriol
Vrine

Lemery’s chemical symbols

The Phlogiston Theory

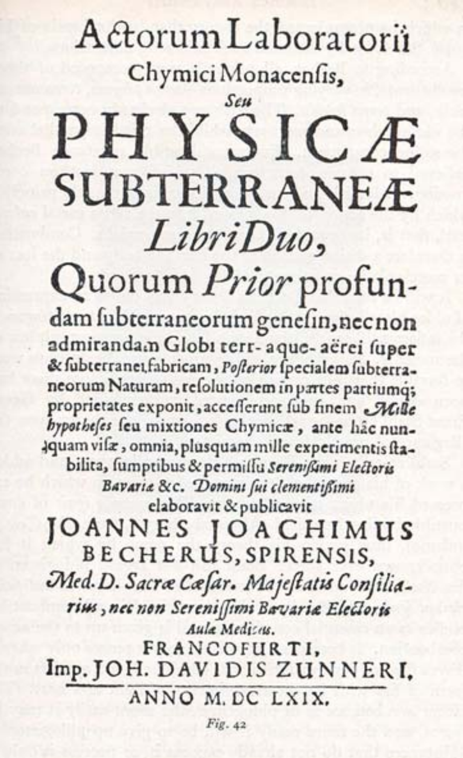
About the same time as Boyle, **Johann Joachim Becher** (1635-1682), in his book *Physicae Subterraneae* (1669) proposed that bodies are composed of three earths:

Terra lapidea: the salt principle - this composed the ash that remained after combustion.

Terra mercurialis: mercurial earth - responsible for fusibility of metals.

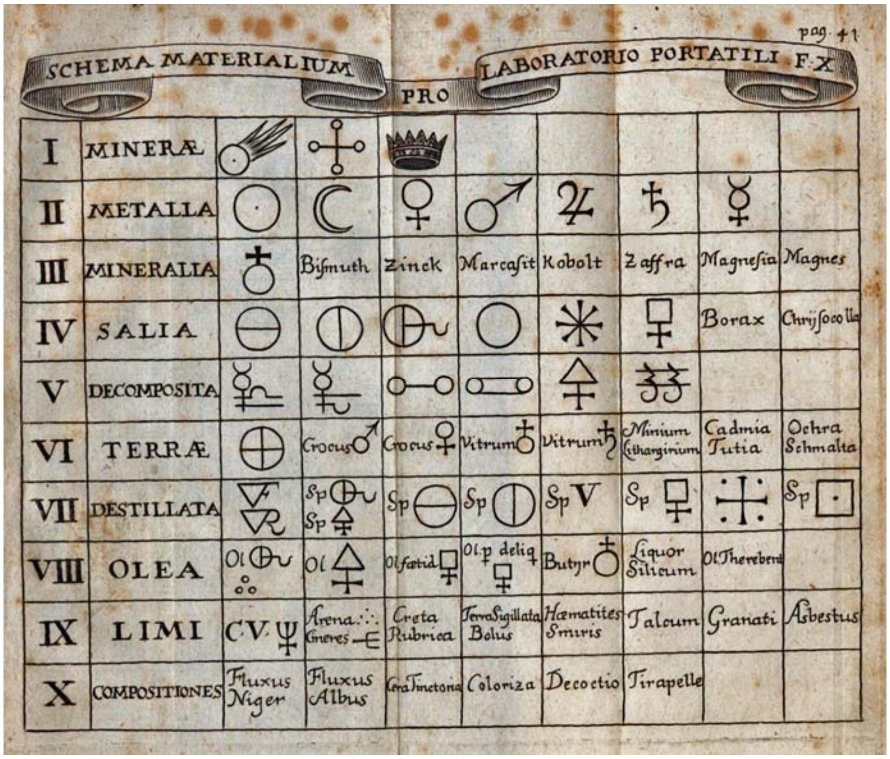
Terra pinguis: the sulfur principle - released by the fire during combustion.

In combination, the terra pinguis was released by the fire, fusibility was due to terra mercurialis, and terra lapedia remained as the calx after complete ignition of a metal or other substance. Thus, combustion, as viewed by Becher, was the breakup of a body with expulsion of its more volatile constituents.



Actorum Laboratorii
Chymici Monacenſis,
Seu
PHYSICÆ
SUBTERRANEÆ
Libri Duo,
Quorum *Prior* profundam ſubterraneorum geneſin, nec non admirandam Globi terr- aque- aërei ſuper & ſubterranei fabricam, *Poſterior* ſpecialem ſubterraneorum Naturam, reſolutionem in partes partiumq; proprietates exponit, acceſſerunt ſub finem *Mille hypotheſes* ſeu mixtiones Chymicæ, ante hâc nunquam viſæ, omnia, plusquam mille experimentis ſtabilita, ſumptibus & permiſſu *Sereniſſimi Electoris Bavariæ* &c. *Domini ſui clementiſſimi* elaboravit & publicavit
JOANNES JOACHIMUS
BECHERUS, SPIRENSIS,
Med. D. Sacræ Cæſar. Majeſtatis Conſiliarius, nec non Sereniſſimi Bavariæ Electoris Aulæ Medicus.
FRANCOFURTI,
Imp. JOH. DAVIDIS ZUNNERI,
ANNO M. DC LXIX.

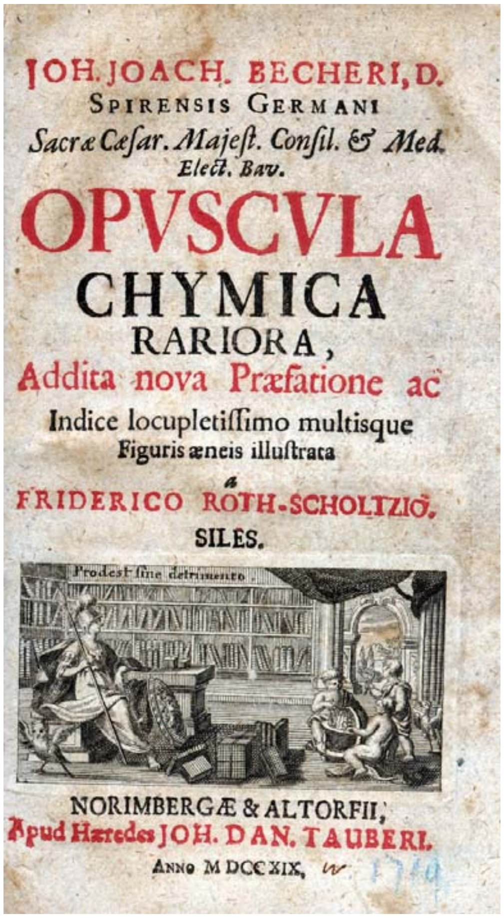
Fig. 42



pag. 41

SCHEMA MATERIALIUM PRO LABORATORIO PORTATILI F. X

I	MINERÆ	☄	⌖	♔					
II	METALLA	☉	☽	♀	♂	♃	♄	☿	
III	MINERALIA	♁	Biſmuth	Zinck	Marcaſit	Kobolt	Zaffra	Magneſia	Magnes
IV	SALIA	⊖	⦶	⊕	○	✳	🜿	Borax	Chryſocolla
V	DECOMPOSITA	☿	☿	o—o	⊂⊃	🜍	333		
VI	TERRÆ	⊕	Crocus ♂	Crocus ♀	Vitrum ♁	Vitrum ♄	Minium Lithargirium	Cadmia Tutia	Ochra Schmalta
VII	DESTILLATA	🜄	Sp ⊕ Sp 🜍	Sp ⊖	Sp ⦶	Sp V	Sp 🜿	⁜	Sp ⊡
VIII	OLEA	Ol ⊕ ∴	Ol 🜍	Ol fœtid 🜿	Ol. p deliq 🜿	Butyr ♁	Liquor Silicum	Ol Therebent	
IX	LIMI	C.V. ♆	Arena ∴ Cineres	Creta Rubrica	Terra Sigillata Bolus	Hæmatites Smiris	Talcum	Granati	Asbestus
X	COMPOSITIONES	Fluxus Niger	Fluxus Albus	Cera Tinctoria	Coloriza	Decoctio	Tirapelle		

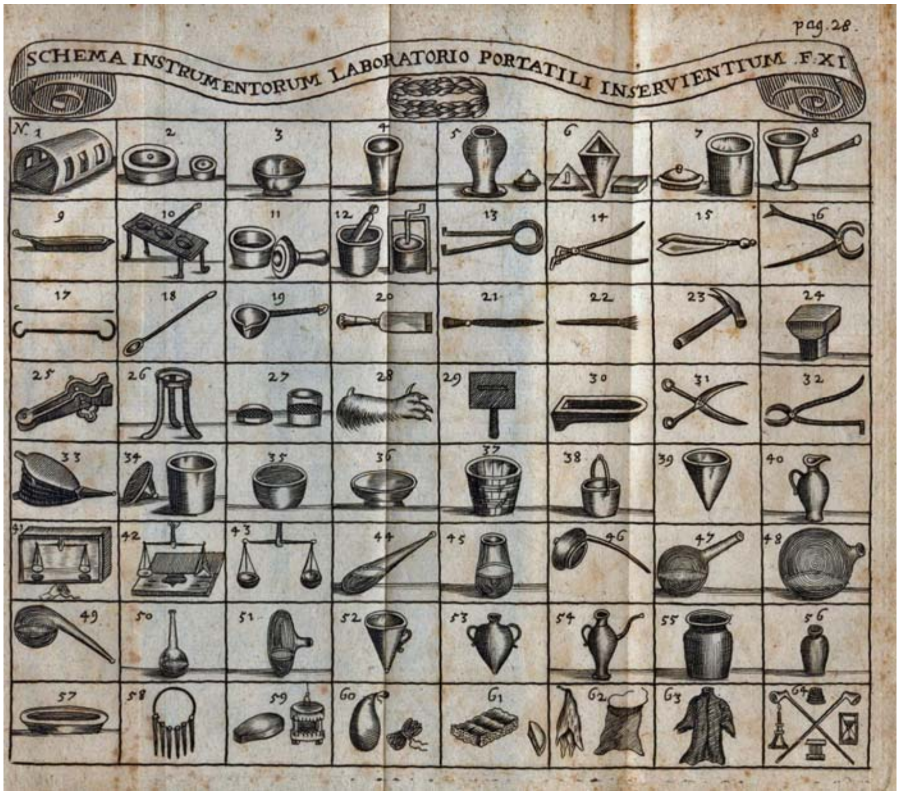


JOH. JOACH. BECHERI, D.
SPIRENSIS GERMANI
Sacræ Cæſar. Majeſt. Conſil. & Med. Elect. Bav.
OPUSCULA
CHYMICA
RARIORA,
Addita nova Præfatione ac
Indice locupletiſſimo multisque
Figuris æneis illuſtrata
a
FRIDERICO ROTH-SCHOLTZIO,
SILES.

Prodest sine detrimento

NORIMBERGÆ & ALTORFII,
Apud Hæredes JOH. DAN. TAUBERI.
ANNO MDCCXIX.

1719



Title page from Becher’s *Physicae Subterraneae* (upper left)

Title page from Becher’s Opuscula Chymica Rariora (left)

Becher’s scheme of materials (above, top)

Becher’s scheme of laboratory instruments (above, bottom)

Georg Ernest Stahl (1660-1734), a pupil of Becher, continued with Becher's work. He renamed the terra pinguis principle *phlogiston* (from the Greek "to inflame") and built up a rational system of chemistry based on experimental observations. (This was the first rational theory to gain widespread acceptance.)

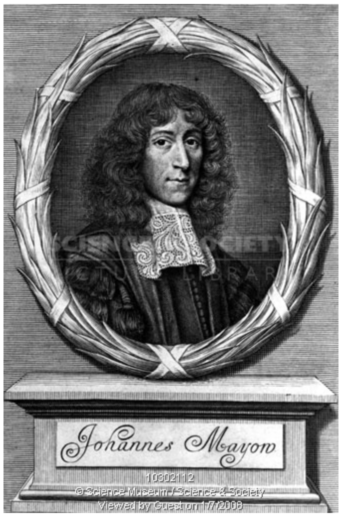
The phlogiston theory assumed that metals were compounds containing phlogiston in combination with metal oxides (calces). On ignition, phlogiston was freed from the metal leaving the calx (oxide) behind. When the oxide was heated with a substance rich in phlogiston, such a charcoal (or any substance which burns away almost completely and leaves little residue), the calx would take up the phlogiston and the metal would be regenerated.

The major objection to the theory was that the calx was heavier than the metal. Stahl dismissed this as an unimportant detail. Although many chemists of the time accepted this concept, others tried to explain it by ascribing a negative weight (or buoyant effect) to phlogiston.

The comprehensiveness of the phlogiston theory proved to be amazingly good in a world in which chemistry still held a qualitative attitude toward matter. The theory not only explained combustion and the calcinations of metals, it also explained the smelting of ores equally well. (Since the ore of the metal, or the calx left by roasting of an ore, was converted to the metal by heating with charcoal resulting in the transfer of phlogiston, the theory made sense to the chemists of the time.) Respiration, as well as many chemical changes, were explained in terms of phlogistic concepts.

The phlogiston theory tended to direct chemical thought toward mineral and pneumatic studies, in contrast to the predominantly medical interests which had previously dominated the science.

Pneumatic Chemistry

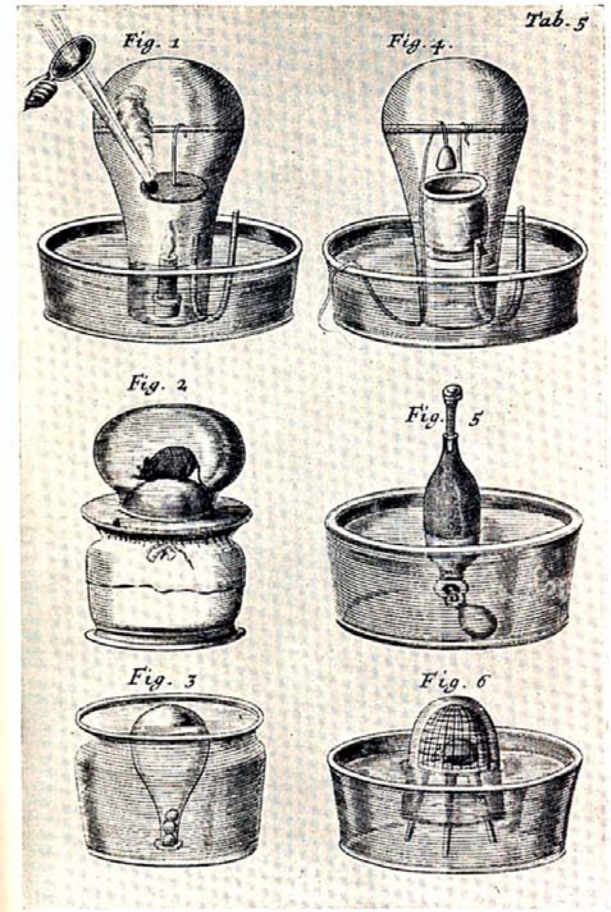


In the field of pneumatic chemistry, **John Mayow** (1643-1678) emphasized the similarity between combustion in air and combustion in saltpetre (potassium nitrate) and suggested there was a common "spirit" necessary to combustion. Mayow called this the *nitro-aerial spirit*. He also noted the increase in weight during calcination and the decrease in volume a limited amount of air undergoes when a candle is burnt in it. Thus, he attributed calcination as a combination with nitro-aerial particles and burning as a loss of nitro-aerial particles from the air.

Mayow's conclusions tend to suggest the presence of oxygen in air and in saltpeter, however, Mayow assigned properties to nitro-aerial particles that show he had no real concept of the nature of burning. He said:

> Although nitro-aerial particles were present in air, they were not part of it.
>
> The sun's rays were imagined to be a chaos of nitro-aerial particles.
>
> Metallic iron, which produces sparks when struck, contains nitro-aerial particles.
>
> Nitro-aerial particles can be annihilated.
>
> Nitro-aerial particles give rise to heat if set in motion.
>
> Nitro-aerial particles are part of the red fumes given off when nitric acid is heated.

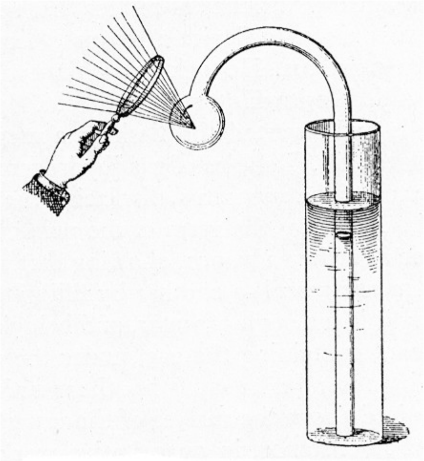
Mayow did show that some gases could be stored in inverted vessels over water. He also showed that a gas could be transferred from one vessel to another by filling a second vessel with water and bringing the mouth of the first vessel, filled with gas, under the mouth of the second – as long as the whole process was done under water. He emphasized the importance of equalizing pressures between the atmosphere and the gas in a bottle by adjusting water levels using a siphon tube.



Mayow's apparatus

In 1697, **Jean (Johann) Bernouilli** (1667-1748) using 4 grams of gunpowder, heated in a flask, using a burning glass, demonstrated that the propulsive force of gunpowder is due to the production of gases that, when liberated, occupy a much greater space than the powder from which they are formed.

Jean (Johann) Bernouilli



Bernoulli's apparatus

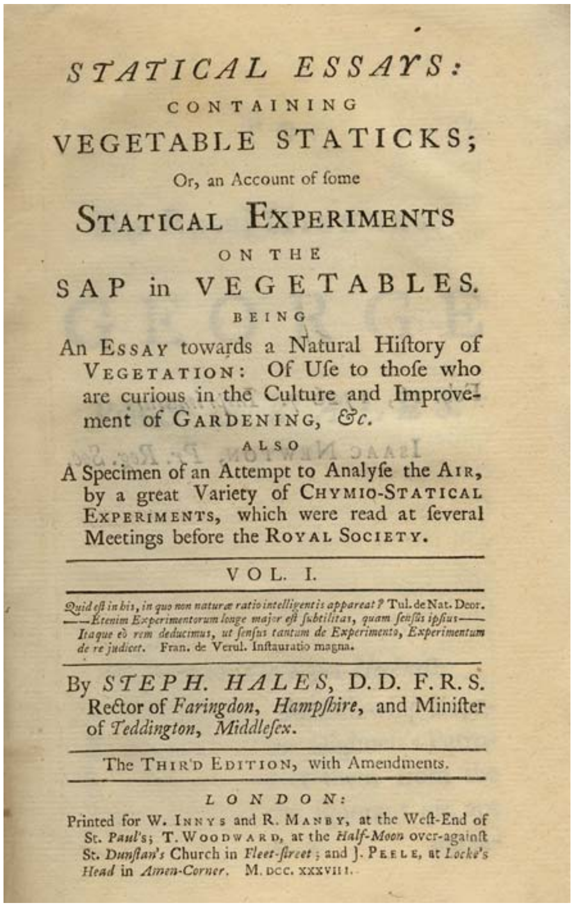
Stephen Hales (1677-1761), an English biologist, performed research on the physiology of plants and, in 1727, published a book titled *Vegetable Staticks*. Hales observed that plants absorb air through their leaves and realized that the air is "fixed" (converted to solid material) in the plant. Since he had many occasions to work with gases, Hales devised several apparatus to collect them and, thus, devised the pneumatic trough.

Stephen Hales

Using the pneumatic trough, Hales was able to collect gases given off by heating blood, tallow, horn, oyster shells, wood, seeds, honey, beeswax, sugar, coal, tartar, and urinary calculi. He also collected gases from fermentation, and putrefaction, as well as those given off when chalk, pyrites, and saltpetre were heated.

Unfortunately, Hales was only interested in the qualitative aspects of his experiments and only measured the volumes of gases collects without observing any properties of the individual gases themselves.

About the same time, **Hermann Boerhaave** (1668-1738), a Dutch physician and teacher of chemistry, expressed the belief that air may take part in combustion and discounted the phlogiston theory.. He introduced exact, quantitative methods by measuring temperature and using the best available balances made by Fahrenheit. His textbook, *Elementa Chemiae*, became a popular textbook and was printed in many editions and translated into several languages.



STATICAL ESSAYS:
CONTAINING
VEGETABLE STATICKS;
Or, an Account of ſome
STATICAL EXPERIMENTS
ON THE
SAP in VEGETABLES.
BEING
An ESSAY towards a Natural Hiſtory of
VEGETATION: Of Uſe to thoſe who
are curious in the Culture and Improvement of GARDENING, *&c.*
ALSO
A Specimen of an Attempt to Analyſe the AIR,
by a great Variety of CHYMIO-STATICAL
EXPERIMENTS, which were read at ſeveral
Meetings before the ROYAL SOCIETY.

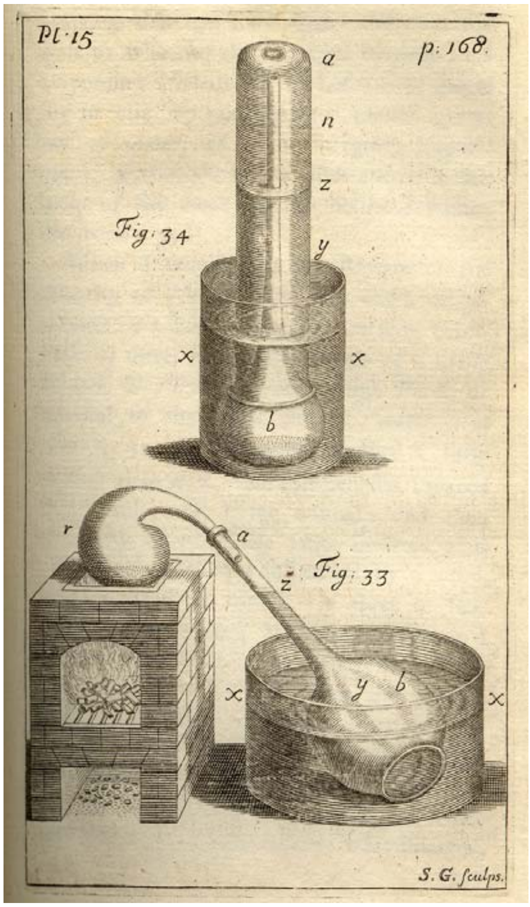
VOL. I.

Quid eſt in his, in quo non naturæ ratio intelligentis appareat? Tul. de Nat. Deor.
——*Etenim Experimentorum longe major eſt ſubtilitas, quam ſenſûs ipſius*——
Itaque eò rem deducimus, ut ſenſus tantum de Experimento, Experimentum de re judicet. Fran. de Verul. Inſtauratio magna.

By *STEPH. HALES*, D.D. F.R.S.
Rector of *Faringdon*, *Hampſhire*, and Miniſter
of *Teddington*, *Middleſex*.

The THIR'D EDITION, with Amendments.

LONDON:
Printed for W. INNYS and R. MANBY, at the Weſt-End of
St. *Paul's*; T. WOODWARD, at the *Half-Moon* over-againſt
St. *Dunſtan's* Church in *Fleet-ſtreet*; and J. PEELE, at *Locke's*
Head in *Amen-Corner*. M.DCC.XXXVIII.

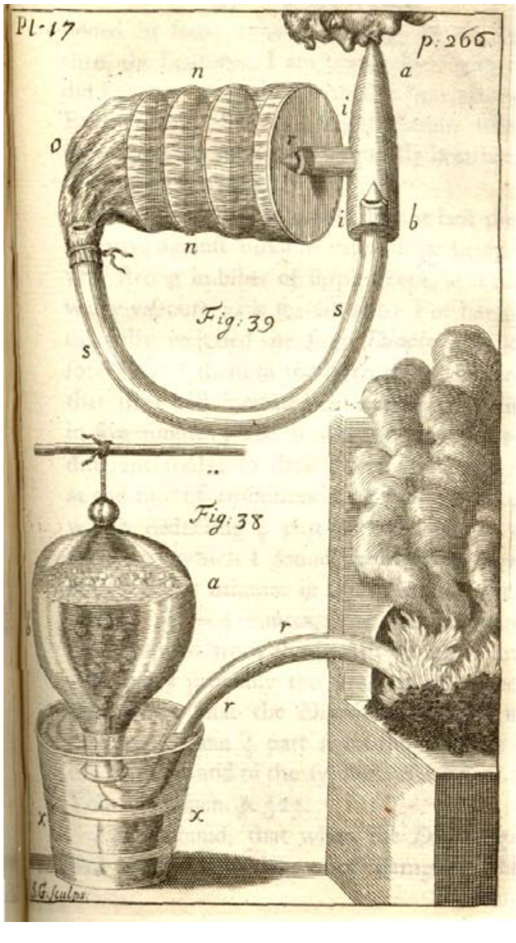


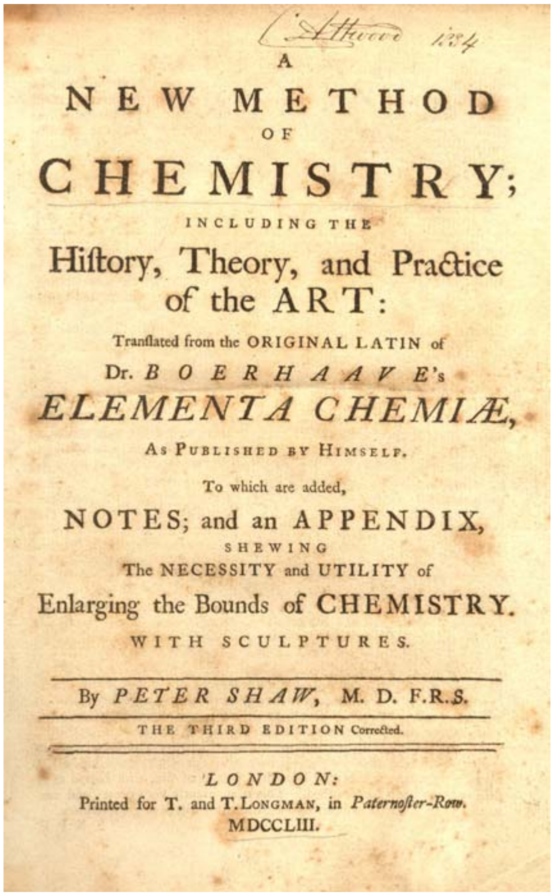
Pages from Stephen Hales, *Statical Essays*

Title page (above)

Figures showing how he collected gases from fermentation and products of distillation (upper right)

Hales' pneumatic trough (right)





Atwood 134

A

NEW METHOD

OF

CHEMISTRY;

INCLUDING THE

Hiſtory, Theory, and Practice of the ART:

Tranſlated from the ORIGINAL LATIN of

Dr. *BOERHAAVE*'s

ELEMENTA CHEMIÆ,

As Published by Himself.

To which are added,

NOTES; and an APPENDIX,

SHEWING

The NECESSITY and UTILITY of

Enlarging the Bounds of CHEMISTRY.

WITH SCULPTURES.

By *PETER SHAW*, M. D. F.R.S.

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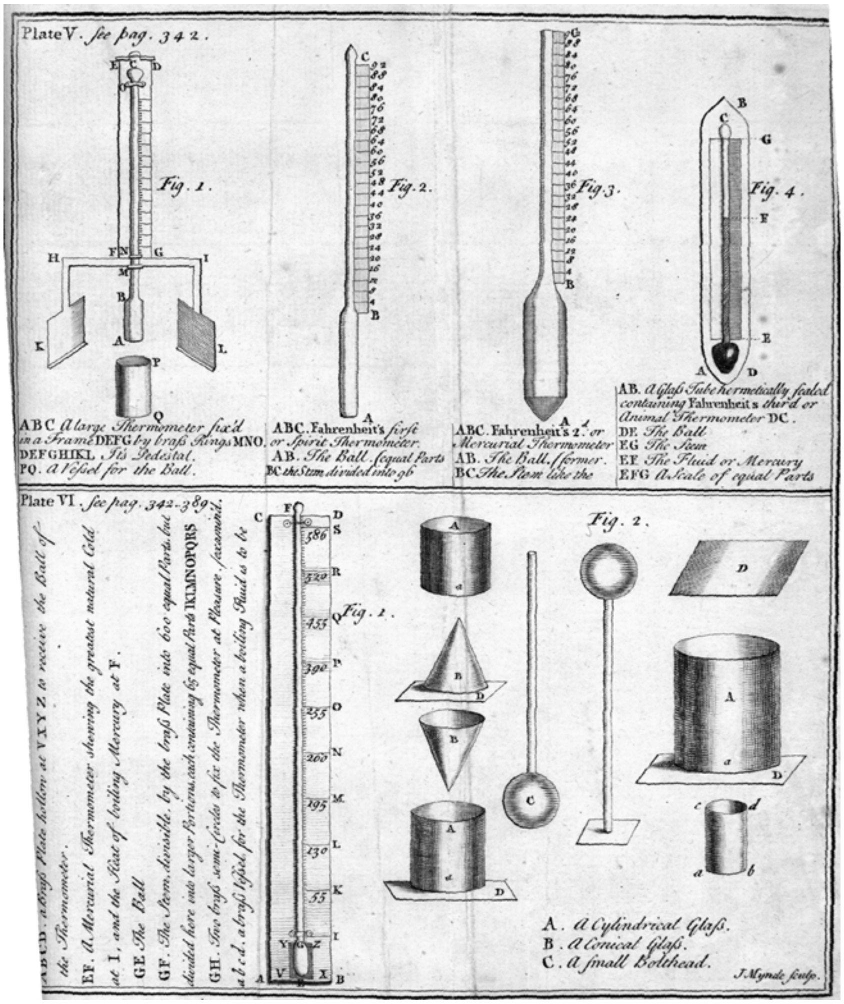
MDCCLIII.

Title page from Boerhaave's Elementa Chemiae



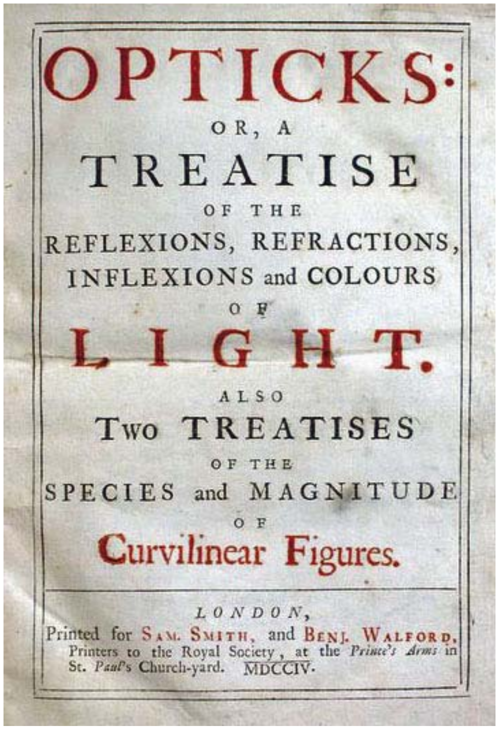
Boerhaave's illustrations of Fahrenheit's thermometers

Sir Isaac Newton, Alchemist

Sir Isaac Newton (1642 -1727), famous for his mathematics and physics, practiced alchemy. In his notebooks, alongside explanations of optical and physical phenomena such as freezing and boiling, are found notes of his alchemical experiments. Although he wrote extensively on the subject, after his death in 1727, the Royal Society deemed that this material was "not fit to be printed." The papers were rediscovered in the middle of the twentieth century and most scholars now concede that Newton was first and foremost an alchemist.

At Trinity College, a part of Cambridge University, Newton maintained a small laboratory where he conducted innumerable alchemical experiments. Newton spent days locked up in his laboratory, he rarely left his chambers or went visiting. One of his servants records: "He very rarely went to bed until two or three of the clock, sometimes not till five or six, lying about four or five hours, especially at springtime or autumn, at which time he used to employ about six weeks in his laboratory, the fire scarce going out night or day. What his aim might be I was unable to penetrate into."

In 1692-1693, Newton experienced a ”derangement of the intellect” (a nervous breakdown) where he broke with associates, accused friends of plotting against him, and reported conversations which never took place. Newton left Trinity College to recuperate and, it appears that he also discontinued his alchemical experiments at that time. That illness is now viewed as a result of heavy metal poisoning as a result of his alchemical studies as Newton not only worked in a confined space breathing fumes from his alchemical experiments, but also from tasting the products. Spargo and Pounds were able to get samples of Newton’s hair and subject them to neutron activation analysis showing abnormally high concentrations of chlorine, gold, arsenic, antimony, lead and mercury.

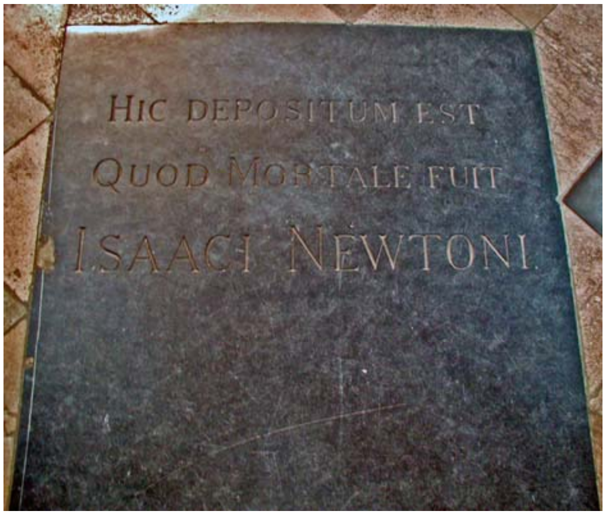


OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

LONDON,
Printed for SAM. SMITH, and BENJ. WALFORD,
Printers to the Royal Society, at the *Prince's Arms* in
St. *Paul's* Church-yard. MDCCIV.

Another event in his life that took him away from his alchemical experiments was that in 1696, Newton was appointed Warden of the Mint and then Master in 1699. In 1696, he moved from Cambridge to London, where he lived until his death.

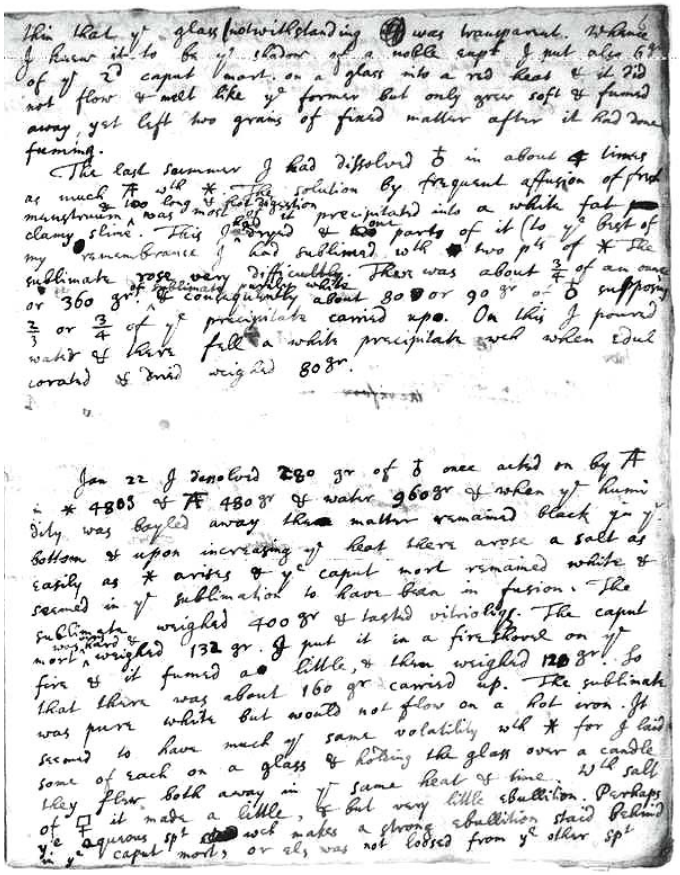
In Book 3, Part 1, Query 31 of his book Opticks, Newton formulated a corpuscular theory in which *elements* consisted of different arrangements of atoms, and atoms consisted of small, hard, billiard ball-like particles. He explained chemical reactions in terms of the chemical affinities of the participating substances.



Above: Newton's tomb in Westminster Abbey, London

Left: Monument to Newton in Westminster Abbey, London. His tomb is located in the floor in front of the monument.

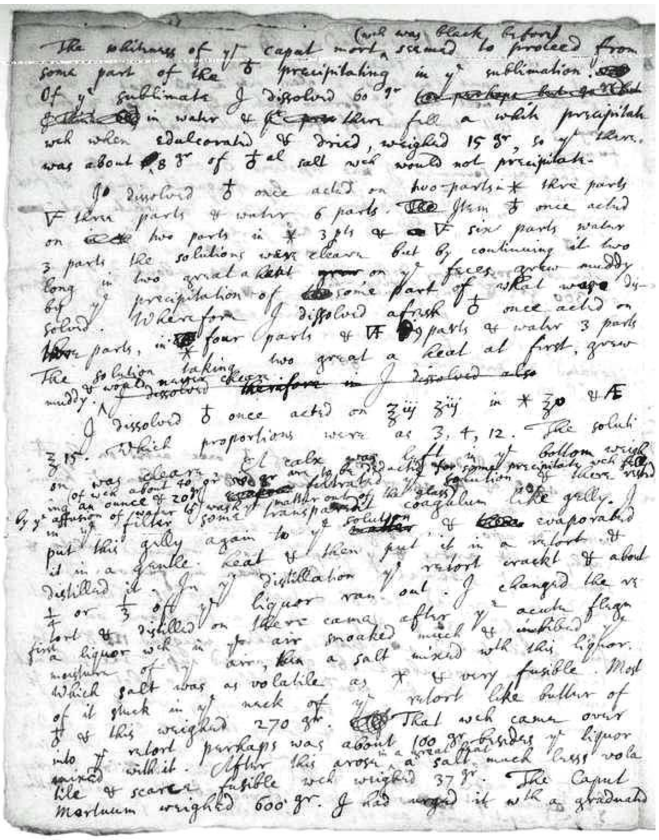
On the following pages are two pages from Newton's notebook from the Cambridge University Library, Cambridge, U.K., Additional MS 3973. A picture of the actual page appears on the right side and the transcription appears on the left.



thin that the glass notwithstanding was transparent. Whence I knew it to be the shadow of a noble experiment I put also 6$^{\text{grains}}$ of the 2$^{\text{d}}$ caput mortuum on a glass into a red heat & it did not flow & melt like the former but only grew soft & fumed away, yet left two grains of fixed matter after it had done fuming

The last summer I had dissolved ♁ in about 4 times as much 🜅 with 🜹. The solution by frequent affusion of fresh menstruum & too long & hot digestion was most of it precipitated into a white fat clamy slime. This I had dryed & one part of it (to the best of my remembrance I had sublimed with two parts of 🜹 The sublimate rose very difficultly. There was about 3/4 of an ounce or 360 $^{\text{grains}}$. of sublimate purely white & consequently about 80 or 90$^{\text{grains}}$ of ♁ supposing 2/3 or 3/4 of the precipitate carried up. On this I poured water & there fell a white precipitate which when edulcorated & dried weighed 80$^{\text{grains}}$.

Jan 22 I dissolved 280 grains of ♁ once acted on by 🜅 in 🜹 480$^{\text{grains}}$ & 🜅 480$^{\text{grains}}$ & water 960$^{\text{grains}}$ & when the humidity was boyled away the matter remained black in the bottom & upon increasing the heat there arose a salt as easily as 🜹 arises & the caput mortuum remained white & seemed in the sublimation to have been in fusion. The sublimate weighed 400$^{\text{grains}}$ & tasted vitriolique. The caput mortuum was very hard & weighed 132 grains. I put it in a fireshovel on the fire & it fumed a little, & then weighed 120$^{\text{grains}}$. So that there was about 160$^{\text{grains}}$ carried up. The sublimate was pure white but would not flow on a hot iron. It seemed to have much the same volatility with 🜹 for I laid some of each on a glass & holding the glass over a candle they flew both away in the same heat & time. With salt of 🜿 it made a little, & but very little ebullition. Perhaps the aqueous spirit which makes a strong ebullition staid behind in the caput mortuum, or els was not loosed from the other spirit

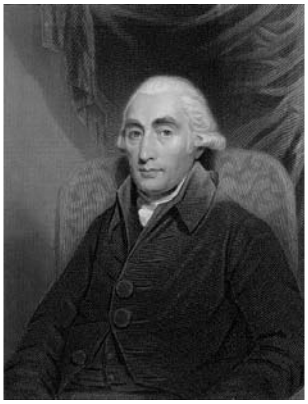


The whiteness of the caput mortuum (which was black before) seemed to proceed from some part of the ♁precipitating in the sublimation.
Of the sublimate I dissolved 60 $^{\text{grains}}$ in water & there fell a white precipitate which when edulcorated & dried, weighed 15$^{\text{grains}}$, so that there was about 8$^{\text{grains}}$ of ♁$^{\text{al}}$ salt which would not precipitate.

I dissolved ♁once acted on two parts in ✳thre parts 🜅three parts & water 6 parts. Item ♁once acted on two parts in ✳3$^{\text{parts}}$& 🜅six parts water 3 parts the solutions were cleare but by continuing it two long in two great a heat on the feces grew muddy by the precipitation of some part of what was dissolved. Wherefore I dissolved afresh ♁once acted on thre parts, in ✳four parts & 🜅9 parts & water 3 parts The solution taking two great a heat at first, grew muddy. & would never cleare.

I dissolved ♁once acted on ℥iij ℥iij in ✳℥v & Æ ℥15. Which proportions were as 3, 4, 12. The solution was cleare, A calx was left in the bottom weighing an ounce & 20$^{\text{grains}}$ (of which about 40 or 50 grains are to be deducted for some precipitate which fell by the affusion of water to wash the matter out of the glass) I filtrated the solution & there rested in the filter some transparent coagulum like gelly. I put this gelly again to the solution, & evaporated it in a gentle heat & then put it in a retort & distilled it. In the distillation the retort crackt & about 1/4 or 1/3 of the liquor ran out. I changed the retort & distilled on there came after the acute flegm first a liquor which in the air smoaked much & imbibed the moisture of the air, then a salt mixed with this liquor. Which salt was as volatile as ✳& very fusible. Most of it stuck in the neck of the retort like butter of ♁& this weighed 270$^{\text{grains}}$. That which came over into the retort perhaps was about 100$^{\text{grains}}$ besides the liquor mixed with it. After this arose in a great heat a salt much lesss volatile & scarce fusible which weighed 37$^{\text{grains}}$. The Caput Mortuum weighed 600$^{\text{grains}}$. I had urged it with a graduated

X. Chemistry in the 18th Century: The Events Leading to the Overthrow of the Phlogiston Theory



Dr. Joseph Black

Dr. Joseph Black (1728-1799), a Scottish physicist and chemist, isolated carbon dioxide in its pure state, in 1754, and named it "fixed air" because it could be present (or fixed) in a solid. In 1756, he demonstrated that air may be involved in chemical reactions by showing the uptake of fixed air (carbon dioxide) by quicklime (calcium oxide) to form chalk (calcium carbonate) and the reverse reaction when chalk is heated. This study, by Black, was all quantitative, using an analytical balance of his own design, and through careful weighings, revealed the role of fixed air in the cycle of reactions he studied.

Black's experiment with fixed air: (using modern chemical equations)

Chalk (calcium carbonate, $CaCO_3$), upon heating, formed quicklime (calcium oxide, CaO) and fixed air (carbon dioxide, CO_2)

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2$$

Quicklime reacted with water to form slaked lime (calcium hydroxide, $Ca(OH)_2$)

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Slaked lime reacts with potash (potassium carbonate, K_2CO_3) to form chalk and caustic potash (potassium hydroxide, KOH)

$$Ca(OH)_2 + K_2CO_3 \rightarrow CaCO_3 + 2\,KOH$$

On standing in air, slaked lime absorbed fixed air forming chalk and water.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

On merely standing in air, quicklime absorbed fixed air forming chalk.

$$CaO_2 + CO_2 \rightarrow CaCO_3$$

In 1761, Black discovered that when ice melts it absorbs heat without changing temperature. From this he concluded that the heat must have combined with the ice particles and become latent. (This heat is now called the latent heat of fusion.) This, along with his work showing that different substances have different specific heats, earned Black the title of founder of calorimetry.

Torbern Bergman (1735-1784), a Swedish chemist, published his *Dissertation on Elective Attractions* in 1775, which contained a table of chemical affinities of all the substances known to him. He states in his dissertation:

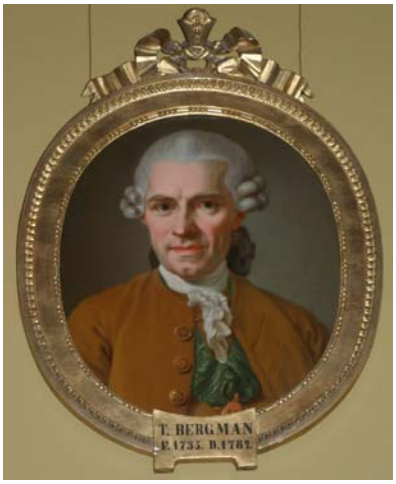
> "I contend that almost all of Chemistry rests upon this doctrine of elective attraction like a solid base, and if we want a reasonable theory which conveniently and clearly binds things together in a single idea, this theory serves us well."

This was not the first table of elective attractions, but the most complete table of the time. Bergman states that

> "The tables which exist up to now are quite scanty with regard to the number of materials shown, and any substances which are included are compared with very few of the others."

In addition to the tables, Bergman used a number of four-cornered Schemes to represent chemical reactions. At the time, chemical equivalents were not established, so these schemes are not to be considered as balanced chemical reactions, but they were a systematic way of writing chemical reactions.

The tables, on the following pages, show Bergman's elective attractions, the third shows Bergman's schemes, and the fourth shows modern equivalents of some example schemes. Also included is a table of the symbols used by Bergman.



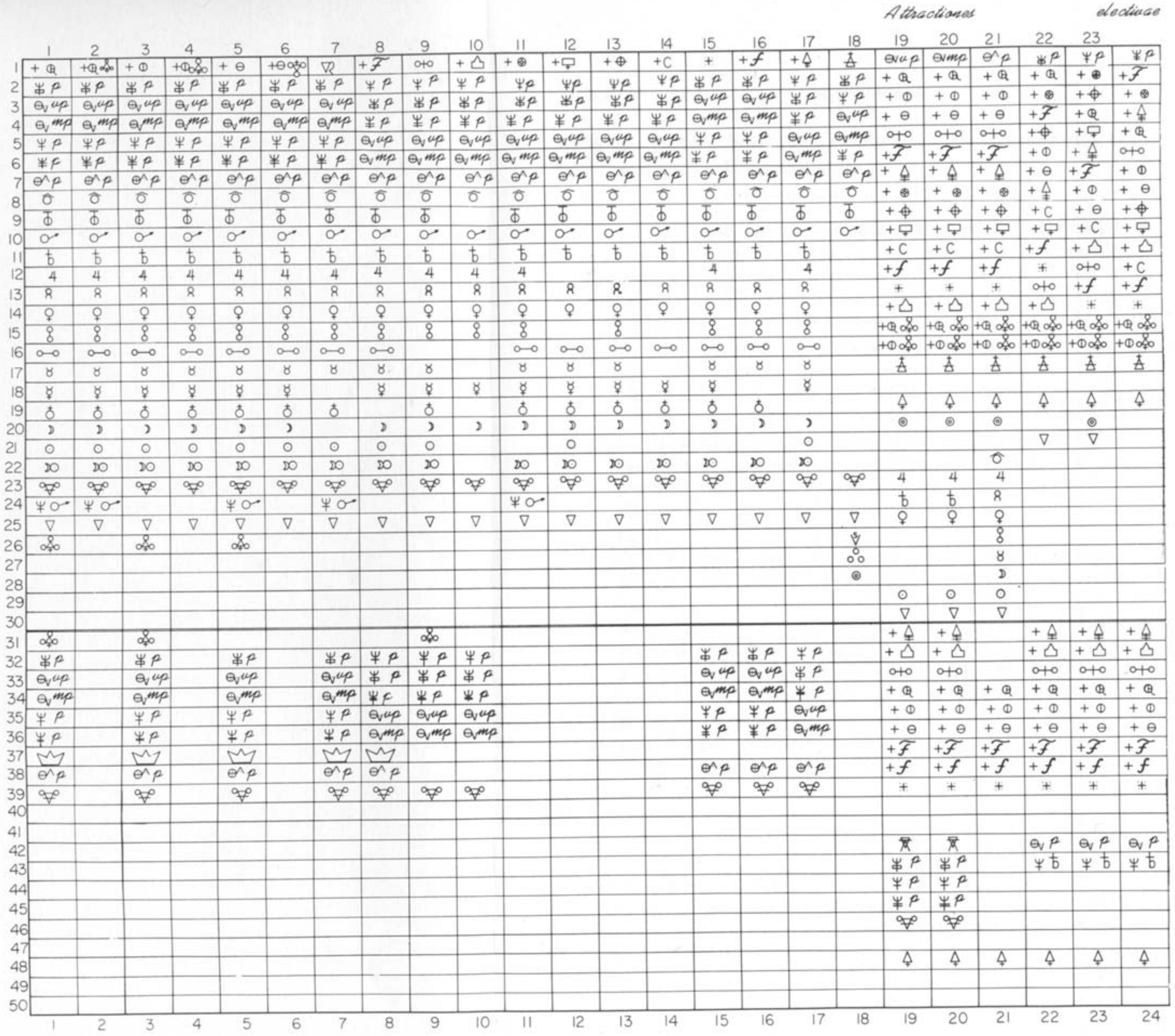


Figure 1a. Left half of Bergman's Table of Simple Elective Attractions (Tab. VIII). Each column is headed by an element for which the elements listed below it in the column have attractions. The most strongly attracted substances are listed at the top and the other substances are listed in decreasing order as their attraction decreases. The part of the table above the heavy horizontal line deals with attractions in *via humida,* i.e., in water solution. The lower part of the table, below the horizontal line, refers to attractions in *via sicca,* i.e., dry reactions such as those caused by melting substances together in a crucible.

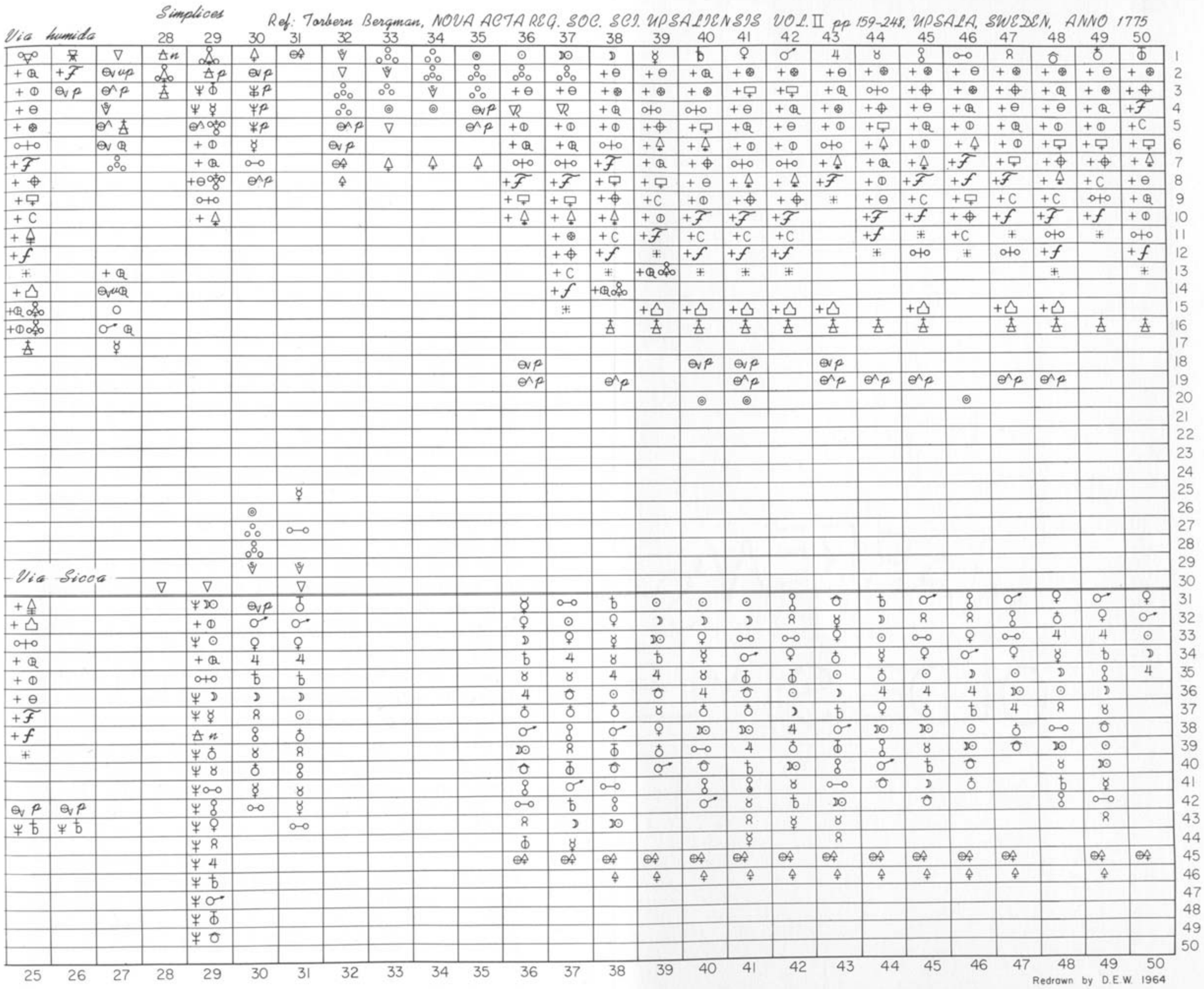


Figure 1b. Right half of Bergman's Table of Simple Elective Attractions (Tab. VIII).

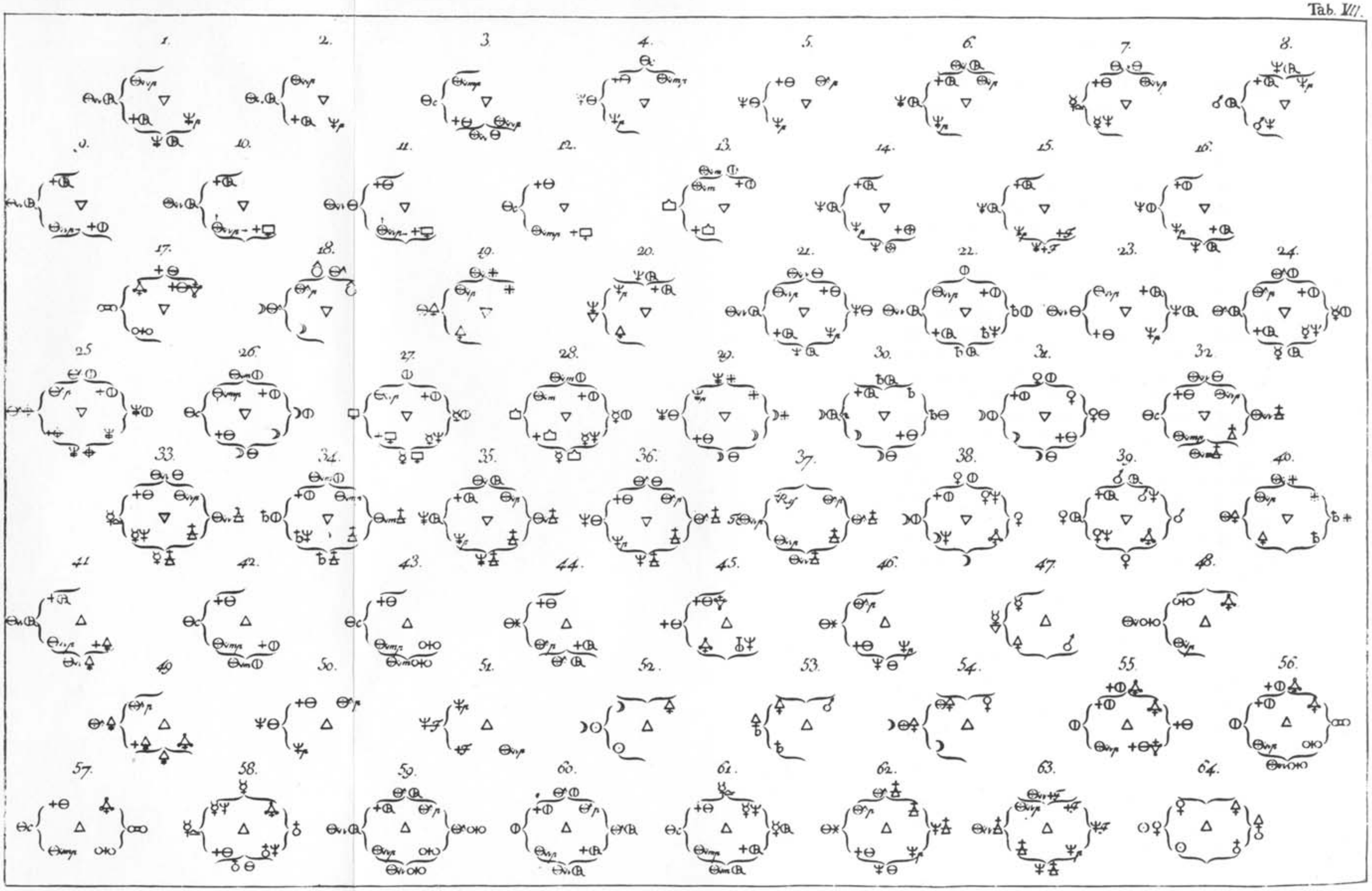


Figure 3. Bergman's "Schemes." Table VII in Bergman's manuscript. A summarization of the chemical reactions with which Bergman was familiar. Where the symbol for fire, an upright triangle, appears in the center of the "Scheme," the reaction was carried out in *via sicca,* usually by melting in a crucible. When the symbol for water, an inverted triangle, appears the reaction was carried out in *via humida,* in aqueous solution. The meaning of the other symbols is given in Figure 2.

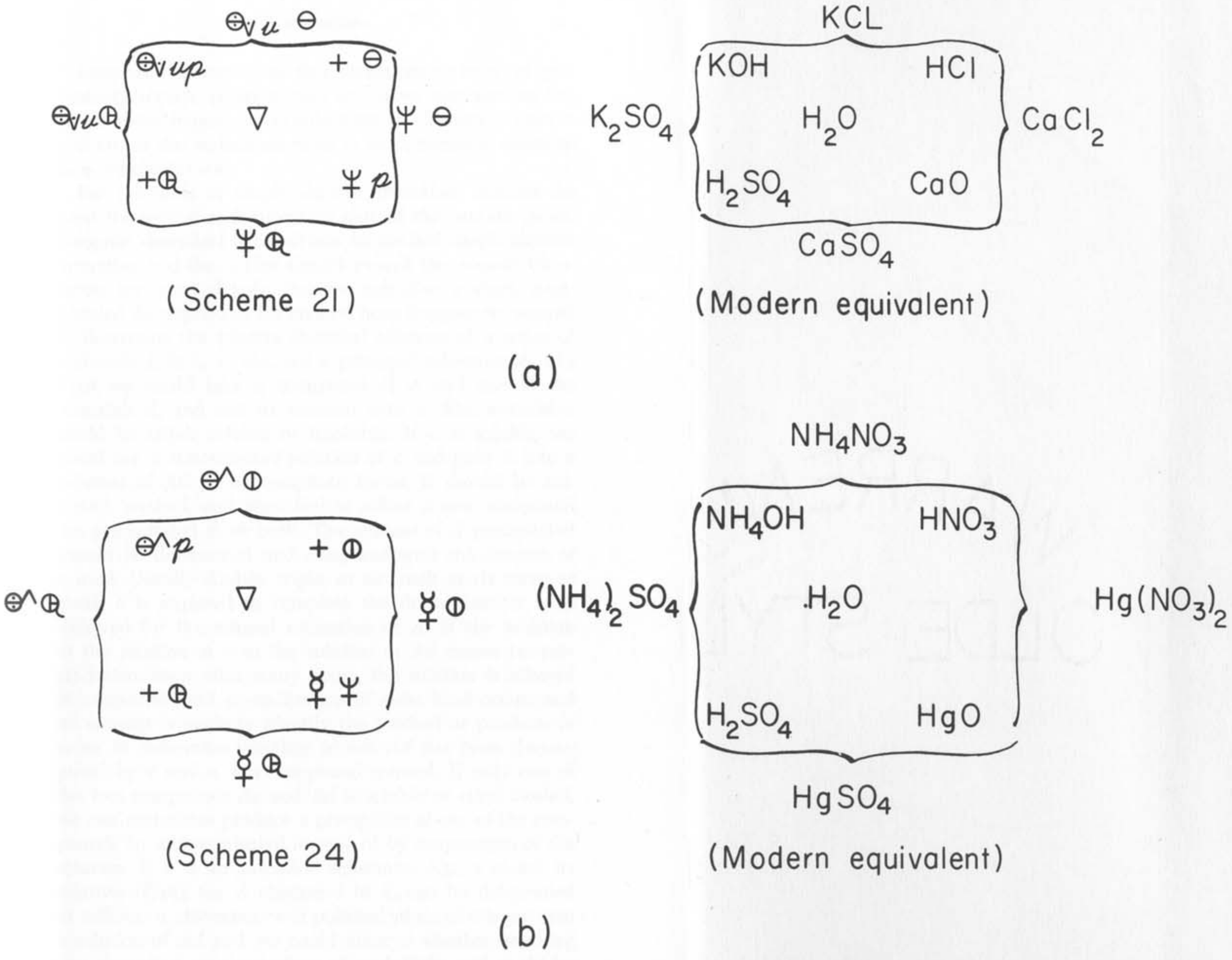
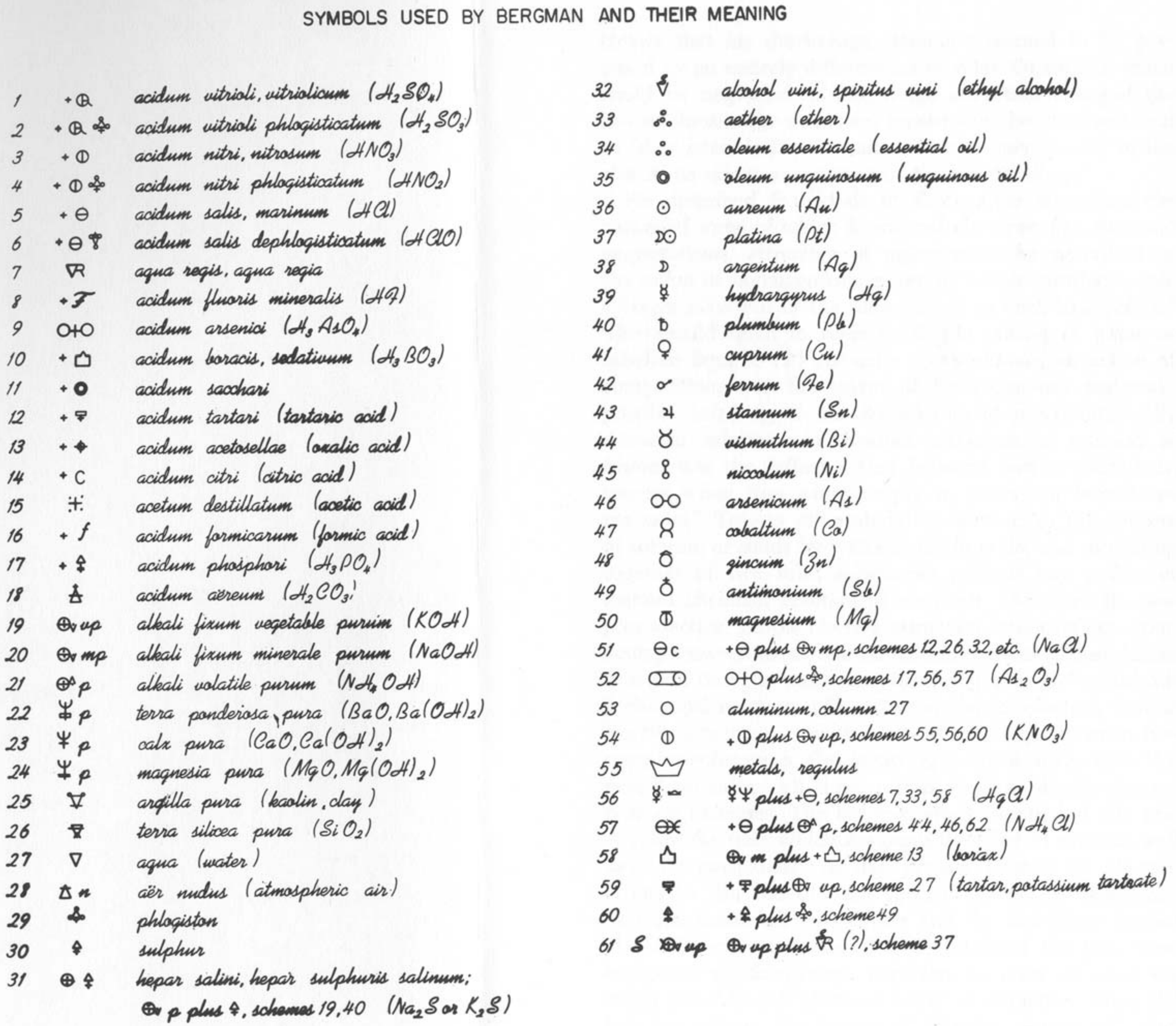


Figure 4. Examples of Bergman's Schemes, and modern equivalents.



SYMBOLS USED BY BERGMAN AND THEIR MEANING

1	+ 🜖	acidum vitrioli, vitriolicum (H_2SO_4)
2	+ 🜖 ♧	acidum vitrioli phlogisticatum (H_2SO_3)
3	+ ⦶	acidum nitri, nitrosum (HNO_3)
4	+ ⦶ ♧	acidum nitri phlogisticatum (HNO_2)
5	+ ⊖	acidum salis, marinum (HCl)
6	+ ⊖ ☿	acidum salis dephlogisticatum ($HClO$)
7	∇R	aqua regis, aqua regia
8	+ 𝓕	acidum fluoris mineralis (HF)
9	O+O	acidum arsenici (H_3AsO_4)
10	+ ⌂	acidum boracis, sedativum (H_3BO_3)
11	+ ◉	acidum sacchari
12	+ ₸	acidum tartari (tartaric acid)
13	+ ◆	acidum acetosellae (oxalic acid)
14	+ C	acidum citri (citric acid)
15	⸭	acetum destillatum (acetic acid)
16	+ 𝑓	acidum formicarum (formic acid)
17	+ 🜎	acidum phosphori (H_3PO_4)
18	🜁	acidum aëreum (H_2CO_3)
19	⊕▿ vp	alkali fixum vegetable purum (KOH)
20	⊕▿ mp	alkali fixum minerale purum ($NaOH$)
21	⊕^ p	alkali volatile purum (NH_4OH)
22	♆ p	terra ponderiosa, pura ($BaO, Ba(OH)_2$)
23	Ψ p	calx pura ($CaO, Ca(OH)_2$)
24	⚴ p	magnesia pura ($MgO, Mg(OH)_2$)
25	⊽	argilla pura (kaolin, clay)
26	⧗	terra silicea pura (SiO_2)
27	🜄	aqua (water)
28	🜁 n	aër nudus (atmospheric air)
29	♧	phlogiston
30	🜍	sulphur
31	⊕ 🜍	hepar salini, hepar sulphuris salinum; ⊕▿ p plus 🜍, schemes 19, 40 (Na_2S or K_2S)
32	🜅	alcohol vini, spiritus vini (ethyl alcohol)
33	⁖	aether (ether)
34	∴	oleum essentiale (essential oil)
35	◉	oleum unguinosum (unguinous oil)
36	☉	aureum (Au)
37	☽☉	platina (Pt)
38	☽	argentum (Ag)
39	☿	hydrargyrus (Hg)
40	♄	plumbum (Pb)
41	♀	cuprum (Cu)
42	♂	ferrum (Fe)
43	♃	stannum (Sn)
44	♉	vismuthum (Bi)
45	⚲	niccolum (Ni)
46	○○	arsenicum (As)
47	☋	cobaltum (Co)
48	Ŏ	zincum (Zn)
49	♁	antimonium (Sb)
50	Φ	magnesium (Mg)
51	⊖c	+⊖ plus ⊕▿ mp, schemes 12, 26, 32, etc. ($NaCl$)
52	⊖⊖	O+O plus ♧, schemes 17, 56, 57 (As_2O_3)
53	○	aluminum, column 27
54	⦶	+⦶ plus ⊕▿ vp, schemes 55, 56, 60 (KNO_3)
55	♔	metals, regulus
56	☿ ⌢	☿Ψ plus +⊖, schemes 7, 33, 58 ($HgCl$)
57	⊖✱	+⊖ plus ⊕^ p, schemes 44, 46, 62 (NH_4Cl)
58	⌂	⊕▿ m plus +⌂, scheme 13 (borax)
59	₸	+₸ plus ⊕▿ vp, scheme 27 (tartar, potassium tartrate)
60	🜎	+🜎 plus ♧, scheme 49
61	𝓢 ⊗▿ vp	⊕▿ vp plus 🜅R (?), scheme 37

Figure 2. Table of chemical symbols which Bergman used, their Latin name and the closest approximation possible for a modern name.

In 1766, **Henry Cavendish** (1731-1810), a British scientist, published 3 papers in which he described the preparation of an "inflammable air" (hydrogen) by the action of dilute sulfuric or hydrochloric acid on zinc, iron or tin. He also determined the density of the gas (although his value was very inaccurate) and its chief chemical properties.

Henry Cavendish

Cavendish believed this gas to be nearly pure phlogiston and to be derived from the metals, not the acids. In the case of nitric acid, which reacted with metals to give a brown, noncombustible gas, he explained it by assuming the phlogiston had reacted with the acid.

Cavendish also studied Black's fixed air and he introduced a method of drying gases by passing them through dry potassium carbonate (K_2CO_3) or through pearl ashes. He also found that gases could be stored safely in containers over mercury. (This inspired Joseph Priestley to use mercury in his pneumatic trough instead of water.)

Cavendish also accurately determined the composition of Earth's atmosphere. He found that 79.167% is "phlogisticated air", now known to be nitrogen and argon, and 20.833% is "dephlogisticated air", now known to be 20.95% oxygen. Cavendish, using electric sparks, diminished the nitrogen and oxygen in a sample of air and absorbed the products in alkali, leaving a small residue. He could not, however, account for a small bubble of phlogisticated air, which amounted to 1/120 of the Earth's atmosphere. (In 1984, Lord Rayleigh, prepared that small amount of gas, using the same method as Cavendish, and identified it as a third gas, argon.)

Carl Wilhelm Scheele (1742-1786), a Swedish apothecary chemist, discovered many new substances. Always in poor circumstances, hoe could only devote his spare time to chemistry, but he had an instinctive flair for experimental work and published many papers in his short life.

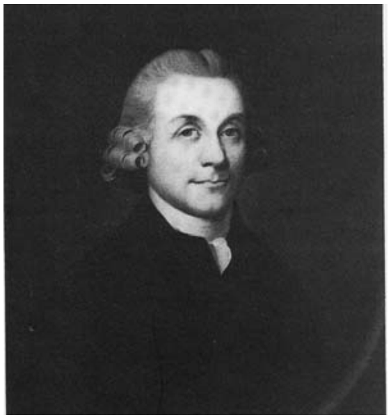
Carl Wilhelm Scheele

Sheele discovered the inorganic acids: hydrofluoric, hydrocyanic, nitrosulfonic, molybdic, tungstic, fluorosilicic and arsenic acids; the organic acids: tartaric, oxalic, gallic, pyrogallic, uric, mucic, latic and citric acids; isolated glycerin from saponification of olive oil and lactose from milk. He ascertained the nature of hydrogen sulfide, borax, microcosmic salt and prussian blue. Also discovered ammonia, hydrogen chloride, and chlorine. Scheele prepared compounds of cyanide, including gaseous hydrogen cyanide, and even described its taste. Scheele was an independent discovered or oxygen, ammonia and hydrochloric acid and was the first chemist to isolate chlorine.

Between 1771 and 1773 he discovered and experimented with a gas he called feuerluft (fire air) - actually oxygen gas – which he prepared by several means. He wrote about it in his book *Chemische Abhandlung von der Luft und dem Feuer* (*Chemical Treatise on Air and Fire*) but, although his manuscript was in the hands of his publisher in 1775, these results were not published until 1777.

Working in his cold shop without proper ventilation, Scheele was frequently exposed to toxic vapors from his experiments. It is thought that this exposure seriously damaged Scheele's health and significantly shortened his life. Scheele was aware of the cause of his poor health and he referred to it as "the trouble of all apothecaries."

Joseph Priestley (1733-1804), a Unitarian pastor and natural philosopher who had no formal training in chemistry, devoted his work to the study of gases. He used no definite working plan in his experiments and tended to stray where his fancy took him. His studies leaned mainly on experiments with electricity and with gases. He is the discoverer of soda water.


Joseph Priestley

In 1774, Priestley was using a new burning glass to burn various substances in an inverted container in his pneumatic trough to see what kinds of "airs" were given off. Taking some red calx of mercury (mercury(II) oxide), Priestley noted that the calx "burned" into mercury, giving off a colorless gas. He was amazed to find that a candle burned brilliantly in this gas and that a mouse would live longer in this gas than in an equal volume of air.

As a firm believer in phlogiston, Priestley was at a loss to explain this. Finally, he arrived at the conclusions:

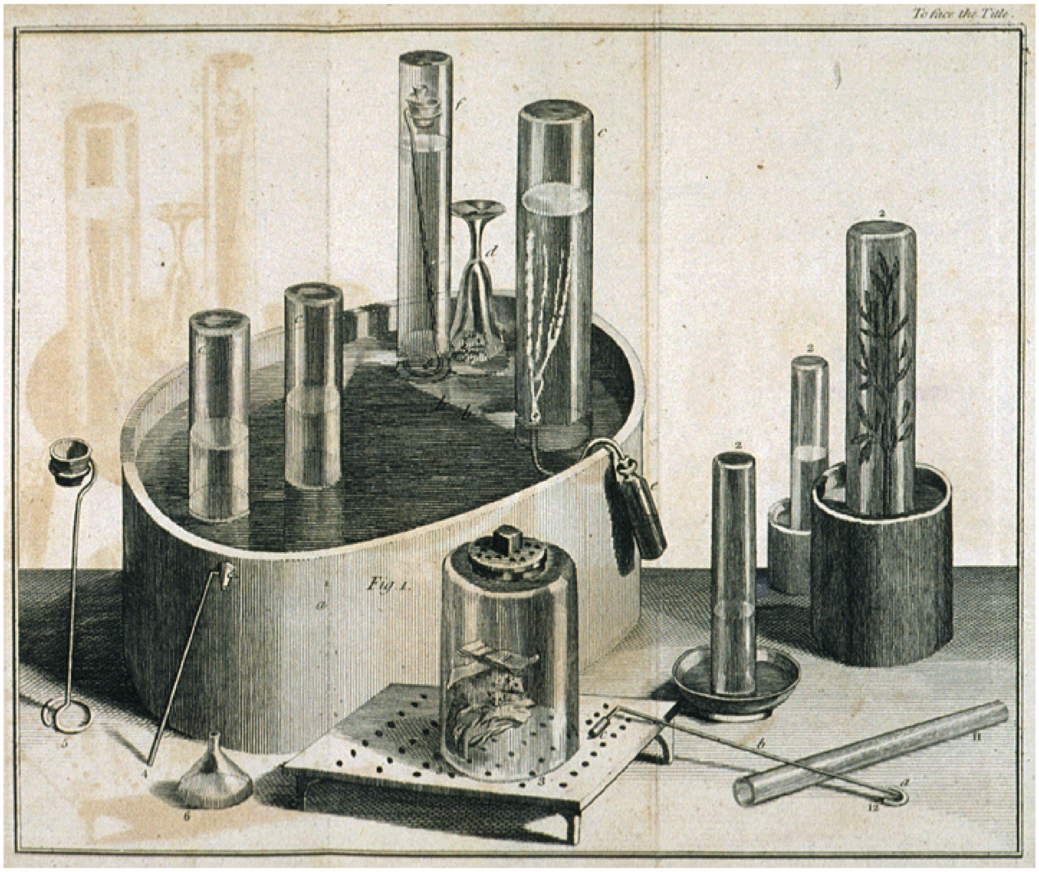
Ordinary air must contain phlogiston

This new gas must be air deprived of its phlogiston.

Therefore, he called the gas *dephlogisticated air*.

Since it was believed, at the time, that air was a carrier of phlogiston, Priestley explained how dephlogisticated air could be evolved.

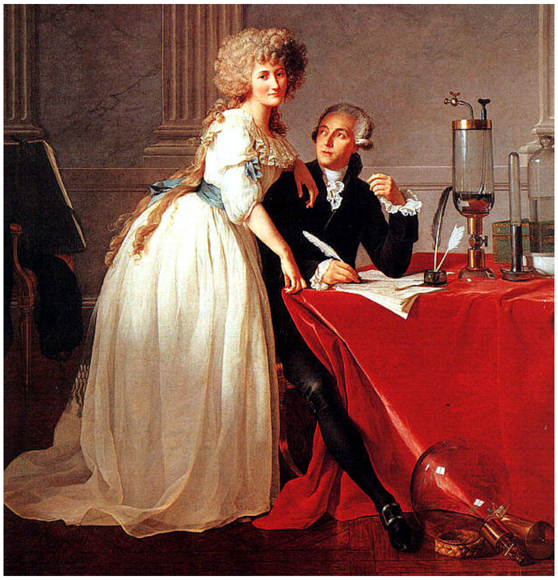
> The phlogiston belonging to the metal unites with that air (pure or dephlogisticated air) so as together to form *fixed air* (which is not, in this case, carbon dioxide, as explained by Black), and therefore the calx may be said to be the metal united to fixed air. Then, in a greater degree of heat then that in which the union was formed, this factitious air is again decomposed; the phlogiston in it reviving the metal, while the pure air is set loose. Consequently the precipitate mercury calx actually contains within itself all the phlogiston that is necessary to the revival of the mercury.



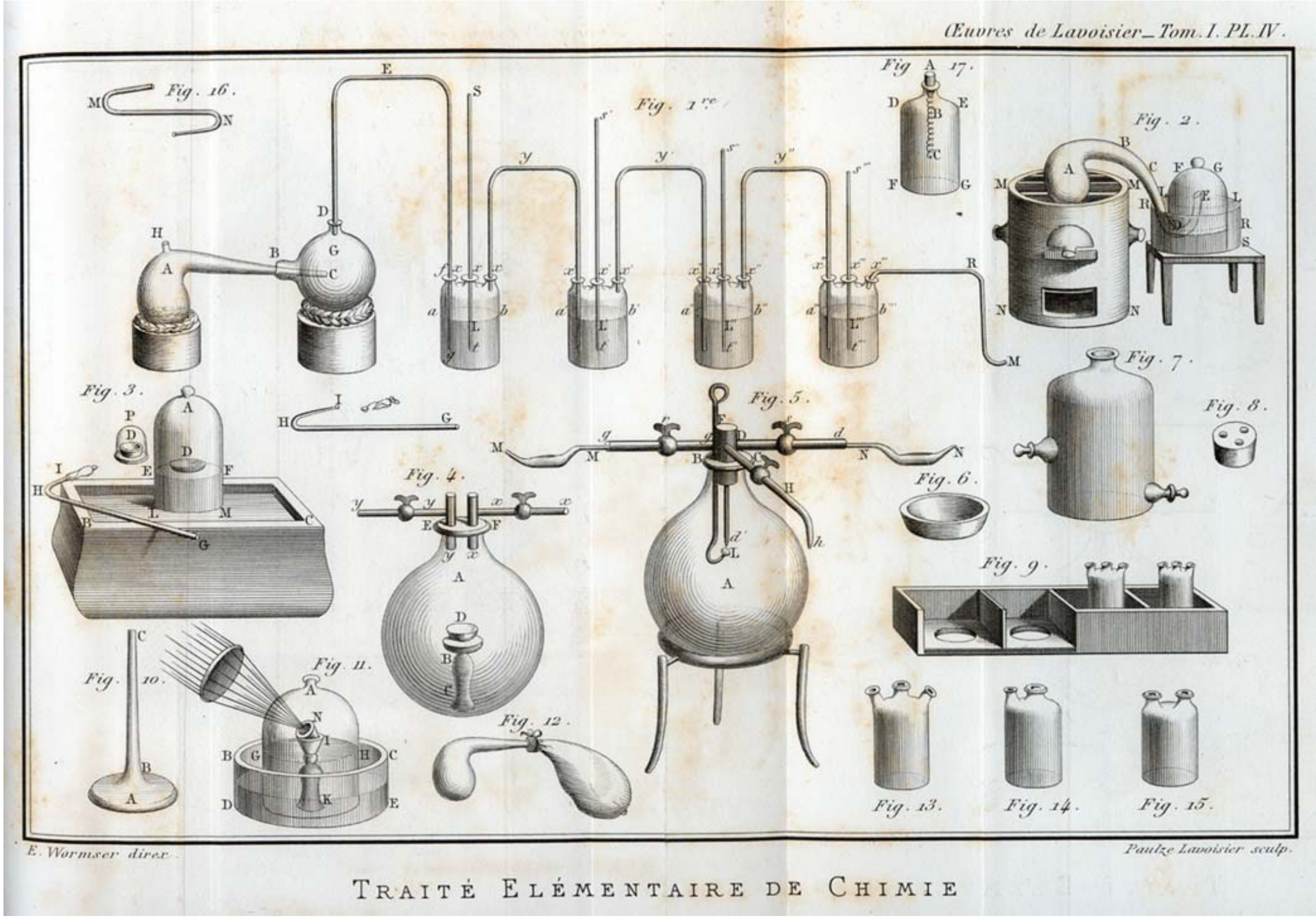
Priestley’s apparatus

The final overthrow of the phlogiston theory was accomplished by **Antoine Laurent Lavoisier** (1743-1794). Lavoisier studied combustion as early as 1770. In 1774, he demonstrated that the gain in weight in the calcining of metals was at the expense of air and that the loss of weight of the air was equal to the gain in weight of the metal. These experiments enable Lavoisier to deduce that the air must consist of at least two gases, one of which is involved in calcination.

Lavoisier learned of dephiogisticated air in 1774 from Priestley when the latter visited his laboratory. Convinced that Priestley’s dephlogisticated air was the active constituent of the atmosphere, he repeated and extended Priestly's experiments in the winter 1774-1775.



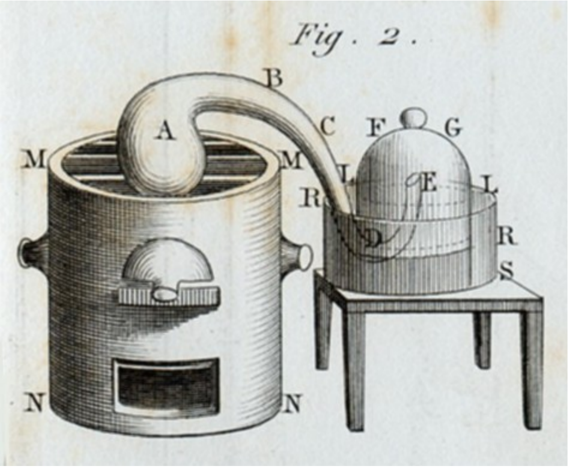
Painting of Monsieur Lavoisier and his wife, Marie-Anne Pierrette Paulze by Jacques-Louis David



Lavoisier's apparatus for studying gases

Lavoisier's famous experiment:

> In a matrass (A) having a long neck (BCDE) which was bent and inserted under a bell glass (FG) and placed in a trough of quicksilver (RRS), the level of the quicksilver was marked (LL) and mercury was added to the matrass. The furnace (MMNN) was lighted and maintained for twelve days during which time the mercury in the matrass formed the red calx and the air in the bell jar decreased by 1/6 of its volume.
>
> The air remaining in the bell jar would not support combustion, nor would it support repiration.
>
> Upon heating the red caix of mercury, the gas which Priestley had called dephiogisticated air was formed and it was found to be capable of supporting both combustion and respiration.



Lavoisier called this gas *highly respirable* air or, later, *vital* air.

In 1777, Lavoisier presented a paper on “The considerations Upon the Nature of Acids” in which he named this “purest part of the air” oxygine, which was derived from the Greek “acid former” since this gas was found in all acids.

In 1781, Priestley and his friend Warltire found that on firing a mixture of common and inflammable airs in a vessel by means of an electric spark, the inside of the glass vessel became dewey. Cavendish studied this in more detail and finally concluded that water was a compound (not an element) consisting of inflammable air (hydrogen) with a part of the common or atmospheric air (approximately 1/5 of common air – the other 4/5 of air was phlogisticated air [nitrogen]). When he used Priestley’s dephlogisticated air, Cavendish found that water consisted of two parts inflammable air and one part dephlogisticated air. Unfortunately, he interpreted this to mean that Priestley’s dephlogisticated air was actually dephlogisticated water (i.e., water = dephlogisticated air + phlogiston).

Using the information from Cavendish, Lavoisier attacked the phlogiston theory in 1783. He showed that:

> Air consists of at least two gases, one of which combines with metals on calcination and causes an increase in weight.
>
> The same gas is the active agent in combustion.
>
> "Fixed air" is a compound of carbon with this gas.
>
> Metallic calces were not elements, but compounds of metals with this gas.

By 1785, other chemists were slowly being won over to Lavoisier’s theory of combustion. By 1791, all the phlogistonists, except Priestley, recognized the new theory. (Priestley defended the phlogiston theory to his death in 1804.)

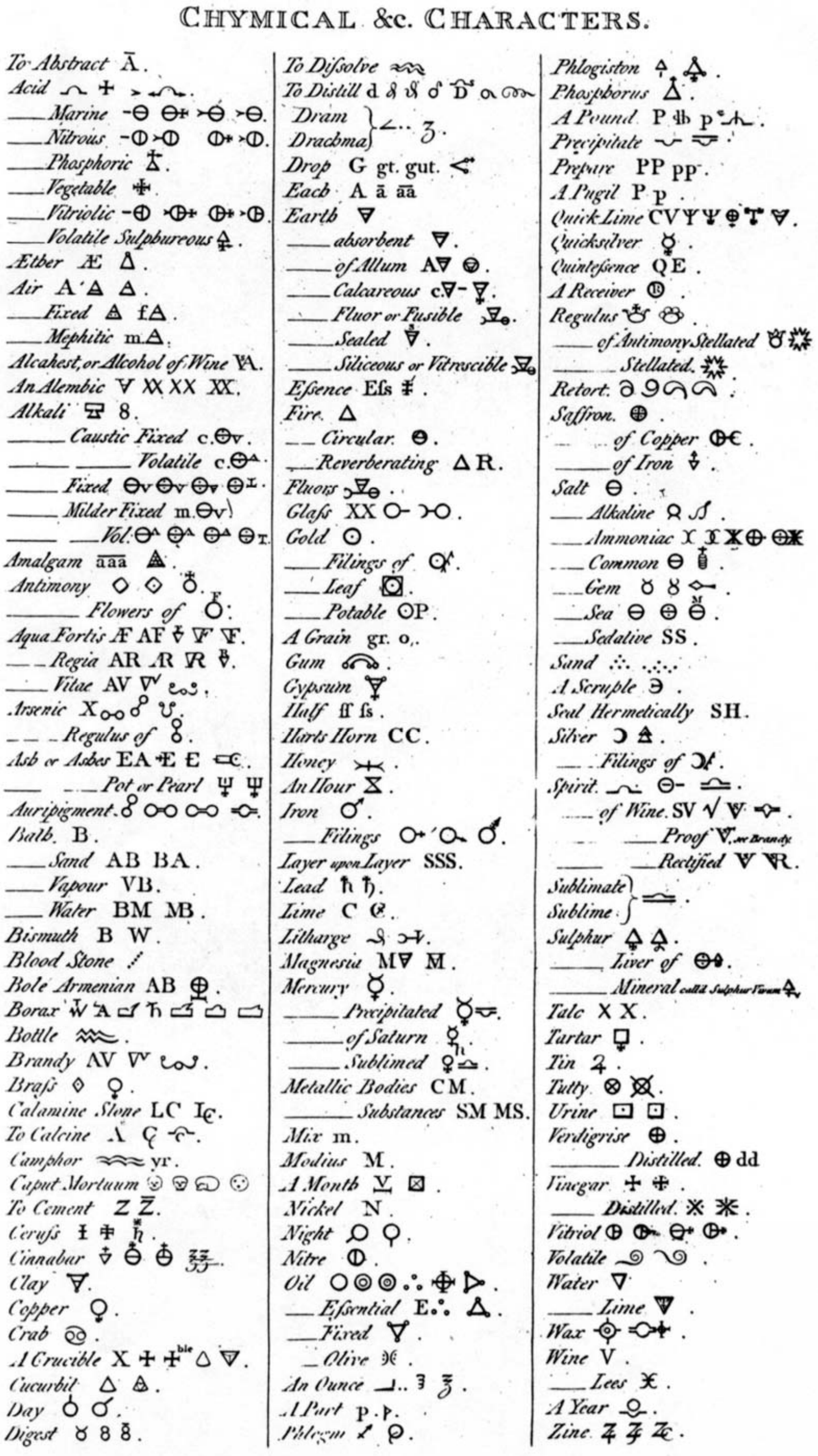
In addition to overthrowing the phlogiston theory, Lavoisier worked on chemical affinity, chemical nomenclature, and chemical analysis (especially of organic compounds).

It should be noted that Lavoisier discovered no new substances and devised no new improved apparatus, but his fame lies in that he was a careful experimentalist who was able to give first correct interpretations to facts already known.

With the phlogiston theory eliminated, quantitative determinations became possible and chemistry as a modern science was established.

Lavoisier was a French nobleman in addition to his work in chemistry and biology, he was also involved in finance and banking. He was an investor and administrator of the "Ferme Générale” a private tax collection company; chairman of the board of the Discount Bank (later the Banque de France); and a powerful member of a number of other aristocratic administrative councils. All of these political and economic activities enabled him to fund his scientific research. But because of his prominence in the pre-revolutionary government in France, at the height of the French Revolution he was sentenced to death by guillotine.

Lavoisier’s wife Marie-Anne (1758-1836) was accomplished in chemistry, art, and reading English. She managed the schedule of her husband's laboratory, maintained notebooks, and created fine detailed drawings of apparatus. She receives no credit, but the figures in his books carry her signature. (See detail of Plate IV from “Traité Élémentaire de Chimie” on the right.) After her husband's death, Marie-Anne was thrown into bankruptcy as the new government confiscated all her money and property in addition to all of Lavoisier’s notebooks and laboratory equipment. Marie-Anne organized the publication of Lavoisier’s final memoirs, *Mémoires de Chimi*, a compilation of his papers and those of his colleagues diagramming the principles of the new chemistry. The statesman Pierre-Samuel duPont de Nemours, friend of Thomas Jefferson and namesake of the Dupont Company, courted her until she rejected him. In 1805 she married the notorious expatriate American scientist, Count Rumford, but that union quickly devolved into raging squabbles and lasted only a few months.



CHYMICAL &c. CHARACTERS.

To Abstract Ā.
Acid
— Marine
— Nitrous
— Phosphoric
— Vegetable
— Vitriolic
— Volatile Sulphureous
Æther Æ
Air A
— Fixed f△.
— Mephitic m△.
Alcahest, or Alcohol of Wine
An Alembic
Alkali 8.
— Caustic Fixed c.
— — Volatile c.
— Fixed
— Milder Fixed m.
— — Vol:
Amalgam aaa
Antimony
— Flowers of
Aqua Fortis Æ AF
— Regia AR
— Vitae AV
Arsenic X
— — Regulus of
Ash or Ashes EA E
— — Pot or Pearl
Auripigment
Balb. B.
— Sand AB BA.
— Vapour VB.
— Water BM MB.
Bismuth B W.
Blood Stone
Bole Armenian AB
Borax
Bottle
Brandy AV
Braſs ♀.
Calamine Stone LC
To Calcine
Camphor yr.
Caput Mortuum
To Cement Z Z̄.
Ceruſs
Cinnabar
Clay
Copper ♀.
Crab
A Crucible X
Cucurbit
Day
Digest

To Diſsolve
To Distill
Dram }
Drachma } ʒ.
Drop G gt. gut.
Each A ā āā
Earth ▽
— absorbent
— of Allum A
— Calcareous c
— Fluor or Fusible
— Sealed
— Siliceous or Vitrescible
Eſsence Eſs
Fire △
— Circular.
— Reverberating △R.
Fluors
Glaſs XX
Gold ☉.
— Filings of
— Leaf
— Potable ☉P.
A Grain gr. o.
Gum
Gypsum
Half ſſ ſs.
Harts Horn CC.
Honey
An Hour
Iron ♂.
— Filings
Layer upon Layer SSS.
Lead ♄.
Lime C
Litharge
Magnesia M▽ M.
Mercury ☿.
— Precipitated
— of Saturn
— Sublimed
Metallic Bodies CM.
— Substances SM MS.
Mix m.
Modius M.
A Month
Nickel N.
Night
Nitre
Oil
— Eſsential E.
— Fixed
— Olive
An Ounce ℥
A Part p.
Phlegm

Phlogiston
Phosphorus
A Pound P ℔ p
Precipitate
Prepare PP pp.
A Pugil P p.
Quick Lime CV
Quicksilver ☿.
Quinteſsence QE.
A Receiver
Regulus
— of Antimony Stellated
— Stellated.
Retort.
Saffron.
— of Copper
— of Iron
Salt ⊖.
— Alkaline
— Ammoniac
— Common ⊖
— Gem
— Sea ⊖
— Sedative SS.
Sand
A Scruple ℈.
Seal Hermetically SH.
Silver ☽.
— Filings of
Spirit.
— of Wine. SV
— — Proof, see Brandy
— — Rectified
Sublimate }
Sublime }
Sulphur
— Liver of
— Mineral called Sulphur Vivum
Talc X X.
Tartar
Tin ♃.
Tutty ⊗
Urine
Verdigrise ⊕.
— Distilled. ⊕ dd
Vinegar
— Distilled.
Vitriol ⊕
Volatile
Water ▽.
— Lime
Wax
Wine V.
— Lees
A Year
Zinc

Chemical Symbols and Characters, 1780

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