Communicating about Matter with Symbols: Evolving from Alchemy to Chemistry

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Communicating about Matter with Symbols: Evolving from Alchemy to Chemistry

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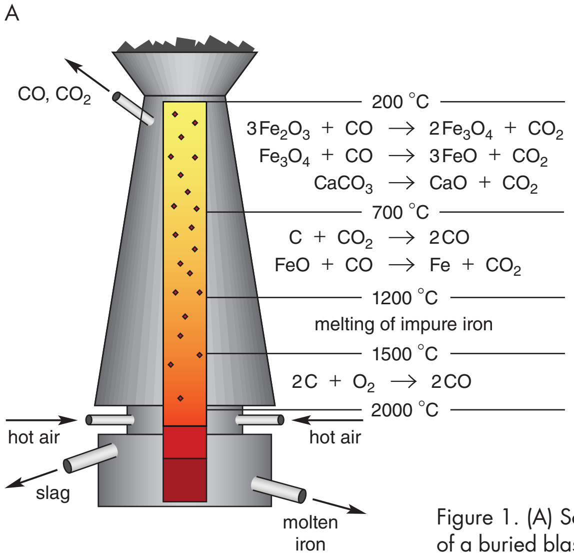
Most chemists typically have difficulty in communicating about their work with the world. Other scientists—physicists, mathematicians, biologists—participate actively in public debates and television talk shows, write books on general subjects and articles in newspapers, because they use a language understandable to everyone. Chemists do not; they use a specialized language, comprising symbols and formulas, poorly understood by ordinary people. Why? This is a long story dating back several thousand years ago.

Humans began domesticating animals, such as goats, sheep, and pigs as early as ca. 10,000 B.C.E. About 500 years later, humans started cultivating cereals and crops, establishing agrarian society, which continues today. The first elements of technology were introduced in ca. 8000 B.C.E. with the invention of pottery, then in ca. 6500 B.C.E. with spinning and weaving. However, the official entrance of humans into the world of technology took place ca. 5500 B.C.E., with the invention of metallurgy—the extraction of metals from ores and the working of metals.

Such an invention has been considered so important by historians that early human time is demarcated into ages associated with the metal humans were able to extract and work at that time. Thus, the Copper Age now indicates the period of 6000–3000 B.C.E., even if this relatively soft metal did not completely replace stone as the base material for utensils and weapons. For instance, among the items belonging to Ötzi, the mummified body of a hunter found in an alpine glacier between Austria and Italy in 1991 and who died ca. 3300 B.C.E., there was a copper axe, but also a flint knife and arrows with flint heads. The mechanical properties of copper were later improved by addition of tin, to give bronze (the Bronze Age period is considered to be 3000–1200 B.C.E.). However, the most spectacular progress in metallurgy—with amazing consequences for society—occurred with the extraction of iron *(1)*. Metal extraction typically takes place in a furnace and the key parameter of the process is temperature. Thus, progress in metallurgy reflected the capability to reach and maintain high temperatures, through the choice of a convenient combustible, the use of refractory materials, and the favorable design of the furnace. Copper was worked some 5000 years before iron because its working required a much lower temperature (compare the melting points of copper, 1085 °C, and of iron, 1538 °C).

Today, iron is extracted from its ores in a blast furnace, as schematically illustrated in Figure 1A. Iron oxides, coke, and limestone are charged from the top, while hot air is blown from the bottom. At the end of a complex, multistep process, molten iron comes out from the bottom of the furnace. Old furnaces of the Iron Age were probably not too different. In Figure 1B, the remains of an interred furnace for iron extraction of the 11th century C.E. are shown; holes in the top (for charging) and in the bottom of the furnace (for bellows-blown air and for metal recovery) are still visible. The furnace is near the Monastery of Vasco (Cuneo), in northwestern Italy, and was operated by Benedictine monks (this is also shown by the presence of a cross on the furnace). Indeed, in the Middle Ages monks took care of maintaining not only the humanities, but any kind of tradition, including technology. However, while European countries were going through a politically and socially troubled period, with minimal cultural progress, fortunately for human civilization, science and technology progressed in the Islamic world, in the so-called Islamic Golden Age (8th–13th centuries) *(2)*.

A



B

Figure 1. (A) Schematic drawing of a modern blast furnace for iron extraction; (B) Photograph of a buried blast furnace for iron extraction close to the Monastery of Vasto in Cuneo, Italy. This furnace was operated by Benedictine monks during the 11th century C.E. Photo by the author.

The flow of a molten metal from the outlet port of an interred furnace was an impressive phenomenon that must have fascinated users and stimulated their creativity and ingenuity. Some wanted to reproduce and extend the process on a smaller scale, under controlled, private conditions, and set up small furnaces at home, in the kitchen or cellar, testing the behavior of a variety of minerals on heating and eventually collecting the products of the thermal process. Experiments at home with small furnaces may have provided the basis for the development of alchemy.

Figure 2. *Alchemist at the Furnace* (1312–1313), fresco, Palazzo della Ragione, Padua, Italy, by Giotto (1267–1337). All the frescos in the palace were destroyed by a fire in 1420 and restored by Nicolò Miretto and associates during the period 1425–1440. (Image used by kind permission of the Municipality of Padua.)

The classical alchemical laboratory in Europe contained one or more furnaces and among the ordinary tools of alchemists there were bellows and pliers. The alchemist featured in the fresco by Giotto in Figure 2 (Palazzo della Ragione, Padua, 1312–1313) sits in front of his furnace and proudly points at the collecting vessel. Alchemy—intended as manipulation of substances in an equipped laboratory, carried out for both practical and speculative purposes—involved the controlled use of fire from its beginning and could be considered as a primitive chemistry under extreme conditions of temperature.

The Appearance of Symbols

Chemistry derives from European alchemy, which, in turn, is related in a temporal sequence to Arabic alchemy, Greek alchemy, and Egyptian alchemy, as illustrated in Figure 3 *(3)*. 331 B.C.E., the year of the conquest of Egyptum by Alexander the Great and of the foundation of the town Alexandria, is conventionally chosen as the event marking the transition from Egyptian to Greek alchemy. On the other hand, the conquest of Alexandria by Arabs (642 C.E.) marks the passageway to Arabic alchemy. In any case, Alexandria was the capital of alchemy for more than a millennium. During the 10th–11th centuries, alchemy spread throughout Europe from Spain, at that time under Arabic rule.

Experimental procedures of alchemy had to be recorded in volumes to keep memory alive and to hand down culture, or, more simply, noted on a piece of paper, to be used as a guide by the workers in the laboratory. The English word recipe has an alchemical origin and must be intended as the imperative (second person) of the Latin verb *rĕcĭpĕre*, to receive: in fact, it was exactly what the alchemist-in-chief told the technician or young assistant—take!—when handing him the sheet with the written procedure for the experiment of the day. In written alchemy substances were indicated not by words, but with symbols. This practice was quite obvious for Egyptians, who used an ideographic writing system; the symbolic system was kept even after the appearance and diffusion of alphabets. There are several

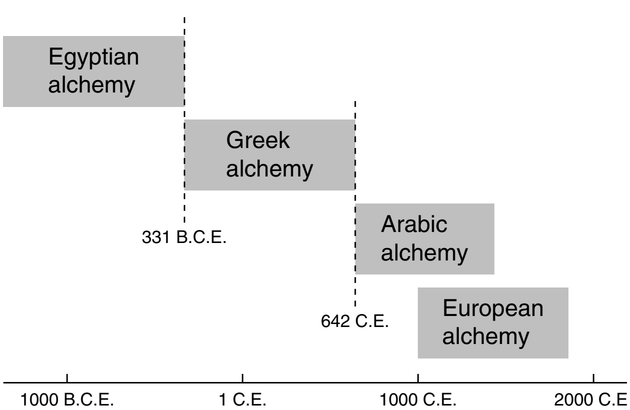


Figure 3. The chronology of alchemy in Mediterranean and Western cultures. Egyptian alchemy began around 5000 B.C.E. The dates 331 B.C.E. and 642 C.E. refer to the foundation of Alexandria by Alexander the Great and the conquest of Alexandria by Arabic forces, respectively. Chinese alchemy, which developed from the 8th century B.C.E., had a major impact on Arabic alchemy and, consequently, on European alchemy; an important invention of Chinese alchemy was gunpowder (9th century C.E.).

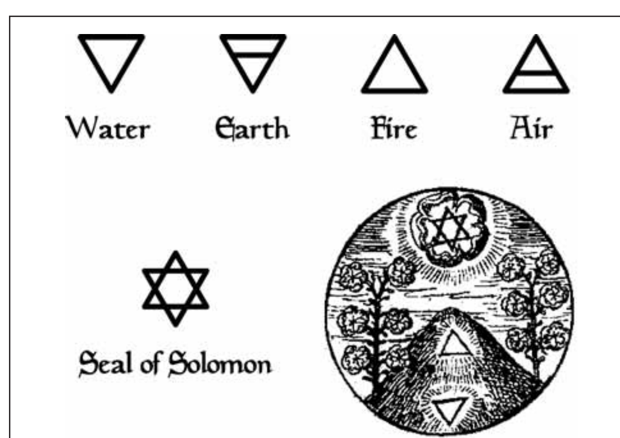


Figure 4. The symbols of the Four Elements constituting matter, according to Aristotle. The four symbols can be combined to give the Seal of Solomon, a pictogram appearing in many alchemical documents. (Figures adapted from *http://www.chembio.uoguelph.ca/chemzine/v1i1feb02/page1.shtml* and *http://www.levity.com/alchemy/symbols.html* [accessed Jul 2008].)

reasons for the extended use of symbols in alchemy. First, symbols, rather than complete words, allowed the operator to save time and space when writing, a useful feature under the stress of the activity in the lab. Second, alchemists were conscious of the huge potential of their discipline and did not want uneducated people to read and understand their recipes, or make improper uses of their findings.

Alchemists were essentially practitioners, mainly concerned with producing new substances or devising new procedures for preparing precious materials at low cost. They were not interested in or capable of establishing theories for the rationalization and explanation of the many experiments described. The time was not yet ripe: the quantitative investigation of nature was still distant, and, it seemed, everything had been said already and organized clearly by Aristotle *(4)*. Thus, it was natural for alchemists of the Greek period to accept the Aristotelian idea that matter was constituted by the Four Elements: Water, Earth, Fire, Air, whose symbols, all based on the triangle, are shown in Figure 4.

Symbols were also assigned to the true champions of alchemy: metals. The known metals were seven, like the planets. Each metal was associated with a planet and received the corresponding symbol, as previously defined by astronomy (or astrology) *(5)*. Metal–planet correspondences with symbols are illustrated in Figure 5.

Gold corresponds to the Sun (which, according to the geocentric Ptolemaic view, was considered a planet), probably for the color similarity. Silver was associated with the Moon, and, again, color affinity may have played a role. Copper corresponds to Venus, both the planet and goddess of beauty, whose symbol is the hand mirror, the emblem of feminine appeal. Mercury is the only metal that, moving from alchemy to chemistry, has kept the original name of the planet and of the corresponding Latin god (Mercurius). The association may be because of the unique mobility of the liquid metal, well represented by the messenger of gods, who was typically equipped with winged shoes and a winged cap. The symbol explicitly refers to a typical item of the god Mercury: the caduceus, “the staff of the herald,” a winged rod with two snakes wrapped around in a double-helical mode. The caduceus is present in paintings and sculptures featuring the god Mercury (or his Greek precursor, Hermes), from Hellenic art to the Renaissance.

As an example, the images in Figure 6 include a bronze statue by Giambologna (1580): Mercury wears a winged petasus, a soft cap typically worn by ancient travelers, and winged shoes, and clasps the caduceus. The caduceus had and still has a great significance as an emblem of different human activities, for example, commerce and medicine. However, in the case of medicine, some confusion is currently made with the rod of Asclepius, which has a single snake wrapped and no wings.

Iron was reasonably associated with Mars, god of war and of weapons: indeed, the corresponding symbol features the main weapons of war in ancient times: the shield and the lance. It is not accidental that the logo of the Swedish car company Volvo is the symbol of Mars–iron: indeed, Scandinavia has a long tradition of iron extraction and metallurgy. While the number of planets remained constant, until the Copernican revolution, the number of discovered metals increased with the progress of alchemy and new names and symbols had to be introduced. For instance, platinum was associated with the Greek god Uranus (not with the planet, which was discovered in 1781) and its symbol was obtained from the combination of those of gold (from which platinum took the incorruptibility, or resistance to oxidation) and of iron (from which platinum took the color). Quite curiously, when modern astrologists had to assign a symbol to the freshly discovered planet Uranus, they borrowed the alchemical one.

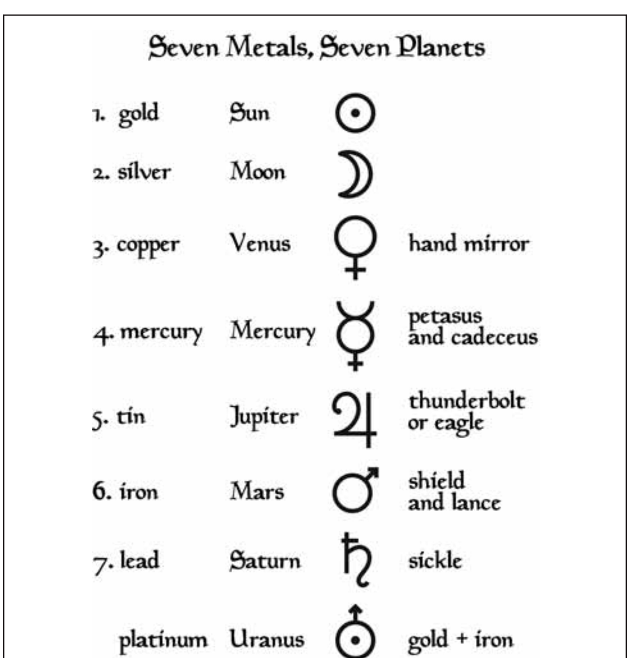


Figure 5. Alchemical symbols of the seven metals were borrowed from the astrological symbols of the seven planets. When platinum was discovered, a new symbol was created from those of gold and iron. Subsequently, astrologists assigned to the newly discovered planet Uranus (1781) the alchemical symbol of platinum.

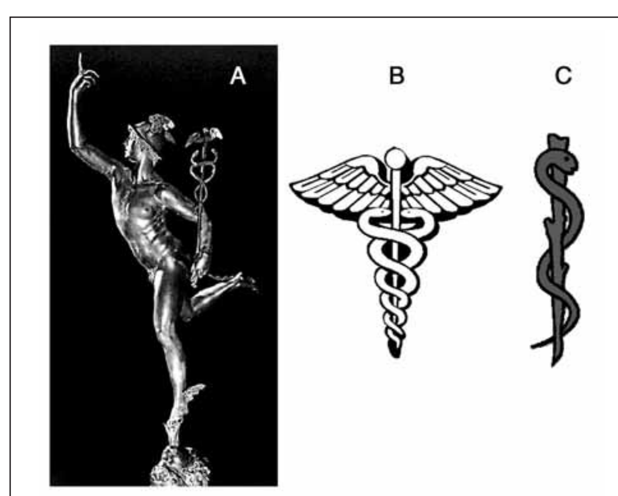


Figure 6. (A) *Statue of Mercury* (1580), bronze, by Giambologna, Museo del Bargello, Florence. (Image used by kind permission of the Italian Ministry of Cultural Activities and Heritage.) The god wears his distinctive cap, the winged petasus. (B) Caduceus, typical staff of Hermes–Mercury. (C) The rod of Asclepius, god of medicine.

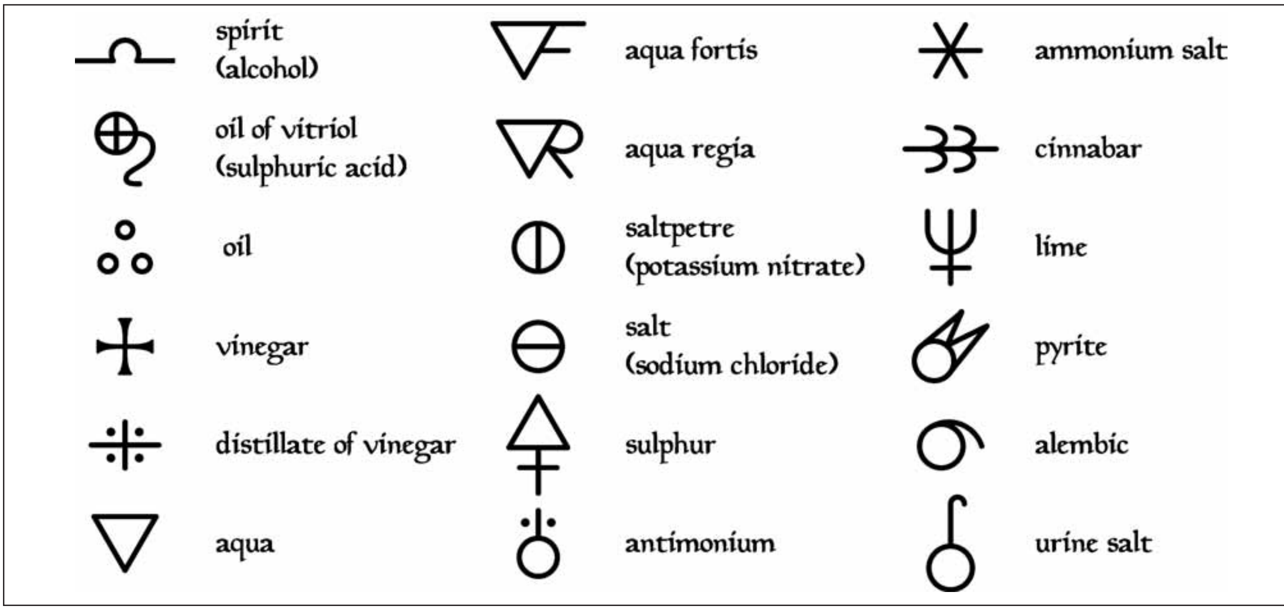


Figure 7. Example alchemical symbols of some substances. Adapted from Symbols.com Encyclopedia of Western Signs and Ideograms, *http://www.symbols.com/index/wordindex-a.html,* and *http://www.levity.com/alchemy/symbols.html* (both accessed Jul 2008).

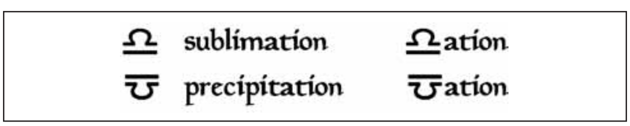


Figure 8. Basic processes in alchemy were associated with the 12 zodiacal signs. Sublimation was associated to the balance (Libra). For precipitation, not included in the 12 basic techniques, a new symbol had to be invented: the balance turned upside-down.

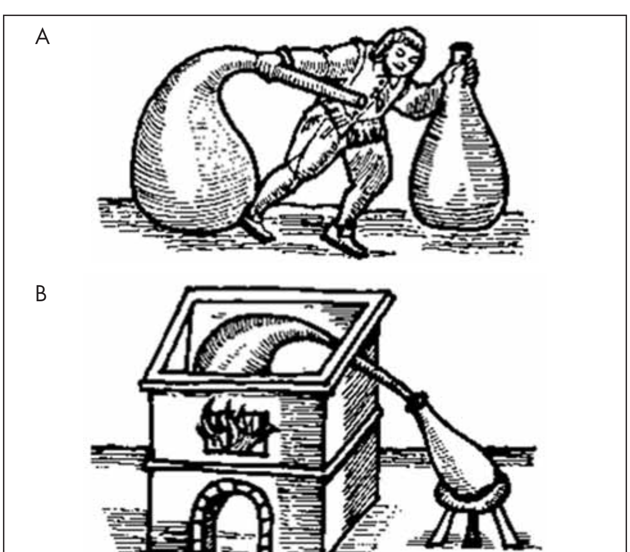


Figure 9. Woodcuts from *The Art of Distillation* (1651), by John French (1616–1657). (A) An alchemist moving an alembic and a collection vessel, each of which could have considerable size; moving them required well-trained operators. (B) Distillatory furnace.(See *http://dewey.library.upenn.edu/sceti/printedbooksNew/index.cfm?TextID=french_distill&PagePosition=89* [accessed Jul 2008].)

Substances other than metals were indicated by their own symbols, as illustrated by some selected examples in Figure 7. Symbols were in most circumstances conventional and in any case we find it difficult, today, to detect a clear relationship between the icon and the properties of a substance. An exception is perhaps that of oil, represented by three drops. Oil was any liquid obtained through dry distillation of solids—the oil of vitriol (sulfuric acid) was obtained in the form of drops condensing from a distillatory furnace. Vinegar was conventionally indicated by a cross and the symbol of distilled vinegar was a cross with four dots or drops. *Aqua fortis* (nitric acid) and *aqua regia* (nitric acid and hydrochloric acid combined) were indicated by a triangle up (the symbol of water) with an incorporated F and R, respectively, to give a monogram, rather than a symbol.

To create symbols for laboratory procedures, alchemy sought help from astrology, and each experimental technique was associated with one of the twelve signs of the zodiac. For instance, sublimation was indicated with the sign of the balance (see Figure 8) and the corresponding verb (to sublimate) is often found written in alchemical texts according to a mixed alpha-symbolic style (see Figure 8). Again, the number of laboratory procedures soon exceeded twelve, and new extra-zodiacal symbols had to be introduced. Quite logically, alchemists indicated precipitation (not included in the twelve classical procedures and to be considered the inverse of sublimation) with the symbol of the balance turned upside-down (see Figure 8).

However, the most important technique in the alchemical laboratory was probably distillation (indicated by the zodiacal symbol of Virgin). Distillation had been introduced around 800 C.E. by Arab alchemists, who invented the most famous glassware apparatus, the alembic, which has assigned its own iconic symbol (see Figure 7). Alcohol was obtained by distilling wine and its current name in many countries—spirit—gives us insight into the very special significance alchemists attributed to distillation. The Latin word *spiritus* primarily indicated the vital breath, the essence of the life, the soul. Alchemists' feeling was that heating in a furnace forced any substance to liberate its true essence, to exhale its soul, which was respectfully collected in a cold retort.

While today distillation remains the most important technique for separation and purification of liquids, alchemists also put solids in the furnace, which were heated to extremely high temperatures, until decomposition and eventual formation of gas and vapors. The liquid collected in the receiving retort, from vapor condensation, was denoted oil or spirit. Thus, dry distillation of vitriols (hydrated sulfates of copper(II) or iron(II), of vitreous appearance) gave oil or spirit of vitriol (sulfuric acid); from salt (sodium chloride) the spirit of salt (hydrochloric acid) was distilled, from saltpeter (potassium nitrate), *aqua fortis* (nitric acid). Drawings in Figure 9 indicate that distillation was carried out on a multi-kilogram scale and that (al)chemists had to be (and still should be, hopefully) physically well trained.

A

B

Figure 10. Alchemists at work. (A) *The Alchemist* (1663), oil on panel, by Cornelis Pietersz Bega (1620–1664), The Getty Center, Los Angeles. (Image used by permission of the J. Paul Getty Museuem, Los Angeles). (B) *An Alchemist* (1657), oil on oak, by Adrian van Ostade (1610–1685), National Gallery, London. (Image used by permission of the National Gallery Picture Library, London).

Alchemy and Society

Alchemists used a private language, operated in secret rooms, and apparently were not too open to society. What opinion did society have of alchemy? Let us listen to a famous scholar of the late Middle Ages, the Laureate Poet Francesco Petrarch (*De remediis utriusque fortunae* [Remedies for Fortune Fair and Foul], 1366):[1]

> [V]ery rich individuals ruin themselves for this futility [alchemy]. And, while striving to get richer, engaged in this nasty job, they badly waste well-earned wealth. And finally, after dissipating their fortune, they cannot fulfil even their most elementary needs. Some of them avoid conversation with other citizens and stay on their own, anguished and sad, because they are used to think only of bellows, pliers and coal and to associate only with the members of that heretical company; and, at last, they become nearly feral…

Thus, Petrarch considered alchemy as an irreversible mental illness, originated by an insane desire of riches and ultimately leading to misery, distress, and social isolation. Very dangerously, alchemy was defined a heresy, a charge that, at that time, could send one to the stake. In any case, the mention of "bellows, pliers, and coal" demonstrates that Petrarch had visited an alchemical laboratory, whose most important apparatus was the furnace. Three hundred years later, the general opinion on alchemy had not changed very much, judging from the two oils by Flemish painters featuring alchemists at work, shown in Figure 10. Both alchemists were portrayed as shabby and dirty individuals, whose mental disorder was reflected by the extreme mess of the laboratory. Indeed, the two paintings appear as the exact visual translation of Petrarch's text. This may raise the suspicion that we are in presence of a cliché, rather than of an objective representation of reality.

A more favorable view of alchemy is offered by the painting in Figure 11, from another Flemish painter, Jan van der Straet,

Figure 11. *The Alchemist's Studio* (1570), oil on panel, by Jan van der Straet (alias Giovanni Stradano), Studiolo di Francesco I de' Medici, Museo di Palazzo Vecchio, Firenze. (Image used by kind permission of the Municipality of Florence.)

who worked in Florence in the 16th century, under the protection of the Medici family. The painting was commissioned by Francis I of Medici, who was an alchemist himself and had his private laboratory in Palazzo Vecchio. In fact, the painting does not portray the stereotypical character of the alchemist, according to a pluricentennial tradition, but shows an active team of people working in agreement and serenity and showing self-consciousness and dedication. We are inclined to believe that this painting provides a more credible illustration of reality, also considering that alchemical practice, like chemistry today, was a rather complex activity that required the concerted efforts of several expert people. The question is: who is the head of the laboratory featured in the painting, who is the professor? The answer is easy: the head or professor is the only individual doing nothing—the elderly man seated at the right side of the painting. This is obviously true, even if we cannot minimize the role of that authoritative person, handing recipes to the assistants and controlling the correctness of the procedures. What is not true is that he was a professor. In fact, alchemy, in spite of the expectations of many worthy and renowned researchers in the field, was never accepted as a discipline in universities. Chairs of implausible disciplines like astrology were instituted in Europe, but not even one chair of alchemy. This may have upset the most famous European alchemist: Philippus Theophrastus Aureolus Bombastus von Hohenheim, known as Paracelsus (1493–1541), who held the chair of medicine at the University of Basel for less than one year, when he was fired and began a wandering life in Europe, Turkey, and Arabia *(6)*. Paracelsus pioneered the use of chemicals and minerals in medicine and also characterized zinc metal, to which he gave the name "zink", inspired by the sharp pointed appearance of its crystals after smelting ("zinke" in Old German means "pointed"). It is not too difficult to imagine the fierce opposition to the institution of a chair of Alchemy from professors of medicine on one hand, worried for the competition for patients, and by professors of law and theology on the other, still influenced by the prejudices on the "heretical company", as defined by Francesco Petrarch.

Although alchemy was not successful in academic circles, chemistry was. A chair of chemistry, the first in all Europe, was established in Cambridge, UK, in 1702 *(7)*. The chair's first holder was the Italian Giovanni Francesco Vigani (ca. 1650–1713), an intimate friend of Isaac Newton, professor of physics in Cambridge and a secret alchemical practitioner himself, who may have exerted his authoritative pressure on the Senate of the University for the institution of the chair (even if it was without a stipend). Thus, in 1702, chemistry officially evolved from alchemy and emerged as an independent field of study distinct from its association with the encumbering and smothering disciplines of pharmacy and medicine.

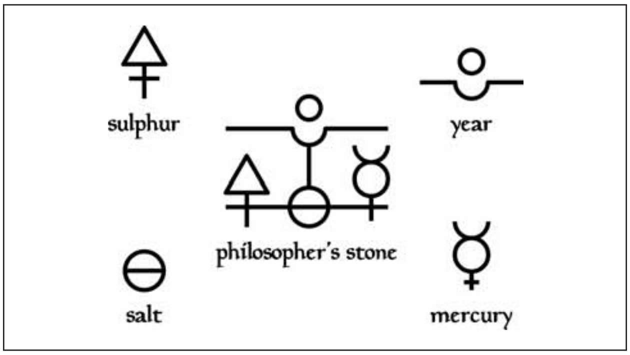


Figure 12. The complex symbol of philosopher's stone, which results from the combination of the symbols of the three components (mercury, sulphur, and salt), plus the symbol of the year.

Figure 13. *The Announcement of the Angel to Zacharias* (detail) (ca. 1487), fresco, by Domenico Ghirlandaio, Cappella Tornabuoni, Church of Santa Maria Novella, Florence. The fresco features the philosopher Marsilio Ficino, first from left, and the poet Agnolo Poliziano, third from left, active in Florence during the second half of the 15th century. (Image used by kind permission of the Italian Ministry of Cultural Activities and Heritage.)

The Central Character of Alchemy: Mercury

Alchemy had two main objectives: (i) the transmutation of cheaper metals into gold (to be achieved with a *philosopher's stone*); (ii) the preparation of the *elixir of life*, which makes humans younger, thus delaying death *(8, 9)*. The two goals were, at least formally, related because gold was considered the "immortal" metal. Metals were divided in two classes: the *corruptible* ones (lead, tin, iron, copper) and the *incorruptible* ones (silver, gold), according to a sequence paralleling the resistance to the oxidation and, roughly, the values of the electrode potentials for reduction. Mercury was in the middle and, indeed, played a very special role. In fact, mercury was considered as the *prima materia* of which all the metals were made. In particular, metals were believed to differ one from the other just in the relative quantity of mercury and sulphur they contained. Later, Paracelsus added a third component: salt. Accordingly, the philosopher's stone was represented by the complex pictogram shown in Figure 12, which ultimately results from the composition of the symbols of the three ingredients, plus the symbol of the year, probably to show that the way to gold was not straightforward, but needed time and dedication.

In any case, mercury was required to transform (*transmute*) any impure metal into gold. Why did mercury play such a central role? The obvious answer is that mercury is a unique metal, in that it is liquid and distils at a relatively low temperature (bp 357 °C), easily accessible in the furnaces of alchemists. Mercury was extracted without difficulty from cinnabar, HgS, a mineral which was found mainly in Spain. Its toxicity had been known for a long time; ancient Romans used as miners prisoners sentenced to death (an event unavoidably occurring after a few months of convict labor). Powdered cinnabar was used as a red pigment and represented the basis of the popular vermilion color so frequently observed in paintings from the Renaissance and before. For instance, vermilion is the color of mantles and suits of the gentlemen featured in the fresco by Domenico Ghirlandaio (ca. 1487), shown in Figure 13, discussed below.

The extraction of mercury from its ore was very simple and could be carried out even on a small scale in the distillatory furnace. The process involved the roasting of the sulfide, $HgS(s) + O_2(g) \rightarrow Hg(g) + SO_2(g)$, and was spectacular and intriguing. In fact, on heating in the furnace, the red solid vanished to reappear in the form of a liquid metal in the collecting retort. This may have induced or reinforced the belief that mercury was the "soul" of the metals. Moreover, mercury was able to dissolve other metals (except iron) to give amalgams and, very interestingly, reacted with sulfur, to reconstitute cinnabar, $Hg(l) + S(s) \rightarrow HgS(s)$: this unique behavior (thermal decomposition and reconstitution of HgS) could have directed alchemists to stoichiometry and quantitative chemistry, but, unfortunately, did not.

Mercury and its compounds were used as drugs to treat a variety of diseases. In particular, metallic mercury, finely dispersed in water, was used in the treatment of constipation, headache, and melancholy (more generically and prosaically defined today as depression); calomel (Hg_2Cl_2) as a diuretic, laxative, and topical disinfectant; corrosive sublimate ($HgCl_2$) was specific for syphilis. We know today that mercury derivatives have a destructive effect on nerve cells, inducing tremor, insomnia, confused speech, and hallucination and that alchemists themselves could not be unaware of the highly toxic nature of mercury compounds. How, then, could they and their associates (physicians and pharmacists) deliberately administer a poison to their patients? The answer is provided by the famous statement of Paracelsus: "the dose makes the poison" (i.e., nothing is toxic when taken up in a controlled amount, under the direction of a specialist). Troubles could come when one is exposed to poisonous substances under uncontrolled and prolonged circumstances. This happened in working environments where mercury derivatives were systematically used: for instance, felt, to make hats, was prepared by curing skin with a hot solution of mercuric nitrate. This may have seriously damaged the nervous system of people involved in manufacturing felt and hats, from which the expression derived: "mad as a hatter" an idiom well known to Lewis Carroll, when writing *Alice's Adventures in Wonderland* (1865) and to Walt Disney, when drawing cartoons for the movie of 1951.

A traveling companion of Mercury along the way to gold was sulfur. Sulfur was a cheap material, directly extracted as an element from mines. The Latin name *sulphur* derives from the Arabic word *sufra*, meaning "yellow". However, the Greek name of sulphur was θειον, a term related to Θεος, Zeus, the king of gods. This has influenced modern chemical nomenclature in that the names of some sulfur derivatives contain the prefix thio- (thiosulphate, thioethers, etc.). The question is: why did Greek alchemists associate a humble substance like sulfur with the most important god of the Greek pantheon? To answer this, one should go back in time to the 5th century B.C.E. and visit the Temple of Zeus in Olympia (destroyed by an earthquake in the 3rd century C.E.). In the temple there was the very famous and impressive statue of Zeus, made by the great sculptor Pheidias around 440 B.C.E. consisting of a wooden frame covered by sheets of gold and ivory. The height of the statue was 13 m (something like a four-story building of modern times!) and was considered one of the Seven Wonders of the Ancient World. The temple was visited each day by thousands of pilgrims, who presumably stopped in prayer in front of the statue, asking for favors and graces from Zeus. However, direct communication between the believer and the God is rarely allowed; instead, a specialist intermediary was required: the priest. In Olympia, the priest had first to demonstrate being in personal contact with Zeus and to prove the divine presence inside the statue. To do that, the priest threw with dexterity a handful of sulfur in one of the sacred braziers in front of the statue, inducing the exothermic formation of sulfur dioxide ($S + O_2 \rightarrow SO_2$). The blue flash, the associated bang, and the acrid smell spreading out reproduced quite well the stroke of lightning, the tool traditionally used by Zeus to reveal himself to humans. At this point, the believer was definitively convinced.

A

B

Figure 14. Self-portraits by Francesco Mazzola, called Parmigianino (1503–1540). (A) *Self-Portrait in a Convex Mirror,* 1524, oil on wood, Vienna, Kunsthistorisches Museum. (Image used by permission of the Kunsthistorisches Museum, Vienna). (B) *Self-Portrait,* 1539, oil on wood, Parma, Galleria Nazionale. (Image used by kind permission of the Italian Ministry of Cultural Activities and Heritage.)

Art and Alchemy

Few examples exist of the direct connection of artists to alchemy during the Middle Ages and the Renaissance. However, one well-documented case is that of the painter Francesco Girolamo Mazzola (1503–1540), commonly known as "Parmigianino", a nickname meaning "the little one from Parma" *(10).* In fact, Francesco was born in Parma, in a family of painters, and revealed a precocious talent, which is explicitly demonstrated by the *Self-Portrait in a Convex Mirror* (1524), shown in Figure 14A. The portrait was painted on the surface of a wood hemisphere with a diameter of 24.4 cm and reproduces exactly, in size and shape, the mirror typically used by barbers and used by Parmigianino for portraying himself. This painting was sent by Parmigianino to Pope Clemente VII (of the Medici family), as a calling card. The pope was positively impressed and invited the painter to Rome. The situation was very favorable for young painters at that time, because the great Raphael had died three years before and the Vatican was looking for a suitable replacement.

Parmigianino went to Rome and made a number of frescoes on religious subjects in different churches of the town. However, in 1527 the troops of Charles V, Holy Roman Emperor, invaded Rome, bringing destruction and violence and prompting artists of the Vatican court to a precipitous escape. Parmigianino repaired first to Bologna, to move a few years later to his hometown. Probably at that time, Parmigianino began to practice alchemy seriously. It is possible that he became familiar with chemicals and alchemical procedures when practicing a technique of etching that involved the treatment with *aqua fortis* (concentrated nitric acid) of a copper plate covered by a thin layer of wax on which the drawing had been engraved.

Figure 15. *Portrait of Gian Galeazzo Sanvitale, Count of Fontanellato* (1524), oil on wood, by Parmigianino, Museo Nazionale di Capodimonte, Naples. The Count shows off in his right hand a coin, on which figures 7 and 2 have been engraved: 7 may refer to the number of known metals, 2 to the constituents of *materia metallica:* mercury and sulfur. (Image used by kind permission of the Italian Ministry of Cultural Activities and Heritage.)

A

B

Figure 16. (A) *Madonna of the Long Neck* (1534–1540), oil on wood, by Parmigianino, Galleria degli Uffizi, Florence. (Image used by kind permission of the Italian Ministry of Cultural Activities and Heritage.) (B) *Venus—Peacock's Tail,* from *The Splendor Solis* (1532–1535) attributed to Salomon Trismosin. An alchemical crowned flask featuring copper, the metal associated with Venus (shown at top, driving a chariot). (Image used by permission of the Kupferstichkabinett, Staatliche Museen zu Berlin).[3] The vessel held by the angel in Parmigianino's painting may be reminiscent of a crowned flask.

Let us read what Giorgio Vasari wrote on Parmigianino in the first edition (1550) of *The Lives of Most Excellent Painters, Sculptors, and Architects (11).*[2]

> [A]nd it happened that he searched for the alchemy of gold, on distillation, and that fool did not realize that his alchemy was in drawing figures, which, with some color spotting and no expenses, withdraw hundreds of scudi from someone else's pockets. But, insane for this affair, he lost his head and was definitively poor…"

Thus, it appears that (i) Parmigianino was seriously involved in the affair of the philosopher's stone and (ii) distillation was considered by laymen the principal alchemical technique. Moreover, Vasari, as a talented painter himself, was well conscious that painting was a much more profitable business than alchemy. In the 1568 edition of *The Lives (11),* he depicted a worsening situation:

> [A]t that time, he [Parmigianino] devoted himself to alchemy and, thinking to become rich in a short time, he tried to freeze mercury… and, because of the many furnaces and expenses, he could not collect from painting enough money for compensating the costs of alchemy…

The expression "to freeze mercury" is very eloquent. In this case, freezing is not to be understood as the temperature dependent liquid-to-solid phase change of mercury, taking place at −39 °C, since the refrigerating baths of Fahrenheit and Celsius would not be known for a century or more to come, and in any case alchemists liked to heat rather than to refrigerate substances. "To freeze mercury" thus most probably refers to the room temperature addition to mercury of the correct amounts of sulfur, to induce solidification and simultaneous transmutation to the yellow metal of kings. From this source readers can ascertain the passion of Parmigianino for alchemy. Pursuing this line of thought further leads to the question: Are alchemical practice and culture reflected in any painting by Parmigianino? An intriguing example is provided by the portrait of Gian Galeazzo Sanvitale, Count of Fontanellato, a patron of Parmigianino in the early times in Parma, shown in Figure 15.

Galeazzo gazes at the observer with disquieting intensity and shows a coin on which two figures are engraved: 7 and 2. One interpretation is that 7 is there to indicate the number of metals in alchemical philosophy, and 2 the number of the constituents of metallic matter: mercury and sulphur. Apparently, the wealthy count was involved himself in the transmutation business, not for avidity, but for fun.

However, the most significant of Parmigianino's paintings in an alchemical context is the oil on wood exhibited at the Uffizi Gallery, in Florence, featuring "Madonna of the Long Neck" (1534–1540), shown in Figure 16A. Indeed, the unusually and untruthfully long neck of Our Lady has been tentatively interpreted as an allusion to the neck of the glass containers typically used in alchemical labs. A more significant hint in the painting is provided by the dark vessel held in the hands of the angel in the left side. Such a recipient is strongly reminiscent of the seven alchemical crowned flasks, an example of which is shown in Figure 16B. In particular, each metal was represented by a glass container including a symbolic item. The flask in Figure 16B refers to copper and includes a peacock, a bird conventionally associated with Venus, and so to her corresponding metal.

According to Vasari, alchemical practice did not produce beneficial effects for Parmigianino's health and appearance. Vasari stated *(11):*

> [A]nd for this reason [alchemy], he had the look of a fool; and, because of the long hair and beard, his face was that of a wild man, rather than that of the graceful person he was...

Probably, Vasari compared the attractive self-portrait of 1524 with the one of 1539, both shown in Figure 12. Indeed, in 1539 Parmigianino looked much older and in worse shape than expected for his 36 years. In fact, Parmigianino died one year later, persecuted by creditors and probably poisoned by the toxic substances unwisely manipulated during the course of his alchemical activities.

To see a painting of intriguing alchemical content within the Uffizi Gallery, one should probably go to the most famous masterpiece exhibited there: *La Primavera* by Sandro Botticelli, shown in Figure 17. Giorgio Vasari was the first to propose the rather simplistic interpretation of the painting as an allegory of Spring. More recently, it has been suggested that the painting visually reproduces *On the Wedding of Philology and Mercury,* a mythological–allegorical tale by the pagan rhetorician Martianus Capella (5th century C.E.) *(12),* much in fashion in the humanistic circles of Florence in the second half of 15th century.[4]

However, the presence and the attitude of Mercury remain enigmatic and may refer to alchemy. Nonetheless, one should preliminarily assess whether Sandro Botticelli was an alchemist himself. The answer is no. However, Botticelli was a member of the intellectual circle of the Medici family, who often suggested to him themes of inspiration for paintings. Prominent personalities of the circle were the philosopher Marsilio Ficino and the poet Agnolo Poliziano, featured in Ghirlandaio's fresco shown in Figure 13. The Medicis themselves were interested in alchemy: they were at that time rich and powerful bankers, but they had started their business (and made money) as weavers and dyers, being therefore highly concerned with dyes and mineral pigments. In particular, Cosimo de' Medici charged Marsilio Ficino to translate from Greek to Latin the *Corpus Hermeticum* by Hermes Trismegistus, the summa of Egyptian and Greek alchemy teachings (1463–1468) *(13).* The text circulated all over Europe and had a great influence on the development of alchemy *(14).*

In the painting, Mercury appears completely disconnected from the rest of the scene: he turns his back on the other characters, he looks at the sky, to which he directs the caduceus, as if he were on the point of flying up. However, quite surprisingly, Mercury does not wear his other distinctive item, the winged petasus: he wears a helmet, in particular the Hades' helmet, which has the property of making the wearer invisible. According to Greek mythology, Mercury–Hermes gave Perseus that helmet when he went to cut off Medusa's head. The unusual presence of Hades' helmet, never observed in Mercury–Hermes iconography at any time from Ancient Greece to the European Renaissance, suggests that the god Mercury, in Botticelli's painting, is already (or is becoming) invisible and disappearing, exactly as the metal mercury, when heated in the furnace, distils and vanishes (to reappear elsewhere). It is possible that the alchemically oriented Medici intellectual circle wanted to pay in this way a tribute to the central character of alchemy, Mercury, and to its unique properties.

Alchemy Evolves to Chemistry

In the 18th century, a revolutionary instrument entered into the alchemical laboratory: the precision balance. As a consequence, the mass of the reagents and that of the products could be exactly determined and the discipline became quantitative. This led Antoine Lavoisier (1743–1794) to formulate the law of conservation of mass *(15),* and later John Dalton (1766–1844) to put forward his atomic theory *(16).* According to Dalton, (i) a defined number of elements exists (he counted 36) and elements are made of tiny particles called atoms; (ii) atoms of one element can combine with atoms of other elements to form compounds. Dalton indicated elements with symbols, as shown in Figure 18, still following the alchemical style. Then, compounds were described by formulas, obtained through the appropriate combination of symbols. Symbols of elements were conventional, some of which were confused with those of alchemy (e.g., hydrogen had assigned the alchemical symbol of gold). In other cases, they were obtained by including in a circle the initial letter of the English name of the element (see copper and lead in the Figure 18).

Figure 17. *Primavera* (ca. 1482), tempera on panel, by Sandro Botticelli, Galleria degli Uffizi, Florence. The role of Mercury (left) is intriguing: rather than his typical winged petasus cap, he wears Hades' helmet, which makes the wearer invisible. One senses that the god Mercury is going to disappear, just as the metal mercury disappears when distilled in a furnace. (Image used by kind permission of the Italian Ministry of Cultural Activities and Heritage.)

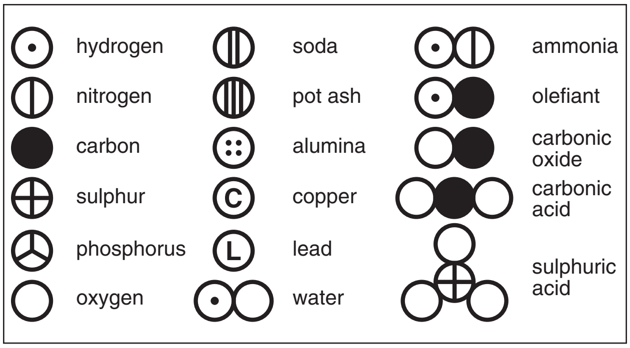


Figure 18. Some chemical symbols and formulas, as introduced by John Dalton (1808). Olefiant is now called ethene.

Indeed, an advance in nomenclature had been obtained, but the difficulty in memorizing symbols remained. Thus, in 1813, Jöns Jakob Berzelius (1779–1848) decided to give up symbols and invented modern chemical notation: (i) each element is indicated with the initial letter of its Latin name, in capital; (ii) if two elements have the same initial, a second letter from the name is added, as a small character *(17).* Thus, what we still continue to call the symbols of the elements are no longer symbols, but abbreviations. Berzelius' invention may have comforted the students of chemistry and, in particular, the typesetters who had to print chemistry textbooks and articles.

Thus, with the beginning of the 19th century, alchemy definitively ended. However, chemistry had not yet fully disclosed its potentiality. In particular, the chemistry of organic substances had yet to appear. This might be a consequence of the typical attitude of alchemists to work at the furnace, where organic substances could only be "cooked" and carbonized. But this essentially resulted from the long-accepted prejudice that for synthesizing an organic substance a "vital force" is required and that organic substances can be ultimately made only by living organisms. Accordingly, chemists in the laboratory could only manipulate, transform, and synthesize inorganic substances (metals, minerals, salts).

This belief, which dated back to Aristotle (again!) and to his division of the natural world into a mineral kingdom, on one side, and an animal and vegetable kingdom on the other, was quietly accepted by scientists, including Berzelius. In 1828, a young German chemist, a former associate of Berzelius, Friedrich Wöhler (1800–1882), was recrystallizing ammonium cyanate from water, while investigating the cyanate–isocyanate isomerism, in competition with his friend and rival Justus von Liebig. However, on concentration, a new and unexpected compound precipitated: urea, which formed through the reaction: $NH_4^+ + NCO^- \rightarrow (NH_2)_2CO$. Alchemists knew urea, a white solid residue that formed at the bottom of the heated retort during distillation of urine, to which a name (salt of urine) and a symbol (see Figure 7) were assigned. Urea had been characterized as an organic substance in 1773 by the French chemist Hilaire Marin Rouelle (1718–1779) and, as an organic substance, could be rightfully generated only by living organisms.

Wöhler published his discovery in a journal of physical chemistry *(18).* The paper had a determining influence on the development of chemistry, marking the beginning of the continuing story of organic synthesis *(19).* Wöhler's article was for chemistry what Galileo Galilei's *Dialogo sopra i Due Massimi Sistemi* (1630) was for physics and Charles Darwin's *On the Origin of Species* (1859) was for biology. However, the impact of Wöhler's work on society was much less crucial, if not negligible. This shows both the limited attention that society paid to chemistry at that time (and pays today), and, probably, the equally limited capability chemists had (and perhaps still have) to communicate effectively with the external world.

The development of organic chemistry and the synthesis of increasingly more sophisticated molecules stimulated chemists of the 19th and 20th centuries to introduce a new type of graphical representation, that of structural formulas, in two and three-dimensions. Structural formulas still have a high symbolic content (for unexperienced people they are reasonably viewed as letters of the Latin alphabet arbitrarily linked by strokes of a pen). However, they are intended to represent an objective reality and a stylized portrait of the substances; in particular, harmony and originality of a newly designed molecular architecture may whet the aesthetical sense of the observer *(20).* Such an aspect has dramatically increased with the development of molecular graphics on computers. Therefore, beauty has become a further molecular property and the covers of journals of chemistry often depict impressive pictures of complex and aesthetically agreeable molecules, which, transferred on canvas and framed, could be rightfully exhibited in galleries of modern art.

Epilogue

For perhaps thousands of years, some individuals have chosen to withdraw themselves into rooms equipped with sources of heat and hoods, and operate with matter using vessels of varying complexity. They have worked with attention and dedication enjoying the pleasure of investigating and manipulating matter.[5] Fortunately for current chemists, society has modified its opinion of them and has finally realized that chemistry is a helpful discipline, as it produces goods improving the quality of life. Thus, chemists are no longer considered the members of a *heretical band*—unless one considers a heretic a person who does not accept any dogma, but looks at the world with an open mind and a desire of learning. In this sense, chemists would be proud of being heretics.

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Notes

1. Francesco Petrarca (1304–1374) Italian scholar, poet, and early humanist. He wrote both in Italian (*Canzoniere*, which made the sonnet one of the most popular forms of poetry to date) and in Latin. *De Remediis Utriusque Fortunae* (Remedies for Fortune Fair and Foul) is a collection of short dialogues written in Latin prose during the period 1360–1366. It consists of 254 cross talks between allegorical entities: first, Happiness and Reason, then Pain and Reason. Reference text: Rawski, C. H. *Petrarch's Remedies for Fortune Fair and Foul* A Modern English Translation of *De remediis utriusque Fortune*, with a Commentary, 1991.

2. Giorgio Vasari (1511–1574) Italian painter and architect, active in Florence under Medici's patronage. He wrote in Italian a famous book of biographies of Italian artists, from ancient times to his days: *Vite de' Più Eccellenti Pittori Scultori e Architettori*, in two consecutive editions, 1550 and 1568. Reference text: Vasari, G. *The Lives of the Artists,* translation by J. Conway Bondanella and P. Bondanella, Oxford University Press, Oxford, 1998.

3. The image is reproduced from the *Splendor Solis*, an alchemical text with 22 colored drawings, most of which are displayed in ornate frames. The earliest known version of the manuscript, now in the Kupferstichkabinett in the Prussian State Museum in Berlin, is dated 1532–1535. However, the style suggests an earlier date of preparation of the drawings, which may have circulated well before all over Europe and reached alchemists and painters, including Parmigianino.

4. This interpretation of *Primavera* has not yet been described at an international level in books or specialized journals. Original references, in Italian, are: (i) Villa, C. Per una Lettura della *Primavera.*

Mercurio "Retrogrado" e la Retorica nella Bottega di Botticelli. *Strumenti Critici*, **1998,** *XIII,* 1; (ii) Reale, G. *Botticelli. La "Primavera" o le "Nozze di Filologia e Mercurio?";* Idea Libri: Rimini, Italy, 2001.

5. Working for the pleasure of investigating matter and inventing new substances and materials is the typical attitude of chemists today. It is possible that during the alchemical period, the hope of making a fortune through successfully transmuting base materials into gold may have represented a further powerful driving force, even if, as Giorgio Vasari pointed out for Parmigianino, there were more comfortable and safer ways to make money.

Literature Cited

1. Tylecote, R. F. *A History of Metallurgy,* 2nd ed.; Institute of Materials: London, 1992.
2. Turner, H. R. *Science in Medieval Islam;* University of Texas Press: Austin, TX, 1997.
3. Newman, W. R. *Atoms and Alchemy: Chymistry and the Experimental Origins of the Scientific Revolution;* University of Chicago Press: Chicago, 2006.
4. Barnes J. *The Cambridge Companion to Aristotle;* Cambridge University Press: Cambridge, 1995.
5. *Secrets of Nature: Astrology and Alchemy in Early Modern Europe,* 1st ed.; Newman, W. R., Grafton, A., Eds.; The MIT Press: Boston, 2001.
6. Ball, P. *The Devil's Doctor: Paracelsus and the World of Renaissance Magic and Science;* Farrar, Straus and Giroux: New York, 2006.
7. *The 1702 Chair of Chemistry at Cambridge, Transformation and Change;* Archer, M. D., Haley, C. D., Eds.; Cambridge University Press: Cambridge, 2005.
8. Greenberg, A. *A Chemical History Tour: Picturing Chemistry from Alchemy to Modern Molecular Science;* Wiley: New York, 2000.
9. Thompson, C. J. S. *Alchemy and Alchemists;* Dover Publications Inc.: New York, 2002.
10. Gould, C. *Parmigianino: Life and Work, with a Catalogue of Paintings and Prints;* Rizzoli International: New York, 1994.
11. Vasari, G. *The Lives of the Artists,* translation by Conway Bondanella, J., Bondanella P.; Oxford University Press: Oxford, 1998.
12. Stahl, W. H. *Martianus Capella and the Seven Liberal Arts: Volume II—The Marriage of Philology and Mercury;* Columbia University Press: New York, 1992.
13. *Marsilio Ficino: His Theology, His Philosophy, His Legacy;* Bridgman Allen, M. J., Rees, V., Davies, M., Eds.; Brill: Leiden, The Netherlands, 2002.
14. *The Way of Hermes: New Translations of the Corpus Hermeticum and the Definitions of Hermes Trismegistus to Asclepius* (translations by Salaman, C., van Oyen, D.; Wharton, W. D., Mahe, J.-P.); Inner Traditions—Bear and Company: Rochester, NY, 2004.
15. Lavoisier, A. L. *Traité Élémentaire de Chimie, Présenté dans un Ordre Nouveau et d'après les Découvertes Moderne,* 2nd ed.; Cuchet: Paris, 1793.
16. Dalton, J. *A New System of Chemical Philosophy;* R. Bickerstaff: London, 1808.
17. *Enlightenment Science in the Romantic Era: The Chemistry of Berzelius and Its Cultural Setting;* Melhado, E. M., Frdngsmyr, T., Eds.; Cambridge University Press: Cambridge, 2003.
18. Wöhler, F. Über die Künstliche Bildung des Harnstoffes [On the Artificial Formation of Urea]; *Poggendorfs Annalen der Physik und Chemie* **1828,** *12,* 253–256.
18. Kauffman, G. B.; Chooljian, S. H. *Chem. Educat.* **2001,** *6,* 121–133.
20. Vögtle, F. *Fascinating Molecules in Organic Chemistry;* Wiley: Chichester, 1992.

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