# Was Leonardo a Chemist?**

**Pedro Cintas***

The inaugural editorial and the cover illustration of the first issue of *Angewandte Chemie* for January 2000 describe a famous pencil drawing—the Vitruvian man—by Leonardo da Vinci.[1] This genius of the Renaissance was admired in his lifetime for his many facets and unlimited desire for knowledge; qualities that have remained undimmed to the present day. Most biographies concentrate on Leonardo as a great artist, architect, musician, and military engineer. His varied scientific ability has also been documented, albeit largely overlooking his contributions to chemistry and physics.

The scientific achievements are contained in a large collection of manuscripts, mostly disconnected notes for his own use, which were written between 1490 and 1518. Several of his codices, especially the comprehensive *Codex Atlanticus* and the *Codex Arundel*, contain abundant drawings and descriptions of chemical preparations and apparatus such as furnaces, a mixing mill, alembics, and ingenious balances.[2–4] Many readers will know well that all these studies were written down with in Leonardo's peculiar hand: the notebooks can be read with the aid of a mirror. Contrary to a held belief, this practice should not be considered a secret handwriting. Leonardo was left handed and mirror writing came naturally to him. Unlike his artistic studies, his scientific notes are not clearly arranged. Leonardo had a remarkable and unusual power of observation combined with a strictly empirical approach to explain natural phenomena, often with the help of mechanical models. Leonardo advocated the repetition of experiments and measurement of weights, distances, and velocities entered into all of his observations. He did not invent the balance, at least in the way as we know it, but he designed several devices to compare weights.

Leonardo's scientific activity was particularly important from 1482 to 1499 (during this period he completed only six paintings) in the service of Duke Ludovico Sforza in Milan, registered as "pictor et ingeniarius ducalis" (painter and engineer of the duke). Later, in 1502, he entered the service of Cesare Borgia as a military architect and general engineer. Leonardo studied the composition of bronzes for gun casting, noting that tin can be replaced by lead; the bronze for guns should contain from six to eight percent of tin. Likewise, he described a gunpowder, which he called Greek fire, made from saltpetre (potassium nitrate), willow charcoal, spirit of wine, sulfur, pitch, frankincense, and camphor boiled together and spread over "lana etiopica" (wool). He anticipated the invention of gas warfare consisting of fumes of burnt feathers, sulfur, and realgar (arsenic sulfide), whose effects lasted for seven to eight hours. Some chemical recipes describe the preparation of "aqua fortis" (nitric acid) from equal amounts of Roman vitriol,[5] saltpetre, verdigris,[6] and cinnabar (or colcothar).[7] Such a preparation dissolved copper and Leonardo noted that pyrites do contain copper if their treatment with aqua fortis gives a green solution, from which a precipitate is obtained with saltpetre and soft soap.

Leonardo's notes on chemistry are also formulas for paints and pigments, which he used in his artistic works. Thus, the *Codex Atlanticus* contains numerous recipes: "For 'vetro giallo' (yellow glaze) take one ounce tuzia (zinc oxide), ¾ ounce Indian saffron, ¼ ounce borax, and grind it all together into a powder." Unfortunately, other notes do not include precise amounts: "To make scent take fresh rose water and moisten the hands, then take flower of lavender and rub it between the palms, and it will be good." One of his pigments, denoted as green fire, was obtained by soaking verdigris in oil of turpentine and filtering, and other colors were extracted from flowers by alcohol. Leonardo also utilized proteins, in the form of a concentrated solution of gelatin or egg white, to which pigments or plant extracts were added. Such mixtures were applied to ceramic molds which were dried and varnished, thereby making objects that imitated agate, jasper, or amber. Impregnation of paper with the same pigments gave dense plates which, after varnishing, resembled glass and were impermeable to water, an almost perfect imitation of a modern plastic material.

A significant portion of his chemical studies were devoted to combustion. A drawing of a chemist's furnace with two alembics appears in the *Codex Atlanticus*. Leonardo also invented a lamp chimney to bring fresh air to the flame as well as a lamp with constant oil level. Leonardo was aware of the

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importance of air to make a flame bright and in the maintenance of life. He described in detail a flame with pictures showing the blue inner cone. Some scholars have interpreted that Leonardo was close to the discovery of oxygen (which was achieved by Priestley in 1774): "Where flame cannot live, no animal that draws breath can live" (*Codex Atlanticus*). However, for Leonardo, flame and breathing were two different phenomena with nothing in common and it is therefore speculative to suppose that Leonardo thought that air contained a fluid essential for life.

Even though Leonardo admired alchemy as a means of making things which not found in nature, he faced in fact many misconceptions and frauds of alchemists (*Codex Atlanticus*):

"I bugiardi interpitri di natura affermano lo argento vivo essere commune semenza a tutti i metalli, non si ricordamo che la natura varia le semenze secondo la diversitá delle cose che essa vole produrre al mondo"

("The false interpreters of nature declare that quicksilver (mercury) is the common seed of every metal, not remembering that nature varies the seed according to the variety of the things she desires to produce in the world").

Moreover, he notes "Nature does not produce gold from mercury or sulfur of any kind, but only by the fire or heat of nature giving life to the world."

Leonardo was in practice conversant with the inductive method, when so few people in the Renaissance had established a direct dialog between observation and experiment. He had studied works by Archimedes and appreciated the value of mathematics. He compared the densities of liquids by balancing columns in a U-shaped tube, noting that fresh water is lighter than salt water, the latter leaves its salt behind when filtered through clay, and water becomes denser as it becomes colder until it freezes.

Although Leonardo discussed concepts such as movement, weight, or force, all in the context of the Aristotelian elements of air, fire, water, and earth, he was also skeptical about the "spirits or fluids" in matter. He assumed that all heat in the universe comes ultimately from the sun. Heat from the sun can be reflected by a mirror and refracted by drops of water and does not heat water in passing through it. He noted that salt is not a sweat of the earth, since springs penetrating the earth are not salty. The saltness of the sea is due to springs in the earth dissolving mineral salt and carrying it into the sea.

There is no doubt that Leonardo was ahead of his time. His scientific contributions make him a man closer to the Enlightenment and not to the Renaissance. Many of his observations or descriptions are comparable to those reported by his contemporaries. If Leonardo had lived in our epoch, he would also be a chemist because he was clearly active in chemical research during his lifetime.

[1] P. Gölitz, *Angew. Chem.* **2000**, *112*, 3–4; *Angew. Chem. Int. Ed.* **2000**, *39*, 3–4.
[2] A series of classical books are focused on the scientific side of Leonardo: L. Goldscheider, *Leonardo da Vinci: Life and Work*, Graphic, New York, **1959**; I. B. Hart, *World of Leonardo da Vinci: Man of Science, Engineer and Dreamer of Flight*, Viking, New York, **1962**; J. H. Randall in *Roots of Scientific Thought* (Eds.: P. P. Wiener, A. Noland), Basic Books, New York, **1957**, pp. 207–218; V. P. Zubov, *Leonardo da Vinci*, Harvard University Press, Cambridge, **1962**.
[3] L. Reti, *Chim. Ind. (Milan)* **1952**, *34*, 655–721.
[4] F. Klemm, *Chem. Exp. Didakt.* **1976**, *2*, 361–365.
[5] It should be sulfuric acid, although during the Middle Age the term vitriol was also applied to different metal sulfates.
[6] A green or blue crystalline substance obtained by the action of acetic acid on copper and used as fungicide and pigment. The name derives from old French "vert de Grice" (green of Greece).
[7] Presumably both minerals were used by Leonardo in his preparations. Cinnabar corresponds to the red form of mercuric sulfide and used as a pigment. The term comes from Latin "cinnabaris" meaning "of oriental origin". Colcothar (from a French or Arabic word), denotes a finely powdered form of ferric oxide produced by heating ferric sulfate and used as a pigment as well.

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