FRANCIS BACON: AN ALCHEMICAL ODYSSEY THROUGH THE *NOVUM ORGANUM*

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One of the most fascinating and thought-provoking periods in the history of chemistry is the coexistence in Western Europe of the ancient alchemy (having most likely arisen from Hellenistic and Arabic influences) and the rational, scientific chemistry we know today. By its own nature, this is a rather indeterminate period ranging from the Renaissance (around the 15th and 16th centuries) to early in the 19th century when chemical gold making–*transmutation*–was conclusively refuted by scientific evidence. Although the origin of alchemy is uncertain, it had a double aspect: on the one hand it was a practical endeavor aimed to make gold or silver from ordinary and abundant metals such as lead or copper, whereas on the other it was a cosmological theory based on the interaction between man and the universe. Thus, basic goals of alchemy correspond to those of astrology in an attempt to discover the relationship of man to the stars and how to exploit that knowledge to obtain wealth, health and immortality (1). There is no doubt, however, that alchemy largely contributed to the development of chemistry with a variety of novel substances and techniques. Superficially speaking, the chemistry of alchemy involved a complicated succession of combinations or heatings of several materials, operations supposed to be within reach of any initiated person, with the ultimate objectives of obtaining gold or an elixir of immortality (2). Unfortunately, a clear-cut distinction between alchemy and the then emerging field of *chymistry* or *chemistrie* (the Old English words related to the present chemistry) cannot be made (3, 4).

During that time, especially the 17th century, some philosophers and artists were interested in alchemical practices, although they did not waste their effort and money in pursuit of the philosopher's stone and other alchemists' dreams. Among these natural philosophers, the figure of Sir Francis Bacon (1561-1626) should chiefly be mentioned. Bacon is best known as a philosopher of science and a master of the English tongue (5). In the former case, many of his writings were concerned with the natural sciences and the theory of scientific method, which he considered incomplete and taking little account of observation while giving too much credit to tradition and authority. He had an acute power of observation and advocated the repetition of experiments as a means to verify hypotheses, rather than to consider the latter ones as if they were incorrigible axioms. Through his famous *Idols* (doctrines or attitudes of mind that are seemingly corroborated by empirical observations, but in fact ideas that are forced to be in accord with a favored theory), Bacon ridiculed the learning methodology of his time.

Bacon was a prolific writer, even during his political career as a member of Parliament and later Lord Chancellor in the service of James I, a period spanning more than 35 years (6). He devoted much more time to natural sciences and philosophy after his fall from power in 1621. Two major books constitute the core of Bacon's philosophy of science: *De Dignitate et Augmentis Scientiarum* ("On the Dignity and Advancement of Learning," 1605), and especially the *Novum Organum* ("The New Organon or Method," 1620) after the Greek word organon meaning instrument (7). Bacon in fact prepared several drafts of the latter book between 1608 and 1620. Other works also contain abundant references to empiricism, collections of observations, and interpretation of natural phenomena. Such works, along with the two above-mentioned works, constitute what Bacon called the *Great Instauration* (8).

The *Novum Organum (NO)* is, however, his most important and lasting opus, intended to be a collection of novel directions for the interpretation of Nature. Globally considered, this work, also published in two books, is no more than a series of short essays called aphorisms which deal with an enormous variety of subjects with considerations often rooted in metaphysics, not to say that some kind of occultism is also present in his thought. It is, however, possible to discover Bacon's achievements in science which emerge from his remarkable power of observation. He described with admirable detail phenomena taken from both animate and inanimate bodies, realized his own measurements, and suggested further experiments. In addition, he gave new interpretations to such natural phenomena, often challenging the accepted theories of his time.

The present manuscript is a brief journey through the *Novum Organum* with emphasis on chemical descriptions and experiments. The aim is to present Bacon's interesting work on physico-chemical phenomena and his particular vision of alchemy.

Bacon's Alchemy: Currents of Thought

At first glance it is difficult to understand the interest of Bacon toward *Chymistry* (3,4) beyond that of a natural philosopher occupied in the observation of phenomena. Unlike other branches of natural philosophy, chemistry was not deemed worthy of academic study; and in most cases it was considered a mere collection of craftsmen's recipes. This situation has been analyzed in detail by Principe in his comprehensive biography of Robert Boyle, which also gives an overview of the history of alchemy and chemistry in the 17th century (9).

Bacon's works, and the *Novum Organum* is no exception, were influenced, at least to some extent, by the different systems of thought that prevailed in England in the 16th and 17th centuries: Aristotelian scholasticism, humanism inspired by Plato and a number of Italian philosophers, and occultism. Bacon largely deviated from scholasticism, although in the time Bacon began to write an official criticism of Aristotle's philosophy was focused on logic and not, as Bacon's critique was to do, on knowledge of nature. Bacon, however, was closer to humanism and shared with it the idea that knowledge of nature derives from observation and perception by the senses (10). Bacon also added the key element of experimental verification, i.e., observations worthy to support theories must be repeatable (11).

The third significant mode of thought in the Baconian philosophy is occultism or esotericism: that is, the search for a mystical relationship between man and the cosmos, as in alchemical speculations, and the knowledge of magical or unnatural forces. Occultism was prevalent in Latin Europe for several centuries and flourished especially with the work and legacy of Paracelsus (1493-1541), who sought out the most learned figures of practical alchemy, not only to discover the most effective methods of chemical therapy, but also, and importantly, to discover the latent forces of nature and how to use them (12). Occultism and its Paracelsian influences were also rooted in England at the time of Bacon and his contemporaries, Robert Fludd (1574-1637) being one of the most salient exponents (13, 14). A vision of Bacon as a mystic has been supported by some scholars (15), who regard Bacon's writings as steeped in alchemy and magic. However, most laymen will not find much of a mystical character in the *Novum Organum*, even though Bacon often alludes to Paracelsus and his theories and experiments (*vide infra*). A considerable portion of the *Novum Organum* is devoted to answer how scientists should proceed in order to increase knowledge of the natural world. In doing so, Bacon concentrates on the "how" rather than the "why" of Aristotelianism. Most hypotheses and explanations provided by Bacon through the second book of the *Novum Organum* contain little theological and esoteric arguments.

Bacon was arguably no great friend of alchemists, although he was able to pick up the pluses of alchemy, especially the value and technical importance of certain chemical substances. Bacon did not reject any experimental evidence provided by the alchemists but rather the way of making things, paying attention to minute details not involved directly in the result of their experiments (16, 17, 18):

> The empirical school of philosophy yields more deformed and monstrous ideas than the sophistical or rational, because it is based, not on the light of common notions…, but on the narrow and obscure foundation of only a few experiments… A notable example of this is to be found in the alchemists and their teachings.
>
> It is true that alchemists have some achievements from their labors, but these came by chance, incidentally, or by some variation of experiments, such as mechanics are accustomed to make, and not from any art or theory… Those too who have applied themselves to *natural magic*, as they call it, have made few discoveries, and those trivial, and more like deceptive tricks.
>
> The alchemist nurses eternal hope, and when the thing does not succeed, he blames error of his own, and in self-condemnation thinks he has not properly understood the words of his art or of its authors, whereupon he turns to traditions and auricular whispers; or else thinks that in his performance he has made some slip of a scruple in weight or a moment in time, whereupon he repeats his experiments endlessly.

As severe as these criticisms may be viewed, they were also expressed by Bacon's predecessors who were sworn enemies of the malpractices of alchemists and, nevertheless, they also advocated the use of chemicals in medicine (Paracelsus) or art. For instance, Leonardo da Vinci (1452-1519) was acquainted with the frauds of alchemists (19):

> The false interpreters of nature declare that quicksilver is the common seed of every metal, not remembering that nature varies the seed according to the variety of the things she deserves to produce in the world.

Bacon's natural philosophy is frequently impregnated with chemical studies and analyses of observable properties. His rather eclectic approach is often obscure as Bacon sometimes recurs to Aristotelian elements, while other discussions are focused on Paracelsian principles, or both, which were invoked by alchemists in the 17th century. The oldest Aristotelian vision that matter was composed of air, water, earth, and fire, each representing a particular property or quality, was widely accepted in Western Europe by natural philosophers. Aristotelian philosophy also suggested that such elements compared one with the other were in a proportion of ten to one, an assumption that Bacon considered to be false (20):

> The ratio of density of the so-called elements is arbitrarily fixed at ten to one; and other dreams of that kind. And that sort of vanity is rife not only in dogmas but also in simple notions.

Bacon alludes to primary elementary qualities that can be inferred from Aristotelian elements such as moist, dry, hot, and cold, whereas he also suggests the existence of occult properties and specific virtues named secondary qualities. These constitute a series of terms utilized by physicians at that time such as *attraction*, *repulsion*, *attenuation*, *dilation*, *maturation*, etc., which, on the other hand, are close to Paracelsian concepts (21).

The Aristotelian elements are also discussed by Bacon in his *Clandestine Instances*, that is, those that show the nature at its weakest, in its rudiments, or hidden aspects (22):

> Although air plainly does not attract air nor water, water in whole bodies, nevertheless a bubble placed near another bubble more easily dissolves than if that second bubble were not there, because of the tendency to coition of water with water, and air with air. And *Clandestine Instances* of this kind present themselves conspicuously in the small and subtle portions of bodies.

Bacon also agreed with the principles identified by Arabic alchemists, who conceived of sulfur and mercury as basic constituents of matter, especially in metals. The idea of "philosophical" sulfur and mercury was once again associated with specific properties of matter such as combustibility and metallic character, respectively. Later, Paracelsus extended this theoretical framework to salt, which accounts for solubility (1, 2b). Bacon was willing to accept the first two of these alchemical principles as sulfur consents with fatty fumes, oil, or inflammable things, and mercury with water, vapors, interstellar ether, and nonflammable substances. However, he refused the third salt principle (23):

> It has been well observed by the chemists, in their triad of first principles, that sulfur and mercury pervade as it were the whole universe. For the case for salt is absurd, and is added only so that their triad can embrace bodies earthy, dry, and fixed.

This semi-Paracelsian scheme and the reasons for Bacon's rejection of this saline principle have been analyzed in detail by Rees, who suggests that Bacon adhered to "axiological antitheses" rather than triads (24). Although in his comprehensive essay (Aphorism 50 in Book II), Bacon does not clarify the source of his rejection, Rees and others also suggest that Bacon's beliefs in a sulfur-mercury theory are related to cosmological speculations (25). To Bacon, the properties of matter in the universe appear to be consistent with those of sulfur and mercury only. Bacon also writes (26):

> Their first and chief diversity [of things] lies in the fact that some bodies, while differing to some extent in the quantity and rarity of their matter, yet agree in their *schematism*, and others, on the contrary, agree in the quantity or rarity of their matter, but differs in their *schematism*.

There are some paragraphs in the *Novum Organum* where a certain degree of occultism and magic can be appreciated, although Bacon considered sorcery, divination, and invocation of spirits to be superstitious and fraudulent practices. Bacon speaks of magic in a "purified sense of the word" (27), as the knowledge of hidden forms of nature to the production of wonderful operations. This idea had been advanced by Bacon in his *Advancement of Learning*, although its original source should be attributed to Giambattista della Porta (1535-1615) who, through his *Magia Naturalis*, first published in 1558, had a profound influence on Bacon's writings. Porta deals with magic as a technique to be acquired in order to control natural phenomena. Bacon also extended this idea in his *Magic Instances*, "in which the material or efficient cause is slight or small in relation to the magnitude of the ensuing work and effect, so that even when they are common, they seem to be miraculous" (28).

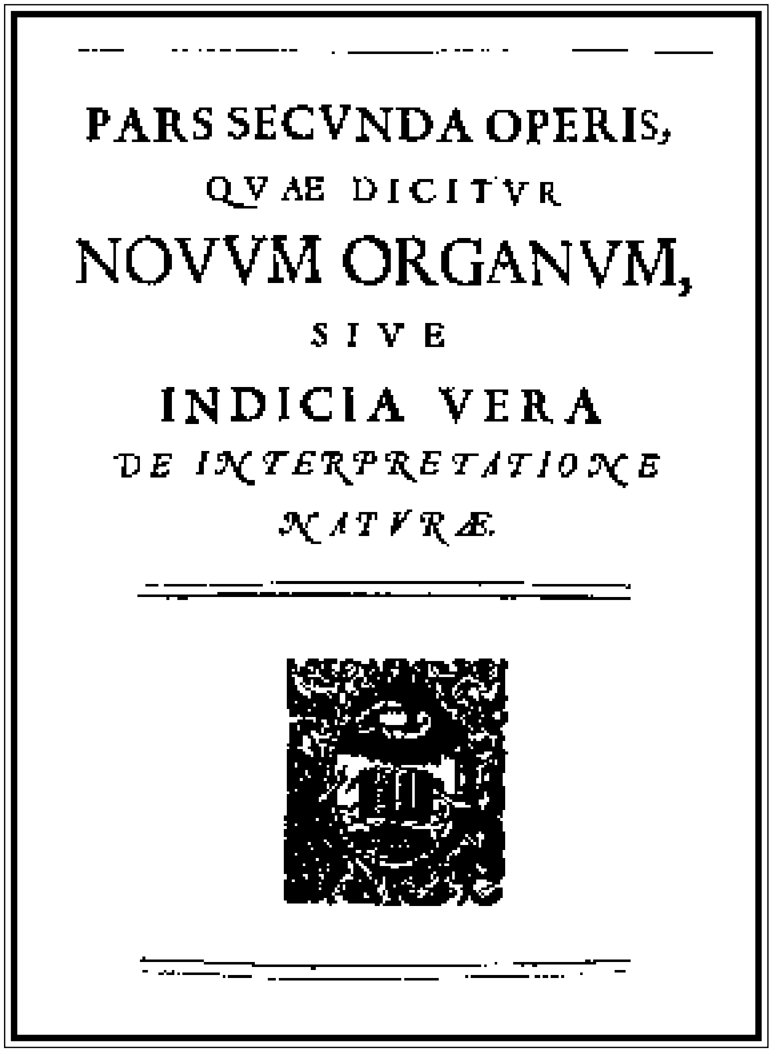
Aside from alchemical and cosmological speculations, Bacon was undoubtedly aware of numerous substances and minerals employed by the alchemists of his time. He often refers to preparations taken from Paracelsus and others and, presumably Bacon carried out empirical tests concerning the properties of such substances. These include pigments and salts such as *verdigris* (basic copper acetate), *mars yellow* (an iron oxide generated by combustion of iron or iron sulfide), *quicklime* (calcium oxide), *white lead* (probably a mixture of lead carbonate and lead oxide), *loadstone* (the naturally occurring magnetite), *saltpetre* (potassium nitrate), and others which are mentioned through the *Novum Organum*. Common explosives of that time like gunpowder (a mixture of sulfur, saltpetre, and charcoal) (29), and the so-called Greek fire (30), an unknown flammable mixture employed in naval warfare from the 6th century A.D. are equally highlighted.

Bacon's aphorisms often refer to *spirit of wine* (ethyl alcohol) and vinegar, the former identified as a flammable substance (31). He also describes in detail a personal experiment for extracting scent of violets with vinegar (32). Bacon mentions the term *oil of vitriol*, common among alchemists, which is generally agreed to be sulfuric acid. He also utilized the rhetoric name of *oil of sulfur* presumably to denote the same substance. Nevertheless, in his subsequent work on *History of Density and Rarity*, which constitutes a collection of observations within the third part of the *Great Instauration*, Bacon listed the two oils separately with different densities (33). Similarly, he used freely the Latin terms *aqua fortis* (nitric acid) and *aqua regia* (1:3 nitric acid:hydrochloric acid) without a clear-cut distinction between them, as well as the collective *aquae fortes* to include both terms (34). His aphorisms reveal the properties of such liquids, although some observations were presumably taken from those of alchemists (35, 36):

> Iron first dissolved by *aquae fortes* in a glass vessel, even without being placed near fire; similarly tin, but not so intensely.

> [Liquids] operate in proportion to the porosity of the substance to which they are applied. *Aqua regia* dissolves gold, but silver hardly at all. On the other hand, *aqua fortis* dissolves silver, but gold hardly at all. Neither dissolves glass, and so on with others.

Gold, the favorite metal of alchemists, is extensively mentioned by Bacon through the *Novum Organum*, especially its particular properties with respect to other metals and substances. Besides the solubility of gold in *aqua regia*, Bacon noted its high density (37). Bacon focuses repeatedly on the virtues of gold such as its incorruptibility, poor affinity to mix with other substances, and the extent of its weight. He often uses the latter term as synonym for density (38).


PARS SECVNDA OPERIS,
QVAE DICITVR
NOVVM ORGANVM,
SIVE
INDICIA VERA
DE INTERPRETATIONE
NATVRÆ.

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With alchemy in its heyday in the 17th century, it is somewhat surprising that Bacon seldom mentioned transmutation, although he, like other contemporaries, presumably accepted this possibility (39). In alchemy and other forms of occultism, transmutation was originally related to the idea of change and its control, but never involving degradation.. Examples were passing from sickness to health, from sadness to happiness, and even in passing from old age to youth. Alchemists also understood transmutation in the changes that were called *chemical*, that is, in a magical relationship with nature to accelerate the maturation of the "fruits of the earth" (minerals) yielding noble substances (*e.g.* gold and silver) with impressive character and qualities. While the first objective seems to have been important in Chinese alchemy, the Western world was not resistant to the lure of gold making and the latter became rapidly the almost exclusive objective (2b). Moreover, in Aristotle's theory the four elements were believed to exist in every substance and transmutable each into the other. Likewise, "philosophical" sulfur and mercury, or the Paracelsian triad were used as a starting point for transmutation, and this turned out to be feasible to some scientists (40, 41).

In the *Novum Organum,* however, transmutation is still viewed as a foolishness of alchemists and their followers (42):

> Empty talkers and dreamers who, partly from credulity, partly by imposture, have loaded the human race with promises, proffering and holding out the hope of the prolongation of life, the delaying of old age, the relief of pain,…the transmutation of substances, strengthening and multiplying of motions at will,…divination of future events, representations of remote ones, revelations of things, concealed and many more.

A more subtle idea on transmutation appears at the beginning of the second book, where Bacon suggests that if one wished to induce (43) on silver the properties of gold, a series of precepts or guidances must be considered. He then goes on with a philosophical discourse about the transformation of bodies without reaching definitive conclusions (44). Bacon, however, does seem to be rejecting the practices of alchemists; it is simply more fundamental to discover what nature does or undergoes (45):

When inquiry is made into the generation of gold, or any other metal or stone; from what beginnings it came, how and by what process, from its first seeds or earliest rudiments down to the perfect mineral; or similarly, by what process plants are generated, from the first coalescence of juices in the Earth, or from seeds, to the fully-formed plant…; similarly, how animals are generated and develop through the stages from copulation to birth.

Bacon's Atomism: Facts and Fiction

Although, as mentioned before, Bacon's natural philosophy has been analyzed in terms of a semi-Paracelsian cosmology (24), some scholars definitely suggest that Bacon accepted atomism as a plausible explanation of numerous phenomena, yet without reaching a consistent view on this topic (46, 47). Indeed, there are several cases in which Bacon faced up to interpretations based on what can be regarded as a variation of atomism. Nevertheless, atomism in Bacon cannot be separated from the historical transition between philosophical and scientific atomism (from the 17th to the 19th century), in which the original Greek philosophy of atomism was adorned with important variations and speculations. Notable figures such as Descartes, Newton, and Leibniz, to name a few, provided particular views about the corpuscular nature of matter, the association and qualities of such corpuscles, and the existence or absence of the void. (48). There is no doubt that Bacon also adhered to the concepts of mechanical philosophy, concerned with explaining all the phenomena of nature in terms of matter and motion, as well as a fashionable corpuscular theory to which he also offered his particular insights.

Philosophical atomism focused on general aspects of natural phenomena in order to reach a rational explanation of such aspects. Atomistical philosophers tried in essence to explain the existence in nature of different forms in continuous change (*i.e.* multiplicity and change), and not concrete phenomena in detail. The latter was only possible in the 19th century when chemists supposed that each identified chemical element had its own atoms, with specific properties, and was capable of forming fixed combinations, that is, molecules in our modern language (49). Philosophical atomism in the 17th century, however, was associated with a realistic and mechanistic view of the world. Atoms were not considered philosophical abstractions, but minute and immutable particles, which are too small to be visible. Furthermore, the mechanistic theory holds that all observable changes are caused by motions of the atoms (50).

Apparently, Bacon suggests (51) that matter is composed of indivisible particles without a vacuum (52):

> We shall be led, not to the atom, which presupposes a vacuum and immutable substance, both of which are false, but to real particles, such are found.

Moreover, he saw no reason to adopt an atomism in which the ultimate particles had different sizes and shapes. Bacon coined the obscure term "latent schematism." used extensively in the second book, referring to the inner structure of a body or of matter, by which physical properties emerge (53):

> Every natural action proceeds through the smallest particles, or at least those too small to be perceived by the sense, no one should expect to control or alter nature unless he has properly understood and noted them.

But the concepts of "schematism" and "latent schematism" are too vague to be precisely defined. He seems to mean that physical properties of matter arise from its inner structure (54). This idea appears to be related to the fundamental and broadest sense of philosophical atomism, for which the multiplicity of visible forms in nature is based upon differences in such minute particles and in their configurations or arrangements (50). Remarkably, Bacon also suggested that latent schematism might be seen through a microscope and, in addition, there could be a chance to visualize atomic particles (55):

> Aids of the first kind are those recently invented optic glasses (microscopes), which show the latent and invisible fine details of bodies, and their hidden schematisms and motions, by greatly increasing the size of the inspected object…Microscope is only useful for looking at very small things, and if Democritus had seen such an instrument, he would perhaps have jumped for joy, and thought that a method had been found for seeing the atom, which he declared to be completely invisible.

The different ways in which Bacon understood atomism cannot be directly related to the idea of atoms as lumpish corpuscles. The more familiar the concept of schematism becomes, the more clearly it is understood in terms of an inner, but indefinite, structure characterized by bulk properties (56):

> The more subtle structures and schematisms of things (although visible or tangible over the whole body) can neither be seen nor touched, so that information about these also comes by deduction. But the principal and most fundamental difference of schematism is taken from the abundance or scarcity of matter that occupies the same space or dimension…; Now the aggregation of matter and its ratios are brought down to what can be perceived by means of weight. For weight corresponds to the abundance of matter, in respect of the parts of a tangible thing.

Thus, a main feature of schematism appears to be density, although he listed an extensive series of other schematisms such as rare, heavy, light, hot, cold, tangible, volatile, fixed, fat, crude, hard, soft, fragile, porous, homogeneous, heterogeneous, specific, nonspecific, animate, inanimate, etc., which would reflect a particular arrangement of the intimate structure of matter (57).

With such qualities of matter or schematisms, Bacon tried to give more detailed explanations of concrete phenomena, such as his detailed observations on the relative expansion or contraction of matter in bodies, that is to paraphrase Bacon, how much matter fills how much space in each case, as noted in Aphorism 40 (58):

> So one could rightly say that a given amount of gold contains such an aggregation of matter, that for spirit of wine to make up an equal quantity of matter, twenty-one times the space occupied by the gold would be needed.

This extended aphorism also contains an interesting sentence concerning the transformation of matter (58):

> Nothing is made from nothing, nor can anything be reduced to nothing; the actual quantity of matter, its sum total, remains constant, being neither increased nor diminished.

Bacon was of course unaware of the principle of the conservation of matter in chemical reactions, at least in a quantitative form, which was firmly established by Lavoisier in the late 18th century. Bacon's concerns are more related to the properties and densities of bodies. Thus, he notes that "if anyone were to assert that a certain volume of water could be converted into an equal volume of air, it is as if he were to say that something could be reduced to nothing."

In a subsequent aphorism Bacon attempted to provide an explanation of expansion and contraction through the concept of "folding of matter" (59), folding and unfolding itself through spaces, within definite limits, and without invoking the vacuum hypothesis as postulated by Greek philosophers. Based on his own calculations of density, Bacon estimated that there would have to be 2,000 times as much vacuum in a given weight of air as in the same weight of gold (60).

His explanations of color and heat constitute likewise two salient examples of a similar reasoning based on latent schematisms. Bacon considers that color is just a modification of the appearance of the light that is sent and received. The nature of color in a body is due to the arrangement of the body's inner parts (61):

> Bodies uniform in their optical portions give transparency; those that are uneven but through a simple structure give whiteness; those that are uneven but through an ordered, composite structure give the other colors, except black; a totally disordered and confused structure gives blackness.

Bacon paid considerable attention to the observation of flames and the actions of heat and cold on bodies. He utilized the inductive reasoning to reject early speculations about the necessary attributes of heat. Thus, brightness should be rejected as a necessary condition for the existence of heat, because boiling water reveals that a body may be hot without being bright. Furthermore, brightness cannot be a sufficient condition for heat either as the bright Moon evidences that a body may also be bright but not hot (62). Bacon advanced the idea that heat was not an indestructible fluid as suggested by the caloric theory, but rather that heat was some form of motion of particles, thereby invoking the corpuscular variation of atomism, and thus, to some extent, he anticipated the modern kinetic theory of heat (63):

> Heat is a motion that is not a uniformly expansive motion of the whole, but a motion that is expansive through the smaller particles of a body.

Baconian Influence on Chemistry and Science

Bacon's scientific achievements are based on a detailed, often rhetorical description of natural phenomena. Although Bacon often deviated from Aristotelianism and scholastic philosophy because "they have come to decisions and axioms without taking proper account of experience" (64), it is likewise difficult to unravel their metaphysical explanations.

Bacon's language is essentially philosophical and his conception of natural phenomena is markedly different from the more elaborated and precisely defined concepts of posterior centuries which rest on accumulated experiments. Intellectually, Bacon claimed all knowledge as his domain and, as an immediate consequence, he lacked depth; and very often he paid attention to superficial events. His style is often authoritative, giving the impression that his rationale constitutes the last word.

Bacon described a vast collection of physical, chemical, and biological phenomena. Descriptions of chemical substances and their properties are sometimes close to previous observation of alchemists. Although a certain occultism is present in his writings, Bacon was one of the first figures to disapprove of the superstitious practices and claims based on authority criteria of alchemists. Bacon had a profound influence on the founders of the Royal Society, such as Robert Boyle and Robert Hooke (1635-1703), as well as on other British scientists. Although he was both attacked and applauded by other philosophers in the 18th and 19th centuries, his chemistry was nevertheless ignored (65). Evaluation of Bacon's works cannot be ahistorical as such an analysis lacks perspective. In a series of one lecture and two dissertations, published between 1863 and 1864 in the *Augsburger Allgemeine Zeitung* (66), the eminent German chemist Justus von Liebig (1803-1873) strongly censured Bacon's learning method and his natural philosophy. Obviously, Liebig ignored the context of science in the 17th century, and even worse, the poor status of chemistry within natural philosophy.

Neither Bacon's observations nor even the method of arriving at truth have exerted much influence upon the progress of science. But the way in which Bacon understands the advancement of science, leaving all preconceptions aside and based on systematic experiments, is significant. One of the least mentioned attributes of Bacon's philosophy is the conception of science as an impersonal and collaborative activity undertaken for the benefit of mankind, an utopian idea that appears more clearly in his literary testament *The New Atlantis* (67). The *Novum Organum* gives a glimpse of something that should reflect the attitude of man towards nature and the use of science (68, 69):

> We can only command nature by obeying her, and what in contemplation represents the cause, in operation stands as the rule.
> So much then for the several kind of idols and their trappings, which must be steadily and sternly disowned and renounced, and the understanding entirely rid and purged of them, so that the entry into the kingdom of man, which is founded on sciences, may be like the entry into the kingdom of heaven.

In conclusion, Bacon was a man with extraordinary insight who, as a key figure of the 17th century in Europe, remains unsurpassed. His inductivism and contributions to educational methodologies are noteworthy. Bacon cannot be considered a scientist, but it is hoped that historians of chemistry, and of science in general, will be able to discover novel aspects of his natural philosophy (70).

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2. For some analyses on the chemistry of alchemy: a) J. C. Schroeder, "A Chemical Interpretation of Alchemy," *J.*

Chem. Educ., **1987**, *64*, 994-995; b) V. Karpenko, "Transmutation: The Roots of the Dream," *J. Chem. Educ.*, **1995**, *72*, 383-385.

3. In a recent article Principe states that "since all the topics we today associate under the two terms "alchemy" and "chemistry" were indiscriminately classed under either term by early modern writers, we advocate the use of the archaically-spelt *chymistry* to express inclusively the undifferentiated domain. This usage will help evade the potential arbitrariness and consequent misunderstandings when the terms "alchemy" and "chemistry" are used casually in reference to activities between the time of the Reformation and the end of the seventeenth century:" L. Principe, "Alchemy vs. Chemistry: The Etymological Origins of the Historiographic Mistake," *Early Sci. & Medicine*, **1998**, *3*, 32-65.
4. Although the latter argument (Ref. 3) is basically correct, it should be noted that the words "chymistry" and "alchymy" coexisted until the 19th century. The transition between alchemy and chemistry appears to be associated with the advent of mechanical philosophy by the end of the 17th century. Thus, starting from Robert Boyle, numerous scientists attempted to explain all natural phenomena in terms of matter and motion, without recurring to the Aristotelian elements or the Paracelsian principles.
5. Like other noblemen and cultivated people in the Elizabethan period, Bacon was fluent in Latin, and some works, notably his *Great Instauration*, were written in this language. Translating the Latin of a 17th-century Englishman back into English may certainly be a difficult task; should it be the English Bacon could have written at that time? Translators and scholars often find themselves returning to the Latin to be reassured that Bacon's original intent has been rendered. Although this constitutes a serious drawback because several interpretations on the same subject are possible, the advantage of having his work in Latin as the universal language of scientists in past times is the fact that new translations from time to time give new insights into Bacon's work in the language of the day.
6. a) H. B. White, *Peace Among the Willows. The Political Philosophy of Francis Bacon*, International Archives of the History of Ideas, Vol. 24, Martinus Nijhoff Publishers, Dordrecht, The Netherlands, 1968; b) For a recent analysis of the scope of Bacon's writings on philosophy, science, and politics: P. Zagorin, *Francis Bacon*, Princeton University Press, Princeton, NJ, 1999.
7. Bacon wrote the *Novum Organum* in Latin, thereby hoping to gain a wide audience in Europe. There are some recent and annotated translations that have been utilized in the preparation of the present manuscript. See for instance: a) M. Silverthorne and L. Jardine, Ed., *F. Bacon, The New Organon, Cambridge Texts in the History of Philosophy*, Cambridge University Press, Cambridge, 2000; b) P. Urbach and J. Gibson, Ed., *F. Bacon, Novum Organum with Other Parts of the Great Instauration*, Open Court, Chicago-La Salle, IL, 1994.
8. A comprehensive compendium of the works by Francis Bacon can be found in: J. Spedding, R. L. Ellis, and D. D. Heat, Ed., *The Works of Francis Bacon*, Vols. 1-5, Longman, London, 1857-1858.
9. L. M. Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest*, Princeton University Press, Princeton, NJ, 1998. Principe comments on the general denigration of chemistry, "It has long been recognized that one of the problems of *chymistry* before the 18th century was its status as a practical or technical art rather than as a branch of natural philosophy. The low status of chymistry as determined by its use amongst low technical appliers militated against its acceptance by many natural philosophers."
10. In the first aphorism (*NO*, Book I, Aphorism 1), Bacon declares, "Man, the servant and interpreter of nature, only does and understands so much as he shall have observed, in fact or in thought, of the course of nature; more than this he neither knows nor can do."
11. There are numerous aphorisms paying attention to correct and regular procedure as a means of obtaining appropriate conclusions: "Further progress in knowledge, in fact, can only be looked for with any confidence when a large number of experiments are collected and brought together into a natural history; experiments which, while they are of no use in themselves, simply help the discovery of causes and axioms." (*NO*, Book I, Aphorism 99, and succeeding aphorisms).
12. a) W. Pagel, "Recent Paracelsian Studies," *Hist. Sci.* **1974**, *12*, 200-211; b) D. Merkur, "The Study of Spiritual Alchemy: Mysticism, Gold-making, and Esoteric Hermeneutics," *Ambix*, **1990**, *37*, 35-45.
13. a) J. Godwin, *Robert Fludd: Hermetic Philosopher and Surveyor of Two Worlds*, Phanes Press, Grand Rapids, MI, 1991; b) W. Huffman, *Robert Fludd*, Aquarian Press, London, 1992.
14. a) P. M. Rattansi, "Paracelsus and the Puritan Revolution," *Ambix*, **1963**, *11*, 24-32; b) A. G. Debus, *The English Paracelsians*, Oldbourne, London, 1965.
15. a) P. Rossi, *Francis Bacon: From Magic to Science* (trans., S. Rabinovitch), Routledge and Kegan Paul, London, 1968; b) F. A. Yates, *The Rosicrucian Enlightenment*, Routledge and Kegan Paul, London, 1972.
16. *NO*, Book I, Aphorism 64.
17. NO, Book I, Aphorism 73.
18. *NO*, Book I, Aphorism 85.
19. J. P. Richter, *The Literary Works of Leonardo da Vinci*, Oxford University Press, London, 1939, Vol. II, p 250.
20. *NO*, Book I, Aphorism 45. The same criticism was analyzed in depth in his *History of Density and Rarity*, see Ref. 8, Vol. 5, p 354: "The conceit that the variety of the elements compared one with the other is in a proportion of ten to one, is a thing fictitious and arbitrary. For it is certain that air is at least a hundred times rarer than wa-

ter, and flame than oil; but that flame is not ten times rarer than air itself."

21. Bacon lists specific cases of these secondary qualities in Book I, Aphorism 66.
22. *NO*, Book II, Aphorism 25.
23. *NO*, Book II, Aphorism 50.
24. a) G. Rees, "Francis Bacon's Semi-Paracelsian Cosmology," *Ambix*, **1975**, *22*, 81-101; b) G. Rees, "Francis Bacon's Semi-Paracelsian Cosmology and the Great Instauration," *Ambix*, **1975**, *22*, 161-173; c) G. Rees, "The Fate of Bacon's Cosmology in the Seventeenth Century," *Ambix*, **1977**, *24*, 27-37.
25. For early studies on the natural philosophy of Bacon and some of his cosmological views: a) J. C. Gregory, "Chemistry and Alchemy in the Natural Philosophy of Sir Francis Bacon, 1561-1626," *Ambix*, **1938**, *2*, 93-111; b) M. West, "Notes on the Importance of Alchemy to Modern Science in the Writings of Francis Bacon and Robert Boyle," *Ambix*, **1961**, *9*, 102-114; c) S. J. Linden, "Francis Bacon and Alchemy: The Reformation of Vulcan," *J. Hist. Ideas*, **1974**, *35*, 547-560.
26. NO, Book II, Aphorism 50. Bacon speaks of the "schematisms" (from Latin *schematismus*) of bodies or of matter to presumably denote "structure" or "constitution." (One might argue that sulfur and mercury schematisms are then present in chemical substances). The term is also important in relation with Bacon's ideas on atomism and it will be treated in the subsequent section.
27. *NO*, Book II, Aphorism 9.
28. *NO*, Book II, Aphorism 51. Bacon mentions some instances that lie under this class due to the hidden cause that produces a large effect such as in "motions that are increased in power by passing from wheel to wheel," or "in self-multiplication as in fire or poisons."
29. Bacon mentions this composition when discussing in detail the generation of flames from gunpowder: *NO*, Book II, Aphorism 36.
30. *NO*, Book II, Aphorism 13, under Instance 21.
31. *NO*, Book II, Aphorism 13, under Instance 25: "Some ignited substances are found to be much hotter than some flames. For instance, ignited iron is much hotter and more consuming than the flame of spirit of wine."
32. *NO*, Book II, Aphorism 46.
33. Ref. 8, Vol. 5, p 341.
34. Literally *aqua fortis* means "strong water" whereas *aqua regia* is "royal water," referring to its use in dissolving gold, the royal metal. English translators and historians often translate *aquae fortes* as "strong waters" or, even worse, "strong solvents," both being confusing from a chemical viewpoint.
35. *NO*, Book II, Aphorism 11, under Instance 19.
36. *NO*, Book II, Aphorism 12, under Instance 28.
37. *NO*, Book II, Aphorism 24: "A revealing instance of weight is quicksilver [mercury]. It is by far the heaviest of all substances except gold, which is not much heavier." Bacon reported later in the *History of Density and Rarity* his own measurements of the densities of numerous substances. The three densest substances he found were, in order of decreasing density, gold, quicksilver (mercury), and lead. Conversely, the spirit of wine (ethyl alcohol) was found to be the least dense of bodies.
38. *NO*, Book II, Aphorisms 33, 34, 40, and 48.
39. For a detailed discussion on Bacon's concepts of transmutation: A. Clericuzio, "Le Transmutazioni in Bacon e Boyle" in *Francis Bacon: Terminologia e Fortuna nell XVII Seculo*, M. Fattori, Ed., Edizioni dell'Ateneo, Roma, 1984, pp 29-41.
40. Robert Boyle (1627-1691) believed that transmutation could take place under the right conditions. This possibility was noted in his 1670 work "The Generation and Transmutation of Metals" and in his "Historical Account of the Degradation of Gold by an Antielixir." See: M. Hunter and E. B. Davis, Ed., *The Works of Robert Boyle*, Pickering & Chatto, London, 1999, Vol. 4, pp 3-201.
41. Newton (1643-1727) was equally engaged in alchemical experiments and speculations and, following the alchemical principles, he tried to isolate a "mercury of gold." For Newton's alchemical work: B. J. T. Dobbs, *Foundations of Newton's Alchemy*, Cambridge University Press, Cambridge, 1975.
42. *NO*, Book I, Aphorism 87. The last part of this criticism seems to have been applied to Paracelsus, who expressed the possibility of seeing things that are hidden, secret, present, or future through the science of necromancy: A. E. Waite, *The Hermetic and Alchemical Writings of Paracelsus*, R. A. Kessinger Publishing, Kila, MT, 2002, Vol. 2, pp 296, 301.
43. Bacon uses explicitly the term "superinduce," meaning to bring in or induce something on top of something (see *NO*, Book I, Aphorism 31). In the second book of the *Novum Organum* the term is used when treating the possibility of adding novel properties to things or bodies.
44. *NO*, Book II, Aphorisms 4-10.
45. *NO*, Book II, Aphorism 7.
46. For opposite assertions about Baconian atomism: a) R. Kargon, *Atomism in England from Hariot to Newton*, Oxford University Press, Oxford, 1966; b) A. Clericuzio, "Chemistry and Atomism in England (1600-1660)," in *Elements, Principles, and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century*, Kluwer, Dordrecht, 2000.
47. For a recent study questioning whether Bacon did in fact reject atomism: S. Clucas, "Francis Bacon and Atomism: A Reappraisal," in C. Lüthy, J. E. Murdoch, and W. R. Newman, Ed., *Late Medieval and Early Modern Corpuscular Matter Theories*, Brill Academic Publishers, Leiden, 2001.
48. A good perspective can be found in: A. Thackray, *Atoms and Powers: An Essay on Newtonian Matter Theory and the Development of Chemistry*, Harvard University Press, Cambridge, MA, 1970.

49. L. L. Whyte, *Essay on Atomism: From Democritus to 1960*, Wesleyan University Press, Middletown, CT, 1961.
50. a) E. Cantore, *Atomic Order: An Introduction to the Philosophy of Microphysics*, MIT Press, Cambridge, MA, 1969; b) *The New Encyclopaedia Britannica*, 15th ed., Encyclopaedia Britannica, Inc., Chicago, IL, 1990, Vol. 25, pp 574-580.
51. The existence of the void was one of the main problems of philosophical atomism. Greek philosophers assumed that without a void the atoms could not move. Newton agreed with this conception that gave an explanation of his theories of action at a distance, while Descartes considered that there was no empty space into which particles could move. They could only move by taking the places vacated by other particles, which were also in motion. See Ref. 50b.
52. *NO*, Book II, Aphorism 8.
53. *NO*, Book II, Aphorism 6. See also P. Urbach, *Francis Bacon's Philosophy of Science*, Open Court, Chicago-La Salle, IL, 1987.
54. "Schematisms, which are related to dissimilarities of the parts contained in the same body, and to their arrangements and dispositions": *NO*, Book II, Aphorism 40.
55. *NO*, Book II, Aphorism 39.
56. *NO*, Book II, Aphorism 40.
57. These and other schematisms had been mentioned by Bacon in the first part of the *Great Instauration* ("On the Dignity and Advancement of Learning"), first appearing in 1605.
58. *NO*, Book II, Aphorism 40.
59. *NO*, Book II, Aphorism 48.
60. According to some Bacon translators, this explanation through the folding of matter is obscure: See Ref 7b, p 271, footnote 275.
61. *NO*, Book II, Aphorism 23.
62. *NO*, Book II, Aphorisms 36 and 37.
63. *NO*, Book II, 20; see also Book II, Aphorism 17.
64. *NO*, Book I, Aphorism 63.
65. For assessment and influence of Bacon: *The New Encyclopaedia Britannica*, 15th ed., Encyclopaedia Britannica, Inc., Chicago, IL, 1990, Vol. 14, p 549 and references cited therein.
66. These contributions were collectively compiled in *Reden und Abhandlungen von Justus von Liebig* (Lectures and Dissertations of Justus von Liebig), C. F. Winter Verlag, Leipzig-Heidelberg, 1874, pp 220-295. The first lecture, "Francis Bacon von Verulam und die Geschichte der Naturwissenschaften" (Francis Bacon of Verulam and the History of Natural Sciences), was given by Liebig in a public session of the Academy of Natural Sciences on March 28, 1863. The second, "Ein Philosoph und ein Naturforscher über Francis Bacon von Verulam" (A Philosopher and Naturalist About Francis Bacon of Verulam), and third dissertations, "Noch ein Wort über Francis Bacon von Verulam" (Further Comments on Francis Bacon of Verulam), were published by the *Augsburger Allgemeine Zeitung* in 1863 and 1864, respectively.
67. *The New Atlantis* seems to have been written in 1614 but did not get into print, yet unfinished, until 1626, after Bacon's death.
68. *NO*, Book I, Aphorism 3
69. *NO*, Book I, Aphorism 68.
70. One of the most recent homages to Bacon has been provided by Hoffmann and Laszlo in a recent essay focused on *Proteus*, in which they discuss the dynamic and multifaceted character of chemistry: R. Hoffmann and P. Laszlo, "Protean," *Angew. Chem. Int. Ed. Engl.*, **2001**, *40*, 1033-1036. Chemistry is always dynamic and multifaceted, possessing inherent tensions. Such tensions are expressed by something that attracts our interest continually and invite for intellectual challenges, also assuming calculus of risks and benefits as the wrestler does. Chemists are then *Protean Artists*, who create or discover new substances, rules, and languages which, may be modeled, thereby responding to a series of scientific, technological, and even social requirements. *Proteus* is a figure of Greek mythology. He had the power of prophecy and the capability of changing his shape at will. Bacon used this myth in a subsequent part of the *Great Instauration*: see Ref. 4b, p 306: "Aphorisms on the Composition of the Primary History," Aphorism 5.

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