Around 1950 I was part of the early years of the Society for Social Responsibility in Science. I was delighted to read recently that both the head of DuPont and the editor of *The Scientist*, Eugene Garfield, one of our symposium speakers, were calling on scientists and on the chemical industry to pledge themselves to an ethic of social responsibility and environmental sensitivity. The way I put it is that, just as biologists are the guardians of the biosphere, so we of the chemical community must become the guardians of the lithosphere, the guardians and protectors of the material world.

My interests in the concepts and history of science and the role of science and scientists in society have remained intense ever since. Hence the title of this symposium: "The Context of Chemistry: Conceptual, Historical, Social".

References and Notes

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CORPUSCULAR ALCHEMY

The Transmutational Theory of Eirenaeus Philalethes

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Among the most influential works of 17th-century alchemy, the treatises attributed to "Eirenaeus Philalethes Cosmopolita" surely deserve a prominent place. As I have recently shown, several works attributed to this Philalethes were actually written by an American alchemist educated at Harvard, George Starkey (1). Starkey was born in 1628 in Bermuda, then considered part of "America." He entered Harvard College in 1643 and graduated with an A.B. in 1646. In 1650 Starkey immigrated to London, where he became a member of the scientific circle centered around Samuel Hartlib. In the early 1650s he performed a series of experiments with Robert Boyle, who was also a member of the Hartlib group. During this same period, Starkey wrote two works of major importance under the pseudonym of Eirenaeus Philalethes - the *Introitus apertus ad occlusum regis palatium* and the *Tractatus de metallorum metamorphosi*; both texts were published after Starkey's death during the great London plague of 1665.

The well-known Danish savant Olaus Borrichius reported posthumously in 1696 that Philalethes' *Introitus* was considered "by the whole family of chemists" to belong among "their classics" (2). Similar accolades had been uttered by Daniel George Morhof in his *Epistola ad Langelottum* of 1673 (3) and, to judge by the translations of the *Introitus* into English, German, French, and Spanish, and its numerous printings between 1667, when it first appeared in Amsterdam as the printing of Johann Lange, and 1779, it would seem that Philalethes' popularity was great indeed (4). Three further works by Philalethes, collectively named the *Tres tractatus*, were printed by Martin Birrius of Amsterdam in 1668 (5). In the following year the *Introitus* was translated into English and published as *Secrets Reveal'd* by William Cooper of London (6). Cooper became one of Philalethes' greatest promoters, publishing other *opuscula* by the alchemist whom he referred to in his *Philosophical Epitaph* as the "English phoenix." Cooper even advertised in the hope of discovering lost Philalethan manuscripts, promising to print whatever he could find (7).

Despite the almost frenzied interest in Philalethes during the Scientific Revolution, historians of science have been happy to ignore this alchemist until quite recently. Before the mid-1970s, virtually all the scholarship devoted to Philalethes had focused on the question of his identity, and most of this had been written by scholars in fields other than the history of science. Philalethes' alchemical writings have recently come to occupy an important place in the historiography of early modern science, however, thanks to the current interest in Isaac Newton's alchemy.

It is well known, of course, that Newton transcribed and composed a massive amount of alchemical literature, according to Richard Westfall's estimate over a million words (8). Those hardy few who have tried to ascertain the sources of Newton's alchemy, such as Westfall, Betty Jo Teeter Dobbs, and Karin Figala, agree in assigning an important role therein to Eirenaeus Philalethes (9). As a result of this discovery, virtually all serious analysis of the Philalethan *corpus* has been done by Newton scholars. Anyone who presently wishes to know what Philalethes thought will have to view his ideas through a Newtonian prism, which exercises its own peculiar refraction on our image of the American alchemist. It is my intention here to reconstruct the theory that lies behind the alchemy of Philalethes. In the course of this I shall make occasional reference to the recent work on Newton's alchemy, especially that of Figala. A judicious examination of Newton's debt to Philalethes will therefore serve both to illuminate some trends in Philalethan alchemy and to determine whether or not Newton's interpretation of it was in reality faithful.

De metallorum metamorphosi

Although the most famous of the Philalethan works is the *Introitus*, this work has more the character of an extended riddle than that of an alchemical *theorica*. For the latter we are much better off looking at the *Tractatus de metallorum metamorphosi*, first published as part of the *Tres tractatus* appearing in 1668. *De metallorum* is in fact the most sustained treatment of alchemical theory that I have found in the Philalethan *corpus* and thus will form the primary focus of this paper. Philalethes begins his theoretical treatment of alchemy there by saying that the metals do not differ essentially but accidentally. The base metals are really immature gold, and they contain its substance *in potentia* along with a supervenient humidity which, due to their incomplete cooking in the bowels of the earth, has not been expunged from them. It is this immature humidity that is responsible for the defects of the base metals, defects such as friability, corrodibility, and low melting point. Evidence for this is found in mines, where lead, for example, usually coexists with silver: obviously the lead is merely a less mature form of the noble metal (10).

After giving further evidence that the metals are all composed of a substantially identical material that differs only in maturity and purity, Philalethes says that what is needed for transmutation is a "homogeneous agent excelling in digestive power" (11). This agent, furthermore, is simply gold "digested to the highest possible degree" (12). Such digested gold can penetrate metals radically, tinting them and fixing them so that they lose their volatility and low melting point. Even natural gold, if one ounce be used to gild six pounds of silver, will unite with the smallest particles of the exterior silver to the degree that it can be drawn out to a hair's breadth without any silver being exposed. But gold that has been alchemically digested will become much more subtle than natural gold, and so will be able to penetrate the very depths of a base metal and color it from the inside out. In fact, Philalethes continues, such digested gold will be fiery, due to what he calls the "law of the disproportion in subtlety between the four elements" (13). As we shall see, Philalethes is the exponent of a naive corpuscularism. The import of this "law of disproportion" is that the so-called four elements merely represent different sizes of constituent corpuscles - *minimae partes* or simply *minima*. What traditional philosophers call "fire" is made up of the smallest particles, so if gold is going to be digested, that is, broken down to the smallest possible particles, it will therefore become fiery. Only then, Philalethes says, will it be able to be mixed *per minima intrinsice* with the base metals (14).

Does this mean that Philalethes believes all mixture among the four elements to result from agglomerated particles of different sizes? Perhaps surprisingly, it does not. Rather, he says, the great "disproportion" in size between particles of different elements prohibits "the mixture of things suitable to generation, or even the possibility thereof" (15). Why? To use his words, because (16):

> ... natural generation comes about by means of a general union of ingredients. Union, moreover, is the ingress of the things to be united *per minima*. Yet if the minimum of one be ten times or a hundred times smaller than that of another, these minima (not having been made equal to one another) cannot combine, since it is necessary to bring together *per minima* what we wish to unite *per minima*.

Water mixed with wine, Philalethes says, can be separated precisely because this *mixtio per minima* has not taken place. Nor can it take place, because the particles of water are too big to conjoin with those of the subtle spirit in wine. The same is true of mixtures involving phlegm and spirit in wine, as well as earth and water. Let us now return to Philalethes' words (17):

> If anyone should say that in order to bring about [true] mixture, one [element] acquires the subtlety of another, and thus they are united immediately, I reply that if that (which was thick) becomes subtle to the degree that it can enter the liquid (by uniting with it), it is necessary that it be brought to the same nature, and what then I ask is the earth but water ... and thus, how fatuous must this be considered, that earth must be converted into water in order that it (be mixed) with water (to) bring forth the generation of a concrete body ...

Philalethes' argument hinges on the fatuity of earth retaining its earthiness after its minima have been reduced to the size of aqueous minima. Clearly he is assuming that the qualities traditionally associated with the four elements depend primarily on particle size. Indeed, when he continues to discuss water and its relationship to air, this becomes quite clear (18):

> ... if water should have the same subtlety as air, it is held to have the same primary qualities as air, and the same must be said of the earth that was made equal in rarity to water.

In other words, particles of earth reduced to the size of water particles will in fact be water particles, as they will share the same primary qualities. But if this is so, no *mixture* will have taken place, since there will be no more earth present to mix with the water. To drive the point home further, Philalethes asks rhetorically (19):

> I wish to know (the following:) if one *primum* takes on the primary (qualities) of another *primum*, will not the first really become that *primum* whose qualities it assumed? To argue otherwise is not philosophical.

Having thus proven to his satisfaction that natural things do not come about from a mixture of four elements, Philalethes concludes in truncated fashion that all the so-called elements really derive from one origin, which, echoing Van Helmont, he says to be water. In other words, there are not really four elements in the sense of original constituent bodies, but one, water, and its particles really do undergo the subtiliations described above, which result in material change. The reader might then ask how the *minima pars* of water, if it is a true *minimum*, can be reduced in size to produce air, for example. But Philalethes has already pre-empted this. The particles of water *per se* are not true minima. Water particles contain yet smaller particles or *semina*: these act on grosser matter, operating by means of a fermentative force, to produce products of varying subtlety. The fermentative force is itself supplied by "a certain ineffable particle of light" found within the *semen* (20). This "particle of light" is therefore the true *minima pars*, and it appears that all grosser matter is capable of division down to that terminus.

From this account we know that matter is corpuscular in composition, and that the root of all matter is water, which is acted upon by *semina* contained within itself, thus producing other substances. Philalethes then proceeds to detail a theory of artificial transmutation based on the above. Returning to his concept that metals vary only in their degree of purity and digestion, he remarks that the alchemist must therefore find an agent which both digests the metallic substance and expunges its impurities. In his words (21):

> Our *Arcanum* (because it is a spiritual, homogeneous substance) enters into imperfect metals of this sort *per minima*, and what it finds like itself, it seizes and defends from the violence of the burning fire by means of its own powerful force, and it preserves it with its own more than perfect fixity, while Vulcan destroys the combustible with its burning flame. And once the combustible is consumed by the fire, there remains pure gold or silver.

To understand this the reader must recall that Philalethes earlier said that the alchemical elixir was simply gold digested to the highest degree, and that this was a homogeneous, spiritual substance. This meant that the particles of gold had been reduced to a smallness like that of fire particles, and because all impurity had been removed, all these minute particles were of the same size, that is, homogeneous. It is because of this uniformly minute character of the elixir's particles that it can penetrate into base metals *per minima*, that is, between the smallest particles of the base metals. Once the particles of elixir have entered into the internal structure of the base metals, their affinity with the pure metallic substance within the base metal allows them to mix with it. They are after all materially identical with this pure substance, and they are particles of the same size.

An idealized portrait of George Starkey at his furnace with reagents pictured above him. The Biblical caption reads "You must earn your bread by the sweat of your brow." From *Pyrotechnia ofte Vuur-stook-Kunde* (Amsterdam, 1687), a Dutch translation of several works by Starkey.

After the elixir's particles have mixed with those of the pure metallic substance in the base metal they form a protective barrier between the latter and the destroying fire. The fire then burns up whatever impurities are found in the base metal, and the substance that remains will be composed of minute, homogeneous particles: in Philalethes's words, a "Chrysopoetic transmutation" will have taken place, and gold will have been produced (22). It is possible, however, to produce silver rather than gold, depending, Philalethes says, "on the quality of the medicine." But what determines the quality of the medicine? How should the alchemist go about the production of this elixir?

As we now know, the elixir is itself highly digested gold. Gold contains in each of its minimal parts the *semina* responsible for transmutation, but in natural gold as it is dug from the mines, the *semina*, are sealed up and hidden "under very dense coverings" (23). Therefore Philalethes says the following (24):

> Let the sons of art know, that in order to arrive at our *arcanum* it is necessary to manifest the most occult *semen* of gold which may not happen without the full and total volatization of the fixed, and therefore the corruption of its form.

In other words, the *semina* hidden deep within the substance of the gold and thus "occult," must be revealed, made "manifest" by a breaking down of the metal's gross substance. In corpuscular terms this means that the grosser particles of the metal must be made to disintegrate, thus freeing the smaller particles or *semina* contained therein. As Philalethes says, "properly and exactly speaking, the *semen* is the *minima pars* of the metal" (25). It is thus possible to convert the entire substance of gold into *sperma* by a simple breaking down of its metallic corpuscles into still smaller corpuscles, that is, into *semina*. As Philalethes also tells us, when the *semina* have been released, the metal will liquefy at room temperature. In other words, metals owe their solidity to what are, relatively speaking, gross particles. When the gross particles are eroded to become more subtle, the internal rigidity of the metallic substance is lost. Liquidity, therefore is a macroscopic property of extremely small particles making up the microscopic structure of a metal. As I have shown elsewhere, the origin of this theory lies in medieval alchemy (26).

The Epistle to King Edward Unfolded

The terminology that Philalethes uses in *De metallorum* suggests that he had a definite idea about the corpuscular structure of metals on the micro-level. He repeatedly speaks of the *semina* as existing within the larger corpuscles or *partes* of gold, for example. The *semina* are found *in profunditate* or *in occulto*, or *sub involucris densissimis*. What exactly does he have in mind here? At this stage it will be useful to turn to another Philalethan work, *The Epistle to King Edward Unfolded*, which has already been analyzed by Karin Figala in her work on the alchemy of Newton (27). Here Philalethes lays out a theory that Figala calls the "shell-theory" of matter, employed by Newton in his alchemical studies. In *The Epistle* Philalethes adopts the well-worn sulfur/mercury theory of the metals, according to which metals are composed of these two substances. To use his words (28):

> ... all metalls, & severall mineralls have [mercury] for their next matter, to wch for the most part (nay allways in imperfect metalls) there adheres, & is concoagulated an externall [sulfur].

In what may be called the traditional form of the sulfur/mercury theory, mercury is in effect a passive material that is acted upon by sulfur to produce the different metals. This is in the back of his mind when Philalethes says that an external sulfur is "concoagulated" to the mercurial substance of the metals. But Philalethes has far more than this in mind. He maintains that metals in general are composed of three different types of sulfur in conjunction with mercury. Although the three types of sulfur may be removed to some degree from their mercury, it is impossible to isolate mercury from all its sulfur: indeed sulfur itself is merely an active, mature form of mercury (29).

The base metals have first an "externall [sulfur], wch is not metalline, but distinguishable from the internall kernell of the mercurie" (30). This external sulfur acts as the principle of corrosion in imperfect metals, and must be removed if they are to be perfected. The second type of sulfur lies within the first, and is called the "metalline sulphur" (31). This metalline sulfur is found in all metals, and is responsible for the coagulation of their mercurial substance into a solid form. In gold and silver, however, the metalline sulfur is pure, while in other metals it is less pure. But Philalethes tells us that even this metalline sulfur is "externall to, because separable from the Secret Nature of [mercury] ... in form of tincted sweet oyle..." (32). Once the metalline sulfur has been removed, Philalethes continues (33):

> The remaining [mercury] then is voyd of all [sulphur], Save that wch may be called its centrall incoagulable [sulphur], on which no corrosive can then worke ...

As Figala has shown, the import of this theory is well represented by three concentric circles depicting the layers or "shells" of sulfur. The outermost shell is the "external" or mineral sulfur which, acting on the metallic mercury, only causes corruption and corrosion in the base metals. Within this is the layer of "metallic sulfur" responsible for the mercury's solidification in metals. Finally, at the center of the circles we encounter the "centrall, incoagulable" sulfur which can never be separated from its mercury (34).

Figala's use of the term "shell-theory" is indeed appropriate for Philalethes' concept of three sulfurs. By comparing *The Epistle* to the passages in *De metallorum* where Philalethes describes the structure of gold, we can further see that when he speaks of external and internal sulfurs, Philalethes has in mind the different layers of a complex corpuscle. The external sulfur of *The Epistle* is identical to the gross, superfluous impurities of *De metallorum* that had to be removed from base metals in order to effect their transmutation. This external shell is absent in gold, thus accounting for its resistance to corrosion.

The *minima* of gold *per se*, that is the smallest parts of natural gold, correspond to the second type of sulfur - the "metalline sulfur" that in base metals is covered by the outward, unclean shell of the mineral sulfur. This metalline sulfur, as Philalethes told us, is responsible for coagulating the mercury of gold, which exists within it. In other words, particles of gold are composed of an outward metalline sulfur surrounding a central core of incoagulable sulfur and mercury. But since the central, incoagulable sulfur cannot be separated from its mercury, the two can be conflated and referred to simply as "mercury." As Philalethes says in *The Epistle* (35):

... one [sulfur] is the most pure red Sulphur of gold, which is Sulphur *in manifesto* and Mercurius *in occulto* ...

Particles of this sort make up the homogeneous solid, gold, and thus may be called the *minimae partes* of the metal. But as Philalethes already told us, more properly speaking, the *minimae partes* within the metal are the *semina* contained within the corpuscles of gold, existing *sub involucris densissimis*. These *semina*, I propose, correspond to the "incoagulable," "central," "fiery," sulfur that Philalethes tells us exists at the kernel of the metal. In *De metallorum* Philalethes told us that the *semina* are freed when the gold is disintegrated and made liquid in the course of its digestion. What he has in mind clearly is the removal of the metalline sulfur, the agent responsible for metallic coagulation: when this has been deleted, the remaining substance will thus be incoagulable. Its lack of solidity will be due to the extreme fineness of its particles: as we stated before, Philalethes makes use here of a medieval theory relating solidity to particle size. Similarly it will be "fiery," again because its corpuscles will be extremely small, like those of fire. Finally it will be "central" in the sense that it composed the central "nucleus" of the complex corpuscle whose outer shells have now been removed (36).

In *De metallorum metamorphosi* Philalethes clearly describes the concept of a complex corpuscle, where the *minima pars* of gold, for example, is composed of yet smaller particles, down to the "ineffable particle of light" that forms the smallest of all corpuscles. As we have shown, the complex corpuscle was tied up in Philalethes' mind with the notion of different shells of sulfur, which are described in *The Epistle*. At the center of the complex particle there is a "nucleus" composed of extremely fine "sub-particles." The very subtlety of these corpuscles prevents their "coagulation" into a solid mass: indeed, Philalethes speaks of them as being "spiritual." But when tightly packed into the center of the complex *sub involucris densissimis*, their concentration yields tremendous weight. Philalethes' alchemical sources explicitly link the subtlety and close-packing of ordinary gold's particles to its ponderosity and great malleability.

But Philalethes has altered their corpuscular ruminations by adding on his shell theory of matter. Surrounding the central kernel of tiny, densely packed corpuscles, there is a shell composed of larger particles, which are responsible for compacting the tiny particles in the center into their concentrated mass. This compaction results in the solidification of metals: hence Philalethes calls it the "metallic sulfur," as we earlier discussed. Finally, in impure metals, there is yet another shell,

Isaac Newton

the layer of "external sulfur" which can easily be removed. Philalethes told us that this external sulfur was responsible for the corrodibility of base metals. If we now envision this shell of external sulfur as being composed of particles that are still larger than those of the metallic sulfur or incoagulable sulfur, the reason for its inability to withstand corrosion will be clear. Just as the density of gold and mercury is due to the fact that they are made up of small particles which can be closely packed, so the presence of large particles in a substance will result in loose packing. The external sulfur shell will be made up of precisely such loosely packed large particles, separated by large pores. The presence of such large pores in a metal allows the corpuscles of a corrosive agent to enter into its structure and attack it, resulting in the breakdown of its metallic integrity (37). The absence of such pores in gold leads to the opposite effect - hence it is far more difficult to corrode gold than base metals. Similarly, the presence of large particles and pores will result in a loss of density, and so the base metals will be of lighter specific weight than gold.

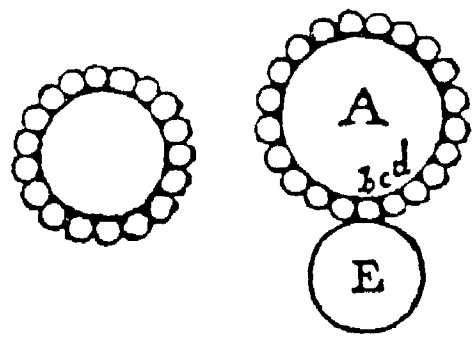
Philalethes and Newton

In order to see where a corpuscular theory of this sort can lead, let us now turn to the detailed exposition of Newton's transmutational theory given by Figala. In the *Opticks* and in his opusculum *On the Nature of Acids*, Newton develops a highly un-Cartesian corpuscular theory. It was named the "nutshell theory of matter" by Joseph Priestley, because it allowed that all the solid matter in the universe could be fit into a walnut shell. Now in his *Opticks*, Newton argues for the existence of "solid, massy, hard, impenetrable" particles or atoms, out of which all gross matter is made (38). These totally solid particles are, to use Arnold Thackray's phrase, inertially homogeneous; they are composed of a uniformly dense matter separated by great expanses of void. In order to account for the differentiation of matter on the macro-level, Newton says these solid particles combine with an equal quantity of void, to form what Newton calls the "first stage of composition." Such particles of the first stage of composition in turn combine with an equal quantity of void to produce particles of the second stage of composition. Higher stages of composition are produced in the same way (39). As none of the metals known to Newton belong to a composition stage lower than the first, they therefore contain vast quantities of void. As the quantity of their void diminishes, their specific gravity increases. Now Newton argues that the reactions of "vulgar chemistry" - what we would call simply chemical reactions - take place between the particles of higher composition. If one wants to transmute metals, which is not merely a process of "vulgar Chymistry" but of "Hermetick" philosophy, he must break down the particles of higher composition to arrive at the simpler, denser ones, then recombine them with the proper amount of void requisite to the specific gravity of the desired metal (40).

It is important to note that Newton's hierarchical schema, while giving the proportion of void to matter in different types of particles, does not necessarily describe the physical structure of the particles themselves. In Query 31 of the *Opticks*, Newton pictures the micro-structure of a salt particle in the following manner (41):

As Gravity makes the Sea flow round the denser and weightier Parts of the Globe of the Earth, so the Attraction may make the watry Acid flow round the denser and compacter Particles of Earth for composing the Particles of Salt ... Now, as in the great Globe of the Earth and Sea, the densest Bodies by their Gravity sink down in Water, and always endeavour to go towards the Center of the Globe; so in Particles of Salt, the densest Matter may always endeavour to approach the Center of the Particle: So that a Particle of Salt may be compared to a Chaos; being dense, hard, dry, and earthy in the Center; and rare, soft, moist, and watry in the Circumference.

So in the case of a salt particle, at least, the denser, simpler, sub-particles migrate towards the center of the corpuscle, to find themselves surrounded by their rarer counterparts. Newton calls the denser particles "earth" and the rarer ones "acid." Hence the salt particle is composed of a kernel-like center surrounded by a shell-like circumference (42). It is fascinating that Newton, in various draft additions to *On the Nature of Acids* argues that "what is said by chemists, that everything is made from sulphur and mercury, is true, because by sulphur they mean acid, and by mercury they mean earth" (43). Hence he meant his theory that salt is composed of earth and acid to



Figures from Newton's letter to Robert Boyle of 1678/9. The sphere surrounded by smaller particles illustrates Newton's concept of saline particles "encompassing the metallick ones as a coat or shell does a kernell ..." The same terminology appears in the corpus of Eirenaeus Philalethes, with which Newton was intimately acquainted. From the 1744 edition of Boyle's *Works*.

apply also to metals. As a result, their internal structure must also in his eyes have resembled a dense kernel surrounded by a lighter shell.

To anyone familiar with Philalethes, Newton's reference to a mercurial core surrounded by a layer or layers of sulfur will bring to mind at once the alchemist's shell-theory of matter (44). Once we make this terminological substitution, it is easy to see how Philalethes' sulfurous shells, progressing inward towards ever greater perfection, correspond to the complex Newtonian particles, whose density - and hence perfection - increases as we approach the center. The transmutational import of this can be better appraised if we now consult the so-called *Clavis* previously thought by various scholars to be by Newton. In reality it is but part of a letter written by Starkey to Boyle, probably in 1651 (45).

The *Clavis* or *Key* teaches the production of an amalgam composed of mercury, antimony, silver, and ultimately gold. Starting with the specifically light antimony sulfide, the alchemist strips off its "external sulfur" to produce metallic antimony (46). The antimony is then fused with the denser silver, which Starkey says will act as a mediator between the antimony and mercury. When the silver/antimony alloy is added to the still-denser mercury, blackness is given off, and a "great stink." This reveals that the second sulfurous shell has been removed from the previously solid silver/antimony alloy. The product, a mercury/silver/antimony amalgam, called "actuated mercury," is then added to gold. The idea is that the "actuated mercury" will then penetrate into the central kernel of the gold, free it, and by a process of "fermentation," lead to the philosophers' stone (47).

If one now views this shell theory in the light of Newton's hierarchical arrangement of particles, especially as described in Query 31 of the *Opticks*, it is easy to see how Newton's corpuscular theory may have been influenced by Philalethes. The particle of salt described there did in fact consist of a dense earthy kernel surrounded by a rarer acid shell. And we know from Newton's additions to *On the Nature of Acids* that he meant this earth and acid to be coextensive with mercury and sulfur. There he maintained that "what is said by chemists, that everything is made from sulfur and mercury, is true, because by sulfur they mean acid, and by mercury they mean earth." Thus Newton's alchemical practice, described in his manuscripts, consisted of penetrating to the "innermost core" of a gold particle by employing a special mercury whose particles were small and dense enough to work their way through the interstices in the outer shell. Once this had been achieved, Newton seems to have believed that the Philalethan "actuated mercury" would produce the philosophers' stone. Newton refers to this reduction of gold to its "first matter," not only in his unpublished alchemical manuscripts, but also in his work *On the Nature of Acids* (48).

The introduction of Newton into an analysis of Philalethes raises certain questions which must now be answered. Despite the clear affinities between Newton's transmutational theory and that of Philalethes, there are obvious differences as well. First, there is no evidence that Philalethes associated mercury and sulfur with void and matter, as Figala argues that Newton did. Indeed, there is little reason to think that Philalethes was committed to the existence of absolute void, a concept that in Newton's work had profound resonances with his theology and physics. The corpuscularism of Philalethes is not a Democritean or Epicurean atomism. There is no indication that he was attracted to the philosophical atomism of antiquity, with its insistence on the existence of void. The direct sources of Philalethes' corpuscular theory, as we shall show elsewhere, are alchemical, not philosophical, and their ultimate origins are peripatetic and academic, not atomistic. Second, the abstractly quantitative aspect of Newton's work is totally absent in Philalethes. Newton committed himself to a determination of the relative proportion of particles and pores in all sorts of matter. He even derived a sort of formula for relating the different "stages of composition" to the relative proportion of void to matter in a given substance (49). This work was significant not only to Newton's alchemy, but had importance for his optical theory, where he attempted to relate color to particle size, and by extension to the relative proportion of matter to void (50). Again, this is an aspect that is totally lacking in Philalethan alchemy.

Despite these differences, the similarities between Philalethes' "shell-theory" and that of Newton are still striking. One of the most suggestive traces of Philalethes' influence lies in the already quoted Newtonian description of a particle of salt, where the physicist compared the dense core of the particle to the globe of the earth, saying that just as gravity makes the sea flow round the globe, so chemical attraction causes the acid in salt to encase the central core of earth. In each case, the denser matter exists at the core, and is surrounded by a rarer counterpart. Newton goes on to compare the salt particle to a "chaos," saying that it is "dense, hard, dry, and earthy in the Center; and rare, soft, moist, and watry in the Circumference." At first sight, this analogy between a salt corpuscle and a "chaos" seems inexplicable. In antiquity, "chaos" of course meant an indistinct mixture of elements, or a prime matter which existed before the elements per se. In the early 17th century, the term had taken on a new sense with Van Helmont's creation of the word "gas," which he claimed to derive from "chaos." But neither sense seems to apply here - Newton is thinking neither of an indistinct mass nor of a vapor. What he has in mind is a complex particle composed of two layers. The outer shell is in a sense the opposite of the inner core, being "rare, soft, moist, and watry," while the center is "dense, hard, dry, and earthy."

Where does Newton get this peculiar usage of the term "chaos," and what is he trying to impart to his reader? Let us consult the *Index chemicus*, an alchemical dictionary gathered together by Newton in the 1680s (51). After giving the conventional definition of chaos as a "confusion of elements" or "materia prima," Newton goes on to paraphrase the *Introitus apertus* of Philalethes (52):

> This chaos is earth on account of its coagulation, and the mother of minerals on account of the minerals hidden in it, and yet it is a volatile air, and it contains a [sulfurous] heaven, in which the stars revolve in its center, which center is astral and which illuminates the earth up to its surface.

Philalethes' description of "chaos," loosely quoted by Newton, refers obliquely to antimony and to its role in the amalgamation process of the *Key*. Antimony is indeed a metallic substance, and thus an earth "on account of its coagulation." Yet it is also volatile upon heating, and so an "air." In its center it contains a "heaven" - in other words, the volatility of antimony is a function of the subtle matter forming the nucleus of its particles. Being small, these sub-particles at the center of an antimony particle are fluid and volatile, as in Philalethes' description of the incoagulable sulfur at the center of a metal. The solidity of the antimony, on the other hand, is literally a property of its "surface" - it is due to the coagulative power of the metallic sulfur surrounding the otherwise fluid core.

We see in Philalethes' description of "chaos" a reference to the shell-theory of matter complete with its terminology of "center" and "surface" describing the respective extremes of the particle. In the passage quoted from the *Opticks*, however, Newton seems at first to have reversed the order of the kernel and shell. While Philalethes calls the kernel "volatile" and links the coagulation of antimony to its shell, Newton calls the center "dense, hard, dry, and earthy," while the circumference is "rare, soft, moist, and watry." Why this reversal? The answer is easy to locate if we remember that when Philalethes describes the central kernel of a particle as being "fiery," "incoagulable," and "volatile," in *De metallorum metamor-*

phosi and *The Epistle to King Edward Unfolded*, he is not thinking of the pent-up sub-particles as they naturally exist, for example in gold, imprisoned *sub involucris densissimis*. Rather Philalethes has in mind the constituent sub-particles of the kernel as they would exist in their free state, if unrestrained by the exterior shells surrounding the core. Otherwise, he would be committing himself to the absurd conclusion that natural, undigested gold is under normal conditions (what we would nowadays call room temperature and normal atmospheric pressure) volatile and liquid. Newton, on the other hand, is thinking primarily of the central core and surrounding shell of the corpuscle as they exist in their natural state, before an alchemist has tried to liberate them. Within the close-packing of a salt-particle, the central corpuscles do indeed make up a "dense, hard, dry, and earthy" nucleus, being pressed into a rigid structure. The external shell, on the other hand, is "rare, soft, moist, and watry," since it is composed of loosely packed particles, less tightly bonded to a rigid structure. Newton is surely thinking in terms of his different "stages of composition," according to which each ascending particle contains the previous stage of particles plus additional void. This is precisely what he attempted to quantify by means of his formula linking different stages to their proportion of void and matter. This element is of course absent in the naive corpuscularism of Philalethes, since he eschews any overt reference to a vacuum, Philalethes could hardly have determined its proportion to the absolute matter in a particle. In his peculiar use of the term "chaos," then, we see Newton apparently borrowing from Philalethes for his use of that term to mean a complex corpuscular structure composed of kernel and shell. And yet we also see Newton adding to Philalethes that most Newtonian of characteristics - the urge to order his chaos by means of quantification.

References and Notes

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10. *Philalethae tractatus de metallorum metamorphosi*, in Manget, reference 2, Vol. II, p. 677.

11. *Ibid.*, p. 678, "... Agens Homogeneum digestiva vi pollens ..."

12. *Ibid.*, "... Aurum in supremum gradum ... digestum ..."

13. *Ibid.*, "... ex lege disproportionis in subtilitate inter Elementa quatuor ..."

14. *Ibid.*

15. *Ibid.*, p. 68; "Disproportio siquidem miscendorum mixturam generationi idoneum tollit, ejusve possibilitatem."

16. *Ibid.*, "Nam Physica generatio fit per generationem [*sic* Manget. Royal Society, Boyle Papers XLIV, 9r *legit* generalem] ingredientium unionem. Unio porro est per minima rerum uniendarum ingressio, sin autem minimum unius minimo alterius decuplo vel centuplo subtilius, non possunt haec minima adaequata [*sic* Manget. R. S., B. P. XLIV, 9r *leg.* (minime adaequata)] coire, siquidem per minima convenire oportet, quae per minima unire quaerimus."

17. *Ibid.*, "Si quis dixerit: ad mixturam hanc faciendam unum subit alterius subtilitatem, atque ita deinceps uniuntur; Insto, quod si aeque subtile fiat [spissum prius quod fuit] ut liquidum possit [uniendo sese] ingredi, oportet ut ad eandem naturam prorsus deducatur, et quid tum quaeso terra quam aqua ... & sic, quam fatuum hoc imaginari, terram in Aquam esse convertendam, ut cum aqua concreti generationem promoveat ..."

18. *Ibid.*, "... siquidem ut aqua eandem habeat cum aere subtilitatem, eadem cum illa qualitates primas habere tenetur, idem & de terra judicandum est, ut adaequetur raritati aquae."

19. *Ibid.*, "... scire cupio, utrum, si unum primum alterius primi primas induat, non fiat realiter illud primum, cujus sic induit primas. Contrarium asseverare non est Philosophicum."

20. *Ibid.*, p. 681, "... lucis quaedam ineffabilis particula ..."

21. *Ibid.*, p. 682, "Arcanum proin nostrum (quia Spiritualis Substantia homogenea) istiusmodi metalla imperfecta per minima intrat, & quod simile invenerit, apprehendit, & praepollenti sua vi ignis flagrantis violentia defendit, & fixitate sua plusquam perfecta retinet, interea Vulcanus ardens combustibile quoque flamma sua depascitur, quo per ignem consumpto, purum remanet Aurum, Argentumve."

22. *Ibid.*

23. *Ibid.*, p. 684, "... sub involucris densissimis ..."

24. *Ibid.*, "Sciant itaque omnes Artis filii, quod ad arcanum nos-

trum consequendum opus sit Auri semen ocultissimum manifestare, quod non fit nisi per plenariam omnimodam fixi volatisationem, ac proinde formae istius corruptionem."

25. *Ibid.*, p. 683: "... proprie & exacte loquendo minima pars metalli est semen ..."

26. W. Newman, *The "Summa perfectionis" of pseudo-Geber*, Leiden, 1991, pp. 143-192.

27. Figala, "Newton as Alchemist," reference 9, pp. 123-124.

28. [Eirenaeus Philalethes,] *Sir George Ripley's Epistle to King Edward Unfolded*, MS. Glasgow University, Ferguson 85, pp. 1-80, p. 11.

29. MS. Ferguson 85, p. 13. Cf. also Philalethes, *Introitus apertus*, in *Bibliotheca chemica curiosa*, in Manget, reference 2, Vol. II, p. 664.

30. *Ibid.*, MS. Ferguson 85, pp. 11-12.

31. *Ibid.*

32. *Ibid.*, pp. 15-16.

33. *Ibid.*

34. Figala, "Newton as Alchemist," reference 9, p. 120.

35. [Eirenaeus Philalethes,] *Sir George Riplye's Epistle to King Edward Unfolded*, in *Chymical, Medicinal, and Chyrurgical ADDRESSES: Made to Samuel Hartlib, Esquire* (London, 1655), p. 22.

36. The word "nucleus" is the Latin term for "kernel" or "nut." Philalethes uses it in his unfinished manuscript of the *Vade mecum Philosophicum* (British Library, MS. Sloane 633, 107v).

37. This explanation of corrodibility as a product of porosity in the base metals was a commonplace in the alchemical tradition utilized by Philalethes. Cf. Newman, reference 26, p. 158, again quoting the *Summa*: "Propter enim eorum [i.e. copper and iron] multam terreitatis quantitatem et sulphureitatis adjustive et fugientis mensuram, defacili hoc modo adducuntur in calcem. Et illud ideo, quoniam ex multa terreitate argenti vivi substantie intermixta turbatur argenti vivi continuatio, et ideo porositas in eis creatur, per quam et sulphureitas transiens evolare potest. Et ignis ex causa illa ad eam accedens comburere et elevare potest illam. Per hoc igitur derelinguitur et partes rariores fieri et in cinerem per discontinuitatem raritatis converti."

38. I. Newton, *Opticks*, Dover, New York, NY, 1952, p. 400.

39. A. Thackray, *Atoms and Powers*, Harvard University Press, Cambridge, MA, 1970, pp. 25 and 64.

40. For Newton's distinction between "vulgar Chymistry" and "Hermetick" philosophy, see P. M. Rattansi, "Newton's Alchemical Studies," in A. G. Debus, ed., *Science, Medicine, and Society in the Renaissance*, Neale Watson Publications, New York, NY, 1972, pp. 176-177, and 170.

41. Reference 38, p. 386.

42. I. B. Cohen, *Isaac Newton's Papers & Letters on Natural Philosophy*, Harvard University Press, Cambridge, MA, 1958, p. 252. Also Dobbs, *Foundations*, reference 9, p. 219.

43. Dobbs, *Foundations*, reference 9, p. 220.

44. Figala argues, furthermore, that Newton associated the alchemists' mercury with the presence of "pores" (and hence void) in matter, echoing the Paracelsian view that mercury was the principle of volatility and hence attenuation. Similarly she thinks that Newton viewed sulfur, the traditional principle of coagulation or solidification, as representing "matter." See "Die exakte Alchemie", reference 9, pp. 163-167, 183-186.

45. W. Newman, "Newton's *Clavis* as Starkey's *Key*," *Isis*, **1987**, *78*, 564-574.

46. Philalethes, *Introitus apertus*, *BCC*, II, 663, "... sulphur externum ..."

47. Reference 45, pp. 572-574.

48. Dobbs, *Foundations*, reference 9, p. 218.

49. Figala, "Die exakte Alchemie", reference 9, p. 164.

50. Dobbs, *Foundations*, reference 9, pp. 222-225.

51. Westfall, *Never at Rest*, reference 8, p. 358.

52. Here it will be useful to give both Newton's paraphrase (Cambridge University Library, Keynes MS. 30, f. 22[r]) and the original (Philalethes, *Introitus apertus*, in *Bibliotheca chemica curiosa*, Vol. II, p. 663):

Newton: Hoc chaos est terra propter coagulationem suam, et mineralium matrix propter mineralia quae in ipsa occultantur, et tamen aer volatilis, et caelum [sulphureum] in quo astra revolvuntur continet in centro suo, quod centrum astrale est & terram ad usque superficiem illuminat. Introit. apert p. 10.

Philalethes: Chaos etenim Nostrum est quasi Mineralis Terra, coagulationis suae respectu, & tamen aer volatilis, intra quod est Coelum Philosophorum in Centro suo, quod Centrum est revera Astrale, irradians Terram adusque superficiem suo jubare.

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ROBERT MAYER AND THE CONSERVATION OF MATTER

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Robert Mayer (1814-1878) is well known as one of the discoverers of the principle of the conservation of energy. A physician from the kingdom of Württemberg in southwestern Germany, Mayer sailed to the Dutch East Indies in 1840, where he was startled by the brighter-than-expected color of the blood he let from European sailors recently arrived in the tropics. Reflecting on the implications of Lavoisier's combustion theory of animal heat, and of his own failed childhood attempt to construct a perpetual motion machine, Mayer employed a widely invoked analogy between organisms and machines to conclude that there must be a constant numerical relationship