NEWTON AND LUCRETIUS
Some Overlooked Parallels

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1. Exposure. Though the manuscript of the epic poem, *On the Nature of Things*, by the Roman Epicurean, Titus Lucretius Carus (96-55 BC), was first printed in book form in 1473 and in many subsequent editions, it was not until the 17th century that it began to impact significantly on scientific thought, leading to what the Dutch historian, Eduard Dijksterhuis, has aptly termed "the mechanization of the world picture" (1, 2). Sir Isaac Newton (1642-1727) was a second-generation participant in this revival of atomism and so could build upon the earlier atomism of such 17th-century writers as Pierre Gassendi (1592-1655), Walter Charleton (1619-1707) and, especially, that of his older British contemporary, Robert Boyle (1627-1691) (3).

Figure 1. A Roman finger ring thought to depict Lucretius and used on the title page of H. A. J. Munro's 1864 translation of *De rerum natura*.

Examination of the "philosophical" notebook kept by Newton while a student at Cambridge shows that he was first exposed to Epicurean atomism around 1664 through the reading of Walter Charleton's 1654 work, *Physiologia Epicuro-Gassendo-Charltoniana*, whose subtitle, *A Fabrick of Science Natural Upon the Hypothesis of Atoms Founded by Epicurus, Repaired by Petrus Gassendus, and Augmented by Walter Charleton*, is perhaps more transparent to the modern reader (4, 5). This notebook shows that Newton explicitly favored the atoms and void of Epicurus over the competing plenum theory of René Descartes, which rejected both a lower limit to particle divisibility and the existence of an interparticle void. Whether Newton was also directly exposed as a student to the famous poem of Lucretius is not known. However, by the 1680s, when he began seriously writing the *Opticks*, he had almost certainly read Lucretius in the original, since among the surviving books of his personal library is a 1686 Latin edition of *De rerum natura*, which one Newtonian scholar has described as "showing signs of concentrated study" (i.e. numbering of lines and dog-earing) (6, 7). Likewise, the Scottish mathematician, David Gregory, reported a conversation with Newton in May of 1694 in which Newton stated that he could demonstrate that (8):

The philosophy of Epicurus and Lucretius is true and old, but was wrongly interpreted by the ancients as atheism.

2. Some Caveats. However, the above connections should not be taken as implying that Newton uncritically accepted all of the tenants of Epicurean atomism. Like Gassendi, Charleton, and Boyle before him, Newton vehemently rejected the Epicurean premise that the world was created through the fortuitous collision of eternal self-existent atoms, opting instead for a Christianized version in which God both created and directed the atoms for his own predetermined ends (9). Newton also came to reject the Epicurean mechanism for interparticle interactions based on mechanical entanglement of complex particle shapes, favoring instead the assumption that they were the result of short-range, centro-symmetric, interparticle forces of attraction – an assumption which further fostered the view that all atoms were in fact spherical in shape.

Nor should one expect to find any explicit references to either Epicurus or Lucretius in Newton's published writings. Though he often referenced the authors of specific experimental and observational results, he was never particularly generous when it came to citing earlier anticipations of his own particular theoretical views and, in any case, by the 1680s the assumptions of atomism were already becoming a part of the accepted *Zeitgeist* in which Newton worked. In addition, Newton's religious views made him hypersensitive to the possibility that, by explicitly mentioning Epicurus or Lucretius, he might run the risk of stigmatizing his work with the charges of atheism so frequently leveled at these two classical authors. In these respects, Newton was not unlike his older, super-religious, contemporary, Robert Boyle. Thus the index to the recent, complete, 14 volume edition of Boyle's collected works contains only 28 references to Lucretius and four to Charleton, even though the historian, Robert Kargon, showed many years ago that entire passages from Boyle's essay, *The History of Firmness* (1659), for example, are based on direct paraphrases of Charleton's *Physiologia* of 1654 (3, 10).

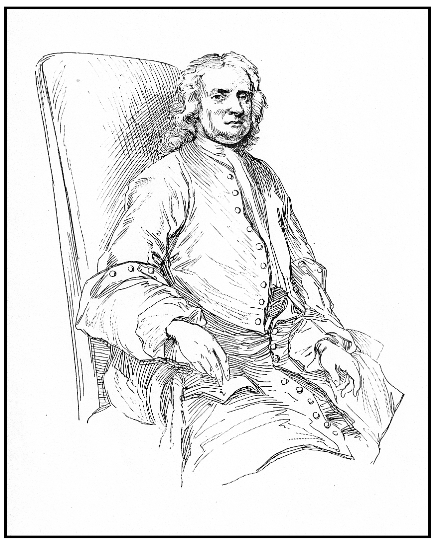

Figure 2. Sir Isaac Newton at age 83.

One tactic used by Boyle to minimize the necessity of directly referring to either Epicurus or Lucretius was to adopt the suggestion of Ralph Cudworth, on the authority of Posidonius, that the atomic theory was not the invention of atheistic Greeks but of an ancient Phoenician by the name of Moschus, and that the latter was, in fact, none other than Moses of Old Testament fame (11). That Newton was well aware of the Phoenician ploy is apparent from one of his few direct references in print to ancient atomism, which occurs in Query 28 of the *Opticks* when discussing opinions on the possible existence or nonexistence of an interparticle ether (12):

And for rejecting such a Medium, we have the Authority of those, the oldest and most celebrated Philosophers of Greece and Phoenicia, who made a Vacuum, and Atoms, and the Gravity of Atoms, the first Principles of their Philosophy.

Thus, while not possible to gauge the influence of Epicurus and Lucretius on Newton via direct quotation, I do hope to show that a comparison of certain passages in Lucretius with related passages in Newton's famous work on optics does provide indirect evidence of a significant influence.

3. Matter and Void. Let us begin our comparison with what Lucretius has to say about the relative quantities of matter and void in various materials and their bearing on the observed properties of said materials (13):

Since the universe is neither wholly full nor wholly empty, it follows that matter has been set apart from void discretely; thus there exists definite bodies marking off empty space from full. These atoms can neither be disintegrated when assailed by blows from without, nor be penetrated and unwoven from within, nor yet can they fail when attacked in any other way ... For it is seen that whatever contains no void can neither be crushed, nor broken, nor divided into two parts by cutting; nor can it receive moisture, disruptive cold, or penetrating fire, the means by which all created things are brought to an end. The more void an object contains, the more easily it is attacked by these means and falls into utter ruin. Therefore, if the first bodies are solid and without void, as I have shown them to be, they must be eternal.

In more modern terms, what Lucretius is postulating in this quote is that such properties as the hardness of a material, its melting point (attack by penetrating fire), and its resistance to chemical attack (attack by moisture and other fluids), are a direct function of the ratio of matter to void in the material or, in more symbolic terms:

$$\textit{hardness, melting point, chemical resistance} = f(\phi_m/\phi_v) \qquad [1]$$

where ϕ_m and ϕ_v are the fractions of matter and void, respectively, in a unit volume of the material. Note that this ratio goes to infinity whenever the fraction of void is zero, thus making true atoms infinitely hard and infinitely resistant to both melting and chemical attack.

If we now turn to Newton's *Opticks*, we find that he fully accepts these premises, though, following both Charleton and Boyle, he prefers to talk of pores rather than void (14):

Now if compound Bodies are so very hard as we find some of them to be, and yet are very porous, and consist of Parts which are only laid together; the simple Particles which are void of Pores, and were never yet divided, must be much harder. For such hard Particles being heaped up together, can scarce touch one another in more than a few Points, and therefore must be separable by much less Force than is requisite to break a solid Particle, whose Parts touch in all the Space between them, without any Pores or Interstices to weaken their Cohesion.

In other words, as per Lucretius:

$$hardness = f(matter/pores) = f(\phi_m/\phi_v) \quad [2]$$

4. Hardness and Strength of Interaction. However, the ratio of matter to void is not the only factor which affects the properties of a material. Again, in the words of Lucretius (15):

Next, the same force and the same cause would destroy all things together unless eternal matter, more or less closely interwoven, preserved them; a touch would certainly be sufficient cause for destruction, for there would be no seeds of eternal body whose interweaving only an appropriate force could dissolve. But as it is, because the bonds between the atoms differ and matter itself is eternal, a thing remains with its body uninjured until assailed by a force whose keenness is a match for its own structure.

Here Lucretius is telling us that a second factor – the strength of mechanical entanglement between the various particles – also comes into play. Whereas the ratio of matter to void determines the number of contact points between the various particles, the degree of mechanical entanglement (bonds between the atoms) determines the strength of those individual contact points and thus both factors, operating together, ultimately determine the overall stability of the material in question. In short:

hardness, melting point, & chemical resistance =
f(matter/void, entanglement strength) [3]

Once again Newton tacitly accepts this model in the *Opticks*, though he replaces the mechanism of mechanical entanglement with the operation of short-range interparticle forces of attraction (16):

Now the smallest Particles of Matter may cohere by the strongest Attractions, and compose bigger Particles of weaker Virtue; and many of these may cohere and compose bigger Particles whose Virtue is still weaker, and so on for divers Successions, until the Progression end in the biggest Particles on which the Operations in Chymistry, and the Colours of natural Bodies depend, and which by cohering compose Bodies of a sensible Magnitude.

or in symbolic terms:

hardness = f(matter/pores, force of attraction) [4]

5. Density and Void. Finally, in a truly remarkable passage, Lucretius tells us how to experimentally determine the ratio of matter to void in a material (17):

Next, why do we see that some objects weigh more than others, although they are of no greater size? If there were as much matter in a ball of wool as in one of lead, it would indeed weigh the same, since it is a property of matter to cause all things to press downward, while on the contrary empty space is always without weight. Therefore that which is of equal size and is seen to be lighter surely gives evidence that it has more void within itself. The heavier thing, on the other hand, asserts that there is more matter within itself and less void.

Essentially Lucretius is telling us that the relative fractions of matter per unit volume for two materials, A and B, are directly proportional to their relative weights per unit volume or, in modern terms, are directly proportional to the ratio of their densities:

$(\phi_m[A]/\phi_m[B]) = (density[A]/density[B])$ [5]

This identity is likewise implicitly accepted by Newton in the *Opticks* where it is applied to the question of the relative degree of rarity or rarefaction of water versus gold (18):

And hence we may understand that Bodies are much more rare and porous than is commonly believed. Water is nineteen times lighter [i.e. less dense], and by consequence nineteen times rarer than Gold; and Gold is so rare as very readily and without the least opposition to transmit the magnetick Effluvia, and easily to admit Quicksilver into its pores, and to let water pass through it ... From *all which we may conclude, that Gold has more Pores than solid Parts, and by consequence that Water has above forty times more Pores than Parts.*

Since the modern value for the density of water is 1 g/mL and that of gold is 19.3 g/mL, we find, on substituting into equation 5, that:

$$(\phi_m[gold])/(\phi_m[water]) = (density\ gold)/(density\ water) = (19.3)/1 = 19.3 \quad [6]$$

or that water is, as Newton states, about 19 times "rarer" than gold.

But we can go further. Since Newton tells us that water has "above forty times more Pores than Parts" (though he doesn't tell us how he has arrived at this result), we are able to determine both the fraction of matter per unit volume and the fraction of void per unit volume in water:

$$\phi_m[water] = 1/41 = 0.024 \text{ or } 2.4\% \text{ matter} \quad [7]$$

$$\phi_v[water] = 40/41 = 0.976 \text{ or } 97.6\% \text{ void} \quad [8]$$

When substituted into equation 6, these figures allow us to also calculate the fractions of matter and void per unit volume of gold as well:

$$(\phi_m[gold]) = (\phi_m[water])(density\ gold)/(density\ water) \quad [9]$$

$$(\phi_m[gold]) = (0.024)(19.3/1) = 0.463 \text{ or } 46.3\% \text{ matter} \quad [10]$$

$$(\phi_v[gold]) = 1 - (\phi_m[gold]) = 0.537 \text{ or } 53.7\% \text{ void} \quad [11]$$

Hence we find that the ratio of void to matter in gold is (0.537/0.463) = 1.16 or that it contains, as per Newton, slightly more pores than parts.

6. A Plausibility Calculation. In the *Opticks* Newton's interest in the question of the relative porosity or degree of rarefaction of materials was driven not by its possible relevance to questions of hardness, ease of melting, or degree of chemical reactivity, but rather by its possible relevance to how matter interacted with light. Like Epicurus, Newton viewed light as being composed of very tiny, rapidly moving particles, and he was interested in how the porosity of a body was related to its ability to transmit, reflect, refract, and/or selectively absorb these particles of light. His speculations on this subject led to the conclusion that bodies must contain far more void or pores than commonly supposed and in order to make this conclusion more plausible to his readers, Newton performed the following hypothetical calculation (19):

How Bodies can have a sufficient quantity of Pores for producing these Effects is very difficult to conceive, but perhaps not altogether impossible ... Now if we conceive these Particles of Bodies to be so disposed amongst themselves, that the Intervals or empty Spaces between them may be equal in magnitude to them all; and that these Particles may be composed of other Particles much smaller, which have as much empty Space between them as equals all the Magnitudes of these smaller Particles; And that in like manner these smaller Particles are again composed of others much smaller, all which together are equal to all the Pores or empty Spaces between them; and so on perpetually till you come to solid Particles, such as have no Pores or empty Spaces within them; And if in any gross Body there be, for instance, three such degrees of Particles, the least of which are solid; this Body will have seven times more Pores than solid Parts. But if there be four such degrees of Particles, the least of which are solid, the Body will have fifteen times more Pores than solid Parts. If there be five degrees, the Body will have one and thirty times more Pores than solid Parts. If six degrees, the Body will have sixty and three times more Pores than solid Parts. And so on perpetually. And there are other ways of conceiving how Bodies can be exceedingly porous. But what is really their inward Frame is not yet known to us.

What Newton is assuming in this quote is a particle hierarchy similar to that described in the earlier quote on interparticle attractions and that each level of this hierarchy, with the exception of the lowest or true atomic level, is composed of 50% particles and 50% interparticle pores or void. Thus the total fraction of matter per unit volume is given by the equation:

$$\phi_m = (1/2)^n \qquad [12]$$

where n is the degree of the largest particle, and the total fraction of void per unit volume is simply the difference between this value and one:

$$\phi_v = 1 - (1/2)^n \qquad [13]$$

As may be seen in the table at the top of the following page, which applies these equations to the cases of n = 0 ... 6, for true atoms or particles of the zeroth order ($n = 0$), they give values of 1 and 0, respectively, for the fractions of matter and void, and thus a ratio of void to matter of 0; for particles of the first order ($n = 1$), they give values of 1/2 and 1/2 and a ratio of 1; for particles of the second order ($n = 2$), they give values of 1/4 and 3/4 and a ratio of 3, etc., just as verbally summarized by Newton in the above quote.

7. An Alchemical Hiatus. To understand why the above rather obvious and somewhat trivial comparisons between Lucretius and Newton are important, and

n	ϕ_m	ϕ_v	(ϕ_v/ϕ_m)
0	1	0	0
1	1/2	1/2	1
2	1/4	3/4	3
3	1/8	7/8	7
4	1/16	15/16	15
5	1/32	31/32	31
6	1/64	63/64	63

why an historian of chemistry is talking at a symposium on Lucretius about Newton, we need to look at an event that happened in the field of Newtonian studies more than 40 years ago.

It has long been known that, beginning about 1669 and continuing until about 1696, Newton devoted a great deal of his time to the laboratory study of chemistry and alchemy. While there is *nothing remotely alchemical* about any of Newton's published scientific works, a substantial quantity of manuscript material relating to his alchemical studies has survived, though this was not examined in detail by historians until the 1970s and, in particular, by the American historian, Betty Jo Teeter Dobbs, who ultimately published two monographs on the subject in 1975 and 1991 respectively (7, 20). Somewhat disappointingly, it turned out that the vast majority of this alchemical manuscript material consisted of transcriptions and/or translations in Newton's own hand of known alchemical books and manuscripts by various authors, as well as glossaries, bibliographies, and summaries. Regrettably, the authorship of a few of the manuscripts could not be unambiguously established and this soon led to disputes as to whether they were actually alchemical works written by Newton himself or merely transcriptions of previously unknown alchemical works by others – a question which has still not been resolved to everyone's satisfaction (21).

Although this material indisputably verified the fact that Newton had a strong and abiding interest in alchemy, it failed to provide definitive answers to the important questions of *why* he was interested in alchemy in the first place (and thus whether it is correct to view him as a practicing alchemist) and whether his study of the alchemical literature had provided him with important concepts which he then incorporated into his published scientific work. This lack of unambiguous evidence, however, proved no barrier to historians drawn to the subject, who simply replaced evidence with speculation. Soon a deluge of papers and books began to appear attributing virtually every aspect of Newton's scientific thought to his study of alchemy. Having supposedly proven that

Newton was an alchemist, any belief or thought appearing anywhere in the alchemical literature was automatically attributed to Newton as well.

Anyone objecting to this binge of speculation was stereotyped as an outdated, semi-senile, proponent of Whig history and essentially shouted out of court. The culmination of this trend came in 1997 with the publication of a popularized biography of Newton by the science journalist, Michael White, entitled *Isaac Newton: The Last Sorcerer*, which not only took the alchemy hypothesis to the extreme but also insinuated that Newton was drawn to "occult practices and the black arts" as well (22). Thus the great Newton, once viewed as the apex of the scientific revolution and the father of the scientific enlightenment, was reduced instead to a Faustian, schizophrenic, dabbler in alchemy, magic and mysticism.

8. Matter and Void Reinterpreted. Nor did the material quoted earlier from the *Opticks* on the relationships between matter, void and density escape this alchemical onslaught. In 1977 Karin Figala, in a 35-page essay review of Dobb's first book (23), then once again in 1984 in a 71-page article in German (24), and finally, in an appendix to Rupert Hall's 1992 biography of Newton (25), argued that, not only were these concepts found in the alchemical literature (though she never stated exactly where), they also held the key to Newton's understanding of the alchemical corpus. Nowhere did she mention that these relationships were simple mathematical elaborations of those found in Lucretius and the 17th-century literature on Epicurean atomism.

Ignoring Newton's explicit statement that his hypothetical $(1/2)^n$ model was designed merely to illustrate the plausibility of the proposition that bodies are far more porous than commonly believed and that it was in no way to be taken as a true picture of the actual structure of bodies, whose real "inward Frame is not yet known to us," Figala did the exact opposite and assumed it to be Newton's real theory of atomic structure and the key to his theory of alchemy. Though Newton explicitly discusses only the relative rarity of water, gold, and mercury in the *Opticks*, Fagala expanded these examples into the triangular diagram shown in figure 3 using density values mentioned by Newton in other contexts, as well as those reported by Newton's follower, John Freind. In this diagram true atoms appear at the apex and materials of greater and greater rarefaction as one moves from the top towards the base. The numerical values listed along the right side of the triangle indicate the fraction of void in the material in question, whereas those listed along the left side indicate the fraction of matter, both values having been calculated from the material's density and the fractions of matter and void assumed by Newton for water in the same fashion as was done earlier in the case of gold. The solid horizontals connecting these numbers indicate the ratio of void to matter or "degree of rarefaction" for the materials in question, and the broken horizontals indicated the void to matter

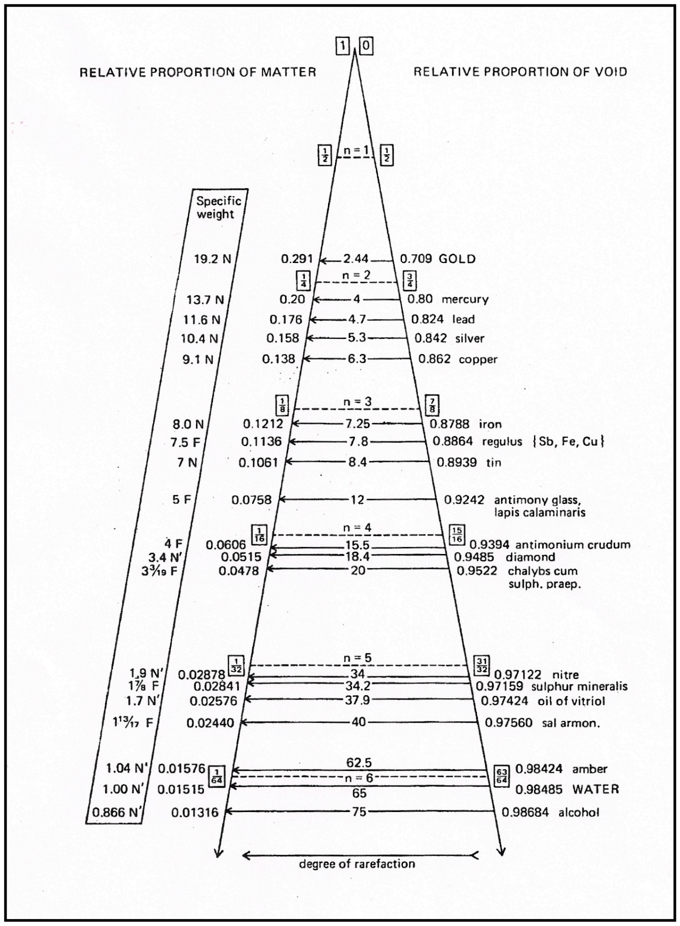

Figure 3. Figala's triangular matter-void hierarchy

ratios calculated using the *(1/2)*^{n} model and listed in the last column of the above table. Finally, in the box on the far left are listed the experimental densities of the various materials as given by Newton (*N* and *N*') and Freind (*F*).

There are several problems with this diagram:

1. As already noted, Figala used the term "degree of rarefaction" for the ratio of void to matter (ϕ_v/ϕ_m), whereas Newton used it for relative density or matter fraction $(\phi_m[A]/\phi_m[B])$.

2. In her calculations, Figala claimed that Newton assumed that water contained "one part matter to sixty five parts of void" – which approximates the 1 to 63 ratio calculated from the $(1/2)^n$ model, whereas in the *Opticks,* as we have seen, Newton claimed that it contained closer to 1 to 40 parts (26). Use of the latter, rather than the former, value obviously shifts the positions of all of the materials in the diagram relative to the hypothetical values calculated using the $(1/2)^n$ model.

Seven variations of this triangular diagram appear in Figila's 1977 article, six in the 1984 article, and one in the 1992 summary. Nowhere is it indicated where such diagrams appear in either the published or unpublished writings of Newton or in the alchemical literature and, indeed, a close reading of the text reveals that these diagrams are in fact the invention of Dr. Figala, though the figure captions fail to make this important point explicit. As such, there would, of course, be no objection to viewing them as a clever way of summarizing Newton's elaboration of the Epicurean-Lucretian theory of matter. But to do so would be a naive mistake, since this would overlook what Figala believed to be the "real" meaning of these diagrams.

Noting that these triangular diagrams have the shape of the Greek letter lambda (λ), thus allowing one to recover "the Great Pythagorean Tetraktys," Figala proceeded to point out that the ratios of void to matter calculated using Newton's $(1/2)^n$ formula, and listed in the last column of the above table, form a recurrent series which can be mathematically generalized using the recursion formula:

$$3a^n = 2a^{n-1} + 1a^{n+1} \quad [14]$$

from which she drew the following remarkable conclusions (25):

We may detect a trinitarian interpretation: three times the middle term ($3a^n$) unites in a certain way its parent ancestor ($2a^{n-1}$) and its son successor ($1a^{n+1}$); a more "substantial" interpretation would be that a^n mediates between "solid" (Earth) and "thin" (Heaven), a^{n-1} being more solid than a^n and a^{n+1} being more rarified with respect to a^n. Thus a^n also mediates between "down" and "above" and so on. Seen in an alchemical way, the "soul" a^n mediates between "matter" (the full) a^{n-1} and "void" (the empty, without matter = spirit) a^{n+1}. The mediator is part of what it joins together; its nature is hermaphrodite. In traditional alchemy Mercury plays this role and on yet another level Mercurius is Hermes, the messenger of the gods, who mediates between the gods and mankind. Thus Newton's scheme has the additional advantage of conforming to magic-alchemical-religious ideas.

Where exactly Newton explicitly makes all of these magical-alchemical-religious connections with a matter diagram which he apparently never drew or used is never explained or supported by direct quotations – it is simply asserted. If such direct evidence existed one would have thought that Dr. Figala would have been anxious to cite it, since, to paraphrase David Hume, extraordinary claims (and these are indeed extraordinary) demand extraordinary documentation. In the end, one must conclude that the ideas presented in these papers are 99% Figala and only 1% Newton. Though they may well form an intriguing approach to the interpretation of the alchemical literature, they fail to make the case that it is Newton's approach we are looking at rather than that of Dr. Figala. Rather ironically, if this was indeed Newton's approach, then it would strongly suggest that he was attempting to scientifically rationalize the alchemical literature in terms of Epicurean matter theory modified to take into account the operation of interparticle forces of attraction and repulsion – an interpretation which is strenuously opposed by most who have speculated on the nature of Newton's alchemical activities.

In the end, the effort of trying to sort speculation from fact leaves one agreeing with the evaluation given by the great British historian, Herbert Butterfield, over a half century ago of much of the work published on the history and meaning of alchemy (27):

Concerning alchemy it is more difficult to discover the actual state of things, in that historians who specialize in this field seem sometimes to be under the wrath of God themselves; for, like those who write on the Bacon-Shakespeare controversy or on Spanish politics, they seem to become tinctured with the kind of lunacy they set out to describe.

9. Conclusions. I hope I have shown that a textual comparison of Newton's published scientific writings with those of Lucretius and various 17th-century proponents of Epicurean atomism – something which, to the best of my knowledge (and great surprise), has apparently never been done in detail – promises to provide a far more plausible explanation of the origins of many of Newton's ideas on matter, light, and even gravitation, than does the study of the alchemical literature and would go a long way towards offsetting some of the more embarrassing excesses of the Newtonian alchemical hiatus (28).

All of this in no way negates the evidence of Newton's abiding obsession with the alchemical literature – an obsession very much in keeping with his other personal obsessions, such as Biblical prophecy or the exact dimensions of King Solomon's temple. That a great scientist may harbor irrational views on topics unrelated to his field of scientific competency is hardly a novel discovery. One could list dozens of famous late 19th-century and early 20th-century scientists who believed in psychic phenomena and spiritualism, and the present author had a roommate in graduate school, who, though now a top-ranking chemist at the National Bureau of Standards, spent much of his time as a student trying to prove the truth of astrology. Few scientists maintain a self-consistent, rational, scientific world view which extends much beyond the confines of their areas of technical specialization. Rather, like most humans, they are capable of harboring mutually contradictory views side by side in their psyches without experiencing the least degree of cognitive dissonance. As long as these personal eccentricities do not spill over into their published scientific work, their prestige as scientists remains unimpaired. The fact that Newton never attempted to publish his work on alchemy strongly suggests that he consciously or unconsciously knew where the boundaries of acceptable mathematical physics began and ended, and attempts by some historians to forge significant links between his various intellectual "hobbies" – be they alchemy or biblical prophecy – and his published scientific legacy appear to me to be ill-advised at best and misleading at worst.

10. References and Notes

1. T. Lucreti Cari, *De rerum natura*, Brescia, 1473.

2. E. Dijksterhuis, *The Mechanization of the World Picture*, Clarendon: Oxford, 1961.

3. For background see R. H. Kargon, *Atomism in England from Hariot to Newton*, Clarendon Press: Oxford, 1966.

4. J. E. McGuire, M. Tamny, *Certain Philosophical Questions: Newton's Trinity Notebook*, Cambridge University Press: Cambridge, 1985, pp. 6, 20, 26-36, 213-215, 284.

5. The 1654 edition of Charleton's book is available as a modern photoreproduction, see W. Charleton, *Physiologia Epicuro-Gassendo-Charltoniana: or a Fabrick of Science Natural Upon the Hypothesis of Atoms*, *Founded by Epicurus, Repaired by Petrus Gassendus, Augmented by Walter Charleton*, Johnson Reprint Corporation: New York, NY, 1966.

6. J. Harrison, *The Library of Isaac Newton*, Cambridge University Press: Cambridge, 1978, item 990, p. 183.

7. B. J. Teeter Dobbs, *The Janus Faces of Genius: The Role of Alchemy in Newton's Thought*, Cambridge University Press: Cambridge, 1991, p. 216.

8. H. W. Turnbull, Ed., *The Correspondence of Isaac Newton*, Vol. III, 1688-1694, Cambridge University Press: Cambridge, 1961, p. 338.

9. See, for example, Newton's correspondence with Richard Bentley as reprinted in I. B. Cohen, R. E. Schofield, Eds., *Isaac Newton's Papers and Letters on Natural Philosophy and Related Papers*, Harvard University Press; Cambridge, MA, 1958, pp. 271-394.

10. M. Hunter, E. B. Davis, Eds., *The Works of Robert Boyle*, 14 Volumes, Pickering and Chatto: London, 1999-2000.

11. H. Jones, *The Epicurean Tradition*, Routledge: London, 1989, pp. 210-211.

12. I. Newton, *Opticks or a Treatise of the Reflections, Refractions, Inflections and Colours of Light*, Dover Books: New York, NY. 1952, p. 369. The first edition of the

Opticks appeared in 1704, the second in 1717, the third in 1721 and the fourth in 1730. The Dover edition used here is a reprint of the 4th London edition of 1730.

13. *On Nature*, I: 523-540. All quotes are from the translation of R. M. Geer, *Lucretius on Nature*, Bobbs-Merrill Co: Indianapolis, IN, 1965, though other translations would serve as well.

14. Reference 12, pp. 389-390.

15. Reference 13, I: 239-248.

16. Reference 12, p. 394.

17. Reference 13, I: 359-367.

18. Reference 12, p. 267.

19. Reference 12, pp. 268-269.

20. B. J. Teeter Dobbs, *The Foundations of Newton's Alchemy*, Cambridge University Press: Cambridge, 1975.

21. For background on these disagreements concerning authorship and further references, see W. R. Newman, *Gehennical Fire: The Lives of George Starkey, An American Alchemist in the Scientific Revolution*, Harvard: Cambridge, MA, 1994, Chapter 7. While discounting Newton's authorship of many of the unidentified manuscripts, Newman, not unexpectedly (given the subject of his book) attempts to argue that Newton's ideas on matter were derived from Starkey rather than from 17th-century Epicurean atomism. In addition, readers should be aware that Newman often uses the word alchemical to describe chemical writings that are traditionally not considered to be explicitly alchemical in nature.

22. M. White, *Isaac Newton: The Last Sorcerer*, Perseus Books: Reading, MA, 1997.

23. K. Figala, "Newton as Alchemist," *Hist. Sci.*, **1977**, *15*, 102-137.

24. K. Figala, "Die exakte Alchemie von Isaac Newton," *Verhand. Naturforsch. Gesell. Basel*, **1984**, *94*, 157-228.

25. K. Figala, "Newton's Alchemical Studies and his Idea of the Atomic Structure of Matter," in A. R. Hall, *Isaac Newton: Adventurer in Thought*, Blackwell: Oxford, 1992, Appendix A, pp. 381-386.

26. The 1 to 65 figure for the ratio of matter to pores in water is from a fragment found among Newton's unpublished manuscripts and printed in A. R. Hall and M. Boas Hall, Eds, *Unpublished Scientific Papers of Isaac Newton*, Cambridge University Press: Cambridge, 1962, p. 317. The Halls tentatively identified this as an unused draft addition to Book III, Proposition VI of the *Principia*, though it is very similar in content to the section of the *Opticks* quoted in reference 18 in which Newton revises his estimate to 1 to 40.

27. H. Butterfield, *The Origins of Modern Science*, Bell: London, 1957, p. 129.

28. Other historians have certainly discussed Newton's atomism and its relationship to Epicurus in general terms, but none, to the best of my knowledge, has conducted a detailed comparison of specific physical points based on direct quotations as was done here. For general treatments, see Kargon, reference 5; and H. Guerlac, "Newton et Epicure," in H. Guerlac, *Essays and Papers in the History of Modern Science*, Johns Hopkins University Press: Baltimore, MD, 1977, pp. 82-106.

11. Publication History

Published in T. J. Madigan, D. B. Suits, Eds., *Lucretius: His Continuing Influence and Contemporary Relevance*, RIT Graphic Arts Press: Rochester, NY, 2011, pp. 13-27.

12. Update

Further evidence of the influence of Lucretius on Newton is cited by Jennifer Michael Hecht in her book, *Doubt: A History* (Harper, 2003, p. 326), where she claims that in early drafts for the second edition (1713) of the *Principia*, Newton included ninety lines from Lucretius dealing with the subject of inertia and gravity. Unfortunately she doesn't cite the source for this claim nor speculate on why they were deleted from the final published version, though this deletion may reflect Newton's fear of having his work associated with the name of a supposed atheist. For a detailed analysis of their content and context see:

* J. E. McGuire, P. M. Rattansi, "Newton and the 'Pipes of Pan'," *Notes Rec. Roy. Soc. London*, **1966**, *21*, 108-143.

Further discussions of the relationship of Newton's concept of inertia to that of Lucretius may be found in:

* I. B. Cohen, "'Quantum in Se Est': Newton's Concept of Inertia in Relation to Descartes and Lucretius," *Notes Rec. Roy. Soc.*, **1964**, *19(2)*, 131-155.

* W. L. Hine, "Inertia and Scientific Law in 16th Century Commentaries on Lucretius," *Renaiss. Quart.*, **1995**, *48*, 728-741.