ROBERT BOYLE ON THE ELEMENTS

Conleth Patrick Loonan

This thesis is submitted with a view to obtain the degree of M.Litt.

NUI Maynooth

Faculty of Arts, Celtic Studies and Philosophy

July, 2010

Supervisor and Head of Department of Philosophy:

Dr Michael Dunne

Table of Contents

Chapter 2

Boyle on Matter

Chapter 3

Boyle and the Elements – I

Chapter 4

Boyle and the Elements – II

Author's Declaration

I hereby declare that this project represents my own work and has not been submitted, in whole or in part, by me or by another person, for the purpose of obtaining any credit/grade. I agree that this project may be made available to future students of the College.

Signature: ______________________________

Date: ______________

Acknowledgements

The author wishes to express his gratitude to the following:

Dr Michael Dunne, Head of the Philosophy Department, for accepting this project and then, by his sensitive yet thorough supervision, guiding it to its conclusion;

Breege Lynch for her dextrous and meticulous preparation of the typescript;

The John and Pat Hume Scholarship Scheme for generous financial support during the term of this project.

Abstract

Robert Boyle (1627-91) hypothesised that all matter subsisted of corpuscles, differentiated only by size, figure and shape, and believed that water played a central rôle in the created world: it may even have been the prime matter. He considered the question of the elements and, defining them as ‘simple’, ‘primitive bodies’ into which compound bodies were ultimately resolved, offered evidence for the elements from a variety of sources, largely centred on demonstrating that water is transmuted into earth which, in turn, is transmuted into metals.

Boyle considered various physical entities which might be considered as elemental, ranging from suggesting that no elements exist, to the acceptance of some of the sets of proposed elements then current.

The following questions are considered: the elements as primary qualities of matter; primary qualities of the elements; weight as a primary quality of the elements; weight as a Boylean primary quality; the epistemic and ontological reality of the elements; and the elements in relation to their individuation and identity.

A comprehensive literature review is presented.

Introduction

I. General

One of the greatest figures of the Scientific Revolution was the Honourable Robert Boyle (1627-91) born the fourteenth child of the Earl of Cork in Lismore, Co. Waterford and educated at Eton as a young boy, then later in France, Italy and Switzerland (along with his brother Francis) under the care of their tutor Isaac Marcombes. His early adulthood was spent in Stalbridge, Dorset, in an estate bequeathed to him by his father, the rest of his life being divided between Oxford and London. His output stretches from literature, to philosophy and theology, to the natural sciences.

Opinions on Boyle's importance are almost universally high, with Hunter saying that he was the dominant figure in English science in the late seventeenth century, and that only in the eighteenth century was his reputation eclipsed by his younger contemporary Isaac Newton.[1] According to Pilkington, 'no man did more than Robert Boyle to ….. lay the foundations of science firmly upon lines which are still followed in our own time.'[2] He was '… *une figure emblématique de la philosophie expérimentale anglaise*'.[3] One of the tags by which Boyle is characterised is that he is 'The Son of the Earl of Cork and the Father of Modern Chemistry'.[4]

[1] Michael Hunter, *Boyle* (Yale University Press, 2001) p. 1.
[2] Roger Pilkington, *Robert Boyle Father of Chemistry* (London: John Murray, 1959) p. 13.
[3] Myriam Dennehy and Charles Ramond, *La Philosophie Naturelle de Robert Boyle* (Paris: Vrin, 2009) p. 15.
[4] D. Thorburn Burns, 'Robert Boyle (1627-1691): A Foundation Stone of Analytical Chemistry in the British Isles, Part 1', *Anal. Proc*. May 1982, 224-233, p. 229.

Boyle was, according to Boas, passionately interested in chemistry and the majority of his experiments, except for some of his work in pneumatics and hydrostatics, were chemical in nature.[5] Boyle as researcher applied Francis Bacon's precepts on the application of an inductive experimental method to the uncovering of nature's secrets, and developed an impressive experimental technique which he applied to whatever problems in natural philosophy aroused his curious and penetrating mind.

Interestingly, the best known fruits of Boyle's experimental programme are in the field of physics, where 'Boyle's Law' states that for air, its volume is inversely proportional to its pressure'.[6] During his lifetime, much of Boyle's fame developed from his introduction of an improved version of von Guericke's air pump, which could partially evacuate a large glass sphere 'and the *vacuum Boylianum* became a standard scientific term'.[7] Boyle also practiced alchemy, and his efforts in this area are covered in detail by Principe.[8] Newman states that he tried '… throughout his life to effect the transmutation of base metal into gold, in which he was much abetted by his enigmatic teacher, the American émigré, George Starkey, and others; …'.[9]

Boyle did however, intentionally and conscientiously study chemistry during his stay in Oxford. 'In 1659 he invited the German chemist Peter Staehl – who had been

---

[5] Marie Boas, 'The Establishment of the Mechanical Philosophy', *Osiris*, Vol. 10 (1952) 412-541, p. 494.
[6] Strictly speaking, for a gas at pressure P and volume V, Boyle's Law can be expressed as:
$PV = \text{constant}$,
where the amount of gas (N) and the temperature (T) are fixed.
From: F.J. Keller, W.E. Gettys and M.J. Skove, *Physics Classical and Modern*, 2nd edn. (New York: McGraw-Hill, Inc., 1993) p. 417.
[7] Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958) p. 185.
[8] Lawrence M. Principe, *The Aspiring Adept* (Princeton University Press, 1998).
[9] William R. Newman, *Promethean Ambitions* (University of Chicago, [2004] 2005) p. 271.

recommended to him by both Morian and Clodius – to teach chemistry at Oxford'.[10] More says that Boyle employed Staehl as private tutor, 'a noted chemist and Rosicrucian of Strasbourg, who taught him geometry, the Cartesian philosophy and chemistry'.[11] Boyle lived in a house in High Street, Oxford, next to University College[12] and Stewart states that 'excavation a few years ago uncovered what is thought to have been some of his glassware'.[13] Boyle left Oxford in 1668, 'by then an Honorary Doctor of Medicine of the university'.[14]

Throughout his career Boyle maintained extensive contacts with the bourgeoning scientific community of the time. As an example Oster remarks on 'Boyle's scientific affiliations through the interregnum from the Invisible College[15] and Hartlib's Agency to the Oxford Experimental Club and Gresham College'.[16] He was 'a Founder Fellow and frequent attendant at meetings of the Royal Society'.[17] Boyle's independent mindedness would surely have placed him at one with the proud motto of that society: '*nullius in verba*'.[18] While living in London with his sister Katherine, Viscountess Ranelagh, he

[10] Antonio Clericuzio, 'From van Helmont to Boyle. A Study of the Transmission of Helmontian Chemical and Medical Theories in Seventeenth-Century England', *The British Journal for the History of Science*, Vol. 26, No. 3 (1993) 303-334, p. 318.
[11] L.T. More, *The Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944) p. 92.
[12] R.E.W. Maddison, *The Life of the Honourable Robert Boyle* (London: Taylor & Francis, 1969) Plates XIV and XV.
[13] M.A. Stewart, *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991) p. xi.
[14] Ibid., p. xi.
[15] 'The name Invisible College is perhaps a *jeu d'espirit* on the part of Boyle to describe a small group of persons interested in the utilitarian aspects of natural philosophy, and calling themselves the Philosophical College'. In: R.E.M. Maddison, *The Life of the Honourable Robert Boyle*, p. 69.
[16] Michael Hunter (ed.) *Robert Boyle Reconsidered* (Cambridge University Press, 1994) p. 30.
[17] D. Thorburn Burns, *The London of Robert Boyle*, p. 2, at: http://www.bbk.ac.uk/boyle/ThorburnBurns.htm, (Consulted 15/06/2009).
[18] http://royalsociety.org/nullius-in-verba, (Consulted, 10/06/2010).

kept a laboratory in her house in Pall Mall, and in addition, may have had ‘a laboratory in the Covent Garden area’.[19]

II. Mechanical / Corpuscularian Philosophy

Dijksterhuis sets the natural philosophical scene into which Boyle reached manhood by saying that around the middle of the seventeenth century there were four different currents of thought about the structure of matter existing side by side and partially overlapping with one another:

i. The Aristotelian doctrine of the four elements, earth, air, fire and water.

ii. The Paracelsian doctrine of the *tria prima,* salt, sulphur and mercury.[20]

iii. The Cartesian doctrine that matter is identical with extension, and that it exists in three degrees of fineness.

iv. The Democritic-Epicurean theory of atoms, revived by Gassendi (1592-1655).[21]

Each of these systems was strongly contested and argued for in the intellectual ferment of the early Scientific Revolution. As a Scientific Realist Boyle strove to banish concepts such as occult powers and qualitative descriptions of phenomena in favour of contact action and quantitative descriptions, and although he admired Aristotle as one of ‘those famed ancients whose learning about Alexander’s time ennobled Greece’,[22]nevertheless he ‘observed Aristotle in his Physics to write very often in so dark and ambiguous a way,

---

[19] D. Thorburn Burns, *The London of Robert Boyle*, p. 2.
[20] According to Paracelsus: ‘*Der Mercurius aber ist der Spiritus, der Sulphur ist Anima, das Sal das Corpus*’. In: Reijer Hooykaas, *The Concept of Element: Its Historical-Philosophical Development* (Utrecht, 1933) [Doctoral Dissertation] trans, H.H. Kubbinga, 1983.
[21] E.J. Disksterhuis, *The Mechanization of the World Picture* (Oxford University Press [1961] 1969) pp. 433-434.
[22]M.A., Stewart, *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991) p. 10.

that it far more difficult than one would think to be sure what his opinion was'[23] For Boyle an acceptable hypothesis had to be simple, intelligible, plausible, consistent both with itself and other observed phenomena. The workings of a clock in which the movements of the hands could be traced back through the motion of various cog-wheels directly to a coiled spring whose stored energy was slowly and smoothly released to drive the entire mechanism, provided Boyle with an exemplar for the workings of the observed universe. According to Cook: 'Boyle's mechanical corpuscularianism explained all natural phenomena as the operations of a vast machine that ultimately depends on the external agency of the Divine Author who created it.'[24]

Boyle was one of the greatest proponents of the Democritic-Epicurean theory and his Corpuscularian Philosophy hypothesised that matter subsisted as corpuscles differing only in size, figure and shape. Matter and motion (or rest) underlay Boyle's understanding of sensible things. All material entities resulted from assemblages of those corpuscles, and with all changes in the constitution of materials accounted for by the aggregation and disaggregation of the corpuscles from which they were composed. Boyle says in *The Excellency and Grounds of the Mechanical Hypothesis*:

> 'For the chemical ingredient itself, whether sulphur or any other, must owe its nature and other qualities to the union of insensible particles in a convenient size, shape, motion or rest, and contexture, all of which are but mechanical affections of convening corpuscles'.[25]

[23] Ibid., p. 6.
[24] Margaret G. Cook, 'Divine Artifice and Natural Mechanism: Robert Boyle's Mechanical Philosophy of Nature', *Osiris*, 2nd series, Vol. 16 (2001) 133-150, p. 140.
[25] J.J. MacIntosh, (ed.) *The Excellencies of Robert Boyle* (Peterborough, Ontario: Broadview Editions, 2008) p. 239.

Although Boas says that 'the application of atomic theory to physical science began, as is well known, in the seventeenth century',[26] more recent scholars disagree, with Newman saying that pre-Boylean alchemists had a well-developed and persuasive corpuscular theory of matter, and that the alchemists employed a long-standing corpuscular theory, which originated in the High Middle Ages and continued to thrive in an unbroken tradition that lived well into the seventeenth century.[27] Murdoch argues that the ultimate source for the idea of *minima naturalia* is the text in Book 1 of the *Physics*, chapter 4, in which Aristotle criticises Anaxagoras.[28]

Clericuzio explains Boyle's corpuscular system by saying that the simplest particles, which are not actually divided by nature, were called by him *minima naturalia*. They are not identical with the *minima* mentioned in his early manuscript notes on atoms, because they have only mechanical properties. Their close and strict adhesions form the primitive concretions or clusters, which are indeed corpuscles of the second order.[29] Boas points out that Isaac Beeckmann (1588-1637) anticipated Boyle in stating the relationship between matter and motion, as she credits the Dutchman with saying that the *variation* in the motion of the atoms could explain some of the properties of the bodies made up from the atoms [Boas's italics]. He wrote: 'therefore all properties arise from motion, shape and size, so that each of these things must be considered'.[30]

---

[26] Marie Boas, 'The Establishment of the Mechanical Philosophy', *Osiris*, Vol. 10 (1952) 412-541, p. 413.
[27] William R. Newman, 'The Alchemical Sources of Robert Boyle's Corpuscular Theory', *Annals of Science*, 53 (1996) 567-585, p. 570.
[28] C. Lüthy, J.E. Murdoch and W.R. Newman, *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: Brill, 2001) p. 96.
[29] Antonio Clericuzio, 'A Redefinition of Boyle's Chemistry and Corpuscular Philosophy', *Annals of Science*, Vol. 47 (1990) 561-589, p. 579.
[30] Op. cit. p. 438.

III. Boyle's Epistemology

Boyle, as a pious lay theologian, accepted the importance of the Two Books – that of Scripture and that of Nature – and as a natural philosopher set himself the task of deciphering the latter one. Boyle the theologian was a voluntarist and as such believed that at the time of Creation God was utterly free to create any kind of world He chose, and that once created, God remained at liberty to intervene at will in His own creation. Wojcik quotes Boyle as saying that 'the laws of nature, as they were at first arbitrarily instituted by God, so, in reference to Him, they are but arbitrary still'.[31]

A similar interpretation is given by Zaterka when she says that we perceive the impossibility of our speaking of necessary natural laws, since on the one hand, God is the ultimate cause of all things, but on the other, the immediate cause of miracles. Therefore, she continues, according to Boyle, we can only speak of an ordinary and extraordinary course of nature, seeing that: 'although for us the laws of movement be necessary (*sejam necessárias*) at the moment in which they were instituted by the Creator of Matter (*Criador da Matéria*) were arbitrary for Him and depended only on His will, [and] could have been completely different than they are.'[32]The dependence of the created world on God is expressed by Shanahan as: 'Natural bodies can be said to possess causal powers in virtue of the motion they impart to one another through impact, but they are incapable of sustaining the lawful order of the universe without the continued assistance of God.'[33]

---

[31] Jan Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997) p. 196.

[32] Luciana Zaterka, 'Os Limites do Projeto Epistemológico de Robert Boyle: As Verdades Acima da Razão', *Cadernos de Historia e Filosofia da Ciência*, Campinas, Série 3, Vol. 12, Nos. 1-2 (2002) 209-223, p. 216.

[33] Timothy Shanahan, 'God and Nature in the Thought of Robert Boyle', *Journal of the History of Philosophy*, Vol.26, No.4 (1988) 547-569, p.567.

Boyle himself expresses the independence of God from the laws governing His creation by saying that '... nature is confessed to be a thing inferior to God, and so but a subordinate agent ...'.[34] God's independence from His own creation is also stressed by Boyle, when he says: 'and so, being obliged to none, either as His superior or benefactor, He was not bound to make or administer corporeal things after the best manner that He could, for the good of things themselves – '.[35] Not alone does God not necessarily act for the benefit of His creation, He can also lay aside the natural laws He instituted for that creation whenever He desires to act punitively towards humanity: '... as God is an independent, free and wise, so He is also a just agent, and therefore may very well be supposed to cause many irregularities and exorbitances in the world to punish those that men have been guilty of'.[36]

In his *About the Excellency and Grounds of the Mechanical Philosophy* Boyle states that the reasons for his promotion of the Corpuscularian Philosophy are '... the *intelligibleness* or *clearness* of the mechanical principles and explications'.[37] He extols their economy by saying that 'there cannot be *fewer* principles than *matter* and *motion*'. Neither can there be more '*primary*' or '*simple*' principles than those, and their great '*comprehensiveness*' also recommends them. [Boyle's italics].[38] Boyle's use of these various descriptions of his Corpuscularian Philosophy might be reduced to qualities representing economy and lack of complexity.

---

[34] Robert Boyle, *A Free Enquiry into the Vulgarly Received Notion of Nature*, B. Davis and M. Hunter (eds) (Cambridge University Press, 1996) p. 69.
[35] Ibid., p. 70.
[36] Ibid., p. 70.
[37] M.A. Stewart (ed.) *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991) p. 139.
[38] Ibid., p. 141.

By contrast he says that among the Aristotelians there are ‘many and intricate’ disputes about ‘*matter, privation, substantial forms* and their *eduction*, & c.’, and the ‘more dark and intricate’ doctrines of the chemists (Paracelsians) ‘about the *archeus*, *astral beings, gas, blas*, and other odd notions’. [Boyle’s italics].[39] Boyle seems eager at all times to contrast the simplicity and clarity of his mechanical principles with the obscurity of those of his adversaries. Clearly for Boyle, the principles of the Paracelsians possess no more clarity than those of the Aristotelians. He adds: ‘And if the principles of the Aristotelians and the Spagyrists are thus obscure, it is not to be expected the explications that are made by the help only of such principles should be clear.’ [40]

Wojcik draws an interesting comparison between the respective positions taken by the theological voluntarists, such as Boyle, and the theological rationalists. She argues that whereas theological rationalists assume that God had created the world according to reason, that the created world embodies at least some necessary relations, and that human reason is capable of discerning the nature of that creation either because of God-implanted innate ideas about the creation or because God has created the human intellect in such a way that it might discern the necessary relationships inherent in the creation, by contrast, theological voluntarists believe that the world is completely contingent on God’s will, and that human beings can attain knowledge of what kind of world God has created only by investigating the world empirically.[41]

[39] Ibid., p. 139.
[40] Ibid., p. 9.
[41] Jan Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997) p. 190.

Such a view of the created world could well give rise to Boyle's belief in the importance of a scientific method grounded in experience, since, for him, '... *a priori* insight into the structure of nature is not possible since there exists no intrinsic relations along physical phenomena'.[42]

When Boyle went about arriving at a suitable and appropriate model for his experimental system he '... showed a clear preference for the Baconian way of experiment. It supplies, he believes, the best means of discovering truths about nature'.[43] Superb experimenter that he was, Boyle was far more than a 'sooty empirick' concerned only with practical demonstrations of age old principles: his Corpuscularian Philosophy was arrived at rationally through a consideration of earlier particulate theories. The operational if not ontological status of the corpuscles is stressed by Meinel, who says that Boyle admitted that there was little systemic connection between empirical facts and the corpuscular philosophy.[44]

Even though Boyle did attempt to employ the Mechanical Philosophy to explain various physical phenomena, he could not convincingly describe all mechanical effects.[45] Although it must be said that our contemporary understanding of matter, which sees contact action as not always necessary, with, for example, electrical forces playing an

---

[42] J.E. McGuire, 'Boyle's Conception of Nature', *Journal of the History of Ideas*, Vol. 33, No. 4 (1972) 523-542, p. 528.
[43] Rose-Mary Sargent, *The Diffident Naturalist* (University of Chicago Press, 1995) p. 35.
[44] Christoph Meinel, 'Early Seventeenth-Century Atomism: Theory, Epistemology, and the Insufficiency of Experiment', *Isis*, Vol. 79, No. 1 (1988) 68-103, p. 70.
[45] See, for example: Alan Chalmers 'The Lack of Excellency of Boyle's Mechanical Philosophy', *Studies in the History of Philosophy of Science*, Part A, Vol. 24, Issue 4 (1993) 541-564.

important rôle in the behaviour and functioning of matter at the atomic level. Such forces were almost unknown in Boyle's time.

MacIntosh argues that Boyle thought of his experiments as being *ultimately* confirmatory of the corpuscular hypothesis, but he was more interested in the experimental result itself. [MacIntosh's italics]. Macintosh holds that one reason for this was Boyle's dubiety, shared by many of the leading thinkers of his day, concerning the possibility of ever knowing the actual inner structure of things. He goes on to say that Boyle was not an ontological anti-realist, but he was an epistemological anti-realist: in the seventeenth century little was known about *actual* structure of the supposed *minima naturalia*, and there was little optimism about coming to know this structure. [MacIntosh's italics].[46] And here too Boyle was at an epistemic disadvantage *vis-à-vis* his Aristotelian adversaries because as McMullin points out: 'it was not until the time of Galileo and Boyle that the notion, *element* (unlike *matter* or *principle*) demanded a different sort of analysis than the philosopher could provide, and one that could not rest on distinctions of sense-quality'.[47] [McMullin's italics].

Reason gave Boyle his Corpuscularian Hypothesis, but its working out in his laboratory called on his considerable skills and resources as experimenter, and although he considered *autopsia* as the surest way of obtaining experimental information, he frequently had to resort to reliable authorities for such information. Hooykaas argues that for Boyle, whenever reason and experience clash, experience wins out, for in the end his

[46] J.J. MacIntosh, 'Robert Boyle's Epistemology: The Interaction between Scientific and Religious Knowledge', *International Studies in the Philosophy of Science*, Vol. 6, No. 2 (1992) 91-121, p. 105.

[47] E. McMullin (ed.) *The Concept of Matter in Greek and Medieval Philosophy* (University of Notre Dame Press, 1963) p. 183.

science is an experimental science, and, whatever the merits of his 'Corpuscularian Philosophy' it is the experimental nature of his science that imposes limits on reason for him.[48]

Yet human reason itself is limited by its Divine Creator, with Wojcik stating that Boyle believed that God created the world as His infinite intellect thought fit, with human understanding left to speculate about the world as best it could.[49]

IV. Boyle's Use of Language

Boyle had a famously prolix style of writing; his inability to bring a sentence to a conclusion being familiar to those who take on the task of reading and understanding his voluminous writings. An apposite opinion in this regard is expressed by Hooykaas, who says: 'The long-winded titles of his [Boyle's] works makes one fear for the worst for their content'.[50]

Boyle's spellings are another matter. He is quite capable of spelling the same word in two different ways on the same page. In any event they frequently differ from modern spellings. Editors adopt different strategies in dealing with this – some reproduce Boyle's own spellings: others modernise them.

---

[48] R. Hooykaas, *Robert Boyle [A Study in Science and Christian Belief]* (University Press of America, 1997) p. 26.
[49] Jan Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997) p. 180.
[50] R. Hooykaas, *Robert Boyle [A Study in Science and Christian Belief]* (University Press of America, 1997) p. 12.

In the present work, quotations from Boyle are given as they occur in the particular edition of the work from which they are taken, Stewart, for example, modernises Boyle's spellings as the situation warrants, whereas the Dover edition of *The Sceptical Chymist* reproduces the 1661 edition of that work. Consequently, some of the quotations from Boyle give his own spellings, others have modernised ones.

V. Chapter Summaries:

Chapter 1 Literature Review

A comprehensive literature review is presented in which the interpretations of some twenty-three authors on Boyle's understanding of the elements are quoted and evaluated. The authors in question vary from those wishing to present an account of Boyle as 'the Father of Chemistry' to young readers new to the study of science, to works on the history of chemistry, to Boyle's writings on Natural Philosophy. The works surveyed cover a time-span from 1902; Duhem, to 2002; Duddy. Some of the writers are scientists, such as Duhem, Kuhn, Partington and Brock, some are historians of science including Boas, Hall, Multhauf and Hooykaas, others still are philosophers – Copleston, Alexander, Sargent and Duddy.

As one might expect from a wide variety of authors, the breadth of interpretations offered on the subject of Boyle on the elements is substantial. In fact there seems little agreement on what Boyle understood by the elements, due as much perhaps to reading him in the light of our contemporary understanding of science rather than making an effort to interpret him and his works strictly in terms of his own time. Boyle, as a central figure in the development of science, is apt to have his work so much incorporated into the very structure of how matter is conceived of that it may sometimes be overlooked that in his own time he was a figure struggling to promote a new scientific account of the world. In fairness too to some of the contributors of opinions on Boyle's understanding of the elements, some of these are probably meant to present him in the wider context of his contribution to scientific knowledge and not just for his insights on the elements.

Chapter 2 Boyle on Matter

Boyle hypothesised that all matter existed originally as universal- or prime-matter, which came to be corpuscularised through divine agency. The corpuscles – which Boyle held to be equivalent to atoms – differ from one another in size, figure and shape. Boyle speculated as to the origins of the universal matter, and argued that the Book of Genesis, as well as other sources, claimed water as the primal matter.

Water's rôle for Boyle went beyond that of brute matter: he also considered – based on his own experiments on plants, and van Helmont's in growing a willow tree – that water might be the prime element, and which could transmute into other elements, as water comes to be converted into plant tissue and wood. Yet Boyle is not completely at ease with the opinion that growing things convert water into plant tissue or its woody counterpart.

Boyle's theory of matter was based on his Corpuscularian Philosophy, and any account of his natural philosophy which deals with sensible entities must take account of his understanding of matter. Boyle's definitions of the elements (discussed in Chapter 3) leave no doubt that he defined them in material terms, employing terms such as 'simple', 'primitive bodies'. So before setting out to investigate what he meant by these terms as they relate to the elements, it was deemed necessary to discover what he meant by these same terms in relation to his general theory of matter. Boyle considered matter as consisting of corpuscles or atoms but also of other, perhaps smaller, simpler or less active entities. These are the *minima* or *prima naturalia*, whose names imply their identity as the smallest, most primitive particles of matter that can exist.

Initially Boyle seems to have considered the atoms as indivisible, though later came to accept them as capable of division in certain circumstances. Then he raises the intriguing possibilities on the nature of the materials from which the corpuscles are made. If the prime matter is itself liquid, as we commonly understand the term, would the corpuscles divided off from it themselves be divisible, as drops of liquid are capable of subdivision into even smaller droplets?

Boyle believes that in certain chemical reactions corpuscles fragment and become active chemical species by separating the corpuscles with which certain bodies are made up. In seeing fragments of corpuscles as participating in some chemical reactions, Boyle is showing that another class of materials – more minute than corpuscles, *minima* or *prima naturalia* – may also serve as active material species, and bring about corpuscular rearrangement, without themselves being considered as elemental.

Chapter 3 Boyle and the Elements – I

Chapter 3 deals with Boyle on the elements proper, and is divided into two parts: Boyle's definitions of the elements in which he formulates different definitions; then goes on to examine experimental evidence for them.

Four definitions are put forward, each one seeming to represent a different stage in the development of Boyle's thinking on the matter, culminating in his fourth and final definition in which the elements are expressed as 'small', 'primitive bodies'. Boyle then seeks to examine whether such bodies actually occur in nature. Various accounts are given of the production of materials, both animal and mineral, occurring in the natural world, most coming from authorities other than Boyle himself. The thrust of these accounts is that transmutation is occurring from water to other materials, from water to earth, and from earth to metals. In giving reliable examples of the production of various materials through a mechanism of transmutation, Boyle is offering experimental evidence for the formation of an array of products, and attempts to make sense of these as occurring through the transformation of water into other materials. This time the plant and tree growing experiments of Boyle and van Helmont are extended to accounts of a range of materials carried out, or at least observed by a wide variety of commentators, from classical times to Boyle's own, to Boyle himself as experimenter.

Chapter 4 Boyle and the Elements – II

Chapter 4 is a continuation of Chapter 3. One of the central theses of this chapter is the connection between the elements and Boyle's Corpuscularian Philosophy. The question of the corpuscularisation of the prime matter and the subsequent appearance of other materials is considered. Water and earth as produced at the Creation – did these materials precede the production of corpuscularised materials?

Given that the elements have always enjoyed an epistemic reality, going back as far as the ancient Greeks, did Boyle's conception of the elements see them as having ontological reality as well?

Boyle considers reliable sources of information on the elements, their various methods of experimentation for revealing the elements, including the universal solvent or *alkahest* of van Helmont, and decomposition by the fire. He also realises that decomposition may reduce bodies to a level below that of the elements.

What Boyle considers as elements is considered, as apart from the standard lists of the elements current in Boyle's day, other entities too might be considered as elements.

Boyle made use of the concept of primary and secondary qualities of matter as a means of distinguishing between the properties inherent in matter and those which are not so. Might the elements be considered as primary qualities of matter? Might they have primary qualities attributed to them? Could weight, which is not considered as a primary quality by Boyle, actually be considered as such in the Boylean scheme of things, and might weight also be considered as a primary quality of the elements? The question of the identity of the elements in relation to their subsistence as individual entities is also considered.

Finally, how the elements came to be understood after Boyle's time is considered, with the contribution of Lavoisier, in particular, discussed.

BIBLIOGRAPHY TO INTRODUCTION

Boas, Marie, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958).

Boas, Marie, 'The Establishment of the Mechanical Philosophy', *Osiris*, Vol. 10 (1952) 412-541.

Boyle Robert, *A Free Enquiry into the Vulgarly Received Notion of Nature*, B. Davis and M. Hunter (eds) (Cambridge University Press, 1996).

Burns, D. Thorburn, 'Robert Boyle (1627-1691): A Foundation Stone of Analytical Chemistry in the British Isles, Part 1', *Anal. Proc*. May 1982, 224-233.

Burns, D. Thorburn, 'The London of Robert Boyle', at http://www.bbk.ac.uk/boyle/*ThorburnBurns*.htm. (Consulted 15/06/09).

Chalmers, Alan, 'The Lack of Excellency of Boyle's Mechanical Philosophy', *Studies in the History and Philosophy of Science*, Part A, Vol. 24, Issue, 4 (1993) 541-564.

Clericuzio, Antonio, 'A Redefinition of Boyle's Chemistry and Corpuscular Philosophy', *Annals of Science*, Vol. 47, (1990) 561-589.

Clericuzio, Antonio, 'From van Helmont to Boyle. A Study of the Transmission of Helmontian Chemical and Medical Theories in Seventeenth-Century England', *The British Journal for the History of Science*, Vol. 26, No. 3 (1993) 303-334.

Cook, Margaret G., 'Divine Artifice and Natural Mechanism: Robert Boyle's Mechanical Philosophy of Nature', *Osiris*, 2nd series, Vol. 16 (2001) 133-150.

Dennehy, Myriam, and Ramond, Charles, *La Philosophie Naturelle de Robert Boyle* (Paris: Vrin, 2009).

Disksterhuis, E.J., *The Mechanization of the World Picture* (Oxford University Press [1961] 1969).

Hooykaas, Reijer, *Robert Boyle [A Study in Science and Christian Belief]* (University Press of America, 1997).

Hooykaas, Reijer, *The Concept of Element: Its Historical-Philosophical Development* (Utrecht, 1933) [Doctoral Dissertation] trans. Kubbinga, H.H. (1983).

Hunter, Michael, *Boyle* (Yale University Press, 2001).

Hunter, Michael, (ed.) *Robert Boyle Reconsidered* (Cambridge University Press, 1994).

Keller, F.J., Gettys, W.E., and Skove, M.J., *Physics Classical and Modern*, 2nd edn. (New York: McGraw-Hill, Inc., 1993).

Lüthy, C., Murdoch, J.E., and Newman, R.W., (eds) *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: Brill, 2001).

Maddison, R.E.W., *The Life of the Honourable Robert Boyle* (London: Taylor & Francis, 1969).

MacIntosh, J.J., 'Robert Boyle's Epistemology: The Interaction Between Scientific and Religious Knowledge', *International Studies in the Philosophy of Science*, Vol. 6, No. 2 (1992) 91-121.

MacIntosh, J.J. *The Excellencies of Robert Boyle* (Peterborough, Ontario: Broadview Editions, 2008).

McGuire, J.E., 'Boyle's Conception of Nature', *Journal of the History of Ideas*, Vol. 33, No. 4 (1972) 523-542.

McMullin, Ernan, (ed.) *The Concept of Matter in Greek and Medieval Philosophy* (University of Notre Dame Press, 1963).

Meinel, Christoph, 'Early Seventeenth-Century Atomism: Theory, Epistemology, and the Insufficiency of Experiment', *Isis*, Vol. 79, No. 1 (1988) 68-103.

More, Louis Trenchard, *The Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944).

Newman, William R., *Promethean Ambitions* (University of Chicago, [2004] 2005).

Newman, William R., 'The Alchemical Sources of Robert Boyle's Corpuscular Theory', *Annals of Science*, 53 (1996) 567-585.

Pilkington, Roger, *Robert Boyle Father of Chemistry* (London: John Murray, 1959).

Principe, Lawrence M., *The Aspiring Adept* (Princeton University Press, 1998).

Sargent, Rose-Mary, *The Diffident Naturalist* (University of Chicago Press, 1995).

Shanahan, Timothy, 'God and Nature in the Thought of Robert Boyle', *Journal of the History of Philosophy*, Vol. 26, No. 4, (1988) 547-569.

Stewart, M.A., *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991).

Wojcik, Jan, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997).

Zaterka, Luciana, 'Os Limites do Projeto Epistemológico de Robert Boyle: As Verdades Acima da Razão', *Cadernos de Historia e Filosofia da Ciência*, Campinas, Série 3,Vol. 12, Nos. 1-2, (2002) 209-223.

http://royalsociety.org/nullius-in-verba/ (Consulted, 10/06/10).

Chapter 1

Literature Review

Table of Contents

Chapter 1

Literature Review

1.1. Introduction to Chapter 1

Various authors have given their interpretations of Boyle's writings on the elements. The scope of the undertakings of these writers encompasses a wide range, from popular books on Boyle, whose aim seems to be to introduce 'the Father of Chemistry' to a young readership, to serious works on the history of chemistry, to scholarly works on Boyle's contribution to natural philosophy. Consequently, the interpretations offered as to Boyle's doctrine on the elements vary widely both in their understanding of Boyle's definitions and in the depth of analysis expressed.

This literature review has followed the pattern sketched above. The first two works, by Allen and Sootin, provide general introductions to the life and work of Robert Boyle, written in a serious style, but intended for a young readership, especially those who are new to the study of science. The next two works – those of Lehmann and Leicester – treat of Boyle's contribution to the unfolding understanding of matter, which eventually led to our contemporary insights into the nature and arrangement of the elements.

These are followed by six works, those from Leicester to Brock, which are concerned with the history of chemistry, and in which Boyle's contribution to the development of the modern science of chemistry is explored. The next three works, by Hall, Moran, and More, deal with Boyle's rôle in the Scientific Revolution, and in particular the part he played in the emergence of chemistry from alchemy. More, Kuhn, Boas, and Hooykaas provide the next four works, all of whom are Boylean scholars offering detailed analyses of Boyle's doctrine on the elements. The next three – by Pattison Muir, Davis, and Duhem – all scholars of the history or philosophy of science, investigate in some detail selected aspects of Boyle's writings, including his work on the elements.

Finally, four philosophers, from Copleston to Alexander, who change the perspective on Boyle and consider aspects of his theory of matter, including the elements, from a philosophical viewpoint.

The literature review presented here is intended as comprehensive rather than selective. There exists quite an extensive literature on Boyle, going back to his own autobiographical account of his early life.[51] Not all of these works concern themselves with his writings on the elements, but every attempt has been made to locate those works in which he does. The earliest work surveyed is that of Duhem, dating from 1902, by which time a definition of the elements substantially the same as that in use today had been established; the latest, that of Duddy, dates from 2002.

1.2. Allen, John, *Robert Boyle Father of Chemistry*[52]

Allen gives Boyle's definition of element as[53]:

[51]Michael Hunter (ed.) *Robert Boyle by Himself and His Friends* (London: Pickering, 1994) pp. 1-25.
[52] John Allen, *Robert Boyle Father of Chemistry* (Detroit: Thomson Gale, 2005) p. 48.

> ‘I now mean by elements, as those chymists that speak plainest do by their principles, certain primitive and simple, or perfectly unmingled bodies; which not being made of other bodies; or of one another, are the ingredients of which all those perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved.’[54]

Allen says that, in other words, an element was something that was not a compound or mixture of other substances, but that any given substance that could be broken down by chemical means was not an element. This analysis reiterates Boyle’s definition of an element as simple and unmixed; however it goes beyond Boyle’s definition in stating that an element could not be broken down by chemical means. This particular distinction only developed a hundred years or so after Boyle’s time, and was made by Lavoisier. Allen goes on to say that only by experimenting could one determine if something was an element, but he does not specify where exactly Boyle says this. Allen continues that Boyle played down the importance of his statement, even referring to it as ‘laboriously useless’, but that many would say that his definition was the starting point of modern chemistry.

It could be argued that Boyle did not so much play down the importance of his definition as to say that it was one thing to define something and quite another to adduce experimental evidence to back up the definition. That this definition was said by many to be the starting point of modern chemistry is debatable as Boyle’s actual experiments in chemistry might better mark the beginnings of the modern science of chemistry, with its

---

[53] This is Boyle’s most famous definition of the term element, given by him on p.187 of *The Sceptical Chymist*, and is the one most quoted in the literature. It is discussed in Ch. 3, where it is called ‘Definition no. 4’. It will hereafter be referred to under this title whenever it appears in this literature review.
[54] Ibid., p. 48.

twin emphasis on the rational and the experimental approach to the investigation of matter and its behaviour.

1.3. Sootin, Harry, *Robert Boyle Founder of Modern Chemistry*[55]

Another popular book on Robert Boyle begins the examination of the subject of Boyle on the elements by quoting what Boyle had to say on what an element was not:

> 'I … must not look upon any body as a true principle or element, but as yet compounded, which is not perfectly homogeneous, but is further resolvable into any number of distinct substances, how small soever.'[56]

Sootin takes this to mean that it depends on the number of ingredients in a substance; if there are more than one, the substance must be a *compound* [Sootin's italics] or mixture, but definitely not an element.

This definition of what an element is not is based on the rational assumption that if a body is found to consist of more than one ingredient then it is not a simple body. Boyle's problem lay in determining *experimentally* evidence which could validate a body's simplicity. If a body could not be decomposed into simpler ones it provided evidence that it was a simple body or element.

Sootin goes on to give Boyle's definition of an element as his Definition no. 4:

He says that Boyle with typical honesty admitted that he was not certain how many elements there were in the world. This is true enough, but it is not so much Boyle's honesty that leads him to say this but rather a limitation placed on him by the

[55] Harry Sootin, *Robert Boyle Founder of Modern Chemistry* (London: Chatto & Windus, 1963) pp. 82-83.
[56] Ibid., p. 82.

experimental tools available to him, for Boyle himself says that there is not 'any one determinate number into which the fire (as it is wont to be employed) does precisely and universally resolve all compound bodies whatsoever'.[57]

Sootin also says that Boyle suspected that air was a mixture of various gases, or *effluviums* [Sootin's italics]. This is true enough, although Boyle did not state that these gases might be elements. Sootin goes on to say that Boyle suggested that gold and silver might well be elements, since countless experiments had failed to alter either of these metals in any way. This is hardly the case, as Boyle describes experiments in which silver can be dissolved by *aqua fortis* [nitric acid] and gold by *aqua regia* [nitric and hydrochloric acids mixed] and silver and gold compounds, respectively, thereby produced. However, Sootin does emphasise Boyle's approach to his analysis of the elements as pointing the way towards the use of analytical techniques in determining the elemental nature of certain substances, which followed in later centuries.

1.4. Strathern, Paul, *Mendeleyev's Dream*[58]

Strathern says that Boyle asserts that elements are primary particles, and gives his [Boyle's] definition of element as his Definition no.4:

Strathern says that, in other words, any substance which could not be broken down into a simpler substance was an element. One could hardly find fault with this analysis as it merely reiterates what is stated in the definition itself. He goes on to say that here for the first time is an understanding of the element which matches the idea we have today. This

[57] *Sceptical Chymist*, p. 228.
[58] Paul Strathern, *Mendeleyev's Dream* (New York: Thomas Dunne Books, 2000) p. 178.

is disputed as both Hooykaas and Boas accord this distinction to de Clave's definition of 1641. As to Boyle's asserting that elements are primary particles, this is not the case, for the primary particles to Boyle were the corpuscles, *prima naturalia* and *minima*: none of which he considered as elements.

Strathern goes on to say that Boyle went on to make a fundamental distinction: these elements could combine together in groups or clusters to form a compound. He gives as an example iron which when dissolved in an acid and give rise to a compound salt, this was a stable substance, yet it could also be broken down and the iron recovered.

What Strathern says here is true insofar as it refers to how our contemporary understanding of the elements involves their ability to react together to form compounds, which can then be decomposed and the original elements recovered. However, Boyle did not share our understanding, as he had not yet decided which substances were elemental and which were not. He never said that iron, gold or silver were actually elemental.

Strathern also states that Boyle concluded that all these compound substances depended for their properties upon the number and position of the elements they contained, that this description is uncannily accurate, and was the flash of insight which would later lead to molecular theory.

Again, these unreferenced statements show Boyle as having much the same understanding of the elements as we have today. This is disputable, as when Boyle spoke of materials in combination he did so in terms of clusters or combinations of corpuscles, but never actually specified how these entities relate to elements or compounds as we now understand these terms.

In fairness to Strathern, he is writing a general survey of the elements, and is attempting to place Boyle's contribution to chemistry, and in particular to his understanding of the elements, in the overall context of the discovery of the elements.

1.5. Lehmann, Walter, J., *Atomic and Molecular Structure: The Development of Our Concepts*[59]

Lehmann states that perhaps Boyle's most far-reaching contribution was his redefinition of the word 'element', and that, according to Boyle: 'An element is a substance that is not made up of other substances'; non-elemental substances are composed of two or more elements and can be decomposed into these elements. He says that Boyle went on to show that the four 'elements' of the Greeks (earth, air, fire and water) were not elements in the sense of his definition, and that he did this by demonstrating that these substances could be converted into each other; therefore, they were not 'elemental'. For example, he converted water into 'earth' (in the form of plants), and he generated 'air' (gas) from 'earth' (iron) by the action of acid. Lehmann says that Boyle could thus use his definition to demonstrate experimentally that a given substance is *not* an element, but that his definition did not explicitly provide a positive test for telling whether a given substance *is* an element. [Lehmann's italics]

[59] Walter J. Lehmann, *Atomic and Molecular Structure: The Development of Our Concepts* (New York: John Wiley and Sons Inc., 1972) p. 5.

As already noted (in 1.4.) Hooykaas and Boas have stated that the first modern definition of element comes from de Clave, in 1641, and not Boyle as Lehmann would have us believe. Lehmann does, however, neatly paraphrase Boyle's definition of element, but it is not the case that he [Boyle] had a clear definition of which substances were or were not elements, simply because Boyle, as Lehmann notes, did have a definition of element but did not have a fixed list of them, and lacking this could not say with any certainty what was or was not an element.

What Lehmann does correctly point out is that Boyle's definition of element required to be qualified as to how far the reduction of an element could go before it would no longer simply be elemental, but something at an even simpler level, such as the corpuscular, by saying that an element could be better defined as: 'a substance that cannot be broken down by chemical means into two or more other substances'. We call this an 'operational definition' Lehmann says, and he is presenting Boyle as an early modern chemist who was beginning to understand the elements as we do today. Although this is perhaps a useful way to portray the rôle of Boyle as a pivotal figure in the development of the concept of element, that is to say Boyle as the first one to glimpse a definition of element as the term came later to be understood. Nevertheless, Boyle's understanding of the elements as simple substances did not entail his being able to tell whether a given body was indeed an element, as Lehmann seems to believe.

1.6. Leicester, Henry M., *The Historical Background of Chemistry*[60]

[60] Henry M. Leicester, *The Historical Background of Chemistry* (New York: Dover Publications Inc., 1956) pp. 115-6.

Leicester says that although Boyle conceived of matter as entirely corpuscular, his ideas of elements were not at all modern, and that he gave a definition of an element in *The Sceptical Chymist* that has often been quoted as a forerunner of the ideas of Lavoisier, and goes on to quote Boyle's Definition no. 4.

Leicester goes on to say that Boyle did not believe in the elements in our sense of the word, and that to him the aggregates of the ultimate particles made up most known substances which could therefore be transmuted into almost any other substance by a rearrangement of the particles.

Leicester is correct in grasping that Boyle did not share our modern conception of the elements, and that his definition was built upon later by Lavoisier. Boyle did indeed believe in transmutation, but could only provide real experimental evidence of it in the transmutation of water into earth, in the growth of plants and trees, and in the growth, as he understands it, of iron ore on the island of Elba. From the last-named account Boyle says that 'we may deduce that earth, by a metalline plastick principle latent in it, may be in processe of time changed into a metal'.[61] He may also have viewed transmutation as a process of rearranging the ultimate particles, by which Leicester probably meant corpuscles, and by which most known substances could be changed into almost any other, but if he did, he never actually expressed any mechanism by which the corpuscles of matter could be related to the transmutation of one substance into another.

[61] *Sceptical Chymist*, p. 191.

Leicester also states that Boyle, believing as he did in the process of transmutation, was interested in transmuting gold, not for alchemical reasons, but to prove his corpuscular theory. It is true that Boyle did believe in the possibility of the transmutation of base metal into gold, and actually petitioned to have the law against this process repealed.[62] He did not, as Leicester says, believe in the transmutation of gold: what he actually believed in was the degradation of gold, and recounts how, using a *menstruum* [solvent] of 'so piercing and powerful a quality' he had with it 'destroyed even refined gold, and brought it into a metalline body of another colour and nature'.[63]

1.7. Stillman, John Maxson, *The Story of Alchemy and Early Chemistry*[64]

Stillman says that Boyle held the possibility of the existence of substances that might properly be called elements, though in his extended discussion of the problems he does not venture to assert that any known substance can safely be asserted to be such an element, though he knows, for example, no fact that would prove that gold, for instance, might as well be called an element as anything else.

Stillman is correct in his statement that Boyle did believe in the possibility of the existence of actual entities which could be called elements, and is also correct in saying that Boyle was not wiling to assert that any particular substance could be called an element. However, in stating that Boyle knew no fact that would prove that gold might not as well be called an element as anything else, Boyle did not say this. He did say that

---

[62] R.E.W. Maddison, *The Life of the Honourable Robert Boyle F.R.S.* (London: Taylor & Frances, 1969) p. 176.
[63] *Sceptical Chymist*, pp. 215-6.
[64] John Maxson Stillman, *The Story of Alchemy and Early Chemistry* (New York: Dover Publications Inc., 1924) pp. 396-7.

gold was very ‘fixt’ or unreactive, and made the following reference to gold’s not being an element: ‘the corpuscles of gold and mercury, though they be not primary concretions of the most minute particles of matter, but confessedly mixt bodies’.[65] Both gold and mercury, to Boyle, consist of compound and not elemental bodies. He also refers to the degradation of gold by means of a powerful *menstruum* or solvent, with which Boyle ‘destroyed even refined gold’,[66] and as discussed in 1.6. in relation to Leicester.

Taking the above example in another way: when Stillman says that ‘he [Boyle] knows, for example, no fact that would prove that gold, for instance, might not as well be called an element as anything else’,[67] it may well be that the ‘for example’ and ‘for instance’ arise from Stillman rather than Boyle, and that the former simply chose gold as an example to illustrate an argument that Boyle *might* have made. If this is the case then Stillman seems to be saying that Boyle knows no fact capable of establishing gold as an element rather than as some other kind of entity, such as a compounded body or ‘mixt’. Boyle could not point to some defining mark of gold, be it a property of this metal, a defining characteristic or a quality of some kind, which this material lacks and disallows one from considering gold as an element. In fact Boyle could never apply any one criterion which would establish the actual status of gold and locate it in its proper place among material things. The best he could do was declare certain substances as ‘mixts’ or compounds because they could be broken down experimentally, either by the fire or a *menstruum* or solvent. He was not confident to argue the opposite: a substance cannot be broken down, therefore it is an element. Boyle, as experimenter, realised two important

[65] *Sceptical Chymist*, p. 32.
[66] Ibid., p. 215.
[67] Op. cit., p. 397.

facts about the behaviour of materials: some were unreactive or 'fixt', which meant that a non-elemental substance might not easily be broken down, not because it was elemental, but because it was unreactive and not amenable to decomposition, and some materials could be broken down by the action of a powerful *menstruum* or solvent. However, he did not know the limiting power of such solvents, and forever sought new, more powerful ones. He thereby understood that an unreactive non-element might not be broken down, and a substance hitherto believed to be elemental could be broken down by a newly-discovered, powerful *menstruum* or solvent. The experimental processes available to Boyle prevented him from establishing absolute criteria in relation to whether a given substance was an element.

1.8. Multhauf, Robert P., *The Origins of Chemistry*[68]

Multhauf says that in the light of his own subsequent works, we must assume that Boyle's conclusion, in *The Sceptical Chymist*, that we do not know what the elements of bodies may be, carried the implication that it does not much matter. He continues that like Becher, [1635-82] Boyle and most chemists after him, was principally interested in the constitution and interrelationship of compounds.

What Multhauf says here is rather harsh towards Boyle, who did indeed concern himself deeply with understanding the origin, nature, and behaviour of matter, but in addition sought justification and validation for any assertion made on the subject of matter, and also of the elements. And rather than being apathetic or disinterested in the existence of the elements, Boyle was concerned with arriving at experimental evidence for them. For

[68] Robert P. Multhauf, *The Origins of Chemistry* (London: Oldbourne, 1966) p. 278.

Boyle says that the 'objections I made against the quaternary of elements and ternary of principles' needed not to be opposed so much against the doctrines themselves as against 'the unaccurateness and the unconcludingness of the analytical experiments vulgarly relied on to demonstrate them'.[69] Boyle would be quite prepared to consider the validity of the doctrine of the four elements of the Aristotelians, or the *tria prima* of the Paracelsians, but there simply was no experimentally rigorous evidence applied by their proponents in support of their hypotheses.

That Boyle was interested in the composition and interrelationships of compounds is without doubt, but he also saw these as part of a larger scheme of things. He conceived of material entities as deriving from the universal matter, divided into corpuscles and imbued with motion. These 'minute particles' came together with neighbouring ones and 'associated into minute masses or clusters' which 'primary concretions or masses' were not 'easily dissipable into such particles as composed them'.[70] These 'mixt bodies' when subjected to decomposition by the fire, yield 'a determinate number' – but exactly how many he does not know – 'of substances'. These substances which 'concretes generally afford or are mode up of' may be called 'the elements or principles of them.'[71]

So for Boyle, in advancing from corpuscles in motion to 'mixt body' or 'concrete' [chemical compound] there was an intermediate stage of aggregation of matter which he identified as a collection of 'distinct substances[72] or the elements.

[69] *Sceptical Chymist*, p. 230.
[70] Ibid., pp. 30-31.
[71] Ibid., p. 34.
[72] Ibid., p. 34.

Multhauf is correct in stating that Boyle, as a practical chemist, was principally interested in how these larger entities, the chemical compounds, formed and behaved, as much of the chemists' work concerns itself with these matters. Boyle was, however, interested in discovering the link between these materials and the more primary ones; hence his quest for the elements.

1.9. Partington, James Riddick, *A Short History of Chemistry*[73]

Partington gives Boyle's definition of the elements as his Definition no.4.

Partington goes on to say that by 'perfectly mixt bodies' Boyle means chemical compounds, as distinguished from mechanical mixtures. Also, 'elements and principles' mean 'those primitive and simple bodies of which the mixt ones are said to be composed, and into which they are ultimately resolved'. Boyle, he says, argues at some length that the action of fire upon bodies, previously used as a method of resolution into elements, is unsatisfactory for this purpose.

What Partington seems to be referring to is Boyle's saying that to make the 'reasoning' of the Aristotelians 'correct' 'it must be first proved, that the fire does not only take the elementary ingredients asunder without otherwise altering them.'[74] Boyle reinforces his argument with an example in which it is obvious that bodies 'may afford substances

[73] James Riddick Partington, *A Short History of Chemistry* (New York: Dover Publications, Inc., 1987) pp. 70-71.
[74] *Sceptical Chymist*, p. 24.

which were not pre-existent in them',[75] and says that meat which has been stored too long produces maggots, and old cheese, mites.

Boyle as a skilled experimenter perceives a problem which will continue to dog science long after his time: how does one know that the analytical tools brought to bear in the examination of a particular system may not themselves interact with the system in such a way that they distort, affect, combine, or otherwise interfere with the system? Boyle tried to cope with this difficulty by modifying the way in which the analytical tool was employed; in the case of fire varying the manner in which it was employed. He did not always exploit 'the great violence of the refiner's fire',[76] meaning that this would be a large-scale fire, in fact a furnace, but in the case of 'distilling man's blood', he still carried out this 'analysis by fire', only this time the reactants were heated in closed glass retorts by a more modest fire which caused the various liquid fractions to distil over.'[77]

Partington continues that Boyle was not as clear and dogmatic in his discussion of the chemical elements as could have been wished for his time, and that he still seemed to regard the different elements as being made up of some primary matter. He also says that Boyle held that the varying properties of the elements might be due to the different shapes and motions of the particles of the primary matter.

It could be argued that there was an excess of 'clarity' and 'dogmaticism' among Boyle's adversaries who adhered to the Aristotelian and Paracelsian doctrine of the elements, but

[75] Ibid., p. 25.
[76] Ibid., p. 25.
[77] Ibid., p. 27.

that these beliefs stemmed from a *rational* understanding of the elements. Boyle speaks of the Aristotelians who ‘have not been very solicitous to gather experiments to prove their doctrines’ and are content with a few only, carried out in order ‘to satisfy those that are not capable of a nobler conviction.’[78]

The ‘nobler conviction’ being referred to here of course means being persuaded by a rational argument regarding the composition of material things, rather than one based on experiment. And as Boyle came to understand as his laboratory work progressed, finding convincing experimental evidence, which would enable him to formulate a sound theory on the elements, proved a difficult undertaking.

Boyle, in holding a theory of matter which viewed the universal matter present at Creation as converted into corpuscles or ‘little particles of several sizes and shapes’ meant that all substances, including the elements, would have to share in this corpuscular nature, and all the properties of materials, Boyle believed, derived from the corpuscles ‘variously moved’.[79]

Although Partington seems to express surprise that Boyle should still regard the elements as being composed of some primary matter, there really was no other material in Boyle’s scheme of things from which they might be made.

[78] Ibid., p. 20.
[79] Ibid., p. 30.

Partington goes on to say that if Boyle had made up a table of bodies which he regarded as satisfying his definition of an element, such as gold, copper, and sulphur, some chemists would no doubt have followed him, but that he left the matter in too indefinite a form, and nowhere says what he considered to be elements.

This is an easy argument for Partington to make. The trouble is, he has already identified at least one reason why Boyle could not decide why some of the substances we now consider as elements were not so considered by him. Partington lists gold as one of the substances that Boyle could have identified as an element, but he has already quoted Boyle as saying that gold and mercury were not elements, when he says that 'though they may not be primary concretions of the most minute particles of matter', rather they were 'confessedly mixt bodies'.[80]

For Boyle to have drawn up a table of the substances he considered as elements, would have required of him to be much closer to us in his thinking than he actually was. Despite his definition of an element being quite close to the one in use in our own time, in some respects, Boyle, in common with his adversaries, devoted much of the effort he put into the study of the elements in analysing and identifying the elements as the decomposition products from the breakdown of organic materials. Such materials do not yield metallic elements – simply because they do not contain them. In the case of plant materials, Boyle thought that the element from which all of them were produced was water. When he analysed mineral substances he did realise that some of them at least would yield a metal and sulphur, yet he was slow to accept these as elements, saying that

[80] J.R. Partington, *A Short History of Chemistry*, p. 70.

it does not seem necessary 'that nature should make up all metals and other minerals of pre-existent salt, and sulphur, and mercury, though such bodies might by fire be obtained from it'.[81]

Partington is correct in saying that Boyle left the matter of the elements in too indefinite a form for him to attract followers, but Boyle did strive to investigate the elements and to base his findings on an experimental foundation. This approach did bear fruit though not until about a hundred years after Boyle's time, in Lavoisier's table of the elements, which did include several metals.

1.10. Thorpe, Thomas Edward, *History of Chemistry*[82]

Thorpe says that Boyle was the first to formulate our present conception of an element in contradistinction to that of the Greeks and the Schoolmen who influenced the theories of the Iatro-Chemists. He says that in the sense understood by Boyle, the Aristotelian elements were not true elements, nor were the salt, sulphur and mercury of the Paracelsians.

Again, it is stated by Hooykaas, and by Boas Hall, that de Clave, in 1641, was the first one to give the 'first' modern definition of an element, rather than Boyle, as Thorpe states. Thorpe is correct in saying that in the sense understood by Boyle neither the four Aristotelian elements nor the *tria prima* of the Paracelsians were true elements. This is the argument made by Boyle in his *Sceptical Chymist*, and specifically against the

[81] *Sceptical Chymist*, p. 195.
[82] Thomas Edward Thorpe, *History of Chemistry* (London: Watts & Co., 1909) p. 59.

Paracelsians in *On the Imperfections of the Chymists' Doctrine of Qualities*. What Thorpe does not point out is that Boyle could not frame a better list of which bodies were elemental and ended up by affirming the *tria prima* as the decomposition products of many mineral bodies, and by naming two of the Aristotelian elements, earth and water, as resolution products of almost all living bodies.

Thorpe says that Boyle set out to prove that the number of the Aristotelian elements hitherto assumed by chemists was, to say the least, doubtful. He gives Boyle's definition of 'element' or 'principle' as:

> 'Those primitive and simple bodies of which compounds may be said to be composed, and into which these compounds are ultimately resolvable.'

He says that Boyle held that three is not precisely and universally the number of the distinct substances or elements into which all compound bodies are resolvable by fire, inasmuch as some bodies afford more than three principles, and that earth and water are as much chemical principles as salt, sulphur, and mercury.

What Thorpe says here of Boyle is indeed true, but he does not qualify this statement by saying that Boyle made a distinction between the decomposition products obtained from mineral bodies and those from living things. Boyle was happy to go along with the *tria prima* of salt, sulphur, and mercury for 'divers mineral bodies',[83] but he also says that he 'could never see any earth or water, properly so called, separated from either gold or silver'.[84] However, water (as phlegm) and earth are separable by the fire from 'almost all

[83] *Sceptical Chymist*, p. 228.
[84] Ibid., p. 197.

vegetable and animal concretes'.[85] As to the number of substances separable by the fire, Boyle held that three were separable from mineral bodies and five from plants and animals.

Thorpe goes on to say that according to Boyle, earth and water are as much chemical principles as are salt, sulphur and mercury, and that even the limitation to five chemical principles is too narrow. Such is proved to be the case by the mode in which bodies, animal and vegetable, grow, and by the analysis of minerals and metals.

Thorpe is quite right in saying that Boyle holds that earth and water are as much chemical principles as are salt, sulphur and mercury. For Boyle says that 'earth and water are elementary ingredients' though as has already been noted, 'not of mineral concretes.'[86] And on the question of the number of the chemical principles, although Boyle holds that living things could be separated by distillation into five elements, he does acknowledge that 'these principles, though they be not perfectly devoid of mixture' may be 'stiled the elements of compounded bodies.'[87] The obvious implication is that some or all of the elements might by some process be further divided into simpler ingredients, which might mean in turn that the number of the elements is greater than five. However, this comes to be known from the analysis of living things rather than of minerals. As to Thorpe's stating that this is proved to be the case by the mode in which bodies, animal and vegetable, grow: Boyle's own experiments, and van Helmont's, in the growing of plants

---

[85] Ibid., p. 228.
[86] Ibid., p. 204.
[87] Ibid., p. 229.

and a tree, inclined Boyle towards the belief that plant material was composed of one element only, viz. water.

1.11. Brock, William H., *The Norton History of Chemistry*.[88]

Brock gives Boyle's definition of the element as his Definition no.4:

He argues that Boyle may be said to have united the proto-disciplines of chemistry and physics, but that the partnership proved premature, for Boyle succumbed to the danger of not replacing the elements and principles of the chemists with a Mechanical Philosophy that was useful to the working chemist. Brock says that this criticism can be clearly made when discussing Boyle's definition of the element (i.e. the one given above) and says that following this definition Boyle went on to deny that the concept served any useful function, and gives the following quotation:

> '…..now whether there be any such body to be met with in all , and each, of those that are said to be elemented bodies, is the thing I now question.'

What Brock seems to be arguing is that Boyle in his Corpuscularian Hypothesis on matter may be said to have provided both a theory on the most fundamental material particles that can exist, with his *minima*, *prima naturalia*, and corpuscles, and thereby supply a theoretical foundation for the constitution of matter which would satisfy the physicists, but which also theorises that these same species participate in chemical reactions, thereby providing a theoretical underpinning to the fundamental particles as species possessed of chemical properties, and in so doing serve the chemists' requirements. If this is indeed what Boyle attempted then he did not completely succeed in applying the Mechanical

[88] William H Brock, *The Norton History of Chemistry* (New York: W.W. Norton & Co., 1993) pp. 68-69.

Philosophy to chemical reactions to such effect as to oust the traditional elements from the scheme.

However, it is not an easy matter to connect this criticism of Boyle with the quotation from him given by Brock (the second quotation given above) especially so, as in this quotation Boyle seems simply to be saying that he questions whether there is one particular element, ‘one such body’ present in all those materials which are supposed to be constituted of elements, ‘elemented bodies’. It is difficult to see how this can be interpreted as Boyle in any way doubting the existing of elements, *per se*, rather than his pondering whether a particular one is present in all such bodies.

Brock goes on to give a modern analogy which, he says, will make Boyle’s scepticism clear. If all matter is composed of sub-atomic particles, then the simplest of these should be, for Boyle, the ultimate level of analysis and explanation for the chemist, and not the so-called ‘elements’ that are deduced from chemical reactivity.

This is a partially true argument and would be stronger if Boyle had actually decided which of his simplest units of matter was actually the most primitive, but in fact, he believed in three most simple levels of subdivision of matter in the corpuscles, *minima* and *prima naturalia*, without ever deciding which of the three was the most primitive. In addition, he believed that in certain circumstances corpuscles could be broken down, as when he speaks of a body’s corpuscles being altered, by fire or other agents ‘altering the shape or bigness of the constituent corpuscles of a body'[89] or even changed, as when a powerful *menstruum* or solvent 'destroyed even refined gold'[90] and converted it into a 'metalline body of another colour and nature'.[91] This means that as Boyle never could nominate a particular entity as the simplest one of all, consequently he was not in a position to refer to any one body as the elemental unit of his corpuscularian system.

Brock continues that to Boyle, materials such as gold, iron and copper were not elements but aggregates of a common matter differentiated by the number, size, shape and structural patterns of their agglomerations, and that although he clearly accepted that such entities had an independent existence as *minima*, he was unable to foresee the benefit of defining them pragmatically as chemical elements. Brock says that for Boyle an element had been irreversibly defined by the ancients and his contemporaries as an omnipresent substance.

Brock here brings out an important distinction between the conception of the elements held by the pre-Boyleans on the one hand, and the post-Boyleans on the other. To the former there existed a small set of elements which bore some relationship to matter, and to some other defining qualities of materials, all of which combine or interact in some way to produce the identifiable bodies of the created world. In the century after Boyle's time more and more the elements came to be identified with the smallest subdivisions of matter: the atoms. Each type of atom – a simple, indivisible body – constituted a particular element, with as many elements as there were distinct atomic types.

[89] *Sceptical Chymist*, p.223
[90] Ibid., p. 215
[91] Ibid., p. 216

Boyle himself as the proponent of the Corpuscularian Hypothesis shared with his adversaries a belief that matter was central to the bodies that occur in the created world. For them, matter somehow came to constitute all the physical bodies in creation, whereas for Boyle these same bodies were accounted for by matter, motion, and rest. Neither side could adduce a clear mechanism, capable of withstanding scientific scrutiny, which would account for how exactly matter came to differentiate itself to form all the material substances of the visible world. Nevertheless, Boyle laid the foundation for a new scientific understanding of matter, which in time would come to be validated by both physicists and chemists, even though he never achieved a detailed working out of his own theory. One obvious explanation is that he did not know where to place the elements in his scheme of material things. He posited that corpuscle equals atom, but did not go on to posit that atom equals element. We can, of course, see how simple these relationships are; it was apparent a hundred years after Boyle's time, but in fairness to Boyle, it was not apparent to him.

1.12. Hall, A. Rupert, *From Galileo to Newton*.[92]

Hall says that Boyle's account of elementary principles and of their rôle in chemical theory contained nothing new nor, though he gave some good knocks against the evidence presumed to prove their existence in all substances, did he succeed in effacing belief in their reality, and that Boyle drove neither the Aristotelian elements nor the Spagyric principles out of chemistry.

[92]Rupert A. Hall, *From Galileo to Newton* (New York: Dover Publications, Inc., 1981) pp. 228 – 229.

Hall is only partially correct in stating that Boyle's account of elements and principles contained nothing new. It is true that Boyle did not name any new elements, and was content to accept two sets of elements current in his own time, but this does not necessarily mean that he conceived of those same elements as his contemporaries had done. Boyle's Corpuscularian Philosophy hypothesises that all materials are actual substances possessed of quantifiable properties; in addition they have to relate to compound bodies in specifiable ways. For example, he speaks of mercury as the familiar mobile, silver-coloured liquid, by saying that it 'weighs twelve or fourteen times as much as water of the same bulk',[93] and of sulphur as 'yellow and brittle', which would 'burn blue' and give 'a scarce supportable stink', [94]all of which are recognisable properties of sulphur. Boyle could consider these two of the *tria prima* and identify them as substances having properties which necessarily defined them as unique materials. By contrast, he says of the Paracelsians that what they call the 'salts, sulphurs of bodies are not so pure and elementary as they presume, and as their hypothesis requires'[95]

As to Boyle's not having succeeded in effacing belief in the reality of the chemical principles, and that he drove out neither the Aristotelian elements nor the Spagyric principles out of chemistry, again, this is only partially true, as it is the case that the older accounts of the elements did have their adherents, even after Boyle's time, but as time went on his Corpuscularian Philosophy came progressively to be incorporated into a revived atomic theory of matter at the expense of the earlier hypotheses on the elements.

---

[93] *Sceptical Chymist*, p.78
[94] Ibid., p. 45.
[95] Ibid., p. 49.

Hall goes on to say that it requires careful reading of *The Sceptical Chymist* to discover that Boyle's rooted objection to the whole concept of element arose from the impossibility of finding out how many kinds of fundamental particles there are; for to his mind – very logically – only these could be considered as true elements.

This would indeed have been a satisfactory and logical conclusion to Boyle's investigations into the elements as presented in *The Sceptical Chymist*. It is easy to see that if Boyle had postulated a Corpuscular Hypothesis of matter, with corpuscles differentiated by 'size', 'figure, and 'shape', [96]then it would have been a simple matter to postulate a direct connection between corpuscle and element, by saying, for example, that Corpuscle of Type A represented Element A, Corpuscle of Type B represented Element B, and so on. Unfortunately, however much one desires Boyle to have made these simple, direct connections, he never actually did make them. We can, with the wisdom of more than three hundred years of scientifically-laden hindsight, make certain associations on Boyle's behalf. The trouble is, Boyle never did arrive at a satisfactory connection between element and corpuscle, and so never could say which substances could be considered as 'true elements', as Hall wills him to have done.

1.13. Moran, Bruce T., *Distilling Knowledge Alchemy, Chemistry, and the Scientific Revolution*[97]

[96] *Selected Philosophical Papers of Robert Boyle*, p. 20.
[97] Bruce T. Moran, *Distilling Knowledge Alchemy, Chemistry, and the Scientific Revolution* (Harvard University Press, 2005) p. 145.

Moran says that for Boyle 'Aristotelian elements and Paracelsian principles were out,'[98] and that what replaced them was a particulate view of matter in which all the tiny bits obeyed physical laws determined and sustained by God.

It could be argued that Boyle's approach to the elements is not as simple as Moran might have us believe. Boyle never did oppose the beliefs on the elements held by the Aristotelians and Paracelsians in a dismissive way, but was more qualified in his criticism of their doctrines than Moran suggests. It is true that Boyle did accuse the Aristotelians and Paracelsians of failing to account for the number and variety of physical substances by the application of their doctrines of the four and three hypostatical elements, respectively, and that what he hypothesised, as an alternative to their schemes, was his Corpuscularian Philosophy. Boyle, however, did not object to the idea of the four elements of the Aristotelians *per se*, but rather to how they conceived of them. For he says that 'some chymists and other innovators in philosophy' are inclined to object against the Aristotelians that from 'the mixture of their four elements there could arise but an inconsiderable variety of compound bodies'. Yet if they accepted the Corpuscularian Hypothesis they could account for a large variety of compound bodies. Boyle says that 'if we assigne to the corpuscles, whereof each element consists, a peculiar size and shape' it may easily enough be demonstrated that such 'differingly figured corpuscles may be mingled in such various proportions' and may be connected in to many different ways, that an 'almost incredible number of variously qualified concretes may be composed of them'.[99]

[98] Ibid., p. 145.
[99] *Sceptical Chymist*, p. 32.

Boyle reiterates his opinion that if each of the four Aristotelian elements represented four different corpuscular species, then they might be able to account for a large number of chemical species, by saying that 'the Aristotelians might with probability deduce a much greater number of compound bodies from the mixture of their four elements, than according to their present hypothesis they can', if instead of vainly attempting to deduce the variety and properties of all compound bodies from the combination and temperaments of the four elements, endowed as they believe with the 'four first qualities', but had instead endeavoured to do it by the 'bulk and figure of the smallest parts of those supposed elements'.[100] Boyle had no doubt but that a great variety of materials, properties and qualities can result from a small number of primary substances, when he says that from these 'more catholic and fruitful accidents of the elementary matter may spring a great variety of textures', and from these may come 'a multitude of compound bodies', which may differ greatly from one another. He also says that what he believes of the four Aristotelian elements 'may also be applied *mutatis mutandis* (as they speak) to the chymical principles'[101] [i.e. to the *tria prima* of the Paracelsians].

1.14. More, Louis Trenchard, *The Life and Works of the Honourable Robert Boyle*[102]

More says that Boyle gives as his opinion that fire, or other agent, does not resolve bodies into just four elements, or into three principles; some are composed of three sensible elements; others of four, and others of more. He goes on to quote Boyle: 'it can scarce be

[100] Ibid., p. 33.
[101] Ibid., p. 33.
[102] Louis Trenchard More, *The Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944) p. 249.

denied, but that the major part of bodies, that are divisible into elements, yield more than three. For, besides those, which the chemists are pleased to name hypostatical, most bodies contain two others, phlegm [i.e. water] and earth'.[103]

More here expresses Boyle's doubt as to the number of bodies obtained from plants and animals when subjected to thermal decomposition, and rightly identifies that Boyle does believe that such bodies contain a 'determinate number (whether three, four, or five, or fewer or more) as substances'.[104] He quotes Boyle as saying that most bodies do contain phlegm and earth, but does not indicate that Boyle was here speaking of living things only, and was opposed to the notion that water was a constituent of minerals, for he says that it would not be possible to 'avoid acknowledging that earth and water are elementary ingredients, though not of mineral concretes, yet of all animal and vegetable bodies'.[105]

1.15. Kuhn, Thomas S., *The Structure of Scientific Revolutions*[106]

Kuhn says that Boyle gave a definition of element quite close to that in use today, but that according to Boyle, his 'definition' of element was no more than a paraphrase of a traditional chemical concept. He goes on to say that Boyle offered it only to argue that no such thing as a chemical element exists, and that as history the textbook version of Boyle's contribution is quite mistaken. Kuhn says that this mistake is trivial, but what is not trivial is the impression of science fostered when this sort of mistake is first compounded and then built into the technical structure of the text. He says that like

[103] Ibid., p. 249.
[104] *Sceptical Chymist*, p. 34.
[105] *Sceptical Chymist*, p. 204.
[106] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (University of Chicago Press, 1962) pp. 141-3.

'time', 'energy', 'force', or 'particle', the concept of an element is the sort of textbook ingredient that is often not invented or discovered at all, and that Boyle's definition, in particular, can be traced back at least to Aristotle and forward through Lavoisier into modern texts. Kuhn argues that this is not to say that science has possessed the modern concept of an element since antiquity.

It could be argued that Boyle would agree with Kuhn to the extent that his definition of element was no more than the restating of a concept of natural philosophy, going back at least as far as Aristotle. Boyle, however, did not offer it 'only in order to argue that no such thing as a chemical element exists',[107] but rather he questions 'whether there be any one such body to be constantly met with in all and each of those that are said to be elemented bodies'.[108] In other words Boyle did not question the existence of the elements *per se*, what he did query was how they were distributed in material bodies.

Boyle might also agree with Kuhn that the concept of element was nothing new, and that he [Boyle] was also too well aware that the concept of element was constant and invariable, with the Aristotelians, Paracelsians and others using the same term, but that what they meant by that same concept differed as between the different groups of natural philosophers.

Kuhn goes on to say that verbal definitions like Boyle's have little scientific content when considered by themselves, and that they are not fully logical specifications of

---

[107] Ibid., p. 142.
[108] *Sceptical Chymist*, p. 187.

meaning (if they are such) but more nearly pedagogic aids. What exactly Kuhn means by 'scientific content' is unclear. He may mean that Boyle's use of words such as 'principles', 'primitive', 'simple', 'unmingled', could be applied in various circumstances and to different cases, not necessarily related to science at all. The very word 'element' has numerous uses totally unrelated to scientific endeavour, simple because the concept 'element' and its synonyms can be employed across a wide range of literal, metaphorical, and hypothetical applications.

Boyle, however, might take issue with Kuhn's saying that they are not 'fully logical specifications of meaning' but 'more nearly pedagogic aids',[109] as, although Boyle did apply a more or less standard set of words to his definition of element, he would surely have believed that real entities corresponded to his definition, which entities were not simply specifiable logically but could also be specified materially. For to Boyle the elements were corporeal entities, amenable to laboratory manipulation, and possessed of physical properties. They were, in short, capable of being identified and verified experimentally. What Boyle did not know, and set out to question, was how many elements subsisted in those bodies 'said to be elemented'.[110]

Boyle might have agreed with Kuhn that the elements did indeed have a pedagogic rôle, not in the dismissive sense that Kuhn seems to reserve for them, but as fully functioning chemical entities which lay at the foundation of the newly emerging experimental science of chemistry.

---

[109] Op. cit., p. 142.
[110] *Sceptical Chymist*, p. 187.

Kuhn goes on to say that the scientific concepts to which the pedagogic aids gain full significance only when related, within a text or other systematic representation to other scientific concepts, to manipulative procedures, and to paradigm applications. From this he says that it follows that concepts like that of an element can scarcely be invented independent of context, but then says that given the context they rarely require invention because they are already at hand. Kuhn is quite right in his last statement: the term element has been part of the furniture of natural philosophy since the time of the Ancient Greeks. The concept of element is an antique one, that is to say the idea of identifying the primary constituent or constituents of nature is as old as systematic speculation on the nature of material things itself. Nor was there any shortage of lists of the elements arrived at by rational enquiry. What Boyle uniquely did was to take an ancient concept and to subject it to scrutiny both *rational* and *experimental*. An element for Boyle had to be a substance capable of experimental verification; any body whose existence as an element was claimed, had to have this demonstrated in the laboratory.

Kuhn goes on to say that both Boyle and Lavoisier changed the chemical significance of 'element' in important ways, but they did not invent the notion or even change the verbal formula that serves as its definition. Kuhn is correct in saying that Boyle and Lavoisier changed the chemical significance of element. Boyle called on those who claimed to have identified the elements in substances that had been subjected to analysis, to account for those elemental bodies in terms of real quantifiable entities. He would simply not accept the claims of the Aristotelians, saying that they 'have not been very solicitous to gather experiments to prove their doctrines, contenting themselves with a few only, to satisfy those that are not capable of a nobler conviction'.[111] The rational doctrine of the four Aristotelian elements could never satisfy Boyle: he demanded experimental evidence to back up any claims grounded on reason alone.

Lavoisier, inspired by Boyle and in possession of the considerable body of chemical experimentation of the eighteenth century, qualified Boyle's definition of element by naming as elements only those substances that were incapable of further decomposition by *chemical means*.[112] Once a substance could no longer be reduced to simpler bodies by the techniques of chemical analysis available at a given time it could legitimately (though in the light of subsequent findings, sometimes incorrectly) be called an element.

Kuhn argues rightly that Boyle's historical function as leader of a Scientific Revolution was to transform the notion of element into a tool quite different from what it had been before, and in doing so, transformed both chemistry and the chemist's world in the process. However, it could be argued that Boyle left the concept of element untouched – he defined the term, after all, in much the same words that Aristotle had employed – but what he did change was what was *meant* by element, and the means by which one was allowed to confer the status of element on any given substance. This, of course, meant justification in terms of strict experimental criteria, and it was this change that led to what Kuhn refers to when he speaks of Boyle's having 'transformed both chemistry and the chemist's world'.[113]

[111] *Sceptical Chymist*, p. 20.
[112] A.L. Lavoisier, *Elements of Chemistry,* trans. R. Kerr, in: *Great Books of the Western World*, Vol. 45 (Chicago: Wm. Benton, 1952) p. 4.
[113] Op. cit., p. 143.

Boyle's legacy to chemistry did not lie in his redefining the word 'element', a word in no need of redefinition, as what it meant had long since been agreed, but Boyle called into question what his adversaries – the Aristotelians and Paracelsians – could actually adduce, under controlled conditions, as elements, and how they might substantiate any claims they made with respect to any substances defined by them as elemental.

Kuhn presents a skilfully argued account of the question, although it does seem that what he expresses is an adaptation of Boyle's doctrine on the elements that fits in with his own analysis of the Scientific Revolution rather than a faithful interpretation of Boyle's account of the subject.

1.16. Boas, Marie, *Robert Boyle and Seventeenth-Century Chemistry*[114]

Boas says that by the time he had finished demolishing the established theories of elements, either Aristotelian, Paracelsian or Helmontian, Boyle was increasingly dubious about the possible existence of any elements. She gives Boyle's definition of the elements as his Definition no. 4, and then continues with his questioning:

> ' now whether there be any one such body to be constantly met with in all, and each, of those that are said to be Elemented bodies, is a thing I now question.'[115]

She says that this is an excellent definition of an element, which is especially good if one does not quote it in full, for the full version shows that he was not original; this honour she confers on de Clave who, in 1641, defined the elements as: 'simple bodies, which enter originally into the composition of mixts, and into which these mixts resolve

---

[114] Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958) pp. 95-97.
[115] Ibid., p. 95.

themselves or may be finally resolved'.[116] She says that Boyle's full definition of the elements shows that not only was it not original, but that it shows that he was not inclined to believe that the concept of elements was a very useful one.

It could be argued that Boyle did not so much doubt the existence of the elements *per se*, in the definition quoted by Boas, above, but that whether there was 'any one such body', present in all things 'said to be elemented bodies' was the thing he said that 'I now question'. The one body which he considered as possibly being present in all elemented bodies may well have been water, as Boyle, under the influence of van Helmont, and following his own efforts at plant growing, was inclined towards the belief that water was the sole element. The fact that water and earth were present at Creation seems to have led Boyle to the belief that these two substances had some kind of unique standing in relation to the rest of terrestrial things, for he says that 'I look upon earth and water, as component parts of the universe or rather of the terrestrial globe, not to all mixt bodies.'[117]

Earth and water predate all other substances, as they are simply far older than any other material, so that when it might be objected that quicksilver or sulphur may be obtained from a mineral or metal Boyle 'need not concede either of them to be an element in the sence above declared'.[118] Of course it could be asked of Boyle what exactly he meant when he said that earth and water, although elemental, were not a part of 'all mixt bodies'. He might simply have replied that some process had to be effected by which

[116] Ibid., p. 85.
[117] *Sceptical Chymist*, p. 187.
[118] Ibid., p. 187.

water seems to have been transmuted into earth, as in the case of growing vegetables and plants, from ‘which experiments it seems evident, that water may be transmuted into all the other elements’.[119]

As to Boyle’s definition of element, Boas says that it shows that Boyle is at pains to accept the common definition of elements or principles, as generally given by both Peripatetics and chemists. This is true as his definition is really the standard definition of the term, in which the simple and fundamental nature of the elements is set down. It is not so much what the definition of an element is, but rather what it must be, by definition, and which definition is no more than a tautology.

Boas goes on to say that this definition differs markedly from that of modern chemical elements and this difference is such as utterly to destroy the modernity of the definition. The assumption is that the same few elements are to be found in *all* bodies, that *all* bodies should be resolvable into the same number of elements so that every body consists of different arrangements of the same elements. [Boas’s italics]. There is never a suggestion that, except for the elements themselves, there can be any substance which consists of fewer than all the elements.

What Boas seems to be doing is taking the definition of the elements of the ‘chymists that speak plainest’, which of course states that bodies are composed of the *tria prima* of mercury, salt and sulphur, and saying that this is the definition that Boyle had in mind when he gave his own understanding on the subject. On this reading of Boyle it would

[119] Ibid., p. 188.

mean that the *tria prima* are the elements or principles of which all material bodies are compounded and into which they can be decomposed. Every body would be composed of these same three elements and would yield these same three substances unfailingly upon analysis.

Again on this reading of Boyle's definition she is also correct in asserting that this definition differs markedly from that of modern chemical elements, insofar as our contemporary understanding of the elements is that they are simple bodies from which all materials are composed, and into which they can be broken down, but that the number of elements in any particular body can vary from one to many. And of course the same fixed number of elements is not present in all materials.

Crucially, though, to this definition is the fact that Boyle is not necessarily presenting it as his own, for he says '*I* now *mean* by elements *as* those chymists that speak plainest …'. [Italics added]. The words in italics imply that he [Boyle] is not necessarily asserting that it is the definition of the elements that he actually holds, but rather the definition held by the 'chymists'. There is no reason why Boyle could not regard this as a reference definition, one which was accepted by the chemists and perhaps others, though not by Boyle himself. Moreover, Boyle may have quoted this definition merely to comply with the commonly held understanding of the elements as the three principles of which all bodies were composed.

The fact that Boyle gives this definition as what he means by the elements, rather than what he believes or accepts them to be, may explain why immediately after delivering it, Boyle questions whether there be 'one such body to be constantly met with in all, and each of those that are said to be elemented bodies'. The term 'one such body' can hardly refer to the *tria prima*, because if these are what he had in mind he would surely have rephrased the above statement as 'three such bodies'.

Boyle gives a good indication of the line of enquiry he wishes to pursue in his investigations into the 'one such body' present in all bodies said to be constituted of elements, by saying that 'in matters of philosophy, this seems to me a sufficient reason to doubt of a known and important proposition, that the truth of it is not yet by any competent proof made to appear'.[120] He is not, in other words, trying to deny any given proposition in relation to the elements, but rather attempting to test it for its validity. This would mean that the assertion that 'all elemented bodies consist of the *tria prima*' would be evaluated by subjecting real bodies to analysis by the fire or other means, and examining what simpler bodies, if any, were yielded by this process. If three elemental bodies are obtained by this analysis, it would provide evidence in favour of the *tria prima*; however, if on the analysis of several bodies three different entities were obtained for each one, or if fewer or more than three were obtained, it would provide grounds for doubting the validity of the initial proposition. Boyle uses this examination process to good effect in the various investigations made by him on a variety of different substances and processes.

[120] *Sceptical Chymist*, p. 188.

Boas says that the assumption that the same few elements are to be found in all bodies, that every body consists of different arrangements of the same elements, and that apart from the elements themselves there is no suggestion that there is any substance which consists of fewer than all the elements, mean that Boyle's rejection of the chemists' notion of the elements makes more sense than it otherwise would do. What is not clear is: where exactly did this rejection by Boyle take place? Not in his definition of the elements as quoted by Boas, nor in Boyle's statement following immediately on this definition in which he states that whether there be 'one such body' to be found in all bodies reputedly elemented, he simply says 'is the thing I now question'. There is no mention here of the rejection of any opinions or doctrines on Boyle's behalf.

Boas most likely, then, in speaking of Boyle as having rejected the chemists' notion of the elements, is referring to the quotation from Boyle which she places immediately after his definition of the elements, in which she says, that he, 'after considerable discussion', added: 'I see not why we needs must believe that there are any primogeneal and simple bodies, of which as of pre-existent elements, nature is obliged to compound all others.'[121] In fact the 'considerable discussion', referred to above, occurs after a thirty-seven page discussion by Boyle on the subject of the elements. It might also be useful to check what Boyle was saying just before delivering the above quotation as given by Boas. Boyle actually says that it is possible that the true differences between bodies may be accounted for by changes at the corpuscular level. For he says that the 'difference of bodies may depend merely upon that of the schemes whereinto their common matter is put'. The fire and other agents may simply be capable of breaking into different shapes, uniting them,

[121] Op cit., p. 95.

or by ‘altering the shape or bigness of the constituent corpuscles of a body’, and the ‘new texture of its minute parts’ make the new material thus formed ‘deserve a new and distinct name’.[122] Boyle seems here to be viewing changes in materials as happening purely at the corpuscular level, which given Boyle’s understanding of the corpuscular nature of matter, show him as attempting to devise a mechanism by which change in matter could be rationalised.

Boyle then goes on to discuss the alternations of inanimate bodies by the fire and other agents by which ‘the same portion of matter’ may be ‘turned into so many different bodies’, ‘since the matter, cloathed with so many differing forms, was originally but water’. Here Boyle is reiterating a belief he consistently holds: that water is the only element, and that by the transmutation of which, other materials are produced. Boyle argues from this that matter may go through many transformations, but is never reduced to any of those substances which are ‘reputed to be the principles or elements of mixt bodies’. The ‘violence of the fire’ does not divide bodies into elements but into ‘new compounds’. Only then does Boyle go on to say that ‘since, I say, these things are so, I see not why we must needs believe that there are any primogeneal and simple bodies, of which, as of pre-existent elements, nature is obliged to compound all others.’[123]

Looked at in the broader context of Boyle’s discussion on the transformation of matter, Boas’s understanding of Boyle’s latest quotation given above may be seen in a different light. For her statement that Boyle had rejected the chemists’ notion of the elements does

[122] *Sceptical Chymist*, p. 223.
[123] *Sceptical Chymist*, p. 224.

make sense if he is interpreted as having put aside the *tria prima* of the chemists or Paracelsians in favour of van Helmont's doctrine of water as the sole element.

Boyle, having first of all considered that all changes in matter are simply manifestations of occurrences at the most fundamental level, in which the corpuscles, all of which have been produced from a common universal matter, undergo a number of proposed transformations, then goes on to argue that these changes, occurring as they do at the most microscopic level, come to be manifest at the macroscopic level by visible variations in the appearance, properties and behaviours of materials. Boyle here seems to be saying that there is only one true elemental matter – the universal matter – and from it the enormous diversity in materials and their properties derives. This is simply a variation of Boyle's oft quoted belief that matter, motion (or rest) are the fundamental principles of the created universe.

He then considers that water is the fundamental element and that all other materials have been produced by the transmutation of water. His evidence which supports this belief is derived from his own experiments in growing plants and vegetables, and in van Helmont's experience of growing a tree nourished only by water. Viewed in this light, Boyle could justify his belief that nature needs no 'pre-existent elements' from which to compound all other bodies. The 'primogeneal and simple' substances from which all other things were made, were already at nature's disposal, and in each case there was no complex of elements but a single material: the universal matter produced at Creation, or the single element, water, produced also at the time of Creation.

Boas, having said that an entirely different concept of element, that of a substance not to be further broken down, which was not necessarily present in many bodies, let alone in all, was what was necessary before the modern definition could really be set up. She says that Boyle's destruction of the old notion is perhaps the first step. She here identifies three qualities inherent in the modern definition of element:

a) A substance not made from other bodies;

b) A substance not capable of further reduction;

c) A substance not present in all materials.

She argues that a) above makes Boyle's definition sound modern. Of course it could be argued that this stated requirement not alone is modern but is simply a standard part of the definition of the term element, going back at least as far as Aristotle. For her part, she seems to admit as much when she says that Boyle's statement on the elements 'is identical with that made by other chemists'.[124]

Requirement b) is not a part of Boyle's definition; nevertheless it did increasingly inform his thinking on experimental justification for the elements to substances obtained by him in the laboratory. He realised that there were experimentally imposed end points to the breakdown of substances attainable by him, which inclined him towards the belief that the definition of element would have to include some reference to the limits of decomposition attained by experimental means. For he says that 'these principles, though they be not perfectly devoid of all mixture, yet may without inconvenience be stiled the elements of compounded bodies'.[125] Boyle is here referring to substances produced by

[124] Op. cit., p. 96.
[125] *Sceptical Chymist*, p. 229.

the destructive distillation of wood; he admits that these individual products, even though they may not be pure substances, he is happy to call elements. Not that Boyle is prepared to call these substances elements without good reason, he realises that none of them 'is divisible by the fire into four or five differing substances'.[126] Boyle's criterion for determining a substance's elemental status is thermal decomposition. Once a material is incapable of further reduction by the fire he is willing to accept its status as a corpuscle or atom, even though it may not fulfil the strict requirements of simplicity and indivisibility set down by Boyle in his definition of the elements.

The quality c) is interesting in that Boyle never seems to have stipulated it in relation to his understanding of the elements. He is quite capable of referring to elements as individual entities, rather than as necessary pairs or groups. He looks upon earth and water 'as component parts of the universe, or rather of the terrestrial globe, not of all mixt bodies'.[127] So whatever Boyle may say about the aqueous material phlegm being one of the elements he is ascribing it to 'almost all vegetable and animal concretes'.[128] It is possible that he can also accept that there may be some bodies of an organic nature that do not contain an aqueous component.

Boas continues that in the light of Boyle's definition of the elements it is easier to understand not only his rejection of the existence of elements which together compose all

[126] Ibid., 229.
[127] *Sceptical Chymist*, p. 187.
[128] Ibid., p. 228.

other bodies, but also his alternative suggestion that it is enough to suppose individual corpuscles as the one kind of substance constituting all bodies.[129]

Of course Boyle always keeps in mind his hypothesis on the formation of the universal matter and its subdivision into corpuscles, as for example when he states that 'although matter, motion and rest' seemed to him to be the 'catholick principles of the universe'.[130] He also states that the principles of the world as it now is are three: '*matter*, *motion* and *rest*'.[131] [Boyle's italics]. Given that he considers 'elements and principles as terms equivalent',[132] and given that the 'universal matter' at the time of Creation was 'divided into little particles of several sizes and shapes variously moved',[133] it follows that 'the little particles' 'variously moved' along with rest, are the principles which underlie the created world, and since principles and elements are equivalent terms to Boyle, then matter, motion and rest can be looked upon as the elements from which the terrestrial world is constituted. So when Boyle offers, as an 'alternative suggestion',[134] the hypothesis that 'it is enough to suppose individual corpuscles as the one kind of substance composing all bodies',[135] it is not so much an alternative suggestion, worthy of consideration by those interested in arriving at an understanding of the elements, but rather Boyle's starting position on the subject. Moreover, it is a position which may be deduced from Boyle's fundamental understanding on the nature of the created world, and a position which Boyle must surely take for granted as validly explaining, and accounting

---

[129] Op cit., p. 96.
[130] *Sceptical Chymist*, p. 201.
[131] Ibid., p. 200.
[132] *Sceptical Chymist*, p. 218.
[133] Ibid., p. 30.
[134] Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry*, p. 96.
[135] Ibid., p. 96.

for, the principles underlying the material world. Although this explanation may account for how the created universe is, Boyle still needs an account which would provide a valid explanation for the actual substances observed by him in his laboratory and the changes, transformations and behaviour manifested by them.

Boyle is careful also to distinguish between the materials from which a given body is made and those obtained by its decomposition. He says that '… it were not necessary that nature should make up all metals and other minerals of pre-existent salt, and sulphur and mercury, though such bodies might by fire be obtained from it'.[136] Boyle is not committed to any declaration as to which substances constitute bodies, all he is willing to do is to note which decomposition products they yield on analysis. The only element he is more or less ready to accept as a starting point for the production of living things is water. He is even willing to accept that the *tria prima* of the Paracelsians – mercury, sulphur, and salt – may have their origin in water too, for he says '… and that (as appeared by the experiment of pompions [pumpkins] the *tria prima* may be made out of water'.[137] Otherwise when he refers to the elements he speaks of them as the decomposition products of minerals and living things, and not as the ingredients from which these bodies are made or as their actual constituents. Boyle says that 'divers mineral bodies may be resolved into a saline, a sulphureous, and a mercurial part,' and that 'almost all vegetable and animal concretes may … be divided into five differing substances, salt, spirit, oyle, phlegme and earth'.[138]

[136] *Sceptical Chymist*, p. 195.
[137] Ibid., p. 203.
[138] Ibid., p. 228.

Boas goes on to say that where Boyle went wrong was *not* in rejecting totally the notion of element as known, but rather in deciding that there was nothing between corpuscles and compounds, that is, in failing to evolve a totally new concept of the nature of elements. [Boas's italics]. What was needed, she says, was for a century's progress in the understanding of the composition of bodies before 'Lavoisier could give his definition of a chemical element'.[139]

Boas seems adamant in stating that where Boyle went wrong was not in rejecting totally the notion of element as known to him but 'in deciding that there was nothing between corpuscles and compounds'.[140] However, if this is what he really did believe it is curious that a few pages later she quotes him as saying that he distinguishes:

> 'The principles or more primitive or simple Ingredients of mixt Bodies into three sorts, *first*, Primary Concretions or Coalitions, *next*, Secondary mixts, and thirdly, decompounded mixts, under which name I comprehend all sorts of Mixt Bodies, that are of a more compounded Nature, than the Primary or Secondary ones newly mention'd and in some cases even mixt Bodys may be lookt upon at Primary or Secondary compounds, viz. in reference to very odd Compounded Bodys, constituted by them.'[141]

Boyle seems to be saying here that his Primary Concretions or coalitions are his corpuscles, *minima* or *prima naturalia*, which aggregate to form Secondary mixts, and which then can further aggregate to form 'decompounded mixts'. Interpreted in this way Boyle seems to be giving two possible levels of aggregation which could be identified as elementary; the first level, his Primary Concretions or Coalitions, or the second level, his Secondary mixts. However, his third category, the decompounded mixts, would have to be capable of decomposition into simpler bodies, and therefore could not be considered

[139] Op cit., p. 87.
[140] Op cit., p. 97.
[141] Op cit., p. 100.

as elemental. Logically, the bodies occupying the first category could be accorded the status of elements, as they are of the ‘simplest’ most ‘primitive’ possible state of matter. So too could the second category, not because they are the simplest bodies possible, but because they could not readily be divided into smaller entities. The reason is simple: Boyle says that the ‘considerations that induce men to think that there are elements’ may be presented under two headings. He gives these as: it is necessary that nature ‘make use of elements to constitute the bodies that are reputedly mixt’, on the one hand, and on the other hand that the resolution of such bodies ‘manifests that nature had compounded them of elemental ones’.[142]

Looking at Boyle’s scheme again, his decompounded bodies cannot be considered as elemental as they are compounded from simpler bodies, and the simplest bodies of all, those at the simplest stage of complexity must, by definition, be considered as elemental. What of those in Boyle’s second category? These are neither the simplest bodies nor the most complex, but might not they be considered as elemental? It could be argued that there is no reason why they should not be considered as elements, even if strictly speaking, they are capable of resolution into simpler bodies. The reason for this being that Boyle understood that his criterion for the elemental state was not one of absolute simplicity that principles or elements ‘may not be devoid of all mixture’, but rather bear the names of those substances which they most resemble, and which are manifestly predominant in them, and especially for the reason that ‘none of these elements is divisible by the fire into four or five differing substances’.[143]

---

[142] *Sceptical Chymist*, p. 188.
[143] Ibid., p. 229.

Boyle, in the light of his experimental findings and in considering the products he obtained in decomposing various materials, found that he was not arriving at the simplest state possible for the subdivision of materials. From this he concluded that his definition of element would of necessity entail more than a definition based on ‘simple’, ‘primitive’ bodies, and would have to take account of the processes by which bodies are decomposed into simpler entities. He was, in effect, tending towards a pragmatic, experimentally based definition of the elements, and one which increasingly equates simplicity with that level of decomposition which the experimenter was capable of achieving using the analytical tools available to him.

1.17. Hooykaas, Reijer, *The Concept of Element*[144]

Hooykaas quotes Boyle as giving his definition of an element as Definition no.4, and, in common with Boas, gives Boyle’s subsequent statement of intent:

> ‘now whether there be any one such body to be constantly met with in all, and each of those that are said to be elemented bodies, is the thing I now question.’

Hooykaas says that Boyle doubts whether there are a certain number of elements, and even whether it is necessary to assume the existence of elements. He is probably referring here to Boyle’s statement that ‘it may as yet be doubted whether or no there be any determinate number of elements’, and where he continues that it may also be doubted ‘whether or no all compound bodies do consist of the same number of elementary ingredients or material principles’.[145] Boyle goes on to say that the experiments of the ‘common peripateticks’ (Aristotelians) or of the ‘vulgar chymists’ (Paracelsians) which

---

[144] Reijer Hooykaas, *The Concept of Element: Its Historical-Philosophical Development* (Utrecht, 1933) [Doctoral Thesis] trans. Kubbinga, H.H., 1983, pp. 196-199.
[145] *Sceptical Chymist*, p. 183.

are meant to demonstrate that all ‘mixt bodies’ or chemical compounds, are made up either of the ‘four elements’ or the ‘three hypostatical principles’, of the Aristotelians and Paracelsians, respectively, do not ‘evince what they are alleged to prove’.[146]

As to the number of entities actually present in compound bodies, Boyle considers the methods of ‘those patriarchs of the Spagyrists, Paracelsus and Helmont’, and says that they employ as analytical tools fire and the *alkahest*, or universal solvent, respectively. He argues, very sensibly, that the number of elements obtained from a given body would depend on which of the two methods of analysis was actually applied to it, and that it would have to be agreed beforehand which of the two instruments of resolution, fire or *alkahest*, ‘shall determine the number of the elements’.[147]

Boyle, in recognising that two different analytical systems, brought to bear on the analysis of substances, would lead to the recovery of two different sets of decomposition products, and that as there is no crucial test that one could apply to these products, realises that it would have to be decided which of the two tools of analysis, fire or *alkahest*, leads to a set of decomposition products which could be recognised as elemental.

Hooykaas says that Boyle shows that many bodies, on analysis, do not yield three or five principles. He seems to be referring to Boyle’s statement where he says that it does not appear that three is precisely the number of the distinct substances or elements ‘whereinto

[146] Ibid., p. 184.
[147] *Sceptical Chymist*, p. 184.

mixt bodies are resoluble by the fire.'[148] Boyle here refers to the resolution of bodies into three substances, but makes no mention of five being a possible number of the elements, as Hooykaas seems to suggest.

Hooykaas continues by quoting Boyle as saying on the above matter, 'the most obvious instance of this truth is gold, which is a body so fixt, and wherein the elementary ingredients (if it have any) are so firmly united to each other […] etc'.[149] This would seem to be a correct reading of Boyle, in which he claims that no matter 'how violent soever' the fire, it was not capable of causing the gold to be 'dissipated into those principles',[150] i.e. from which Paracelsian doctrine holds it to be constituted, viz. salt, sulphur and mercury.

Hooykaas says that [for Boyle] analysis should prove something to be an element, and that in saying this he does not claim to be stating something new, for he argues that even the chemists derive the alleged demonstration of their principles *a posteriori* from analysis, though they did assume them *a priori*.

Hooykaas seems to be quoting Boyle here when he said that in speaking of the origin of metals, that his deductions from his observations need not be incontestable because his adversaries, the Aristotelians and Paracelsians do not 'I presume, know any better than I, *a priori*, of what ingredients nature compounds metals and minerals'.[151] He goes on to

---

[148] Ibid., p. 95.
[149] *The Concept of Element*, p. 196.
[150] *Sceptical Chymist*, p. 39.
[151] Ibid., p. 196.

say that their argument to prove that these bodies are made up of such principles is drawn *a posteriori*. He says that upon the analysis of mineral bodies they are 'resolved into these differing substances'.[152]

Boyle seems to be saying that his adversaries know no better than he does, *a priori*, the ingredients from which nature 'compounds metals and minerals'. Boyle, whatever he may think of the beliefs of the Aristotelians and Paracelsians, is not here saying that they are assuming the existence of their principals *a priori*, as Hooykaas seems to believe. In fact Boyle, in speaking of nature as having compounded metals and minerals, seems to be at least suggesting that they are compound bodies rather than simple elementary substances. What Boyle seems to be arguing here is that as his adversaries' argument on the composition of metals and minerals is drawn by them *a posteriori*, and if they arrive at their principles *a posteriori*, it is difficult to see how they can be said to be holding these principles *a priori*.

Hooykaas says that the molecules of saltpetre, some metals, and sal-ammoniac [ammonium chloride] 'as far as analysis goes can thus be considered as "elements",'[153] although he adds that in Boyle's opinion, they are not even primary concretions, but distinctly 'mixt bodies'. What he seems to mean is that Boyle, in stating that some bodies yield not so many as the three principles on analysis, and that there are 'many others' that in their resolution exhibit 'more principles than three'. Boyle takes this as

[152] Ibid., p. 196.
[153] Op cit., pp. 196-7.

firm evidence that all bodies are not constituted of the ‘ternary number’ of elements.[154] He argues that of the elementary corpuscles there may be more than either three, four or five, and that as corpuscles of ‘a compounded nature’[155] may be considered as elementary, he considers it as possible that as *aqua fortis* [nitric acid] or *aqua regia* [a mixture of hydrochloric and nitric acids] can separate silver and gold respectively, though the fire cannot, there may be found some agent ‘so subtle and so powerful’ at least in respect of ‘those particular compounded corpuscles’ as to be able to resolve them into the more simple bodies of which they consist, and thereby increase the number of the ‘distinct substances’ into which the ‘mixt body has been hitherto thought resoluble’.[156]

Boyle shows here that he understands the distinction between fixity or chemical reactivity and thermal decomposition, as agents capable of modifying the composition of corpuscular species. He realises that, although there seems to be a limit to the power of fire to modify bodies such as gold – it can liquefy it but not effect any chemical change in it – yet if one reagent, *aqua regia*, could dissolve gold, then there may be other still more powerful ones capable of not just reacting with gold corpuscles but of actually breaking them down.

Hooykaas states that, notwithstanding the fact that they are almost undecomposable, Boyle does not consider the metals as elements, and consequently, he admits the possibility of their transmutation. Hooykaas continues that, as regards the primary

---

[154] *Sceptical Chymist*, p. 103.
[155] Ibid., p. 104.
[156] Ibid., p. 104.

concretions of the atoms, these are very firm and can be considered as the elements proper of the bodies, and that they are preserved in the compounds.

Hooykaas seems here to be referring to Boyle's use of experimental evidence – 'something out of experience' – which seems to him to be providing evidence in favour of the existence of 'elementary bodies'.[157] Once again Boyle gives the example of gold, which he says may take part in various chemical reactions with a number of metals and minerals and will form reaction products 'very differing both from gold, and the other ingredients of the resulting concretes'. Gold will also be reduced by various *menstruums* including *aqua regis* into 'a seeming liquor' and by evaporation into 'a crystalline salt'. It can also be converted into 'red crystals of a considerable length' by means of 'a certain saline substance' prepared by Boyle, and by 'many other wayes may gold be disguised' and form bodies differing both from the metal itself, and from one another. Nevertheless these materials may subsequently be reduced to the 'self-same numerical, yellow, fixt, ponderous, and malleable gold it was before its commixture'.[158]

Having dealt with the most fixt or unreactive metal, gold, Boyle goes on to describe how the 'most fugitive' metal, mercury, can be reacted with *aqua fortis* [nitric acid] to form either 'a red or white powder or precipitate', [possibly mercuric nitrate and mercuric oxide] and with sulphur a 'blood-red and volatile cinaber', [mercuric sulphide] and he lists other compounds formed from mercury. He continued that 'out of all these exotic

[157] Ibid., p. 31.
[158] *Sceptical Chymist*, p. 31.

compounds we may recover the very same running mercury' that was the main ingredient in them, and was so 'disguised' in them.[159]

Boyle explains that his reason for listing the formation of a variety of compounds by gold and mercury is to illustrate his belief that the 'little primary masses or clusters' may remain 'undissipated' even though they enter into various combinations with other materials. Crucially Boyle says that the reason why these two metals can form a multitude of compounds and yet be recovered intact, and in their original condition, from all of their compounds, is because the 'corpuscles' of 'gold and mercury', are not 'primary concretions of the most minute particles of matter, but confessedly mixt bodies'.[160]

Boyle here seems to be saying that the corpuscles of gold and mercury, despite not consisting of unitary bodies, but aggregates of even simpler entities, are able to regain their specific identities in passing through various chemical transformations and emerge intact and in their pristine condition when the chemical entities in which they are present are decomposed.

Hooykaas rightly says that Boyle does not consider the metals as elements, even though they are almost incapable of further reduction as Boyle says that they are 'confessedly mixt bodies'. However, it is not clear from the above reading of Boyle how Hooykaas

[159] Ibid., pp. 31-32.
[160] Ibid., p. 32.

can make out that, since Boyle does not consider the metals as elements, he consequently admits the possibility of their transmutation.

Neither is it clear from the above how Hooykaas can read into it the fact that as regards the primary concretions of the atoms, these are very firm and can be considered as the elements proper of the bodies, and that they are preserved in the compounds. It may be that Hooykaas is not quoting Boyle but is himself extending Boyle's line of thought on the matter to its logical conclusion: gold and mercury remain unchanged through various chemical reactions and can be recovered intact from the chemical compounds they form and are, therefore, elements proper (rather as the term is understood in our own time) if not elements as Boyle understood the term.

Hooykaas says that Boyle deviates in his doctrine of elements from other chemists in that he is not willing to establish their number, and that Boyle very prudently remarks that if the primary concretions of practically equal atoms form the elements, there would be more than three or five of them, and furthermore, that not all bodies necessarily contain all of the elements.

Hooykaas is correct in saying that Boyle is not willing to establish the number of the elements, and Boyle most likely holds this belief because he argues that different materials contain different numbers of atoms. He says that one sort of compound body may contain 'two kinds of elementary ones' and gives glass as an example of this. He adds that other compound bodies 'may be composed of three elements, another of four, another of five, and another perhaps of many more'. Boyle continues that according to this notion there can be no definite number assigned 'as to that of the elements'.[161] As to Hooykaas's saying that if the primary concretions of practically equal atoms form the elements, there would be more than three or five of them; this does seem to be a correct reading of Boyle. He seems to be referring to Boyle's statement that if it be 'granted rational' to suppose that the elements consisted at first of certain small and primary coalitions of particles of matter into very numerous corpuscles which were 'very like each other', and he argues from this that the primary clusters may be of 'far more sorts than three or five'.[162] So for Boyle, the corpuscles themselves are composed of even more primary forms of matter, probably the *minima* and *prima naturalia*, and if this is the case then the number of the smallest entities that go to make up the corpuscles may not be restricted. The net result of this being that the total number of possible corpuscular types may indeed be far more than three or five.

Hooykaas says that Boyle holds that not all bodies necessarily contain all of the elements. This seems to be a valid reading of Boyle, for he says that different bodies may contain different numbers of elements. He holds that different bodies may consist of two, three, four, five or 'many more' elements.[163] Obviously a body consisting of just a small number of elements, out of a larger number of possible ones, cannot be said to consist of all of the elements. Boyle says that from the various instances of the formation and modification of bodies, it does not sufficiently appear to him that there is any 'one determinate number of elements to be uniformly met with in all the several sorts of

[161] *Sceptical Chymist*, p. 97.
[162] Ibid., p. 96.
[163] Ibid., p. 97.

bodies allowed to be perfectly mixt'.[164] In this statement Boyle seems to reiterate his belief that a limited number of elements is not consistently present in all compound bodies. Not alone is there not a measurable number of the elements, but whatever number of them there may be is not present in all bodies having a mixed composition.

Hooykaas continues that if there were only three elements, then there could be more bodies which cannot be detected as non-elementary by our methods of analysis. What he seems to be referring to here is Boyle's example of gold and silver, in which he argues that the 'permanency' of gold and silver, which he says are of a 'compounded nature' may be of so 'durable a mixture' as to resist the normal means of decomposition of bodies by chemists using the fire to thermally degrade them.[165] In making this argument, it would seem that Boyle is aware that it may not be possible to determine how many elements exist, as any analysis of a given body may not reveal the true number of elements present in that body.

Hooykaas says that Boyle is not satisfied by a hypothetical element, never isolated in the pure state, but demands a product of analysis that is not only as yet undecomposed but forever indecomposable.

It is true to say that Boyle is not satisfied by a hypothetical element, as when, for example, speaking of the Paracelsians, he argues that their claim that the distilled oil of a plant is composed mainly of 'the pure principle called sulphur' will not be accepted as

---

[164] Ibid., p. 98.
[165] *Sceptical Chymist*, p. 97.

valid by him until they have given ‘an ocular proof’.[166] In other words, they must obtain from the oil a large quantity of the familiar yellow, crystalline material, recognised by Boyle and others familiar with chemicals, as sulphur.

However, when Boyle defines the elements as ‘primitive’, ‘simple’, ‘perfectly unmingled bodies’, into which compound bodies are ‘ultimately resolved’,[167] he is not affirming that such materials actually exist, for at the end of his definition of the elements he queries whether one such body is to met with in bodies ‘said to be elemented’.[168] It is noteworthy too that Boyle’s definition of element does not include any statement to the effect that such bodies can actually be isolated by him or by other workers; the closest he comes to this type of statement is to question whether bodies conforming to this definition can actually be found in material things.

Hooykaas continues that Boyle mentions gold as an example of something that could be an element (permanence, practically not decomposable) and says that Boyle believes that he has had a means to destroy it and to transform it into another metal.

Despite Hooykaas’s statement to the contrary, Boyle makes no mention of gold as something ‘that could be an element’.[169] What he does say is that in a discussion intended to prove the existence of ‘elementary bodies’, he cites gold as ‘an ingredient in a multitude of differing mixtures’ and ‘yet retain its nature’ despite all the efforts of the

[166] Ibid., p. 132.
[167] Ibid., p. 187.
[168] Ibid., p. 187.
[169] *The Concept of Element*, p. 198.

chemists by ‘fires and corrosive waters’ to destroy it.[170] Hooykaas is correct in saying that Boyle believed that he had a means to destroy gold and to transform it into another metal, for Boyle says that he knows ‘a certain *menstruum*’ [solvent] which is of ‘so piercing and powerful a quality’ that he seems with it to have ‘destroyed even refined gold’ and to have brought it to ‘a metalline body of another colour and nature’,[171] and of course because of this, Boyle could not have considered gold as an element.

Hooykaas argues from this that this is not a proof for its being an element, because such a means might still be found in the future. What he seems to be referring to here is Boyle’s statement that not alone can ‘seemingly elementary corpuscles’ be modified by ‘pulling [their] parts asunder’ by some agent ‘found in nature’.[172] Although Hooykaas seems to place such a discovery as happening some time in the future, Boyle makes no claim as to when a suitable agent might be found. In fact when he says ‘there may be agents found’[173] it could even be taken to mean that these agents already exist, but are not being exploited as yet. Hooykaas says that in this case the question remains whether we will ever know the true elements, for the solvent could be inseparably bound to the supposed one, or the solvent could change the texture of the latter. What Hooykaas says here is true, for Boyle did consider that a body hitherto considered as elementary could have its corpuscles broken down by some agent or solvent, and that such a change would mean that the original body could no longer be looked upon as an element. Boyle does indeed say that a reagent may react with a putative element and thereby form a new body with it,

[170] *Sceptical Chymist*, p. 215.
[171] Ibid., p. 217.
[172] *Sceptical Chymist*, pp. 216-7.
[173] Ibid., p. 216.

rendering it no longer elemental, as the new species formed would be 'little to be expected' that its parts should be 'pulled asunder'.[174] He also hypothesises that a corpuscle thought to be elemental may 'have its nature changed without suffering a divorce of its parts' by means of some powerful reagent, as a result of which the nature of the corpuscles can somehow be changed, even though they remain intact throughout the process. What Boyle is referring to here is not a breakdown of corpuscles into simpler entities, but rather some kind of reshaping process which modifies the physical attributes of the corpuscles whilst retaining their integrity. This process could still result in one elementary body being changed into another by whatever modifying agents are brought to bear on it.

Hooykaas argues that strangely enough, however, Boyle at the same time deems analysis unable to find the elements, and that from his definition it appears that he demands absolute elements, and analysis is not able to establish an element in that sense. What Hooykaas seems to be referring to here is Boyle's statement on the inability of the Paracelsians to produce their *tria prima* from bodies upon analysis. Boyle argues that if all bodies consist of salt, sulphur, and mercury, that it should be possible to separate these three materials from various bodies by a process of thermal degradation. He accuses his adversaries of pretending to obtain from some bodies 'salt', from others 'running mercury', and from others still 'a sulphur',[175] yet they have not been able to demonstrate a method by which the Paracelsians are able to obtain any one of these principles from all sorts of minerals, without exception. Boyle draws the conclusion from this that there is

[174] Ibid., p. 217.
[175] *Sceptical Chymist*, p. 196.

not any of the elements that is an ingredient of all bodies, since there are some of which this is not so.

Boyle makes a further argument in which he infers that even if either ‘sulphur or mercury’ were obtainable from all sorts of materials, that this sulphur or mercury would not be elementary but rather, ‘acompounded’ or part of a ‘mixt’ or chemical compound. He demonstrates the validity of this argument by stating that the familiar, silvery mercury is *not* what the Paracelsians obtain from their analysis of plants and animals, but which they ‘have been pleased to call their mercury’.[176]

In Boyle’s third argument he challenges the Aristotelian doctrine of the four elements. He says that he could never see any earth or water ‘properly so called’[177] separated from either silver or gold. He concludes from this that earth and water are not universally present in all mixed bodies or chemical compounds.

Hooykaas’s argument that Boyle deems analysis unable to find the elements might well be qualified to say that the elements Boyle had in mind were those of the Paracelsians and the Aristotelians, which analysis was unable to produce from all bodies. What the Paracelsians claimed as elements, their *tria prima* of salt, mercury and sulphur, would not withstand independent scrutiny, in Boyle’s opinion. Hooykaas continues that elements satisfying these demands, i.e. absolute elements, whose elemental status is determined by

[176] *Sceptical Chymist*, pp. 196-197.
[177] Ibid., p. 197.

analysis, are very difficult to find and that even components known to be present can hardly be distinguished from other products of analysis.

What Hooykaas seems to be referring to here is Boyle's argument that nature does not always need to have elements at hand from which to make chemical compounds. Boyle draws this conclusion from his consideration that bodies may be modified not simply by producing new ones from the elements proper by a process of chemical reaction in which new materials may be produced by effecting change through a rearrangement of the elements already present in the body, or which are available from other bodies, but rather that the 'fabrick' of a body may also be altered by varying the 'figure, size, motion, or situation'[178] of the corpuscles from which the bodies are composed. Boyle seems to be arguing that a body's nature may be changed in ways other than by changing its situation in relation to corpuscles of a different nature from its own – other corpuscles which might be considered as different entities – but that the corpuscles making up a body may themselves be modified so as to change the nature of the material they constitute. In this way a new species might be produced without the reacting or combining of different corpuscles, that is to say, without the reacting or combining of different elements.

Boyle continues that as a large number of decomposition products may be obtained from the thermal decomposition of materials, it is very difficult to decide which of these substances are elements, and which not, it is even more difficult to determine what 'primogeneal and simple bodies convened together to compose it'.[179]

[178] Ibid., p. 217.
[179] Ibid., p. 218.

Hooykaas continues that the change of texture of parts of the general matter, however, satisfactorily explains the emergence of new qualities, and that it is an open question whether nature utilises simple, primary bodies as pre-existing elements. What he seems to be referring to here is Boyle's considering of how exactly change in a material's nature may be effected, as discussed above. This time Boyle widens the scope of possibilities of how change in materials can occur, as he considers different means by which a body may be given a new 'texture', of its minute parts, and thereby make it deserve a new and distinct name.[180] Boyle makes the point that 'blending others with them',[181] is only one means of altering the corpuscles of a body. Hooykaas is correct in saying that it is an open question whether nature utilises simple, primary bodies as pre-existing elements, for Boyle says that 'I see not why we must needs believe that there are any primogeneal and simple bodies, of which, as of pre-existent elements, nature is obliged to compound all others'.[182]

1.18. Pattison Muir M.M., (Introduction to) *The Sceptical Chymist*[183]

Pattison Muir states that Boyle says the following about elements and principles:

> 'I … must not look upon any body as a true principle or element, but as yet compounded, which is not perfectly homogeneous, but is further resoluble into any number of distinct substances how small soever …[184]

He then quotes Boyle's Definition no. 4 as his definition of the elements.

Pattison Muir says that this is very clear, and that the only thing wanting is an experimental method of determining whether a given substance is, or is not, an element.

[180] *Sceptical Chymist*, p. 223.
[181] Ibid., p. 223.
[182] Ibid., p. 224.
[183] Robert Boyle, *The Sceptical Chymist* (London: J.M. Dent & Sons, 1911) p. xvii.
[184] Op cit., p. xvii.

It would seem that he is quite right in identifying the lack of an experimental method as the only barrier to establishing whether a given substance is an element. However, in saying this he at once identifies the nub of the issue in relation to the elements, and at the same time puts his finger on the very thing on which Boyle and his adversaries could not reach common ground. For the Aristotelians and Paracelsians were perfectly content with *their* experimental method, as their methods of thermal degradation yielded their elements to them in a perfectly satisfactory order. Unfailingly, they could identify their earth, mercury or other elements using their particular means of analysis, from any given body that they chose to examine. If the expected elements did not appear, as is the case when diamond is analysed, it was simply taken as evidence that the *tria prima* are so firmly bonded together as to resist separation by the fire. In any case the doctrines of the elements had sufficient explanatory power to explain to the satisfaction of their proponents whatever results arose during the analysis of various bodies.

The fact is that Boyle's method of thermal analysis did not reveal the elements any more clearly or unambiguously than the same process in the hands of his adversaries, nor did it greatly add to the number of distinct substances obtained and identified by him, over and above what the others had achieved. In all, he settled for five elements in the case of living things; three for minerals. Of course Boyle also employed strong acids or *menstruums* [solvents] either to react with, or to break down various substances, but this process did not increase the number of possible elements as counted by him. Taken to their extreme, experiments such as these inclined Boyle to the belief that an *alkahest* or universal solvent, as proposed by van Helmont, might reduce all materials to a common state, so that a doctrine 'that doth not assert any elements in the sence before explained', would be its logical conclusion.[185] What Boyle needed was a means or criterion for deciding on when the elemental stage had been arrived at, using the analytical methods available to him. This, of course, he never satisfactorily achieved.

1.19. Davis, Tenney, L., '*Boyle's Conception of Element Compared with that of Lavoisier*'[186]

Davis says that in *The Sceptical Chymist* Boyle takes the prevailing notion of chemical element and sets out to enquire whether the so-called 'elements' and 'principles' of the alchemists and chemists of his time are in conformity with that notion. He states that Boyle concludes that they are not, or, at least, that the evidence already adduced in favour of their conformity is inadequate.

It could be argued that this cannot have been Boyle's thesis in writing this work, as the prevailing notion of chemical element in his time was still that of the Aristotelians and Paracelsians, for this was the notion held by the chemists and alchemists alike. Rather what Boyle does is give a definition of the elements, which is not a novel one, and then seeks evidence for the presence of 'any one such body' in all of those bodies 'said to be elemented'.[187] Boyle includes the elements of the Paracelsians and Aristotelians in his search for elementary bodies, and Davis is only partially right in saying that the evidence adduced by his adversaries in favour of the conformity of their notion of the elements

---

[185] *Sceptical Chymist*, p. 226.
[186] Tenney L. Davis, 'Boyle's Conception of Element Compared with That of Lavoisier', *Isis*, Vol. 16, No. 1, (1931) pp. 82-91.
[187] *Sceptical Chymist*, p. 187.

with their ‘elements’ and ‘principles’ is, at least, inadequate, for following on from his own experimental evidence, he broadly concurs with their list of the elements.

Davis continues that the real purpose of the book appears to be a search after criteria by which it may be determined whether a given substance is or is not an element in the sense of the prevailing conception. However, against this it could be argued that Boyle was more interested in vindicating his Corpuscularian Hypothesis of matter, and in promoting its superiority over whatever alternative theories of matter were then current, rather than in trying to establish criteria by which a substance’s elemental nature might be determined.

Boyle faced the dilemma of those who seek something: one cannot find what one is looking for unless one knows what one is looking for. Boyle would first of all have had to affirm: X and Y are elements, and then find criteria which would justify his claim for the elemental nature of these substances. However, because he never could arrive at a set of elements whose elemental status he could then attempt to justify by finding them incapable of being analysed into simpler substances, Boyle never could do what Davis claims for him: he never could try to search for the list of criteria by which materials could be assessed as to their elemental status.

1.20. Duhem Pierre, *Mixture and Chemical Combination and Related Essays*[188]

[188] Pierre Duhem, *Mixture and Chemical Combination and Related Essays,* [1902] ed. and trans. Needham, Paul (Dordrecht: Kluwer Academic, 2002) pp. 31-32.

Duhem says that the elementary corpuscles might unite in a particularly intimate fashion and that according to Boyle ‘form a new body endowed with an individuality as that of the elementary corpuscles before their union’ and that ‘neither fire nor analysis can further divide this body’. Duhem goes on to say that Lémery, then Stahl, then de Venel adopt Boyle’s idea and apply it to metals which preserve their individuality through the hottest fires and most complicated chemical transformation, and that it is this idea that inspired the school of Lavoisier to define the chemically simple substance.

Boyle defined the elements as ‘primitive’, ‘simple’ bodies,[189] so Duhem, in referring to Boyle’s account of elementary corpuscles uniting to form larger entities, cannot have been speaking of the formation of elements, but rather of ‘mixts’ or chemical compounds. Boyle, of course, did regard some ‘mixts’, such as gold, as very ‘fixt’ or unreactive and which could not readily be caused to react with other materials, or to be broken down. There is a fundamental distinction between an element which, by definition, cannot be further broken down, and a ‘fixt’ material which can be further decomposed, but only with difficulty.

Which metals Duhem had in mind is unclear; the most unreactive or ‘fixt’ metal known to Boyle was gold, which could, however, be broken down to form ‘a metalline body of another colour and nature’[190] and which can also be reacted with *aqua regia* [a mixture of hydrochloric and nitric acids] to form a ‘mixt’, in this case auric chloride, as Boyle was

[189] *Sceptical Chymist*, p. 187.
[190] Ibid., p. 216.

well aware.[191] It may be that Duhem was referring to Boyle's example of some 'mixt' bodies from which the fire cannot separate the three Paracelsian principles. Boyle says that there are 'some mixt bodies' from which it has not been possible that any fire, no matter how hot, can 'separate either salt or sulphur or mercury, much less all the three'. He says that the most obvious instance of this truth is gold, which is a body 'so fixt' and in which 'the elementary ingredients (if it have any) are so firmly united to each other', that it loses none of its 'fixedness or weight',[192] and is far from being decomposed into three principles.

Boyle is saying here that gold, even when subjected to high temperatures in the fire, does not lose any of its weight whatsoever. He is affirming that gold is so non-volatile or unreactive that it undergoes no change in the fire; it does not separate into other ingredients. Obviously if it released sulphur, this would burn off and leave the gold degradation product lighter in weight, but as no weight change occurs, Boyle does not take this as evidence that gold is elemental, but rather that it is unreactive and non-volatile, irrespective of its primary constituents. He makes no claims here regarding gold's elemental status and, in fact, in referring to it as one of the 'mixt bodies', he is accepting that it is *not* an element.

Boyle does speak of the elementary ingredients of gold, 'if it have any', and here he is referring most likely to the salt, sulphur and mercury of the Paracelsians, and he doubts

[191] Ibid., p. 31.
[192] *Sceptical Chymist*, p. 39.

that these particular materials are indeed constitutive of gold. He never expresses doubt that gold was anything but a mixt rather than an elemental body.

Duhem states that gold's ability to withstand the hottest fire without decomposition led some of Boyle's successors to confirm its elemental status. However true this may be, for Boyle, gold was a very unreactive material, and the fire failed to separate out the *tria prima* of the Paracelsians, but this did not confirm it as an element, as Boyle clearly believed all along that it was a mixt body.

1.21. Copleston, Frederick, *A History of Philosophy*, Vol. 5[193]

Copleston says that Boyle in his *Sceptical Chymist* (1661) criticised with effect not only the doctrine of the four elements but also the current theory of salt, sulphur, and mercury as the three constituent principles of material things. He continues that according to Boyle's definition, a chemical element is a substance which cannot be decomposed into simpler constituents, though he was unable himself to supply a list of these elements.

Expressing it succinctly as he does, Copleston puts his finger on the core difficulty or shortcoming of Boyle's interpretation of the two theories of the elements proposed by his adversaries. Boyle found that he could legitimately criticise the two theories in question as not accounting for the products of analysis obtained from things of plant and mineral origin, but he himself could not say with certainty which substances actually were elements. Epistemically this puts him in a weaker position than either the Aristotelians or the Paracelsians *vis-à-vis* the elements. At least they could name the elements to their

[193] Frederick Copleston, *A History of Philosophy*, Vol. 5 (London: Continuum, 1959) p. 143.

own satisfaction, whereas Boyle could not do so confidently. In the longer term Boyle's position came to be vindicated when the metals, and a growing list of other substances, came to be recognised as elements.

1.22. Duddy, Thomas, *A History of Irish Thought*[194]

Duddy says that the closest Boyle comes to the modern theory of elements is in the summation of his corpuscularian position, in which he says that:

> 'if it be granted rational to suppose … that the Element consisted at first of certain small and primary Coalitions of the minute particles of matter into Corpuscles very numerous, and very like each other, it will not be absurd to conceive, that such primary Clusters may be of far more sorts than three or five.'

Duddy says that in this passage Boyle is postulating not only the existence of primary particles, but also the bonding of some particles into primary clusters or elements, and that although he is a long way from postulating the complex atomic structure of elements in the modern sense, nevertheless he is groping in the right direction.

Duddy is drawing attention to an interesting part of Boyle's understanding of the fundamental state of matter in its corpuscular form: he is here hypothesising that the corpuscles may not be composed of individual but of compound bodies. Boyle does sometimes equate the corpuscles with atoms and regards them as individual, indivisible entities. However, he does at other times view them as complex entities, compounded from the primary *minima* or *prima naturalia*. (See also 2.31., 2.35. and 2.4.). It could be argued that on this latter reading of Boyle, in speaking of corpuscles as consisting of smaller particles he presaged our contemporary understanding of the elements, in which

194 Thomas Duddy, *A History of Irish Thought* (London: Routledge, 2002) p. 67.

they are perceived as complex structures. An individual element, although in itself representing the simplest, most primitive unit of the material in question, nevertheless is compounded of even smaller units, but an element cannot be broken down into these smaller entities either by fire or by chemical means. (See also 2.1.).

1.23. Sargent, Rose-Mary, *The Diffident Naturalist*[195]

Sargent says that Boyle had learned from his trials, for example, that the *tria prima* were 'not primary', because salt, sulphur, and mercury are 'each of them endowed with several qualities which must be due to another, more primary cause'.

Sargent is correct in stating that the *tria prima* of the chemists are not, in fact, primary, or as Boyle himself puts it, they are not 'fontal enough',[196] meaning that their so-called primary qualities do not come from these elements themselves, but from a source still more fundamental. Boyle gives the example of sulphur which he says is according to them 'a body fusible', but he also quotes this property as belonging to other materials as well, such as 'saltpetre, sea-salt, vitriol and alum'. He argues that the explanation given for the quality of fusibility is that it is a principle inherent in sulphur 'and therefore we are not to exact a reason why it is so', but he rejects this explanation as 'grounded but upon a supposition'. He is confident, however, that one may deduce a 'good mechanical explication of fusibility' in general, from the 'primary affections of bodies'[197] – size, bulk and shape – without having to resort to an explanation in which such properties stem from primogeneal principles such as sulphur.

---

[195] Rose-Mary Sargent, *The Diffident Naturalist* (University of Chicago Press, 1995) pp. 73-74.
[196] *Selected Philosophical Papers of Robert Boyle*, p. 126.
[197] Ibid., p. 127.

In making this argument Boyle is, of course, reaffirming his belief in his Corpuscularian Philosophy, and he is at pains to reiterate that if all the physical properties observed in materials can be traced back to primary qualities possessed by the corpuscles, then the *tria prima* of salt, sulphur and mercury, must themselves have a corpuscular nature. If this is indeed the case then the most primary qualities must stem from the most primitive material bodies, the corpuscles, and not from any entities such as the *tria prima* which are, of necessity, derived from more complex assemblages of the corpuscles.

1.24. Alexander, Peter, *Ideas, Qualities and Corpuscles*[198]

Alexander says that Boyle was still a long way from the concepts of modern chemistry, such as those of a *chemical* reaction and of an element as a *chemical* entity that could remain unchanged through a reaction [Alexander's italics], but that he was even further from the mystical and arcane ideas of alchemy, so his work marks an enormous step in the direction of modern chemistry.

That Boyle was a long way from the concepts of modern chemistry such as those of a chemical reaction and of a chemical element is only partially true, in that he did display a knowledge of how chemicals react, with good examples being provided by the reaction of *aqua fortis* to form silver nitrate, and from which chemical compound the silver could be recovered intact. (See 2.3.1.). Not only did Boyle show an understanding of how materials can be reacted together, but that substances originally present can be regenerated from the reaction products, but he could posit a mechanism for the process in terms of his Corpuscularian Philosophy. Of course Boyle did not recognise silver as an

[198] Peter Alexander, *Ideas, Qualities and Corpuscles* (Cambridge University Press, [1985]2009) p. 19.

element, this was to come later – it appears as an element in Lavoisier's Table of the Elements in 1789 – and it is true that his understanding of the mechanisms of chemical reaction was far short of those which came to be postulated in later centuries. However, Boyle in being able to explain some chemical reactions in terms of his Corpuscularian Hypothesis, (see also 2.3.5., *re* gold) did believe that other chemical reactions could also be explained using his new hypothesis, and in so doing he opened the door on a new way of explaining changes in materials without recourse to mystical and arcane ideas, as Alexander himself observes. And Alexander is correct too in acknowledging Boyle's work as an important precursor to modern chemistry.

Alexander continues that Boyle defines element and principle in at least two places in *The Sceptical Chymist*, and that it is of the utmost importance to realise that these are not definitions of 'element' in the sense of modern chemistry, and references Boas for this comment.[199] (See also 3.14**.** for comments on Boas's opinions). Alexander gives Boyle's definition of element as:

> 'Those primitive and simple bodies, of which the mixt ones are said to be composed, and into which they are ultimately resolved'

and later quotes Boyle's Definition no. 4.

Alexander says that Boyle immediately goes on to cast doubt on the existence of such elements and eventually to deny it.

What Alexander seems to be referring to here is where Boyle, immediately following his definition of element (part of which is quoted by Alexander as Boyle's second definition

[199] Alexander here quotes Boas's *Robert Boyle and Seventeenth-Century Chemistry*, pp. 95-97.

of the term, and given above) in speaking of the elements, says that he questions whether there be 'any one such body' to be met with in 'all and each of those bodies said to be elemented'.[200]

Whether Boyle is actually doubting the existence of such elements here seems unlikely: he seems, in fact, to be accepting the existence of at least one element, and then goes on to question whether it is present in all bodies supposed to consist of elements. Boyle, believing as he did in his Corpuscularian Hypothesis, held that all matter, however it might be arranged in material bodies, could somehow be reduced to a simple, primitive state, i.e. the corpuscular level. So whatever elements Boyle may have believed in had to have a fundamentally simple nature, in other words, they had to subsist in some way, at the corpuscular level. So by the 'one body' … 'met with' in all 'elemented bodies', Boyle may have meant matter itself in its corpuscular state.

Alexander continues that what Boyle particularly objected to is the idea, to be found in both the Peripatetics and the Spagyrists, that every substance in nature is compounded out of some proportion of *all* the elements or principles. [Alexander's italics].

Again this is only partially true, as it could be argued that Boyle was not so much critical of the doctrine that all bodies were composed of either the *tria prima* of the Paracelsians or the four Aristotelian elements, but that he drew a distinction between the decomposition products of a given body and its elemental constituents. He argues that even if mercury, salt and sulphur could be obtained from a body by a process of thermal decomposition, this is no proof that the body is actually constituted of these materials.

[200] *Sceptical Chymist*, p. 187.

He quotes the examples of metals and minerals where he says it is not necessary that 'nature should make up all metals and other minerals' of pre-existent salt, sulphur, and mercury, even though 'such bodies might by fire be obtained from it'.[201] Boyle's reasoning behind this belief is quite simple: he argues that fire itself is an active agent capable of reacting with the materials it is decomposing. For he says that when an object is resolved by the fire into its supposed elements, these may not, in fact, be true and proper elements but rather are 'accidentally produced by the fire',[202] which means that such elements may not have pre-existed in the material in question, but were actually generated during the thermal decomposition of the material.

Boyle observes that there are some mixt bodies, or chemical compounds, from which it has not been proven possible to separate any of the *tria prima*, much less all three. He says that the obvious example of this is gold, which is a body so unreactive and in which the elementary ingredients, if it have any, are so firmly united to each other, that no fire, however hot, is able to resolve it into any or all of the Paracelsian principles.[203] Boyle is here willing to accept that the *tria prima* may be present in gold; at least he does not say that they are not, but he is unwilling to accept their presence until experimental evidence is adduced in support of any such claim.

1.25 Conclusion to Chapter 1

The many opinions expressed in the foregoing accounts serve to illustrate the breadth of interpretations of Boyle's work, even when the scope of the investigation is confined to

[201] *Sceptical Chymist*, p. 195.
[202] Ibid., p. 224.
[203] Ibid., p. 39.

his writings on the elements. Each writer did attempt a sincere analysis of Boyle's understanding of the subject, nevertheless some of them provide a more thoughtful or penetrating analysis of the question.

One obvious pattern is the unconscious tendency to shift Boyle out of his own time and locate him much closer to our own. In so doing he is presented as belonging to a world of science where ideas, theories and insights not actually present in the 17th century had already developed. Worse still, he has statements attributed to him which, not alone did he not make, but did not come to be stated until years after his time. For example, Allen in 1.2. , attributes to Boyle the definition of an element as a substance incapable of being broken down by chemical means. Of course, Boyle never did make this stipulation in relation to the elements: it was actually made by Lavoisier almost a hundred years after Boyle's death.

The opposite can also occur, for example, attributing the first use of the 'modern' definition of element to Boyle, by authors such as Strathern, in 1.4., and Lehmann, in 1.5., and Thorpe in 1.10., whereas both Hooykaas and Boas rightly accord this distinction to de Clave in his definition of 1641.

Causing a Boylean concept to appear as a subject in a debate devised by another author may also occurs as when Kuhn, in bundling 'element' with other scientific terms such as 'time', 'energy', 'force' or 'particle' is including it in a set of concepts which have existed as meaningful terms since antiquity, but whose use in scientific terminology has developed only since the Scientific Revolution. Two such terms – element and particle – have acquired their modern definitions in more recent times. Lavoisier began the process of shaping the modern definition of element in the 1780s, and the definition of particle, meaning 'constituent part of an atom', came into use in the late 1800s.

This anachronistic reading of him puts Boyle in a near impossible position *vis-à-vis* the elements when Kuhn interrogates Boyle's writings on the subject for an account of the elements which would comply with his own particular understanding of the term. One is left wondering whether he is seeking Boyle's insights into the elements, or employing him as a foil against which Kuhn's own interpretation of the Scientific Revolution can be articulated and promoted.

The tendency towards an anachronistic reading of Boyle is also apparent when Pattison Muir says that the only thing lacking in Boyle's definition of element (i.e. Definition no.4) is an experimental method of determining whether a given substance is, or is not, an element. As discussed in 1.16, Boyle's adversaries had such experimental techniques available to them as would reveal *their* elements to them. And what Pattison Muir seems to mean is that Boyle did not have experimental procedures available to him that would deliver the elements as those who followed him, such as Lavoisier, understood the term.

Of those writers who considered Boyle in relation to the history of chemistry, Brock provides the best analysis of Boyle's difficulties when faced with the problem of applying his Corpuscularian Philosophy to the question of the elements. Boas presents a reasoned account of Boyle's approach to the question of the elements, with good insights as to how he approached the issue, but what she says is only a part of a wider commentary on Boyle and of his contribution to the developing science of chemistry. Of all the writers surveyed, the one who makes the greatest attempt at studying and analysing Boyle's own doctrine on the elements is Hooykaas, who clearly read carefully Boyle's writings on the subject and offers an in-depth, well argued analysis of them.

Another keen interpreter of Boyle is Alexander who, in 1.22, recognises him as a transitional figure acting between the precepts of alchemy and those of modern chemistry. He also seems to be a careful reader of the ideas expressed by Boas on Boyle, yet is able to disagree with her. For example, when he says that Boyle objects to the idea, held by Peripatetics and Spagyrists alike, that every substance in nature is compounded of all elements or principles, he is going against Boas who holds the contrary view: that Boyle believes that the same few elements are to be found in all bodies (as discussed in 1.14).

BIBLIOGRAPHY TO CHAPTER 1

Alexander, Peter, *Ideas, Qualities and Corpuscles* (Cambridge University Press, [1985] 2009).

Allen, John, *Robert Boyle Father of Chemistry* (Detroit: Thomson Gale, 2005).

Boas, Marie, *Robert Boyle and Seventeenth - Century Chemistry* (Cambridge University Press, 1958).

Boyle, Robert, *The Sceptical Chymist* (Minneola, N.Y.: Dover Publications Inc., 2003).

Boyle, Robert, *The Sceptical Chymist* (London: J.M. Dent & Sons, 1911).

Brock, William H., *The Norton History of Chemistry* (New York: W.W. Norton & Co., 1993)

Copleston, Frederick, *A History of Philosophy*, Vol. 5 (London: Continuum, 1959).

Davis, Tenney, L., 'Boyle's Conception of Element Compared with that of Lavoisier', *Isis*, Vol. 16, No. 1 (1931) 82-91.

Duddy, Thomas, *A History of Irish Thought* (London: Routledge, 2002).

Duhem, Pierre, *Mixture and Chemical Combination and Related Essays,*[1902] ed. and trans. Needham, Paul (Dordrecht: Kluwer Academic, 2002).

Hall, A. Rupert, *From Galileo to Newton* (New York: Dover Publications, Inc., 1981).

Hooykaas, Reijer, *The Concept of Element: Its Historical-Philosophical Development*, (Utrecht, 1933) [Doctoral Thesis] trans. Kubbinga, H.H., 1983.

Hunter, Michael, (ed.) *Robert Boyle by Himself and His Friends* (London: Pickering, 1994).

Kuhn, Thomas S., *The Structure of Scientific Revolutions* (University of Chicago Press, 1962).

Lavoisier, A.L., *Elements of Chemistry,* trans. Kerr, R., in: *Great Books of the Western World*, Vol. 45 (Chicago: Wm. Benton, 1952).

Lehmann, Walter J., *Atomic and Molecular Structure: The Development of our Concepts* (New York: John Wiley and Sons Inc., 1972).

Leicester, Henry M., *The Historical Background of Chemistry* (New York: Dover Publications, Inc., 1956).

Maddison, R.E.W., *The Life of the Honourable Robert Boyle, F.R.S.* (London: Taylor & Francis, 1969).

Moran, Bruce, *Distilling Knowledge Alchemy, Chemistry, and the Scientific Revolution* (Harvard University Press, 2005).

More, Louis Trenchard, *The Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944).

Multhauf, Robert P., *The Origins of Chemistry* (London: Oldbourne, 1966).

Partington, James Riddick, *A Short History of Chemistry* (New York: Dover Publications, Inc., 1987).

Sargent, Rose-Mary, *The Diffident Naturalist* (University of Chicago Press, 1995).

Sootin, Harry, *Robert Boyle Founder of Modern Chemistry* (London: Chatto & Windus, 1963).

Stewart, M.A., (ed.) *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991).

Stillman, John Maxton, *The Story of Alchemy and Early Chemistry* (New York: Dover Publications, Inc., 1924).

Strathern, Paul, *Mendeleyev's Dream* (New York: Thomas Dunne Books, 2000).

Thorpe, Thomas Edward, *History of Chemistry* (London: Watt & Co., 1909).

Chapter 2

Boyle on Matter

Table of Contents

Chapter 2

Boyle on Matter

2.1. Introduction to Chapter 2

Ask a chemist today how matter is constituted and he will explain that matter is composed of atoms, and that atoms combine to form molecules which can consist of from two to several thousand atoms. Atoms of different species which react together to form compounds retain their individual identities even though the compounds they form may differ markedly in properties from their constituent atoms. He will tell you that the original atoms can be reconstituted by breaking down the compound which they had formed in reacting together (although this may be difficult to achieve in practice). However when a chemical compound is broken down no species smaller than atoms are obtained, no matter what means at the chemist's disposal are resorted to. The reason why is simple. The contemporary interpretation is that material is composed of atoms, but there are two distinct parts to every atom: a set of electrons, and a central nucleus about which they revolve, rather like a solar system in miniature in which the planets are in orbit around the sun. And just as the planets are linked in various ways to their parent star, but yet have a certain independence from it, so too the electrons are linked to their nucleus but still retain properties of their own. One crucial such property is the ability to form chemical bonds, both with atoms of their own species and with others. In fact, chemical reactions occur solely as a result of interactions between the electrons of the reacting atoms, with the nuclei playing no part at all in the process. A variety of bonds can form between different atoms, but all chemical bonding involves only the electrons of those atoms. All chemical changes – synthesis of chemical compounds, degradation of those compounds by fire, light, acids or other agencies – require only changes in the electrons of the atoms concerned, as chemical bonds are made and broken, and transformation from one chemical species to another occurs.

Ask a physicist whether matter is composed of atoms and she will say that, yes, of course it is, and that atoms are indeed composed of electrons orbiting a nucleus, but that is not the whole story. Atoms themselves are built up of even smaller particles. In fact, there is a perfect menagerie of sub-atomic particles, you will be told, but when you enquire as to what the most fundamental particles are, she will tell you that the smallest particles known to date are the quark and the lepton. So, are quarks and leptons the most fundamental particles, or are they, in turn, made up of something even smaller? Our physicist will have to admit that these are indeed the most fundamental particles known, but that something more fundamental may actually exist, and that, yes, something even more fundamental than these may also exist, and so on, into a seemingly endless regression.

Let us return to the chemist's viewpoint. He realises that there may well be particles more fundamental than atoms, but as only the electrons, acting as electrons, are involved in chemical reactions, and only atoms, acting as unitary species, contribute to physical properties, then the fundamental constituents of these atoms are not of any real relevance to him. The chemist sidesteps the questions of infinite regression and fundamental particles simply by stopping his research into atomic structure at the level of integral atoms.

In fact, chemists have been able to do so for more than two hundred years, ever since William Higgins (1763-1825) and John Dalton (1766-1844) devised their versions of the modern Atomic Theory in 1789 and 1803, respectively, but more on this later.

2.2. The Nature of Matter

2.2.1. *Materia prima*

Robert Boyle began his speculation of the nature of matter with a consideration of the opinions of the ancient Greeks on the subject. He says that according to Aristotle and, in his opinion, 'according to truth', there is but one 'common mass' of all things,[204] which he 'has been pleased to call *materia prima*'.[205] However unlike Aristotle, Boyle believed that prime matter existed only *in actu* and not *in potentia*, and is critical of Aristotle's philosophy to the extent that 'one distinction of *actu* and *potentia* runs through almost all of Aristotle's philosophy', and is employed to shift off 'those difficulties he could not clearly explicate'.[206] Boyle states that we 'may without absurdity conceive that God, of whom in the scripture it is affirmed *that all his works are known to him from the beginning* [Boyle's italics] to make such a world as this of ours'. Boyle does seem uncertain as to what state the matter in the created would take on, for he says that ' [God] did divide' the matter into 'an innumerable multitude of variously figured corpuscles', but that He may have proceeded to create the world in this way 'at least if he did not create it incoherent'.[207] What exactly Boyle means by 'incoherent' is unclear, for according to the Biblical account, at the point of Creation 'the earth was a formless void' (Genesis 1:1)[208] but that all things proceeded from this through divine agency. Although he does not state so explicitly, perhaps Boyle was echoing Plato's *Timaeus* who, in describing the origins of the world, speaks of the whole visible sphere not 'at rest but

---

[204] According to Anstey it was '…most likely a motionless block of extended substance'. In: Peter Anstey, *The Philosophy of Robert Boyle* (London: Routledge, 2000) p.41.
[205] *Sceptical Chymist*, p. 83.
[206] *Selected Philosophical Papers of Robert Boyle*, p.9.
[207] Ibid., p.159.
[208] *The Jerusalem Bible.*

moving in an irregular and disorderly fashion'. Out of disorder the god brought order, 'considering that this was in every way better than the other' (*Timaeus* 30A).[209]

Boyle believes that there is 'only catholic or universal matter common to all bodies' by which he means a 'substance extended, divisible, and impenetrable'.[210] Then at the first production of 'mixt bodies' the universal matter, of which they as well as other parts of the universe consisted, was actually divided into 'little particles of several sizes and shapes'.[211]That matter in all its manifestations really does consist of the same prime matter is reinforced by Boyles' analogy with wood. Some tools reduce bulk wood into parts of 'several shapes, bigness and other qualities'. It can be divided into larger parts by axes and wedges, some long and slender, as splinters, and some thicker and more irregular as chips, but all of these wooden pieces are of considerable bulk. They could be likened to corpuscles, all of which differ in size and shape but none of which is extremely small or very large. Then wood can be converted into smaller units than these, as when it is converted into sawdust, into wood shavings when planed, or into 'shives or thin and flexible'[212] pieces of wood that are obtained by borers. In all of these cases the same wood is converted into smaller pieces, but in the second set of examples larger cuttings of wood taken from the block are converted into much smaller pieces. However, regardless of their size, shape and aspect, they are all compounded of the common ligneous material.

---

209 *The Collected Dialogues of Plato*, p.1162.
210 *Selected Philosophical Papers of Robert Boyle*, p. 18.
211 *Sceptical Chymist*, p. 30.
212 Ibid., p. 212.

Boyle might well have had in mind some of the Greek terminology used in connection with wood, as his example of a primary material which can be subdivided to give various shapes and sizes of that same matter suggests. For the Greek word *hylē* can indeed mean matter, stuff, raw material, but its primary meaning is wood,[213] and Boyle might well have had in mind the association of wood with matter. This would be consistent with Boyle's considering all materials as fundamentally constituted of the same woodiness or universal matter.

2.2.2. The Rôle of Water

Boyle has another insight into the identity of the primordial substance from which all other matter is built up, and for him 'the primitive and universal matter'[214] and that this has been stated by many ancient authorities, including the Book of Genesis, 'where the waters seem to be mentioned as the material cause',[215] not only of sublunary compound bodies, but of all those that make up the universe. He says that other ancient authors who shared this view included Thales, and the Greek author the Scholiast of Apollonius, who affirms (out of Zeno) that the chaos from which all things were made, was, according to Hesiod, water. And water, settling first, became slime, which then condensed into solid earth. Boyle goes on to say that Strabo offers the opinion that the Indians held that 'all things had different beginnings, but that of which the world was made, was water'. He adds that the same opinion has been ascribed by some of the ancients to the Phoenicians, from whom Thales is believed to have borrowed it.

[213] Liddell and Scott, *Greek-English Lexicon*, p. 829.
[214] *Sceptical Chymist*, p. 71.
[215] Ibid., p. 71.

Boyle, being a devout Christian, would surely have taken the Old Testament very seriously. (He had, after all, gone to the trouble of learning Hebrew so that he could read it in the original). It could be argued that he would have taken the authority of the Bible more seriously than that of the Greeks and other ancient sources, but what would have counted heavily for him, apart from the Bible, was the experimental evidence obtained directly by him, or under his direction, and by van Helmont. He had his gardener grow a 'pompion'[216] [pumpkin] in earth which had beforehand been dried and weighed. The earth was then dried and reweighed, when the pumpkin had been harvested, and negligible weight loss found to have occurred. He himself also grew several small plants: 'a top of spearmint, about an inch long' which he grew in a 'good vial full of spring water'.[217] He also 'tried the like' with 'sweet marjoram, balm and peniroyal'.[218] He distilled these vegetables and obtained both a liquid distillate and a small solid residue 'which appearing to be a coal, I concluded it to consist of salt and earth'.[219] He also recounted van Helmont's experiment of growing a tree for five years in a weighed quantity of earth, and that of the original 200 pounds of earth the final weight loss amounted to 'a couple only of ounces', so that 164 pounds of the root, wood and bark, which constituted the tree, seem to have 'sprung from the water'.[220] From which experiment 'the bold and acute' van Helmont drew the conclusion that 'all mixt bodies spring from one element' [water].[221]

[216] Ibid., p. 65.
[217] Ibid., p. 66.
[218] Ibid., p. 67.
[219] Ibid., p. 67.
[220] Ibid., p. 68.
[221] Ibid., p. 69.

There can be little doubt but that Boyle greatly admired the experimental work of van Helmont, and says that he was ‘an author more considerable for his experiments than many men are pleased to think him’.[222] Boyle reinforces this view by acknowledging that his own efforts at growing plants in water (all of which were of much shorter duration than the five years spent by van Helmont in growing his willow tree) were such that he should ‘scarce think it fit to have his experiment and mine mentioned together’.[223] Nevertheless the hypothesis put forward by van Helmont that plant growth occurred purely from the transmutation of water seems to Boyle so ‘paradoxical’ a truth that the findings of these experiments ‘need to be confirmed by more witnesses than one’.[224] What Boyle seems to be saying here is simply that van Helmont’s experiment had not been tested for its reproducibility, but then Boyle makes a rather ambiguous statement on van Helmont as experimenter. Firstly, he questions his trustworthiness by doubting some of his experimental findings ‘especially since the extravagancies and untruths to be met with in Helmont’s treatise of the Magnetic Cures of Wounds, have made his testimonies suspected in his other writings’.[225] Secondly, by contrast, Boyle testifies to van Helmont’s veracity by saying that as to some of the ‘unlikely matters of fact’ he delivers in those other writings ‘I might safely undertake to be his compurgator’.[226] Boyle, then, seems to accept some of van Helmont’s experimental findings but to reject others.

---

[222] Ibid., p.67
[223] Ibid., p.67.
[224] Ibid., p.67.
[225] Ibid., p.68.
[226] Ibid., p.68.

The difficulties faced by van Helmont in carrying out this experiment are stated by Boyle to be 'so uneasie to be made and to be judged of'.[227] Boyle may simply be sympathetic to the difficulties encountered by a fellow experimenter in controlling the experimental conditions in an experiment of five year's duration. Boyle's understanding of van Helmont's experimental difficulties notwithstanding, his feelings of unease at the latter's experimental method would surely have contributed to his scepticism on the outcome claimed by that experimenter.

Boyle then makes reference to what is probably the greatest shortcoming of all in van Helmont's experimental method, and this is that 'his inference from them is somewhat disputable'.[228] And here Boyle puts his finger on the real failing in van Helmont as an experimenter by his concluding that for a tree grown in earth the only substance necessary for its growth is water. One could argue that although trees do push roots into the ground, and require water in order to grow, in a rigorously designed experiment van Helmont would have had to exclude the possibility that air and light play a part in plant growth. This he could have done by planting up four willow trees instead of one, and putting one into a dark cupboard and subjecting it to the same maintenance regime as the tree grown in the presence of air and light, then excluding the air from the third tree (perhaps by submerging it in water) and placing the assembly in a well illuminated area. The fourth tree could simply have been grown outdoors and exposed to normal growing conditions, as a control. van Helmont would then have found out in far less than five years that the tree grown in darkness and the one grown under water did not grow

[227] Ibid., p.69.
[228] Ibid., p.69.

successfully. In short, van Helmont in asserting that the proposition 'a willow tree needs water in order to grow' and which is valid, does not entail the proposition 'a willow tree needs only water in order to grow', which he took to be the case, and which is invalid.

One might speculate as to whether van Helmont was a Naïve Inductivist. Certainly Boyle's description of his experiment in growing a willow tree would lend credence to such an opinion. Boyle does say that van Helmont holds the opinion that 'all mixt bodies spring from one element' [water], and as to his reasons for this belief, 'you may find divers of them scattered up and down his writings'.[229] This does seem to indicate that van Helmont was not using the tree growing experiment as a means of formulating this belief that water is the primal element, but rather as providing further evidence for a belief he already held. If this is indeed the case then one might take issue with van Helmont over this experiment, for Ladyman says that the Naïve Inductivist must 'observe the world carefully and without preconception',[230] as otherwise the resulting beliefs will not be justified. It may well be that van Helmont did not comply with the requirement of having no preconceptions when he commenced his tree growing experiment, as it is quite possible that he already believed that water was the original element. Boyle did express his unease as to van Helmont's experimental rigour, and to his concluding that only water was necessary for plant growth, both of which serve to cast doubts on van Helmont as a true Naïve Inductivist.

[229] Ibid., p.69.
[230] *Understanding Philosophy of Science*, p.29.

Boyle is cautious in accepting van Helmont's hypothesis that the growth of wood occurs solely from the transmutation of water. As a careful observer of nature, he would have noticed how all growing plants seek the light, and that if the light is excluded plants become blanched. For he also mentions, besides water, the influence of 'streams of several bodies wandering in the air'[231] which may simply refer to dust or other particulate bodies extracted by some filtration process from the air by the growing plant. He also refers to a 'certain spirituous substance'[232] which the plant may somehow absorb from the air. This may well be a prescient understanding by Boyle that the air plays a necessary rôle in the formation of plant material. Of course we now know that this substance is carbon dioxide, which is fixated through photosynthesis, in which carbon (from carbon dioxide) and water are converted into plant tissue, using light energy absorbed by chlorophyll. It must be said against Boyle, however, that he did not follow up on any of the hunches he might have had regarding what else, apart from water, might be necessary for plant growth to occur.

Interestingly, if Boyle did indeed believe that water is the universal matter, he would have presaged our contemporary understanding of what the fundamental element actually is. For physicists now believe that the primordial element is, in fact, hydrogen, the simplest atom in terms of atomic structure, with the atomic number 1, and which is believed to constitute approximately 88% of all the matter of the visible universe.[233] The present-day understanding is that in stars, such as the sun, hydrogen is fused into helium, which the release of vast quantities of energy, and that helium, with atomic number 2, is

---

[231] Ibid., p. 67.
[232] Ibid., p. 67.
[233] Emsley, John, *Nature's Building Blocks* (Oxford University Press, 2001) p. 4.

in turn transformed into lithium, atomic number 3, and so on until higher and higher atoms are built up and eventually distributed throughout the universe. And of course a theory which posits the production of all atoms simply by building them up from smaller ones provides a simple and elegant account of how matter in all its varieties comes to be.

It is perhaps worth considering that water itself consists of two atoms of hydrogen to one of oxygen, which means that hydrogen in the form of a 'mixt' or chemical compound would have been constitutive of the primordial water.

2.2.3. Matter and Motion

Having agreed 'with the generality of philosophers' that there is one 'catholic or universal matter' common to all matter, by which he means a 'substance extended, divisible, and impenetrable',[234] Boyle goes on to say that because this matter is of but one nature, the diversity we see in bodies must consist in something other than the matter from which they are composed, and since we cannot see how there could be any change in matter if all its parts were always at rest among themselves, it follows that to differentiate the universal matter into a variety of natural bodies, it must have motion in all its specifiable parts. This motion, in turn, must have various tendencies, which is evident in the great quantity of motion in the universe or general mass of matter.

Boyle considers the fact that local motion in many parts of matter is 'manifest to sense',[235] but goes on to discuss how matter came by this motion. He says that the

[234] *Selected Philosophical Papers of Robert Boyle*, p. 18.
[235] Ibid., p. 18.

ancient corpuscularian philosophers, not acknowledging an ‘Author’ of the universe, were thereby reduced to make matter and motion connate and therefore coeval. Boyle, however, rejects this line of reasoning. He argues that local motion, ‘or an endeavour at it’, is not included in the nature of matter, which is as much matter when it rests as when it moves’.[236] He says that matter in motion can be reduced to rest, and will remain in a state of rest until acted upon by an external agent and set in motion again. He goes on to say that one of the Greeks, ‘an eminent philosopher of old’ (whom he does not name) proposed ‘that opinion (for the main) that the excellent Descartes hath revived amongst us that the origin of motion in matter is from God’.[237] The unnamed Greek philosopher may well have been Aristotle who said that ‘the prime mover must be essentially immovable’.[238]

---

[236] Ibid., p. 19.
[237] Ibid., p. 19.
[238] Aristotle, *Metaphysics*, 1073[a], XII, viii, xxvii.

2.3. Corpuscles, Atoms and *Minima*

2.3.1. Divisibility of Atoms

Boyle speaks of 'indivisible corpuscles called *atoms*',[239] [Boyle's italics] in *The Origin of Forms and Qualities*, which seems to mean that to him the term 'corpuscle' is equivalent in meaning to 'atom', and meaning the smallest unit of matter that can exist in the free state. However, later on in the same work he speaks of a great quantity of particles of matter which 'being entire or undivided, must needs both have its determinate shape and be very solid' and, because of its smallness and solidity, nature 'doth scarce ever divide it' and these particles may be called '*minima* or *prima naturalia*'.[240] [Boyle's italics]. Here Boyle introduces two new terms for the smallest divisions of nature, viz. *minima* and *prima naturalia*, which seems to have the same definition as corpuscles and atoms, given above.

He does, however, introduce a new condition into his definition of the smallest entities, by saying that they are capable of being divided by nature, although with difficulty. One could argue that this cuts across one of the key criteria by which atoms are defined, viz. indivisibility. Boyle does call these entities *minima* and *prima naturalia,* rather than atoms, in his example just referred to, and yet the descriptions he applies to them, of 'determinate shape' and 'solidity', are the same as those used in his definition of the term 'atom'.

---

[239] *Selected Philosophical Papers of Robert Boyle*, p. 7.
[240] Ibid., p. 41.

It may be that Boyle's thinking on the question of the definition of the atom had evolved over time and that by the time he wrote *The Origin of Forms and Qualities* (published in 1666) he might simply have believed that atoms were, in fact, divisible, and that in stating they were indivisible earlier in the article, it was part of a stock definition of the word 'atom', which, by definition, implies indivisibility, but which he had, in reality, already abandoned, and that he gave his considered opinion on atoms when he said they were divisible. The reason why Boyle's thinking on the question of the definition of the atom seems to have undergone such a significant change may simply reflect his own development as an experimenter. Early on in his career in his *Of Ye Atomicall Philosophy* he seems not to have agreed with the Aristotelian representation of the opinion of Democritus and Epicurus that atoms were 'mathematical points',[241] which are 'absolutely indivisible and without quantity',[242] but rather as the smallest particles of bodies which can be 'further divided by imagination, yet they cannot by nature'.[243] These bodies, however small they may be, are material entities, and are therefore possessed of extension: they are allowed of both 'quantity and figure'. That nature cannot subdivide them further Boyle attributes to her inability to resolve bodies beyond a certain limit, which means that she cannot proceed *ad infinitum* in her resolution of natural bodies but must 'necessarily stop somewhere' and end up with bodies which are no longer capable of being subdivided *by nature*.[Italics added]. These bodies at the limits of the natural subdivision of matter may be 'justly termed atomes'.[244] Crucially for Boyle in his rôle as experimenter, the existence of atoms as the smallest subdivision of particulate

[241] Richard S. Westfall, 'Unpublished Boyle Papers Relating to Scientific Method – II', *Ann. Sci*. Vol. 12 (1956) p.112.
[242] Ibid., p.112.
[243] Ibid., p.112.
[244] Ibid., p.112.

matter can be argued for precisely because most of the phenomena of nature seem to 'evince the being of atomes' in their various manifestations. He says that for most 'similar bodies' [i.e. homogeneous materials] it is 'very probable' that they are composed of atoms since it is so that their constituent particles are very small and of the same nature as the bulk material which they make up, and gives as example silver. (He is careful to state that there are some materials which seem to be homogeneous in composition, such as milk and wine, but which can, in fact, be separated into distinct fractions). Boyle says that silver can be dissolved in *aqua fortis* [nitric acid], one of the most powerful reagents known. Even when the solution has been so well filtered that it can pass through cap paper [filter paper] the solution appears perfectly clear, indicating that the silver particles are now so small as to be invisible. He could then argue that the silver has indeed been reduced to the ultimate extent, i.e. to the atomic state. Yet bulk silver can be recovered from the solution 'by precipitating',[245] verifying that silver was present there all along.[246] [247]

Boyle, then, employs an argument centred on the reduction of a bulk material, in this case metallic silver, to its smallest subdivision, brought about by the action of a powerful and aggressive reagent, nitric acid, to serve as strong evidence in favour of the atomic hypothesis. His experimental procedure is set out: silver as bulk metal is replaced by a clear solution which shows no evidence of the presence of the metal, only for the bulk

[245] Ibid., p.112.
[246] Lüthy *et al*. make the point that Sennert employed this same experiment for one of his most important demonstrations for the existence of corpuscles, the *reductio in pristinum statum*. They state that Boyle borrowed a number of such demonstrations from Sennert. In: C. Lüthy, J.E. Murdoch and W.R. Newman, *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: Brill, 2001) p.15.

[247] Newman offers a photographic demonstration of this Sennertian experiment in: William R. Newman, *Atoms and Alchemy* (University of Chicago Press, 2006) figs. 1 – 8.

silver to be reformed out of the solution through precipitation. A detailed account of preparing the clear solution of silver is provided, enabling other workers to repeat the experiment if they so wished. Boyle reasons that, because bulk silver is present at the beginning and end of the experiment, then silver must also be present during every intermediate stage as well. Therefore, the clear solution must also contain silver, and because the *menstruum* employed, nitric acid, so thoroughly and effectively dissolves the bulk metal, there are no grounds for believing that the dissolution process does not go to completion i.e. that the metal is indeed reduced to the smallest subdivisions possible – the atomic state. Boyle's conclusion that the atomic state is arrived at, in which the miniscule particles arrived at are indeed metallic silver (and not some degraded form of the metal) is demonstrated by the fact that the original bulk silver can be regenerated from the solution by precipitation. So, for Boyle, atoms had extension, which means that they consisted of some kind of matter, yet they were not actually divisible, by nature.

Atoms, then, are very small, but can persist intact through various chemical operations, and can be restored to their original bulk condition by appropriate chemical manipulation. The dissolution of a metal and its subsequent restoration, Boyle takes as evidence that atoms retain their identity intact during chemical reactions.

By the time Boyle came to write *Certain Physiological Essays*, published in 1661,[248] his thinking on the divisibility of atoms seems to have developed to the point where he no longer considered them to be indivisible. He gives some examples of his understanding on how exactly atoms behave.

[248] *Works of Robert Boyle,* Vol. 2, 1661.

His first example seems to be inspired by the case of diamond, which he understands to be the hardest stone of all. He has been advised by 'artificers vers'd in the trade'[249] that diamond resists attrition by any other stone, yet he realises that diamonds may be 'reduc'd to powder'[250] by other diamonds. He presents the case of two cubical corpuscles lying on top of one another to which a third is added. If this aggregation is given a violent knock by some other corpuscles it can be broken in the centre of the entire assemblage, and consequently in the middlemost body. This would be the case even if the corpuscles consisted of diamond. Irrespective of how hard corpuscles are, they can be broken if a sufficiently high force is applied to them. Boyle simply seems to understand that a very hard material, such as diamond, is also brittle, and that if an assemblage of brittle bodies is bent by applying a bending moment to each end, the aggregate will break where the bending moment reaches its maximum, which is at the centre of the collection of bodies. (Provided, of course, that the bending force is sufficient to actually rupture the material).

2.3.2. The Nature of Corpuscles

Boyle also seems to speculate on the nature of corpuscles themselves, and wonders whether they might be solid or liquid in behaviour. He realises that solid corpuscles can, under the proper circumstances, create a liquid-like substance, when in bulk form. He gives as an example 'bodies which are all or most of them hard'[251] and appear so when 'commodiously connected'[252] to each other, and yet constitute a fluid body when reduced

[249] Ibid., p. 164.
[250] Ibid., p. 164.
[251] Ibid., p. 186.
[252] Ibid., p. 186.

to a sufficiently small particle size and put into a ‘convenient motion’.[253] Solid corpuscles can behave as a liquid, simply by the constituent corpuscles moving smoothly past each other.

This insight indicates that Boyle understands an important fact in relation to the behaviour of solids and liquids. Solids are not necessarily composed of solid corpuscles; neither do liquids have to consist of liquid corpuscles. He gives two good examples to illustrate his insight. The first is that of the ‘dust of alabaster’,[254] the particles of which were still visible as solid powder, and when put into motion behave as a liquid, but once the agitation ceased, returned to the appearance of a compact powder. Boyle can see from this examples that solid corpuscles (or in this case dust particles) can, under certain conditions, behave as a liquid. In fact when the corpuscles can move easily with respect to one another they behave in a liquid-like manner.

Boyle gives as his second example the freezing of water. The ‘particles of water’[255] constitute a liquid under normal conditions, yet those same particles of water can form hard and brittle ice. Boyle makes a connection between the liquidity of water and the solidity of ice, with the apparent liquidity of the moving particles of alabaster dust, and its apparent solidity when it is no longer agitated, for he says that liquid water is turned into solid ice when the corpuscles from which water is constituted ‘are reduced to be at rest’.[256] He seems to realise that when water is cooled down, the agitation of its

[253] Ibid., p. 186.
[254] Ibid., p. 187.
[255] Ibid., p. 187.
[256] Ibid., p. 187.

corpuscles is reduced until they are no longer in motion, at which point they constitute a solid material, i.e. ice. This linking of corpuscular motion with liquidity, or the liquid state, was not demonstrated until two hundred years after Boyle's birth, when Brownian motion was first observed in 1827. The botanist Robert Brown (1773-1858) '…reported that grains of pollen suspended in a liquid move erratically from one place to another, as if under constant agitation.'[257]

Boyle has still another perspective on the question of the nature of atoms or corpuscles. Given that the same corpuscles can form either solids or liquids, it invites such questions as what solidity and liquidity actually are. It is not simply a question of solid corpuscles forming solid materials and liquid corpuscles forming liquid materials, and Boyle could not really say how atoms or corpuscles were configured in the first place. His stock description of them is that each one:

> 'Being entire or undivided, must needs both have its determinate shape and be very solid'.[258]

However, given that qualities such as 'solidity' and 'liquidity' are not inherent in materials but only depend upon whether the corpuscles of the material are at rest or in motion, the question does arise as to the nature of the corpuscles themselves: can they really be solid or liquid? Boyle, also, reflects on this problem and gives as an example the 'least particles'[259] of fluid bodies if they were not (many of them at least) endowed

[257] Raymond A. Serway, *Physics for Scientists and Engineers*, 4th edn. (Philadelphia: Saunders College Publishing, 1996) p. 529.
[258] *Selected Philosophical Papers of Robert Boyle*, p. 41.
[259] *Works of Robert Boyle,* Vol. 2, 1661, p. 186.

with their own ‘bigness and shape’[260] but instead such fluid bodies could be always divided into ‘fluid ones’[261] and even into very small fluid particles indeed. So fine could they become that they could pass through any filter. If this is the case, is there any limit to the divisibility of truly liquid corpuscles?, as they would always ‘be divided into particles fluid also’,[262] and if the corpuscles themselves were inherently fluid in nature, could they not be subdivided *ad infinitum*? However, Boyle then says that divisibility is a ‘primary affection of matter itself’, and that the possibility of subdivision belongs as much to solid bodies as to fluid ones. He does accept that ‘an endless division, of matter, fluid or solid, might be made mentally’, yet it remains to him ‘a great question’,[263] exactly how far nature subdivides bodies.

Although Boyle does not pursue the subject any further, the question he really seems to be beginning to consider was: what physical description could be applied to the smallest units of matter? Could they have labels such as ‘solid’ or ‘liquid’ applied to them, if these qualities belong only to aggregates of corpuscles? If even diamond – the hardest substance – can be broken, could not the hardest corpuscles be broken as well?, and if corpuscles are intrinsically liquid, can there be any limit to their possible subdivision? Boyle might simply have been coming to the realisation that ‘solidity’ and ‘liquidity’ were not qualities inherent to corpuscular entities *per se*, but rather could only be applied

[260] Ibid., p. 186.
[261] Ibid., p. 186.
[262] Ibid., p. 186.
[263] *Works of Robert Boyle,* Vol. 2, 1661, p.187.

to aggregates of corpuscles. In other words, ‘solidity’ and ‘liquidity’ were terms which could only legitimately be applied to bulk materials and not to the individual corpuscles from which these materials were constituted.

Of course, the same problems are faced today. Are atoms solid, liquid or what? Just how solid is a solid block of material? Are atoms really indivisible? As to solidity, we look upon an atom as consisting largely of empty space, rather as the solar system, from the point of view of detectable matter, consists of a great deal of empty space between the planets themselves, and between the planets and the sun. And just as most of the detectable matter of the solar system is located in the sun, so too is most of the mass of an atom concentrated in its nucleus. One can visualise an atom as an assemblage of charged particles undergoing curious exchanges, attractions and repulsions, the sum total of which give no sense of such familiar properties as solidity, liquidity, colour, shape and texture. It could be argued that we sidestep the question of describing an atom in familiar terms by pleading that the properties of atoms as atoms belong to the realm of quantum mechanics rather than to the macroscopic world of sense-perception, which is better represented by Newtonian mechanics.

Boyle is at pains to differentiate between his Corpuscularian Philosophy and the Atomic Theory of the Epicurians. He does not accept ‘that *atoms*, meeting together in an infinite *vacuum* [Boyle’s italics] are able of themselves to produce the world and all its phenomena’.[264] Nor does he go along with ‘some modern philosophers’ that ‘supposing God to have put into the whole mass of matter such an invariable quantity of motion’, he

[264] *Selected Philosophical Papers of Robert Boyle*, p.38.

needed to do no more than to make the world, ‘the material parts being able by their own unguided motions to cast themselves into such a system’.[265] Instead, for Boyle, who argues only for such a system as reaches only to corporeal things, and, differentiating between ‘the *first original of things* and the subsequent *course of nature*’ [Boyle’s italics], teaches in relation to the former not only ‘that God gave motion to matter, but that in the beginning He so guided the various motions of the parts of it as to contrive them into the world he designed they should compose’ and in addition furnished with the seminal principles and structures or models of living creatures. It was God who established those ‘*rules of motion*, and the order amongst things corporeal, which we are wont to call the *laws of nature*’. [Boyle’s italics]. Boyle is anxious to locate his Mechanical Philosophy not among atheistic systems, but rather to anchor it firmly as a Christian one, and says that ‘the universe being once framed by God’, and the laws of motion being settled and all upheld by ‘his incessant concourse and general providence’, the phenomena of the world are physically produced by the ‘mechanical affections of the parts of matter’, and that they operate upon one another ‘according to mechanical laws’.[266]

It might well be that the questions which emerged to confront Boyle as well as ourselves really only arose when one realises that atoms are not, in fact, indivisible. As discussed earlier in 2.3.1., Boyle, in common with Epicurus and other ancient atomic theorists, initially had accepted indivisibility as a fundamental atomic property, but later he seems to have come to consider atoms as, in fact, divisible. An obvious reason why he would have rethought his opinion on atoms’ indivisibility may simply have resulted from his

[265] Ibid., pp. 137-138.
[266] Ibid., p.139.

own religious convictions. In framing his hypothesis on matter, he believed in the divine creation of the world, and this may have led him to the conception of all created matter as collectively constituting prime matter. And prime matter is, in turn, converted into corpuscles or atoms. For this process to be effected prime matter must be divisible, and Boyle acknowledges it to be so, but if prime matter is divisible and all corpuscles or atoms are split off from this common primordial stuff, how then can these same corpuscles or atoms not be as divisible as the prime matter from which they derive?

Although Boyle did come to believe that atoms were divisible, he did qualify his opinion by stating that they were actually divisible only with difficulty. It could be argued from this that prime matter itself may be as difficult to divide as the corpuscles or atoms into which it was divided at the time of Creation. This could, in turn, lead to the conclusion that under normal circumstances matter is not divisible but that in some special circumstances it can actually be subdivided. Divine intervention may be cited to account for the initial splitting up of the primeval universal matter into atoms or corpuscles, and some special conditions could be invoked to facilitate the division of atoms or corpuscles. Boyle suggests severe mechanical forces, acting on an assemblage of three corpuscles, in his discussion of the cleavage of those hard corpuscles.

We, of course, face the same problem in explaining how atoms can be split, and our account also invokes the proviso that the process can only be effected under special circumstances. Our present understanding is that atoms consist of electrons far removed from the tiny nucleus which they surround. All chemical reactions involve only the electrons of the participating atoms. The atomic nuclei simply do not play any rôle whatsoever in chemical reactions, and remain untouched and uninvolved in all chemical processes. However, atoms can be made to split by applying vast quantities of energy, not to the electrons, but rather to the nuclei which those electrons surround, and under these very special conditions atomic nuclei can be caused to split and to form other, smaller, atoms. Whereas chemical reactions have been caused to occur for millennia, atoms were first induced to split in an experiment carried out by Ernest Rutherford (1871-1937) in 1919.

It seems that Boyle did not distinguish between the stuff of universal matter and that of corpuscles or atoms. He seems to have believed that all atoms were made of the same universal matter and differed only in outward physical characteristics. For he says that at the first production of 'mixt bodies'[267] [chemical compounds] the universal matter, of which they and other parts of the universe were constituted, was actually divided into 'little particles of several sizes and shapes variously moved'.[268]

What Boyle does not seem to say is whether all of the particles of a particular size or shape constitute a particular chemical species. For example, are all pyramidal-shaped particles of a particular size constitutive of a single atomic species? Boyle seems to hint that the variations in the 'figure or shape' and 'size'[269] of the universal matter represent the variety of atomic species. And although he makes frequent reference to the importance of motion in his scheme of things, nevertheless he seems to rule it out as an

[267] *Sceptical Chymist*, p. 30.
[268] Ibid., p. 30.
[269] *Selected Philosophical Papers of Robert Boyle*, p. 20.

inherent characteristic of corpuscles or atoms, for he says that 'local motion, or an endeavour at it, is not included in the nature of matter, which is as much matter when it rests as when it moves'.[270] Matter then, is the same matter when in motion or at rest.

2.3.3. Corpuscular Density

In fact it could be argued that Boyle does not really come to grips with the question of variations in density between different materials. Given that he holds that there is but one universal matter, yet allows of a large number of materials, of different densities, causally derived from it, how does he actually account for their production from this common source? His analogy of the dividing up of wood to give a great variety of shapes, sizes and textures has already been discussed (in 2.2.1), but no matter how wood is subdivided all of its derivative products are as wooden as the blocks from which they are cut, scraped or sawn. The universal matter is divided into atoms or corpuscles, each having its own 'magnitude, or rather size, and its own *figure* or *shape*' [271] [Boyle's italics], but to what degree can variations in size or shape of its constituent corpuscles or atoms affect the density of a material? Boyle discusses three materials: water, mercury and gold.[272]

He says that mercury is a little less than fourteen times as heavy as water and gold about nineteen times heavier. However, because all corpuscles, whether water, mercury or gold are derived from the same prime matter, the density (i.e. the weight per unit volume) of all corpuscles, as corpuscles, must be the same. Of course, Boyle does say that corpuscles differ in figure or shape, and this could surely account for at some differences

[270] Ibid., p. 19.
[271] Ibid., p. 20.
[272] Ibid., p. 124.

in density. It can, but the differences in the density of various materials cannot simply be accounted for by differences in the shapes of the corpuscles of which they are composed. One can illustrate this by considering two corpuscular shapes – cubes and spheres. If a given volume is filled with identical, contiguous wooden cubes, the cubes can, of course, fit perfectly together, without any spaces between them. Therefore, corpuscles of this shape fitting snugly together would give a material as dense as could be achieved from wood. Call this density two units. Now imagine, if you would, that wooden spheres of the same breadth as the wooden cubes were substituted for them. Wooden spheres would now occupy the same total volume as that previously occupied by the wooden cubes. However, because wooden spheres when packed tightly together can only touch one another at six points, leaving several spaces between each one, they will not weight as much as an equal volume of cubes. In fact, the density of the assembled spheres would be slightly over one unit, i.e. little more than half of the density of the cubes, but Boyle acknowledges that there is approximately a nineteen-fold difference in density between water and gold. It is difficult too see how such a difference could be accounted for by changing the shapes of the corpuscles, as moving from cubes to spheres changes the density by only about half. Substituting pyramidal, conical, or ovoid corpuscles simply will not lead to a nineteen-fold decrease in density relative to that of cubical corpuscles.

Perhaps the differences in density could be accounted for by positing that corpuscles are compressible or spongy and can be forced together into a smaller volume, and thereby form a more dense material? However, Boyle refers to the universal matter as ‘impenetrable’.[273] This implies that it is also a hard, incompressible material, and consequently corpuscles are not likely to be capable of being squeezed into a smaller volume to yield a higher density. In the *Producibleness of Chemical Principles* Boyle says that mercury and the other metals derive their great weight from the ‘solidity and close order of the corpuscles they consist of’,[274] but how can a metal owe its weight to the solidity of its constituent corpuscles, given that all corpuscles derive from the same universal matter? On this account gold corpuscles should be no more or no less solid than those of water. In other words, if all corpuscles are made from the same prime matter they should all weigh the same for a given volume. And on the question of the ‘close order’ or packing together of the corpuscles, no matter how close the corpuscular packing may be, it is difficult to account for more than about a two-fold difference in the density of materials simply by differences in the packing together of their corpuscles.

If one poses the question: how does a given material, such as gold, have a particular identity? Is it because it is composed of corpuscles of a certain, distinct, size or shape? In his essay *About the Excellency and Grounds of the Mechanical Hypothesis*, Boyle gives some insights into his thoughts on the matter. He says that there can be no ingredient that has a real existence in nature that may not ‘be deriv’d either immediately, or by a row of decompositions, from the universal matter, modifi’d by its mechanical affections’.[275] He gives as an analogy the building of structures with bricks. He argues that if walls, houses, furnaces and other structures, as vaults and pyramids, may be constructed by various arrangements of the more or less identical bricks, then how much greater a

[273] Ibid., p. 18.
[274] *The Works of Robert Boyle,* Vol. 9, 1678-83, p. 90.
[275] *The Works of Robert Boyle,* Vol. 8, 1674-76, p. 114.

variety of structures may be produced by the various coalitions and contextures of corpuscles',[276] that need not, like bricks, be of much the same size and shape, but may have amongst them 'both of the one and of the other, as great a variety as need be wish'd for, an[d] indeed a greater than can easily be so much as imagin'd'.[277]

Although Boyle may seem to be making the obvious point that if a large number of structures can be built from a single building unit, then a much greater number of structures can be produced from a larger number of primary building units, he nevertheless seems to have an insight into the nature of the structure of chemical compounds, especially organic compounds, i.e. compounds of carbon with some other atoms. For it is now understood that from a number of 'building units' such as carbon, hydrogen, oxygen and a handful of other atoms, by varying both the *structure* of the atoms in combination, as well as the atoms themselves, a vast number of chemical compounds can be synthesised.

2.3.4. Dalton's Atomic Theory

It is interesting to note that Partington says that the Atomic Theory did not prove fruitful in chemistry until John Dalton endowed the atoms of the chemical elements with fixed and different weights (i.e. different for the different elements).[278] It may also be remarked that when the theory re-emerged in the early nineteenth century, the property of indivisibility was a key concept of it. This theory was set down by Dalton in 1803 and

[276] Ibid., p.113.
[277] Ibid., p.113.
[278] *A Short History of Chemistry*, p. 167.

makes only three simple, and Partington says, not obviously illuminating, assertions,[279] the first two of which are given below:

‘i. The chemical elements are composed of very minute indivisible particles of matter, called atoms, which preserve their individuality in all chemical changes.

ii. All the atoms of the same element are identical in all respects, particularly in *weight.* [Partington’s italics]. Different elements have atoms differing in weight. Each element is characterised by the weight of its atom’.[280]

Boyle seems to have presaged some of the key concepts of Dalton’s theory by almost one hundred and fifty years. The minuteness of atoms he obviously accepted, as well as the hypothesis that atoms preserve their individuality in all chemical changes. He gives a good example of how tiny atoms are by citing the case of ‘good camphor’[281] which can be dissolved in ‘pure spirit of wine’[282] [alcohol] to give a solution which is as clear as ‘fair water’.[283] Yet if you add a ‘competent quantity’[284] of water [i.e. if you add a large quantity of a non-solvent, in this case water, to the solution of camphor in alcohol, the camphor will be precipitated as the original white material]. As Boyle himself puts it, the ‘scattered corpuscles’[285] of the camphor will, by ‘reuniting themselves’[286] become white, and consequently visible, as before their dispersion.

As for Dalton’s hypothesis that all atoms retain their individuality in all chemical changes, Boyle seems also to accept this. He gives as example an account of the reaction

[279] Ibid., p. 169.
[280] Ibid., p. 169.
[281] *Selected Philosophical Papers of Robert Boyle*, p. 42.
[282] Ibid., p. 42.
[283] Ibid., p. 42.
[284] Ibid., p. 42.
[285] Ibid., p. 42.
[286] Ibid., p. 42.

of gold to form auric chloride, by the action of '*aqua regis*'[287] [a mixture of hydrochloric and nitric acids]. In this experiment, the gold can be dissolved by the action of the acid mixture, and the 'corpuscles of gold'[288] will, with the *menstruum* [solvent], pass through 'cap paper' [filter paper] from which a red crystalline line solid (auric chloride) can be recovered. Yet this crystalline solid can, in turn, be reduced to the familiar metallic gold. The same holds true of mercury, which can be reacted with other materials to form various compounds, obviously quite different and quite distinct from the metal. However, all of these compounds of mercury too can be reduced to the original metal from which they were produced.

So, Boyle seems to have no doubt but that atoms or corpuscles are capable of participating in chemical reactions to form new chemical species, but retain their identity in these compounds and can be subsequently reconstituted into their original bulk form.

2.3.5. *Minima* or *prima naturalia*, again

Although Boyle does seem in some contexts to use the terms 'corpuscle', 'atom' and '*minima* or *prima naturalia*' all to mean the smallest particles of matter, it does seem that in his *Origin of Forms and Qualities* he speaks at some length of these terms where he seems to draw a distinction between corpuscles and *minima* or *prima naturalia*. What he seems to be doing, in fact, is presenting a scheme by which he believes the smallest units of matter aggregate to form the units of which he speaks. In this scheme the smallest units of matter are the *minima* or *prima naturalia,* each of which has its own determinate

[287] *Sceptical Chymist*, p. 31.
[288] Ibid., p. 31.

shape and is very solid. These are present in ‘great store’[289] Coalitions of several of these entities go to form multitudes of corpuscles whose size is so small, and their ‘adhesion so close and strict’[290] that each of these primitive little concretions or clusters of particles is individually below the level of sense perception, and though ‘not absolutely indivisible by nature into the *prima naturalia* that composed it’[291] or perhaps into other little fragments, yet are very rarely actually dissolved or broken, but remain entire in a great variety of ‘sensible bodies’.[292]

What Boyle seems to be saying here is that the smallest bodies, *minima* or *prima naturalia,* aggregate to form assemblages or corpuscles, which although composed of smaller particles, rarely subdivide to give either these *prima naturalia* or other particulate entities. He gives as examples of corpuscular materials quicksilver [mercury] and camphor. However *minima naturalia* have their own specific size and shape, and when they aggregate to form corpuscles it must *always* be that the size and *often* [Boyle’s italics] the figure of the corpuscle formed by their ‘juxtaposition and cohesion will be changed’,[293] and the same will happen when the corpuscles that compose a cluster of particles are disjointed, or anything of the little mass is broken off. And whether any material is either added to or taken away from a corpuscle, the size of it must be altered, and for the most part the shape or figure of it also, and this will cause the corpuscle to operate on ‘divers occasions much otherwise than it was fitted to do before’.[294]

---

289 *Selected Philosophical Papers of Robert Boyle*, p. 41.
290 Ibid., p. 41.
291 Ibid., p. 42.
292 Ibid., p. 42.
293 Ibid., p. 42.
294 Ibid., p. 42.

The stipulation by Boyle that when the corpuscles constituting a cluster of particles are separated, the size, and usually the shape, of the assemblage is altered, and this may then operate much differently than before, must have been prompted by the case of chemical reactions such as when gold reacts with *aqua regis* to form auric chloride. Boyle might well be accounting for the fact that gold, in forming auric chloride, must undergo a change at the corpuscular level. Gold corpuscles must somehow add corpuscles from the *aqua regis* to form new ones different in size (they are necessarily larger) than those of gold, and probably different in shape as well (but he cannot be certain that the corpuscles of auric chloride, though certainly larger than those of gold, are necessarily different in shape from gold corpuscles). If these changes at the corpuscular level did not occur to the gold, then it could not have been changed to auric chloride. And there is no doubt but that auric chloride is quite different from gold, it is, for example, a red crystalline solid, and must have corpuscles different from those of gold. Gold obviously adds something in changing from the familiar yellow metal to auric chloride, but then auric chloride can be changed back to gold again. And this change also must occur at the corpuscular level. So, whatever happens to the corpuscles of gold in changing to those of auric chloride must now be undone in a precise and reproducible way, so that whenever auric chloride is reduced, gold will always be the end result. And this must occur at the corpuscular level, for when auric chloride is acted upon to reform metallic gold, this change must also occur at the corpuscular level, with the corpuscles of auric chloride splitting off chlorine and leaving behind corpuscles of gold.

Alexander[295] says that Boyle uses the word 'corpuscle' in a wide sense, applying it to both the smallest particles that actually exist and stable complexes of them below the level of observation. He gives as an example Boyle's referring to the smallest undivided particles as '*minima* or *prima naturalia*' and then he (Boyle) says that there are also multitudes of corpuscles which are made up of several of the former *minima* or *prima naturalia*.

It may well be that Alexander's explanation that Boyle used the term 'corpuscle' in a wide sense is the simplest one. Boyle, having introduced the term, may not have settled on a precise meaning for it. The word itself is derived from *corpusculum*, diminutive of *corpus* (body),[296] but it could be argued that a small body may not necessarily have a single, unitary identity. In other words it may itself be composed of parts which, when combined, constitute the small body. Of course, a small body may indeed be a simple, individual entity, and it may be that Boyle exploited this ambiguity in definition to apply different meaning to the term 'corpuscle'.[297] [298]

2.3.6. Fragmented Corpuscles

---

[295] *Ideas, Qualities and Corpuscles*, p. 66.

[296] *Chambers Dictionary of Etymology*, p. 222.

[297] Clericuzio states that in Boyle's manuscript of 1651-53 (date estimated by Clericuzio) entitled '*Of ye Atomicall Philosophy*' (as mentioned in 2.3.1.) the term *minima naturalia* denotes atoms endowed with qualities, while in the [later] published works the same term means simple corpuscles having purely mechanical qualities. In: Antonio Clericuzio, *Elements, Principles and Corpuscles* (Dordrecht: Kluewer Academic, 2000) p. 117.

[298] Boas makes a similar point when she states that Boyle '…. went from his *prima naturalia*, which had physical characteristics, but no apparent chemical ones, to the chemical corpuscles which take part in chemical reactions,…'. In: Marie Boas, *Robert Boyle and Seventeenth – Century Chemistry* (Cambridge University Press, 1958) p. 100. It does seem on these two readings of Boyle that he revised his opinions on the qualities possessed by the *minima naturalia*, with only mechanical properties possessed by them, thereby excluding them from participating in chemical reactions.

Boyle gives a good example of why and how he believes corpuscles may be broken down. In his *Producibleness of Chemical Principles* he gives an account of why nitric acid, which is now categorised as a strong mineral acid, derives its acidic properties from nitre, or potassium nitrate, which although employed in Boyle's time in the manufacture of gunpowder, was used also in food preservation. Of course we now say that events actually take place the other way round – nitre is a salt produced by the neutralisation of two aggressive chemicals, nitric acid and potassium hydroxide. Boyle himself might have been aware of this too, for he says that saltpetre may be produced artificially by the reaction of a 'nitrous spirit and a fixt alcali'.[299] He knew also that nitre is produced naturally through the oxidation of decaying organic matter.

Boyle seems to find it difficult to account for the acidic properties of nitric acid, which can, for example, dissolve silver. He wonders how a strong acid can come from a material totally lacking in acidic properties. He accounts for the change, as he sees it, from a saline material (nitre) to an acidic one (nitric acid) in terms of a change at the corpuscular level. He believes that the acidic properties of the nitric acid are caused by the violent action of the fire, which, 'by cleaving the nitrous corpuscles'[300] 'or by rubbing them one against another … or by both these wayes, and perhaps by some others, makes a comminution of them into fragments or particles'.[301]

This account is interesting for a number of reasons. Boyle, in explaining the nature of corpuscles, says that they are in principle divisible but that this is a rare occurrence. He

[299] *The Works of Robert Boyle,* Vol. 9, 1678-83, p. 56.
[300] Ibid., p. 55.
[301] Ibid., p. 55.

quotes the examples of silver, gold, mercury and camphor, which are all capable of transformation, either by chemical reaction or by dissolution, yet all of which can be returned intact to their original condition, with, he argues, their corpuscles intact. Yet here, in the case of nitre, fire can break down the corpuscles, by splitting or rubbing or some other means, into fragments or particles. Now, Boyle does believe that corpuscles themselves may be built up from even smaller units of matter – the *minima* or *prima naturalia*. For example he speaks of huge numbers of corpuscles which are built up from 'the coalition of several of the former *minima naturalia*,[302] but when the corpuscles of nitre are broken down by the action of the fire, Boyle makes no mention that they are simply breaking down into their constituent *prima naturalia*, he simply states that they break into fragments or particles. Neither does he intimate that these are composed of small groupings of *prima naturalia*, or of single or even cleaved *prima naturalia*. And if these particles or fragments are themselves subdivisions of *prima naturalia,* where exactly do they fit into his scheme of things? They can hardly be chemical species, as it is corpuscles that take part in chemical reactions. However, if they cannot participate in chemical processes, how can they be reintegrated into larger material units? Perhaps they simply accumulate into some kind of material detritus, the leftovers from violent chemical processes, but then Boyle does say that they do, in fact, play a rôle in the production of nitric acid from nitre. For he says that these same particles or fragments, precisely because of their smallness and lightness, may be elevated by the action of the fire, and their sharp and pointed figures may get into the pores of 'many other body's and divide their parts'.[303] So these fragments or particles are part of a mechanism by which

---

[302] *Selected Philosophical Papers of Robert Boyle*, p. 41.
[303] *The Works of Robert Boyle,* Vol. 9, 1678-83, p. 56.

larger bodies may be reduced into smaller units, and it does seem that they have indeed been broken off from larger units of matter, possibly *prima naturalia*, because they are sharp and pointed. However, for this to happen, these sharp pieces must find a way into the larger bodes of matter, which they can then split apart, and they effect this by getting into the pores of these larger bodies, but what exactly are these other bodies? Are they corpuscles, or assemblages of corpuscles? Boyle does not say, but if corpuscles were split, then the *prima naturalia* resulting from their cleavage would surely not be capable of taking part in chemical reactions, as it is corpuscles and not *prima naturalia* that participate in chemical processes. So it may be that the corpuscles themselves are split off from one another by the action of the sharp fragments and it is the freeing up of these corpuscles which forms the end point of the process in question, i.e. nitric acid corpuscles are released from their association with corpuscles of nitre. In other words, in splitting up the assemblages of various corpuscles, nitric acid corpuscles are released from their association with nitre corpuscles.

Boyle offers no account of the ultimate fate of the particles or fragments that participate in the production of nitric acid from nitre. These particles are material entities, but being in a broken or fragmentary condition, seem not to be *minima* or *prima naturalia*, and seem to have no more function than to act as sharp wedges cut or broken from corpuscles which then go on to force corpuscles apart.

However, these small fragments or particles consist of real matter, as real as corpuscles, *minima* or *prima naturalia*, and so must persist after they have fulfilled their function in chemical transformation. So what exactly becomes of them? Boyle does not say. Do they reunite to form either *minima* or corpuscles?, again he is silent on this point. Boyle gave (the already discussed in 2.2.3.) example of bricks which can be combined to form a variety of structures, from one simple unit of construction, and went on to say that if corpuscles of various shapes and sizes are substituted for the bricks, then a much greater variety of structures can be produced. However, by extension, only complete bricks or complete corpuscles are of any value in building structures, broken bricks and fragments of corpuscles would be of no use to the builder; simply nothing could be constructed from them. How could fragments of corpuscles be accommodated in nature?, and if it cannot make use of them, would they simply accumulate as some kind of real, but characterless, leftover matter? Boyle is silent on this point.

The above account notwithstanding, Boyle does speak in a tentative manner of how crystalline corpuscles, having an angular shape, might be hypothesised as fracturing their fault lines into smaller, wedge-shaped fragments, which might then go on to combine with similar fragments of a different chemical species to form a distinct chemical compound. He describes experiments by which nitre [potassium nitrate, or saltpetre] is synthesised by the reaction of spirit of nitre [nitric acid] which is strongly acidic, with a solution of fixt nitre [potassium carbonate] which is alkaline. Boyle deduces that because the larger and best formed crystals of nitre are of a prismatic shape with six sides, ‘we should suppose the corpuscles of nitre to be little prisms’. The crystals of nitre which are crystallised out of solution, when dried and freed from any adhering impurities will, when tasted, ‘have upon the tongue neither a sharp nor an alkalizate [alkaline] tast’.

Rather, if pure, they will have ‘that faint and scarce sensible bitterness that belongs to salt-peter’.[304]

Boyle here presents a report by which the sharp, acid-tasting nitric acid, which when reacted with the soapy, alkaline-tasting potassium carbonate, gives as reaction product the almost neutral, slightly bitter-tasting potassium nitrate. He is fascinated by the complete contrast in taste between the reactants and the reaction product, and wonders whether the transformations in taste might be explained by changes at the corpuscular level. However, he is hesitant in presenting the changes in taste as reflecting differences at a corpuscular level, and says that ‘the main conjecture may not be worthy any farther prosecution’.

Boyle’s hypothesises that the crystals of nitre with their ‘prismatic shape with six sides’ is an extension of order at the microscopic level, where he supposes the corpuscles of nitre to be ‘little prisms’, but he supposes that these corpuscles have angles and ends which are too obtuse or blunt to make ‘vigorous and deep’ impressions on the tongue. Yet if these little prisms are split or otherwise broken either by ‘violent heat’ or forcibly made to grind against one another ‘they may come to have parts so much smaller than before, and endowed with such sharp sides and angles, that being dissolved and agitated by the spittle that usually moistens the tongue’ their small size may give them ‘great access to the pores of the tongue’. The sharpness of their sides and points may enable them to ‘stab and cut’ and to ‘fear’ [i.e. to frighten] the ‘nervous and membranous parts of the organ of tast’, in accordance with their own individual diversity of shape and bulk.

[304] *The Works of Robert Boyle, Vol.8*, 1674-76, p.366.

He further argues that, if blunt prisms of nitre can be fractured in such a way as to give sharp fragments, capable of cutting and stabbing the taste buds so as to give the sensation of a 'sharp' taste, it seems 'conceivable' to Boyle that when alkaline and acidic particles come to be put together in the same common solution they might by chance come together, so as to 'recompose little prisms or convene into other bodies' 'almost' like those made up of the original crystals of nitre. Boyle illustrates his argument by considering a prism of iron which, because of its shape, will not pierce the skin, but if is now cut transverse-wise into wedges, such wedges would be capable of cutting through the skin or of splitting wood. Yet they could then be reassembled so as to 'recompose a prism' which would revert to its former condition of bluntness. He gives another example: that of a 'dry stick circularly cut off at the ends' which is unable to prick the hand, yet if it is 'violently broken' the resulting ragged ends and splinters may well prove sharp enough to pierce the hand. However he then says that one might, as he himself does, think that the 'main conjecture might not be worthy any further prosecution'.[305]

Boyle seems here to be attempting to employ the explanatory power of his Corpuscular Hypothesis to solve two separate problems: how to account for the combining of two kinds of corpuscles, constituting two different reagents, to give a reaction product which is quite distinct from the starting materials, and how to reconcile the marked difference in taste between these same two reagents, one alkaline, the other acidic, and that of the near neutral taste of their reaction product.

[305] Ibid., p. 367.

Both explanations cleverly exploit the differences in size, figure and shape which, along with motion (or rest) Boyle never tires of telling the reader underlie all physical phenomena. He states the obvious fact that the best formed crystals of nitre are in the shape of six-sided prisms, which means that they are angular bodies with planar sides, then makes the reasonable assumption that the visible structure of these crystals derives from a like structure at the microscopic scale, in fact at the corpuscular level. Boyle then attempts to provide a mechanistic account of the sensation of taste by positing a physiological linkage between the shape of the corpuscles of nitre and their giving rise to a particular experience of taste. He supposes that the angular corpuscles of nitre are not sufficiently sharp to prick the taste buds and so have a rather bland, only slightly bitter taste. But these corpuscles of nitre are the reaction product of two quite different chemical species i.e. nitric acid and potassium carbonate, which themselves have distinctive tastes, the one acidic, the other alkaline. Boyle wonders whether the corpuscles of nitre result from the fitting together of two acutely angled corpuscles. Individually these wedge-shaped corpuscles produce a sharp taste because their acute shape pricks the taste buds, but when reacted, they fit neatly together to form the more obtuse-angled corpuscles of nitre, which are simply too blunt to prick the taste buds, and give a relatively mild tasting sensation.

Boyle is, however, curiously hesitant in promoting his hypothesis, even though a single model – acute-shaped, sharp tasting corpuscles, and behaving as reactants, fitting neatly together to become an obtuse-shaped, mild tasting reaction product – would seem to provide an elegant example of the Corpuscularian Hypothesis providing a convincing mechanism for a chemical reaction and at the same time provide an account of why reaction products can taste so different from the reactants from which they derive. It is all the more surprising that Boyle did not see this particular application of the Corpuscularian Hypothesis as providing a viable hypothesis on the functioning of the sense of taste, incorporating insights going back to the Ancient Greeks. In speaking of acute-shaped particles as stabbing and cutting the tongue he is saying that sharp tasting materials prick the pores of the tongue as a needle might prick the hand. In making this comparison Boyle is implying that taste is closely related to touch, and Aristotle seems to have held a like opinion when he stated that "taste is a sort of touch".[306] And as to the influence of particle shape on the experience of taste, Descartes held that it would be sensible to attribute different taste sensations to the various shapes causing taste. For Descartes, the nerves of the tongue and the parts adjacent to it are moved by bodies floating in the mouth along with the saliva. "And these nerves are variously moved according to the diverse shapes or movements of the particles, thereby causing the sensations of diverse tastes".[307] Boyle, if he had so wished, could have employed the explanatory power of his Corpuscularian Hypothesis to link together the physiological and the chemical in just one simple model, but seems to have had no inclination to so do.

There is, however, another perspective on the question of the instrumental participation of subatomic particles in interactions with matter, as free agents acting upon the system, but not as reagents involved in chemical reactions. Some of the (then) astonishing physical phenomena discovered towards the end of the nineteenth century, which at that

[306] *Aristotle On the Parts of Animals* (660ª 21).
[307] *Principles of Philosophy,* p.279.

time could not be explained, resulted from the interactions of electrons, stripped away from the outer layers of atoms, moving away from their parent atoms and interacting physically with other atoms. Two obvious examples are X-radiation,[308] discovered by Röntgen (1845-1923) in 1895 (the 'X' simply meaning unknown) and beta-radiation, discovered by Becquerel (1852-1908) the following year.[309] Each of these phenomena involve the removal of electrons from their parent atoms, in one case acting to generate X-radiation, and in the other, fast-moving electrons themselves constituting beta-radiation.

In both of these cases, parts of atoms are removed and then go on to function as independent entities. It took some time before it was understood what exactly was happening, but it did come to be realised that atoms did not always simply act as unitary bodies, and that sometimes particles removed from them could be responsible for a set of phenomena quite different and distinct from chemical reactions. Of course, electrons are not broken off as fragments from solid atoms, as they are present in atoms as discrete particles in perpetual orbit around the nucleus of their parent atom, but rather they are stripped away from the outer reaches of the atomic assemblage. Nevertheless, it could be argued that Boyle, more than two-hundred years before the discovery of X- and beta-radiation, in conceding the divisibility of atoms, predicted that particles or fragments removed from atoms could behave instrumentally, in a manner quite distinct from that of corpuscles. This having been said, it does seem that Boyle did not conceive of atoms as having a structure, as the term is understood in our own time, but this is hardly surprising

[308] P.A. Tipler, R.A. Llewellyn, *Modern Physics*, 3rd. edn. (New York: Freeman & Co., 1999) p.592.
[309] E.J. Wenham, G.W. Dorling, J. A. N. Snell & B. Taylor, *Physics Concepts and Models*, 2nd. edn. (Longman, 1993) pp. 522-523.

as real consideration of how atoms were actually constructed did not come about until the late nineteenth century, and the first truly modern model of atomic structure was published in 1911 by Ernest Rutherford (1871 – 1937).[310]

[310] Ibid., pp.539-543.

2.4 Conclusion to Chapter 2

How did Boyle view matter *per se*? He seems to have had three major influences on him in expounding his theory on matter: the Aristotelian doctrine of prime matter which conceived of a material somehow behind or underlying the various manifestations of matter visible in the world, and the Biblical account of Creation with its stating that the matter, from which the world is constituted, as having been created by the Old Testament God. In addition he was influenced by the atomic theory of Epicurus, and others. He refers to the primeval material, as he understood it, as 'universal matter'. He then had to hypothesise how one gets from this homogeneous bulk matter, which for him existed only in actuality, to its various subdivisions evident in the enormous number of manifestations of matter to be found in the world. Boyle posited the division of this universal matter into minute corpuscles (a word which Boyle himself is credited with having coined).[311] These corpuscles, impenetrable and indivisible, varying in size and shape, and combined with motion, could, Boyle believed, account for the physical world as we experience it. He likened this process of converting universal matter into corpuscles to the production of the various subdivisions of wood, all cut from the same block of wood. However, this leads to the question: if universal matter is divisible, then what of the corpuscles 'cut' from it, surely they too must be as divisible as the prime matter from which they are derived? And although Boyle seems in his early writings to have agreed with the Epicurean doctrine of the indivisibility of atoms, later on he seems to have accepted that they were, in fact, divisible, albeit with difficulty.

[311] *Chambers Dictionary of Etymology*, p. 222.

Boyle seems not to have been content with the idea that corpuscles were the primary subdivision of universal matters, for he also specified the smallest possible units of matter as *minima* or *prima naturalia*, which in turn aggregated to form corpuscles. And although he does seem to have used the words ‘atoms’ and ‘corpuscles’ to mean the same thing, he seems to have regarded his *minima* or *prima naturalia* as more fundamental than either. In adopting this opinion, Boyle may simply have been attempting to account for what it was exactly that corpuscles formed when subdivided, he might argue that they formed particles even more fundamental in *minima* or *prima naturalia* (although he does not state this explicitly).

It is perhaps understandable that Boyle would end up in a difficult situation simply by conceding that corpuscles or atoms were divisible, a concession ruled out by both Epicurus in ancient times, and John Dalton a century and a half after Boyle’s time. By hypothesising that atoms are indivisible one neatly closes off any discussion as to what the ultimate constituents of matter are. Boyle in accepting that atoms are indeed divisible then spoke of *minima* or *prima naturalia* as the building blocks of corpuscles or atoms. So far, so good, at least he can account for *their* behaviour, but what of the smaller fragments or particles produced by the violence of the fire? These do participate in chemical reactions, but merely in an instrumental way, only to be left hanging there as some kind of material detritus, not having any function or application once they have been employed in a specific chemical process.

Although John Dalton, in 1803, hypothesised that atoms were indivisible, as the nineteenth century progressed it came to be realised that atoms were, in fact, divisible. And each stage in the development of our contemporary model of the atoms may have left mysteries and questions, but there were no loose ends in the model proper, no material which was hypothesised as existing without being capable of finding its place in the increasingly complex understanding of atomic structure. And the present-day understanding of leptons and quarks exchanging gauge bosons still leaves the question of what these entities are made from. Yet we do not hypothesise the existence of particles that do not fall within the rubric of an overall atomic structure which, however increasingly mysterious it may be becoming, still has all its particles, forces and exchanges building up to give a coherent account of the nature of matter.

Copenhaver[312] makes the point that when Boyle and Locke argued from bodies visibly in motion to analogous but invisible notions of microscopic matter, their theories were more credible than the doctrine of occult qualities because they depended on atomic motions which, unlike occult qualities, were intelligible precisely in their likeness to gross mechanical phenomena. And the future progress of science after their time proves just how right they were. However, it must surely be counted as a weakness in Boyle's theory on matter, that in positing two doctrines at least, viz. the divisibility of the atom, and the derivation of all types of material from a common universal matter divided into contiguous corpuscles, differing only in size and shape, he was left with some consequences which are difficult to explain, such as how great differences in density

[312] Garber, D. and Ayers, M. (eds) *The Cambridge History of Seventeenth-Century Philosophy*, Vol. 1, p. 493.

between different materials, such as gold and water, can arise, and how small fragments of matter, broken away from the corpuscles, can be accounted for in his overall scheme of matter.

However, it could be argued that it is easy for us to point to the shortcomings of his account of matter, from a vantage point three and a half centuries removed from Boyle's time. The weaknesses of Boyle's atomic model might be explained by saying that he adopted a 'rock model', whereas we have come to realise that a 'clock model' may be more appropriate. (Let us simplify things a little by assuming that all rocks are made from the same material, and are homogeneous in composition and that all clocks are of the old-fashioned, mechanical variety). For Boyle, atoms or corpuscles were as miniature rocks, and just as rocks can be split by mechanical action, so too could atoms be split in like manner. Rocks can be reduced to fragments which can then serve purposes quite distinct from those to which rocks can be put. In other words, the fragments can function instrumentally. With the 'clock model', on the other hand, an atom can be viewed as a set of distinct components, each somehow connected to the others, yet all are discrete and separate, and every individual piece plays its own particular rôle in the proper functioning of the overall assemblage, but at the same time the individual components are spaced out one from another, which means that an atom or a clock consists of a considerable amount of empty space. This contrasts with rocks which, being solid entities, always have a direct proportionality between weight and volume, e.g. double the volume of a rock and its weight is also doubled, whereas for clocks there is no simple relationship between their weight and volume. A grandfather clock will surely weigh more than an alarm clock, but there is no simple relationship between the weight and volume difference for the two. This means that difference in weight per unit volume is easier to explain in the case of clocks than it is for rocks.

One could remove certain components from some clocks and still leave both the clock and the part taken away in working order. It is possible, for example, to remove the cuckoo from a cuckoo clock or the bell from an alarm clock and use them instrumentally, which would leave their parent clocks in some way impaired (they would be quieter) but still capable of functioning as clocks.

What is remarkable about Boyle's atomic theory is that despite its apparent crudeness, it does make a number of predictions of atomic properties which came to be borne out in future centuries. He posited that atoms existed and were not all identical. In addition, he believed that they were divisible, and that parts of them could be used instrumentally.

BIBLIOGRAPHY TO CHAPTER 2

Alexander, Peter, *Ideas, Qualities and Corpuscles* (Cambridge University Press,[1985] 2009).

Barnes, J. (ed.) *The Complete Works of Aristotle*, Vol. 2 (Princeton University Press, 1984).

Barnhart, R.K. (ed.) *Chambers Dictionary of Etymology* (New York: Chambers, 1988).

Boas Marie, *Robert Boyle and Seventeenth – Century Chemistry* (Cambridge University Press, 1958).

Boyle, Robert, *The Sceptical Chymist* (Minneola, N.Y.: Dover Publications, 2003).

Clericuzio, Antonio, *Elements, Principles and Corpuscles* (Dordrecht: Kluewer Academic, 2000).

Descartes, R., *Principles of Philosophy*, trans. Miller, V.R., & Miller, R.D. (Dordrecht: R.D. Reidel, 1983).

Emsley, John, *Nature's Building Blocks* (Oxford University Press, 2001).

Garber, D. and Ayers, M. (eds) *The Cambridge History of Seventeenth-Century Philosophy*, Vol. 1 (Cambridge University Press, 1998).

Hamilton, E., & Cairns, H. (eds) *The Collected Dialogues of Plato* (Princeton University Press, 1961).

Hunter, M., and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 2 (London: Pickering & Chatto, 1999).

Hunter, M., and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 8 (London: Pickering & Chatto, 2000).

Hunter, M. and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 9 (London: Pickering & Chatto, 2000).

Kane, G.L., *Modern Elementary Particle Physics* (Addison-Wesley, 1987).

Ladyman, J., *Understanding Philosophy of Science* (Oxford: Routledge, 2002).

Lennox, J.G., trans., *Aristotle on the Parts of Animals* (Clarendon Press Oxford, 2001).

Liddle & Scott, *An Intermediate Greek-English Lexicon (*Oxford University Press, [1889] 2000).

Newman, William R., *Atoms and Alchemy* (University of Chicago Press, 2006).

Partington, J.R., *A Short History of Chemistry* (New York: Dover Publications Inc., 1989).

The Jerusalem Bible, (London: Geoffrey Chapman, 1971).

Tipler, P.A., Llewellyn, R.A., *Modern Physics*, 3rd. edn. (New York: Freeman & Co., 1999).

Serway, Raymond A, *Physics for Scientists and Engineers*, 4th edn. (Philadelphia: Saunders College Publishing, 1996).

Stewart, M.A. (ed.) *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991).

Wenham, E. J., Dorling, G.W., Snell, J.A.N., & Taylor,B., *Physics Concepts and Models*, 2nd. Edn. (Longman, 1993).

Westfall, R.S., ‘Unpublished Boyle Papers Relating to Scientific Method – II’, *Ann. Sci*. Vol. 12 (1956)103-117.

Chapter 3

Boyle and the Elements – I

Table of Contents

Chapter 3

Boyle and the Elements – I

3.1. Introduction to Chapters 3 & 4

What does the term element mean? The Oxford English Dictionary defines it as: 'A component part of a complex whole'; (of material things) 'one of the simple substances of which all material bodies are compounded'. It also says that in modern chemistry the word is applied to those substances: '… which have hitherto resisted analysis and which are provisionally supposed to be simple bodies'.[313] This definition seems to fit neatly into two parts: in a general sense elements are either simple substances or units of more complex bodies, and in the context of chemistry, elements are also defined as simple substances, but only in so far as they have not yet been broken down into even smaller units. In the general understanding of the word, an element is accepted as being a simple thing, but which somehow goes to produce more complex bodies. The impression gained from the definitions is that elements are not really expected to occur in the free state, but rather to subsist as the identifiable parts of some larger, more complex whole. When applied to modern chemistry, elements are 'supposed' to be simple bodies, and this only because as yet they have not been broken down into even smaller units. So, an element's simplicity is a relative, rather than an absolute term, and could be redefined as an even smaller unit if a substance, currently regarded as elemental, could somehow be broken down into smaller parts. This idea of relative simplicity is reinforced by the same dictionary's additional definition of the term element by stating that in a wider sense an

[313] Oxford English Dictionary online, http://dictionary.oed.com/templates/entrance_main.html (Consulted 17-7-09).

element is 'one of the relatively simple substances of which a complex substance is composed'. An element, then, does not seem to enjoy the status of *absolute* simplicity but rather whose simplicity is tentative, and which could in time be found to be still further reducible, as scientific analysis progresses.

Another definition of the term 'element' is provided by Lloyd, who says that the word is ambiguous:

> 'Being used of (i) original substances – substances that have existed as long as anything has existed – and (ii) of "simple" substances – the substances into which compound things can be analysed, but which themselves cannot be further reduced.'[314]

The second part of this definition speaks of simple substances produced by the analysis of compound bodies. And the simplicity of the elements is affirmed by their not being capable of undergoing further reduction. This second part of Lloyd's definition is firmer, more definite or assertive in its determination of what is actually elemental. The first part of Lloyd's definition is interesting in that it speaks of an element as a primal substance, and here the complexity of the substance is not at issue, only its age. In fact, it is the material's antiquity and not its composition that confers on it the right to be considered as an element, but for a substance to be elemental, by this definition, it must be coeval with the first appearance of matter itself. This implies, to the believing Christian, that it must have been produced at the time of Creation.

One of the problems encountered in considering the word 'element' is purely a linguistic one: the word means *by definition* something *simple*, *fundamental*, *irreducible*. These

---

[314] G.E.R. Lloyd, *Early Greek Science: Thales to Aristotle* (New York: Norton, 1970) p. 40.

words occur in various definitions of the term, such as in the 'simple substances' given by the 'Oxford English Dictionary' and by Lloyd (already referred to) and in the words 'fundamental, irreducible' given by Collins.[315] This means that there is nothing remarkable about the wording of the various definitions of the term 'element' as the aforementioned words will appear in most, if not all of them, from Aristotle onwards. The real problem lies in naming substances which fulfil the definition of 'element'. This point is made by Boas who says that the first definition of the term 'elements' is given by de Clave (in 1641) as:

> 'Simple bodies, which enter originally into the composition of mixts, and into which these mixts resolve themselves or may be finally resolved'.

She says this sounds very modern, and is one of the reasons why the *name* of the element has remained with us, though the *thing* has not. [Boas's italics].[316]

Looking at the various definitions of element in this light, it is not the form of words used to state what an element is – as these definitions will all be quite similar – but rather which substances are actually considered as elements, that forms the nub of the issue in relation to the elements. Sets of elements have been named from Aristotle to Paracelsus and others in the late Middle Ages, which differed in the elements named, but all of which had in common the meaning of element as simple substance. The *thing* that these substances represent has changed completely between then and now.

---

315 *Collins English Dictionary* (Glasgow: HarperCollins, 2005) p. 532.

316 Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958) p. 85.

Boyle, too, recognised this distinction when, in giving his definition of 'element' he used the words; 'primitive', 'simple', as the bodies from which mixed ones were composed, and into which they are ultimately resolved. This is hardly a surprising definition of the term as it is more or less the definition entailed by the very word element. Boyle really did no more than give what might be expected of a standard dictionary definition. The difficulty faced by Boyle, as it had faced others, was in providing an account of what materials might actually *be* elements. So in his most famous definition of the term 'element' on p. 187 of *The Sceptical Chymist*, once Boyle gave his general definition of element as 'primitive', 'simple', 'unmingled bodies', he then went on to the next stage of his definition in which he speaks of those substances he considered as elements. And instead of listing the materials he believed to be elements, he actually doubts whether there are any elements *per se*.

3.2. Boyle's Definitions of the Elements

3.2.1. Definition No. 1

Boyle gave a number of definitions of the term 'element', the first of which appeared in an early work (written between 1651 and 1657)[317] and which runs as follows: '… I premise, that I here understand by elements those bodies, of which the mixt ones are composed, and into which they are ultimately resolved'.[318] Let us call this Definition no. 1.

Here Boyle is defining the elements as simple bodies; in fact they must be the simplest bodies possible, as they represent the ultimate point of resolution of compound bodies. Their nature is such that they can be made to constitute more complex bodies. It is not quite clear how complex the bodies they form actually are, but Boyle uses the term 'mixt' to mean a chemical compound, and this is probably what he means in this instance. This definition contains a certain symmetry, as Boyle's 'mixt ones' can themselves be decomposed, and the simplest bodies into which they can be broken down are the elements.

3.2.2. Definition No. 2

Early in *The Sceptical Chymist* Boyle gives the following definition of the elements:

> '… Elements and principles as terms equivalent: and to understand both by the one and the other, those primitive and simple bodies of which the mixt ones are said to be composed, and into which they are ultimately resolved'.[319]

[317] Marie Boas, 'An Early Version of Boyle's: Sceptical Chymist', *Isis*, Vol. 45, No. 2 (1954) 153-168, p. 154.
[318] Ibid., p. 158.
[319] *Sceptical Chymist*, p. 18.

Let us call this Definition no. 2.

Boas says that this definition differs 'hardly at all'[320] from the definition just given as no. 1, although it does seem that in the interval of time which elapsed between the two definitions Boyle had both refined and broadened his thinking on the elements. The 'bodies' of the earlier definition came to be replaced by 'primitive and simple bodies', emphasising the idea that elements were indeed simple but also somehow rudimentary, and the word 'primitive' has the sense of undeveloped or primary, again harking back to their being produced at a primeval stage in the development of the created world. Apart from this, the word 'bodies' gives no indication as to the complexity of those entities; they might well be, for example in their own right, complex but irreducible bodies.

Perhaps the most curious thing about this definition is Boyle's use of the words 'said to be' in Definition no. 2. In the first definition, elements are the 'bodies' into which mixed ones are ultimately resolved, but in the second definition elements are the 'primitive and simple bodies' of which the mixed ones are 'said to be composed', and into which they are ultimately resolved. Perhaps Boyle really was not sure about the reality of the existence of the 'primitive and simple' bodies of which he spoke, either as constituting mixed bodies, or of their being the entities into which the more complex bodies were resolved. However, *The Sceptical Chymist* is a dialogue involving, among others, an Aristotelian and a Paracelsian, and the definition just given, i.e. Definition no. 2, was presented as one which all of the participants of the dialogue would accept. Or as Boyle himself put it, had 'agreed promiscuously to use when they pleaded',[321] and because this

[320] Op. cit., p. 155.
[321] *Sceptical Chymist*, p. 18.

definition of the elements was agreed between the adherents of two different systems of Natural Philosophy, Boyle may simple have wished to present the definition as a non-controversial, agreed one, thereby avoiding any disagreements which dogmatic assertions might provoke. He simply may have chosen to present this definition using the more unanimous tone of what the elements are 'said to be'.

3.2.3. Definition No. 3

Later on in *The Sceptical Chymist* Boyle gives another definition of the term element:

> 'It may likewise be granted, that those distinct substances, which concretes generally afford or are made up of, may without very much inconvenience be called the elements or principles of them'.[322]

Let us call this Definition no. 3.

The terminology employed here is rather different from that used in the two earlier definitions, with Boyle using the word 'concretes' rather than 'mixt bodies'. Boyle avoids the use of the words 'bodies' and 'primitive and simple bodies' and speaks instead of 'distinct substances' which are the entities from which the 'concretes' are both constituted and into which they are resolved. There is no mention of the 'distinct substances' being the entities into which the concretes are ultimately resolved; they are simply 'afforded by the concretes'. Although the distinct substances are elements or principles, Boyle is not insistent on the matter, and couches his definition in rather tentative language: 'It *might* likewise be granted …', and the distinct substances: '*may without very much inconvenience* be called the elements or principles …'. [Italics added].

[322] Ibid., p. 34.

That Boyle takes care to choose his words in this definition of the word element can also be seen when he says that by premising the words *very much* to the word *inconvenience*, though the inconvenience of calling the distinct substances mentioned in the proposition *elements* or *principles* [Boyle's italics] is not very great, it still constitutes an 'impropriety of speech'[323] and therefore in as important a definition as this, is not to be overlooked.

3.2.4. Definition No. 4

Boyle's most famous definition of the term element, and the one most quoted in the literature, is the final one given by him in *The Sceptical Chymist*. It runs as follows:

> 'And, to prevent mistakes, I must advertise you, that I now mean by elements, as those chymists that speak plainest do by their principles, certain primitive and simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixt bodies are immediately compounded, and into which they are ultimately resolved:'[324]

Let us call this Definition no. 4.

In contrast with Definition no. 3, Boyle reverts to speaking of elements as 'primitive' and 'simple', emphasising the simplicity of elements as entities, as well as the fact that they, as primitive bodies, must be close to the universal matter which underlies all the material things in creation. Boyle then introduced another term not found in his earlier definition of the elements, viz. perfectly unmingled. Not alone are the elements 'primitive' and 'simple', but they are also perfectly or completely unmixed, and he continues in his definition that these 'unmingled bodies' are neither composed of any other bodies, or

[323] Ibid., p. 35.
[324] Ibid., p. 187.

indeed of one another. What Boyle seems to be saying is that these bodies are so simple in composition that they are not in any way associated with any other bodies, including one another, in their composition. So, they must be individual entities of the most primitive kind. These most simple bodies combine to form mixt bodies, or chemical compounds, and are, Boyle emphasises, the entities arrived at when these mixt bodies are once again reduced to the ultimate extent.

3.3. Evidence for the Elements

3.3.1. One Element Only

Having delivered the above definition of the elements (i.e. no. 4) always using terms in the plural, such as 'elements' and 'bodies', Boyle then shifts to the singular when he queries whether any one particular element can be found in all material things. He poses his question as follows:

> 'Now whether there be any one such body to be constantly met with in all, and each, of those that are said to be elemented bodies, is the thing I now question'.[325]

Boyle uses the term 'one such body' in posing the question as to whether this one element is to be found in all bodies 'said to be elemented'. Taking 'elemented' to mean 'composed of, or consisting of, an element or elements', Boyle, despite his consistent use of the singular, may still be asking whether a body may actually consist of more than one element, but that all of these elements may simply be derived from one primary element. This 'one such body' would then by some means or other transform into all of the other elements, and 'elemented bodies' could then be said to consist, ultimately, of this one original element. It may well be the case that Boyle considered that there was in fact only one element, viz. water, and that this one elemented substance may somehow transform itself into various materials, such as he had described how water seems to have been converted into a tree, a pumpkin, and some plants, as discussed in 2.2.2. This time, he broadens his discussion to include inorganic or non-living things such as metals and minerals. The formation of materials such as these, we would now consider as occurring due to geological processes or chemical reactions. Boyle, mindful of his own and of van

[325] Ibid., p. 187.

Helmont's experiments in growing things of plant origin, now goes on to consider the growth of inorganic materials and ponders whether they too might owe their growth to the transmutation of water.

He begins his questioning by accepting the existence of earth, water, quick-silver [mercury] and water, but says that they are component parts of the 'universe' or 'terrestrial globe' and not of all 'mixt bodies'. He concedes that there may sometimes be either a 'running mercury' or a 'combustible substance' obtained from a 'mineral' or 'metal'. Yet he does not accept these to be elements in 'the sence above declared', i.e. in Definition no. 4. Boyle says that there are two reasons why men hold the existence of elements:

i. The necessity that 'nature make use of elements to constitute the bodies that are reputedly mixt', and

ii. That the resolution of such bodies manifests that nature had 'compounded them of elementary ones'.[326]

Boyle's use of the word 'men' in this context is curious in that most of his time is spent questioning or examining the opinions of named groups – such as the Aristotelians or the Paracelsians, or named individuals – whose opinions he either praises or disparages. In identifying a group of interested parties to the debate as 'men' he may be attempting to establish or refer to a group of people who are neutral to the debate in hand, a group who might be considered as non-specialists – neither philosophers nor scientists – but perhaps intelligent laymen. Maybe also laymen in the sense that they are not clerics, and are not looking at things from a specifically religious perspective. Nowadays they might be

[326] Ibid., pp. 187-188.

represented by an intelligent, perhaps curious and thoughtful ‘man in the street’, who can come to consider a given matter – in this case the question of the elements – without any particular training, preconceptions or doctrines to guide or influence his thinking on the matter in hand.

Boyle then gives what he considers as the ‘laymans’ opinion as to why there should be elements, and comes up with what might be considered a ‘common sense’ view on the question: elements are the fundamental ‘building blocks’ at nature’s disposal, from which compound bodies are constituted and into which they can be broken down.

Interestingly, Boyle gives as the reason for the existence of the elements not any necessity that material bodies, being of diverse natures, themselves need to be constituted out of a number of fundamental materials – no – the reason for the existence of the elements is that men believe that there should be elements. Seemingly, Boyle is not saying that the elements were present at the time of Creation, for if they were they would have been instituted by the ‘Divine Author’. The fact that it is ‘men’ who regard the elements as a necessity may well mean that Boyle himself holds that they may simply be mistaken, and that the true source of the elemental matter is to be found in the divinely created universe as revealed in the Bible. Boyle goes on to reiterate the importance of water in the growth of plants and trees, and of course he had already spoken of water as a primal substance, as stated in the Book of Genesis (and as discussed in 2.2.2.).

3.3.2. Experimental Evidence

In relation to the former considerations, Boyle reminds the reader of the experiments he carried out concerning the growth of pumpkins, mint and other vegetables out of 'fair water'. He believes from these experiments that it seems evident 'that water may be transmuted into all the other elements', and argues that it may be inferred from this that not everything that the 'chymists' call salt, sulphur or spirit needs always be a 'primordiate and ingenerable body',[327] and that nature can produce a complex plant without having recourse to an array of pre-existing elements from which to compound it.

3.3.3. De Rochas

Boyle then quotes the assertion by the French chemist de Rochas, who wrote on the generation of things according to 'certain chymical and metaphorical notions' which Boyle confesses are 'not to me intelligible'. De Rochas claimed that he was able to generate earth from water simply by the application of heat, which earth then produced animals, vegetables and minerals. On analysing the animals he found them to be composed of 'much sulphur, little mercury, and less salt'.[328] Boyle has, however, 'some suspicions concerning this strange relation, which makes me unwilling to declare an opinion of it', simply because de Rochas has not given a clear account concerning 'divers material circumstances' about his experiments. However, he is not willing to dismiss de Rochas's findings out of hand, as he himself believes that 'it needs not seem incredible' that living creatures 'both vegetable and sensitive' can be produced out of 'common water'. This is so because such water is often 'impregnated with variety of seminal

[327] Ibid., p. 188.
[328] Ibid., p. 72.

principles and rudiments', and when it has been kept for a long time 'in a quiet place will putrifie and stink', and then may 'produce moss and little worms, or other insects, according to the nature of the seeds that were lurking in it'.[329]

Boyle is careful to say that whatever animals or plants are produced in stagnant water, will only grow from seeds already present in the water. He is not claiming that spontaneous generation of living things is occurring, as de Rochas seems to have believed to be the case. Of course, Aristotle believed in that same process, for example when he says that some bloodless animals: 'come into being not from a union of the sexes, but from decaying earth and excrements' (*Generations of Animals*, 715^{a} 24-25).[330]

Boyle does accept that 'water may by various seminal principles be successively transmuted into both plants and animals' and quotes as evidence for this his own experiments in growing various plants in water. Furthermore, he believes that if these same plants had been left to putrify they would 'have likewise produced worms or other insects' but only through the agency of 'various seminal principles',[331] by which water may be successively transmuted into both plants and animals.[332]

What Boyle seems to be saying is that the transmutation of water into both plants and animals can occur, but only if the seeds, eggs or other 'seminal principles' are initially

[329] Ibid., p. 73.
[330] J. Barnes (ed.) *The Complete Works of Aristotle*, Vol. 1 (Princeton University Press, 1984) p. 1111.
[331] *Sceptical Chymist*, p. 188.
[332] Clericuzio says of Boyle: '….seminal principles which he considers a specific kind of corpuscles, namely corpuscles endowed with a formative power.' In: Antonio Clericuzio, *Elements, Principles and Corpuscles* (Kluwer Academic, 2000) p. 125.

present in the water. Once these agents are in place the growth of the plants and animals occurs through a process of transmutation of water. He says that there is 'little doubt'[333] that this is the mechanism by which the growth of plants and animals in water occurs. Boyle seems to be more sure of the veracity of his opinion in this instance than was the case when he described his own plant growing experiments and commented on that of van Helmont in growing a tree (as discussed in 2.2.2.) when he found van Helmont's hypothesis that tree growth proceeds purely from the transmutation of water so 'paradoxical' a truth, as to be in need of verification by other experimenters.

3.4. Production of Mixed Bodies

3.4.1. Men, Sheep and Plants

Although Boyle does seem willing to accept that a variety of things, of animal, plant and mineral nature may be produced by the transmutation of water, he also wished to show that there are other means by which mixed bodies are formed. He seems to take a step back on the question of the production of bodies simply by transmutation of water. He begins by saying that as a plant may be 'nourisht [by]' and consequently may consist of common water, so may both plants and animals, perhaps even from their 'seminal rudiments' consist of compound bodies, without having anything 'merely elementary' given to them by nature from which to produce compound bodies. Boyle gives as an example 'divers men' who as infants were fed only milk, and who afterwards live only on 'flesh, fish, wine, and other perfectly mixt bodies'.

[333] Ibid., p. 188.

Boyle seems at pains to stress the point that some plants and animals are seen to derive their bodily substance not from the simple transmutation of water but from compound bodies, and that it is these bodies which account for the growth of the plant or animal. Boyle had to make this point simply because few plants (or animals) are seen to be living purely on water; most living things are fed on bodies more complex than water. He then mentions sheep which grow very fat by feeding on grass, without 'scarce drinking at all', and 'magots' that breed and grow to full size within the pulps of 'apples, pears or the like fruit'. He then acknowledges that 'corn and other vegetables' grow much better in the presence of 'dungs that abound with a mixt salt' than water alone. Again, Boyle is stating the obvious fact that plant growth occurs much faster when suitably fertilised than when simply watered. There is no doubt that plants will grow when watered only, but they grow much more satisfactorily when substances necessary to the production of plant tissue are within easy reach of the roots of the plants. Of course we now understand that plant growth occurs not as a result of the transmutation of water into plant tissue as Boyle seems to have believed (and as discussed in 2.2.2.), but rather by the plant's roots and leaves absorbing from the soil and air the nutrients necessary for their growth. Boyle simply relates the fact of the effect of fertiliser on plant growth; he makes no effort to explain it, but does make an interesting observation. Boyle was assured 'by a man experienced in such matters' that sometimes when a plant is prematurely uprooted, which had been over-fertilised, the 'very substance of the plant has tasted of the dung'. Boyle seems to allow that fertiliser is absorbed by plants, then converted into plant tissue, and that if the process is interrupted the unconverted fertiliser taints the plant. Although he does not say so explicitly, he seems to believe that before being incorporated into the plant tissue the fertiliser is broken down, possibly into neutral-tasting water, by the plant, before being absorbed by it. If this is indeed what Boyle believes, it would provide a mechanism by which water is still transmuted into plant tissue, but such water would originate from the fertiliser applied to the plant. A plant grown without fertiliser would simply absorb water from the soil and transmute it directly into plant tissue.

3.4.2. Growth of Mixed Fruit Trees

Boyle then quotes the example of the growth of a fruit tree by grafting 'the scion of the pear upon a white-thorne'. He notes that the 'ascending liquor' is altered on passing from the rootstock through the scion, as he is aware of the different qualities to be met within the 'saps of several trees'. Boyle argues that the scion must still produce its fruit from the sap made from a different variety of tree, as this is the only sap available to it. His argument seems to be that nature, in producing vegetable tissue, must facilitate some form of chemical transformation, for only in this way could the sap drawn up by a whitethorn root be transformed into pear sap, and then go on to produce pears as fruit, rather than the fruit of the whitethorn, viz. haws. Of course we now realise that trees grow and flourish not just by the moisture and minerals absorbed by their root systems, but also by their leaves and the rôle they play in photosynthesis (as mentioned in 2.2.2.). Boyle himself is aware that more than the roots may be involved in sap production by trees when he mentions the possible influence of the bark in altering the liquor rising from the roots. He says that the ascending liquor is altered 'either by the root, or in its ascent by the bark, or both ways'.[334] Boyle seems to be saying that in either case

[334] Ibid., p. 189.

chemical transformation occur within the tree, both in the production of sap, and in the conversion of sap into fruit.

Boyle gives another example of the operation of different chemical reactions by discussing the transformation of vegetables consumed by animals into ‘blood’ by those animals. He argues that for vegetables eaten by an animal to be converted into animal tissue it must make many transformations under the influence of ‘one presiding form’. He believes that for such transformations to occur the ‘blood’ of the animal may be a ‘strangely decompounded body’, i.e. may have undergone chemical transformations through the building up of one chemical species into another. This building up of more and more complex chemicals may simply have been brought about by one chemical compound reacting with another, rather than from the reactions of pure elements with one another. Boyle believes that for the ‘mixtures’ that nature makes in both animal and vegetable bodies, it is not necessary that she should have ‘pure elements at hand’[335] from which to make these compositions.

Boyle makes an important digression here in his argument about the transmutation of water into other substances. He argues that if biological processes are to be explained, this can only happen if one accepts that the transformation of one chemical compound into another occurs in the course of the normal functioning of a living organism. His first argument is one of plant to plant transformation, by considering how it is that a pear scion, grafted onto a whitethorn rootstock, produces as fruit pears and not haws.

[335] Ibid., p. 190.

He believes, with some reservations, that it is the sap of the tree that provides the means by which the tree produces the wood, leaves and fruit characteristic of that particular species of tree, and that the sap is generated by the root system. This leads to an obvious difficulty in that, in the case of a grafted tree, it is the tree proper, and not the rootstock, that determines the nature of the fruit produced. Boyle explains this by saying that the sap, produced by a whitethorn rootstock onto which a pear scion has been grafted, must be transformed into pear sap as it rises through the tree, and that this transformation can only occur as a result of chemical change. The whitethorn sap itself is not simply water, but more complex chemically than that, so that when it changes into pear sap it must do so through chemical transformation rather than the simple transmutation of elemental water into another substance.

Why Boyle seems to be more secure in his opinion on the growth of plants solely through the transmutation of water is unclear. He may simply have always *believed* it to be the case, even though as an experimenter he may have realised that it had not been tested by a rigorous experimental process, and therefore could not state definitively that transmutation was indeed the mechanism by which plants and animals developed from seeds or eggs. In other words Boyle may have *believed* in an hypothesis which he was unable to *prove*. [Italics added].

3.5. Growth of Minerals and Metals

Boyle then goes on to discuss the growth of minerals and metals. First he discusses the occurrence of minerals deposited in the bodies of humans and animals in the form of stones, and later discusses the growth of metals and minerals in the earth's crust. He admits that such deposits cannot be produced by human experiment as he realises that the 'growth or increment of metals being usually a work of excessively long time'.[336] He concludes from this fact that instead of experiments he must rely on observations of natural processes. His strategy here is to examine the investigations of various writers on the subject of the growth of minerals or metals in the ground, and to evaluate the veracity of the various accounts.

Boyle's almost insatiable curiosity on the natural world was fed by a variety of sources. According to Hunter he read travel books, earlier works of natural philosophy, and the like. He also interviewed visitors – fellow aristocrats, sailors and artisans.[337]Hirai and Yoshimoto state that an important source of Boyle's information on the occurrence of metals is Johann Gerhard's *Decas quaestionum physico-chemicarum de metallis* of 1643, in which among his favourite authors are Aristotle, Theophrastus, Galen and Pliny, from the Ancient World, the Medieval writers Avicenna and Albertus Magnus, and the Renaissance writers Agricola, Cardano, Falloppio and Cesalpino.[338]

---

336 Ibid., p. 190.

337 Michael Hunter (ed.) *The Boyle Papers* (Aldershot: Ashgate, 2007) p.143.

338 Hiro Hirai and Hideyuki Yoshimoto, 'Anatomising the Sceptical Chymist: Robert Boyle and the Secret of his Early Sources on the Growth of Metals', *Early Science and Medicine*, Vol. 10, Issue 4 (2005) 453-477.

3.5.1. Calcite

Boyle begins by commenting on the growth of the calcite structures in limestone caves resulting from the evaporation of water containing dissolved calcium carbonate. He realises that such stones are not ‘all made at once’, but that some of them are still being produced, and ‘are nowadayes generated’. He is obviously aware of the growth of calcite stalagmites on cave floors by the continual dripping of water rich in dissolved calcium carbonate; as the water evaporates the dissolved mineral is left behind, eventually forming substantial calcite structures. However, the mechanism by which these calcium carbonate deposits is produced is not understood by Boyle, as he says that water falling from the upper parts of the cave to the ground does ‘presently condense there into little stones’. He seems to believe that a process of petrification occurs in which small stones are formed, having the same shapes as the falling drops themselves. These water drops ‘falling either severally or upon one another and coagulating presently into stone’ are believed by Boyle to form calcite deposits on the cave floor. The shapes of the deposits are dependent on whether the drops fall individually, when small stones are formed, or in a shower, when the stones aggregate to form larger structures. The exact process of petrification is effected by the drops ‘coagulating presently into stone’. He gives proof of the result of this stone-forming process by saying that some friends of his had presented him with some ‘of these stones’ from Les Caves Goutieres in France. Boyle seems to be trying to give an explanation of how mineral formation occurs. For him it seems to involve a process of transmutation whereby water is transmuted into some mineral deposits, in this case calcite. Water drops falling from the upper parts of the cave to the ground by some means find themselves being petrified as they fall, to form calcite. That the process of transmutation comes about through the falling of water is clear, but it does invite the question as to the length of time involved in the process by which the water petrifies. The length of time taken for water drops to traverse the height of a cave from roof to floor would be measured in seconds, even in a large cave. Boyle states that the coagulation into stone occurs ‘presently’. However, what he means by the word ‘presently’ is not clear, as it could mean: ‘immediately’ or ‘in a short while, soon’.[339] In either case, the process occurs in a short time, even though Boyle acknowledges that the ‘growth or increment of minerals’ takes place in the ‘bowels of the earth’ over an ‘excessively long time’.[340] And, of course, the rate of growth of the plants and trees spoken of by Boyle in relation to the transmutation of water into plant tissue, would have occurred over time-scales to be measured in weeks, months and years. However, if Boyle is to account for the various shapes formed by water falling in caves, then the process of petrification would have to occur as the water falls through the air. Otherwise water, being a liquid, falling onto the cave floor would simply find its own level and then form some kind of a petrified pond or river, rather than the upright structures or stalagmites which actually form in caves through the continual dripping of water, containing calcium carbonate, from the cave roof.

Boyle is here trying to account for a geological process, the formation of calcite structures, a century or so before the birth of the science of geology. It is now understood that in limestone areas rainwater containing dissolved atmospheric carbon dioxide, being acidic, may dissolve limestone to form a solution of calcium carbonate. This solution

[339] *The Oxford English Dictionary* – online (Consulted 17-7-09).
[340] *Sceptical Chymist*, p. 190.

may in underground caves deposit its dissolved calcium carbonate through evaporation to form deposits of the mineral calcite as structures in the cave roof, such as stalactites and calcite curtains, and on the cave floor, stalagmites and gours. The time-scale of these processes is measured in millenia, and, of course, this would not have been either understood (or perhaps accepted) by Boyle, who as a believer in the Biblical account of Creation would most likely have accepted Ussher's calculated date of Creation as 4004 BCE. And although Boyle did say that the growth or increase of minerals usually took place over an 'excessively long time'[341] he probably meant long in relation to the timescale of any experimental work he might have carried out on the matter.

Boyle would, therefore, have had to seek an explanation of calcite formation in which it occurred over quite a short timescale. In addition, in not actually understanding the process by which calcite forms, i.e. evaporation of water and deposition of the mineral, he would have to provide a mechanism by which this occurred. He was, perhaps, influences in his thinking by Aristotle's *Meteorology*, in particular by the latter's account of the formation of hailstones, amber and calcite.

Speaking of hail formation, Aristotle says that it results when the 'cloud is thrust up into the upper region, which is colder' (*Mete*. 1. 348[a] 15-16). He goes on to say that upon arrival there, the water freezes. The hailstones thus formed differ in size and shape, some being large and angular, others 'round and smaller in size' (*Mete*. 1. 348[a] 36).[342] Boyle makes a similar distinction between the drops that fall 'severally' and form small calcite

[341] Ibid., p. 190.
[342] J. Barnes (ed.) *The Complete Works of Aristotle*, Vol. 1 (Princeton University Press, 1984) p. 569.

stones, and those that fall 'upon one another' as they fall through the cave and then 'coagulating presently into stone'.[343]

Aristotle says that there are different processes involved in the formation of solid bodies; some being formed by cold only, such as hail, others by heat only, or by both heat and cold. Interestingly amber and other bodies 'called "tears" are formed by refrigeration, like myrrh, frankincense, gum' (*Mete*. 4. 388^b 19-20). And some of Boyle's calcite stones are 'of such figures as the drops'.[344] For Aristotle, stalactites 'cannot be melted or softened' (*Mete*. 4. 388^b 25), and are formed not through the agency of fire but rather cold which 'draws out the moisture with it' (*Mete*. 4. 388^b 29) and causes it to solidify. For Boyle, by contrast, no heat is involved in the formation of calcite in caves. The drops of calcium carbonate solution falling through the air undergo a process involving 'coagulating' into stone, with no mention of the water from which they are largely constituted. Presumably, the solution in its entirety becomes transmuted into calcite through a mechanism of coagulation, although Boyle does not state this explicitly.

3.5.2. Diamonds

Boyle quotes van Linshoten, the 'sober relator' of his voyages, and another 'good author' as relating that in 'the diamond mines (as they call them)' in the East-Indies, when having dug the earth to 'no great depth' they find diamonds 'and take them quite away'. Yet in a 'very few years' they find in the same place 'new diamonds produced there since'.[345]

[343] Op. cit., p. 190.
[344] Ibid., p. 190.
[345] *Sceptical Chymist*, p. 191.

Healy says that beliefs about the regeneration of diamonds in India and South Africa have endured to the present day.[346] He says that diamantiferous sandstones, which have been removed from their natural bed, and from which the diamonds have been extracted, are often allowed to be exposed to the various atmospheric weathering agencies for some time, and are then worked over, when a further yield of diamonds may be found, and that this process is sometimes repeated. Healy says that such occurrences have given rise to a belief among the people that this second crop of diamonds has originated in the waste rocks, or that it is the result of a fusion together of smaller diamonds originally left behind. He goes on to say that, of course, the diamonds have simply been released by the weathering of larger fragments of rocks in which they are embedded.

3.5.3. Sulphur

Boyle quotes P. Fallopius as saying that sulphur '*quae nutrix est caloris*' once mined, '*infra terram citissimè renasci testantur historiae metallicae*'.[347] The use of the words '*nutrix*' and '*renasci*' creates the understandable belief that the growth of this mineral is a biological rather than a geological process, and that once mined it re-grows under the earth. Sulphur does occur as encrusting masses produced around volcanic vents and fumaroles, by the process of sublimation. That is to say, it can issue from vents in the earth in gaseous form which condenses to crystalline sulphur on being cooled by the air. If the vents are active, then sulphur can be deposited around their mouths continuously, which means that it can be quarried repeatedly from the same location. That sulphur can be exhaled from the earth was mentioned by Aristotle when he said that 'two exhalations,

[346] J.F. Healy, *Pliny the Elder on Science and Technology* (Oxford University Press, 1999) p. 178.
[347] *Sceptical Chymist*, p. 191.

one vaporous the other smoky' (*Mete*. 3. 378^{a} 19-20)[348] issue from the earth, and he includes sulphur among the minerals produced from the smoky or dry exhalations.

3.5.4. Iron

Boyle speaks of the assurances of 'authors of good note' that metals were not all produced together 'but have been observed to grow'. He is not content, however, to confine himself to the opinions of 'professed chymists', probably because in distrusting their opinions regarding chemical change, he does not feel secure in quoting them on what might now be called geological change. He chooses instead to quote from more reliable authorities, which he refers to as 'more unsuspected writers'.[349] Boyle quotes Pliny as saying; '*In Italiae insula Ilva, gigni ferri metallum*'. Again the use of the word '*gigni*' suggests a process of organic birth, and of coming to be by a natural power.

Boyle continues that Strabo says more forcefully that in the workings on Elba the metal is always regenerated: '*Strabo multo expressius; effossium ibi metallum semper regenerari*'. Not only is the metal regenerated, but taking '*ibi*' to mean 'there in the mine', he seems to be saying that the very iron ore that has been mined is somehow renewed. He goes on to say that if mining ceased for the space of a hundred years, the miners would return to find '*maximam copiam ferri regeneratam*'. This statement seems to suggest that the growth of iron ore is time-dependent, and that if a mine-shaft is left idle for a long period of time, the iron ore will have had the opportunity to regenerate

[348] Op cit., p. 607.
[349] *Sceptical Chymist*, p. 191.

itself. It is as though in allowing the iron ore to regrow the miners are rewarded with a bountiful harvest of metal.

Boyle then quotes the 'learned Cesalpinus, who says of Elba that: '*incredibili copia etiam nostris temporibus eam gignens*'. He states that when the earth is dug out '*dum vena offoditur tota, procedente tempore in venam convertitur*'.[350] Here again the iron is regenerated over time, but now there is a condition to be met before this becomes possible – the vein of iron ore in question must first have been excavated completely.

Boyle goes on to say that the last (Latin) clause quoted is very notable because from it we may deduce that earth 'by a metalline plastic principle latent in it',[351] may over a period of time be changed into a metal. In fact all the authors just quoted seem certain that iron ore when removed from a mine, once certain conditions are met, is regenerated over time. It is interesting to note that all of these authors speak of the island of Elba, which, despite its small size, has yielded an estimated 60 million tons of iron ore over the last three millennia.[352]

The final example of the growth of iron is given by Boyle in which he quotes Agricola who 'acknowledges thus much and more' (i.e. in relation to the regeneration of metals) by saying that at a town called Saga in Germany 'they dug up iron in the fields, by

---

[350] Ibid., p. 191.
[351] Ibid., p. 191.
[352] L. Piccardi and W. Bruce Masse (eds) *Myth and Geology* (London: The Geological Society, 2007) p. 229.

sinking ditches two foot deep' then within the space of ten years 'the ditches are digged again for iron, since produced'.[353]

This is the only example given in relation to the growth of iron where actual regeneration of the metal may actually have occurred, and the reason for this is due to the fact that one form of iron ore – bog iron – grows by an organic process. Bog iron ore is a brownish-yellow deposit of iron compounds, chiefly iron hydroxide, which occurs in bogs or swamps, produced by the oxidising action of bacteria, algae or the atmosphere. This deposit derives from the soluble iron compounds dissolved in the wetland's waters.[354] Economically useful deposits of this ore can regrow within twenty years of harvesting.[355] Boyle's statement that the ditches in Saga, Germany, were reworked for whatever iron ore was produced within a ten year period, may well have occurred in an area of wetlands where fresh deposits of bog iron ore were continually produced. It may be that it was the growth of such deposits of iron ore that gave rise to the belief that iron comes to be as the result of an organic process.

Although Boyle does use the word 'may' in relation to the growth or iron on the island of Elba, as described as Cesalpinus, nevertheless he does seem to accept that earth over a period of time is changed into a metal, by the action of a 'metalline plastick principle' (as already quoted). He says that this principle is 'latent' in the earth.

3.5.5. Lead

[353] Ibid., pp 191-192.
[354] Antony Wyatt (ed.) *Challinor's Dictionary of Geology* (Cardiff: University of Wales Press, 1986) p. 35.
[355] www.britannica.com/bps/search?query=bog+iron (Consulted 7-5-10).

Boyle then goes on to discuss the fact that lead, as noted by Galen, will increase 'both in bulk and weight' if it is kept for a long time in vaults or cellars, where the air is 'gross and thick'. He says that Galen collected [lead] 'from the swelling of those pieces of lead' that were employed to fasten together the parts of old statues. Boyle then quotes Boccacius Certaldus concerning the growth of lead, who says that Mount Fiesole in Etruria, which overlooks the city of Florence, has lead bearing stones, which when mined, in the space of a few years are restored with new growth, and that this is known for certain. This is nothing new, for Pliny, he continued, in his *Natural History*, Book 34, Chapter 17, says that:

'*mirum in his solis plumbi metallis quod derelicta fertilius reviviscunt*'.[356]

Returning to his account of Mount Fiesole, Boccacius Certaldus says that the inferior ore (*secundo lapide*) which has been put into heaps for safe storage, when exposed to the sun and rain for a few years, yields an increased amount of metal.

Healy says that Pliny repeats the commonly held belief in the ancient world that minerals grow,[357] but Galen seems to go one step further and say that metallic lead itself, when kept in storage, increases in both bulk and weight. This increase cannot be attributed to the oxidation of the metal: lead does indeed form an oxide layer (which manifests itself as the dull grey film which forms on the surface of freshly cut lead and gives it its characteristic colour). Once the layer of oxide forms, however, metallic lead does not continue to oxidise but simply retains its distinctive appearance over long periods of time.

[356] *Sceptical Chymist*, p. 192.
[357] Op. cit., p. 177.

Galen was greatly influenced by Plato, as Lloyd says 'Plato holds a place in his admiration second only to Hippocrates himself'.[358] So, he would no doubt have been familiar with Plato's account of the formation of rock, as given in the *Timaeus*. According to Plato, water which mixes with earth is broken up in the process and changes into air, and in this form rises to its own place. In rising, it displaces an equal volume of air, which mixes with the neighbouring air, thereby increasing its density. This denser air, having been poured around the mass of earth:

> 'forcibly compresses it and drives it into the vacant space whence the new air had come up, and the earth when compressed by the air into an indissoluble union with water becomes rock'. (*Timaeus*, 60c).[359]

Plato is not describing the production of metals, but he is saying that by compressing the air it becomes denser, and this denser air then acts on another body, in this case air, to change it into a different substance, i.e. rock.

Plato seems to be saying that:

Earth and Water (under the influence of Dense Air) = Rock

Galen, following Boyle's account, seems to be making a similar argument and, taking moisture to be present in 'vaults or sellers'[360] one might express his mechanism for the production of additional quantities or lead as:

Lead and Moisture (under the influence of 'Gross Thick Air') = Lead

---

[358] G.E.R. Lloyd, *Greek Science After Aristotle*, (New York: Norton, 1973) p. 138.
[359] E. Hamilton and H. Cairns, (eds) *The Collected Dialogues of Plato* (Princeton University Press, 1961) p. 1185.
[360] *Sceptical Chymist*, p.192.

In each case the air seems to play an important rôle in the production of the new substance, with Plato's 'dense air' and Galen's 'gross thick air' somehow acting on earthy matter, in the presence of moisture, causing a denser, more solid material to be produced. It is interesting to note that Galen, alone of the commentators quoted by Boyle, speaks of an increase in quantity of bulk metal whereas the others spoke only of metals in the form of ore, as increasing, and as lead does not occur native, it could only be present in the earth in the form of ore.

Although it is difficult to justify Galen's claims regarding the growth of lead on the basis of modern insights into the production and occurrence of metals, the same cannot be said of Boccacius Certaldus's account of the increase in the heaps of inferior ore built close to the lead mines of Mount Fiesole. The most commonly occurring lead ore is galena, lead sulphide, which like the metal derived from it, is a very dense material, much denser than the rocks, clay or stones with which it occurs in the natural state. This means that the galena crystals or granules in a pile of low grade ore could over time sink to the bottom, especially as rain caused the pile to become wet. So, in the '*paucis annis*'[361] quoted by Boyle, the galena could make its way to the bottom and settle on the earth as a concentrated vein of lead ore.

3.5.6. Silver

Boyle says that he has met 'many things' concerning the 'generation of gold and silver'. He quotes from 'Gerhardus the physick professor': '*in valle* (saies he) *Joachima argentum graminis modo et more è lapidibus minerae velut è radice, excrevisse digiti*

[361] Ibid., p. 192.

longitudine'. Gerhardus give Dr Schreterus as witness who had some of these finger-length growths of silver in his home '*aspectu jucundas et admirabiles*', which he often showed to others. Similarly, Boyle says, there was some sky blue water found at Anneberg: '*ubi argentum erat adhuc in primo ente, quae coagulata redacta est in calcem fixi et boni argenti*'.[362]

Boyle here is speaking of the growth of silver, which is quite an inert metal, and although it frequently occurs in the form of ores, it does occur native, as crystals having wiry or scale forms.[363] Some of these wiry growths, reaching about 10cm in length, could be described as being of finger length. The actual occurrence of silver can sometimes be in hydrothermal veins, and if these vent to the open air their water could well take on the sky-blue colour as reported in Gerhardus's account. The small amounts of silver formed in these veins would have a fine, more or less dendritic structure, and would indeed be pleasing in appearance. Of course the silver comes into being by virtue of geological activity, nevertheless it does seem to be growing from the water, in one sense, rather than out of the walls of the hydrothermal veins, as is actually the case.

Boyle then speaks of an incident related by that 'industrious chemist' Johannes Valehius, about a discovery made by a workman at the mine town of Mariakirch, eight miles distant from Strasbourg. During the course of his mining activity, 'in a grove or mine-pit' he came upon a large piece of 'pure fine silver' weighing 500 pounds. It was free standing 'having no vein or ore by it', and it had under it 'something like a burnt matter'. Boyle

362 Ibid., p.192.
363 A.L. Bishop, A.R. Woolley, and W.R. Hamilton (eds) *Minerals, Rocks and Fossils* (London: George Philip, 1999) p.16.

says that Valehius understood that the 'noble metalline spirits (sulphurous and mercurial)' were carried from the neighbouring galleries or vaults, through some smaller cracks and clefts into that cavity, and 'there collected as in a close chamber or cellar', wherein in time they did 'settle into the forementioned mass of metal'.[364]

This account is interesting because Valehius seems to accept the mercury-sulphur theory of metal formation, and simply seems to have believed that the presence of these two materials as 'metalline spirits' was sufficient, in the favourable conditions obtaining at this particular location, to account for the formation of the large lump of silver. What the workman actually seems to have discovered was a deposit of native silver (which if converted into a block of the metal, would measure approximately 200mm x 200mm x 400mm in size) and which occurred in a vein of silver ore.

3.5.7. Antimony

Boyle goes on to give another account from a German source by the 'laborious chymist Johannes (not Georgius) Agricola' who in his notes upon 'what Poppius has written of antimony' relates that when he was 'among the Hungarian mines in the deep groves' he observed that there would often arise in them 'a warm steam' which fastened itself to the walls. When he came to look at it again after a couple of days, he 'discerned that it was all very fast, and glistering'. Having collected it and distilling it in a retort, he obtained from it a 'fine spirit', and the miners informed him that this steam, or 'damp' [probably

[364] *Sceptical Chymist*, p.193.

derived from *Dampf* (steam), as Boyle says that they retain the 'Dutch', *sc*. German, term] would 'at last have become a metal, as gold or silver'.[365]

Given that the 'warm steam' which fastened itself to the walls, and which in a couple of days was found to be 'glistering', and that all of this happened in relation to antimony, seems to indicate that the material observed on the walls was the mineral stibnite. This is a sulphide of antimony, and is the most common antimony ore. It is a soft, opaque lead-grey mineral which is sometimes tarnished and iridescent.[366] The 'warm steam' would simply have condensed on the walls, so that what was actually scraped off the walls by Agricola probably amounted to nothing more than some stibnite dispersed in water, and the 'fine spirit' that distilled over in the retort would simply have been water.

According to Healy, stibnite appears to have been known to Pliny, who gives a garbled account of the mineral:

> '*spumae lapis candidae nitentisque non tamen tralucentis; stimmi appellant, allii stibi*'.[367]

This description of a stone made of a white, shiny but not transparent froth is not unlike the 'glistering' mineral on the mine walls described by Agricola, and two of the names for this mineral given by Pliny are defined by Lewis and Short as: 'stibium, stibi, stimmi; antimony, a sulphuret of antimony'.[368]

---

[365] Ibid., p. 194.
[366] *Minerals, Rocks and Fossils*, p. 30.
[367] Op cit., pp. 338-339.
[368] *A Latin Dictionary* (Oxford University Press, 1879) p. 1758.

As antimony also occurs native, in hydrothermal veins, often associated with silver or arsenic, and accompanied by stibnite,[369] it is quite possible that the condensation on the walls observed by Agricola was associated with a hydrothermal vein where antimony and silver deposits could have built up over time. Hence the reference to the condensate becoming a metal 'as gold or silver'.

3.5.8. Nitre

Boyle believes evidence that such 'alterations of terrestrial matter are not impossible' seems to him as coming from the work of the saltpetre boilers (who prepare saltpetre, nitre, or potassium nitrate, from decaying organic matter). They 'unanimously observe' not only in England but in other countries as well, that even if 'an earth pregnant with nitre' has all of that chemical present in it washed away by water, yet after some years the same earth will yield a quantity of nitre again. Boyle says that for this reason some of the most skilful of them keep heaps of decaying organic matter as 'a perpetual mine of salt-petre'. Of course we now understand that saltpetre, which is a crystalline white solid, is continuously produced by organic matter as it decays. Being highly water soluble, the saltpetre can simply be removed by washing it out of the original material in which it formed. The liquor thus produced is reduced in volume by boiling, and when cooled, saltpetre crystallises out of the solution and can be collected for use. A given heap of organic material can have its saltpetre washed out, only for new quantities of this product to form when the organic matter is reformed into a heap and left alone. The process of decomposition recommences, and with it the renewed production of saltpetre.

[369] *Minerals, Rocks and Fossils*, p. 18.

Boyle is correct in saying that a heap of organic matter does, over the course of a number of years, produce quantities of saltpetre which can be washed out of it from time to time, and he hypothesises how it comes to be produced. He says that 'it may appear that the seminal principle of nitre [saltpetre] latent in the earth does by degrees transforme the neighbouring matter into a nitrous body'. For Boyle, the power by which organic matter comes to be converted into a 'nitrous body' appears to be present in the earth. This would seem to be a reasonable enough way to attempt a rational explanation of the formation of saltpetre. A solid material seems to be produced from organic matter which itself was made from the earth. Boyle states that 'I deny that some volatile nitre may by such earths be attracted (as they speak) out of the air'.[370] The reason for this seems valid at first blush as he argues that the centres of 'such great heaps' are so remote from the air that the explanation that they 'should borrow from it all the nitre they abound with' is improbable, he argues. However, it is not just the remoteness of the air from much of the decaying organic material that leads Boyle to this conclusion, he has other reasons as well, although he does not have 'the leasure to mention them'.[371]

Boyle, in discounting the influence of the air in the production of saltpetre, meant that he could never give a true account of how this material is formed. He simply did not understand the rôle played by nitrogen in the growth of plants, as nitrogen, although making up almost 80% of the atmosphere, was not discovered until 1772 by Daniel Rutherford (1749-1819),[372] and included in Lavoisier's list of the elements of 1789.[373]

[370] *Sceptical Chymist*, p.194.
[371] Ibid., p. 195.
[372] John Emsley, *Nature's Building Blocks* (Oxford University Press, 2001) p. 290.
[373] J.R. Partington, *A Short History of Chemistry* (New York: Dover Publications, 1989) p. 135.

What we now understand about the natural circulation of atmospheric nitrogen by living organisms – the nitrogen cycle – came to be appreciated two hundred years or so after Boyle's time. Ammonium compounds in dead organic material are oxidised by atmospheric oxygen and converted into nitrates by soil bacteria, thereby making nitrogen available to plants, and saltpetre is one of the nitrates thus produced. Although the nitrogen and oxygen involved in this process originate in the atmosphere, this fact is not obvious, as although most plants grow and decay at, or close to, the surface of the earth, in full contact with the atmosphere, it was the rootedness of plants in the earth, and what those roots extracted from the soil, that Boyle perceived as significant, and to which he paid most attention in his investigations into the growth of plants.

Saltpetre is a mineral produced from the decay of organic material, and its growth occurs over a period of months and years, that is to say, a timescale short enough to allow the curious observer to investigate the process. Boyle begins his investigation by stating that he believes it improbable that minerals or metals are produced by the salt, sulphur or mercury of the chymists or Paracelsians, but is more inclined to accept that 'certain *halitus* or steams' of Aristotle may play a rôle in the production of metals and minerals. For Boyle believes that the 'mineral earths or those metalline steams (wherewith probably such earths are plentifully imbued)' contain in them 'some seminal rudiment, or something equivalent thereto' by whose 'plastick power' the rest of the matter, even though it is 'terrestrial and heavy' is 'in tract of time fashioned into this or that metalline ore'. Then Boyle makes a telling comparison, viz. he wants to establish a connection between the production of plants from water and the production of metals from earth. He says that 'fair water' was 'contrived' into the various plants 'mint, pompions, and other vegetables' by the action of a 'seminal principle', and attempts to connect the conversion of earth into minerals or metals with the conversion of water into plants. Boyle understands that plants grow from seeds by the action of some power or 'seminal principle' that causes the seeds to turn into plants. And he argues that a parallel principle must be at work in the production of metals, some 'seminal rudiment' or equivalent, which acts by way of a 'plastick power'[374] on the matter from which the metal is made. That such transformations are possible, Boyle believes, are provided by the production of the mineral substance, saltpetre, which can be removed from some decaying organic matter by skilled saltpetre boilers, only to be seen to reform on the same organic matter over a short number of years.

3.5.9. Vitriol

Boyle discusses the production of vitriol [iron sulphate] by two different routes – one by an unnamed 'person of great credit, and well acquainted with the ways of making vitriol' – the other by Boyle himself. In the first account the experimenter in question 'affirmed to me [Boyle]' that a 'kind of mineral which abounds in that salt [vitriol]' being kept indoors and not exposed to the 'free air and rains', of its own accord turned into vitriol in a short while. This transformation did not occur only in the 'outward or superficial' but even in the 'internal and most central parts'.[375]

[374] Ibid., p. 194.
[375] *Sceptical Chymist*, p.195.

What Boyle seems to be saying is that a mineral rich in vitriol, over a period of time, comes to be converted completely into vitriol. Of course what is really happening is a chemical transformation, in which the mineral pyrite, iron pyrites, or iron sulphide, is oxidised to iron sulphate, through the agency of atmospheric oxygen. Boyle does not name the mineral in question but does mention that vitriol or iron sulphate is formed from it when kept indoors, away from rain and the open air, and that the conversion into vitriol occurs not only at the surface but throughout the bulk of the mineral.

What seems to have happened is that the worker in question had some rather small pieces of the mineral iron pyrites which can oxidise to iron sulphate or vitriol, (as already mentioned). For oxidation to occur the mineral would simply have to be left in contact with the air, and the process would still occur if placed in a drawer or cupboard. If the pieces of mineral were quite small they could oxidise through their entire bulk, which would mean that they would turn from lumps of iron pyrites into lumps of iron sulphate, over time. Oxidation, being caused by contact with the air, begins at the surface of the mineral and in time, works through the thickness of the piece. This is probably what Boyle was referring to when he said that the mineral in question turned into vitriol even in the most ‘central parts’. And when Boyle spoke of a mineral abounding in vitriol, he probably meant that the pieces of iron pyrites in the possession of the unnamed experimenter had already undergone some oxidation to vitriol at the surface, even though the mineral originally consisted purely of iron pyrites.

That this mineral was most likely iron pyrites is supported by the account given by Boyle of marchasite (which is chemically the same as iron pyrites, but forms a different crystal system). He says that ‘a certain kind of marchasite’ present under the ground in ‘great quantities’, but even in his chamber, began in a few hours to turn into vitriol, which so convincingly verified the previous account ‘that we need not distrust the newly recited narrative’.[376] Both iron pyrites and marchasite, being chemically identical, oxidise in the same way to form vitriol, and Boyle, in linking his own findings with those of the unnamed authority, lends credence to the explanation that they were observing the same effect on two chemically identical minerals.

Boyle seems to give his account of the production of vitriol as a further example of the production of a chemical compound by transmutation from another. His intention is to show that the production of a chemical species cannot be effected through the agency of the air and must, therefore, occur through a different mechanism. He hypothesises that, as the air can be ruled out as playing a rôle in the transformation of one chemical substance into another, the most likely explanation is that the transformative power, instead, comes from the earth.

In each example he speaks of materials – in the centre of a pile of organic matter in the case of the production of saltpetre, and in the centre of pieces of iron purites and marchasite in the production of vitriol – which turn into those minerals without possibly having come into contact with the air. Having given a detailed account of how saltpetre is produced even at the centre of a heap of decaying organic matter, he argues that as the

[376] Ibid., p. 195.

air cannot reach this part of the mass of material, it can be ruled out as participating in any way in the production of the saltpetre. He then goes on to reinforce this argument by saying that vitriol forms even in the centre of the pieces of iron pyrites and marchasite, again eliminating the possibility that air is in any way responsible for the production of vitriol.

3.6. The Origin of Metals and Minerals

Boyle makes a comparison between his own argument regarding the origins of metals and those of the Aristotelians and Paracelsians on the same subject. Having delivered various accounts of the growth of metals and minerals, in which he says that he was given some ‘hints’ regarding the origin of metals, he then says it is not necessary to the validity of his argument that his ‘deduction’ from them should be ‘irrefragable’ because his adversaries, the Aristotelians and ‘vulgar chymists’ do not ‘I presume, know any better than I, *a priori*, of what ingredients nature compounds metals and minerals’.[377]

He goes on to state that the arguments employed by his adversaries that metals and minerals are made up either of the four elements of the Aristotelians or the *tria prima* of the Paracelsians are drawn *a posteriori*, meaning that the materials from which these bodies are composed are revealed by resolution in the fire. Knowledge of the elements of which bodies are composed is obtained only by resolving these bodies into their fundamental components, which in turn means that the sole claim that can be confidently made in relation to the elements is that they result from the analysis of bodies by some form of thermal analysis. Boyle is sceptical as to the claims made by his adversaries in

[377] *Sceptical Chymist*, p.196.

relation to what exactly those decomposition products actually are. He says that, although chemists pretend to draw salt from some materials, from others a sulphur, and from still others running mercury, yet they have not indicated any method in use among them to separate 'any one principle' whether salt, sulphur or mercury, from 'all sorts of minerals without exception'.[378]

Interestingly, Boyle concludes from this that there is not any one of the elements that is an ingredient of all bodies, and that the reason he has for saying this is that there are 'some of which this is not so'.[379] Curiously, Boyle is not asking whether all of the *tria prima*, or even two of them, are present in all materials, his real question seems to be whether one particular element of the *tria prima* is present, without fail, in all compound bodies. He may be attempting to argue back from the *tria prima* to one primary element, for such a move would neatly complement his other argument on the production of all materials from the primal element, water. This he could achieve by arguing that water as the original element is transmuted into both earth and other earthy substances such as plant tissue or metals. He could then explain that plant tissue when distilled yields water again, albeit not in the pure state but as 'phlegme' with a 'little empyreumaticall spirit',[380] a small quantity of 'adult oyl' and a solid residue or *caput mortuum*, which Boyle concluded to consist of 'salt and earth'.[381]

So Boyle could argue that water is absorbed by a growing plant and converted into woody tissue, which, when distilled, yields water again (in the form of the liquid products

[378] Ibid., p. 196.
[379] Ibid., p. 196.
[380] 'Empyreumatic = tasting or smelling of burnt organic matter.' In: M.P. Crosland, *Historical Studies in the Language of Chemistry* (New York: Dover Publications Inc., [1972] 1978) p. 269.
[381] *Sceptical Chymist*, p. 67.

of distillation). However, the distilled product also yielded a solid residue which shows no signs of reverting to water-like condition. Boyle's experiment, then, can be taken as evident that water is transmuted into other materials, salt and earth, but a fraction of the water remains in a watery condition in the form of phlegm, spirit and oil.

A Boylean could argue from this that water, present at the commencement of Boyle's plant growing experiment, was still to be found after the distillation of the plant into its various fractions. However, a Paracelsian could argue that the plant when distilled was separated into the *tria prima*, as attested by the presence of a mercury (the phlegm) a sulphur (as the combustible oil and spirit) and a salt (as the solid residue) and conclude from this analysis that the plant was simply constituted of the standard Paracelsian elements.

The problem is that when specific materials are not identified as the products of distillation (or other means of separating materials into their primary components) differences in interpretation of what exactly these products are, arise. This means that a liquid product of distillation which behaves as a liquid but is not capable of identification as a particular material, such as alcohol, *aqua regia*, or oil of vitriol, can be identified as any number of liquids, and Boyle's 'phlegm' could be the 'running mercury' of the Paracelsians. The same set of products can be identified on analysis in two ways, using the explanatory capabilities of two distinct theoretical systems, neither one capable of being employed to decide the matter as to which side was correct.

3.7 Transmutation as a Mechanism

Boyle seems to conceive of materials as having what might be called a structural plasticity. That this is so can be inferred from Boyle's belief that matter can transmute from one element into another. Water can transmute into earth, earth into a metal, and if the corpuscles are plastic with respect to their outer structure, then individual corpuscles can change shape, in the same way that molten glass can be worked into different shapes. In addition, corpuscles can break, or be abraded to give new shapes, and in the case of water at least, the wearing smooth of some angular corpuscles can result in the formation of water, which itself then takes on some of the lack of sharpness of the particles from which it is constituted.[382]

The changes in corpuscular shape and identity are facilitated by the other principle with which matter is imbued, viz. motion. Motion of its nature confers on matter a dynamic quality which means that the corpuscles themselves can move about in relation to one another (at least in certain circumstances) but it may also give to the corpuscles a sort of inner dynamic, a quality by which they can change shape or transmute. For Boyle, although he frequently speaks of transmutation as occurring between elemental materials, never actually suggest a mechanism by which it may be effected. He may have looked upon it as an extension of the motion possessed by the corpuscles, in which their motion is directed inwards in the corpuscles causing them to undergo so radical a change as to transmute into a different element.

[382] *The Works of Robert Boyle*, Vol. 9, 1678-83, pp. 107-108.

In the light of the foregoing it could well be argued that Boyle's sense of the elements owes more to the Aristotelian model than to the atomic, at least as the latter came to be understood after Boyle's time, in that atoms came to be perceived as fixed, stable material entities in motion. Atomic motion was incapable of effecting any change in the structure of the atoms themselves, its function being purely translational. Whatever identity atoms possessed, such as size and shape, were hypothesised as being retained, unchanged, through time.

By contrast Boyle's Corpuscularian Hypothesis seems to have been influenced by Aristotle's explanation that transmutation is a fundamental quality of elements, and unlike Boyle he can explain it by changes in qualities. He too can account for the transmutation of water into earth and of earth into another element, all of which changes overlie the *hypokeimenon* of prime matter. For Boyle also all corpuscles are subdivisions of the same prime- or universal-matter, and although he does not speak of this as underlying all material changes in bodies, it is surely the case that all changes in matter occur in and through the corpuscles. So for Boyle the corpuscular state of matter acts as a kind of *de facto* material substrate, in that whatever changes occur in matter – even those mechanisms he does not explain – take place with the matter in the corpuscular state being the actual material in which change occurs. For Boyle, as for Aristotle, changes at the elemental level of matter can be effected through a process of transmutation.

That Boyle was considerably influenced by the Aristotelian explanation for the behaviour of matter can be seen from his statement that, although matter, motion and rest are 'catholick principles of the universe' the principles of particular bodies are 'matter' – and here Boyle hesitatingly seeks another word which might best match the explanatory capability of Aristotle's 'form' – whilst assiduously attempting to choose an alternative term. He suggests the words 'structure' and 'texture', but struggle as he might he eventually plumps for 'forme', with the strict proviso that he does not mean the Scholastic 'substantial forme', which he says 'so many intelligent men profess to be to them altogether unintelligible'.[383] Boyle seems content to give at least limited acceptance to Aristotle's hylomorphism, strictly interpreted as its originator intended. That Boyle was not totally averse to the Stagyrite's theory of matter is noted by Brykman when she says that Boyle is neither a true Cartesian nor a radical atomist, and that he did not completely abandon Aristotle, when the latter is stripped of his faded Scholastic finery (*oripeaux scholastique*).[384]

[383] *Sceptical Chymist*, pp, 201-202.
[384] Myriam Dennehy and Charles Ramond (eds) *La Philosophie Naturelle de Robert Boyle* (Paris: Vrin, 2009) p. 246.

BIBLIOGRAPHY TO CHAPTER 3

Barnes, J., (ed.) *The Complete Works of Aristotle*, Vol. 1 (Princeton University Press, 1984).

Bishop, A.C., Wooley, A.R. and Hamilton, W.R., (eds) *Minerals, Rocks and Fossils* (London, George Philip, 1999).

Boas, Marie, 'An Early Version of Boyle's: Sceptical Chymist', *Isis*, Vol. 45, No. 2 (1954) 153-168.

Boas, Marie, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958).

Boyle, Robert, *The Sceptical Chymist* (Mineola, N.Y.: Dover Publications, 2003).

Clericuzio, Antonio, *Elements, Principles and Corpuscles* (Dordrecht: Kluwer Academic, 2000).

Collins English Dictionary (Glasgow: HarperCollins, 2005).

Crosland, M.P., *Historical Studies in the Language of Chemistry* (New York: Dover Publications, [1962] 1978).

Dennehy, Myriam and Ramond, Charles (eds) *La Philosophie Naturelle de Robert Boyle* (Paris: Vrin, 2009).

Emsley, John, *Nature's Building Blocks* (Oxford University Press, 2001).

Encyclopaedia Britannica – Online, www.britannica.com/bps/search?query=bog+iron (Consulted 7-5-10).

Hamilton, E. and Cairns, H. (eds) *The Collected Dialogues of Plato* (Princeton University Press, 1961).

Healy, J.F., *Pliny the Elder on Science and Technology* (Oxford University Press, 1999).

Hirai, Hiro, and Yoshimoto, Hideyuki, 'Anatomizing the Sceptical Chymist: Robert Boyle and the Secret of his Early Sources on the Growth of Metals', *Early Science and Medicine*, Vol. 10, Issue 4 (2005) 453-477.

Hunter, Michael, (ed.) *The Boyle Papers* (Aldershot: Ashgate, 2007).

Hunter, M. and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 9 (London: Pickering & Chatto, 2000).

Lewis and Short (eds) *A Latin Dictionary* (Oxford University Press, 1879).

Lloyd, G.E.R., *Greek Science After Aristotle* (New York: Norton, 1973).

Partington. J.R., *A Short History of Chemistry* (New York: Dover Publications, 1989).

Piccardi, L., and Bruce Masse, W. (eds) *Myth and Geology* (London: The Geological Society, 2007).

The Oxford English Dictionary – Online, http://dictionary.oed.com/templates/entrance_main.html (Consulted 17-7-09).

Wyatt, Anthony (ed.) *Challinor's Dictionary of Geology* (Cardiff: University of Wales Press, 1986).

Chapter 4

Boyle and the Elements – II

Table of Contents

Chapter 4

Boyle and the Elements – II

4.1. Elements as Corpuscular Entities

A subject worthy of investigation is Boyle's application of his Corpuscularian Philosophy to the question of the elements. Given that he set this hypothesis as the foundation-stone of his system of natural philosophy, it is somewhat surprising that Boyle never employed it in relation to his understanding of the elements. He maintained that the three principles upon which his system was based were matter, motion and rest, with matter divided into corpuscles, which in turn were distinguished by size, figure and shape. Boyle extended his hypothesis to argue that the corpuscles themselves were capable of being broken down, under certain conditions, to form some kind of smaller, though unspecified entities (as discussed in 2.3.6.). He believed that corpuscle and atom were equivalent terms, but in coining the word corpuscle he was able to ascribe to its properties not possessed by atoms, the most obvious of these being divisibility, which property is excluded from the range of qualities attributed to atoms, by definition.

Boyle in his definitions of the elements employs a vocabulary in which he speaks of them in terms of 'minute particles', 'primitive', 'simple', which constitute 'elemented bodies', leaving little doubt but that he considers the elements as partaking of the corpuscular nature of matter in general. Given that he treats of the elements as 'bodies' or corporeal entities – elements as consisting of material might well be expected to share the same corpuscular nature as other natural bodies – yet Boyle never states this explicitly. In not doing so, it could be argued, Boyle does not take full advantage of the explanatory power of his Corpuscularian Hypothesis. He is content to postulate that matter is corpuscular in nature, and that the elements, being as they are simple, corporeal bodies are, logically, both material and corpuscular in nature. However, in stating that corpuscles and atoms are equivalent terms, but not going on to say where exactly elements fitted in to his scheme of material things, it does seem that he concluded that corpuscles are equivalent to atoms, but that neither atoms nor corpuscles are the same as elements. In other words he never did state the relationship: corpuscle equals atom, equals element.

Of course it could be argued that Boyle's sceptical instincts prevented him from making claims regarding the subdivisions of matter which he could not justify by experimental means, but against this it could be said that he was happy to state that corpuscles were the same as atoms, even though he did so without adducing any experimental evidence whatsoever. Boyle did adduce sound experimental evidence in support of his understanding that at least two materials, gold and silver, could be reduced to their corpuscular state through appropriate chemical manipulation (as discussed in 2.3.1.).

In failing to state explicitly his placing of the elements in relation to other material entities – be they named substances such as gold and silver, as well as the corpuscles themselves – he could not locate his understanding of where the elements lay in relation to those of his adversaries. In lacking a firm conviction of where exactly the elements fitted into his overall scheme of things he was not in a position to offer a telling critique of the hypotheses of the Aristotelians or Paracelsians. Neither could he explain how his own hypothesis differed from theirs or how it might be superior to them. His adversaries could provide detailed accounts of the nature, function and working out of their hypotheses, giving derivations for their elements, how they behaved in various materials, and how their presence in bodies could be verified.

4.1.1. The Function Served by the Elements

If one considers the elements either today or going back to the Aristotelians or Paracelsians, their function is to act somehow as building blocks, and they are the entities which combine to give all of the materials of the sensible world. The elements underlie all other bodies, and are by definition the simplest entities – if this were not the case the elements themselves would be composed of even smaller bodies, or even simpler elements – in fact. Clearly then the elements represent the ultimate subdivision of matter, just one step above the *materia prima* or universal matter.

Boyle says as much in his definitions of the elements. For him the elements are ‘simple’, ‘primitive’ bodies. Their simplicity is stressed by his saying that are ‘unmingled’ and go to form ‘mixt bodies’. On this reading of Boyle the elements must not only be simple but the *simplest* bodies, because being unmingled they cannot be composed of anything smaller than themselves, which in turn means that they must be the simplest material bodies. In addition the ‘mixt bodies’ which they constitute can be broken down to yield the elements of which they consist; the elements are those bodies into which the compound ones are ‘ultimately resolved’. So the elements must retain their individuality when combined to give these ‘mixt bodies’, and must retain their identity as simple bodies, otherwise they could not be released to revert to their original elemental state when the same compound bodies are decomposed.

Boyle has much to say on the subject of the smallest division of matter as his Corpuscularian Philosophy is based on the three principles of matter, motion and rest, with matter in its primal form being the universal matter present at Creation, and which came to be divided into corpuscles, *prima naturalia* and *minima*. Matter subsists in the form of corpuscular entities, in other words, material things could only be understood as having a corpuscular nature. Consequently when Boyle speaks of chemical entities they are invariably referred to as consisting of corpuscles.[385] It is clear from the foregoing that whenever Boyle speaks of matter itself, of the matter participating in chemical reactions, or of the constituents of chemical compounds, he understood these are changes to, or rearrangements of, the corpuscles from which these material entities are composed.

Curiously then when he speaks of the elements, they are defined using terms such as 'distinct substances' (Definition no. 3), 'bodies' (Definition no. 1), 'primitive and simple bodies' (Definition no. 2), and 'unmingled bodies' (Definition no. 4). In none of these definitions of the elements does the word corpuscle appear, even though Boyle is defining the elements in terms of the most fundamental material entities. Yet the

[385] For example the following references: '… corpuscles that constitute the quick-silver…' (*Works*, Vol. 2, p. 183),
'… the saline corpuscles that chiefly compose it,' (Ibid., p. 186),
'… alabaster … through its corpuscles …' (Ibid., p. 187),
'… fiery or calorifick corpuscles …' (Ibid., p. 102),
'… cleaving the nitrous corpuscles,' (Ibid., p. 55),
'… acid corpuscles', (Ibid., p. 62),
'… mercurial corpuscles' (*Sceptical Chymist*, p. 209),
'… corpuscles of the gold,' (*Works*, Vol. 8, p. 438),
'… constitution of the corpuscles that compose the air;' (Ibid., p. 438).

corpuscles are the primary subdivisions of matter, so why did Boyle not include the term 'corpuscle' in any of his definitions of the elements? In employing the word 'bodies' in his definitions he leaves no doubt that he includes the elements among corporeal entities, so they cannot subsist as 'qualities', or as immaterial 'principles' or 'powers' of some kind, which somehow act on or in matter, and cause it to be elemented.

Perhaps the elements, though simple bodies, are constituted of corpuscles after all. Strangely enough, this does seem to be the case, as when he speaks of:

'... the corpuscles whereof each element consists, ...'[386]

'... the corpuscles of one element ...',[387]

'... minute elementary corpuscles ...',[388]

'... the corpuscles of one principle ...',[389]

It would seem, from the above, that Boyle considered the elements themselves to be composed of corpuscles. One explanation may be that he believed that a single corpuscle constituted a single unit of an element. This would allow him to consider both corpuscles and elements as simple bodies, and would also mean that every element consisted of simple, individual corpuscles. However, if this is what Boyle had in mind, why did he not at some point equate corpuscles with elements? Given that he was content to equate corpuscles with atoms, as when he spoke of 'indivisible corpuscles called atoms'.[390]

---

[386] *Sceptical Chymist*, p. 32.
[387] Ibid., p. 32.
[388] Ibid., p. 42.
[389] Ibid., p. 64.
[390] *Selected Philosophical Papers of Robert Boyle*, p. 7.

4.1.2. Is Matter Purely Corpuscular?

Boyle's Corpuscularian Philosophy, based as it is on the hypothesis that matter, present at Creation, was divided into corpuscles, is remarkable in that he never does give a clear, consistent account of what he actually means by the term 'corpuscles'. These are the basic units of matter, the subdivisions into which the universal matter was separated, differing from one another in size, figure and shape. He also says that corpuscle and atom are equivalent terms. However, he also mentions *prima naturalia* and *minima* as the smallest subdivisions of matter, and wrestles with the problem as to which of these bodies is the most fundamental. He speaks of corpuscles of various materials – giving one to understand that these individual bodies are the most fundamental units of these substances – but then he mentions the corpuscles of some mixed bodies, which being mixed must necessarily consist of more than one corpuscular type. Boyle's ambiguity on the question of the corpuscles has already been noted by Alexander. (See also 2.3.5.).

A further question one might pose about the corpuscular nature of matter is whether all created bodies subsist in corpuscular form. Boyle is clear that the universal matter produced at Creation was divided into corpuscles, and that these entities were imbued with motion by God. What is not clear, however, is whether *all* of the material present during Creation was actually subdivided into corpuscles. Two materials in particular – water and earth – occupy a special place in Boyle's account of the production of matter, and are spoken of as being present throughout the unfolding process of Creation, in their primary states. There is no actual mention by Boyle of these two materials as having been divided into corpuscles in the same way as happened with universal matter. There is also the possibility that earth and water are themselves a part of the universal matter, or perhaps produced at the same time as it, but in any event did not undergo the subdivision into corpuscles experienced by the universal matter. Boyle is unclear on this point, but what is clear is that he regards earth and water as somehow different from other materials, in some way privileged in relation to other substances. He says simply that:

> '... I look upon earth and water, as component parts of the universe, or rather of the terrestrial globe, not of all mixed bodies.'[391]

What Boyle seems to be saying here is that to him earth and water are distinct and separate from the rest of created matter; they are constitutive of the entire cosmos, although he qualifies this assertion by confining his remarks to the earth itself. It appears that he believes that these two materials are the foundational elements from which the globe is composed – a reasonable supposition given that the substances from which the earth is made are obviously earth and water. When Boyle says that he sees earth and water as part of the terrestrial globe, but does not believe that they are present in all mixed or compound bodies, it is not clear whether he means that earth and water are not constitutive of such bodies, or that these two materials are not present in these bodies because they have been transmuted from earth and water into other materials.

Boyle believed that it was possible that some 'plastick power' over time comes to act on matter 'though perhaps terrestrial and heavy' and, from it fashions 'this or that metalline

[391] *Sceptical Chymist*, p. 187.

ore.'[392] And here he makes a comparison between the probable transmutation of earth into metal ore with that of the conversion of water 'by the seminal principle.'[393]

Similarly, earth yields saltpetre and when this is harvested the saltpetre boilers are rewarded, as the 'earth will after some time yeeld them salt-petre again'.[394] In addition, Boyle holds that earth could be produced from water through a process of transmutation, when he says that 'earth itself may be produced out of water; or if you please, that water may be transmuted into earth'.[395]

In each case the transmutation of earth into a metallic ore, and water into plant material is effected through the agency of a power or principle, exactly how these act is unclear, but Boyle could justify their action by treating them as parallel examples to that of plant growth. It is clear to him that the seeds he, or his gardener, sowed did grow into mature plants, and that this growth must have occurred through the action of a transformative agency of some kind. In like manner Boyle could have reasoned that earth is transmuted into a metallic ore, again through the power of a transformative agency.

4.1.3. The Dual System of Matter

Boyle, in effect, maintained both his corpuscularian hypothesis on matter, and a separate, distinct, understated system in which the primal earth and water remain somehow separate from, or excluded or removed from, the division of the prime matter into

[392] Ibid., p. 194.
[393] Ibid., p. 194.
[394] Ibid., p. 194.
[395] Ibid., p. 215.

corpuscles. The existence of the two systems is not made explicit by Boyle; it may well be that he did not consciously or knowingly seek to create a dual system on the formation of matter. His only stated objective is to devise a corpuscularian hypothesis, and this he does clearly, explicitly and intentionally. He leaves no doubt that the system he wanted to found was his Corpuscularian Philosophy, and is keen to promote his new system and take full advantage of the explanatory power which it offered him.

Boyle's account of the production of the corpuscles upon which his philosophy is grounded speaks of their having been produced from the 'universal matter whereof they among other parts of the universe consisted'.[396] He says that the above events occurred at the 'first production of mixt bodies',[397] indicating that these events were unfolding close to, or at, the time of Creation. Boyle affirms his belief in a primal matter when he says that 'there is one catholic or universal matter common to all bodies',[398] and that he holds this belief in common with 'the generality of philosophers'.[399] Who exactly these philosophers are, or from which tradition they arise, Boyle does not say. More explicitly he says that 'according to Aristotle, and I think according to truth, there is but one common mass of all things, which he has been pleased to call *materia prima*'.[400] Here Boyle is making a direct connection between the concept of the prime- or universal-matter and Aristotle. He does not credit the Stagirite with having originated the idea, but that if he did not, then at least he espoused the idea, in common with most other philosophers. Although Boyle does not state it explicitly, the fact that he mentions only

[396] Ibid., p. 30.
[397] Ibid., p. 30.
[398] *Selected Philosophical Papers of Robert Boyle*, p. 18.
[399] Ibid., p. 18.
[400] *Sceptical Chymist*, p. 83.

philosophers in connection with the concept of the prime- or universal-matter at least carries the implication that it is of philosophical origin.

Boyle says two things of particular interest in his account of Creation: firstly, he says that God 'having resolved before the Creation to make such a world as this of ours',[401] meaning that the totality of the matter in the world came about out of a divine decision to so do, which decision would obviously include the terrestrial globe within the scope of its implementation, being constituted as it is, i.e. consisting largely of earth and water. Secondly, Boyle says that God 'did divide (at least if He did not create it incoherent) that matter which He had provided into an innumerable multitude of very variously figured corpuscles'.[402]

Boyle says that the Creator divided that same matter 'which He had provided' into a multitude of corpuscles. Curiously, he seems here to be referring to God as having divided not all of the created matter into corpuscles, but only whatever portion of matter He had 'provided' or set aside for this particular purpose. Considering Boyle's two statements together he seems to be saying that, having resolved to make the world as we know it, He took a limited quantity only of the matter produced at Creation and converted it into corpuscles, employing other quanta of the totality of created matter to fashion the world as we know it, which still retains in bulk form its primal earth and water. It does seem that however the position of water and earth relative to 'corpuscularised' matter is viewed, Boyle regarded water and earth as somehow distinct from the rest of creation.

---

[401] *Selected Philosophical Papers of Robert Boyle*, p. 159.
[402] Ibid., p. 159.

4.1.4. Water as the Universal Matter

As already discussed in 2.2.1., Boyle believed that, in common with Aristotle, there existed a prime matter which in Boyle's case came to be separated into corpuscles. He says that among those who acknowledge the Bible 'many have been inclined to think water to have been the primitive and universal matter',[403] it does seem then, that water, for Boyle, is the universal matter, which came, in turn, to underlie all the matter of the created world through separation into corpuscles at the time of Creation. Clearly, not all of the water present at Creation came to be converted into the primal corpuscles from which resulted all of the material bodies in the universe, for there is still a vast amount of the primeval water present on the earth in the form of rivers, lakes, seas and oceans. Water does of course cover much of the face of the earth, but it is not the only bulk constituent of the terrestrial globe, much of which consists of plain earth. Boyle did indeed believe that water could be transmuted into earth, although according to the Book of Genesis, 1: 9-10, the first appearance of earth occurred on the third day of Creation: the waters under heaven came together into a single mass, and dry land appeared. God called the dry land 'earth', and from the mass of water 'seas'.[404] This earth seems to have come to be through a process of direct conversion from the primal waters of Creation.

4.1.5. Corpuscles and Elements

[403] *Sceptical Chymist*, p. 71.
[404] *Jerusalem Bible.*

In the light of the above, one can attempt an explanation as to why Boyle seems to maintain simultaneously two theories on matter: his ‘corpuscularian theory’ and his ‘elemental theory’. He employed his corpuscular theory as a means of explaining chemical change in materials, but all of the corpuscular entities which participate in these changes he considers as compound bodies, even those which we now regard as elemental. Materials such as gold, silver, mercury and sulphur, Boyle believed to be ‘mixt’ bodies, and were not considered by him as elements. Apart from this, the corpuscularian bodies are secondary in nature in that they are derived from the prime matter through its subdivision, so these bodies in one sense cannot be primary entities, and therefore are not truly elemental.

On the other hand, water and earth, being coeval with the prime matter, with all three types of material having been produced at the time of Creation, can rightly be considered as elemental. When Boyle considers the five substances which he believes are derived from living things, he says that three of them – salt, spirit, and oil – may be considered as the ‘three active principles’. This is so because they are ‘more operative’[405] than the other two – phlegm and earth. So the latter two elements, water, as phlegm, and earth, are somehow different in their behaviour from the other three, in that they are more passive in their interaction with other matter, indicating that Boyle regarded these two substances as separate and distinct from the other principles.

4.1.6. Corpuscles and Creation

[405] *Sceptical Chymist*, p. 229.

It could be argued that in considering water as the universal matter (as discussed in 4.1.4.) logically Boyle is creating a difficulty for himself. He holds that the universal matter present at Creation was converted into corpuscles through divine agency. This means that matter as we know it only came to be after the corpuscularisation of the universal matter had occurred. In other words, the materials present in the sensible world only came about when the original corpuscles were put into various arrangements: no materials now exist which predate the production of the primal corpuscles.

Water is a constituent of the created world, clearly present among the gamut of sensible things. As a substance not only familiar to everyone but also necessary to life, water's presence on the earth is not to be denied. Being a constituent of the sensible world water must subsist in the same way as all other material entities, that is to say, it must be composed of corpuscles. The trouble is, Boyle posits water as possibly constituting the universal matter, but this can hardly be the case as water, being a corpuscularised material, could only come to be after the subdivision of the universal matter. Logically, water could not have existed as water before the corpuscularisation of the universal matter, as the latter could only have subsisted in a mode or manner unfamiliar to us, as our experience is confined to the entities present in the corpuscularised world. The prime matter, not being corpuscularised, could not have been the same as any of the materials present in the sensible world, all of which exist in corpuscular form. Water, therefore, could not have existed prior to the corpuscularisation of the universal matter, for if it had it would have existed as an amorphous *prōtē hylē*, rather than as the clear, mobile liquid universally recognised as water.

The same difficulty is encountered in attempting to reconcile Boyle's Corpuscularian Philosophy with the Biblical account of Creation. Boyle accepts the Genesis narrative of Creation in which water was the first substance to be created, followed two days later by earth. These two materials, or some portions thereof, were hived off to give the universal matter, which in turn was converted into corpuscles varying in size, figure and shape.

Two types of 'water' and 'earth' would thereby have existed since the time of Creation: in the form of undifferentiated prime matter, then later as corpuscular substances. In the case of water, the same colourless liquid could subsist in two radically different microstructures. Firstly as a prime matter not possessed of any true structure, and secondly as a corpuscularised fine structure. This clearly could not be the case as the materials which constitute the sensible world came to be only as the result of the corpuscularisation of the prime matter. Recognisable materials can exist only as corpuscular entities. Therefore no material could have existed in the same form both as universal matter and as a corpuscular substance. According to Boyle's account of the creation of the world as we know it:

Water, then earth were created; then the universal matter was subdivided into corpuscles; then these went to form the materials of the sensible world (including water and earth).

In this scheme of things water and earth appear twice – before and after the subdivision of the prime matter. It could be argued that Boyle might have been better served by hypothesising that matter exists in the corpuscular state only. In making this move the primal water earth and other materials would simply be regarded as always having subsisted as corpuscular entities. In other words Boyle could have made the assumption that all created matter, right from its inception by the Divine Author, existed only in corpuscular form. In this way Boyle would not have had to contend with water and earth subsisting with different fine structures before and after their corpuscularisation. *All* matter would *always* have existed only in corpuscular form. [Italics added].

Of course it could be argued against this that Boyle did not want to over-step the Genesis account of Creation in any way and specify events, such as the corpuscularisation of the primal water and earth themselves, without Biblical warrant. Viewed from one perspective this is a reasonable approach to take: there is no mention in the Bible of the initial subdivision of the water and earth produced at Creation, but neither are any attributes of water or earth specified there. If a corpuscular structure is posited for water and earth, it could be taken as a non-controversial quality possessed by them even prior to Boyle's primary qualities. He could have hypothesised that sensible matter subsists only in the corpuscular state. He might simply have taken it for granted that: if a material has primary qualities, then it must already be a corpuscular material.

4.1.7. Plastick Power

Boyle attempts to explain the production of metals and nitre (detailed in 3.5.). In the case of nitre he says that 'the seminal principle of nitre latent in the earth does by degrees transforme the neighbouring matter into a nitrous body'.[406]He says that for metals the seminal rudiment 'or something equivalent thereunto' by whose 'plastick power the rest

[406] *Sceptical Chymist*, p. 194.

of the matter ….. is in tract of time fashioned into this or that metalline ore.'[407]This explanation by which the plastic power of a seminal rudiment (or equivalent) acting over time to produce metals from earth may well betray the influence of Ralph Cudworth (1617 – 1688). In 'The Digression concerning the Plastick Life of Nature, or an Artificial, Orderly and Methodical Nature' Cudworth identifies various 'Plastick Natures' including the 'General Plastick Nature of the Universe', 'Particular Plastic Powers in the Souls of Animals', and it is 'not impossible but that there may be other Plastic Natures also'. He also says that different kinds of plants and vegetables may be formed 'according to their different Seeds, as also Minerals and other Bodies framed.'[408]Interestingly in mentioning minerals here Cudworth also allows that the same plastic nature may account for the production of non-living things including, perhaps, nitre and metals.

Boyle's account of the production of metals and nitre given above was published in *The Sceptical Chymist* of 1661. Later he seems to have revised his position on how natural bodies are formed when he says in *A Free Enquiry into the Vulgarly Received Notion of Nature*: 'And whereas philosophers presume that she [nature], by her plastick power and skill, forms plants out of the universal matter, the divine historian [which the editors gloss as: 'i.e. the author of Genesis'] ascribes the formation of them to God's immediate fiat.'[409] On the question of how nature stands in relation to God he says 'I know it may on this occasion be alleged that *subordinata non pugnant* [subordinates do not fight (against their master)], and nature being God's vicegerent, her works are indeed his. But

[407] Ibid., p.194.
[408] C. A. Patrides (ed.) *The Cambridge Platonists* (Cambridge University Press, [1969] 1980) p. 322.
[409] Robert Boyle, *A Free Enquiry into the Vulgarly Received Notion of Nature*, B. Davis and M. Hunter (eds) (Cambridge University Press, 1996) pp. 27-28.

that he has such a vicegerent, it is one of the main businesses of this discourse to call in question,…'.[410]

Davis and Hunter make the point that, for Boyle, one of the most attractive features of the Mechanical Philosophy was the extent to which it removed mediating influences between God and the world thereby preserving God's sovereignty more clearly than the 'vulgar' notion of nature which in Boyle's opinion, elevated nature to the status of a semi-deity.[411]

Boyle wrote *A Free Enquiry* in 'the mid-1660s', but returned to it 'around 1680' and finally published it in 'the summer of 1686'[412]Although he seems to have changed his mind on the rôle of plastic powers in the workings of nature Boyle may simply have found it difficult to apply a strict version of his Mechanical Philosophy to the production of metals and minerals believing them to occur as a result of biological processes. Just as in the case of plant growth a mechanism of transmutation may seem to him the best explanation for their production.

Given that at the time of writing *The Sceptical Chymist* Boyle had not worked out in detail exactly how the primal water and earth fitted in to his corpuscular scheme of things and whether, in fact, earth and water had been completely corpuscularised, it is curious to note his use of the word 'latent' in relation to the 'principles' which are involved in the production of both metals and nitre. The 'seminal principle of nitre latent in the earth'[413]

[410] Ibid., p. 30.
[411] Ibid., p. xv.
[412] Ibid., p. xxiv.
[413] *Sceptical Chymist*, p. 194.

may, Boyle believes, be responsible for the conversion of organic matter into nitre. In the case of metals he believes 'that earth, by a metalline plastic principle latent in it, may be in processe of time be changed into a metal.'[414]

In each case Boyle states that either a seminal principle or plastic power *latent* in the earth [italics added] causes both metals and nitre to be formed, but why are these principles *latent*? The word 'latent' (from *lateo*) with its meanings of 'to lurk'; 'be or lie hid or concealed'; 'to be hidden';[415]seems to imply that Boyle considered these principles to be hidden or concealed in the earth, without suggesting how they came to be there or how long they have been there. Always perhaps, since the first production of earth on the third day of Creation? Does Boyle believe that earth contains a transformative agent, which can change earth, not yet corpuscularised, into minerals and metals? If Boyle considers earth to lie outside of his corpuscular system it may be that the means or mechanism by which it changes cannot be one of modifications to, or rearrangements of, its constituent corpuscles, but rather is an older, more primal mechanism – that of transformation by a residual plastic- or seminal-principle still present in the earth since the time of Creation.

4.1.8. Corpuscles, Atoms, and Elements

When we speak of the elements, at our present remove from Boyle and his times, we define them as simple bodies, and once we have done so, we connect these simple bodies with the simplest *material* bodies known to the physical sciences – the atoms. We define

[414] Ibid., p. 191.
[415] Lewis and Short (eds) *A Latin Dictionary*, p.1038.

an atom as the smallest unit of any material that can exist and equate this with one unit of the element. The system works out neatly for us as we simple say:

Atom A is a unit of Element A,

Atom B is a unit of Element B,

and so on.

Like ourselves, Boyle had a version of an atomic theory in his Corpuscularian Philosophy, and he made it clear that corpuscles and atoms were equivalent terms, so why did he not approach the matter as we do and equate corpuscle with element? A possible answer to this question can be expressed in the following way. When Boyle spoke of corpuscles he meant the primary units of matter, the very smallest particles of matter in the created world. (He did, of course, speak also of other primary particles, the *minima* and *prima naturalia*, as discussed in Chapter 2). However, to him a primary particle meant just that, the smallest amount of material that can exist. Boyle did speak of the universal matter as having been divided into 'little particles of several sizes and shapes'.[416] These particles he identified as the corpuscles, which were in turn capable of associating into 'minute masses or clusters'[417] and form compound bodies or 'mixts'.

Boyle even suggests that elements themselves may be composed of corpuscles, as when he says that the 'primary masses or clusters' may retain their complex corpuscular structure, even when they participate in the formation of a variety of compound bodies, and when these bodies are decomposed, the original constituents do not have their

[416] *Sceptical Chymist*, p. 30.
[417] Ibid., p. 31.

‘cohesion violated’.[418] This seems to mean that to Boyle the elements, as material entities, do not comprise the smallest possible units of matter, as they are assemblages of particles even smaller and more fundamental than themselves – the corpuscles. A further insight into how Boyle envisaged this ‘corpuscular model’ of the elements may be had from his saying that a specific element – he gives the example of iron – can be converted into ‘a variety of phaenomena’ through making up ‘little masses of differing size and figure from their constituent parts’,[419] just as iron can be given various shapes through the efforts of skilled workmen.

What Boyle seems to be arguing here is that a given element, itself an assemblage of corpuscles, may have its constituent corpuscles altered into a variety of arrangements, each one of which signifying a different product. The word ‘phaenomena’ as employed by Boyle, with its root meaning of ‘appear’ or ‘seem’, may suggest that he is envisaging the corpuscles of an element, in being cast or put into different configurations, may give products varying in appearance. Rearrange the corpuscles, he seems to say, and a different product appears.

Boyle finally goes on to say that he is thinking in terms of the possible products which four elements might yield. His language, however, does not suggest that he considers it likely that material entities will be obtained from these four elemental building blocks, for he speaks of ‘being allowed to deduce compound bodies from four differently

[418] Ibid., p. 32.
[419] Ibid., p. 33.

qualified sorts of matter'.[420] He seems to be speaking hypothetically – he is deducing, not actually producing – various bodies from matter, itself possessed of different qualities. He is, in effect, engaging in a mental exercise in which he would be able to derive 'a multitude of differing compounds',[421] from four primary assemblages of material, differing only qualitatively from one another. Moreover, his use of words such as 'phaenomena', 'deduce', and 'qualified' in the above example serves to reinforce the idea that Boyle is speaking more like an Aristotelian philosopher reasoning out which products might result from four elements, each with its different set of qualities, rather than an experimental chemist working at his bench and engaged in the synthesis of new chemical species, with four different chemical elements as his starting materials.

What seems to be the case from the foregoing is that Boyle had not come to consider the individual elements as being equivalent to the smallest material entities possible – the corpuscles, but rather to an assemblage or grouping of corpuscles into a unit which could be considered as elementary. These elementary units combine with similar bodies to produce the compound material bodies of the terrestrial world.

Returning to the question posed at the beginning of this section as to why Boyle did not equate corpuscle with element, a second possible answer is that he considered the elements as more complex than the corpuscles. Even if the elements are produced from corpuscles this does not necessarily mean that they must *necessarily* consist of single corpuscles. Viewed from Boyle's perspective this line of reasoning can make sense. His

[420] Ibid., p. 33.
[421] Ibid., p. 33.

definition of the elements as ‘primitive’, ‘simple’, ‘unmingled’, entities from which compound bodies are produced and into which they are ‘ultimately resolved’, is not presented in any way with respect to the corpuscles, for if it were, Boyle would have included corpuscles in his definition. In fact, the word ‘corpuscle’ does not appear in any of Boyle’s definition of the elements, when he could easily have defined an element as a body consisting of one corpuscle, with each corpuscular type representing a different element. Boyle then, in eschewing the word corpuscle in relation to his definition of element, clearly did not wish to establish an equivalence between the two entities; he had no intention of postulating a one for one connection between corpuscle and element.

When Boyle came to define the elements he defined them in terms of ‘simple bodies’, from which substances are composed and into which they are resolved. This use of the words ‘simple bodies’ implies a continuity of existence of these same entities, before, during, and after their composition into, and decomposition from, compound bodies. Yet his corpuscles were unlikely to be able to fulfil this requirement of stability of their physical form required by his definition of element. Corpuscles which could be broken, reshaped through attrition or plastic reformation, or which could be transmuted, were hardly capable of fitting Boyle’s definition of ‘simple bodies’, in the way in which he seems to have intended the term.

4.2. Epistemic and Ontological Reality of the Elements

An alternative perspective on the question of why Boyle did not equate corpuscle with element may be provided by considering the matter as concerning the epistemic as opposed to the ontological reality of the elements. Viewed in this way it could be argued that the four Aristotelian elements were possessed of epistemic reality, and were regarded as serving to constitute all material things. Earth, air, fire and water were also accorded ontological reality as they could be identified as the decomposition products when wood, for example, was broken down by the fire. Similarly, the *tria prima* of the Paracelsians had epistemic reality as the entities from which bodies were constituted, and were also possessed of ontological reality as these were the decomposition products identified by their proponents in the breaking down by the fire of various bodies.

When one considers Boyle's theory in this way a difficulty arises: in his definition of the elements he had accorded them an epistemic reality, but in not defining them in strict material terms he never accorded them ontological reality. With the possible exception of water and earth, Boyle could not indicate a set of materials and define them as elements. He could identify materials as corpuscular, both epistemically and ontologically, with experimental evidence being provided, for example, by his experiments on silver, as discussed in 2.3.1. He defined the elements as bodies, which entails a corpuscular identity for them (in accordance with his Corpuscularian Philosophy which hypothesises material entities as consisting of corpuscles) but never accorded elements the ontological reality that his definition of them implied. It took Lavoisier to do precisely this a hundred years after Boyle's time. Once the existence of the elements as both epistemically and ontologically definable entities had been established, the way was open for the development of the theory of matter that emerged from the eighteenth century onwards.

In regarding the question of the elements in terms both of their epistemic and ontological reality, it can possibly be explained why Boyle retained a sceptical reserve on the subject. Given his acceptance of a comprehensive Corpuscularian Hypothesis of matter, he could have validly denied any need for an hypothesis which posited the existence of the elements *per se*. He could argue that as all matter subsists as corpuscles differing only in size, shape and motion, then all materials are no more than assemblages of corpuscles possessed of some degree of motion. He could select any group of materials, gold, iron, vitriol and water, for example, and say that they were nothing more than specific arrangements of corpuscles and motion, irrespective of whether these substances were, in his opinion, simple, as in the case of water, or ‘mixt’ (compound) as in the case of vitriol. He could simply argue that, for example, assemblage Q represented gold; assemblage R, iron; assemblage S, vitriol; and assemblage T, water. He did not have to make any further definitions or specifications in order to secure the ontological reality of these substances; they already subsisted as corpuscular entities, and that was sufficient to place them in his corpuscularian scheme of things.

Boyle could have declared, with perfect justification, the theory of elements as otiose, an explanatory necessity only of those not holding a particulate theory of matter, a conceptual device with its origins in the perceived requirement in explaining matter in its near primal, elemental state, which matter then somehow built up or combined to form the complex array of materials present in the sensible world. His hypothesised corpuscles, he could argue, fulfil this function, as they represent the simplest state in which material in the post-Creation world subsists. They are elemental in the sense that no simpler entities are to be found in the created world.

What happened after Boyle's time was that the concept of the elements as independently subsisting simple bodies was abandoned in favour of an atomic theory which could account for all variations between material entities. Compound bodies were described as consisting of discrete, unchanging atoms which were unique as to certain fundamental properties, the most easily characterised of which being weight. And although any given material, from the simplest in composition to the most complex, could be described in terms of its constituent atoms, and could be reduced to these as required, the term element was still retained in naming the different atomic types. This practice could be justified partially on grounds of tradition – materials have been considered as consisting of, or deriving from, the elements since ancient times – but it could also be justified by a strict appeal to reason, as the atoms from which bodies are composed were regarded as the simplest material entities possible and, therefore, they could validly be defined as elements.

4.3. Reliable Sources of Information

Apart from reason itself, three sources defined the scope, interpretation and findings of Boyle's investigations into matter and the elements – divine revelation, reliable authorities and *autopsia*. Divine revelation yields Boyle's insights into the importance of water and earth as primeval elements, and this same source seems to have provided him with the idea that water and earth are distinct from all other material things, even to the point that they do not fully participate as corpuscular entities in his Corpuscularian Philosophy. The same divine source provides Boyle with the universal matter from which the corpuscles, upon which his system of matter is grounded, originated.

Reliable authorities guided Boyle to the hypothesis that the three 'grand and catholic principles of the universe are matter, motion (or rest)' with the matter having been imbued with motion by dint of the will of the Divine Author. Such authorities also provide him with a source of information as to what might be considered as elements. One of the most reliable authorities to Boyle was van Helmont, with his belief that water was the sole element, which opinion was substantiated by his experiment on growing a willow tree (as discussed in 2.2.2.). Boyle's *autopsia* comes into play in this instance when he carries out his own experiments on growing a pumpkin and various plants as a means of verifying van Helmont's claims. Boyle's attitude towards the acquisition of knowledge is neatly summed up by Wojcik when she says that Boyle stated there are only two ways of obtaining knowledge of the created world: sense perception and revelation.[422]

[422] Jan W. Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997) pp. 137-138.

Boyle notoriously vacillates on the subject of the elements, never deciding on the number of the elements, the necessity for their existence in the first place, or on how to decide when the elemental state has been reached when bodies are decomposed. He enquires, quite sensibly, as to why the existence of the elements should be considered a necessity (as discussed in 4.5.). The question of the number of the elements was never resolved by Boyle to his own satisfaction. In fact he inclined towards the belief that there may be more elements than any of the hypotheses than current held. He gives an example of this line of reasoning when he says that although there are some bodies that yield fewer than three principles, other bodies when decomposed 'exhibite more principles that three'.[423] When one considers Boyle's thinking on the 'primary associations of the small particles of matter' – where it is plausible that the number of elemental configurations of these may be quite extensive – so much so that one might not consider it 'improbable' that of such 'elementary corpuscles there may be more sorts than either three, or four, or five'.[424]

Boyle gives a good indication of the line of enquiry he wishes to pursue in his investigation of the elements by saying that 'in matters of philosophy this seems to me a sufficient reason to doubt of a known and important proposition, that the truth of it is not yet by any competent proof made to appear'.[425] Boyle seems here to be arguing that the truth of any philosophical proposition is not tested by seeking its contradiction and denying it, but by testing it for its validity. The propositions of the natural philosophers could be evaluated as to their validity by means of an experimental procedure devised in Boyle's laboratory, rather than by purely rational means. So the Paracelsians' assertion

[423] *Sceptical Chymist*, p. 103.
[424] Ibid., p. 104.
[425] Ibid., p. 188.

that all elemented bodies consist of the *tria prima* could be tested experimentally by subjecting suitable bodies to analysis either by the fire or other means. If three elemental bodies are obtained by this analytical process it would provide evidence in favour of the *tria prima*. However, if on the analysis of several putative compound bodies three different decomposition products were obtained for each one, or if fewer or more than three were obtained, it would provide grounds for doubting the validity of the initial proposition. Boyle employs this examination process to good effect in the various investigations made by him on a variety of different substances and processes.

4.4. Experimental Evidence for the Elements

Having stated his requirement for experimental justification for the elements obtained by the analysis of bodies said to consist of the elements, Boyle then has to find satisfactory means for determining the elemental status of the bodies any such investigation would yield. This, in turn, presents Boyle with a new set of difficulties as he has to choose a method by which the bodies under investigation could be broken down.

One such means of separating bodies is provided by the work of van Helmont on the dissolution of material bodies by his *alkahest* or universal solvent which reputedly has the power to reduce all bodies to a common state. Boyle believes that if van Helmont's claim is true and that the *alkahest* does indeed digest all materials to a common liquid state, then it would cast doubt on the existence of separate elements, with the result that this would cause Boyle to question the existence of 'any elements in the sence before explained'.[426]

Boyle seems to give strong consideration to the possibility that the *alkahest* can act upon materials in such a way that it eliminates all physical differences between them. Although he does not say so explicitly he may retain a suspicion that a sufficiently powerful solvent can act upon all material bodies – however they may be constituted at a microscopic level – and reduce every one of them to the same level of corpuscular subdivision. Perhaps with all bodies subjected to a single corpuscular state, individual corpuscles would differ only in their primary qualities of size, figure and shape, insufficiently differentiated from one another to constitute different elements. He may

[426] Ibid., p. 226.

even believe that the *alkahest* can actually break down the corpuscles themselves, reducing them to the level of broken corpuscular entities, allowing little or no differentiation between them.

Such extreme action on all materials by a single *alkahest*, whose 'marvellous power' in the 'analysing' of bodies, is so 'unparalleled and stupendous' as to make Boyle doubt that any such agent actually exists, and nothing short of *autopsia* 'seems requisite to make a man sure there is'.[427] Boyle's sceptical instincts cause him to doubt that there is such a powerful reagent as this, and any claims for the effectiveness of any putative *alkahest* would have to be rigorously investigated by him in his laboratory. This leads Boyle to the belief that he does not accept the 'paradox that rejects all elements',[428] instead reverting to the more moderate position that elements do indeed exist.

4.4.1. Decomposition by the Fire

Boyle's other method for potentially reducing a compound body to its elements lies in subjecting it to thermal decomposition. Here again he runs into a simple experimental difficulty: how does one know that when a body is decomposed, either directly by the fire or by heating in a closed still, that the ultimate point of resolution of that body has been reached? Boyle is also aware that it may not always be experimentally possible to reduce a material to its true elements, for he says that the principles he accepts as elements 'though they be not perfectly devoid of all mixture'.[429] Although he recognises their

[427] Ibid., p. 226.
[428] Ibid., p. 226.
[429] Ibid., p. 229.

impurity, and in so doing is admitting that these substances have not been reduced to a simple corpuscular form.

Boyle justifies this position by acknowledging that ‘none of these elements is divisible by the fire into four or five differing substances’,[430] which seems to represent an acceptance on his part that these elements may well be further divisible by some means or other, but that fire will not divide them into their simplest form. In employing fire as his agent of decomposition he is content to accept a pragmatic, rather than an absolute definition of the elements. Boyle does express reservations in relation to the power of the fire to reduce all bodies into simpler entities for he says that it may not separate a given body into its constituent elements but rather may cause ‘new compounds’[431] to be formed.

In addition, having accepted a pragmatic level of decomposition as a means of assessing the number of elements present in a body, Boyle goes on to consider that it may be possible to drive decomposition too far and raises the possibility that ‘bodies may afford substance which were not preexistent in them’.[432] What he seems to have in mind here is the plausible objection that when a body is decomposed by fire the fire itself may react with the substances under analysis and react with them to give new chemical entities.

As already discussed in 1.9., Boyle as a skilled and experienced experimenter seems to have intuitively grasped a problem which will continue to concern scientists long after his time: how does one know that the analytical tools brought to bear in the examination of a

[430] Ibid., p. 229.
[431] Ibid., p. 224.
[432] Ibid., p. 25.

particular system may not themselves interact with the system in such a way as to distort, affect, combine, or otherwise interfere with it? Boyle tried to cope with this problem by modifying the way in which the analytical tool was employed; in the case of fire by varying its intensity. He did not always exploit 'the great violence of the refiner's fire',[433] meaning that this would be a large-scale fire, in fact a furnace, but in the case of 'distilling man's blood', he still carried out this 'analysis by fire'[434] only this time the reactants were heated in closed glass retorts by a more modest fire, sufficient to allow the various liquid fractions to distil over, without causing them to decompose strongly and burn.

4.4.2. Pushing Decomposition too far.

Boyle is aware of the possibility of pushing the breakdown of bodies too far, thereby 'fruitlessly contending to force them into more elements than nature made them up of'.[435] What exactly Boyle means is unclear, but he may believe that there are potentially more elements than nature has hitherto produced and that by some extreme process of decomposition the simplest subdivision of bodies can be changed, perhaps by a restructuring or spatial rearrangement of the corpuscles from which they are constituted. He goes on to say that if the process were continued then it might be possible to 'strip the severed principles so naked, as by making them exquisitely elementary to make them almost useless'.[436] This sense of bodies being so reduced by a process of analysis as to make them 'almost useless' may be motivated by the same line of reasoning which made

[433] Ibid., p.25.
[434] Ibid., p. 27.
[435] Ibid., p. 229.
[436] Ibid., p. 229.

him believe that the *alkahest* or universal solvent may also have the effect of reducing bodies to such an extent as to push them below the level of corpuscular structure of the elements – perhaps down to the state of individual corpuscles, or even broken or degraded corpuscles.

4.5. What Boyle Considers as Elements

Given that Boyle agonises over the number of the elements, how they can be arrived at, which authority we can trust on the question of the elements, it comes as no surprise that he does not have clear cut ideas as to which substances constitute the elements. Nevertheless he does give strong indications as to what he considers as elements. These are as follows:

4.5.1. Matter and Motion

Boyle grounded his Corpuscularian Philosophy on matter and motion (or rest) which are common to all material things. In considering that all material bodies can be accounted for by just two principles, Boyles does speak of these as elemental entities. The primal substance which underlies all subsequent subdivisions into corpuscles, *minima* or *prima naturalia*, is matter itself. Only after the production of these smaller entities and the addition of motion to them by the Almighty does Boyle consider that the process leading to the production of individual bodies could commence.

Boyle says that he believes that ‘the principles of particular bodies might be commodiously enough reduced to two, namely matter and ... the motion or rest’.[437] All other qualities of bodies build up from these and can be reduced to these same two principles. Matter and motion are elementary in the sense of the first definition which Lloyd applies to the term element (see also 3.1.). That is to say they are the most fundamental state to which the stuff or material of the created world can be reduced. No

[437] Ibid., p. 201.

greater subdivision of any material can ever be effected by any available means than to these two principles.

However, when Boyle speaks of the elements he usually does so in terms of the second sense of the word i.e. that expressed in Definition no. 4, which refers to the decomposition of bodies as resulting in matter in a higher state of organisation than in the primal condition in which it was produced at the time of Creation. Exactly how much higher Boyle never does specify, and it is this inability to stipulate exactly what subdivision a body must be reduced to in order for the elements of which it is constituted to be revealed, which helps to explain his indecision as to which entities he considers as elements.

Despite Boyle's vacillation on the subject of the elements he does consider 'elements and principles as terms equivalent',[438] (as discussed in 1.14), and given that the 'universal matter' produced at the time of Creation was 'divided into little particles of several sizes and shapes variously moved',[439] it follows that 'the little particles' 'variously moved' along with rest, are the principles which underlie the created world, and since elements and principles are entities of the same value to Boyle, then matter, motion or rest can be looked upon as the elements from which the terrestrial world is constituted. So when Boyle offers, as an 'alternative suggestion',[440] the hypothesis that 'it is enough to suppose individual corpuscles as the one kind of substance composing all bodies',[441] it is not so

[438] Ibid., p. 218.
[439] Ibid., p. 30.
[440] Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry*, p. 96.
[441] Ibid., p. 96.

much an alternative suggestion, worthy of consideration by those interested in arriving at an understanding of the elements, but rather Boyle's starting point on the subject. Moreover, it is a position which may be deduced from Boyle's fundamental understanding on the nature of the created world, and a position which Boyle must surely take for granted as validly explaining, and accounting for, the principles underlying the material world. Although this explanation may account for how the created world is, Boyle still needs an account which would provide a valid explanation for the actual substances manipulated by him in his laboratory and the changes, transformations and behaviour manifested by them.

4.5.2. The Corpuscular State as Elemental

The corpuscles resulting from the first subdivision of the prime- or universal-matter at the time of Creation might also be considered as the state to which bodies can be 'ultimately resolved' as stated in Definition no. 4. This state of ultimate resolution may be the reduction to a simple state, such as the elemental state, or it may be something simpler such as the corpuscular level, which is the true ultimate subdivision of matter. Boyle, in the same definition, also speaks of the 'one body' to be 'met with' in all 'elemented bodies'.

That Boyle is doubting the existence of the elements seems highly unlikely: on the contrary, he seems to be accepting the existence of at least one element, and then goes on to question whether it is present in all bodies supposed to consist of elements. Believing as he did in his Corpuscularian Hypothesis, Boyle held that all matter, however it might be arranged in material bodies, could somehow be reduced to a simple, primitive state. The simplest state which matter could occupy was, for him, the corpuscular. So whatever elements Boyle may have believed in had to have a fundamentally simple nature, that is to say, they had to subsist in some way at the corpuscular level. It is possible that by the 'one body' 'met with' in all 'elemented bodies' Boyle may mean the universal matter itself in its corpuscular state.

That Boyle refers to a state of matter more fundamental than the putative elements is reinforced when he says that the *tria prima* of the Paracelsians are not sufficiently basic, or as he himself puts it, not 'fontal enough',[442] meaning that their so-called primary qualities do not come from these elements themselves, but from a source still more fundamental. Boyle gives the example of sulphur which he says is, according to the Paracelsians, 'a body fusible', but he also quotes this property as belonging to other materials as well, such as 'saltpetre, sea-salt, vitriol and alum.' He argues that the explanation given for the quality of fusibility is that it is a principle inherent in sulphur 'and therefore we are not to exact a reason why it is so', but he rejects this explanation as 'grounded but upon a supposition'. He is confident, however, that one may deduce 'a good mechanical explication of fusibility', in general, from the 'primary affections of bodies'[443] – size, bulk and shape – without having to resort to an explanation in which such properties stem from primogeneal principles such as sulphur.

---

[442] *Selected Philosophical Papers of Robert Boyle*, p. 126.
[443] Ibid., p. 127.

In making this argument Boyle is, of course, reaffirming his belief in his Corpuscularian Philosophy, and he is at pains to reiterate that if all the physical properties observed in materials can be traced back to primary qualities possessed by the corpuscles, then the *tria prima* of salt, sulphur and mercury, must themselves have a corpuscular nature. If this is indeed the case then the absolutely primary qualities must stem from the most primitive material bodies, the corpuscles, and not from any entities such as the *tria prima* which are, of necessity, derived from more complex assemblages of corpuscles.

4.5.3. Water as the Sole Element

Boyle consistently holds the belief that water might be the only element and provided experimental evidence in favour of this hypothesis both from his own experiments and those of van Helmont (as discussed in 2.2.2.). In addition he looks upon water as the universal matter which he says is a belief held in common with many who accept the Bible and who are inclined to think water to have been the 'primitive and universal matter'.[444] Boyle seems to believe that water somehow underlies all of the elements, for he says that 'the *tria prima* may be made out of water'.[445] Although when he investigates the decomposition of metals he finds that neither earth nor water can be 'separated from either gold or silver',[446] nevertheless Boyle quotes the authority of van Helmont, who held that materials of plant, animal and mineral origin 'are materially but simple water

[444] *Sceptical Chymist*, p. 71, and as discussed in 4.1.4.
[445] Ibid., p. 203.
[446] Ibid., p. 197.

disguised into these various forms',[447] and Boyle quotes the same author as believing in 'the ultimate reduction of mixed bodies into insipid water'.[448]

In addition, it is possible that following on from delivering his definition of the elements (Definition no. 4) he questions whether there be 'one such body' to be met within all bodies believed to consist of elements. The one body in question may be water. If water does indeed underlie all of the elements then it would follow that it would somehow be present in all elemented materials. Boyle does not go so far as to say that water as the familiar colourless liquid is present in all such bodies, as clearly some bodies when subjected to thermal analysis do not yield water as a decomposition product. Water may be present in elemented bodies in the form of a material derived from it either by transmutation or by another process of corpuscular rearrangement. Boyle states that 'Mounsieur De Rochas' claims that various bodies, 'not only plants, but animals and minerals too, be produced out of water'.[449]

From the foregoing it does seem clear that Boyle looks upon water as a substance apart in his scheme of things. It is the material first mentioned in the Biblical account of Creation and consequently predates the corpuscularisation of matter by the Divinity. Water is thereby conferred with an elemental status simply by its being the first stuff of Creation, the primal matter from which all other substances derive. Water's special status among materials is attested to by van Helmont's experiment in growing a willow tree and by similar experiments by Boyle himself, all of which adduced evidence in favour of the

[447] Ibid., p. 69.
[448] Ibid., p. 69.
[449] Ibid., p. 188.

conversion of water into other elements, as Boyle believed he had confirmed by subjecting some of his plants to destructive distillation and noting that in addition to water some other products were obtained (as discussed in 2.2.2.). Not only plant tissue is produced in this way, as Boyle quotes the example of falling drops of water being turned into a mineral (calcite) in Les Caves Goutieres (and as discussed in 3.5.1.).

An experimenter could argue that plant tissue is formed out of water, as this is the only substance which seems to be absorbed by them as they grow, and when plants are destructively distilled water is one of the principal distillation products obtained. Water, it could be argued, is the element from which plant tissue is formed, and is one of the ingredients into which the same tissue is decomposed. This puts water in a unique position in relation to the other putative elements in that it can clearly be identified as a substance present in both the growth and breakdown of tree or plant material.

Of course Boyle had reservations on the question of the rôle of water in plant growth, as he rightly suspects that air might also play a part in the production of plant tissue (as discussed in 2.2.2.), and he acknowledges that, in relation to the growth of calcite in Les Caves Goutieres, the process of mineral growth takes such a long time that, instead of 'experiments', he must make use of 'observations' in this case. Boyle's pragmatism forces him to eschew the certainty and security of his own experimental processes in favour of an ocular examination of some of the calcite from the caves with which some friends had presented him. In this case, only the starting point of the calcification process – the dripping water – would have been explained to him by those who had visited the caves, and the end product of the calcification process, the calcite stones which had been presented to him, would not have yielded water to him on decomposition by the fire.

4.5.4. Water and Earth as the Sole Elements

As already discussed, water occupies an important position in Boyle's scheme of material things, and he does consider that it may even be the sole element. He also considers earth as a material distinct from all other created entities, his reasoning in this regard seems to have been influenced by the Biblical account of Creation, with the terrestrial globe coming into being on the third day of Creation. That Boyle regards earth and water as different from the rest of creation and distinct from other substances may be understood from his statement that 'I look upon earth and water, as component parts of the universe, or rather of the terrestrial globe, not all of mixt bodies'.[450] Yet despite their privileged position in relation to other materials, water and earth, for Boyle, do play an important rôle in the production of various bodies. Water may be transmuted into earth during plant growth, and, from the account of the growth of iron by the 'learned Cesalpinus' Boyle says that 'we may deduce that earth, by a metalline plastick principle latent in it, may be in process of time changed into a metal'.[451] The earth referred to here is obviously the material from which the terrestrial globe is constituted, and the metal spoken of by Boyle is in the iron ore deposits which are extracted from mine shafts dug into them in Elba and other places. It is some portion of the earth dating from the Creation which is transformed or transmuted by the appropriate principle into iron ore, which can then replenish the depleted ore bodies.

[450] Ibid., p. 187.
[451] Ibid., p. 191.

Boyle makes another argument in relation to the presence of earth and water, not in all minerals, but in materials of plant origin, even though he does acknowledge that neither earth nor water is a 'universal ingredient' of all compound bodies.[452] His reasoning is that when things of organic origin are subjected to destructive distillation, invariably an aqueous fraction and a '*caput mortuum*' or earth are obtained.[453] He understands that growing things consist of materials much more tough and fibrous than water, so that even if they are made of water this water must somehow be transformed into a substance more solid than itself. Given that a charcoal residue or *caput mortuum* is invariably obtained when living things are subjected to thermal decomposition in closed vessels, it could be argued that this solid product, which is identified by Boyle as earth, is a necessary constituent of all living things.

The connection between water and earth, as understood by Boyle, are well illustrated by his experiment on the repeated distillation of rain-water, which he introduces as 'observations and trials about the transmuting of water into earth'.[454] By subjecting the same sample of rain-water to repeated distillation in a glass still, Boyle found that more and more of a white powdery substance was deposited on the bottom of the glass retort with each distillation.

He speculated as to the origin of the white material. He knew that it could not have come from the rain-water as this was free from solid impurities; he though that it might have

---

[452] Ibid., p. 197.
[453] Ibid., p. 204.
[454] Marie Boas Hall, *Robert Boyle on Natural Philosophy* [an essay with selections from his writings] (Bloomington: Indiana University Press, 1963) p. 221.

resulted from the leaching out of some water-soluble product from the glass-ware. (This he admits he could have checked if he had 'convenient metalline vessels wherein to make the distillations, instead of glass ones').[455] He also considers that it might have resulted from the transmutation of water into earth.[456]

Boyle does seem to favour the explanation that the white substance was produced by the transmutation of water into earth, although with reservations. However, it could be argued that if he thought that this material had come from the glass (which, of course, it had) he could simply have weighed his glass still before and after the experiment, as well as any of the white powder produced in the course of the distillation, and determined whether any reduction in the weight of the glass-ware was matched by the weight of the white powder.

The most likely explanation for Boyle's attitude towards the findings of this experiment is that he believed in the transmutation of water into earth, perhaps holding that the conversion of water into earth was analogous to the production of the earth from the primal waters on the third day of Creation.

---

[455] Ibid., p. 228.
[456] Boas Hall says that the 'chemists who finally found the correct interpretation of this experiment – like Lavoisier in 1770 – were merely following Boyle's suggestions' (Ibid., p. 220).

4.5.5. That No Elements Exist

Although Boyle is unwilling to accept the 'paradox that rejects all elements',[457] nevertheless, because he can never clearly identify an undisputed set of elements, he is unable to say decisively that elements actually do exist. He considers the idea that there are no elements and seems to ground his opinion in this regard on two separate arguments.

Firstly, Boyle never arrives at a firm conclusion as to the number of the elements, and if this cannot be established with any certainty it may simply be that there are no true elements. If the elements were clearly identifiable as substances which could by some means or other have their elemental status established, then it should be possible to identify them, and having done so, name and enumerate them. However, if it proves difficult or elusive to find a means of satisfactorily identifying the elements it may be because there are no such things. It may be that there is no set of substances possessed of a series of properties which mark them off as elemental bodies, and that the search for these substances will never yield positive results.

Secondly, Boyle was cognisant of the work of van Helmont on the subject of the *alkahest* or universal solvent, and was greatly influenced by his thinking on this matter. The powers claimed for the *alkahest* in the 'analysing of bodies'[458] is so great that, if true, then all bodies could be dissolved to form a common liquor. Such a liquor would be the

[457] Ibid., p. 226.
[458] Ibid., p. 226.

same for all materials, which would mean that if they are all resolved into an identical liquid product, then they are all the same in their essential composition.

Boyle is not sure of the validity of van Helmont's claims for the unusual powers of his *alkahest*, saying that it would require *autopsia* to verify the latter's claims. Moreover, Boyle always retained a suspicion that in resolving bodies the fire was actually interfering with the process of resolution itself, and that new bodies could be created by the process of thermal decomposition. Consequently any claims for the number of elements resulting from thermal analysis were, for Boyle, suspect.

Boyle makes a number of references to a subdivision of matter in which the particles of matter – the corpuscles – have been so reduced that they can no longer be as normal material entities. An obvious example of this reduction is provided by van Helmont's *alkahest* which seems capable, if its discoverer is to be believed, of reducing all materials to a common state at, or below, the corpuscular level, as already discussed. Boyle's mind is also exercised by the notion that decomposition might be pushed too far and that bodies could be forced into more elements 'than nature made them up of' or perhaps 'strip the severed principles so naked' as to make them 'exquisitely elementary' resulting in their becoming 'almost useless',[459] and as discussed in 4.4.2. Here again Boyle seems to be concerned that a state of degradation can be reached in which matter subsists at a level below that of the elementary.

Even though the possibility of elements *per se* may not be in doubt, their persistence over time may not be assured, as it is always possible to convert them, through thermal

[459] *Sceptical Chymist*, p. 229.

degradation, to a more stable material condition which is at a level more basic than the elemental. Boyle seems to have an implicit belief or perhaps concern that the truly simplest state of subdivision of matter lies below that of the elemental. In this stage of subdivision no elements would be identifiable, as the only stable condition for matter would be a simpler one than the elemental. Viewed in this way there may be no real possibility for the existence of the elements, as the true 'simple bodies' spoken of by Boyle in his Definition no. 4 may subsist at a level simpler than that which he might accept as elemental.

4.5.6. Two Sets of Elements

Early in *The Sceptical Chymist* Boyle, speaking in the first person says that 'I might be better able … to give them my sense upon the subject of it' i.e. the number of the elements or principles, after the conclusion of *their* conference'. [Italics added]. The use of the possessive *their* in this context seems to indicate that Boyle is not taking personal responsibility for any statement on the elements given in the course of the dialogue, although he had promised to give his opinion on the number of the elements at the end of the 'present debate', or failing this, at 'our next meeting'.[460] 'Mr Boyle' never does reappear at the end of his dialogue to give his personal opinion on the matter. Nor indeed do they have a subsequent meeting, so we never do get to hear his thinking regarding the number of the elements expressed under Boyle's own name.

[460] Ibid., p. 15.

Instead the task is delegated to the informal chairman of the discussion, Eleutherius, who names the elements of Basso and de Clave as the five elements present in living things,[461] and, in addition, names a weaker version of the *tria prima* of Paracelsus as the elements present in mineral bodies. He quotes the elements as:

'A saline, a sulphureous, and a mercurial part' into which 'divers mineral bodies may be resolved', and 'salt, spirit, oyle, phlegm and earth', into which almost all plant and animal matter may be resolved.[462]

Boyle chose the five elements as present in living things because he had experimental evidence for them, as well as Biblical authority to guide him in his choice. He had already separated out these five materials through the destructive distillation of plant tissue. He could, therefore, justify his choice of these particular elements even though he acknowledges that 'these principles, though they be not perfectly devoid of mixture' may be 'stiled the elements of compounded bodies'.[463] Boyle seems to accept that some or all of the elements might by a process other than distillation be further divided into simpler ingredients, which in turn might mean that the number of the elements is greater than five. However, in lacking an experimental means of dividing the five putative elements obtained by distillation into even simpler bodies, Boyle seems content to accept their elemental status.

---

[461] On Basso, see: R.P. Multhauf, *The Origins of Chemistry* (London: Oldbourne, 1966) p. 277;
on de Clave, see: L.M. Principe, *The Aspiring Adept* (Princeton University Press, 2000) p. 38;
Debus says: 'In the seventeenth century a five-element-principle system was most common, but just what the five were varied from one author to the next.'
In: A.G. Debus, *The English Paracelsians* (New York: Franklin Watts, Inc., 1966) p. 39.

[462] *Sceptical Chymist*, p. 228.

[463] Ibid., p. 229.

When it came to choosing the elements from which minerals were composed, Boyle was faced with a particular difficulty. Although he had carried out several experiments on inorganic materials, his efforts had not yielded any set of materials which were reliably and consistently present in all mineral bodies. His choice of elements, a weaker version of the *tria prima* of the Paracelsians, seems more of a compromise than a set of elements enthusiastically stated by Boyle himself. Indeed the two sets of elements quoted in *The Sceptical Chymist* seem to be presented rather reluctantly, in the style of a man whose real belief was that water, and to a lesser extent earth, were the only two elements.

So when Boyle states that the bodies present in 'divers mineral bodies, and therefore probably all the rest',[464] he is not even drawing convincing conclusions as to which bodies actually consist of these elements, and he is definitely not stating that they are present in all such bodies. In fact he seems simply to echo three of the named elements present in living things by saying that there are 'a saline, a sulphureous and a mercurial part', which names are alternatives for the 'salt', 'spirit' (mercury) and 'oyle' (sulphur) which Boyle says are three of the elements present in living things. He seems to be acquiescing in the Paracelsian doctrine of the *tria prima* without actually going so far as to name the elements explicitly as salt, mercury, and sulphur.

Boyle would at least have some experimental evidence that sulphur is present in minerals, as many metal ores do consist of a sulphide, which will yield sulphur (and a saline principle as impurities) when such ores are heated with charcoal. However, not all will

[464] Ibid., p. 228.

produce mercury, even though metal ores produce the molten metal corresponding to the metal present in the metal ore, but only mercury ores actually yield true metallic mercury.

4.6. Boyle and Lavoisier

In speaking of Boyle on the elements Boas says that what was needed was a century's progress in the understanding of the composition of bodies before 'Lavoisier could give his definition of a chemical element'.[465] The implication in this statement is that the Frenchman had advanced the level of insight or knowledge of the elements to a degree not attained by Boyle, and in large measure, this is true.

Lavoisier approaches the question of the elements from two perspectives: the theoretical and the experimental. He says that all that can be said about the number and nature of the elements is, in his opinion, confined to discussion entirely of a metaphysical nature, and that the subject only furnishes us with indefinite problems, which may be solved in a thousand different ways, not one of which, in all probability, is consistent with nature.[466] What Lavoisier seems to be referring to here is the various hypotheses on the number and names of the elements that have been advocated since the time of the Ancient Greeks, but all of which were arrived at by purely rational means. Every one of the systems proposed by the various natural philosophers – from the single element, water, put forward by Thales, to the earth, air, fire and water of Empedocles and Aristotle, and the *tria prima* of Paracelsus, not to mention the different elemental combinations of various workers in the Late Medieval and Early Modern Ages – did not come about from a strict experimental analysis of materials, under controlled conditions, in a laboratory. Instead, a different means of approaching the subject was applied, one derived from a consideration of the various forces, both natural and supernatural, which might come to bear on the materials

[465] Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry*, p. 87.
[466] A.L. Lavoisier, *Elements of Chemistry*, trans. R. Kerr, in: *Great Books of the Western World*, Vol. 45 (Chicago: Wm. Benton, 1952) p. 3.

of the natural world, combined with a rational examination of the substances undergoing change and the products of change. However, none of these systems is, according to Lavoisier, 'consistent with nature',[467] precisely because they have been arrived at by a process other than the experimental investigation of natural change as expressed by the transformations undergone by materials under controlled conditions.

Lavoisier says that if by the term *elements* [his italics] we mean 'those simple and indivisible atoms of which matter is composed', then it is 'extremely probable we know nothing about them'.[468] What he seems to mean is that the putative atoms are of such a size and nature that the analytical tools, available to late eighteenth-century science, would yield little, if any, knowledge of them, and, by extension, of the elements. However, Lavoisier goes on, if instead the term 'elements, or *principles of bodies*' [his italics] is applied to the idea of the 'last point which analysis is capable of reaching', we must admit, as elements, 'all the substances into which we are capable, by any means, to reduce bodies by decomposition'.[469]

Lavoisier seems to be saying that his definition of element is a purely operational one, one might even say that it is rather arbitrary. It simply depends on the degree to which materials can be broken down into smaller bodies using the means available to the chemist at any given time in the history of that science. In taking such a pragmatic approach to the definition of the term element, Lavoisier realises that chemical analysis pursued to its limits will yield bodies of a *relatively* simple nature, but one cannot be sure

---

[467] Ibid., p. 3.
[468] Ibid., p. 3.
[469] Ibid., p. 3.

that they are *absolutely* simple. [Italics added]. A new, more powerful tool of chemical analysis may become available which would allow these 'simple' bodies to be further broken down. Lavoisier adds that those substances, which we consider as simple may, in fact, be 'compounded of two, or even a greater number of principles', but since these principles cannot be separated, or rather since we have not hitherto devised the means of separating them, they act with respect to us as simple substances, and we ought never to suppose them compound until 'experiment and observation has proved them to be so'.[470]

For Lavoisier, then, the word element is a relative term, depending as it does on the power of chemical analysis available to the researcher at any given time. As the capacity of science to investigate matter increases, substances hitherto believed to be simple may be found to be complex. As science evolves, so too does its ability to separate materials into smaller and smaller units, and the list of substances considered as elemental, increases.

If one applies Lavoisier's thinking on the question of the elements to Boyle's work, a better understanding of the latter's position is obtained. Lavoisier simply presents an operational definition of element – philosophically it is of no value at all. The very words 'element' and 'elemental' imply an ultimate state in the resolution of matter. There can be nothing smaller, nothing simpler, by definition. In seeking to establish what is elemental, one must know that one has arrived at the final stage in the decomposition of materials, but how is one to know when this point has been reached? There is really no way of knowing with certainty that this end point has been attained, as the means by

[470] Ibid., pp. 3-4.

which the decomposition of materials is effected itself influences the decomposition products obtained. Boyle, expert as he was in experimental techniques, realises that 'the violence of the fire'[471] was one of the most powerful means by which both the composing and decomposing of materials can be achieved. He also understood the power of various *menstruums* [solvents] as agents of degradation.

Boyle understands that his criterion for the elemental state is not one of absolute simplicity that principles or elements 'may not be devoid of all mixture', but rather bear the names of those substances which they most resemble, and which are manifestly predominant in them, and especially for the reason that 'none of these elements is divisible by the fire into four or five differing substances'.[472] In the light of his experimental findings and in considering the products he obtained in decomposing various materials, Boyle found that he was not arriving at the simplest state possible for the subdivision of materials. From this he concluded that his definition of element would, of necessity, entail more than a definition based on 'simple', 'primitive' bodies, and would have to take account of the processes by which bodies are broken down into simpler entities. He was, in effect, tending towards a pragmatic, experimentally based definition of the elements, and one which increasingly equates simplicity with that level of decomposition which the experimenter is capable of achieving using the analytical tools available to him. Although Boyle understood that his elements might not actually be the simplest substances possible, it was Lavoisier who realised that the final point of resolution of materials might never be reached in practice, making it a necessity that the

[471] *Sceptical Chymist*, p. 171.
[472] Ibid., p. 229.

definition of element would always remain provisional rather than absolute. It is interesting to note that a factor contributing to Boyle's scepticism on arriving at a secure list of the elements should be accepted as a given by Lavoisier, who went on to draw up a table of thirty-three elements, published in 1789, almost a hundred years after Boyle's death.

Paneth makes the observation that Lavoisier 'wishes to use the name "element" for all substances which we cannot decompose further because only in this way can we in fact recognise them'.[473] He goes on to say that this definition has turned out to be extraordinarily successful and that the whole of modern chemistry is based on it. Scerri makes a similar point when he says that Lavoisier seems to have been the first chemist to renounce the 'metaphysical view of the elements',[474] and goes on to say that he replaced this view with a type of experimental method which considered only substances that could actually be isolated as elements.

Lavoisier was able to do this by ignoring the theoretical considerations surrounding the definition of the elements and concentrating on the practical method accepted as pragmatic, but which Boyle as natural philosopher would have rejected as failing to fulfil the requirements imposed by the term element.

4.7. The Elements as Primary Qualities of Matter

[473] F.A. Paneth, 'The Epistemological Status of the Chemical Concept of Element', *British Journal for the Philosophy of Science*, Vol. 13, (1962) 113-145, p. 124.
[474] Eric R. Scerri, *The Periodic Table – its Story and its Significance* (Oxford University Press, 2007) p. xv.

Kragh says that chemists can still justifiably consider the elements as the ultimate building blocks of their science, or to speak philosophically, the primary qualities.[475] If the elements are indeed the primary qualities of matter, then the characteristics which confer this status on them must also be of a primal nature. The elements, in other words, may be defined as primary qualities, and the most economical way in which this can be done is to begin by equating the simplest particle of an element with the simplest particle of matter. This can be achieved by letting one corpuscle equal one elemental unit.

Given that Boyle himself equates corpuscle with atom, one can legitimately make the following connections:

1 corpuscle = 1 atom = 1 elemental unit.

According to one criterion of identity, if each of two things is equal to a third thing, then they are equal to each other. It follows from this that if atoms are the simplest bodies and elements too are the same bodies, then atoms are the same bodies as elements.[476]

Lavoisier and, later, Dalton treat of atoms and elements as identical entities, e.g. the simplest particles of the element gold or iron that can exist as these metals are their atoms. They, in effect, went one step further than Boyle, who, although content to set corpuscles and atoms as identical entities, never went on to make the connection between these and the elemental units.

---

[475] Helge Kragh, 'Conceptual Changes in Chemistry: The Notion of a Chemical Element, *ca*. 1900-1925', *Stud. Hist. Phil. Mod. Phys*., Vol. 31, No. 4, 435-450, 2000, p. 447.

[476] If x is a K and y is a K, then x and y are the same K if and only if x and y stand in relation R. From: *The Oxford Companion to Philosophy*, ed. Ted Honderich (Oxford University Press, 1995), p. 391.
R in this case would be the set of the elements (for Lavoisier this would have 33 members). All members of this set are the simplest material entities, therefore each member, as one of the simplest bodies possible, can be viewed as both an atom and an elemental unit.

Having set the elements as primary qualities of matter, and the units of the elements as equivalent to the corpuscle and the atom, one could then say that there exist as many primary qualities as there are elements. Or, to put it another way, if elements are the primary qualities of matter, then there are as many primary qualities as elements. Each element can be considered as a particular primary quality of matter taken in a general sense.

Even though Boyle was unsure as to the exact number of elements that existed, and in any event the number of putative elements grew in the eighteenth and subsequent centuries, one could still regard these as a growing list of primary qualities of matter. Viewed in this way the number of the elements might no longer be regarded as a fixed number, such as the four Aristotelian or the three Paracelsian, but rather as an indeterminate set of primary qualities predicated of matter. This is, of course, what happened in the centuries succeeding Boyle's own, with some new materials being considered as elemental, and some others, such as fire and light, losing their status as elements.

In this way the elements became an open rather than a closed set of substances, each one possessed of the common property of being a material entity which was predicated of matter in general. The discovery of each new element could then be regarded as a hitherto unknown primary quality of the common matter from which all of the elements derive.

4.8. Primary Qualities of the Elements

Continuing with Kragh's suggestion on the elements as primary qualities of matter, one could also posit primary qualities to the elements themselves. This would be in contradistinction to Boyle whose primary and secondary qualities are applied to matter itself. Whereas Boyle's primary and secondary qualities seem to apply mainly to matter in bulk, with shape, odour and colour capable of being determined for amounts of material well in excess of individual corpuscles, it might be possible to assign primary and secondary qualities to the elements themselves rather than to matter in a general sense. It might be possible, in other words, to posit such qualities of individual elemental units, corpuscles or atoms.

4.8.1. Weight as a Primary Quality of the Elements

It could be argued that the primary quality which could most appropriately be posited of the elements is weight. It has been recognised since antiquity that whatever the materials chosen as elements, they can be differentiated by weight; air and fire are lighter than earth and water, mercury is heavier than sulphur. Any quality which is found to be inherent in various materials can provide a useful means both of identifying materials or differentiating between them. Weight is a property which can be determined for bodies both large and small, and changes in weight are more easily measured than those in size or shape, for example.[477] When materials are reacted together weight is the property

[477] Although the text appears to contain a typographical error – with 'grams' written instead of 'grains' – Boas Hall seems to suggest that the balances in use in Boyle's day had an accuracy of from 6 to 2 milligrams. In: Marie Boas Hall, *Robert Boyle on Natural Philosophy* [An essay with selections from his writings] (Bloomington: Indiana University Press, 1963) p. 232.

most easily monitored, and variations in weight of both reactants and reaction products most easily determined.

In maintaining weight as the dominant property of matter it came to be realised that it could serve as a quantifiable continuum linking the smallest particles of matter – the elementary units, corpuscles or atoms – with bulk matter. The growing body of information amassed in the century after Boyle's on the behaviour of matter showed that reproducibly constant amounts of reactants combine together to yield fixed quantities of reaction products. This gave rise to the realisation that the behaviour of bulk matter mirrored that which was occurring at the level of the least subdivisions of the materials participating in these same chemical reactions.

It could be argued that weight could easily be considered as a primary quality in the Boylean scheme of things. Certainly, following O'Toole's criterion of a primary quality in Boyle's philosophy, weight would seem to be a quality which is inherent to a body, without ever considering its relations to other things.[478] Like the other primary qualities, weight does not change over time for a given body, but remains as constant as size, shape or texture. The great virtue of weight is that it is clearly characteristic of various bodies. Boyle well understands that metallic gold or mercury have a definable weight difference both with respect to each other, and to water. The same can be said of other materials with which Boyle worked, such as lead, silver and wood.

[478] O'Toole defines p as a primary quality of a corporeal object (simple or compound) O, if and only if O has p in itself (i.e. without considering its relations to other things). In: F.J. O'Toole, 'Qualities and Powers in the Philosophy of Robert Boyle', *Journal of the History of Philosophy*, Vol. XII (1974) p. 300.

4.8.2. Weight as a Boylean Primary Quality

Although Boyle does refer to the part played by weight in distinguishing between the various materials, as, for example, when he says that 'mercury weighs 12 or 14 times as much as water of the same bulk',[479] he does not count weight among his primary qualities.[480] Anstey gives Boyle's list of these as: size, shape, motion and texture.[481] Boyle does acknowledge the fact that the 'ancient corpuscularian philosophers'[482] have exerted considerable influence on him. Yet those same philosophers do mention weight as a property of the atoms as understood by them.[483]

Alexander explains Boyle's attitude towards weight by saying that in *The Origin of Forms and Qualities* Boyle pays little attention to weight, and that his corpuscular theory becomes more purely geometrical in pursuit of a view that was current among natural philosophers at the time. He goes on to say that this view is found, for example, in both Descartes and Leibniz'.[484]

---

[479] *Sceptical Chymist*, p. 78.

[480] On the question of primary and secondary qualities: ' Though Boyle and Locke invented and popularised the distinction and the terminology of primary and secondary qualities, the distinction dates back in principle to Democritus…..the distinction was revived by Galileo and accepted by Descartes, Newton and others.' In: Paul Edwards (ed.) *The Encyclopaedia of Philosophy*, Vol. 6 (New York: The Macmillan Company and The Free Press, 1967) p. 445.

[481] Peter Anstey, *The Philosophy of Robert Boyle* (London: Routledge, 2000) p. 29.

[482] *Selected Philosophical Papers of Robert Boyle*, p. 19.

[483] Epicurus says 'neither will heavy atoms travel more quickly than small and light ones'. In: Walter Kaufmann (ed.) *Philosophic Classics* [Basic writings of the Great Western Philosophers] (Englewood Cliffs, N.J.: 1965) p. 547.

The introduction of the term weight into the atomic theory is credited to Epicurus: 'Democritus named two [*sc*. properties of atoms], size and shape, but Epicurus added a third to these, namely weight'. In: G.S. Kirk, J.E. Raven, M. Schofield, *The Presocratic Philosophers* (Cambridge University Press, 1983) p. 421.

O'Brien remarks that Aristotle in *De Caelo* says that 'the larger an atom is, the heavier it will be'. In: D. O'Brien, 'Heavy and Light in Democritus and Aristotle: Two Conceptions of Change and Identity', *The Journal of Hellenic Studies*, Vol. 97 (1977) p. 66.

[484] Peter Alexander, *Ideas, Qualities and Corpuscles* (Cambridge University Press, [1985] 2009) p. 61.

A further insight into Boyle's attitude to weight may be had from the statement in his *Certain Physiological Essays* that qualities such as 'Heat, Cold, Weight, Fluidity, Hardness, Fermentation, etc.' are themselves derived from the 'more primitive and catholick affections of matter, namely, bulk, shape and motion'.[485] Weight is for Boyle one of a suite of qualities which are derived from the most fundamental properties of matter, and however important they may be, considered as qualities – and some of them, at least, supply signature characteristics to a multitude of minerals – nevertheless Boyle looks upon these qualities as reducing to the most primitive properties. In other words weight, in common with some other distinctive qualities, is still no more than a secondary quality of matter.

[485] *The Works of Robert Boyle*, Vol. 9, 1678-83, p. 21.

4.9. Conclusion to Chapters 3 & 4

4.9.1. The Elements as Enduring Entities

Having just given an account of his interpretation of Boyle's chemical theory, Kuhn says that 'the chemical theory described above is incompatible with belief in the existence of enduring elements'.[486] This makes for an interesting insight into elemental theory in general as it may well be that unless and until the elements are identified with specific unchanging primary particles, one cannot attribute persistence through time as a quality possessed by them.

It can be argued that the possibility of transmutation defines and explains an important feature of elemental behaviour, as, for example, when water is transmuted into earth, for both Boyle and the Aristotelians. A transmutation of one element into another also means that there is no overall change in the elemental status of the system as a whole, with one elemental material merely transforming into another.

Once atoms and corpuscles came to be identified with elemental units, and the atoms defined as fixed and indivisible in physical attributes, with each atom (hence element) being conserved through all chemical changes, it meant that elemental transmutation was discounted as one of the properties possessed of material bodies. Brock says that it was Dalton who made these assumptions when he devised his atomic theory in 1803.[487]

---

[486] Thomas S. Kuhn, 'Robert Boyle and Structural Chemistry in the Seventeenth Century', *Isis*, Vol. 43, No. 1 (1952) p. 26.
[487] William H. Brock, *The Norton History of Chemistry* (New York: W.W. Norton & Co., 1993) p. 136.

4.9.2. Boyle as Physicist and Chemist

It is an easy matter to trace the developments in the theories of matter and of the elements which occurred during the last three centuries or so and identify how these changes coped with the questions with which Boyle struggled and never brought to a successful conclusion. However, it could be said that Boyle's theory of matter had to perform a double function: it had to account for matter *ab origine* on the one hand, and for the behaviour of matter as the active agent of chemical reaction, on the other. Boyle had to attempt to devise a theory which could treat of matter as the fundamental stuff of creation, i.e. with matter as a generic type, and of the various species of matter which in their changes and transformations serve to explain the multifarious chemical substances which constitute the sensible world.

Boas says of Boyle that, alone among chemists, he was a natural philosopher who regarded a physicist's theory of matter as one which was necessary to the clear understanding of chemistry.[488] Viewed in this light, Boyle as physicist hypothesises the existence of matter in a corpuscular state, whereas Boyle as chemist has to postulate a system, based on those same corpuscles, which would account for chemical change.

A unitary theory which would serve both functions is difficult in our own time, but was nigh impossible in Boyle's. One could attempt an account of chemicals' behaviour from first principles, i.e. from the fundamental particles and forces (as discussed in 2.1.). Such an exercise would, however, be futile as it is assemblages of the fundamental particles – the atoms – and not those particles themselves, which constitute the simplest units at

[488] Marie Boas, *Robert Boyle and Seventeenth-Century Chemistry*, p. 75.

which chemical change occurs. Boyle was not to know this, neither were Lavoisier or Dalton after him, but the latter two experimenters adopted a pragmatic approach to the behaviour of matter, by equating atoms with elements (Lavoisier) and in treating of atoms as indivisible entities, each type possessed of unique weight, which preserved their identities through all chemical reactions (Dalton). These two workers maintained a 'chemist's' view of the elements; the 'physicist's' understanding of the elements began to emerge only towards the end of the nineteenth century, (as discussed in 2.1.).

4.9.3. The Elements: Individuation and Identity

> 'There is nothing you can sensibly talk about without knowing, at least in principle, how it might be identified'.[489]

It could be argued that this statement by Strawson might be interpreted as making a connection between talking about a thing (taken in this case to refer to a physical entity or body) and how such a thing might be identified. More specifically the example to which it will be applied in the present context is in considering the elements as simple bodies, as defined by Boyle as his Definition No. 4. The simple bodies referred to by Boyle could be viewed in relation to their individuation, with this word taken to mean the following:

a) 'the condition of being an individual'

and

b) 'separate and continuous existence as a single indivisible object'.[490]

The elements as simple bodies were accorded the status of individual entities by at least two of those who followed Boyle – Lavoisier and Dalton. Their simple bodies were the atoms and these were for them separate, distinct, indivisible entities. In addition, each

[489] P.F. Strawson, *Entity & Identity* (Oxford University Press, 1997).
[490] OED online (Consulted 16.6.10).

type of element represented a unit of a particular element. There were, according to Lavoisier, thirty-three elements, each one subsisting in the form of individual atoms. In addition the atoms for Lavoisier and Dalton had an additional quality – that of maintaining a separate, continuous existence. The atoms in fact must do so if they are to give rise to stable products. Stability is required of the individual atom if it is to retain its identity during whatever chemical transformations that such an atom undergoes. In other words an atom may react chemically with atoms of a different species to form a new atomic aggregate, but with each atomic type retaining its unique atomic identity throughout. In addition atoms must retain their unique identity over time. This introduces a quality of durability into the atoms, with a given atom retaining its individualising properties over a long period of time, so long in fact, that no temporal limit is specified for the life-span of the atoms.

In addition if Strawson's statement on identity is applied retrospectively to the atoms as understood by Dalton, different atomic types – different elements – were distinguished by one individualising characteristic: weight. All atoms could be distinguished from one another by weight, and weight is a property easily determined by the chemists. So when Dalton spoke of the elements he could identify them, by setting them as identical to the atoms, and specifying that the atoms were distinguished from one another by weight. Additionally, their individual, indivisible nature persisted unchanged through time. When one considers the question of individualisation and identity as they applied to Boyle's definition of the elements, some obvious difficulties arise. The first of these is the discrepancy Boyle faces between defining the elements and identifying them.

Defining the elements as simple bodies is to specify two of their properties: as bodies they must be corporeal, and as simple they cannot be complex entities. However, properties such as these do indeed partially define the elements, but they do not identify them, as other non-elemental entities may also possess these properties. Boyle's discussions of the elements exemplify the problem described in Strawson's statement – he (Boyle) never arrived at a successful resolution of the question of the elements, very likely because he could not actually identify any elements.

When it comes to the question of individuation in relation to the elements, Boyle's definition of the elements will run into difficulty. One could justifiably claim that Boyle would have understood the elements as individual entities, as laid down in part (a) of the OED definition, but would have been hard pressed to justify his understanding of element in relation to part (b) of that definition, i.e. an element as having 'separate and continuous existence as a single indivisible object'. Separate existence an element would have had for him, but continuous existence would have run counter to Boyle's belief that the elements are capable of undergoing transmutation – water into earth and earth into metals, for example – in addition to the (for Boyle) likely transmutation of water into plant- and woody-tissue. And when the question of the persistence of an element as a single indivisible object is considered, here too Boyle would have had reservations. Single, yes, the elements being for Boyle simple bodies. But indivisibility was a quality that he could not confer on the corpuscles as he hypothesised them, so it is doubtful that he could ever have accorded this quality to the elements as simple bodies.

Not only could Boyle's definition of the elements not permit him to identify any such entities, but even if he had been able to do so he could not define them as indivisible entities which persisted through time. This lack of durability of any Boylean elements worked against the establishment of a clearly defined set of materials which retained their identity over a very long time-scale.

BIBLIOGRAPHY TO CHAPTER 4

Alexander, Peter, *Ideas, Qualities and Corpuscles* (Cambridge University Press, [1985] 2009).

Anstey, Peter. *The Philosophy of Robert Boyle* (London: Routledge, 2000).

Boas, Marie, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958).

Boas Hall, Marie, *Robert Boyle on Natural Philosophy* [An essay with selections from his writings] (Bloomington: Indiana University Press, 1963).

Boyle, Robert, *The Sceptical Chymist* (Mineola, N.Y.: Dover Publications, 2003).

Brock, William, H., *The Norton History of Chemistry* (New York: W.W. Norton, 1993).

Debus, Allen, G., *The English Paracelsians* (New York: Franklin Watts, Inc., 1966).

Honderich, Ted, (ed.) *The Oxford Companion to Philosophy* (Oxford University Press, 1995).

Hunter, M, and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 2 (London: Pickering & Chatto, 1999).

Hunter, M. and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 8 (London: Pickering & Chatto, 2000).

Hunter, M. and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 8 (London: Pickering & Chatto, 2000).

Kirk, G.S., Raven, J.E., Schofield, M., *The Presocratic Philosophers* (Cambridge University Press, 1983).

Kragh, Helge, ‘Conceptual Changes in Chemistry: The Notion of a Chemical Element, *ca*. 1900-1925’ *Stud. Hist. Phil. Mod. Phys*., Vol. 31, No. 4, (2000) 435-450.

Kuhn, Thomas, ‘Robert Boyle and Structural Chemistry in the Seventeenth Century’, *Isis*, Vol. 43, No. 1 (1952) 12-36.

Lavoisier, A.L., *Elements of Chemistry,* trans. Kerr, R., in *Great Books of the Western World*. Vol. 45 (Chicago: Wm. Benton, 1952).

Multhauf, Robert, P., *The Origins of Chemistry* (London: Oldbourne, 1966).

O’Brien, D., ‘Heavy and Light in Democritus and Aristotle: Two Conceptions of Change and Identity’, *The Journal of Hellenic Studies*, Vol. 97 (1977) 64-74.

O’Toole, F.J., ‘Qualities and Powers in the Philosophy of Robert Boyle’, *Journal of the History of Philosophy*, Vol. XII (1974) 295-315.

Paneth, F.A., ‘The Epistemological Status of the Chemical Concept of Element’, *British Journal for the Philosophy of Science*, Vol. 13 (1962) 113-145.

Partrides, C. A. (ed.) *The Cambridge Platonists* (Cambridge University Press [1969] 1980).

Principe, Lawrence, M., *The Aspiring Adept* (Princeton University Press, 2000).

Scerri, Eric, R., *The Periodic Table – its Story and its Significance* (Oxford University Press, 2007).

Stewart, M.A., (ed.) *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991).

Strawson, P.F., *Entity & Identity* (Oxford University Press, 1997).

The Jerusalem Bible (London: Geoffrey Chapman, 1971).

Wojcik, Jan, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997).

Postscript

Boyle's Legacy

Boyle never could arrive at a doctrine on the elements which would satisfy both his own religious convictions, as a pious lay theologian, and his sceptical instincts, as a natural philosopher. As a believer in the Two Books – that of Scripture and that of Nature – his understanding of the Biblical account of Creation informed him of the process by which the material universe came into being, with the sequence in which water, earth and other parts of Creation came to be clearly laid out. His understanding of the Book of Nature was founded on his Corpuscularian Philosophy. This led him to hypothesise that matter originally existed as undifferentiated universal matter which in turn was corpuscularised and imbued with motion through Divine Agency.

It follows as a consequence of his belief in the origins of matter that Boyle had to have two distinct theories on matter as it exists in the sensible world: water and earth from the direct action of the Almighty at the time of Creation, and a corpuscular state of matter, which matter resulted from an unspecified act of creation by God, in which primary matter was corpuscularised. This latter act is hypothesised by Boyle without reference to Scripture. In his standard account of the behaviour of matter he could simple regard the earth and water as given and define all other materials as participating in the corpuscularised state of matter. However, when he came to speak of the elements he had to considered their origin – were they produced at the time of Creation, water and earth surely were – or did they result from the materials corpuscularised from the prime matter?

One source was as revealed by the Almighty, the other as hypothesised by human intelligence. Water and earth would have to be considered as elements, this is incontrovertible, but other supposed elements, those resulting from the corpuscularised material, would be less certain, having their origins in human hypothesis. Viewed in this way Boyle could only say that water and earth are the sole true elements, as their provenance can be traced back to the time of Creation through Scripture, and in addition, their presence in both the growth and decomposition of plant material determined experimentally. Other putative elements could not have their elemental status verified, for they never could be held as elements with the same degree of certainty as the other two, as no secure criteria for determining a given material's elemental status had been developed by Boyle.

In hypothesising the corpuscles as the simplest material entities, and in addition, defining the elements as simple bodies and the ultimate products of resolution, Boyle would have been hard pressed to justify the elements as entities distinct from the other simplest subdivision of matter – the corpuscles. Yet he never did equate the elements as simplest bodies with the corpuscles as simplest bodies. In fairness to Boyle this connection did not take place for another hundred years when Lavoisier equated atoms – as the simplest material entities – with the elements.

Moreover, the aforementioned can be viewed not so much as a failure on Boyle's part but as a qualified success. He transformed the discourse on the nature of the elements from their being considered as Aristotelian hylomorphic entities, or as quasi-spirit principles, to strictly material bodies. The progress of the thinking on the nature of the elements was part of Boyle's larger project of establishing his Mechanical Philosophy.

Immediately prior to Boyle's death, Leibniz wrote to Christiaan Huygens upbraiding the honourable man for only concluding in his books and from his observations what all of us already know: '*que tout se fait mechaniquement*', and goes on to say that excellent men should give us their conjectures, and are wrong if they want to give us only the truths of which they are certain.[491] Leibniz was not to know just how influential Boyle's Mechanical Philosophy would prove to be. Even if we all know that all things in the material world act according to mechanical principles, it was this insight which when applied to chemical change paved the way for later developments in material science. By stipulating that matter and motion underlie changes in particles at the most fundamental level, Boyle opened the way to a theory of matter which saw only minute particles and their affinities for each other as the primary means by which materials behave at the most primitive level.

Kargon says that to Boyle must go a large portion of the credit for the acceptance of atomism in England through his attempts to bring the mechanical hypotheses of both

[491] R.E.W. Maddison, *The Life of the Honourable Robert Boyle* (London: Taylor & Francis, 1969) pp. 191-192.

Gassendi and Descartes within the pale of the experimental philosophy.[492] Lavoisier, Higgins and Dalton, in addition to others whose work served to found our contemporary atomic theory, were able simply to regard their atoms as equivalent to elements with the unquestioned understanding of the two terms not only as equivalent but as purely material entities. Boas offers the opinion that so complete was the introduction into science of the Mechanical Philosophy that some eighteenth-century scientists sometimes wondered what all the fuss had been about.[493]

A telling summation of Boyle's age is given by More when he refers to it as '… like a Janus facing two ways, using and clinging to the past and unwitting of the results to follow from the new ideas …'.[494] The same epithet might be applied to Boyle himself, who, in his work as natural philosopher, lay theologian and alchemist, respected and drew from the past but also presaged some of the developments of the eighteenth century, in particular the acceptance of a theory of matter which set in motion a train of events in which the elements came to be expressed as atoms, and the atoms simply as elements.

It could be argued that Boyle's opinions on the elements reveal him as not having broken away from a conception of matter as not fully corpuscularised, but still partially rooted in an understanding of it as not neatly divided into corpuscles, but as subsisting in the form

[492] R.H. Kargon, 'Walter Charleton, Robert Boyle and the Acceptance of Epicurean Atomism in England', *Isis*, Vol. 55 (1964) 184-192, p. 188.
[493] Marie Boas, 'Boyle as a Theoretical Scientist', *Isis*, Vol. 41, No. 3/4 (1950) 261-268, p. 268.
[494] L.T. More, *The Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944) p. 136.

of elements whose specification in material terms had not yet been worked out by him. The final step in the path linking matter and the elements came only to be recognised after Boyle's time and eluded his efforts, even though he had sketched out how it might be made.

Boyle did not attract around him a set of followers who carried on his style of experimentation and programme of investigation into the natural world after his passing. Various explanations for this are put forward, including:

Hall argues that Newton was the last to theorise in Boyle's manner on the structure of matter, his remarks so transforming the Mechanical Philosophy that the eighteenth century drew upon him, rather than from Boyle, and that as a result the extent to which Newton had followed the pattern created by his older contemporary went unappreciated, although Boyle's influence on Newton in this and other respects was very considerable.[495]

Partington attributes it to the Phlogiston Theory, introduced by Johann Joachim Becher (1635 – 82) in 1669. This theory states that the constituents of bodies are air, water and three earths, one of which is inflammable (*terra pinguis*), the second mercurial and the third fusible or vitreous. These correspond to the sulphur, mercury and salt of the

[495] A. Rupert Hall, *From Galileo to Newton* (New York: Dover Publications, Inc., 1981) p. 237.

Paracelsians.[496] Partington speaks of chemistry leaving 'the path of true discovery opened out by Boyle, Hooke and Mayow for the jungle of the Theory of Phlogiston.'[497]

Finally, for Kuhn, Boyle's structural theory of chemical qualities and his instrumental theory of chemical change exerted little apparent influence on the subsequent development of chemical concepts.[498]

As to the elements, Davis argues that Aristotle's view on the subject was very generally prevalent until the time of Lavoisier (1743 – 94),[499]and another perspective on this apparent lack of immediate influence of Boyle's hypotheses is provided by Kuhn when, speaking of the Copernican Revolution he says that: 'since stereotypes are most readily disbanded during periods of general ferment, the turbulence of Europe during the Renaissance and Reformation itself facilitated Copernicus' astronomical innovation.'[500] Perhaps by the time that Boyle came on the scene over a hundred years after Copernicus the ferment spoken of by Kuhn had subsided somewhat, meaning that new thinking on matter and new ways of experimentation simply had to struggle harder to gain acceptance. Or maybe with a rival hypothesis on the nature of matter in circulation – that of Descartes – the automatic acceptance of Boyle's thinking on the subject was never to be.

[496] J.R. Partington, *A Short History of Chemistry* (New York: Dover Publications Inc., 1989) p. 85.
[497] Ibid., p. 84.
[498] Thomas S. Kuhn, 'Robert Boyle and Structural Chemistry in the Seventeenth Century', *Isis*, Vol. 43, No. 1 (1952) 12-36, p. 32.
[499] Tenney L. Davis, 'Boyle's Conception of Element Compared with That of Lavoisier', *Isis*, Vol.16, No. 1 (1931) 82-91, p. 88.
[500] Thomas S. Kuhn, *The Copernican Revolution* (Harvard University Press, 1957) p. 124.

It could also be argued that a convincing proof of Copernicus' heliocentric system was given when Newton's Law of Gravitation was applied to determining mathematically the validity of Kepler's Laws of Planetary Motion. It proved very difficult to mount a counter-claim to Newton's stunning application of his new theory, thereby facilitating its wide acceptance in the eighteenth century.

It is probably true to say that, apart from the Law that bears his name, Boyle made no fundamental discoveries: he improved von Guericke's air pump and put it to strict scientific use, he made a comprehensive study of the properties of phosphorous, although he did not discover it, and he although he coined the word 'corpuscular' he was not the first to postulate either a Corpuscular Theory of matter or the Mechanical Philosophy. Unlike Newton, none of Boyle's discoveries or hypotheses could be applied to any one contentious scientific issue to such effect as to silence all sensible opposition. Kuhn's assertion that 'each new scientific theory preserves a hard core of the knowledge provided by its predecessors and adds to it'[501] might, however, be applied to Boyle's scientific *oeuvre.* His adoption of pre-existing hypotheses, combined with a Baconian scientific method, allowed him, by dint of a superb experimental technique, to promote a world-view firmly grounded on both reason and experiment. Boyle's view of matter as atomised and behaving in accordance with strict mechanical principles came to be vindicated in time.

[501] Ibid., p.3.

Suggestions for further research.

The heir to Boyle in his investigations into the elements is undoubtedly Lavoisier (1743 – 94). The Frenchman made the connection between the elements and the atoms – which relationship eluded Boyle. The development of Boyle's hypotheses on the elements by Lavoisier is worthy of study, and viewing the question of the elements through Lavoisier's eyes might well provide further insights into Boyle's thinking on the subject.

Given that future workers such as Newton and Dalton assumed the corpuscular or atomic state for matter as a given, yet Boyle speaks of the corpuscularisation of the universal matter at the time of Creation, the question might well be posed why Boyle postulated this doctrine when it was open to challenge as to how the primal water and earth of Creation actually came to be corpuscularised. Was all of it subdivided into corpuscles, or only some of it? One could attempt to get behind Boyle's thinking on the subject.

Boyle seemed committed to a theory of material change which viewed transmutation as a fundamental agent or driver of transformation from one material to another, yet he never explains how and where it occurs. Is it by corpuscular motion, causing them to rearrange?, is it caused by the corpuscles themselves undergoing a change of shape, perhaps through a redirecting of corpuscular motion into causing the corpuscles to be transformed?, or is it brought about by some other agency? Again, this question could well repay further study.

BIBLIOGRAPHY TO POSTSCRIPT

Boas, Marie, 'Boyle as a Theoretical Scientist', *Isis*, Vol. 41, No. 3/4 (1950) 261-268.

Davis, Tenney, L., 'Boyle's Conception of Element Compared with that of Lavoisier', *Isis*, Vol. 16, No. 1 (1931) 82-91.

Hall, A. Rupert, *From Galileo to Newton* (New York: Dover Publications, Inc., 1981).

Kargon, R.H., 'Walter Charleton, Robert Boyle and the Acceptance of Epicurean Atomism in England', *Isis*, Vol. 55 (1964) 184-192.

Kuhn, Thomas,S., 'Robert Boyle and Structural Chemistry in the Seventeenth Century', *Isis*, Vol. 43, No. 1 (1952) 12-36.

Kuhn, Thomas,S., *The Copernican Revolution* (Harvard University Press, 1957).

Maddison, R.E.W., *The Life of the Honourable Robert Boyle* (London: Taylor & Francis, 1969).

More, Louis Trenchard, *The Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944).

Partington. J.R., *A Short History of Chemistry* (New York: Dover Publications Inc., 1989).

COMPREHENSIVE BIBLIOGRAPHY

Editions of Boyle's Works:

Boas, Marie, 'An Early Version of Boyle's: Sceptical Chymist', *Isis*, Vol. 45, No. 2 (1954) 153-168.

Boas Hall, Marie, *Robert Boyle on Natural Philosophy* [An essay with selections from his writings] (Bloomington: Indiana University Press, 1963).

Boyle Robert, *A Free Enquiry into the Vulgarly Received Notion of Nature*, B. Davis and M. Hunter (eds) (Cambridge University Press, 1996).

Boyle, Robert, *The Sceptical Chymist* (Minneola, N.Y.: Dover Publications Inc., 2003).

Boyle, Robert, *The Sceptical Chymist* (London: J.M. Dent & Sons, 1911).

Hunter, M, and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 2 (London: Pickering & Chatto, 1999).

Hunter, M. and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 8 (London: Pickering & Chatto, 2000).

Hunter, M. and Davis, B. (eds) *The Works of Robert Boyle*, Vol. 9 (London: Pickering & Chatto, 2000).

Hunter, Michael, (ed.) *Robert Boyle by Himself and His Friends* (London: Pickering, 1994).

Hunter, Michael, (ed.) *The Boyle Papers* (Aldershot: Ashgate, 2007).

MacIntosh, J.J. *The Excellencies of Robert Boyle* (Peterborough, Ontario: Broadview Editions, 2008).

Stewart, M.A., *Selected Philosophical Papers of Robert Boyle* (Indianapolis: Hackett, 1991).

Westfall, R.S., 'Unpublished Boyle Papers Relating to Scientific Method – II', *Ann. Sci*., Vol. 12 (1956) 103-117.

Other Sources:

Alexander, Peter, *Ideas, Qualities and Corpuscles* (Cambridge University Press, [1985] 2009).

Allen, John, *Robert Boyle Father of Chemistry* (Detroit: Thomson Gale, 2005).

Anstey, Peter. *The Philosophy of Robert Boyle* (London: Routledge, 2000).

Barnes, J., (ed.) *The Complete Works of Aristotle*, Vols. 1 & 2 (Princeton University Press, 1984).

Barnhart, R.K., *Chambers Dictionary of Etymology* (New York: Chambers, 1988).

Bishop, A.C., Wooley, A.R. and Hamilton, W.R., (eds) *Minerals, Rocks and Fossils* (London: George Philip, 1999).

Boas, Marie, 'Boyle as a Theoretical Scientist', *Isis*, Vol. 41, No. 3/4 (1950) 261-268.

Boas, Marie, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge University Press, 1958).

Boas, Marie, 'The Establishment of the Mechanical Philosophy', *Osiris*, Vol. 10 (1952) 412-541.

Brock, William, H., *The Norton History of Chemistry* (New York: W.W. Norton, 1993).

Burns, D. Thorburn, ‘Robert Boyle (1627-1691): A Foundation Stone of Analytical Chemistry in the British Isles, Part 1’, *Anal. Proc*. May 1982, 224-233.
Chalmers, Alan, ‘The Lack of Excellency of Boyle’s Mechanical Philosophy’, *Studies in the History and Philosophy of Science*, Part A, Vol. 24, Issue 4 (1993) 541-564.
Clericuzio, Antonio, ‘A Redefinition of Boyle’s Chemistry and Corpuscular Philosophy’, *Annals of Science*, Vol. 47, (1990) 561-589.
Clericuzio, Antonio, *Elements, Principles and Corpuscles* (Dordrecht: Kluwer Academic, 2000).
Clericuzio, Antonio, ‘From van Helmont to Boyle. A Study of the Transmission of Helmontian Chemical and Medical Theories in Seventeenth-Century England’, *The British Journal for the History of Science*, Vol. 26, No. 3 (1993) 303-334.
Collins English Dictionary (Glasgow: HarperCollins, 2005).
Cook, Margaret G., ‘Divine Artifice and Natural Mechanism: Robert Boyle’s Mechanical Philosophy of Nature’, *Osiris*, 2nd series, Vol. 16 (2001) 133-150.
Copleston, Frederick, *A History of Philosophy*, Vol. 5 (London: Continuum, 1959).
Crosland, M.P., *Historical Studies in the Language of Chemistry* (New York: Dover Publications Inc., [1962] 1978).
Davis, Tenney, L., ‘Boyle’s Conception of Element Compared with that of Lavoisier’, *Isis*, Vol. 16, No. 1 (1931) 82-91.
Debus, Allen, G., *The English Paracelsians* (New York: Franklin Watts, Inc., 1966).
Dennehy, Myriam, and Ramond, Charles, *La Philosophie Naturelle de Robert Boyle* (Paris: Vrin, 2009).
Descartes, R., *Principles of Philosophy*, trans. Miller, V.R., & Miller, R.D. (Dordrecht: R. D. Reidel, 1983).
Disksterhuis, E.J., *The Mechanization of the World Picture* (Oxford University Press [1961] 1969).
Duddy, Thomas, *A History of Irish Thought* (London: Routledge, 2002).
Duhem, Pierre, *Mixture and Chemical Combination and Related Essays,* ed. and trans. Needham, Paul (Dordrecht: Kluwer Academic, 2002).
Edwards, Paul, (ed.) *The Encyclopaedia of Philosophy*, Vol. 6 (New York: The Macmillan Company and The Free Press, 1967).
Emsley, John, *Nature’s Building Blocks* (Oxford University Press, 2001).
Garber, D., and Ayers, M., (eds) *The Cambridge History of Seventeenth-Century Philosophy,* Vol. 1 (Cambridge University Press, 1998).
Hall, A. Rupert, *From Galileo to Newton* (New York: Dover Publications, Inc., 1981).
Hamilton, E., & Cairns, H. (eds) *The Collected Dialogues of Plato* (Princeton University Press, 1961).
Healy, J.F., *Pliny the Elder on Science and Technology* (Oxford University Press, 1999).
Hirai, Hiro, and Yoshimoto, Hideyuki, ‘Anatomizing the Sceptical Chymist: Robert Boyle and the Secret of his Early Sources on the Growth of Metals’, *Early Science and Medicine*, Vol. 10. Issue 4 (2005) 453-477.
Hooykaas, Reijer, *Robert Boyle [A Study in Science and Christian Belief]* (University Press of America, 1997).
Hooykaas, Reijer, *The Concept of Element: Its Historical-Philosophical Development* (Utrecht, 1933) [Doctoral Thesis] trans. Kubbinga, H.H., 1983.

Honderich, Ted, (ed.) *The Oxford Companion to Philosophy* (Oxford University Press, 1995).
Hunter, Michael, *Boyle* (Yale University Press, 2001).
Hunter, Michael, (ed.) *Robert Boyle Reconsidered* (Cambridge University Press, 1994).
Kane, G.L., *Modern Elementary Particle Physics* (Addison-Wesley, 1987).
Kargon, R.H., 'Walter Charleton, Robert Boyle and the Acceptance of Epicurean Atomism in England', *Isis*, Vol. 55 (1964) 184-192.
Keller, F.J., Gettys, W.E., and Skove, M.J., *Physics Classical and Modern*, 2nd edn. (New York: McGraw-Hill, Inc., 1993).
Kirk, G.S., Raven, J.E., & Schofield, M., *The Presocratic Philosophers* (Cambridge University Press, 1983).
Kragh, Helge, 'Conceptual Changes in Chemistry: The Notion of a Chemical Element, *ca*. 1900-1925' *Stud. Hist. Phil. Mod. Phys*., Vol. 31, No. 4 (2000) 435-450.
Kuhn, Thomas,S., 'Robert Boyle and Structural Chemistry in the Seventeenth Century', *Isis*, Vol. 43, No. 1 (1952) 12-36.
Kuhn, Thomas,S., *The Copernican Revolution* (Harvard University Press, 1957).
Kuhn, Thomas S., *The Structure of Scientific Revolutions* (University of Chicago Press, 1962).
Ladyman, James, *Understanding Philosophy of Science* (Oxford: Routledge, 2002).
Lavoisier, A.L., *Elements of Chemistry,* trans. Kerr, R., in: *Great Books of the Western World*, Vol. 45 (Chicago: Wm. Benton, 1952).
Lehmann, Walter J., *Atomic and Molecular Structure: The Development of our Concepts* (New York: John Wiley and Sons Inc., 1972).
Leicester, Henry M., *The Historical Background of Chemistry* (New York: Dover Publications, Inc., 1956).
Lennox, J.G., trans., *Aristotle on the Parts of Animals* (Clarendon Press Oxford, 2001).
Lewis and Short (eds) *A Latin Dictionary* (Oxford University Press, 1879).
Liddle & Scott, *An Intermediate Greek-English Lexicon* (Oxford University Press,[1889] 2000).
Lloyd, G.E.R., *Greek Science After Aristotle* (New York: Norton, 1973).
Lüthy, C., Murdoch, J.E., and Newman, R.W., (eds) *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: Brill, 2001).
MacIntosh, J.J., 'Robert Boyle's Epistemology: The Interaction between Scientific and Religious Knowledge', *International Studies in the Philosophy of Science,* Vol. 6, No. 2 (1992) 91-121.
Maddison, R.E.W., *The Life of the Honourable Robert Boyle* (London: Taylor & Francis, 1969).
McGuire, J.E., 'Boyle's Conception of Nature', *Journal of the History of Ideas*, Vol. 33, No. 4 (1972) 523-542.
McMullin, Ernan, (ed.) *The Concept of Matter in Greek and Medieval Philosophy* (University of Notre Dame Press, 1963).
Meinel, Christoph, 'Early Seventeenth-Century Atomism: Theory, Epistemology, and the Insufficiency of Experiment', *Isis,* Vol. 79, No. 1 (1988) 68-103.
Moran, Bruce, *Distilling Knowledge Alchemy, Chemistry, and the Scientific Revolution* (Harvard University Press, 2005).

More, Louis Trenchard, The *Life and Works of the Honourable Robert Boyle* (Oxford University Press, 1944).
Multhauf, Robert P., *The Origins of Chemistry* (London: Oldbourne, 1966).
Newman, William R., *Atoms and Alchemy* (University of Chicago Press, 2006).
Newman, William R., *Promethean Ambitions* (University of Chicago, [2004] 2005).
Newman, William R., 'The Alchemical Sources of Robert Boyle's Corpuscular Theory', *Annals of Science*, 53 (1996) 567-585.
O'Brien, D., 'Heavy and Light in Democritus and Aristotle: Two Conceptions of Change and Identity', *The Journal of Hellenic Studies*, Vol. 97 (1977) 64-74.
O'Toole, F.J., 'Qualities and Powers in the Philosophy of Robert Boyle', *Journal of the History of Philosophy*, Vol. XII (1974) 295-315.
Paneth, F.A., 'The Epistemological Status of the Chemical Concept of Element', *British Journal for the Philosophy of Science*, Vol. 13 (1962) 113-145.
Partington. J.R., *A Short History of Chemistry* (New York: Dover Publications Inc., 1989).
Partrides, C. A. (ed.) *The Cambridge Platonists* (Cambridge University Press [1969] 1980)
Piccardi, L., and Bruce Masse, W. (eds) *Myth and Geology* (London: The Geological Society, 2007).
Pilkington, Roger, *Robert Boyle Father of Chemistry* (London: John Murray, 1959).
Principe, Lawrence M., *The Aspiring Adept* (Princeton University Press, 1998).
Sargent, Rose-Mary, *The Diffident Naturalist* (University of Chicago Press, 1995).
Scerri, Eric, R., *The Periodic Table – its Story and its Significance* (Oxford University Press, 2007).
Serway, Raymond A, *Physics for Scientists and Engineers*, 4th edn. (Philadelphia: Saunders College Publishing, 1996).
Shanahan, Timothy, 'God and Nature in the Thought of Robert Boyle', *Journal of the History of Philosophy*, Vol. 26, No. 4 (1988) 547-569.
Sootin, Harry, *Robert Boyle Founder of Modern Chemistry* (London: Chatto & Windus, 1963).
Stillman, John Maxton, *The Story of Alchemy and Early Chemistry* (New York: Dover Publications, Inc., 1924).
Strathern, Paul, *Mendeleyev's Dream* (New York: Thomas Dunne Books, 2000).
Strawson, P.F., *Entity & Identity* (Oxford University Press, 1997).
The Jerusalem Bible (London: Geoffrey Chapman, 1971).
Thorpe, Thomas Edward, *History of Chemistry* (London: Watt & Co., 1909).
Tipler, P.A., Llewellyn, R.A., *Modern Physics*, 3rd. edn. (New York: Freeman & Co., 1999).
Wenham, E. J., Dorling, G.W., Snell, J.A.N., & Taylor, B., *Physics Concepts and Models*, 2nd. Edn. (Longman, 1993).
Westfall, R.S. 'Unpublished Boyle Papers Relating to Scientific Method – II', *Ann. Sci*., Vol. 12 (1956) 103-117.
Wojcik, Jan, *Robert Boyle and the Limits of Reason* (Cambridge University Press, 1997).
Wyatt, Anthony (ed.) *Challinor's Dictionary of Geology* (Cardiff: University of Wales Press, 1986).

Zaterka, Luciana, 'Os Limites do Projeto Epistemológico de Robert Boyle: As Verdades Acima da Razão', *Cadernos de Historia e Filosofia da Ciência*, Campinas, Série 3,Vol. 12, Nos. 1-2, (2002) 209-223.

Online Sources:

Burns, D. Thorburn, 'The London of Robert Boyle', at:
http://www.bbk.ac.uk/boyle/*ThorburnBurns*.htm. (Consulted 15/06/09).
Encyclopaedia Britannica – Online, www.britannica.com/bps/search?query=bog+iron. (Consulted 7-5-10).
The Oxford English Dictionary – Online,
http://dictionary.oed.com/templates/entrance_main.html. (Consulted 17-7-09).
http://royalsociety.org/nullius-in-verba/ (Consulted, 10/06/10).