Author:
Leendertz-Ford, Anna S T

Title:
Anatomy of Seventeenth-Century Alchemy and Chemistry

ANATOMY OF SEVENTEENTH-CENTURY ALCHEMY AND CHEMISTRY

ANNA STELLA THEODORA LEENDERTZ-FORD

A dissertation submitted to the University of Bristol in accordance with the requirements for the degree of Doctor of Philosophy in the Faculty of Arts, School of Philosophy.

January 2020

[Word count: 80110]

ABSTRACT

It is claimed that alchemy and alchemists/early modern chymists contributed substantially to proto-chemistry in important ways. To a significant degree, sound science was being practised in the Latin West during the seventeenth century, though not all criteria were met consistently across all nations at all times. This thesis will:

(1) Define the criteria for best practice of science (specifically chemistry) using a Wittgensteinian approach;
(2) Examine the level to which such criteria were appreciated and adhered to across a representative sample of chemical practices during the seventeenth century.

As a counteraction to the extremely negative perceptions of alchemy, often associated with the occult, I demonstrate a dynamic, international community, whose operational practices, far from being unscientific, included many of the criteria which are regarded in modern times as essential prerequisites of science. Determining exactly what constitutes good science is problematic, especially since it is disputed by some that science can even be distinguished from non-science. Therefore, a Wittgensteinian 'family resembles' approach to analysis of science has been selected, establishing the essential characteristics by which good science can be recognised. These criteria are divided into two groups, one designated ‘core requirements’ plus further ‘desirable’ elements.

By evaluating various Early Modern chymistry textbooks, operational procedures, research communities and other components, I conclude that many of the criteria for good science were extant in the period in the Latin West. There are a few criteria which are under-represented or absent, for example, Popperian falsificationism and an inconsistent application of scepticism. The overall conclusion is the core criteria of critical reasoning, robust experimentation techniques, challenges to authorities and many of the important values and methods were present within a research community that had developed significantly in the Early Modern period, spanning Europe during the seventeenth-century and beyond.

DEDICATION AND ACKNOWLEDGEMENTS

This thesis is dedicated to my daughters, Elaina and Adriana.

Acknowledgements

My grateful thanks are due to my supervisor Professor Emeritus Andrew Pyle for his unwavering commitment over the years, for sharing his vast knowledge and experience and whose support has been inestimable. I would like to thank my supervisor Dr. Tzuchien Tho for his insightful reviews, other members of the Philosophy Department of the University of Bristol and fellow students who have made my journey so stimulating and rewarding. The support and encouragement of my family, Robert Ford and my amazing daughters, Dr. Elaina Ford and Dr. Adriana Ford, have been invaluable. My very good friends deserve appreciation and thanks for all their help and enthusiasm.

AUTHOR’S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the requirements of the University’s *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate’s own work. Work done in collaboration with, or the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED………………………………………………DATE…………………….

CONTENTS

TABLES and FIGURES

1 ASSESSING EARLY MODERN ALCHEMY AND CHYMISTRY

1.1 Introduction

"Philosophy of science without history of science is empty; history of science without philosophy of science is blind." Whether one considers Lakatos' neat epigram [Lakatos: 1970] to contain a germ of truth or not, one thing is clear: history of science combined with philosophy of science helps form a richer and deeper, more complete picture of both. History helps place philosophical developments in context. And it is the analysis by philosophy that brings vitality to history; I have attempted to fuse the two together, using historical examples to prove the philosophical propositions.

Chemistry has evolved into a rigorous science, an integral part of modern western society. Its ancestry in the natural philosophy in the Aristotelian tradition seems disconnected to the sophisticated discipline we see today. Significant changes described as revolutionary, were made in many scientific disciplines, especially physics, astronomy and biology, in the sixteenth and seventeenth centuries. In contrast, the major developments in chemistry were delayed until the eighteenth-century. The Chemical Revolution is often considered to have begun with the work of Lavoisier (1743-1794) who is credited with changing chemistry from a qualitative discipline to a quantitative one. In Kuhnian terms, the seventeenth century, as pre-Chemical Revolution, is considered to consist of pre-paradigmatic (pre-consensus) or immature science. As such there would have been little consensus on theory, methods and even what experiments or observations were relevant to a given field. Johann Joachim Becher's (1635-1682) introduction of the phlogiston theory, modified by Stahl (1659-1734) could be described as normal science. Priestley's isolation of oxygen, followed by Lavoisier's rejection of the phlogiston theory and replacing it with his own theory of oxygen, was inspired, but Lavoisier was clearly building on the work of his predecessors and contemporaries, particularly Priestley. One could ask if there was a revolution at all, or whether the accumulation of knowledge was, though not a steady growth, was yet a continuous process, whereby various strands of research, some more successful or fruitful than others, gradually extended. At intervals certain important insights facilitated a rapid advancement. Revolutionary or not, the quieter periods still had their function. Their output may have been more modest but were *essential* precursors to later developments. The view of early modern chymistry as incoherent and lacking structure has been challenged (Newman, Principe, and others). Instead, the period can be considered as a creative, if unsettled, time in which significant developments paved the way for the more dramatic impact of eighteenth and nineteenth century chemistry. Its significance should not be underestimated.

I will argue that the alchemy/chymistry practised in the Early Modern period had the components necessary for it to be judged science by sceptical and informed persons. As such it deserves to be recognised as having a positive, substantial contribution, as proto-chemistry, to the development of the modern discipline of chemistry.

To support this claim, I propose to analyse and evaluate the quality of scientific practice pertaining to alchemy and chemistry. This evaluation will be confined to the Early Modern Latin West, with the focus on the seventeenth century. Did the alchemists and chymists of the seventeenth century practice what could be described as 'good science' as appropriate to their time and milieu? For example, Homberg's work demonstrated a modern-style method although he was not able give a plausible explanation of cause. It did, however, exhibit good scientific practice. I look to see if there was evidence of *epistêmê* (knowledge) and *technê*, (art or craft) the experienced-based practice of alchemy or chymistry.

What constitutes good science? What distinguishes science from pseudo-science, or bad science or even fraudulent practices? This subject has been thoroughly debated in recent years. Laudan's paper, *The Demise of the Demarcation Problem,* concludes that there is no answer to the question "What makes a belief scientific?" and that we should drop terms such as 'pseudoscientific' and 'unscientific' [Lauden: 1983]. Scientific status is "altogether irrelevant" he states. Unsurprisingly, this stance sparked some strong criticism, not least from Pennock [2011], Pigliucci [2013], Mahner [2013], Ladyman [2013], Hansson [2013] and others. A simple distinction between science and pseudoscience is, however, proving difficult to define. There are no necessary and sufficient conditions that are applicable to all of science at all times. Pennock makes the point that almost everyone can tell the difference between science and religion, for example, but philosophers have a hard time defining that distinction [Pennock: 2011]. Similarly, it is difficult to define the difference between science and pseudo-science. Nevertheless, some kind of differentiation is essential between science and pseudo-science or simply poor science, in whatever era. Science has such an important role in modern society that it behoves everyone to be able to tell the difference. No doubt any early modern individual, whether scientist or layperson, would want and expect high standards in their science. Did they have them?

There are inherent difficulties in understanding or evaluating the level and quality of science in historical times; there is no ahistorical scientific method. It is a challenge therefore to pursue a path which balances the level or quality that could reasonably be expected of a natural philosopher/scientist working in the seventeenth-century Latin West with that of a modern-day scientist. Avoidance of Whiggishness is accomplished by taking cognisance of that which a practitioner in the Early Modern era could reasonably be expected to know.

1.2 PHILOSOPHICAL BACKGROUND

How does science develop? Kuhn sought to answer this question, and in doing so overthrew the cherished concept of science progressing by constant accumulation of knowledge. He believed that this accumulation concept, drawn mainly from the study of finished scientific achievements, was misleading in fundamental ways [Kuhn: 1962]. Historians, he found, were finding it increasingly difficult to answer specific questions such as the date on which oxygen was discovered, and by whom. The incremental development concept, with its dismissal of 'erroneous ' or 'unscientific' paths and its lauding of heroes, does not do justice to the historical integrity of the science within its own era. Kuhn describes the emergence of several important scientific theories including those of Copernicus's heliocentric hypothesis, and Newton's theory of light. Later theories of thermodynamics (nineteenth century) and quantum theory (twentieth century) were also considered. His historical studies led him to conclude that there were periods of radical change followed by periods of 'normal' science, of a more mundane nature perhaps, where the reigning paradigm was not seriously questioned, but endorsed. The above theories are of physics. Chemistry is represented by Lavoisier and the discovery of oxygen, plus Black, Scheele, Cavendish and Priestley. These are all achievements of the eighteenth century. But what type of science (if it may be so described) obtained in the discipline of alchemy/chymistry in the early modern period?

Kuhn's radical concepts of revolutionary science with its paradigm shifts were hotly debated. Virtually everything Kuhn has said about scientific development in the *Structure of Scientific Revolutions* [*ibid*] has been challenged; indeed, Kuhn himself modified his stance in later years. An example of such a dispute is made by Bird who challenges the simplistic, bi-modal nature of Kuhn's theory of revolutions, arguing that this model is inadequate, as became apparent when Kuhn added further historical detail [Bird: 2000]. The clear dichotomy between normal and revolutionary science becomes blurred when a range of historical episodes are considered. The most innovative normal science looks just as significant as the least radical of revolutionary science. He concludes: “There is reason to think, on historical grounds, that all points on a continuum from the mundane conservative accumulation to thorough-going revolution are well represented by the facts.” [*ibid* p62]. He adds: “Furthermore there is no great distance between a typical case of what Kuhn takes to be normal science and a typical case of revolutionary science. The difference is a matter of degree, not of kind.” If this is the case, we might look for innovations, perhaps minor breakthroughs that precipitate changes in a sub-discipline or causes new sub-disciplines to come into being. There is a more nuanced theme than a simple dichotomy to be demonstrated; alchemy in the seventeenth century is fruitful ground to see if this is indeed the situation. I argue that representation that Kuhn gives for paradigm shifts does not accurately portray the more subtle achievements of the seventeenth-century. There were no geniuses in the field of chemistry of the stature of a Galileo or a Newton whose influences were immense. This does not mean that the work that was being done was unscientific or ineffectual. Important changes across the century contributed in no trivial way to significant developments in the systemisation of chemistry. These changes include the long drawn out decline of a fragmented Aristotelianism, the general acceptance of the mechanical philosophy, less reliance on authorities, an increase in experimentation, the gradual change from vitalism to a naturalistic outlook, the beginnings of taxonomical classification, all with a supporting structure of a vibrant, international scientific community.

I have included some of Kuhn’s terms and views, such as epistemic values, within my analysis, utilising Kuhn’s conceptual framework. Kuhn’s philosophical theme is not, however, the focus of this thesis. Karl Popper and others had challenged the accumulation concept earlier. Popper is well- known for his attempts to solve the problem of demarcation and offer a clear criterion that distinguishes scientific theories from metaphysical or mythological claims [Thornton: 2018]. “Popper’s falsificationist methodology holds that scientific theories are characterized by entailing predictions that future observations might reveal to be false. When theories are falsified by such observations, scientists can respond by revising the theory, or by rejecting the theory in favor of a rival or by maintaining the theory as is and changing an auxiliary hypothesis. In either case, however, this process must aim at the production of new, falsifiable predictions” [Shea: 2016] [Popper: 1959]. Popper esteems especially bold or risky predictions where the consequences of being wrong will clearly falsify the theory. An example often cited is that of Einstein's calculation of the value of the light bending caused by the sun. He made these calculations in 1915 but it was not until the 1919 total eclipse of the sun that appropriate observations[1] were possible. These measurements were considered confirmation, or corroboration of Einstein's theory, and demonstrated the inadequacies of Newton's laws of motion. This type of risky prediction, with its precision in measurement and its unambiguous outcome, is the kind of theory test of which Popper would approve.

1.3 Terminology

1.3.1 *Alchemy, Chymistry and Chemistry*

The term alchemy invokes various interpretations and meanings. One is the spiritual or allegorical sense where alchemy relates to a spiritual metamorphosis and is used as a path to the soul's enlightenment or virtuousness. Alongside this there are some very negative associations. The alchemists have been described as misguided at best, disingenuous and mendacious at worst. They were linked to spiritualism, the supernatural and the occult. Adepts were considered practitioners of pseudo-science, purveyors of snake-oil, performers of dubious demonstrations shrouded in the smoky esotery of their art. This view has already been challenged in recent times by, for example Newman and Principe. “These interpretations of alchemy identify a spiritual or psychic dimension as the *sine qua non* of ‘true’ alchemy distinguishing it from the more rational or purely physical chemistry” [Newman & Principe: 1998]. The status of alchemy was low even at the time of Boyle, who did distinguish between the skilled practitioners for whom he had respect, and the ‘sooty empirics’ for whom he had little but contempt [Boyle: 1661b].

However, the distinction between alchemy and chemistry is not simple. There is no clear dichotomy of one being pseudoscience and the other science. Indeed, it is not even clear if the two can be disentangled. Newman and Principe argue that there was no distinction between the two in the seventeenth century. They have made a detailed analysis of the etymology of the words and have concluded that the differentiation is both wrong and

---

[1] These were made by Eddington on west coast of Africa and simultaneously by another group of astronomers in Brazil [Dyson: 1919].

confusing. They suggest the neutral term 'chymistry' and 'chymists' to avoid preconceptions [Newman & Principe: 1998].

In this thesis the terms alchemy and chymistry are used interchangeably as both terms can be found in the primary texts. 'Chemistry' will denote the modern discipline. Chrysopoeia may be used where the goal is to transmute base metals into gold, or to create the Philosopher's Stone, while iatrochemistry is for the preparation of medicaments. Philosophical Mercury, Sulphur and Salt will have the first letter capitalised, while the common substances mercury or quicksilver, sulphur or brimstone, salt will be in lower case.

1.3.2 *Mixtures and Compounds*

As is pointed out by Newman [2006] the change in meanings over the centuries may lead to confusion in the terms used. Mixtures, composition and compound are examples where modern meanings are different from medieval ones. They derive from the Latin *mixtio, miscere* and *composito, componere.* In Aristotelian terms, 'mixture' was the result of the component parts being fused together to form a perfectly homogeneous substance – a 'compound' in modern parlance, where chemical bonding will have taken place. Mixtures were generally referred to as mixts. 'Composition' signified a juxtaposition of particles, for example wheat and barley shaken together in a container, such that the separate ingredients can relatively easily be separated out. This is opposite to the modern meaning; we would describe this state as a mixture [*ibid*]. A glossary of esoteric and archaic terms can be found in Appendix B.

1.4 A Harmonised Approach To The Analysis Of Scientific Practice

Wittgenstein's Family Resemblances

To begin an analysis of scientific practice it is necessary to specify and describe the criteria required for science, and how they will be assessed. Given the difficulties in reaching consensus on what constitutes science I propose to employ a Wittgensteinian 'family resemblances' or cluster approach. This approach has been utilised in the attempts to define games (in Wittgenstein's original work [Wittgenstein: 1953]) and more recently in the definitions of biological species, [Pigliucci & Boudry: 2003] and in expert systems for medical diagnoses. The problem is that whilst everyone knows what a game is, it is extraordinarily difficult to define the necessary and sufficient criteria that will encompass all games. Wittgenstein suggested a cluster approach. If sufficient elements of a game are present, such as competition, physical activity, winners and losers, cards, etc. then that activity can be called a game. A game may encompass many variables. In a similar way, there are resemblances between people of the same family, though clearly not every member of that family will exhibit every resemblance. In this approach we may draw boundaries on subsets of family resemblance concepts or elements for purpose of analysis. It is not necessary (or expected) for all of the elements of every subset to be included in a specific analysis.

Expert systems, used for medical diagnoses and many other applications, also utilise clustering techniques for data mining [Tiwari & Mishra: 2011]. An example is the Iliad Expert System which utilises clusters representing entities well known to clinicians [Warner et al: 1988]. “This approach is considered to emulate closely the logical analysis used by domain experts in making medical decisions in practice” [*ibid*, p373]. The criteria used in designing cluster frames (a collection of non-specific findings commonly associated with a particular infection or a variety of conditions) are obtained from the domain experts. Expert opinion may vary but consensus is sought, and the system can be improved by subsequent data obtained from actual patients. “A cluster frame is designed as a Boolean decision model i.e. any one or a combination of findings in the list may be sufficient for the frame to be considered ‘true’.” “This is the natural way for a clinician to describe such an entity; that is the minimum combination of findings that would justify attaching the name of the cluster to a given patient” [*ibid* p373].

I propose that this cluster concept is suitable for the analysis of science in history also. I am not attempting an ambitious system which would be suitable necessarily for all branches of science. Rather this is a tailored scheme for the evaluation of alchemy and chymistry, or proto-chemistry of the aforementioned period. Clearly, one criterion may be closely associated with another criterion, or possibly several, and may successively merge.

For example, each separate criterion to be studied such as peer-review, journals, text books, learned societies, and universities may be closely linked. Universities provide teaching and promulgation of authorities, with Aristotelianism not only being taught but giving rise to debate. Universities and other learned societies should be responsible for promoting epistemic virtues such as accuracy and coherence. In the chymists’/alchemists’ methodology, best practice in experimentation must be linked with reliability/reproducibility, testability, and negative instances. There will be complex interactions between elements.

This does not compromise the effectiveness of the initial segregation into discrete objects or elements for the purpose of analysis. Rather it facilitates both the definition of, and the connexion between, relevant entities. By dissecting the parts, then reintegrating, I construct a representative model of early modern proto-chemistry, mirroring the alchemists' practice of *spagyria* - that is *diakrisis* and *synkrisis*, analysis and synthesis.

1.5 Criteria for Good Science

The Characteristics of Alchemy and Chemistry in the Seventeenth Century

How well was alchemy and chymistry practised in the seventeenth century? Lacking an ahistorical Scientific Method, valid for all scientific pursuits, I have limited my inquiry and analysis to a particular period and timeframe: "How well was science practised in the discipline of alchemy and chymistry in the early modern period?" As noted in section 1.3, the terms alchemy and chymistry will be used interchangeably in this thesis. The approach to the analysis of scientific practice was discussed in section 1.4; the detail is outlined below.

Defining the Elements of Good Science

It is essential therefore to bear in mind the background culture and beliefs of the time-period when attempting an analysis of the kind of science being practised. I am asking if it was conforming with 'best practice' (so far as that can be presumed to be established). Therefore, it is necessary to collate the defining constituents of good scientific practice. I have compiled what I believe to be an all-inclusive list of the components that would have been available to the natural philosophers of the era. Obviously modern elements such as evidence- based medicine (EBM) and statistical methods are not included. In a nutshell, were they adhering to the best practice they could, given the constraints of their knowledge base and technological equipment of their time and place?

The justification of my claim that the alchemy/chymistry practised in the seventeenth-century can be broadly considered scientific (and indeed contributed to modern chemistry) rests upon exhibiting the activities and outputs of a representative sample of natural philosophers, institutions, along with alchemical and chymical practices, the work of which demonstrates adherence to specific components of science. For example, challenges to scholasticism are represented by Bacon, Agricola and others, reproducibility of experiments by Boyle and Homberg. I will discuss each component, or group of components, and justify their inclusion. In the following chapters I will describe the milieu and the background beliefs of the period. Then I will demonstrate which of the components, or existential quantifiers, (listed in Table 1) were present in the era. Although I have deconstructed the discipline into element and clusters to facilitate analysis, there are of course strong links between both similar and disparate elements. The availability and sophistication of instrumentation and apparatus will affect what type and how accurately such experimental process may be executed; new processes or new materials will be an enabling factor. Communication, including peer review of outputs, textbooks and commonality of authorities, for example the universities, will also have a considerable impact. The relationships therefore are quite complex.

I have split the requirements into two groups; core and desirable. These core criteria I consider to be essential elements. I have put critical thinking at the centre, as logical thinking and an ability to reflect, to conceptualise, are essentials of a cognitive toolkit without which it is difficult to see how the overall process could be termed scientific. At a very basic level, scientific practice must include critical thinking, reflective thought, plus observation, data collection and some way (even as a thought experiment) of testing one’s theory. The remaining core quantifiers support these fundamental requirements, adding aims (in the form of epistemic values), critical analysis (scepticism) communication and assistance in positing possible laws of nature. To this cluster I have added the 'Desirable’ group, which challenge, strengthen and hone both theory and practice. The reasons for including each component are discussed in more detail below. In this way I hope to have represented all the significant components of science. I ask whether the element was present, adhered to and disseminated. It would be interesting to have allocated a weighting. Clearly some elements are absolutely essential; some are ‘good to have.’ However due to the complexity of the interactions, and the co-dependence of some, I have declined to attempt a numerical weighting. Any weighting proposed would in any case be likely to be contentious.

Assessing the Evidence

To achieve my objective, I have analysed the work of several important Early Modern alchemist/chymists. This includes details and analysis of a number of key text books published between 1556 and 1685, in approximately chronological order. Although Agricola's textbook was published in the sixteenth-century. I have included this important example as its influence reached into the seventeenth-century. Samples from the geographical areas which include Germany, France and England are represented.

I begin with Georgius Agricola (1494 –1555) who was born in Saxony [Hoover & Hoover: 1950]. He became a doctor in the mining town of Joachimsthal, and subsequently for Chemnitz, Saxony, another famous mining city. *De Re Metallica* [Agricola: 1556] was published in 1556 postumously. The first edition was in Latin; this was swiftly followed by a German translation in 1557 and an Italian in 1563. An English translation was planned, but there is no evidence of its publication in that era [Hoover & Hoover: 1950]. A prolific writer, his other published works included *De Natura Fossilium* (1546), *De Ortu et Causis Subterraneorum* (1546) and many others, including medical and religious tracts. In *De Re Metallica* scores of mining and metallurgical processes have been collated and described, supplemented with dozens of woodcuts to augment the text, describing practical applications. Agricola's work, founded on research and observation, remained the principal mining textbook for nearly two centuries [*ibid*, xiv].

Andreas Libavius (c.1550-1616), was born in Halle, Germany. His principal work, the *Alchymia* (1606) was crucial for preparing the way for chemistry to be considered an independent discipline. It contained details on laboratory processes, hundreds of recipes, matter theory and the principles of sound reasoning [Moran: 2007]. He defended Aristotelianism and attacked (often vehemently) Paracelsianism. It was an important step in establishing a textbook tradition.

Jean Béguin (c 1550-1620) was from Lorraine but lived in Germany as well as France. In Paris he established a School of Pharmacy giving public lectures on the preparation of spagyrical drugs. Notes from these lectures were used as the basis of a book, namely *Tyrocinium chymicum* (*The Chymical Beginner*). It was first published c.1610, and was very successful, becoming available in French, Latin, and English [Patterson: 1937]. There were over forty editions. Boas Hall states that it was still being read in the last quarter of the seventeenth century; it can be considered more influential than Libavius's *Alchemia.* Béguin's textbook format became the standard for the period [Boas Hall: 1958].

Daniel Sennert (1572-1637) was a native of Breslau, Germany and became professor of medicine at the University of Wittenberg. An influential and prolific writer, he published works in medicine, natural philosophy and chymistry over several decades and in many European countries [Michael: 1997]. From his early support of an Aristotelian pluralist stance he developed a corpuscular theory, despite not rejecting Aristotle [Michael: 1997]. His work, especially that of experimentation demonstrating the survival of corpuscles during the process of chymical analysis and synthesis, was influential on Boyle [Newman: 2006]. He was also responsible for introducing the teaching of chymistry into the medical curriculum at Wittenberg.

Born in Sedan, France, Nicolas Le Fèvre (1610-1669) delivered lectures of international renown in pharmaceutical chymistry [Partington: 1962]. His most well-known work was the *Traite de la Chymi*e (*A Compendious Body of Chymistry*) published in Paris in 1660, and later translated into English, French and German. He was appointed demonstrator of chymistry at the Jardin du Roi and later became professor of chymistry to Charles II. In 1660 he was appointed apothecary to the royal household [*ibid*].

The Frenchman Nicolas Lémery (1645-1715) was born at Rouen. He worked with Glaser at the Jardin du Roi, then travelled widely through France before settling back in Paris. Here he gave lectures in chymistry and gained a wide and respectable reputation, which was much enhanced by the publication in 1675 of his *Cours de Chymie*. Editions were available in Latin, German, Italian, Spanish, Dutch and English [Partington: 1962].

Other works assessed were those of Francis Bacon (1561-1626) and Robert Boyle (1627-1691) whose contributions to science are very well known. Both were alchemists, believing in the transmutation of base metals into gold. A lesser known figure is Wilhelm Homberg (1652-1715), whose experimental method is of interest for its startling modernity. Homberg, was a Dutch (or Flemish) natural philosopher who became a member of the *Académie Royale des Sciences* in 1691 [Chisholm: 1911]. Acquainted with both Boyle and Lémery, part of his work was published by inclusion in Lémery's *Cours de Chemie.* In addition, the works of Samuel Cottereau De Clos and other salient members of the *Académie* deserve consideration, as do those of the Royal Society.

In this way I have assessed a selection of the influential technical literature of the century, covering a wide geographical area. Of course, it is only a sample of the extensive alchemical and chymical writings extant; it is outside the scope of this thesis to cover such a vast genre in any depth. The samples were selected on the basis that they were influential, widely read works available in various countries. Often several editions were published. I am confident that the works chosen are a representative sample which gives a clear idea of the level of scientific practice in the chosen era.

1.5.1 *A brief account of the criteria*

Below is a list (Table 1) of each individual criterion, split into groups of 'Core' and 'Desirable'. Following this I will give brief descriptions and reasons for their inclusion. A more detailed analysis will be given in Chapters 3-7.

Group 1-Core Criteria

- Critical Thinking, *including*
  - Syllogism
  - Hypothetico-deductive method (H-D)
  - Induction
  - Inference to Best Explanation (IBE)
- Scepticism
- Epistemic Values, *including* Accuracy/Predictive power and Consistency/Coherence
- Observation, *including*
  - Collection and collation of data
  - Taxonomical classification
- Testability
- Experimentation
- Reproducibility/Reliability
- Negative instances
- Heuristic Paradigms (theory neutral)
- Authorities
- Research Community, *including*
  - Universities
  - Learned Societies
  - Journals
  - Peer Review
  - Text Books

Group 2 – Desirable Criteria

- Challenging Authorities
- Metaphysical paradigms
- Methodological Naturalism
- Values, *including* Parsimony/simplicity, Scope, Fruitfulness
- Falsificationism
- *Epistêmê* informing *technê* and vice versa
- Common Methodology, *including*
  - Apparatus/instrumentation
  - Exemplars/heuristic models
  - Symbolic generalisations
- Progressive Elements, *including*
  - Generation of new chemicals and techniques
- Mathematics

Table 1 List of Criteria

I have grouped some criteria together as they form natural bundles; for example, Universities, Learned Societies, and Journals are linked together under Research Community though details of each will be assessed. The order is not indicative of a level of perceived importance. See *Fig. 1* for a graphic representation.

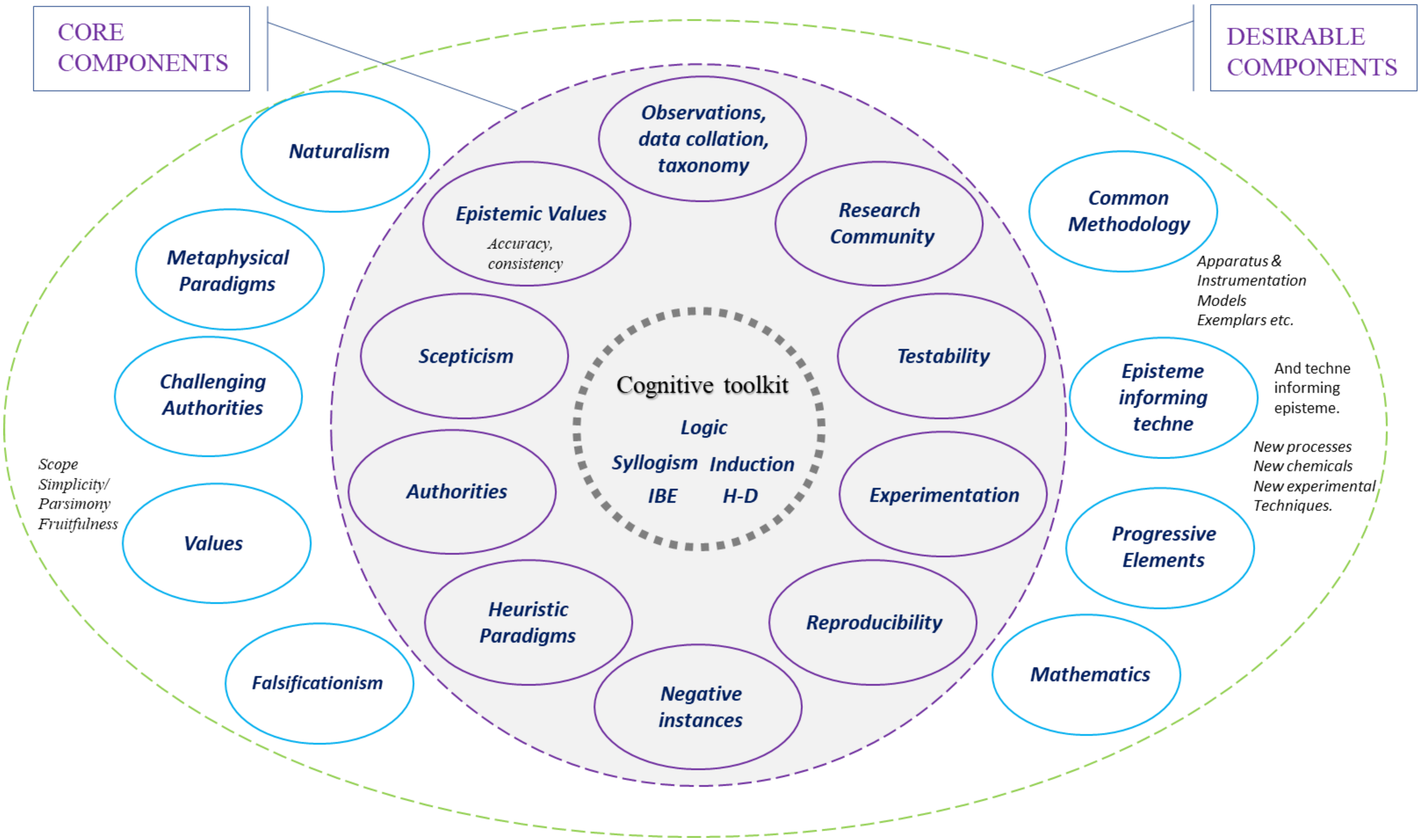


Fig.1. Wittgensteinian clusters approach applied to criteria for Early Modern Chymistry

1.5.2 *The Core Criteria*

Critical Thinking

Critical or reflective thinking, must be a defining component of science. Dewey describes it as "active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends" Dewey [1933]. It has a long pedigree, reaching back at least to Socrates (c. 469-470 to 399 BC), some two and a half thousand years ago. His 'Socratic method' of questioning of common beliefs and explanations led him to conclude that people often could not justify their claims to knowledge in any rational manner [Paul: 1997]. Whether they were in authoritative positions or not, their views might be irrational or confused, lacking epistemic warrant for their beliefs. Plato (c. 428-427 BC to 348–347 BC) continued to work in this vein, recording the output of Socrates. Critical thinking was adopted by Aristotle and the Greek sceptics, all of whom emphasised the need to think systematically, comprehensively and rationally in order to understand the deep mysteries of nature. This tradition was continued in the Middle Ages, and is represented, among others, in the *Summa Theologica* of St. Thomas Aquinas (1225-1274). It is therefore included in the core requirements of syllogism, logic, hypothetico-deductive method, and abduction (IBE). An important adjunct to the above is interpretation. An ability to recognise anomalous results, for example, challenging the hypothesis and perhaps inventing one which better fits the observed data, can result in significant progress. Louis Pasteur's famous quote "chance only favours the mind which is prepared…" was said in reference to Ørsted's discoveries relating to electromagnetism, but it could equally be applicable in a number of other situations, for example in Darwin's monumentally influential work, and that of the botanist John Ray. Ray's extensive studies of plants led him to the appreciation of different taxonomic classes, some of which are still in use today, and contributed to the Linnaean system (Chapter 3).

Hypothetico-deductive method

There have been different stances regarding empirical evidence (logical positivists) versus mental *a priori* knowledge (Descartes, for example.) Taking the modern stance that reason must be engaged and observations made, it surely must be axiomatic that logical reasoning is an essential component of scientific practice, and observation is fundamental such that the reasoning can be tested. We may start the hypothetico-deductive process with observation, make a speculation, then test the hypothesis, by which testing the hypothesis is then collaborated, modified or discarded, depending on the results of observation. Others contend that a hypothesis, however tentatively formed, is necessary to delimit observation, before noting (possible) correlations between these observations. Perhaps it depends upon one's starting point and objective. One might simply observe, reflect then hypothesise, or one might raise a hypothesis to account for phenomena or to solve a problem. Medawar asserts that "there is nothing distinctly scientific about the hypothetico-deductive process". He states "It is not even distinctly intellectual. It is merely a scientific context for a much more general stratagem that underlies almost all regulative processes, or processes of continuous control, namely feedback, the control of performance by the consequence of the act performed". [Medawar: 1969]. It's a process of continuous feedback from inference, constantly updating the conclusions as new data are obtained. It also could be described as Bayesian. There must be delimiting of data; without focus and without some notion of kinds or of patterns (which humans seem predisposed to search for) scientific analysis would be an impossibly daunting task.

Logic and the Syllogisms

That people are rational or logical cannot be taken for granted. However, I make the assumption that those who have been taught the *trivium* and use syllogisms and demonstrations have an understanding of logic and would be expected to be operating logically as far as scientific practice is concerned. But I do not mean to say that people without training are not capable of logical thought. Nor do I suggest that their logic (whether they are learned or unlearned) necessarily extends to all sections of their endeavours. A cautionary note is given in the introduction of the *Port Royal Logic*: "There are no absurdities too groundless to find supporters" [Arnauld & Nicole: 1662].

Aristotle's theory of syllogism was a remarkable system developed in the *Prior Analytics* and the *Posterior Analytics* and in the Middle Ages it was the "dominant model of correct argumentation" [Lagerlund: 2016]. This logical system utilising the square of opposition gave rise to two hundred and fifty-six logically distinct types of syllogisms, though only twenty-four are logically valid, and of these twenty-four, fifteen are unconditionally valid. There is the risk of making fallacious conclusions.

Logic was taught at the universities (the *trivium* included grammar, logic and rhetoric; the *quadrivium* added arithmetic, geometry, music and astronomy; these were the seven 'liberal arts'). Aristotle was being debated despite certain Aristotelain propositions being proscribed at the University of Paris by the Edict of 1277. No such prohibition was in force in the English universities. The teaching of Aristotle's logic continued into the Early Modern period, and dominated Western philosophical thought for many centuries. The Port Royal Logic (*La Logique ou l'art de penser),* written by Antoine Arnauld and Pierre Nicole, first published in 1662, "was the most influential textbook on logic from Aristotle to the end of the nineteenth century" [Buroker: 2014].

Induction

The problems with Inductive reasoning have been discussed from the time of the Pyrrhonist sceptic Sextus Empiricus (c.160-c.210 BC) and there is no need to detail them here. Suffice to say that Inductivism is ampliative, and can expand knowledge, but it is not a logically rigorous process. It is vulnerable to new information and therefore defeasible. Bacon's inductive method inspired many later natural philosophers, including Boyle and Newton. Baconian eliminative induction was an innovation which improved upon naïve inductions, but was still vulnerable to defeasibility.

Abduction and IBE

Abductive inference or inference to the best explanation (IBE) was not formalised until Peirce added it to modern logic in his classification of arguments (1867) but was considered to be the application of general good sense – *le bon sens* in earlier times (see Chapter 3 for Duhem's discussion of ample and deep minds). As Sober describes, abduction can lead to false conclusions if other rules explaining the observation are not taken into account. It is formally equivalent to the logical fallacy of affirming the consequent (or *post hoc ergo propter hoc*) because of multiple possible explanations [Sober: 2012].The application of IBE can be seen in many instances of early modern chymistry.

1.5.3 *Scepticism*

Scepticism in the early seventeenth century was based on Academic scepticism which had been known via Cicero's *Academica* (45 BC) and from Lactantius' *Divinae Institutiones* and Augustine's *Contra Academicos* (386 AD) [Neto: 1997]. Cicero's works were included in the university curriculum. This form of Academic scepticism originated with Arcesilaus (c.315-241 BC) and Carneades (213-129 BC). Academic scepticism held that there is no criterion of truth, knowledge is impossible, but there are degrees of probability by which decisions can be made. In contrast, Pyrrhonic scepticism holds the view that it is impossible to know the truth of things in their own nature; it is the suspension of judgement (*acatalepsia*) leading to a universal scepticism. A revival of Pyrrhonism came about after the rediscovery of the Greek texts, particularly that of Sextus Empiricus' *Outlines of Pyrrhonism* which ultimately led to *La crise pyrrhonienne* an intellectual crisis in what was to prove a very turbulent century (Descartes was confronted by this crisis in 1628-29) [Popkin 1960; 2003]. The level of scepticism in chymical hypotheses will be reviewed, given its importance in driving scientific development.

1.5.4 *Epistemic Values: Accuracy/Predictive power and Consistency/Coherence*

Of the five Kuhnian virtues of a theory, the primary two are accuracy or predictive power and consistency. These are deemed core values in science.

Accuracy /Predictive power

Applications of theory, assertions derived from theory, should be both qualitatively and quantitatively accurate. This value carries great weight, with quantitative accuracy in the sciences having become increasingly important in modern times. "A theory should be accurate: consequences within its domain, that is, consequences deducible from a theory should be in demonstrated agreement with the results of existing experiments and observations" [Kuhn: 1977, p321]. Kuhn takes accuracy to include not only quantitative agreement but qualitative as well. "Ultimately it proves the most nearly decisive of all the criteria, partly because it is less equivocal than the others but especially because predictive and explanatory powers, which depend on it, are characteristics that scientists are particularly unwilling to give up" [Kuhn: 1977 pp322-323]. Kuhn notes that theories cannot always be discriminated in terms of accuracy, giving the example of Copernicus's system, which was not more accurate than Ptolemy's until its drastic revision by Kepler some sixty years later.

Consistency (Coherence)

Kuhn states that theory should be free of internal inconsistencies and be compatible with other accepted theories applicable to related aspects of nature [Kuhn: 1977]. Lack of coherence was one of the criticisms of Aristotelian physical theory, leading to challenges, particularly of substantial form. Notwithstanding the above, the other virtues, scope, simplicity/parsimony and fruitfulness are all desirable values (Chapter 1.6).

1.5.5 *Observation, Cataloguing and Taxonomy*

The recording of observations results in an increase in empirical data, and thus knowledge. The analysis and cataloguing of such data are an essential step in setting up the data in a manner which promotes the process of understanding. "Science (*epistêmê*), for Aristotle, is a body of properly arranged knowledge or learning - the empirical facts, but also their ordering and display are of crucial importance. The aims of discovery, ordering, and display of facts partly determine the methods required of successful scientific inquiry…" [Anderson & Hepburn: 2015]. Bacon of course promoted extensive collection of data, but this was to be collected indiscriminately. The era produced many books detailing impressive collections of plants and minerals, reflecting the huge increase in data which resulted from explorations, particularly in the New World. Agricola's *De Natura Fossilium* contains details of hundreds of minerals and provides a level of taxonomic classification [Agricola: 1556]. John Ray's taxonomic classifications have proved to be a lasting contribution.

1.5.6 *Heuristic Paradigms*

This section discusses paradigms as a reference framework for the pursuit of scientific endeavours. Is a paradigm an essential for the practice of natural philosophy? Here I must differentiate between metaphysical paradigms and what I term heuristic paradigms; Kuhn described these as 'solution paradigms.' These paradigms may be 'theory neutral;' there is no necessity to accept an overarching metaphysical paradigm, though they are commonly accepted *de facto*. One does not have to believe in the metaphysics for a theory to be useful. Many scientists may proceed with the notion that a theory is a 'useful fiction'. (Lémery for example dismisses the extant theory as 'a little metaphysical' and gets on with the practical applications). They utilise it as long as it provides heuristics, a method of problem solving, or discovery. It does not have to be optimal or truth bearing; it just needs to be pragmatic and useful. It is generally accepted that a framework is a useful thing by which to obtain and judge observations and experimental results. There needs to be working assumptions. Without some way of differentiation or cataloguing, no sense could be made of sensory data input. Although core, heuristic paradigms link with exemplar and symbolic generalisation, which will be considered in Chapter 7 on Common Methodology, where standard methods such as analysis and synthesis will be included. Metaphysical paradigms, by no means universally accepted as useful by philosophers, will be considered as part of Desirable elements.

1.5.7 *Testability*

A theory should be able to be subject to test, even if only theoretically. Clearly it is a stronger position for the theory to be actually falsifiable in practice, rather than having to wait for appropriate technology to be developed to test it, which might be a long time into the future. But it has been the case that theories have been corroborated many years or decades after they had first been proposed. If it is tested and the results are shown to be compatible with its predictions, then the theory is corroborated (never verified, according to Popper.) If the results are not in line with the predicted outcome, then the theory is falsified. In practice, a falsified theory is often retained because it is impossible to falsify a theory in isolation; the ancillary hypotheses may be at fault, as has been argued in the Duhem-Quine hypothesis. Additionally, a theory is rarely dropped until another, more viable, theory is available to take its place. [Gillies: 1998]

1.5.8 *Experimentation*

This links to observation but carries it a step further. Baconian experimentation was very influential, on Boyle and Newton for instance. Boyle's work abounds with examples of experimentation - including some of the pitfalls [Boyle: 1661a, in: Hunter & Davis: 1999]. Some of the methods adopted (and their results) by individuals or institutions, will be assessed. This links to reproducibility and reliability. Bacon talks of wresting or forcing Nature's secrets out of her; knowledge is more easily obtained by experimentation than by observation.

1.5.9 *Negative Instances & Falsificationism*

Were negative instances taken into account? Were there attempts at falsification? Here I am using 'falsification' in a weaker sense than Popper. Popper insisted that all theories should be subject to attempts to falsify them. This was, to him, an essential prerequisite of science. In this thesis I use falsification in a weak sense as a term for an attempt to falsify a rival theory, for example, Boyle's redintegration (the decomposition and recomposition) of nitre experiment was designed to falsify Aristotelian theory of forms, leaving the way clear for acceptance of his own corpuscular theory. However, it is clear that is not falsificationism in Popperian terms. This would require a critical attitude to one's own theory.

One example of a collection of negative instances was recorded in the *Memoires Histoire des Plantes*, published by the *Académie Royale des Sciences*, describing their failed attempt to analyse the active constituents of plants by dry distillation.

1.5.10 *Reproducibility and Reliability*

These are essential if laws of nature are to be uncovered and supported by corroborating evidence. Evidence at attempts (not always successful) of reproducibility can be seen in, for example, the work of Homberg and also in the research programmes of the *Académie* as mentioned above. Meticulous recording of detail and careful measurement can be found in diverse projects. The level of precision of the instruments and apparatus, classification and purity of chymical reagents sometimes had an adverse effect on reproducibility, though processes such as gold assaying benefited from a long history of practical experience.

1.5.11 *Authorities*

The prevailing authority was Aristotelian, though Neoplatonism had its revival in the Middle Ages. The Galenic theory of humours was well established. Paracelsianism was an important influence also, as was the Islamic influences, from eleventh century onwards. The Jabirian corpus, including the work of the Latin Geber, plus Averroës and Avicenna were very influential in alchemical theorising. See Chapter 2 on the historical background, which discusses briefly the salient points of the cosmologies from Aristotle's four-element theory through Paracelsianism to the vitalist/corpuscularian hybrid system of van Helmont. These authorities shaped the intellectual milieu.

1.5.12 *Research Community*

I am using this term in a broad sense. It includes Learned Societies, from the informal such as the Invisible College to formal organisations such as the Royal Society and the *Académie Royale des Sciences*, universities, academic Journals, peer review (formal and informal) and text books. It also embraces individuals working in or studying the field and their communications, whether interpersonal networks or published articles or letters. Subjects examined cover experiment results, discussions of theory and also the role of the universities in expressing scientific norms, whether explicitly or implicitly. Without such communities, scientific and artisanal knowledge is likely to be lost. Craftsmen may have passed their expertise from master to apprentice, by verbal or written transmission. But to collate, dispute, review and disseminate is the function of a scientific community. An 'isolated genius' might be inspired to construct amazing theoretical works, but without a conduit to the greater community such works would be lost, and fail to contribute to the growth of knowledge. Details of the thriving research community enjoyed in the period will be given.

1.5.13 *Desirable Criteria*

Authorities Challenged

Debate on the Aristotelian corpus had been under way since the texts (all were translated by the middle of the thirteen century) had become available. Challenges to the established Aristotelian authority were being made, such as the university curriculum (Bacon), theories of the earth (Agricola), Cartesian mechanical theory, and not least by Boyle's corpuscular hypothesis. In the *Skeptical Chymist* (1661) Boyle attacked the Aristotelian four-element theory, the Paracelsian three Chymical Principles, as well as the composite five-elements system of Mercury/spirit, Sulphur/ oil, salt, phlegm, and earth. Fire analysis comes under scrutiny as Boyle discovered experimentally that fire does not separate certain substances (gold and silver for example) into their constituents.

1.5.14 *Metaphysical Paradigms*

The need for a metaphysical paradigm to guide natural philosophy has not achieved ubiquitous acceptance. The range is from the perception that it is absolutely necessary to a wholly negative artificial construct, impeding the progress of science. Kuhn supports the former whilst the latter is Duhem's stance. An intermediate view is that it is helpful, but it is not necessary to believe in the truth of it to use it. Assumptions about the world might be of value heuristically.

1.5.15 *Methodological Naturalism*

Methodological naturalism has a variety of shades of meaning. It is defined here as the study of nature without recourse to supernatural explanations. It does not entail ontological naturalism, which would deny the existence of God or any supernatural being; it simply confines the study of the Nature to natural laws and phenomena without invoking the spiritual realm. The independence of scientific investigations from external influence must be assumed, for example in controlled experiments, otherwise repeatable empirical study could not be performed. Supernatural effects lie outside the realm of scientific investigation.

To what extent did methodological naturalism prevail in scientific thought? In modern times naturalism can be considered a 'given' in any scientific theory. No scientific journal would publish a paper that appealed to supernatural causes. Things were not so clear-cut in the early modern period. Over the seventeenth century there were various attitudes to naturalism, shading from a strong belief in vitalism, a tacit ignoring of metaphysics (Lémery) to an avowed avoidance of theology as explanation in hypotheses (Boyle). Bacon believed in vitalism, but his was a naturalist metaphysics; there was no recourse to supernatural beings. Occult[2] or hidden causes could be admitted, for example magnetism, planetary influences and gravity, where the effects could be observed but an explanation was not available and perhaps not intelligible.

The era was strongly religious, with atheism condemned by most, and certainly by the Church authorities. Descartes was accused of atheism though he made God the initial power in his mechanical philosophy. Examples such as the burning at the stake of Giordano Bruno (1548-1600) for his supposedly heretical views [Knox: 2019] and Galileo's (1564-1642) forced recantation after his publication *Dialogue Concerning the Two Chief World Systems* (1632) supporting the heliocentric theory [Machamer: 2017], would naturally give rise to caution in expounding views that might prove unpopular with the Roman Catholic Church.

1.5.16 ***Values***

These include Kuhn's five main scientific values of Accuracy, Consistency, Scope, Simplicity/parsimony, and Fruitfulness [Kuhn: 1962]. I have put the first two in the 'core' cluster as these are essential epistemic values. The rest, although important, are 'nice to have' but non-essential. In modern theory choice, accuracy is highly valued as a truth value, but fruitfulness may have been highly regarded by the early moderns, for example Bacon.

[2] There has been a drift from its original meaning; the 'occult' of the 15th century was derived from the Latin occultus, meaning hidden, or conceal. The astronomical sense of 'occulere' meaning 'concealment of one heavenly body by another' is first recorded in 1551. [Chambers Dictionary of Etymology]. The early modern sense seems to be hidden or ineffable, but not supernatural. Occultare 'secrete', 'conceal', is related to celare 'to hide.

1.5.17 *Popperian Falsificationism*

I have not found specific examples of attempts to falsify a theory to which the experimenter/philosopher adheres to. There are numerous (and generally successful) attempts at falsifying Aristotelianism, Paracelsianism and other theories. This is not falsification in its strict, Popperian sense. As Popper believed falsification as a defining criterion of a theory being considered scientific, the Early Moderns fail in this particular.

1.5.18 *Epistêmê informing technê*

From Aristotle, we have a defined difference between *epistêmê* (knowledge) and *technê* (art or craft). It would be expected, or hoped, that there would be a circular flow of theory informing practice and vice versa. Klein [2008] suggests that there was considerable interchange between experimental philosophy and artisanal knowledge in the institutionalised laboratories. Alchemical/chymical processes would be utilised for technological advances/commercial goals in many areas – pharmaceutical, metallurgy (especially assaying), dyeing, distilleries, perfumeries etc. There would be a "strong correspondence between academic laboratories, and the pharmaceutical, metallurgical, and other artisanal laboratories" [*ibid* p774].

The Royal Society makes a point of obtaining observations (from seamen, travellers, etc) to be utilised as the basis for natural philosophy. The stated aim, by Oldenburg is "to study Nature rather than books, and form their Observations, to compose such a History of Her, as may hereafter serve to build upon a Solid and Useful Philosophy upon." This was published in the *Philosophical Transactions* [Oldenburg: 1666 vol.8]. Collections of observations were certainly sought; were they received and used for philosophy of chemistry?

1.5.19 *Common Methodology*

Exemplar & Symbolic Generalisation

Exemplars

Kuhn describes exemplars as concrete problem solutions which the student encounters from the start of their scientific education. His examples come from physics; the inclined plane, conical problem, Keplerian orbits, and instrumentation including the Vernier calliper, calorimeter and Wheatstone Bridge. All physicists, he claims, begin by learning these. [Kuhn:

1962]. I suggest that there are parallels with chymistry such as lime processing. Distillation, rectification, calcination, fire analysis and gold assaying were all frequently used processes.

Symbolic generalisation

Kuhn's 'Symbolic generalizations' he defines as "those expressions, deployed without question or dissent by group members, which can readily be cast in a logical form like *(x)(y)(z)ϕ(x,y,z)*. They are the formal or the readily formalizable components of the disciplinary matrix. Sometimes they are found already in symbolic form: f=ma, or I=V/R. Others are ordinarily expressed in words: 'elements combine in constant proportion by weight,' or action equals reaction. This corresponds most closely with what have been traditionally referred to as 'theories' or 'laws'." [Kuhn: 1962, p182]. I will be looking at examples expressed or generally accepted as norms with chymistry.

An example from physics would be might be Boyle's law:

$$P \propto \frac{1}{V}$$

1.5.20 *Progressive Elements*

It would be optimistic perhaps to uncover a progressive research programme as delineated by Lakatos [1969]. Nevertheless, we may find evidence of compositionist chemistry, developed in physics, which has its origins in corpuscular theory. This has been proposed by Banchetti-Robino [forthcoming] and Chang [2018]. Other lines of inquiry are the discovery of acetone, the earliest chemical equation (Béguin) and analytical techniques such as Boyle's experiments with colour indicators. Boyle made considerable inroads to the area of chemical analysis [Boas Hall: 2008].

1.5.21 *Mathematics*

Euclid's *Elements* was the standard mathematical text, and was included in the quadrivium. It was available from Boethius's translation (c A.D.480) and was hugely influential (Book V dealt with measurement). A concept of mass conservation was implicit but not fully articulated until Lavoisier in the eighteenth century. Bacon did not think that mathematics played a useful role in experimental philosophy.

Quantification

Advances were made in quantification of weight, temperature and time (Chapter 7), allowing better accuracy in measurements and improvements in reliability.

1.6 EPISTEMOLOGICAL CONSIDERATIONS

1.6.1 *Knowledge and Belief*

Before turning to the individual components of chymistry as a science, I will outline the typical views and aims of natural philosophers regarding the acceptable criteria for truth, and whether it was considered even possible to obtain truth, true knowledge, or whether such aspirations were outside the realm of possibility for humans. Such knowledge might be considered the province of God.

What were the expectations of early modern science– absolute truth or the likelihood of being right? From Plato's *Theaetetus* there was the concept that at a minimum, knowledge involves true belief. One cannot know something if it is false. One might of course have a false belief, but that cannot be knowledge. Knowledge is not simply true belief, however; there must be justification for that belief. This was accepted in the early modern period.

1.6.2 *Types of Knowledge*

Types of knowledge, 'knowing that 'and 'knowing how' will also be discussed. This is relevant to intellectual knowledge and craft knowledge, *epistêmê* and *technê* and how one may inform the other. Parry (2014) notes that in the *Nichomachean Ethics*, Aristotle defines *epistêmê* as scientific knowledge, and *technê* as skill, art or craft [Parry: 2014]. These can be mapped onto 'knowing that' or propositional knowledge, and 'knowledge how'. There has been debate upon this distinction, partly because of the variations in definitions by the ancient philosophers [Parry: 2014]. Aristotle also discusses *epistêmê* in the *Prior Analytics.* It is generally accepted that they are independent (this is the anti-intellectualist stance) but there is also the view that they are dependent on each other (the intellectualist position.) My view is that art or craft is not dependent upon 'knowing that.' Nevertheless, dependant on the goal, the application of theory can speed up progress and innovation. For example, the making of gold coinage or a piece of jewellery mainly requires practical application. It is not essential to have an overall theory provided one is aware of the effect of different processes and how to manipulate them. One might speculate on the theory, but the practice is dependent upon technical skill. However, the likelihood of success of technical innovations can be greatly enhanced by the guidance of appropriate theory or calculations. These would reduce the time for 'trial and error.' In the other direction, skilled craftsmen can advise on viable techniques; what will work and what probably will fail. Evidence of two-way information flow will be sought.

1.7 Thesis Guide

The following is a brief guide to the layout of the thesis.

Chapter 1: Introduction and Approach

I have outlined the approach, with a brief description of the criteria necessary for good scientific practice in seventeenth-century proto-chemistry and chemistry, and my approach using Wittgensteinian clusters. I have also given the relevant philosophical background to the period, including the epistemic problems of knowledge.

Chapter 2: Historical Context

This gives the historical milieu, from the recovery of the Greek texts [Spade: 2009] through the prevailing metaphysical paradigms. It begins with an outline of Aristotelian hylomorphism, *Meteorologica*, Neoplatonism, Islamic influences (Geber, Averroës and Avicenna), Paracelsianism (including subterranean maturation of metals), Van Helmont, and Bacon's semi-Paracelsian cosmology. Methodological naturalism is also considered and a general review of the position of the occult in the period. These are necessary contextual concepts relevant to the alchemy and chymistry of the early modern period.

Chapter 3: Core Criteria

Having set the scene, in Chapter 3 and subsequent chapters I will explore deeper into the Core and Desirable criteria, and demonstrate where they can be found within the seventeenth-century alchemy/chymistry. In Chapter 3 the application of logic and critical thinking is examined. Both the acceptance of authorities and traditions with concurrent challenges to those authorities is explored in this chapter, as is scepticism. Challenges to authorities are represented by Agricola, Boyle and others. Observation, collation and cataloguing and taxonomical classification are considered here. The research community, including learned societies such as the Royal Society and *Académie Royale des Sciences*, the universities, publications and peer review are examined. This chapter also covers *technê* informing *epistêmê* within the Royal Society, and by Agricola. As well as the epistemic values, non-epistemic values are included.

Chapter 4: Early Chymical Textbooks

This introduces chymistry at the universities followed by a review of selected Early Modern alchemical/chymical text books. The following are considered:

Agricola: *De Re Metallica*, (1556)

Libavius: *Alchemia*, (1597)

Béguin: *Tyrocinium chymicum*, (1610)

Chapter 5: Seventeenth Century Chymical Textbooks

This chapter is a continuation of the review, spanning early to late seventeenth-century chymical textbooks.

Sennert: *De chymicorum cum Aristotelicis et Galenicis consensu ac dissensu* (1619)

Le Fèvre: *Traité de la Chymie*, (1660)

Lémery: *Cours de la chemie* (1675)

In these works can be found ample examples of cataloguing, experimentation and reproducibility as well as challenges to authority. Theory is included to a greater or lesser extent.

Chapter 6: Experimentation, Reproducibility and Negatives Instances

Boyle's Baconian method can be seen in his arrangements of experimental sequences. The issues with reproducibly are demonstrated by Homberg's production of the Bologna stone, the Sympathetic Powder, and Boyle's anti-elixir powder. How negative instances are dealt with in structured experimentation (recorded, reviewed and explained), are also shown by the work of the *Académie Royale*.

Chapter 7: Common Methodology

Covering Common Methodology, this chapter discusses heuristic models, exemplars and symbolic generalisation. Also included are laboratory apparatus and instrumentation, analytical tests, metal assaying and progressive elements such as the prototype of the chemical equation. Progress in quantification is also encompassed.

Chapter 8: Analysis and Conclusions

I analyse the extent to which the criteria can be shown to be present, and to what degree they are embedded. In conclusion, I claim that there is substantial evidence of many of the criteria posited as necessary for good science can be found throughout the seventeenth century, with a move towards greater systemization. It is acknowledged that some criteria are poorly represented, or indeed absent. A lack of rigorous scepticism has been noted and deference to authority, whether it be Aristotle or a trusted savant, allows more credence to be given to some statements than is justified. Examples of Popperian falsification were not found in the sample evidence examined.

Appendix A. References and Bibliography

Appendix B. Glossary of terms.

This includes some of the more esoteric and archaic terms of alchemy and chymistry

Appendix C. Agricola's challenge on classification

Appendix D. Identification of minerals (Agricola)

Appendix E. Agenda of The Academie Royale (Du Clos)

Appendix F. Béguin's Principles

Appendix G. Excerpt from Boyle's 'Heads'

Appendix H. Experiments at the Academie (Bourdelin)

1.8 SUMMARY

My aim is to assess the practice of alchemy in the seventeenth century and to ascertain whether it can be considered scientific, in the light of scientific and intellectual milieu of the period. To achieve this, I have constructed a Wittgensteinian family resemblances framework, reviewing the existential quantifiers appropriate to the discipline. By evaluating a representative sample, I conclude that alchemy deserves to be recognised as having made a substantial contribution to proto-chemistry.

2 HISTORICAL CONTEXT: AUTHORITIES, METAPHYSICAL PARADIGMS AND NATURALISM

2.1 INTRODUCTION

An appreciation of the historical context is a helpful prelude to the understanding of the forces shaping the intellectual milieu in the time-period of relevance. In this chapter I will include a brief recapitulation of the underlying (principally Aristotelian) matter theory that was the prevailing theoretical base to which the early modern alchemists and chymists worked. I will also give a short description of how the Greek corpus became known in the Latin West, and the role of Islamic natural philosophy in the debates that followed.

After describing Aristotle's hylomorphism, and an excerpt from the *Meteorologica*, a very brief outline of Neoplatonism is given. I turn then to the influence of the Islamic philosophers, whose rich heritage drew on Greek philosophy and esoteric hermeticism. The introduction of alchemy to the Latin West in the twelfth-century led to the Late Medieval debates on alchemy. These debates, which considered both the metaphysical underpinnings and theological implications, concerned the validity of aspirations of the alchemists and the resultant risk to the *res publica*, whether or not their claims on transmutation could be sustained. The universities, generally quite conservative, took a long time to accept chymistry as a separate discipline into the curricula; it was usually considered subservient to medicine. Debus (1990) notes that the first chair in Chymistry is given variously as 1609 Johann Hartmann (1568-1631) the University of Marburg or 1639 Werner Rolfinck (1599-1673) at Jena [Debus: 1990]. Some doubt arises as to whether Hartmann's appointment can be considered a chair of chemistry (rather than part of the medical faculty) as he gave lectures on iatrochemistry [*ibid*] (Chapter 4.2).

The Late Medieval alchemist Paracelsus, (1493/4 -1541) was responsible for the formulation of medicines from minerals, and breaking from the traditional Galenic four-humours theory. A controversial figure, he was instrumental in refocussing the alchemists' prime goal away from transmutation and towards iatrochemistry. He introduced the *tria prima,* adding salt to the mercury-sulphur theory of metals typically held by the Islamic philosophers. This is the milieu in which the Early Modern alchemists such as Sennert, Francis Bacon, Van Helmont and Boyle generated and developed their hypotheses.

The seventeenth-century was a period of political turmoil, including the English Civil War (1642-1651), the Interregnum and the Glorious Revolution (1688-1689). Scientific innovations such as the invention of the telescope at the beginning of the century, and its use by Galileo to examine the sky, had far-reaching effects. Galileo's findings that the moon was not perfectly smooth, and that Jupiter was orbited by four moons were a powerful challenge to Aristotelian orthodoxy. The discovery of the Greek texts in the twelfth and thirteenth meant there was little shortage of contentious texts to provoke lively discussion (where permitted by authorities) and the means for such texts to be reasonably easily disseminated. Theological debates were also intense, following Luther's 95 theses in 1517 and the subsequent Reformation. These uncertain times encouraged questioning of the status quo which contributed to significant changes over the century, including those of the sciences. The developments in physics are well-known; those in chemistry less so.

2.2 Translation of the Greek and Arabic Texts

The recovery of the Greek texts was of great significance in the development of natural philosophy in the Medieval and Early Modern periods. Knowledge of Greek had "all but disappeared" in the Latin West [Spade: 2009], and Boethius's translations of the *Categories* and *On Interpretation* were the only Aristotelian texts in general circulation before the 12th century [*ibid*]. Medieval logic was confined to the study of the *ars vetus* or *logica vetus* (old logic) consisting of Aristotle's *Categories* and *De interpretatione,* the Greek Neo-Platonist Porphyry's *Isagoge* (*Introduction*) commentaries on all of these by the sixth-century Roman Boethius, (c.480-545/526) and a few more collections [Marrone: 2010]. It was not until about six hundred years later that translations began in earnest. Spade (2009) describes the recovery of Aristotle as spanning about one hundred years, from the middle twelve century into the mid-thirteenth century, by which time all works had been translated [Dod:1982. In: Spade: 2009]. Until the complete works of Plato were translated by Marsilio Ficino (1433–99), little was known of Platonic texts except for the first half of the *Timaeus* [Spade: 2009] [Pasnau: 2010. (Vol 2)]. The *Timaeus* includes a discussion on the compositions of inorganic and organic bodies and can be considered a rudimentary treatise on chymistry [Partington: 1937, p13].

Given the Aristotelian cosmology prevalent in the Middle Ages, the alchemists' quest for transmutation of metals would not have been considered illogical or irrational. The principle of the four elements, while providing a limited explanatory role to modern eyes, was accepted due to Aristotle's authority. As McInery (1999) describes, St. Thomas Aquinas (1225-1274)] was responsible for the synthesis of Christian faith with Aristotelian philosophy [McInery: 1999] Aristotle's cosmology or cosmogony was by no means fully compatible with the Catholic dogma and his views on the immortality of the soul are difficult to interpret[McInery: 2010]. He stated in the *Physic*s that the world was eternal, so was in conflict with Genesis [Genesis I]. "Thomas… countered both the Averroistic interpretations of Aristotle and the Franciscan tendency to reject Greek philosophy. The result was a new *modus vivendi* between faith and philosophy which survived until the rise of the new physics" [McInery: 2010]. Challenges to this authority were strongly discouraged by the Church throughout the Middle Ages.

2.3 ARISTOTLE

Hylomorphism

The well-established Aristotelian theory of matter, ubiquitous in medieval Europe, was based on the four elements, Earth, Air, Fire and Water. These elements possessed the four 'primary qualities,' hot, cold, dry and wet, with each element associated with one pair: Fire is hot and dry, Air is hot and wet, Water is cold and wet, Earth is cold and dry [Montada: 1996].

This Aristotelian cosmology was compatible with transmutation as Aristotle held that the four elements can change into one another. Heating water converted it into steam (which was considered by Aristotle to be indistinguishable from air); heating air turned it into fire; cooling water turned it into ice, which being solid was considered to be earth; heating earth produced either liquids (water) or vapours (air). Since everything was composed of the four elements, and they were interconvertible into one another then it should be possible to convert anything into anything else.

When the elements combine to form a compound, this mixt is perfectly homogeneous. Every part of it is the same; no physical process would yield discrete particles of the constituents of the compound. Despite this, the compound can be decomposed chemically to yield the elements in a characteristic ratio. McMullin (1963) describes how the elements therefore exist potentially in the compound in the sense that they can be extracted from it. They also exist as 'powers of action.' For example, a particular compound retains its power of heating due to its constituent fire, but in a tempered or attenuated form [McMullin: 1963]. The four elements exist, therefore, in two different senses in a compound.

Aristotle's theory claims that there are three principles of natural things: "prime matter, form, and privation" [Ariew & Gabbey: 1998]. Referencing Aquinas, Ariew & Gabbey continue: "There are two *per se* principles, namely form and matter, and one *per accidens* principle, namely privation." They interpret this as "individual substances consist of two *per se* intrinsic principles, matter (*materia prima*) and substantial form (*forma substantialis*). Privation (*privatio*) is the principle or cause *per accidens* of generation" [Ariew & Gabbey: 1998]. Prime matter has the potential to become a body, but as such it has no form. It requires the substantial form to imprint it, conferring essence upon it and defining it. Thus substantial form informs the passive prime matter to produce a specific ~~substance.~~ entityFor example, a copper pot feels hard because the metal possesses the sensible quality of hardness, i.e. has the quality of hardness [*ibid*].

The Aristotelian position is that a compound may contain only one substantial form. It does not possess the forms of the elements *per se*. A specific compound supposedly possesses a particular ratio of the elements. If the elementary qualities are present, this seems to indicate the presence of the elements. It is not clear whether in this theory such an indication of presence is accepted. This incoherence led to a pluralist position (adopted by both Avicenna and Averroës) in which every mixed body will contain a hierarchy of forms, but will manifest only the form of the compound itself, which will be dominant over the elementary forms, resulting in a uniform and homogeneous compound.

Monism and Pluralism

Newman (2006) describes St. Thomas Aquinas (1225-1274) as a scholastic Aristotelian, who understood bodies to consist of the four elements. These elements contain the sets of primary qualities. Form is imposed on prime matter (*materia prima)* resulting in differentiated bodies[Newman: 2006, pp26-37]. He believed that the primary qualities were accidents of the substantial form. There was an ongoing debate between supporters of the Thomist view versus the pluralist position. This impacted the interpretation of Aristotelian mixts, and the processes of coming-to be and passing-away.

Aristotelian mixts which were completely homogeneous *mixti*, were the result of new substantial form being imposed on the four elements. Newman describes the process: "First the four primary qualities of the elements produced…a single medial quality preserving something of the extremes; this medial quality then provided the disposition necessary for the induction of the new substantial form, the form of the mixture. Yet in such a case, Thomas insisted, the imposition of the new form of the mixture meant that the four antecedent elements would be destroyed-the generation of the one entailed the corruption of the other. All that remained of the fire, air, earth and water would be the primary qualities, the hot, cold, wet and dry that had been paired within the elements before their destruction and that were somehow responsible for the dispositive medial quality which prepared the way for the form of the mixture" [Newman: 2006 p37]. "As for the elements themselves, they were now only present within the mixture only in *virtute* or *virtualiter* –'virtually'" [*ibid*].

Newman continues: "One important result of Thomas's mixture theory was that there could be no intermediate forms between the *forma mixti* -the substantial form of the mixt- and the Aristotelian prime matter. Hence, in order for a mixture to come into being, there had to be a 'resolution' of the previous ingredients all the way up to the first matter (*resolution usque ad essentiam materiae primae*). Only in this fashion could the substantial form inform the prime matter directly and without intermediary." [*ibid* p37].

This ~~hypothesis~~ theory did not allow that there could be substances such as philosophical Mercury or Sulphur from which the chymists believed the metals to be formed. Therefore the Thomistic theory of mixture was at variance with that of the alchemists.

Minima naturalia

As understood by the scholastics, *minima naturalia,* was the limit to which a substance could be divided. This definition altered over time [Banchetti-Robino: 2015]. Sennert regarded *minima* as atoms; Boyle considered these *minima* as particles for which subdivision was not possible, even in nature, though he stopped short of designating them chemical atoms. He distinguished such fundamental particles from chemical atoms which are not ontologically fundamental but are simply the furthest level of chemical analysis, after which it is not possible to proceed further [*ibid*]. [Van Melsen: 1952].

Aristotle's Meteorologica: The formation of metals and minerals.

I have included this part of Aristotle's work as it is relevant to later discussion of Agricola's challenge to authority.

Books I-III of the *Meteorologica* [Aristotle: 350 BC; Webster: 1923] deal with natural phenomena such as the water cycle, rain, wind, earthquakes etc. Eichholz (1949) gives a resumé of Aristotle's work: The concept of two exhalations, one moist and one dry, is used to explain the above phenomena. Rain is attributed to the moist, vaporous exhalation, as is dew, frost and snow. The dry smoky type is responsible for shooting stars, thunder, lightning, wind and earthquakes. He talks of a 'secretion' below the surface of the earth. In Book III he describes what happens when the two exhalations are confined within the earth. Two substances are formed in the earth; ‘fossiles’ (i.e. minerals) produced from the dry exhalation and metals from the moist, vaporous exhalation. [Eichholz:1949]. From this and the *Meteorologica* it can be understood that the heat of the sun causes the earth to exude exhalations, which are of two kinds. One kind, derived from moisture both within the earth and from its surface, is a moist vapour which is “potentially like water”. “The second kind, originating within the earth itself, is hot, dry, smoky, highly combustible (like a fuel) and is described as “the most inflammable of substances” being “potentially like fire” and is a compound of Air and Earth. The moist exhalation is a vapour, but the dry exhalation is more problematic- sometimes fiery and at other times similar to a gas [Eichholz: 1949]. “The moist exhalation is the material cause of the metals” [*ibid*]. Aristotle’s description is in Appendix C.

Aristotle refers to potentiality in his explanations. Agricola challenged Aristotle’s assertion that all fossils are produced from two types of exhalation, but this does not account for the three genera of bodies. Agricola argues his point on the classifications based on his extensive observations in mining and mineralogy (Chapter 3.6).

Metaphysics and Chemical Properties

The legacy of Aristotle’s four-element hypothesis, with the addition of the *tria prima* still extant in the early modern period, was not conducive to the development of a concept of distinct chemical species. The emphasis was on the observed properties being accounted for by the spiritual or metaphysical presence of the elements within the mixt. The properties of a body were considered to be the result of the blending of the properties of the elements. For example, dry substances were thought to have a preponderance of the Earth element, while Sulphur would be the main force behind inflammability. It is an understandable, if simplistic viewpoint; a stone feels hard and dry, therefore is earthy. This belief remained standard throughout the seventeenth and into the eighteenth centuries, though it was being strongly questioned in the early seventeenth century.

Lémery’s view rests on the premise that in the analysis of mixt bodies, chymists find five sorts of substances. From this they conclude that there are five Principles in natural things. These five sensible principles are Water, Spirit, Oil, Salt and Earth. Three are described as active principles - Spirit, Oil and Salt, while Water and Earth are passive. The active ones appear to be causing action, unlike the passive ones which slow the activity [Lémery: 1685].

Metaphysical-Corporeal Ambiguity

In the alchemical texts of the Early Modern period and before, there are sometimes references to Philosophical Mercury and Philosophical Sulphur, but conflation between the material and the metaphysical results in ambiguities in the texts. Mercury for example may be ‘philosophical’ or the ordinary substance. Similarly, Sulphur may refer to the principle of flammability or simply common brimstone. A third option (articulated in Béguin for example) is that chymical principles have a character that is between the two. “Chymical bodies possess a nature between body and spirit” [Béguin: 1610] (Chapter 4.4). These principles “are neither bodies, because they are plainly Spiritual, by reason of the influx of celestial Seeds, with which they are impregnated; nor Spirits, because corporeal, but they participate of either nature.” This is quite hard to reconcile with the modern dichotomy between spirit and corporeal substance.

The hermetic concept of Mercury as a spirit, Sulphur as soul and salt as body has a long pedigree. The comparison of the three principles with body, soul and spirit can be found in the *Rosarium Philosophorum* [Partington: 1961 p144]. This ambiguity persists through the seventeenth century and into the eighteenth. Properties of bodies were considered a blend of the principles of which they are composed. For example, “Salt consists of divers parts, earthy, aqueous, and fiery. Its consistency and solidity, is from earth, its liquidity from water, and its biting properties from fire” [Béguin: 1610, p66]. Le Fèvre was aware of the problems of identity: “See therefore you do not mistake Phlegm for Pituite, Mercury for quick silver, and Sulphur for ordinary brimstone...” (Chapter 5.2).

Passivity of the Air

It is an oddity that air was considered to be chemically inert. Air was conceived as ubiquitous but merely passive. Though known to have ‘elasticity’ and containing emanations from a variety of sources, including volcanoes, it played no part in any chemical process. This of course has implications for chymical analysis. The general view was that atmosphere was of a spirituous nature. Lémery for example, refers to the “spirit of the air”. The air could be impregnated with volatile spirits, such as saline and sulphurous [Lémery: 1685 p22]. This concept held sway until English physiologist and chymist Stephen Hales (1677-1761) and others demonstrated that air had a chemical as well as a physical role.[3] Hales published *Vegetable Staticks* in 1727, where he described his numerous experiments showing that a great proportion of air is included in the composition of animal, vegetable and mineral substances [Hales: 1727]. His analysis of air did not lead him to any clear hypotheses about the composition of the atmosphere. During his experiments he collected gases over water, effectively inventing the pneumatic trough. This was an enabling factor in subsequent experimentation with gases [Parascandola & Ihde: 1969].

2.4 NEOPLATONISM

Neoplatonic vitalism played a significant role in Medieval natural philosophy and this influence continued into the sixteenth and seventeenth centuries [Wildberg: 2016]. This philosophy was transmitted to the Latin West largely through Plato's *Timaeus.* As described by Wildberg, Plato promoted a version of the macrocosm- microcosm world view and a world soul. From the middle of the third-century to the mid-seventh-century a philosophical school of thought, now known as Neoplatonism, emerged and flourished. The founder of Neoplatonism is commonly regarded as Plotinus (205/5-270 AD). Its revival during the Renaissance is probably due principally to the translation and interpretation of Plato and Plotinus by Marsilio Ficino (1433–1499) and others, in the second half of the fifteenth century [Wildberg: 2016].

Hylozoism

Hylozoism is the concept of a vitalist world, which views all matter as alive, inclusive of animal, plant and to an extent mineral substances, either in itself or by participation in the operation of a world soul or some similar principle such as the *Semina rerum*, a formative principle from which all bodies originate. This *Semina rerum* is an Aristotelian doctrine which has had various interpretations. For the Stoics it was immaterial active principles; for the Epicureans it meant physical atoms. Banchetti-Robino describes the Neoplatonists as holding the view that the ordering principle of the universe, the *Logos*, contains active constituents they likened to seeds. Hence the active constituents were known as the *Logoi spermatikoi*, (seminal reasons) later Latinised to *semina rerum.* [Banchetti-Robino: 2015].

[3]Boyle's "*Spring of the Air*" experiments were published in 1660.

The concept of *semina rerum,* in its Stoic form, was prominent in the natural philosophy of the fifteenth and sixteenth centuries. The Renaissance revival of Neoplatonism was to have substantial impact [Banchetti-Robino: 2015] "in particular, Paracelsus… made considerable use of the notion of *semina rerum*, which he interpretsas the forces and active powers in any object" [*ibid*]. Van Helmont's hybrid ontology utilised the non-corporeal construal of spirit and ferment. The formation of metals was thought to be caused by an interaction of matrices with the *semina rerum*; there were various interpretations on the way in which this was achieved [*ibid*].

2.5 ISLAMIC INFLUENCES

Forbes notes that after the fall of the Roman Empire the connexion between the West and the scientific world of the near East was severed for a long period. The situation was different for the Eastern Roman Empire and the Byzantines who profited by their geographical position and their trade connexions with the East [Forbes: 1948, p55]. The origins of alchemy lie in Greco-Roman Egypt in the first centuries AD, when two traditions began to merge [Principe**:** 2013]. One was a practical, artisanal craft of metalworking which included techniques for imitating precious metals. Traces of these traditions survive in the Leiden and Stockholm papyri. The other was Greek philosophical hypothesising on the nature of matter and change, with intellectual routes going back to the Pre-Socratics [Principe: 2016a]. A synthesis of the practical and theoretical appears in the writings of Zosimos of Panopolis (fl. 300 CE), the most significant Greco-Roman alchemist [*ibid*]. The aim of transmutation is informed by the theoretical principle that all metals share a common underlying matter, allowing a reasonable possibility that one can be converted into another. This process of chrysopoeia involved the combining of base metals with other substances. The transmutation agent came to be known as *lapis philosophorum*, the Philosophers' Stone [*ibid*]. Often the transmutation would be expected to be effected very quickly, and by a small amount of material; this was described as a 'projection'. "Thus alchemy represented, from its very beginnings, a fusion of theory and practice, of knowledge and craft, of *epistêmê* and *technê*" [*ibid*, p361].

These treatises on alchemical practices which reached Islam from Greece typically drew on Egyptian magic, philosophy, metaphysics, astrology, Christian theology and hermeticism. Adopting the Aristotelian model of the four elements, the primary aim of the Islamic alchemists was chrysopoeia. Several centuries of endeavour failed, alas, to realise their goal of the transmutation of base metals into gold [Forbes: 1948 p.47]. However, their alchemical processes were not unsophisticated. ‘Fusible’ bodies such as gold, silver, copper, iron, lead, tin were well defined separate entities. Manifest properties such as density, colour, hardness, sound (for example the cry of tin), fusibility, ductility, and ease of alloying were employed in their analytical techniques [El-Eswed: 2002]. As in the Latin West, the terms mercury (quicksilver) and sulphur (brimstone) in the alchemical literature did not correspond to the modern elements, but were abstractions that exemplified concentrations of Aristotle's essential qualities of hot and dry (Sulphur) and wet and cold (Mercury).

The Jabirian corpus

The extensive Geberian corpus encompassed the 8th century Muslim alchemist, Geber *Jābir ibn Hayyān* (c.721–c.800) and Pseudo-Geber, which included the school of Geber of the same period and later writings. Newman and others are confident now that much of the Geberian corpus originates with Paul of Taranto**,** a 13th-century Franciscan monk. Paul’s output included *Theorica et practica*, a defence of alchemy, describing theory and practice. He is also believed to be the author of the highly influential *Summa perfectionis magisterii* (*The Sum of Perfection*) and several other works previously attributed to Geber [Newman: 2006]. Pseudo-Geber’s corpuscular theory had a significant impact on natural philosophy in the seventeenth-century, influencing the corpuscular hypotheses of Daniel Sennert, Kenelm Digby (1601–1665), Robert Boyle, and others. In contrast to the mercury-sulphur theory of metal formation, the *Summa* advances the hypothesis that mercury alone is the basis of metals, while sulphur is described as a corruptor [Newman: 2006].

The Latin Geber’s very influential quasi-particulate hypothesis is utilised in the explanation of many types of processes, including sublimation, distillation, calcination, cupellation, and cementation. He expounded a three-level variation of corpuscular size Geber’s theory is that a combination of very small elementary particles (*minimae partes*) join to form a very strong composition (*fortessima compositio*) which makes the two principles of metals, i.e. mercury and sulphur [Newman: 2006, p27]. This influence is reflected in Boyle’s mechanical hypothesis in the varying levels of corpuscles, where the bonding is tight at one level, becoming progressively looser. Metals represent a very tightly bonded group [Boyle: 1661].

As described by Newman, the four Aristotelian elements combine through the smallest part (*per minima*) resulting in the generation of the compounds of sulphur and mercury. The four elements are minute particles that bind together to form greater, more complex corpuscles which are strongly bonded [Newman: 2006]. Newman suggests that Geber’s theory does not conform to the scholastic model as presented in *De Generatione et Corrputione*, but may have been derived from *Meteorology IV* [ibid, p28]. Aristotle did not support the minimal parts concept. But a minimal substantial form could lose its form if it were subsumed into a larger body, e.g. a drop of water added to a large volume of wine would lose its form of water.

Note the difference between the modern terminology of mixtures, composition and bonds, (Chapter 1) which do not map onto the Aristotelian concepts. Genuine mixt occurs only when the ingredients react to form a state of absolute homogeneity. A true unification of all the ingredients results in a mixture which is homeomerous, that is, identical in all its parts; this is the Aristotelian stance. But this type of unification as described in *De Generatione et Corrputione* cannot fit with the compositional matter theory of the *Summa*. As delineated by Newman, for Geber, a homeomerous substance is one in which the juxtaposed particles, whilst retaining their own identity are sufficiently cohesive that they are very resistant to attempts to analyse them [Newman: 2006].

Thus, Newman states, homogeneous is equivalent to homeomerous, in the opinion of Geber. "In his description of sulfur, Geber equates homoemerity with homogeneity; his sulfur is indeed homogeneous in the sense that a given sample of it must contain the same proportion of fire, air, water and earth particles locked together in each of the sulfur corpuscles, and yet that does not commit Geber to the view that every part of the sulfur corpuscle is materially identical to the whole. Geber's concept of homoemerity or homogeneity is therefore a relativistic one, not committing himself to the absolute uniformity of Aristotelian mixture" [Newman: 2006, p31]. Newman continues: "The second order corpuscles comprising the two principles, while retaining the first-order elemental particles within themselves, are very small and hence easily forced upward by the fire of sublimation" [*ibid*]. It is therefore possible to decompose a heterogeneous mixture into its constituents because a weak heat will be insufficient to raise the larger, heavier corpuscles. The small, light corpuscles will be sublimed while the grosser ones will remain. Geber uses experiments to support his theoretical claims. He also suggests that small particle size is related to the high specific gravity of gold [*ibid*, pp31-32].

Other Significant Islamic influences.

Many Islamic philosophers had substantial influences on Western science in general and chymistry in particular. These include Al-Farabi (c.872-c.950), known as the Second Master and described by Avicenna and later philosophers as the most important thinker of the early Arabic tradition [Adamson: 2016]. The works of Rhazes *Abū Bakr Muhammad ibn Zakariyyā' al-Rāzī* (c. 854 to 925 or 935 CE) on alchemy and medicine were well known and included the famous *Book of Secrets, Book of Alums and Salt, Book of Secret of Secrets.* Unlike many other philosophers of his era, he maintained a naturalistic outlook and emphasised the need for empirical evidence. A renowned medical man, he criticised both Galen and Aristotle. His philosophy was based on Plato's *Timaeus*, as well as certain non-Greek sources [McGinnis: 2018].

The Persian polymath Avicenna *Ibn Sĩnâ* (980-1037) was highly influential in chymistry and early modern medicine. His stance on artificial versus natural products is discussed in section 2.6, as are his comments on transmutation. Latin translations of the main sections of *Book of the Cure (Kitāb al-Shifā,*) reached Early Modern philosophers such as Descartes, Spinoza and Leibniz [Bertolacci: 2013]. Also published was a Latin translation of the *Canon of Medicine* (*Qanun fi al tibb*) [*ibid*]. Avicenna promoted the concept that sense data must form the basis of knowledge; such data then may be subjected to rational analysis and verification [Gutas: 2012, p423]. He maintained that logical tools were essential to remedy the natural shortcomings in our rational capabilities [Black: 2013].

Alhazen *Ibn al-Haythem* (965-1039) was a polymath with interests in medicine, mathematics and optics. His explanations in the field of vision were revolutionary. He is considered by many to be a pioneer of the scientific methodology, establishing the use of systematic and repeatable experimental evidence. Averroës *Ibn Rushd* (1126-1198) known as 'the Commentator' translated all of Aristotle's works, producing summaries and commentaries on most of them [Bolyard: 2017]. He was a significant philosopher who integrated Islamic traditions with ancient Greek thought. The work of *Ibrāhīm ibn Yūsuf al-Biṭrūjī* (Alpetragius) (flourished 1185–1192) was one of the sources for Bacon's speculative philosophy [Rees: 1996].

2.6 Introduction of Alchemy into the Latin West

The *Liber de compositione alchemiae* (*The book of the Composition of Alchemy)* is probably the first alchemical treatise to be translated from Arabic into Latin. [Al-Hassan: 2004] The translation, completed in 1144, was effected by Robert of Chester[4] (Fl. c.1141-c.1150) [Al-Hassan: 2004]. This book therefore introduced alchemy to Europe. In the Latin West the *Liber* became very well known; many Latin copies have survived. Revised versions were first printed in 1559 in Paris and the first English translation was available in the seventeenth-century [*ibid*, p214].

Universities, inaugurated in the middle ages, had philosophy as a core subject in the Arts faculties. Aristotle's newly available works dominated the philosophical landscape of the time, and were treated as unorthodox by some authorities, consequently they were banned from discussion. Despite prohibition, by 1250 open debate and lecturing was taking place [Spade: 2009]. Aristotelian ideas were subjected to in-depth scrutiny and interpretation.

Status of alchemy

Despite the large number of alchemical works that became available during the twelfth to the end of the fourteenth centuries, alchemy was not accepted as a mainstream discipline suitable for inclusion in the university curricula. It would not be included until the early seventeenth century. Why should this be so? The possibility of transmutation was compatible with Aristotle's matter theory, so in that respect it conformed with mainstream thought. However there were many pseudonymous works on alchemy that were attributed to Aristotle, which led to doubt as to whether it was supported or rejected by the Stagirite himself. Alchemy's delayed inclusion cannot be simply due to its low status as an operative art or technology. Alchemy held a medial position between the arts and natural philosophy [Newman: 1989 p426], as did medicine. Medieval universities frequently taught such applied subjects, so there must have been additional reasons rather than simply the traditional disdain for the practical. From the introduction of alchemy in the mid-twelfth and thirteenth centuries there appears to have been a hostility developing towards the discipline by the mainstream Scholastics together with the religious authorities. Together they combined to make alchemy a largely clandestine activity [*ibid*].

Medieval Debates on Alchemy

Debates arose in the High and Late Medieval ages on the role of alchemy. These debates centred around three main areas; whether transmutation was theoretically and practically

---

[4] There is scholarly debate over the identity of the translator, whether he was Robert of Ketton or Robert of Chester.

possible; if it was possible, whether it was legal and whether its pursuit, (successful or not) was heretical [Newman: 1989]. The deliberations spread over several centuries by influential advocates covering various points of view. Taking these in approximately chronological order, I outline the salient points. The debates begin with Avicenna who lists several reasons why transmutations are not possible. Later, the thirteenth century Paul of Taranto raises a defence against Avicenna's objections. Albertus Magnus disputes Avicenna's reasoning and the alchemist Roger Bacon altered his own view to a belief in transmutation.

The three issues are interwoven to some extent. Avicenna's treatises informed much of the ensuing debate on the theoretical side but was used in the case against alchemy raised by the theologians of the later medieval debates.

The theoretical debates included the contentious issue of artificial versus natural products. Latin, Arabic, and Greek authors, including Aristotle, laid down a strict division between the artificial and the natural. Whilst artificers could imitate nature, their products could never be considered equal to those formed naturally. The mechanical arts were learned by copying nature. What we would call technology – manufacture of armaments, agriculture, medicine- were described (pejoratively) as the "adulterine arts" [Newman: 1989, p424] were limited to imitation of nature. However effective and valuable they might be, the natural models were superior; the artificial could never be their equivalent. "Art imitates nature" [*ibid*, p424] was the maxim of the time. In contrast, some alchemical writers of the Middle Ages argued that art, executed by humans, could successfully reproduce natural products and sometimes even improve upon them [*ibid,* p424]. Debates upon the validity of the alchemists' claims were at times intense. Some Medieval scholastic writers such as Albertus Magnus believed in the possibility of alchemical transmutation; others, such as Hugh of Saint Victor, while accepting technology as a division of the natural sciences [*ibid,* p424] maintained that they were no more than mimicry of nature.

The mainly theological arguments commence with Aquinas, who was concerned not so much with alchemy but with understanding the limits of demonic power. Giles of Rome affirms his disbelief in transmutation; even if 'gold' could be made artificially it was not true gold. In later centuries the debates became more polemical, more political, as the fifteenth and sixteenth centuries theologians linked alchemy to magic and heresy.

2.6.1 *The Arguments from Natural Philosophy*

Avicenna

The forceful anti-alchemical debate begins in confusion, centring around a text erroneously attributed to Aristotle. Avicenna's *De Congelatione et conglutatione lapidum*, which was part of the "*Kitāb-al-Shiftā* (*Book of the Remedy*)" [Holmyard & Mandeville: 1927] was mistakenly appended to Aristotle's *Meteorologica IV* by Alfred of Sareshel in c. 1200, and consequently acquired the reputation of being genuinely Aristotelian. [Newman: 1989, p427]. In this treatise, Avicenna states quite explicitly that art is inferior to nature, and it is outside the power of the alchemists to transmute metals. The attack focuses on his pronouncement "*Sciant artifices alkimie species metallorum non posse transmutari.*" (Let the alchemical artificers understand that it is not possible to transform the species of metals.) Though originating with Avicenna, this was taken to be Aristotle's position, and as such was highly authoritative [Newman 1989].

The first issue deals with the possibility of transmutation "It is likely that the proportion of the elements which enter into the composition of the substance of each one of the [metals] enumerated [above] is different from that of any other. If this is so, one metal cannot be converted into another unless the compound is broken up and converted into the composition of that into which its transformation is desired. This, however, cannot be effected by a melting process which preserves the [original] coherence [of the metal] and causes the admixture of only some foreign thing or power." [Ibn Sĩnâ, *aš-Šifā' at-Tabï'iyyât, al-Ma'ádin* pp22-23; Holmyard & Manderville: 1927].

Secondly, "artificial and natural products are intrinsically different, as art is inherently inferior to nature and artificers cannot expect to equal it. Therefore, artificers cannot change an inferior metal to a superior one, although they can produce passable imitations of the precious metals by introducing superficial characteristics." [Newman: 1989, p427].

Thirdly, "the true species-determining characteristics of metals cannot be known, since they subsist beneath the level of sense. Since these specific differences are unknown, it would be impossible to bring about the transmutation of one metal into another, for the alchemist cannot manipulate what he does not know" [*ibid*, p427].

Avicenna's dictum was that the species are not transmutable i.e. *Sciant artifices* (let the artificers know…); in this he takes a considerably stronger stance than did Aristotle himself.

In the *Physics* (2.8, 199a) Aristotle states “one sort of art perfects that which nature cannot complete, while another sort imitates nature” [5] [Aristotle: c350BC. In: Newman: 1989 p428].

Avicenna is quite explicit: “As to the claims of the alchemists, it must be clearly understood that it is not within their power to bring about any true change of species. They can, however, produce excellent imitations, dyeing the red [metal] white so it closely resembles silver, or dyeing it yellow so that it closely resembles gold. They can, too, dye the white [metal] with any colour they desire, until it bears a close resemblance to gold and copper; and they can free the leads of most of their defects and impurities. Yet in these [dyed metals] the essential nature remains unchanged; they are merely so dominated by induced qualities that errors may be made concerning them, just as it so happens that men are deceived by salt, *qalqand*, sal ammoniac, etc. [Avicenna; 1027, Alfred of Sareshel: c1200. In: Linden: 2003]

“I do not deny that such a degree of accuracy may be reached as to deceive even the shrewdest, but the possibility of eliminating or imparting the specific difference has never been clear to me. On the contrary, I regard it as impossible, since there is no way of splitting up one combination into another. Those properties which are perceived by the senses are probably not the differences which separate the metals into species, but rather accidents or consequences, the specific differences being unknown. And if a thing is unknown, how is it possible for anyone to endeavour to produce or destroy it?” [Avicenna; 1027, Alfred of Sareshel: c1200. In: Linden: 2003]

In Avicenna’s view, therefore, transmutation is not possible. The underlying qualities of a substance (as opposed to its accidents, such as malleability, colour, etc.) are simply not known, not available to human senses. It is not possible to manipulate what cannot be known. Even if this was feasible, the imposition of a substantial form is the work of the Creator, or *dator formarum*, (proxies of divine will) not human beings [Newman: 2004].

Avicenna’s argument that it is not possible to manipulate what one doesn’t know sounds a little weak. Artisans are surely able to manipulate to a degree, even without theoretical understanding. (His argument is later rebutted by Paul of Taranto (Chapter 2.6.1)).

---

[5] Aristotle, *De physico auditu*, in *Aristotelis opera cum Averrois commentariis, Vol. IV* (Venice, 1562), fol. 78r, col. 2: "*Et omnino ars alia quidem perficit que natura non potest efficere, alia vero imitatur."* [Newman 1989].

Defence of Alchemy

Paul's *Theorica et practica* is a didactic work covering both the theoretical and practical aspects of alchemy and a defence of the practice [Newman 1989]. It also attempts to negate the *Sciant artifices* of pseudo-Aristotle and justify alchemical efforts to manipulate nature "the genuine physician, horticulturist or alchemist can produce real changes in essence and substance, because he manipulates the first qualities of matter" [Newman 1989,p 434].

As Newman describes, Paul believes that the primary qualities can be manipulated by competent alchemists who understand the theory; mere artisans can only manipulate secondary qualities. Paul goes rather far and claims that "anything short of the animated and the soul itself can be made naturally from anything else"; powers are only limited by the human inability to infuse another soul [Newman 1989, p437]. He attempts to explain the nature of the metallic principles, sulphur and mercury in terms of the four primary qualities, hot, cold, dry and wet. "By arriving at the composition of sulfur and mercury in terms of the four qualities, then showing how the two principles can be manipulated to form the six known metals, Paul is able to satisfy Avicenna's objection that the alchemist cannot manipulate that which he cannot recognise" [*ibid.* p436]. He uses experimental demonstrations underpinned by the theoretical framework of Aristotle's *De Generatione et corruptione* and *Meteorologica IV.* The ability to manipulate primary qualities directly "is precisely what distinguishes alchemists and physicians on the one hand from simple artisans on the other." The latter are craftsmen with technical skills, but they do not attempt to understand theory. Here Paul differentiates between the 'scientist' who derives his skill from a knowledge of the Aristotelian qualities, and the artisan who works without the benefit of knowledge of causes [*ibid*].

Albertus Magnus

In around 1250, Albertus Magnus (c. 1193-1280) wrote a comprehensive review of mineralogy as part of a larger study of natural science. Newman informs us that Albertus concentrated on Avicenna's *Liber de congelatione,* there being a dearth of Aristotelian texts on the subject. [Newman: 1989, p431]. He attacks those who proposed that all metals share one form, that of gold, in varying degrees of completion [*ibid*]. By observation, metals seem to be stable and under normal circumstances do not turn into other metals. Therefore they must have their own substantial form. Each metal has its own particular set of properties;

their accidents are not common. Therefore, the substances and specific form (species) of different metals must be different [*ibid*].

Despite this, Albertus believes, in contrast to Avicenna, that transmutation is possible, as one specific form can be destroyed and replaced by another. His argument relies on a distortion of Avicenna's use of the term 'species'. According to Newman, Albertus uses it not as Avicenna did, meaning a logical entity. Avicenna did not suggest species inhering in matter as in hylomorphism. Instead he meant species as abstract categories that existed in the mind of the Creator. Using this interpretation, Albertus is comfortable that alchemists can process the metals in order to purify them, much as physicians attempt with their patients. The alchemist then strengthens "elemental and celestial powers" in the metal's substance. "As a result the purged metal having a new and better specific form, conferred by the celestial virtues of the stars. Hence, he has not transmuted species as such; he has only removed one specific form and prepared the way for another to be received" [Newman: 1989, p431].

Roger Bacon

Newman asserts that, in his *Opus tertium* (1266) Roger Bacon (1220-1292) a Franciscan friar and alchemist, proposed that alchemy should be utilised as the primary means of reforming Scholastic natural philosophy. Alchemy could teach the generation of minerals, pigments, precious stones, and humours from the elements, subjects not covered by Aristotelian sources. Whilst Albertus saw alchemy as a practical art, Roger thought of it as the basis of all medical and natural knowledge – a far more ambitious stance. His views had changed from his support of the supposedly Aristotelian view (as given in the *sciant artifices)* that the species cannot be transmuted. Having become aware that the *sciant artifices* was not attributable to Aristotle but only a commentary by Alfred of Sareshel, he found it much easier to dismiss. He states, quite straightforwardly, that the proposition "species cannot be transmuted" is not true [Newman: 1989, pp432-433].

2.6.2 *Theological Influences*

Thomas Aquinas

In his observations on Thomas (1225-1274), Newman suggests that he is more interested in the theological aspects of transmutation than the matter theory, but his deliberations on the subject have consequences when later theologians use them to bolster their own claims. In his commentaries, Thomas asks "whether demons can induce a true corporeal effect into corporate matter" [Newman: 1989, p438]. He gives five authorities who deny such power. The last of these refer to the *Sciant artifices:* "Demons cannot work except through the method of art. But art cannot give a substantial form, whence it is said in the chapter on minerals that the authors of alchemy should know that species cannot be transformed. Therefore, neither can demons induce substantial forms" [Newman: 1989, p438]. Legitimate art, such as lighting a fire, involves merely joining passive natural products to active natural products; in a like manner, demons can only apply natural agents to natural patients [Newman: 1989 p438]. These deliberations would be used in later treatises, not necessarily as their author intended, by such influential Dominicans as Eymerich (1316-1399) in the censorship against magic and demonic forces. This would ultimately have an impact on the perception of alchemy as a legitimate operative art [*ibid*].

Newman explains Thomas's stance. In Thomas's commentaries on Book 2 of the *Sentences* by Peter Lombard he remarks: "Art by its own power cannot confer a substantial form, but it can do this by means of a natural agent, as is clear in the following [*hoc*] that the form of fire is produced in logs through art. There are some substantial forms, however, which art cannot induce by any means, since it cannot find the proper active and passive subjects… not true gold, since the substantial form of the gold is not [induced] by the heat of the fire- which the alchemist uses- but by the heat of the sun in a determinate place where the mineral power flourishes. Hence such [alchemical] gold does not operate according to the species [of real gold] and the same is true for the other things that they [alchemists] make" [Newman: 1989 p438]. Hence gold must be produced deep within the earth, where the mineral power or *vitus* is subject to special strengthening. [*ibid*]. Newman continues Thomas's description:

Therefore anything else they may make is also deficient with respect to their natural counterparts. Any artificially generated substance is 'fake'. A form of this argument had been rebutted by the *Book of Hermes*, written around the first half of the thirteenth-century. This book included a defence of alchemy and refutation of Avicenna's assertion that species cannot be transmuted, and also disproving the requirement of a special *virtus loci*, (a power linked to a special place). This work was probably unknown to Roger or Albertus [*ibid* p430].

Giles of Rome

Newman elaborates how Giles (1247-1316) utilises the Thomistic position, the *Sciant artifices* comment to make an attack, but the focus is on theology rather than natural philosophy. Newman (1989) notes that in his *Quodlibeta,* Giles poses two questions: Firstly, he asks whether gold can be made by art, and assuming that it could, would it be legal to sell it? [Newman: 1989, p439]. He argues that natural things are superior to artificial, and invokes the *virtus loci* argument. This the premise that most things need a specific space for generation; for example, "wine is produced only in the depth of the grape (*in ventre vitis*)" and it is "also believable that metals must be generated deep within the earth" [*ibid* p439]. The second question seems purposeless as Giles does not accept that gold can be produced artificially. But he determines to take it further. Even if such alchemical gold could be produced, and complied to the assayers' standards for true gold, "it would still not be legal tender since it would not have the medical properties of true gold" [*ibid* p439]. Giles cannot accept that natural gold and artificial gold could ever be considered equal, specific weight, colour, malleability etc. notwithstanding.

Hostility Increases – Dominican Condemnations

The last three decades of the thirteenth century witnessed an increasingly hostile attitude toward alchemy [Newman: 2004]. Newman observes that the Dominicans alone propounded condemnations of alchemy in 1272, 1287, 1289, and 1323, plus there was a Papal Bull in 1317; this last was aimed more at counterfeiters, alchemical or otherwise. There was little theoretical justification given. [Newman: 1989, p440]. The Dominican friar and Inquisitor General of Aragon, Nicholas Eymerich published the *Contra alchymistas* (1396) a tract denouncing alchemy. He was also responsible for perhaps the most influential medieval inquisitorial handbook *Directorium inquisitorum* (1376) [Tarrant: 2018, p222].

Tarrant describes how Eymerich developed cogent arguments for the investigation and prosecution of alchemists, arguing that their practices were heretical [Tarrant: 2018, p222]. Members of the Dominican Order held varying views on alchemy, coalescing into two main groups, both based on the writings of Aquinas, whose deliberations on alchemy was for primarily theological purposes, to determine the limits of the power of demons. The first group, and arguably closest to Aquinas' own belief, was that alchemy, which used natural processes to achieve its goal, posed no threat to Christian orthodoxy [*ibid*, p212].

The second group, fostered by Eymerich and based on selective readings of Aquinas and Augustine, presented alchemy in a detrimental light. These cherry-picked statements were manipulated to give the impression that that his own conclusions were supported by these two authoritative figures. His objective was to define the extent of authority of inquisitors' authority to investigate magic and divination [*ibid*, p212]. These limits were set wide. He wanted to defend the inquisitors' right to prosecute forms of magic that included a ritual element, because these cases may involve invoking demonic powers. Augustine and Aquinas had concluded that the invocation of demons was the offence of superstition, not of heresy. [*ibid*, p223]. Arts which operated through natural means were acceptable. Eymerich's misrepresented the Augustinian and Thomist view to reach the conclusion that magical offences which included the invocation of demons should be considered a heresy, rather than the lesser offence of superstition. In this he provided a clear rationale for the prosecution of alchemists as heretics [*ibid*, p223].

Fifteenth and Sixteenth Centuries - Observant Reform

The Observant Reform movement, as described by Tarrant (2018), began in the fifteenth-century, aiming at revitalising and reorganising religious houses to effect a spiritual regeneration for friars and the wider Christian community. Motivation to prosecute the practice of magic in the general population as well as friars was stimulated by stories of Satanic worship in the Alpine areas [Tarrant: 2018, p225]. This interest was fuelled by a publication *Formicarius* (c.1348) by Johannes Nider, (1380-1438), himself a Dominican Observant, who played a significant role in incorporating his beliefs on magic and witchcraft into the Dominican exegesis [*ibid* p225]. Like Eymerich, he studied Augustine and Aquinas and put his own gloss on their work. He focussed on the risks of superstition, idolatry and divination, pointing out the risks of entering into pacts with the devil, though unlike astrology, alchemy had rarely been considered a superstitious art [*ibid* p213].

Nider did accept the Thomist view that demons could only work by means of art. He also accepted his view of the possible existence of seeds, hidden in the natural world (but possibly accessible to demons) [Tarrant: 2018]. This would allow for prospect of genuine transmutation of metals, which Aquinas had previously implied was impossible due to the impossibility of changing a substantial form by art [*ibid* pp 217,226] (Chapter 2.6.2). Nider's inventive approach informed the *Malleus maleficarum*, written by Observant Dominican friars Henricus Institoris (c. 1430-1505) and Jacobus Sprenger (c. 1437-1495) [*ibid*, p226]. This was an instruction manual for the prosecution of magic. It was principally aimed at witchcraft, but the possibility of alchemical transmutation was raised. Like Nider, they looked to Aquinas for support of their views, and drew, selectively, on his *Summa theologica* [*ibid* p226].

The Roman Inquisition of the sixteenth century.

Tarrant describes how the Roman Inquisition, established in 1542, was largely driven by Cardinal Gian Pietro Carafa (1476-1559) to combat Protestant ideas from Italy [Tarrant: 2018, p227]. Rather than witch-hunting, they focussed on ritual magic and operative arts. "Alchemy attracted little attention. It was not condemned in either the *Index of Forbidden Books* promulgated in 1559 by the Inquisition or the version produced by Council of Trent in 1564" "The situation began to change in 1578 when Francisco Peña (ca. 1540-1612) published a new version of Eymerich's *Directorium inquisitorum,* along with an accompanying commentary" [*ibid*, p228]. He agreed with Aquinas that any natural magic was acceptable, but cautioned against that such interest might lead to demonic magic. "The act of invoking demons to produce wonderous effects was indeed heresy" [*ibid* p229]. He says that although it was not possible to be certain of the validity of alchemists' claims, their truth was not probable. Practicing alchemy was likely to lead to impoverishment, summoning the devil, or producing counterfeit coin. Peña invoked Pope John XXII's authority for his argument that alchemists "who practised chrysopoeia should not only be considered frauds but potentially heretics" [ibid, p 230]. The Pope confirmed that chrysopoeia was not naturally possible. The situation was not clear cut, however, and the inquisitors investigating alchemy in the late sixteenth-century had a complex set of criteria to interpret [*ibid* p231]. One would imagine that this must have been an uneasy situation for the practising alchemists.

Polemical Attacks on Alchemy

The explanations for alchemy's general disapprobation are several. Some alchemists were wont to claim considerable power to themselves; such arrogance might have resulted in dislike or even fear. There was a perceived risk that alchemists (poor ones at any rate; the rich would not be under the same pressures) might be tempted to invoke Satan to assist in their failed endeavours. Then they might well be driven to produce counterfeit coin which could seriously impact commerce and the *res publica*. The alchemist could be accused of un-Christian activities. In Oldrado's *Consilium* he quotes from the *Canon Episcopi* "whoever believes that anything created can be either mutated or transferred into another species or into another similitude, except by the Creator himself, is an infidel, and worse than a pagan." [Newman: 1989 p440]. Similarly, in the *Sciant artifices,* it is explicitly stated that only God himself can transmute species, and that anyone who believes otherwise is not a Christian [*ibid*]. The conclusions (though not universal) were that transmutation was (very probably) impossible; if it was possible it was very improbable, and if it was found to work, the gold acquired was not true gold, with all the attributes (for example medical) of genuine gold. Alchemists who failed in their quest were likely to end up impoverished, as criminals debasing the coin, or accused of heterodox activities.

2.7 Natural Philosophy at the Universities

The teaching at the European universities during the Early Modern period varied considerably from country to country. Brockliss' (1996) study of the early modern universities gives valuable insights into the curricula and progress of the teaching of the new philosophy. In the late Middle Ages, a course in philosophy was divided into four separate science: logic, ethics, metaphysics and physics [Brockliss: 1996]. Ethics included politics and economics, while included in metaphysics was natural theology; physics included all of the natural sciences. Each part of the course was drawn from the Aristotelian corpus, except for logic, for which the *Summulae* of Peter of Spain was the standard introductory text. The Aristotelian texts offered an inexhaustible supply of *quaestiones* for exploration and debate. At the beginning of the sixteenth-century, the late medieval curriculum came under attack. The dominance of Aristotle over the other classical philosopher, especially Plato, was criticised by the Renaissance humanists, some of whom demanded introduction of Neoplatonic texts in to the courses [*ibid* pp578-579]. The reformers' success was only partial. "Throughout the sixteenth and the first half of the seventeenth centuries the course remained Aristotelian and maintained the same quadripartite system" [*ibid* p579].

Two distinct models of Aristotelianism developed, one associated with Italian universities such as the University of Padua, the other with the University of Paris. The Parisian model became predominant through northern Europe. Its supporters believed their primary task was to analyse Aristotle's texts in a spirit of criticism [*ibid* p580-581].

Peter Ramus (1515-72) at the University of Paris, was "one of the most influential and controversial critics of Aristotelian philosophy of the pre-Baconian era. His importance lay in his revolutionary approach to the study of logic, where he rejected the late medieval (and Aristotelian) belief that logic was a science concerned with the rules of right reasoning and instead that it was merely the practical art of locating and marshalling evidence" [Brockliss: 1996, p581]. He concentrated on developing a dialectic process which could be used as a tool in either the investigation or transmission of knowledge. Ramus's *Dialectique* was used extensively in the Protestant universities.

By the third quarter of the seventeenth century many Parisians, though true Aristotelians dedicated to a qualitative explanation of natural phenomena based on the belief in the existence of substantial forms, were assimilating aspects of the new work being done in physics, including dynamics and pneumatics, astronomy and physiology, but this development was only loosely attached to the university world. [Brockliss: 1996, pp582-3]. Aristotelian matter theory came to be challenged by the mechanical philosophy, a new explanatory strategy for explaining natural phenomena. "Among the first generation of seventeenth-century philosophers to claim that natural phenomena could be explained more successfully in terms of matter and motion alone, only the Epicurean atomist, Pierre Gassendi (1592-1655) professor of philosophy at Aix-en-Provence 1616-24, held a university post" [*ibid* p583].

Rise of the Mechanical Philosophies

Brockliss describes how the mechanical philosophy came to be taught in the universities, slowly supplanting Aristotelianism. The sixteenth century had seen the promotion of Platonic and Hermetic philosophies, but this had been relatively short-lived. Conversely, the mechanical philosophy, attracted support from the majority of contemporary experimental philosophers. In Protestant countries the transformation began about 1650 in the economically more prosperous parts of the Continent. The mechanical philosophy was being taught at Cambridge, Leiden, Herborn and Geneva in the 1650s and 1660s but not until the end of the century in the Calvinist areas of Hungary [Brockliss: 1996, pp584-585]. In the predominantly Catholic countries, the conversion generally began considerable later. Louvain accepted in the late seventeenth-century, Paris and Padua in around 1700 and Spain after 1750 [*ibid*, p584].

Christian theologians, Protestant and Catholic alike, Brockliss explains, were hostile to a mechanical philosophy which seemed to "reduce God to a prime mover, destroyed the concept of the hierarchical 'great chain of being,' and, with the adoption of Copernican heliocentrism, no longer placed man at the centre of the universe" [*ibid*, p584]. The Catholic Church had the influence, mainly by utilising the Society of Jesus, to resist the replacement of Aristotelianism by the mechanical philosophy [*ibid*, p584]. Despite such resistance, on mainland Europe Aristotelianism gave way to the Cartesian form of the mechanical philosophy, initially based on Descartes' *Principia philosophiae* (1644), which included the assertion that perfect knowledge of truth was possible, that mind and matter, though connected, were essentially different, and that the universe was a plenum; a vacuum was an impossibility [*ibid,* p585]. Variations were introduced, based on other Cartesian or neo-Cartesian philosophers [*ibid* p585]. An important mediator between various factions was Nicholas Malebranche (1638-1715). In Lutheran northern Europe the situation was different, being largely under the influence of Christian Wolff (1679-1754) professor at Halle and Marburg. His teachings, although based on Descartes', also drew substantially on Aristotle [*ibid* p585].

In the British Isles Cartesian gained only moderate support. The universities from the late seventeenth-century preferred the empirically-oriented vacuist mechanism of Gassendi (1592-1655) [*ibid* p585]. This was also discussed outside the university, especially though John Locke's (1632-1704) *Essay on Human Understanding* 1690 [*ibid* p585]. Newton's *Principia* (1687) gave mathematical support to the rejection of Descartes' plenum. Brockliss notes that Newton's work was not fully appreciated on the Continent and was viewed as anachronistically Aristotelian. The perception was that Newton's cosmology required occult forces to explain attractive forces between bodies. Alternatively, it would require the phenomenon of a perpetual miracle. For almost fifty years the Gassendi-Newtonian form of the mechanical philosophy was rejected. By 1740 however, a growing proportion of the Continental scientific community came to recognise the superiority of Newtonian physics. The demise of the Society of Jesus in the 1760s-1770s was a factor in liberating the universities from the Aristotelian stranglehold, allowing the mechanical philosophy to be taught and debated without restraint [*ibid p*586].

It can be seen that the conservation from Aristotelianism to the mechanical philosophy was by no means uniform or rapid. Nevertheless, the inexorable transformation, beginning around 1650, led to a general acceptance of the new philosophy although it took over a century to achieve. Resistance came from various quarters, including censorship and prosecution by the Church authorities, plus inertia in the university education systems in embracing new concepts.

In the next section I consider specific Early Modern philosophers and their metaphysical hypotheses with respect to their epistemology and contribution to chymistry.

2.8 LATE MEDIEVAL /EARLY MODERN ALCHEMISTS

2.8.1 *Paracelsus*

A controversial figure, Aureolus Phillipus Theophrastus Bombastus von Hohenheim, is generally known as Paracelsus (1493-1541) was German-Swiss physician and alchemist. Oldroyd (1974) drawing upon Pagel's profound study of Paracelsus, describes his eclectic metaphysics. He emphasises the influence of "Jewish mysticism and cabalism, Neo-Platonism, pantheism, doctrines included the macrocosm and microcosm, naturalism and empiricism, astrology, humoralism, alchemy and magic, the doctrines of sympathies and correspondences, and Christian trinitarianism." [Oldroyd: 1974, p133]. He viewed matter as a kind of corporisation of spirit [*ibid*].

Paracelsus made important contributions to alchemy, perhaps the most important of which was the formation and application of medicaments from minerals and other chemicals. He wrote voluminously, expounding his revolutionary medical theories and cures. A contentious character, not afraid to articulate his views, he frequently came into conflict with the authorities, especially the medical establishment dominated by Galenism. The Galenic physicians and apothecaries favoured herbal remedies over mineral. His refusal to write in Latin (he wrote in his native German), his adoption of folk medicines and reliance on practical experience did nothing to endear him to the learned gentlemen of the universities. His metaphysics was informed by Neoplatonism, Biblical creation and magic. In the *Opus Paramirum* (1520), he expanded the sulphur–mercury dyad by adding a third principle, salt. He claimed that these "three first things" underpinned all matter [Rampling: 2019].

His two major works were the *Archidoxorum* (the *Archidoxis*) c.1525-7 consisting of nine books, and *De Natura Rerum* (*Of the Nature of Things* c.1527) [Partington: 1961, p125]. Much of his work was collected and published posthumously. *Of the Nature of Things*, includes chapters on generation, growth, life, death (or ruin), transmutation, separation, the Last Judgement, and the signatures of natural things [Linden: 2003].

Debus (1977) describes the reception of Paracelsian metaphysics in the seventeenth-century. Quoting Pagel on Paracelsus' philosophy he says "The distinguishing feature of Paracelsus's philosophy is the consequential view of cosmology, theology, natural philosophy in the light of analogies and correspondences between macrocosm and microcosm. Speculation about such analogies had seriously engaged the human mind since pre-Socratic and Platonic times, but Paracelsus was the first to apply such speculation to the understanding of Nature systematically" [Debus: 1977, pp52-53]; [Pagel:1969 p.50]. His ideas were outlined in the *Volumen medicinae paramirum* (ca.1520).[6]

Paracelsus considered chymistry to be the key to nature and to medicine. He vehemently rejected the ancient authorities – Aristotle, Galen and Avicenna – but accepted the four Aristotelian elements. He added his own peculiar twist, identifying Fire with heaven. He introduced an additional system to the four elements, adding salt to the sulphur-mercury theory to give the *tria prima*. The Paracelsian principles could not be isolated but it was possible to recognise their existence. He does this by burning a twig. The vaporous fumes indicate mercury, the flame sulphur, and the resulting ashes, salt. Paracelsus insisted also that the principles differed from one substance to another, negating their value for analysis. [Debus: 1977, p57]

His texts were problematical due to inconsistencies and incoherence. Elementary substances were described on two levels, of body and of soul. The four elements might be described in one text as being on the highest level, as imperceptible elements or matrices, while in another they may be referred to as perceptible substances. The same confusion obtains in his discussions of the principles. Although he might mean salt, sulphur and mercury as sensible agents, this was not always clear. "...The relationship of the two elemental systems was difficult to understand; indeed, it was even possible to cite contradictory passages from within the Paracelsian corpus" [*ibid,* p58].

In medicine, Paracelsus rejected outright the Galenic theory of humours, in which disease was usually attributed to the "imbalance of blood, phlegm, yellow and black bile" [Debus: 1977, p58]. Restoring the balance would re-establish health [*ibid*]. Paracelsus's theory was entirely different. His emphasis was on local manifestations in the body which he believed were due to external causes and sought to relate specific diseases to specific agents. He replaced the alchymists' focus on transmutation to that of chymically prepared medicines. This was a lasting legacy. Folk traditions were to be respected; in the case of poisons, he supported the 'cure by similitude' rejecting the Galenic system which, in direct opposition,

[6] "All that you should know exists in man and realise that the firmament is within man, the firmament with its great movements of bodily planets and stars which result in exaltations, conjunctions, oppositions and the like, as you call these phenomenon as you understand them. Everything which astronomical theory has searched deeply and gravely by aspects, astronomical tables and so forth, - this self-same knowledge should be a lesson and teaching to you concerning the bodily firmament. For, none among you who is devoid of astronomical knowledge may be filled with medical knowledge…" [Debus: 1977, p53].

upheld cure by contraries [*ibid*, p59]. Although the Paracelsian remedies were based on distillation products of earlier medieval traditions, he also advocated the use of mercury, antimony and iron salts. This was the cause of much controversy, and very likely many adverse outcomes.

Subterranean Maturation of metals

Rees (1996) elucidates Paracelsus' explanation of intangible principles sulphur, salt, and mercury, (the *tria prima*) as active spiritual forces in nature which gave bodies their specific attributes: "The principle sulphur bestowed oiliness, inflammability, viscosity, and structure on individual existents; mercury conferred wateriness, 'spirit,' vapor, and vivifying powers; from the saline principle bodies received their rigidity, solidity, dryness, and earthiness. To a greater or lesser extent, all three principles entered into the particular constitution of every natural thing - including natural sulphur, mercury, and salt" [Rees: 1996, p128]. This applied to all natural bodies, including natural sulphur, mercury and salt. In addition to the tria prima was his concept of the four elements. Rees notes that Paracelsus was inconsistent in his descriptions of the element "but his followers generally saw them not as simple bodies possessing fixed combinations of qualities but as matrices which generated groups of objects each specific to its source. These matrices were composite bodies devoid of qualities; they were 'receptacles' in which objects were generated and dwelt. The matrices formed the environments in which the invisible seeds of physical bodies were hatched and endowed with their distinctive qualities by the three principles" [Rees: 1996, p128]. This contrasted with later concepts of matrices, for example, Le Fèvre says that the spirit is universal and imprinted with the character of the mixes (i.e. prime matter is informed) according to the matrices. These diverse matrices receive the spirit to make it a body. Thus, in a vitriolic matrix, it becomes a vitriol; in an arsenical, an arsenic. If it were a vegetable matrix it would become a plant, and so on (Chapter 5.3). Lémery also has a similar view: "The First *Principle* that can be admitted for the composition of Mixts, is an *Universal Spirit,* which being diffused through all the world, produces different things according to the different Matrixes, or Pores of the earth in which it settles" [Lémery: 1685 p3].

This theory was important in the discussions around the claims of artificial metals equivalency to natural; some maintained that the place in which they were developed was definitive. Alchemists aimed to speed up natural processes in the laboratory,

2.8.2 *Francis Bacon*

Sir Francis Bacon (1561-1626), Lord Verulam was famous for his innovations concerning the scientific method, including experimentation and eliminative induction (Chapter 3.2.2).

Bacon's semi-Paracelsian cosmology

Rees (1996) describes Bacon's natural philosophy as "a single philosophy with two aspects, or two philosophies each with its own character" [Rees: 1996, p122]. He describes these two aspects, one being a set of methodological recommendations with the object of establish a legitimate basis for science. These would supersede the sectarian, sterile bodies of knowledge which had obtained. The second Rees depicts as a complete but provisional system of speculative science, a system which affected all his writings. This eclectic system drew upon many natural philosophies and resulted in a theory of the universe modelled on the Mosaic cosmogonies of the Paracelsians combined with the ideas about celestial motion derived from Alpetragius (*Al-Biṭrūjī*). At its heart it owed much to the doctrines of the *tri prima* and Renaissance pneumatology [Rees: 1996]. Bacon's semi-Paracelsian philosophy is too complex to consider in detail here; his scientific method is discussed in Chapter 3.2.

Van Helmont's hylozoism

Jan Baptist van Helmont (1579-1644) Flemish physician, philosopher, and chymist was an influential figure in the transition of chymistry from the vitalism of the medievalists to a corpuscular viewpoint. Van Helmont's cosmology was highly influenced by Thales of Miletus, who believed water was the essence of all matter, and that the world was 'full of Gods.' Banchetti-Robino (2015) describes how Van Helmont claims to explain the phenomena of nature using this ontology which combines atomism with vitalism.

(Van) "Helmont's chemical interpretation of spirit and ferment is central to his hybrid ontology, which combines atomism with vitalism by embracing both the notions of corpuscular minima naturalia and of non-corporeal semina rerum, understood as the formative principles from which all bodies originate. For Helmont, although minima are physical units with mechanical properties, they nevertheless also have 'qualitative' determinations that are accounted for via the semina. Seminal principles work in tandem with ferments to bring about substantial changes in nature by providing the spiritual force of action that causes chemical alterations" [Banchetti-Robino: 2015].

2.8.3 ***Robert Boyle***

Boyle coined the term ‘mechanical hypothesis’ and his *Skeptical Chemist* was a concerted attack on Aristotelianism. He is rightly renowned as an experimental philosopher and supporter of the Baconian method of natural history. In *the Origin of Forms and Qualities* [Boyle: 1666], Boyle used corpuscularianism for explanations of much of the phenomena of nature and his hypothesis and experimentalism were extremely influential in the seventeenth-century. Less well known are his alchemical pursuits. His corpuscularian hypothesis was compatible with transmutation; he believed he had witnessed the transmutation of gold into silver (Chapter 6.2). He was disinterested in any potential monetary gain from alchemy; the acquisition of knowledge was of greater import.

2.9 METHODOLOGICAL NATURALISM

The Supernatural and the Occult

That which is hidden or occult is different from that supernatural. Change of word meaning over the centuries sometimes leads to conflation of terms.

Occult is the opposite of manifest. For example, the magnetic effects of the loadstone are occult, but this just means that the cause is not known. As Hutchison (1982) puts it,

“Augustine cited the occultissimi characteristics of quicklime, characteristics that cannot be directly sensed yet can be "experienced" (*sed compertus experimento*) in the sense that they have sensible effects, as a parallel in the material world to the miracles of Christian tradition. Hence he implied that the behaviour of quicklime, which grows hot when mixed with the cold element water, yet remains cool when mixed with inflammable oil, is beyond man's understanding.” [Hutchison: 1982, p238]. In the case of gravity, its manifestation was clearly recognised, but there were disputes over its intelligibility.

Naturalism means that there is no recourse to the supernatural for accounts of causes. There was a distinction between occult and manifest qualities. Hutchison explains the difficulty the medievals, as Aristotelians, had in accepting the intelligibility of the insensible. [*ibid*, p238] “When an object became known….. it was known through its sense image. As it was sensed, its manifest qualities entered the imagination without the matter composing the object, and the modus operandi of the human intellect was the sifting of these form to abstract the universal and essential forms from the accidental and singular. That process could not occur in the absence of a sense image, and therefore an occult quality was *a fortiori* outside the scope of the human intellect" [Hutchison: 1982, p238].

At the beginning of the seventeenth century, the natural world of the philosopher and of the majority of the population was imbued with vital spirits. Belief in God was almost ubiquitous; punishment for heresy was severe. From a belief in good and evil, angels and demons, it is but a small step to belief in witchcraft, goblins and assorted malicious sprites. The influence of the stars on human affairs was part of the cosmogony prevalent. Agricola certainly believed in goblins; Boyle accepted that there were witches. But as we move through the century a separation of religious beliefs and scientific theory becomes apparent. No longer are astral emanations an acceptable account of phenomena. The change is slow and patchy but nonetheless evident. Boyle, for example, an exceedingly devout Christian, is committed to explaining natural phenomena in mechanistic terms. This in no way compromises his religious beliefs.

The concept of understanding Nature without recourse to the supernatural was already established in the Early Modern period. Although church teachings accepted the possibility of divine intervention, certain philosopher-theologians of the Middle Ages demanded that the study of nature required natural, not supernatural, explanations. These included the fourteenth century cleric Jean Buridan (1300-c.1358) of the University of Paris, and the natural philosopher Nicole Oresme (1325-1382), who was elected the Roman Catholic bishop of Lisieux in 1377. Oresme, an impressive polymath, "was a determined opponent of astrology, which he attacked on religious and scientific grounds" [Kirschner:2017] and claims its refutal in his *Ad pauca respicientes*. He vigorously opposed the "widespread belief in occult and 'marvellous' phenomena, explaining them in terms of natural causes" in *Le livre de divinacions* (*Book of Divinations*) [*ibid*]. He did not deny divine intervention, but his *De causis mirabilium* was a much wider attack on credulity, addressing not only the common people but theologians, urging them to 'believe rarely' [Kirschner: 2017].

Zupko (2018) describes Buridan as perhaps the most influential Parisian philosopher of the fourteenth century. "John Buridan did much to shape the way philosophy was done not only during his own lifetime, but throughout the later scholastic and early modern periods… His most highly acclaimed work was the *Summulae de dialectica* (*Compendium of Dialectic*), a treatise on logic" [Zupko: 2018]. He also helped towards the demise of Aristotelianism though his development of the theory of impetus, or impressed force, to explain projectile motion, rejecting the Aristotelian concept of antiperistasis, in which a projectile continues to move due to a proximate but external moving cause, such as the air surrounding it [Zupko: 2018].

2.10 Adherence to Methodological Naturalism

Boyle was a dedicated advocate of the corpuscular hypothesis. He wrote extensively on the qualities of bodies. His research and experiments were wide-ranging and generally carefully considered; just a few will be mentioned here. His theory of qualities and forms challenged the prevailing scholastic conception of substantial forms, the elimination of which was crucial to his hypothesis. As the mechanical hypothesis attempts to explicate all natural phenomena by means of the two main principles of matter and motion, accounting for the qualities of bodies was clearly imperative [Boyle 1974]. In *The Origin of Forms and Qualities*, [Boyle:1666. In: Hunter & Davis: 1999 vol. 5] he states that he has refrained from employing certain arguments.

"….I have forborne to employ arguments that are either grounded on, or suppose, individual corpuscles called atoms, or any innate motion belonging to them; or that the essence of bodies consists in extension; or that a vacuum is impossible; or that there are *globuli caelestes,* or such a *materia subtilis,* as the Cartesians employ to explicate most of the phenomena of nature" [Boyle: 1666].

It is noteworthy that Boyle was wont to give credence to evidence from authoritative sources. Boyle was a devout Christian and although he did not want to call upon supernatural powers to explain natural phenomena, he did believe in miracles. Whilst accepting that the age of miracles was past, he did insist on their veracity [Deming: 2016 p102]. Boyle made a theological distinction between things that are above reason and things that are against reason.

2.10.1 *Boyle and the Occult*

Boyle assumes that there is "no ultimate distinction between the occult and the seemingly manifest qualities" [Hutchison: 1982].

Anstey [2000] writes that there were four components of occult powers, as understood in the early seventeenth century. Firstly, they were insensible, or hidden. Secondly, they were unintelligible (because they cannot be explicated in terms of the four elements or prime qualities). Thirdly, some occult qualities are considered to be real, where 'real ' in this context means (roughly) qualities that can exist independently of the substance in which they inhere. Fourthly, occult qualities are thought to be powers. An example is the loadstone, the effects of which are said to arise from an insensible cause; this cause brings about observable effects. Boyle accepts that occult qualities are hidden. Anstey suggests that Boyle has two strategies that allow him to include the occult in his philosophy. These strategies are essential because the hidden aspect of occult qualities does not fit comfortably with the corpuscular hypothesis. The first rests upon the Baconian idea of the scale of causes. Such phenomena as magnetism and electricity can be seen and even manipulated, but the cause is unknown, hidden. Boyle uses Baconian Inductivism to infer that as known causes are mechanical, then all the levels below this on the scale of causes must also be mechanical. This, known as the problem of transdiction, is something of a leap, and its epistemic justification is questionable. Anstey (2000) describes Boyle's thinking: “all intermediate causes to which we have epistemic access at various levels on the causal scale are mechanical in nature; therefore we can infer that all causes will be mechanical in nature” [Anstey: 2000]. Boyle does not consider matter to be inert, but its qualities are not power-like. For Boyle, all occult qualities can be explained in mechanical terms. Boyle hoped to explain everything in terms of matter and motion, and in the process to remove forms and occult qualities from the equation. He states that if it were true that all the forms of various bodies were just the result of their determinate figure, motion and connection, and suchlike mechanical affections of their component corpuscles, it would follow that since the occult qualities of bodies flow from their forms, they in like manner could be deduced from the same principles. If this were so, they would no longer be occult qualities.

In his papers such as ‘*Essays of Effluviums, Experiments and Considerations about the Porosity of Bodies, An Essay of the Great Effects of Even Languid and Unheeded Motion and Suspicions about some Hidden Qualities of the Air’*, Boyle shows his intention to explain all material entities by the mechanical philosophy, whether ‘occult’ and therefore hidden, or manifest. He describes occult qualities as natural phenomena which can be explained by the corpuscular hypothesis. Indeed, he considers “these three doctrines of effluvia, of pores and figures, and of unheeded motion, as ~~has~~ the principal keys to the philosophy of occult qualities” [Boyle: 1673; Anstey: 2000].

2.11 SUMMARY

Aristotelianism in the Medieval period was known only though a limited number of texts; similarly, little was known of Plato. Alchemy, developed in Islamic lands, travelled to the Latin West in the twelfth century, in the form of books and treatises translated from the Arabic into Latin. The bulk of the Greek philosophical corpus was translated in the twelfth and thirteenth centuries. Aristotle's writings and concomitant exegeses formed a central, indeed dominant, role in the comprehension of the natural world. His theory of hylomorphism was fundamental to understanding change, and was the guiding light in chymical change. This system was considered entirely compatible with alchemical transmutation of metals. The revival of Neoplatonism in the Renaissance brought back into focus the vitalist philosophy, with its World Soul, hylozoism and the great chain of being. Although the Greek texts had become available in the Medieval period, they were, unsurprisingly, not accepted without challenge. In particular, some of Aristotle's pronouncements (for example those concerning the soul and the eternity of the world) conflicted with Catholic dogma. However, after St. Thomas Aquinas had synthesised Aristotelianism with the Bible, Aristotelianism became part of a new orthodoxy (Chapter 3). Once this integration had been achieved, challenges to orthodox views could be hazardous. Nevertheless, the availability of the new texts, sometimes of illicit status, stimulated lively debate. The specifically alchemical texts reached the Latin West in the twelfth century; these too inspired debate. Major issues included the artificial versus natural substances conflict, the feasibility of transmutation and the possibility of manipulation of species-determining characteristics, which, subsisting below the level of sense, cannot be known.

Islamic material included texts from such intellectually important personages as the Peripatetic al-Farabi, and Avicenna, whose intellectual output included interpretation of Aristotle's *Posterior Analytics*, works on logic and principles of knowledge. Averroës, known as 'The Commentator' was a proponent of Aristotle, arguing against Neoplatonism.

Debates, theological and secular, continued from the thirteenth-century, sometimes focussing on the scientific rationale on which alchemy rested, at other times suggesting that alchemical practices might lead to unorthodox activities. Natural magic, causing wondrous effects by manipulating nature, was acceptable. The invocation of demons was not. Many of the anti-alchemical arguments were aimed at stamping out witchcraft. But another important reason was the fear that alchemists might upset the economic balance if they were successful in their aims to transmute gold, or producing counterfeit coin if they were not - with the same damaging effects to the *res publica.*

The development of chymistry was a long and arduous journey. It was not until the last quarter of the seventeenth century that it was taught as a distinct discipline. Alchemists were variously esteemed as those with the key to nature, disregarded as mere artisans or vilified as frauds. Through time we move through Aristotelianism, Neoplatonism, hylozoism, blends of hylomorphism with corpuscular theories and quasi-atomic theories. Along the way are partisans, variously supporting transmutation, Galenism, Church dogma, and religious houses. The Early Modern alchemists gained from this diverse and complex heritage. Clearly there were authorities. Clearly there were challenges. It seems evident that there were debates amongst highly educated men – theologians, scholars, academicians, practicing alchemists, metallurgists and mineralogists. Change was not uniform, with long periods of relative stability prior to the Middle Ages. The influx of Greek texts in the twelve and thirteen centuries were crucial in the dissemination of intellectually valuable material, a powerful impetus promoting debates and critical assessments. Not to be ignored, though, is the foundational work of people such as Agricola, Libavius, initiating the textbook tradition, gathering data, and the dramatic (and sometimes dangerous) innovations of Paracelsus. Textbooks not only made information available to a wider audience than ever before, but helped ensure the transmission of data through the generations; secrets and techniques passed from master craftsman to apprentice, parent to child, were less likely to be lost. And each generation had the benefit of previous generations on which to build both their understanding of the natural world (and adding new knowledge) and its manipulation.

A change can be seen across the century, which begins with vitalist cosmogonies and generally accepted supernaturalism; but vitalism becomes less prominent by the century's close. Aristotelianism is increasingly under attack. Despite the incoherence of some hypotheses, contradictions and ambiguities, speculations and superstitions, these diverse elements coalesced, forming a more rigorous, reliable discipline as proto-chemistry.

3 CORE REQUISITES FOR SCIENCE

3.1 INTRODUCTION

In this and the following chapters I will be discussing the various elements that form a Wittgensteinian cluster, as outlined in Chapter 1, but in more detail. I will begin here with what might be considered the core requirements, viz, a cognitive toolkit comprising critical thinking, plus scepticism, values, paradigms, authorities (including challenges to authority) observation and cataloguing, experimentation, testability and reproducibly, and the Research Community. I will address specific examples of each, to show how they were applied.

3.2 CRITICAL THINKING

A tradition of critical thinking was already established in the Middle Ages. Exponents in the Renaissance included the influential Dutchman Erasmus (1466-1536) who corresponded with Agricola and Paracelsus, Sir Thomas More (1478-1535) and many other humanist scholars who considered such thinking a necessity across a wide range of disciplines, including education. Francis Bacon was also concerned with the lack of rigour in people's thinking. In *Of Proficience and Advancement of Learning, Divine and Human* (1605), he argued for the importance of empirical methods. In the *New Organon*, (1620) he pointed out the weaknesses in human understanding with his well-known *Idols.*

That which I have designated a cognitive toolkit consists of a bundle of components which includes critical thinking, syllogism, hypothetico-deductive method, and abductive reasoning, or inference to the best explanation (IBE) and their application by the Early Moderns. Additionally, an ability to recognise patterns or possible regularities which promote the postulation of causal laws is of great advantage. Although the methodology was in place, it was by no means considered satisfactory by many of natural philosophers of the time. In this section I will consider the dissatisfaction with the Scholastic teachings, which was widespread, and illustrate the alternatives proposed by Bacon, who criticised the syllogism and promoted eliminative induction as a means of acquiring knowledge.

Duhem remarks "We also need a faculty that allows us to intuit the truth of the first principles or axioms that use *le bon sens"* [Duhem: 1914, 1954, Chp IV]. He classifies two types of very dissimilar minds. These he terms the 'deep' mind, and the 'ample' mind. To these two types (borrowed from Pascal) Duhem added a third [Ariew: 2014, p9]. The discovery of truth requires both reason and argument. "Logic, our ability to link propositions with one another, allows us to deduce one truth from another, but that ability, by itself, merely gets us back to first principles or axioms. We need also a faculty that allows us to intuit the truth of first principles or axioms, that is, *bon sens* (good sense). *Bon sens* is to '*esprit de finesse'* what pure logic is to '*esprit de géometrie*'. Moreover, *bon sens*, our faculty of recognising fundamental truth gets perfected by the practice of history."

"We need logic, the ability to systematize, but we also need intuition, the recognition of truth. When one of these is allowed to dominate, we get a science which is all intuition, all '*esprit de finesse*' but lacking logical coherence; or else we get a science which is all logic *esprit de géometrie'*, lacking *bon sens"* [Duhem: 1914, 1954, Chp IV]. Between the two extremes, one being predominately intuition and the other predominately logic, there lies an ideal science, one in which intuition and logic are tempered with *le bon sens* [Ariew: 2014, 2.3]. It does seem desirable for science to have an appropriate balance of the ability to conceptualise and reflect, and reason in a logical manner. Critical thinking must be an essential element of scientific practice.

3.2.1 *Syllogism*

Aristotelian syllogism from the *Prior Analytics* was taught as part of the university curriculum. At the universities of Cambridge and Oxford education was controlled by statute; Elizabethan Statues for Cambridge (1570) and the Laudian Code for Oxford (1636) respectively, both of which strongly supported the authority of Aristotelianism [Debus: 1977, p212]. Bacon, amongst others (such as Noah Biggs and Van Helmont) is known to have criticised this curriculum and indeed the very structure of deductive logic. Malherbe (1996) describes Aristotle's syllogism as "essentially a logic for deductive reasoning, which goes from the principles to the consequences, from the premises to the conclusions. And, of course, in this kind of reasoning, the truth of the conclusions is necessarily derived from the truth of the premises, so that knowledge will start with primary truths that are supposed to be necessary and universal, that is, essential" [Malherbe: 1996, p79]. Clearly the output of this process is heavily dependent upon the accuracy of the premises. The knowledge of the premises is gained via sense data. But these data may be inaccurate, and certainly cannot be considered reliable. The attempt, then, to deduce principles of nature using unreliable input seems doomed to failure. It scarcely seems reasonable to seek the deep understanding of nature by the application of a logical method where the data are contingent and particular - and not necessarily accurate.

Bacon describes the syllogism with some acerbity: “The one flies from the senses and particulars to the most general axioms, and from these principles, the truth of which it takes to be settled and immoveable, proceeds to judgment and to the discovery of middle axiom.” [Bacon: 1620: Aphorism XIX In: Jardine, Silverthorne: 2000]. He sees this system as haphazard, with discoveries achieved largely by happenstance; there is no structure or planning in it. The problem is made worse by the human propensity to leap to conclusions based on just a few facts, and on relying upon authorities such as Aristotle, or unreliable sources [Malherbe: 1996]. Bacon's work is known to have had considerable influence on Robert Boyle, Sir Isaac Newton and other important philosophers.

3.2.2 *Francis Bacon’s Experimental Method*

Bacon, highly dissatisfied with the current methods of attaining knowledge and understanding the works of nature which was to date based primarily on Aristotelianism, planned a complete overhaul of the system in place. This involved the discarding of much of the Scholastic teachings, replacing the outmoded system with his theory of eliminative induction. It was an ambitious plan, and he himself did not expect to see it completed in his lifetime, though he claimed that his system would be an effective means for the discovery of truths. His aversion to Aristotle, which he had expressed in his early criticism of the Cambridge university curriculum [Klein: 2012], solidified into a desire to transform the acquisition (and application) of knowledge onto a much more secure footing than he believed possible by Scholastic methods. For Bacon, the fruitfulness of a system was its goal, its purpose. His theme, therefore, was two-fold; the first, the *pars destruens*, consisted of his aim to purge science of prejudices and built-in errors (of both mind and method) - including the reliance on ancient authorities -and the deductive method predicated upon unreliable or inaccurate evidence. This traditional method was in need of revitalisation. Aristotle's logic came in for specific criticism. The second part of his argument, the *pars construens*, is a detailed description of how to avoid the many pitfalls in acquiring knowledge, and an account of his method of eliminative induction [Bacon: 1620: Jardine & Silverthorne: 2000]. This includes the gathering of data, experimentation, and some of his own explanations for the phenomena [Tiles: 1993]. Eliminative induction was to be an advance on naïve induction. The Aristotelian term *epagoge*, usually translated as induction, incorporates an intuitive leap to understand the connexion between the collection of data and the universal concept that links them.

3.2.3 ***Hypothetico-Deductive Method***

Hypothetico-Deductive (H-D) method, Anderson states is "In its simplest form, the idea is that a theory, or more specifically a sentence of that theory which expresses some hypothesis, is confirmed by its true consequences" [Anderson: 2015]. One of its earliest exponents is said to be the Islamic polymath *Ibn al-Haytham* (Alhazen), 965–1039, who placed emphasis on experimental data and reproducibility of its results [Gorini: 2003]. An Early Modern version of the hypothetico-deductive method was proposed by the Dutch physicist Christiaan Huygens (1629–95).

Huygens was a natural philosopher and highly regarded mathematician. He was a founding fellow of both the Royal Society[7] and the *Académie royale* [Verbeek: 2015], so his work would have been widely circulated. In the preface to his *Treatise on Light* [8] he says "One finds that demonstration does not carry so high a degree of certainty as that employed in geometry; and which differs distinctly from the methods employed by geometers in that they prove their distinctions by well-established and incontrovertible principles, while here principles are tested by the inferences which are derivable from them. The nature of the subject permits of no other treatment. "It is possible, however, in this way to establish a probability which is little short of certainty. This is the case when the consequences of the assumed principles are in perfect accord with the observed phenomena, and especially when these verifications are numerous; but above all when one employs the hypothesis to predict new phenomena and finds his expectations realised" [Huygens: 1690]. Of course, this is not aiming at falsification, it is a predictivist stance, but it is one of the clearest (and possibly earliest) advocation of confirmation of speculative hypotheses by experimentation and repetition. The risks inherent in H-D method are many, to such an extent that there are those that deny that any knowledge is possible. Newton's famous quote "*hypotheses non fingo*"[9] [Newton: 1713] suggests that caution should be exercised.

---

[7] *List of Fellows of the Royal Society 1660 – 2007.* Royal Society Library Services.
[8] Published in 1690 but presented to the Royal Society in 1678

[9] "I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction" [Newton: 1726]. *General Scholium* (appended to the *Principia).*

Newton does mention 'hypothesis' for example in "*An hypothesis Exploring the Properties of Light"* (1675) in his letter to Henry Oldenburg (c.1615-1677) on which subject he said he "would not 'assume' any hypothesis to explain the properties of light, not deeming it necessary" [Teeter Dobbs: 1975 p204]. Nevertheless, he presented a rather detailed hypothesis, one which he must have been thinking seriously about for some time [*ibid*]. Why then did he suggest that hypothesizing was to be avoided? In his *Principia,* his aim "was to present a method for the deduction of propositions from phenomena such that those propositions became 'more secure' than propositions that are secured by deducing testable consequences from them" [Schickore: 2014; Smith: 2002]. He did not expect that the process would result in absolute certainty [*ibid*]. Perhaps he felt also that there was an inherent risk in proffering explanations that went beyond what was strictly deduced from the phenomena; these explanations are speculative. Though not celebrated for his alchemical studies, Newton believed in 'one Catholic Matter' and in transmutation from virtually anything to anything else. In this his beliefs were in accord with those of Boyle [*ibid*, p231].

Despite the risks of speculation without supporting empirical research, despite the 'cherry picking' of results, despite the difficulties of testing and interpretation of results, the H-D method has its adherents. An effective hypothesis will enable predictions.

3.2.4 *Abduction or IBE*

Inference to the best explanation (IBE), also known as abduction, is a commonly used method. Given a group of possible explanations, the competing hypotheses are weighed up by determining how well the evidence supports each hypothesis, then make an inference. Such factors as parsimony or coherence might influence the choice. Its weakness lies in the possibility of unknown hypotheses, one of which might be the actual cause. Most of the alchemists used IBE, including Bacon, (Chapter 2.8) Lémery (Chapter 5.4), Sennert and Boyle.

3.2.5 *Epistemological considerations*

Boyle was a dedicated experimentalist, but those who were predominantly rationalists such as Huygens and Leibniz were inclined to doubt the value of demonstrating by experiment [Markie:2017]. Rationalists believed that the truth could be known through logical reasoning, but most agreed that there was a role for experiment. Through 1662 and 1663, Boyle conducted (through Oldenburg) a long dispute with the Dutch philosopher Spinoza (1632-

1677) over the question of whether experiments could provide proof [Boas Hall: 2008]. Spinoza, following Descartes, believed logical thought was the only path to surety, while experiment could only confirm or refute a hypothesis. In contrast, for Boyle experiment was an essential ingredient of proof, and logical argument merely meant the employment of an a priori hypothesis [*ibid*]. This represented an important difference between scientific methods in the seventeenth century.

Formerly, the correspondence between Boyle and Spinoza has been portrayed as a conflict between quintessential rationalism and an emergent experimentalism. However, Duffy (2006) claims this portrayal is oversimplified and should be revised [Duffy: 2006]. Rationalism in this instance is characterised as the doctrine that knowledge is deduced from principles that are determined independently of experience, or at least such that they have priority over it. Experimentalism is characterised as an empirical doctrine that advocates the use of experimental methods in determine the validity of ideas, the principles of which are hypotheses. Spinoza questions Boyle's recourse to experiment to prove that which has already been proved (by Descartes) that all tangible properties are dependent on the mechanical features of objects. Spinoza interprets Boyle's experiment with saltpeter as evidence for the Cartesian mechanical philosophy while Boyle explains it by his corpuscular hypothesis [Manning: 2016] (Chapter 3.5.2).

3.3 VALUES

3.3.1 *Epistemic Values*

Accuracy/prediction

Although an important epistemic value, accuracy alone is seldom a necessary or sufficient criterion for theory choice. Copernicus's system, for example, was not more accurate than Ptolemy's until comprehensively revised by Kepler more than sixty years after Copernicus's death [Kuhn: 1977, p323]. Both quantitative analysis and qualitative analysis are important.

In chymistry, the focus had been on qualitative analysis, though quantitative procedures had a long history in areas of *technê* such as assaying of metals, where accurate measurement was commercially important. While not the only criterion, high success in prediction is predicated upon accuracy of measurement. Prediction may be sought at a low level in experiment or a higher theoretical level.

Early chymists failed to include the chemical role of air, and usually ignored the *caput mortuum* in chemical reactions; Boyle did not admit the role charcoal played in his redintegration of nitre experiment (Chapter 3.5.2). Excluding assaying, weight measurements sometimes used non-standard measures, e.g. Le Fèvre (Chapter 5.3). Béguin in his *Tyrocinium chymicum* does give some weight requirements, but not consistently. However, many chymists did give precise weight requirements in their recipes. Accurate measurement of temperature and time were problematic to the early chymists, but significant developments were made in the seventeenth century (Chapter 8).

In his work on colour indicators, *Experiments and Considerations Touching Colours,* [Boyle: 1664] Boyle had used tests for determining acid, alkali and neutral substances; for example, acid solutions reddish by syrup of violets [experiment XX]. Alkalis could be detected by their turning syrup of violets green, by restoring the blue of lignum nephriticum. At the French *Académie*, Bourdelin performed numerous indicator experiments (Chapter 6.3).

Boyle believed that natural phenomena could be tested by experiments and that one could construct hypotheses that might explain observations [Popkin: 2003, p217]. Prediction was important but difficult for seventeenth century chymists studying the course of chemical reactions. Boyle was able to predict the outcome in some few cases [Boas Hall: 1958, pp179-180]. Tables of affinity helped enormously, affording empirical, though not theoretical prediction. The understanding of chemical composition and reactions, essential for eighteenth century chymists, had its roots in the struggles of the seventeenth century chymists to understand, on a limited basis, the way in which chymical reactions did happen [*ibid*].

Consistency/Coherence

It would seem reasonable that one would want a theory should be internally coherent; one that was not would inevitably give rise to challenges against it. It has been suggested that there is a connexion between coherence and truth. Thagard (2007) notes that many epistemologists maintain that epistemic claims are justified, not by a priori or empirical foundations, but by assessment of whether they are part of the most coherent account. However, he argues that “The history of science suggests that coherence…..is a poor guide to truth” [Thagard: 2007]. Some seventeenth-century alchemists such as Bacon believed that it was possible to attain absolute truth; this position is not considered defendable now. One would expect that an increase in explanatory power would lead to a closer approximation of truth, but the evidence of history shows that this is not always the case. For example, the phlogiston theory, while providing wide explanatory power, was found to be erroneous. There were several versions of the theory; these conflicted in various areas. Nonetheless, coherence remains a legitimate aim.

3.3.2 *Non-Epistemic Virtues*

Scope

Scope, in Kuhnian terms should be broad; in particular a theory's consequences should extend far beyond the particular observations, laws, or sub-theories it was initially designed to explain [Kuhn: 1977]. Boyle's corpuscular hypotheses did have a broad scope; he intended to show that everything in the natural world could be explained in terms of matter and motion. It is also far simpler than the Aristotelian matter theory and more intelligible.

Simplicity/Parsimony

The law of parsimony, generally attributed to William of Occam (c. 1287-1347), was probably implicit in theorising**.** Spade suggests that the sentiment of avoiding the multiplication of entities beyond necessity is one "that virtually all philosophers, medieval or otherwise, would accept; no one wants a needlessly bloated ontology" [Spade: 2009].

Fruitfulness

Fruitfulness is of key interest to Bacon. Every step of inquiry must generate the next step; it is this generative power that is of prime importance. He cautions against following paths by which inquiry may be prematurely arrested. He gives priority to experiments of light (which further inquiry) over experiments of fruit which arrest inquiry. He criticises empirics who seek only practical results, and scholastics who merely hand down their disciplines rather than furthering investigation.

3.4 SCEPTICISM

Both Academic scepticism and Pyrrhonism had their adherents, but Academic scepticism was more prevalent. How sceptical were the early chymists? The full Aristotelian corpus, becoming available by the mid-thirteenth-century as well as the works of Plato, made a considerable impact on Renaissance thought, stimulating discussions in many subjects (Chapter 2). For natural philosophers involved with chymistry, Aristotle's logic treatises, especially the *Prior Analytics*, *Posterior Analytics*, and the *Physics*, encompassing the

Meteorologica, and *Metaphysics* were of particular interest. The mediaeval universities were heavily involved in studying the newly translated Latin texts (Chapter 3.7).

Popkin (2003) notes “A scepticism which denied the possibility of human knowledge (in the sense of necessary truths about the nature of reality) had to be moderated by a view which accepted the possibility of knowledge in a lesser sense, as convincing or probable truths about appearances” [Popkin: 2003 p112]. “This type of view which has become what many philosophers today consider the scientific outlook was first presented by Marin Mersenne in the seventeenth century.” It was published in publication *La Verité des Sciences, contre les Sceptiques ou Pyrrhoniens* (1625) and was termed mitigated scepticism. This modern scientific outlook did not find general acceptance until presented by Hume in the eighteenth century, and later by Mill and Comte in the nineteenth [Popkin: 2003. p112-113]. “Beginning with Mersenne, a new type of scientific outlook had arisen, a science without metaphysics, a science ultimately in doubt but for all practical purposes verifiable and useful” [*ibid* p120].

Not all of the *corpus aristotelicum* was taught at the Renaissance universities [Kuhn, H: 2017], but medieval natural philosophy was based on it. De Soldato (2018) comments that “such teaching was heavily controlled by the authorities, with both metaphysics and theology exercising a strong influence, limiting the directions in which scientific hypothesising might progress” [Del Soldato: 2016].

Discussing the impact of the arrival of the Greek translations on medieval thought, McInery and O’Callaghan remark on the influence of Aquinas: “Thomas Aquinas (1225–1274) lived at a critical period when the arrival of the Aristotelian *corpus* in Latin translation reopened the question of the relation between faith and reason, calling into question the *modus vivendi* that had obtained for centuries. This crisis arose just as universities were being founded” [McInerny & O’Callaghan: 2016] i.e. in the twelfth century. Exposed to the newly translated Aristotelian treatises, Aquinas achieved a remarkable synthesis of Aristotelian philosophy and Christian theology [*ibid*]. Building upon Aristotle but also including the Neoplatonic doctrines of St. Augustine (354–430) and the Church Fathers Aquinas’ best-known work was the *Summa theologiae* (1265 or 1266-73) [Adamson: 2019, p249] During the fourteenth century Aquinas’s writings gradually became the standard theological texts of the Dominicans, the order to which Aquinas belonged. In the early fifteenth century important commentaries on his work appeared.

Despite this restriction by the authorities significant advances were made by such thinkers as Buridan and Oresme. However, the return of Platonism ~~allowed~~ led to more freedom within the Aristotelian tradition. Plato was seen as a metaphysicist and theologian while Aristotle was regarded as the investigator of natural phenomena. Del Soldato postulates that as the return of the perceived dichotomy between the two allowed for more freedom of thought within natural philosophy [Del Soldato: 2016] "At the same time, also Platonism and other brands of ancient philosophy—Stoicism, Skepticism, and Epicureanism—stimulated reflection on the natural world in different ways, also in terms of method. The application of these ideas to various fields of inquiry gave Renaissance natural thought a distinctive identity, forged in continuous dialectic with Aristotelianism. Aristotelianism therefore represented the driving force behind Renaissance philosophy of nature, both because of its plurality of approaches and internal debates, and also because it served as the polemical target of those who challenged the traditional paradigm of university teaching" [*ibid*].

3.5 Authorities and their Challengers

The Authority of Aristotle

There were many challenges to Aristotle's metaphysics during the seventeenth century. There was a great diversity of views concerning prime matter, for example. Pasnau (2011) illustrates Gassendi's (1592-1655) attack on Aristotle in his *Syntagma* philosophicum where he states his view: "Aristotle does not have any way saying to describe the matter" he claims [Pasnau: 2011 p41]. Further criticism of Aristotle comes by way of Antoine de Ville and Etienne de Clave in their broadsheet of 1624 [*ibid*]. In the first of fourteen propositions, they state:

"Prime matter, which the Peripatetics set forth as the subject principle of change, whether it has existence of itself, or from form, is utterly fictitious and clearly has been thought up by Aristotle without any foundation" [*ibid* p41]. This event, a clear challenge to Aristotle and seemingly a support of the atomic theory, led to one of the organisers being arrested, the thesis torn up, and an injunction forbidding the promulgation of anything of similar nature under pain of death [Meinel: 1988b]. Aristotle's metaphysics was described as unintelligible, and, worse still, incoherent. This issue is exemplified in Joseph Glanvill's *Scepsis scientifica* (1665) [Pasnau: 2011, p49]. Pasnau gives Glanville's criticism of Aristotle's conception of prime matter: "..for *nec quid, nec quale, nec quantum* is as apposite a definition of Nothing as can be. So that if we would conceive this imaginary matter, we must deny all things of which we can conceive; and what remains is the thing we look for" [Pasnau: 2011, p49][10]. Giacomo (Jacopo) Zabarella (1533-1589) of Padua wrote in his *De rebus naturalibus*, "nothing in the natural world seems to be more obscure and difficult to grasp than the prime matter of things" [Zabarella: 1590; Valverdi: 2006].

Certainly there were multiplicity of views on what (if anything) constituted prime matter; whether it was extended in space or if it could exist entirely at an extensionless point, whether it was pure potentiality (Aquinas's view) or whether it had some kind of actuality. Averroës offered another interpretation – "prime matter falls half way, as it were, between complete non-existence and actual existence" [Pasnau: 2011 p39]. Pasnau gives Peter Auriel's attempt at elucidation by focusing on its indeterminacy: "Prime matter has no essence, nor a nature that is determinate, distinct and actual. Instead, it is pure potential, and determinable, so that it is indeterminately and indistinctly a material thing. And in this way it is the matter of everything generable and corruptible, so that it is not determinately any of the beings in the world – such as stone, earth and so forth – but it can be determined so as to be stone, earth and so forth" [*ibid*].

3.5.1 *Agricola's challenge on classification*

Agricola challenges Aristotle on a different front. In Agricola's book of mineralogy, *De Natura Fossilium* Agricola discusses minerals and their classification. Rather than the metaphysics of prime matter, Agricola disputes Aristotle's classifications, finding them inadequate [Agricola: 1546, p15-16,]. Agricola's conclusions are drawn from his many years' experience and observations on mining and mineralogy. He cannot reconcile his experience with Peripatetic doctrine in this instance. See Appendix C.

Agricola had both the classical education and the practical 'down-to-earth' experience that allowed him to challenge received wisdom by holding it up to demonstrative evidence. Although his treatise does not contain theory or explanations itself, it is founded not only on close observation of chemical operations, but also on a careful reading of earlier texts and, importantly, an attempt to provide a coherent theoretical underpinning for metallurgy and mineralogy. This theoretical base is founded upon Aristotelianism, but by no means accepting

---

[10] See also Glanvill: 1665, Chp.18

of everything without question. Comparing evidence with theory, and finding theory wanting, he sought changes to the theory to make a better fit. He hasn't attempted to overthrow Aristotelianism but had the courage to modify, not the core elemental theory, but ancillary hypotheses.

3.5.2 *Boyle's Challenge to Aristotelianism*

The main aim of the *Sceptical Chymist* was to challenge Aristotelianism and Paracelsianism. Boyle believed that chymistry was the key to understanding nature, and wanted to promote the corpuscular hypothesis. He argues that the mechanical philosophy is simpler than the Aristotelian matter theory, and has a wider scope. Boyle promotes the corpuscular hypothesis and at the same time indicates the inadequacies of the Scholastic doctrine, as briefly outlined below:

Scholastics generally hold that transmutation from one species to another (and especially of base metals into gold) is not only unnatural but impossible. The corpuscular hypothesis rejects scholastic substantial forms and considers bodies to differ only in magnitude, figure, motion or rest, and the configuration of their almost infinitely variable component parts. This seems much more favourable to the achievement of transmutations. Firstly, chymistry enables the purification of bodies and their analysis. Separating them out into their heterogeneous parts, making them more simple, helps us understand what we are dealing with in the experiments. Secondly, the chymical experiments are performed in closed, transparent vessels, making the process clearly visible and excluding grosser extraneous bodies. By this means we avoid impurities affecting the experiment. Lastly, using active ingredients, it is possible to see a series of successive alterations, enabling each change to be more easily understood [Boyle: 1661: In: Hunter & Davis: 1999 Vol 2].

The Redintegration of Salt-Peter Experiment

Boyle's experiment with salt-peter was designed to show that matter could be separated out into its individual parts and then re-integrated back to its original matter. Described in *A Physico-Chymical Essay containing An Experiment with some Considerations touching the differing Parts and Redintegration of Salt-Peter* [Boyle: c1660. In: Hunter & Davis: 1999 Vol 2] has been suggested that his chief reason was in challenging the Scholastic philosophy of qualities. He wants to show that explanations can be made without recourse to "inexplicable forms, real Qualities, the four peripatetick Elements or so much as the three

Chymical Principles" [*ibid* pp87-91]. This experiment was performed by Johann Rudolf Glauber (1604-1670) before Boyle published his results. Boyle's reticence in giving Glauber just recognition has been noted [Hunter: 2000, pp146-7].

In the *Origin of Forms and Qualities*, Boyle appears to be preparing his attack on substantial forms. For the scholastics the characteristic properties of gold, or cats, or apples are due to their substantial forms. Artefacts such as pieces of furniture have accidental forms only. Therefore, one can make a chair from a log, or a clock from a piece of iron assuming one has the appropriate skills and tools. But one cannot make oak wood or iron metal; that would require the right substantial form, and the creation of such forms is the prerogative of the Creator. Boyle's paper is designed to impale the Scholastics on the horns of a dilemma. If they say that 'nitre has its own substantial form' then it seems that mere chymists can make substantial forms, which ought to be a divine prerogative. But if they say 'nitre has only an accidental form and no substantial form, they may ultimately find themselves having to abandon the whole of chymistry to the mechanists. Boyle may have been planning a series of 'redintegration' essays intended to show the role of chymist as micro-mechanic, creating new, (accidental) forms merely by the rearrangement of corpuscles. If this programme succeeds, then the scholastic may be forced to cede victory to the mechanists. Boyle admits that it might not be possible with plants and animals, but that might be just because of their extreme complexity, not that it is fundamentally impossible.

Buyse (2013) points out that without knowing the exact parameters e.g. temperature at which the experiment was carried out, we cannot know for certain what took place, but describes the following explication as very likely to be an accurate reconstruction. [Buyse: 2013]

The first part of the experiment was the analysis (*decompositio*) where Boyle placed hot burning charcoal onto salt-peter (potassium nitrate KNO_3). An exothermic reaction took place with the charcoal, which was mainly carbon (C), resulting in the formation of several gases, including carbon dioxide, nitrogen and nitrogen dioxide, which would have partially escaped from the vessel due to the high temperature. Additionally, potassium carbonate, (K_2CO_3) white salt (often called salt of tartar or potash) was formed.

In the second part of the experiment, the synthesis (*redintegratio*), spirit of nitre (NO_2) reacted with water (H_2O) to form two acids. These were nitric acid (HNO_3) and nitrous acid (HNO_2). Nitric acid, which is part of *aqua fortis*, reacted with the potassium carbonate from the first experiment to form salt-peter, the same substance that Boyle started out with.

Buyse notes that Boyle neglected to include the chemical role of carbon in the experiment – it was just the heat source- and he did not use the same spirit of nitre from the analysis for the synthesis. However, the complete set of experiments represents an analysis and synthesis of the same substance, viz salt-peter. Spinoza, in his correspondence with Boyle (via Oldenburg) criticises what he believes is Boyle's explanation of the redintegration experiment. Spinoza offers a Cartesian interpretation.

Boyle replies that this experiment was never intended as a complete and philosophical analysis of nitre, but a way of proving that the scholastics were wrong with their substantial forms. Spinoza has misunderstood. Boyle is attempting to promote his corpuscular philosophy [Buyse: In review]. Boyle specifically attacks Scholastics such as Sennert, "… that which he [Sennert] ascribes to the dominion of the specifick Form, I attribute to the structure and especially to the connexion of the parts of the compounded body," [Boyle: 1666-7. Hunter and Davis: 1999, Vol 5]. His intention was to provide confirming evidence for his hypothesis that the workings of nature were mechanical.

3.6 Observation, Cataloguing and Taxonomy

Commencing with a discussion on the concepts of natural kinds in the seventeenth-century, including Bacon, Boyle, Locke and Leibniz, I will show that, aside from tremendous quantities of work by natural historians compiling new natural histories (no mean feat in itself) there was a recognition, implicit or explicit, of the need to identify natural kinds. These early attempts to establish a taxonomy are clear in the work of many chymists and natural historians of the period. I shall concentrate on the work of Agricola in mineralogy and John Ray (1627-1705) in botany[11]. Following this I discuss the assumptions made by chymists with respect to natural kinds, real and nominal, and the relationship between inductive inference and natural kinds. I will cover briefly Kornblith's [1993] argument that natural kinds are best explained by homeostatic property clusters, and that the existence of natural kinds serves as a grounding for inductive inference [*ibid* p38]. He suggests that the psychological make-up of human beings is such that there is an innate supposition that natural kinds exist. Because our inductive inferences are tailored to the causal structure of the world, inductive understanding of the world is possible [*ibid*, p82].

---

[11] Ray's impressive output encompassed flora, fauna, fossils and geology.

3.6.1 *Natural Kinds and Real Essences*

In scientific disciplines, the categorisation of objects into groups or kinds is a frequently employed strategy. Natural kinds are those which reflect the structure of the world. Examples of chemical species are elements such as gold, and compounds such as water [Bird: 2008]. The search for accurate classification and taxonomy is a fundamental part of science. This was recognised by the ancient Greeks; the phrase 'carve Nature at its joints' dates to Plato's *Phaedrus.* Were the Early Moderns simply interested in cataloguing of plants, minerals, etc., with classifications being subjective human constructs, or did they hope or expect to discover distinct, natural kinds, to track real divisions in nature?

To take an extreme example of subjectivity consider the writings of Jorge Luis Borges (1988-1986) [Borges: 1942]. Claiming provenance of an ancient Chinese manuscript, the *Celestial Emporium of Benevolent Knowledge,* he describes a fictitious taxonomy of animals.[12] It is of course an absurd compilation, and not one that would be given any credence in the Early Modern or modern age. But it does remind us that there can be very different perspectives on things that might at first seem obvious. Taxonomical classifications may take many forms, not all of which are necessarily useful. One might have different perspectives depending upon one's objectives in classification. Yet it seems axiomatic that classifications should be aimed to pick out real divisions in nature, or at the very least be pragmatic. Additionally, it is important that only necessary, not accidental, properties are included when attempting to define a natural kind.

The distinction between real and nominal definitions can be seen in Aristotle's *Posterior Analytics* [Aristotle: c350 Book II]. For the Scholastics, matter itself is inert and cannot be the cause of anything. Matter informed by substantial form, an immaterial entity, which is its species essence, becomes a determinate member of a particular species and genus. This is entirely independent of any human-defined nomenclature. If we accept that most qualities are derived from the substantial form, and if we know what qualities a particular substance possesses, then its species can be determined by examining the properties that substance exhibits. For example, in the case of gold, a substance which exhibits most of the properties of gold (i.e. the necessary properties) has the substantial form of gold, and therefore belongs

---

[12] In this alternate classification, 'Animals' includes fabulous ones, ones that tremble as though they were mad, those that belong to the emperor, mermaids, things that are included in this classification, those drawn with a very fine camel-hair brush, those that have just broken the flower vase; and other strange bedfellows, making fourteen in all [Borges: 1942].

to the species gold. "Creating a taxonomy for the Scholastics is attempting to discover how nature has already classified substances into species and genera by looking for similarities among their persistent qualities (qualities that tend to remain even when the circumstances or conditions of the object change) that reveal the deeper similarity of sharing substantial forms" [Jones: 2018, sec.2]. In Aristotelian terms, "a real definition is in accordance with the natural hierarchy; it identifies the essence of the species or genus under consideration" [*ibid*].

3.6.2 *Bacon on Forms*

Jones describes Bacon's views: "more general material structures convene to create larger- and more sparse- bodies, and given the laws of nature that correlate powers to these structures, these bodies have their natures and belong to a species or genus due to the structures and causal powers of their constituent parts" [Jones: 2018, sec 3].

Bacon says: "For although nothing exists in nature except individual bodies which exhibit pure individual acts in accordance with law, in philosophical doctrine, that law itself, and the investigation, discovery and explanation of it, are taken as the foundation of both knowing and doing. It is this law and its causes which we understand by the term Forms…" [Bacon: 1620, II, ii].

"But he who knows forms comprehends the unity of nature in very different materials" [*ibid* iii]. "For the form of a nature is such that if it is there, the given nature inevitably follows. Hence it is always present when the nature is present; it universally affirms it, and is in the whole of it. The same form is such that when it is taken away, the given nature inevitably disappears. And therefore it is always absent when that nature is absent, and its absence always implies the absence of that nature, and it exists only in that nature. Finally, a true form is such that it derives a given nature from the source of an essence which exists in several subjects…" [*ibid*, iv]. For instance, if there were two Suns, they would both have the same essence; each would have the same form.

3.6.3 *Locke on Essences*

Dissatisfied with the Scholastic position, John Locke (1632-1704) devised new concepts in the distinction between real and nominal essences. In Scholastic terms the real essence of a thing was its substantial form. Locke thought the substantial forms did not exist. Real essences do exist but are fundamentally unknowable. Only what he termed the nominal essence, which is the collection of sensible features belonging to an individual substance, is accessible to human beings. In *An Essay Concerning Human Understanding* by 1689, Locke writes, “The measure and boundary of each Sort, or *Species,* whereby it is constituted that particular Sort, and distinguished from others, is what we call its *Essence,* which is nothing but an *abstract* idea *to which the name is annexed:* so that everything contained in that *Idea,* is essential to that Sort. This, though it be all the *Essence* of natural Substances, that we know, or by which we distinguish them into Sorts; yet I call it by a particular name, the *nominal Essence,* to distinguish it from the real Constitution of Substances, upon which depends this *nominal Essence*, and all the Properties of that Sort; which therefore, as has been said, may be called the *real Essence,* e.g. the *nominal Essence of Gold*, is that complex *Idea* the word *Gold* stands for, let it be, for instance, a body yellow, of a certain weight, malleable, fusible and fixed. But the *real Essence* is the construction of the insensible parts of that Body, on which those Qualities, and all the other properties of *Gold* depend. How far the two are different, though they are both called *Essence,* is obvious at first sight to discover” [Locke: 1689 III vi2]. Locke’s ontological position is that a nominal essence consists simply of an agreed collection of properties which are collectively given a specific name. The real essence, not being accessible to the senses, he believes is beyond our comprehension, at least during his own time. This being so, the Aristotelian attempts to discover the substantial form is doomed to failure; but the mechanists’ attempts to discover the real essence is also beyond our capabilities.

It also suggests perhaps a kind of arbitrariness in the nominal essence as it is nothing but an abstract, complex idea. There can be no assumption that the abstract ideas map to real divisions. The establishment of division into species or genus cannot be based on sense data; we have no sight into real essences, and therefore we cannot claim to be able to capture the true taxonomy. Only God and His angels have this ability.

“Concerning the real essence of corporeal Substances (to mention these only) there are, if I mistake not, two Opinions. The one is of those, who use the word *Essence,* for they know not what suppose a certain number of those essences, according to which all natural things are made, and wherein they do exactly every one of them partake, so become this or that *Species.*

The other, and more rational Opinion, is of those, who look upon all natural Things, to have a real, but unknown Constitution of their insensible parts, from which flow those sensible Qualities, which serve us to distinguish them from one another, according as we have Occasion to rank them into sorts, under common denominations” [*ibid* III.iii.17].

The first section of the above is an attack on Aristotelian substantial forms. His second option is that things have a real, though unknown constitution of their sensible parts, from which flow those sensible qualities which serve to distinguish one from another. This enables us to rank and sort them under common denominations [*ibid*, III.iii.17]. He insists, though, that we must differentiate between nominal essence, which is in general usage, perhaps for pragmatic purposes, and uselessness of attempting to distinguish species by real essences, which cannot be known. Are there real boundaries in nature or are they mind-dependent? Look (2009) suggests that Locke is arguing that individuals are classified according to sortal terms, that these sortal terms are simply our abstract ideas. There are two strands of thought; the first is that there are no divisions at all, and the second even granting there may be, we cannot have confidence that we are tracking them.

Locke accepts that there are real essences underlying the nominal essences. If there is an internal 'something' on which the sensible properties depend, then it would not be true to say there is no connexion between nominal and real essences. The real essence is the internal constitution of physical substance that is the cause of the discernible properties. This constitution was mechanistic in type. As it was not possible to have knowledge of these real essences, and appealing to them was 'wholly useless' and we should be content with making use of what was within the reach of our knowledge; a pragmatic approach.

"We sort and name substances by their nominal and not their real essences". It is evident that what we call nominal essences are actually constructs of the mind, rather than nature. If it were a natural division of essences, then it would not be the case that different people could attach different meanings to the same term. An example is *animal rationale* versus *animal implume bipes latis unguibus* [Locke: 1689. III. Chp. VI.260]. The first definition captures the essence of what it is to be human; the second does not. If real essences were knowable, then there would be no ambiguity in definitions. This argument does not seem entirely satisfactory, and indeed was challenged by Leibniz.

Locke's claim is that nominal essence is of primary importance in classification; the Aristotelian 'real essence' is practically worthless. But he also suggests that there may not even be any real divisions in nature at all [Look: 2009 p8]. Locke is a mechanist and the difference between objects is just a matter of degree. "In all the visible and corporeal world, we see no chasms or gaps" [Locke: 1689 III, vi.12]. There is a continuum; several species are linked together, differing in almost insensible degrees. Further, he argues against the traditional concept of defining species by propagation. This is referring to the definition of species defined by descent; the genetic component is built in. Resemblances may make it appear that things are kindred, but this is not the real essence. Things are sorted according to their conformity with abstract ideas, for convenience [*ibid* III vi.36-37]. This is his sceptical claim; he uses the distinction between real and nominal essences to provide himself with ammunition against the Scholastics. Debates upon whether Locke based natural kinds on essences is an argument that continues today [Jones, J-E: 2018].

Leibniz's critique of Locke

Look (2009) discusses Leibniz's disagreement with Locke regarding the nature of species and natural kinds [Look: 2009 p1]. He describes Leibniz's view as that each individual substance had an essence though he is not committed to the view that these essences are necessarily known to us [*ibid* p8]. Nor does it necessarily mean that there are essences of natural kind or genera and species [*ibid* p2]. Leibniz accepts Locke's distinction between real and nominal essences, but only up to a point. Leibniz considers that species are defined in part at least in terms of their generation [*ibid* p16]. He distinguishes between non-living matter, such as the minerals and metals, and living plants and animals. On the issue of chemical transformation, we define the difference between organic and inorganic bodies, (or living and non-living matter).

Look quotes Leibniz: "And so we say that water, gold, quicksilver, and common salt remain such, and are merely disguised, in the ordinary changes they undergo; but in the case of organic bodies i.e. the species of plants and animals we define species by generation, so that two similar individuals belong to the same species if they did or could have come from the same origin or seed" [Look: 2009; Leibniz: 1765 A VI vi. 309].

We define man as a rational animal, and although some people do not seem to have this faculty, we believe this is due to an impediment in development rather than the lack of fundamental capability. Whatever rules are applied for nomenclature and the criteria attached to such names, provided the system is methodical and intelligible, it will be founded in reality [Look: 2009, p16]. Although every outer appearance is grounded in the inner constitution, it is possible that two different constitutions result in the same appearance. Look interprets Leibniz as saying that the causal history of a being is part of the essence of an individual; the classification can only be correct if the history is right. Leibniz disagrees fundamentally with Locke over the possibility of knowledge of natural kinds. Leibniz says:

"I would sooner say, in keeping with accepted usage, that the essence of gold is what constitutes it and gives it the sensible qualities which let us recognize it and which make its nominal definition; whereas if we could explain this structure or inner constitution we would possess the real, causal definition. However, in our present case the nominal definition is also real, not in itself (since it does not show us a priori the possibility of this body, and its mode of origin) but through experience, in that we and that there is a body in which these qualities occur together. Otherwise we could doubt whether such a weight was compatible with so much malleability, just as we can still wonder whether glass which is malleable when cool is naturally possible" [Look: 2009, p17].

Jones [2018] notes that Leibniz's *New Essays on Human Understanding* was written in 1704 as a rebuttal of Locke, but was not published until 1765, sixty-one years after Locke's death and nearly fifty years after Leibniz's own death. However, Locke's works were debated in correspondence between Edward Stillingfleet, Lord Bishop of Worcester, and others in the 1690s [Jones: 2018].

3.6.4 *Boyle on Forms and Qualities*

Boyle argues that the inner constitution of substance is relevant to the division of natural species. The inner construction is the species' form. In the *Origin of Formes and Qualities,* Boyle writes: "…though I shall for brevities sake retain the word *Forme,* yet I would be understood to mean by it, not a Real *Substance* distinct from Matter, but only the Matter itself of a Natural Body, considered with its peculiar manner of Existence [corpuscular structure], which I think may not inconveniently be called either its *Specifical* or its *Denominating State,* or its *Essential Modification,* or, if you would have me express it in one word, its *Stamp;* for such a Convention of Accidents is sufficient to perform the offices that are necessary required in what men call *Forme,* since it makes the body such as it is, making it appertain to this or that Determinate Species of Bodies, and discriminating it from all other Species of Bodies whatsoever…" [Boyle: 1666].

Jones remarks: "We see that there are corpuscular versions of natural kind realism afoot in early seventeenth century England where both the roles of determining species or genus membership and of causing and explaining qualities are played by the same entity: corpuscular structure" [Jones, J-E: 2018]. Philosophical debate upon natural kinds clearly occurred in the seventeenth century. I now turn to the classifying and cataloguing labours of the period and examine the extent to which taxonomical classification can be said to be taking place. It is also of interest to note how long such taxonomies remained extant.

3.6.5 *Mineralogical classifications*

Aristotle had presented a comprehensive theory of the origin and nature of minerals in his *Meteorologica* [Bandy & Bandy: 1955]. An early treatise on mineralogy was *De Mineralibus* written by Theophrastus (372-c287BC). The next major work was Pliny's *Natural History* in 77AD. Pliny's encyclopaedic work, intended to encompass the entire natural world, included many apocryphal fables, historical observations and theories of Greek and Latin authors. It was an important source book, but not always reliable as there was no critical analysis of the content. There were a few other publications such as Biringuccio (Chapter 4) and others but nothing as important as Agricola's *De Natura Fossilium* in 1546 [Morello: 2006].

Previous works had relied heavily upon Pliny, and had incorporated many of his, and subsequent authors', more fanciful claims and absurdities, without attempts at verification. Agricola was not prepared to accept theories which failed to conform with observation and experience. The combination of learned study, critical appraisal of ancient authorities, observations and experience of practices in a mining community enabled him to develop a systematic mineral classification, based on physical properties. There was little further substantial development until the 1800s, with the development of the concept of a chemical bond, although there had been speculations on chemical affinities in the seventeenth century, especially Geoffroy's (1672-1731) *Table of Affinities* (1718). The two common systems currently in use are those of Dana, who published his *System of Mineralogy* (1837), and the more recent Strunz Classification of 1941.

Agricola's *De Natura Fossilium* [1546] attempted more than just the cataloguing of minerals, although it is impressive for that alone. Over four hundred minerals are described. The origins and causes of things were discussed in his *De Ortu and Causis Subterraneorum* (1544) (Chapter 4).

Agricola's Taxonomical Classification of Minerals

In *De Natura Fossilium*[13] Agricola (Agricola: 1546] describes both his taxonomy and the methods by which minerals can be identified. Agricola's system was built upon physical

[13] Translated by Bandy and Bandy (1955)

characteristics, including morphology, the study of which enabled the identification of genera and species. He begins with a revision of the ancient classifications, describing his own in detail. Figs. 2a and 2b give schematic interpretations of his system, as described in Book I. He illustrates his system of genera and species.

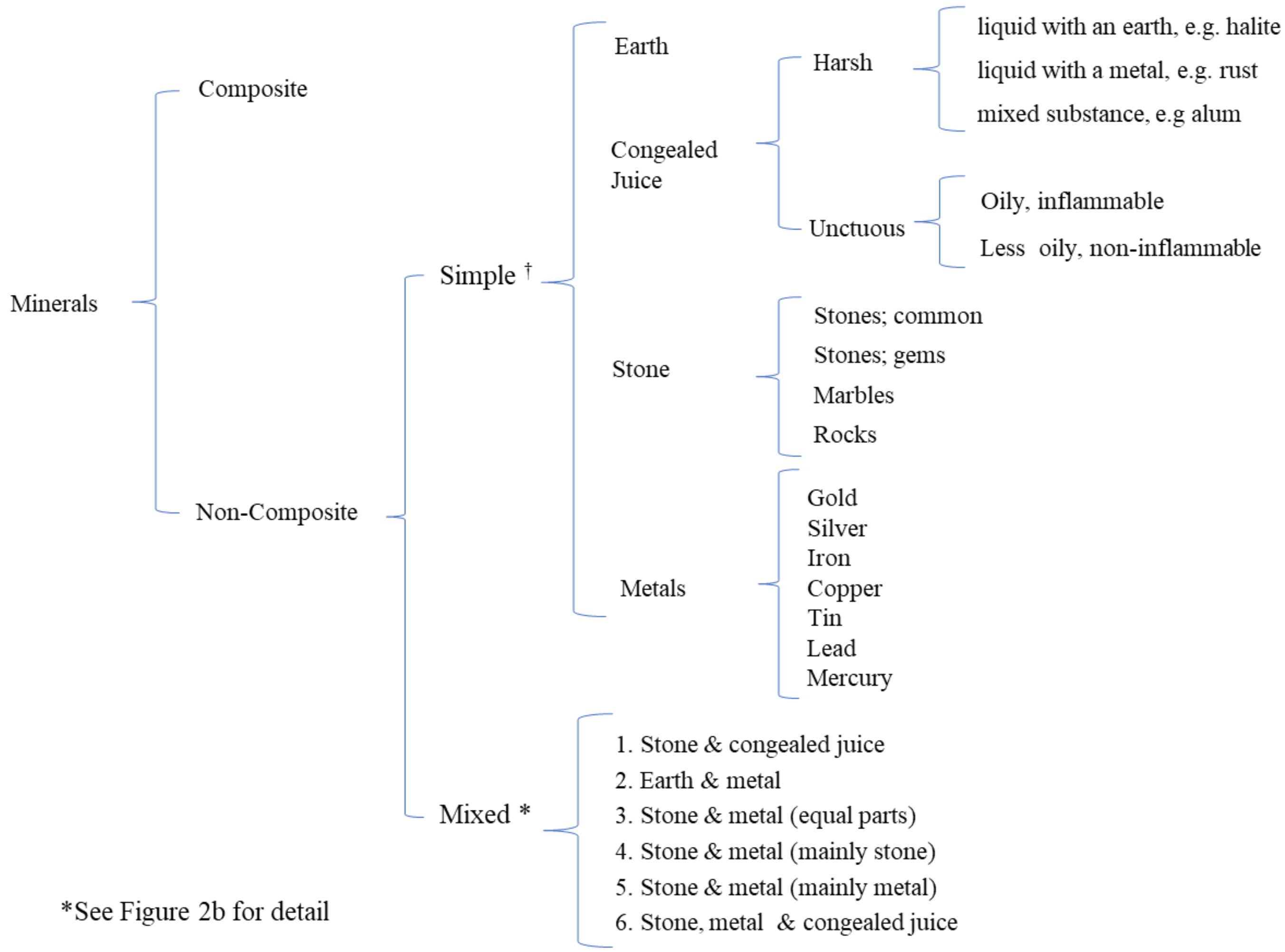
"Mineral substances vary greatly in colour, transparency, lustre, brilliance, odour, taste and other properties which are shown by their weakness, strength and form…. Minerals have no dissimilar portions made up of similar materials. For example, a mineral we call 'complex' nature forms from different kinds of simple substances, none of them dissimilar… Many minerals form from a single species, a few from many similar species. For example, each unit of red ochre is red ochre; each unit of alum is alum; asbestos, asbestos; gold, gold." [*ibid* p5]. It would seem that he has an appreciation of the separation of minerals into separate species, but in general he classifies substances by their sensible qualities. The metals form a neat group in his classifications; can a metal be read as a natural kind? The rest of the classes – earths, congealed juices, stone are rather extensive classes of fairly diverse collection of bodies, though each group shares similar properties which marks it off from the others. These groupings seem to be guided by pragmatism, but it does appear as though they were searching for natural kinds, though they would not have used that terminology. The sensible qualities are, to an extent, good guides to separation into kinds. For some minerals, simple analysis is sufficient to identify different types. Jade is a common term used for the green semiprecious jadeite and another mineral, nephrite, with similar properties [Jones, A: 2013]. The outward appearance of these two substances is very similar, such that it is very difficult to tell them apart. Jadeite, the rarer of the two and consequently more sought after, is very hard, (6.5-7 on the Mohs scale) while its counterpart nephrite (actinolite) is considerable softer (less than 5). Nephrite can be scratched with a knife blade, (a standard test) while the more expensive, denser jadeite is not susceptible.

Other substances present more of a challenge. There were several species known as Alum for example. The most commonly used was potassium aluminium sulphate, usually referred to just as alum; the second was ammonium alum. Pliny described the various types in his Natural History, but it is not always clear to which type he is referring. The twelfth or thirteenth- century works attributed to Geber also mention alum [Hoover & Hoover: 1950, p566]. Nomenclature can be a little confusing; even today alum may refer to potassium aluminium sulphate or ammonium alum or a variety of sulphate salts.

Agricola describes alum (*alumen)* as occurring naturally and also prepared artificially. Natural alum occurs in small quantities. He mentions three types of methods of preparation; from the descriptions it seems that he did recognise that more than one substance went by the name of alum. There are several methods of manufacturing alum. The two principal sources are shale and alunite; both contain aluminium sulphate. Agricola describes the principal processes.

One such process involves extracting aluminium sulphate from shale and roasted pyrites [*ibid* p564]. The process seems to be essentially the same as that used in Yorkshire in the seventeenth-century. This was an important contribution to the Industrial Revolution.

Alum has a rich and varied history, of great importance commercially and politically. Agricola describes it being used as used as a mordant for dyeing, goldsmithing, paper making and for medicinal use**.** The astringency of alum made it useful for the treatment of wounds and ulcers. Goldsmiths clean gold with it and use it in a process for covering copper with gold leaf [Agricola: 1546]. The importance of alum continued until the advent of aniline dyes in 1856. Alum, as aluminium potassium sulphate, was distinguished from other substances commonly called alum. Though the taxonomy was not entirely clear, the different types of alum (and their purity) were identified by colour and crystalline form. The motivation seems to be largely science driven by pragmatic, commercial reasons, rather than scientific interest. Agricola's aims to clarify the taxonomy is demonstrated in his *De Natura Fossilium.* Fig. 2a and 2b overleaf show schematically his classification system. (Note: it is not given schematically in the original text.)



† **Simple Minerals:**

Earth is a simple mineral body; can be worked with the hands when moistened to form mud. Ubiquitous on earth's surface

Congealed Juice is a dry, rather hard mineral body which is not softened in water, but dissolves, or if softened by water it differs from an earth in unctuousness or composition.

Stone is a dry, hard mineral body, may soften a little water after a long time; is reduced to a powder in the fire; melts in only the hottest fire
1st Genera: Common Stone *(lodestone, haematite, geodes etc)*
2nd Genera: Gems (diamond, smaraglus, carbunculus etc.)
3rd Genera: Marbles
4th Genera: Rocks (sandstone, limestone etc)

Metal is a natural mineral body which is either liquid or solid and will melt in a fire. Molten metal, on cooling, returns to its original form. Differs from stone that melts in the fire; becomes hard when cold but does not return to original form and appearance.

(Schematic derived from descriptions in *De Natura Fossilium* [Agricola: 1546])

Fig. 2a ***Agricola's Classification of Minerals***

Mixed Minerals*

Genera

1. Stone & congealed juice
2. Earth & metal
3. Equal parts of Stone & metal
4. Stone & metal (mainly stone)
5. Stone & metal (mainly metal)
6. Stone, metal & congealed juice

Species

8 or more species under each genera.
Examples:

- Chrysocolla;
- Caeruleum;
- Realgar;
- Orpiment.

Identification

Examples of methods to determine the genus and with which salt, soda or congealed juice to find the species are:

- A silver mineral may be of genus 2, 3, 4, or 5; this is disclosed by the smelting process;
- Galena can be pulverised with a pestle in a mortar, argentite flattens out;
- White flint destroyed in the fire breaks with a very loud noise;
- Astringency;
- Colour.

In the class of **mixed minerals** are those which have formed from two or three simple substances that are themselves mineral bodies. These are true minerals but with their constituents so mixed and combined in proper proportions such that the smallest particle of the mixed body contains everything found in the body as a whole. They are so combined that if the mineral contains three simple constituents or bodies, one can be separated from another by the force of fire, or a third from the other two, or two from the third. The two or three constituents are commonly combined in the new mineral in such a manner that the original character of each constituent is not evident.

A **composite mineral,** even though it contains the same simple constituents, differs from a mixed mineral. The simple constituents almost always retain their form and one can be separated from another not only by fire but also by water, or even by hand.

*inanimate substance only

(Schematic derived from descriptions in *De Natura Fossilium* [Agricola: 1546]).

Fig. 2b ***Agricola's Classification of Minerals – detail on mixed minerals***

3.6.6 *Identification of Minerals*

Agricola based his identification of minerals on at set of observations. The detailed study of minerals included colour, hardness, brittleness, odour, taste, lustre, magnetism and density. Other properties examined included cleavage, ‘streak’ (the colour of a mineral when ground to a fine powder, usually tested by drawing a piece across a plate to observe the colour) crystal form, texture, and friability. It is interesting to note how close this comes to modern day techniques. Of course he could not determine actual composition. Modern techniques, such as mass spectroscopy are much more sophisticated, but the basic ideas of checking the streak, whether crystalline minerals cleave well, tasting, smelling, burning – all these indicators were described. Looking at current methods for initial identification of mineral samples the criteria from a modern textbook lists:

Colour	*Crystalline Structure*	*Lustre*
Streak	*Transparency*	*Odour*
Hardness	*Tenacity*	*Taste*
Cleavage or Fracture	*Magnetism*	

[Jones, A: 2013]. See Appendix D for identification of minerals.

Comparison with Modern Methods

Comparing with modern methods, it can be seen that the basic criteria for identification were well known in the Early Modern era. His descriptions show a detailed, in-depth knowledge of a wide range of minerals and metals, and how they might be identified. The majority are described by place of origin, taste, colour, odour, texture, and the colour of flames when burnt. Classification was based primarily on external features.

Agricola has attempted a taxonomic classification based on empirical data, that is, physical characteristic and morphology. He has improved classification but there is limited attempt to sort into natural kinds. The metals are quite distinct, but the divisions of earths, stones, congealed juices, are assessed by external characteristics, coupled with simple chemical analysis, for example resistance to melting by fire. He refers to degrees of a quality, such as the degrees of unctuousness (completely unctuous, semi-unctuous and meagre) when describing minerals. In addition to the physical characteristics, he often adds reference to place of origin, and medicinal properties. The medicinal properties receive but scant attention, unlike Renaissance authors who were wont to include in their descriptions all the information that was available at the time.

De Re Metallica, [Agricola: 1556] in which Agricola gives a detailed account of assaying (Chapter 8) coupled with *De Natura Fossilium* [Agricola: 1546] together form a detailed and comprehensive account for the understanding and practice of mining, metallurgy and mineralogy.

3.6.7 *Classification of Flora*

The cataloguing of plants was a momentous task in the seventeenth-century. The arrival of hundreds of unknown species brought back during the fifteenth- and sixteenth-centuries (the Age of Discovery) meant that the Renaissance natural histories needed substantial review and update. The identification and classification of plants was considered particularly important in the development of medicinal cures. The *Académie Royale* had spent considerable time and effort attempting to determine the active constituents of plants (Chapter 6) with disappointing results. However the descriptions and illustrations of many newly discovered plants were published in the *Mémoires pour servir à l'histoire des plantes,* complied by Dodart, 1676.

This would encompass not just the external appearance but uses in heraldry and mythology, sympathies and antipathies [Albury & Oldroyd: 1977]. Foucault writes "In the sixteenth century, and right up to the middle of the seventeenth, all that existed was histories… until the time of Aldrovandi (1522-1605) history was the inextricable and completely unitary fabric of all that was visible of things and of the signs that had been discovered or lodged in them: The history of a living being was that being itself, within the whole semantic network that connected it to the world" [Foucault: 1966, Part1, 5]. The intent of these histories was to record everything that had previously been noted about a plant or animal; everything was considered relevant. A major change occurred in the seventeenth century was the abandonment of writing such all-encompassing histories, later natural histories omitting extraneous information. This change could have been due to several factors. An increase in scepticism of the ancient authors, and the recognition of the importance of experimentation and observations based on personnel experience undoubtably played their part. Additionally, the new species brought back from various parts of the globe were unlikely to have complete histories with them. Medicinal properties were probably noted, but the indigenous mythology might well have been lost.

The Swiss-French botanist Gaspard Bauhin (1560-1624) whose major works were *Phytopinax* (1596) and *Pinax Theatri Botanici* (1623) was an important figure in the rationalisation of plant nomenclature as Ogilvie (2000) describes. He tackled the confusion arising from the preponderance of synonyms, as the same plant could have a dozen or more Latin names. Earlier lists were usually short lexica identifying Greek, Latin and common names. Bauhin combined these lists with precise references to the literature, and, drawing on his herbarium, a collection of dried plants, he was able to determine decisively the plants' identities [*ibid*]. This book was recognised for its great utility and was followed by an extended version, some twenty-seven years later. This illustrated exposition of plants, *Pinax theatri botanici* (1623), which is considered a landmark of botanical natural history, describing and classifying some 6,000 species [Ogilvie: 2000]. For example, Bauhin divided the *Verbasculum seu Primula veris* into three main types, each with several species and genera. His descriptions and classification may be considered forerunners to the later binomial nomenclature of Linnaeus [*ibid*].

John Ray (1627-1705) was an English naturalist and theologian who travelled widely in England and the Continent and was elected fellow of the Royal Society in 1667 [Sloan: 1972]. Ray's major work was his *Historia plantarum*. Consisting of three volumes, the first two volumes, published in 1686 and 1688, described 6,900 species of British and European plants. The third volume came out in in 1704 and described a further 11,700 entries, encompassing plants from the Philippines, Maryland, Africa, the Far East and Jamaica. He endeavoured to enumerate all the species already described and published in a clear and lucid way, eliminating errors and confusion, and to facilitate learning. Sloane describes how Ray was responsible for the classification of plants by their embryonic leaf in their seeds. He divided the species into monocotyledons and dicotyledons. The monocotyledons are considered a natural group and one of the major divisions of the angiosperms (flowering plants), a grouping that has been recognized since the sixteenth century. Mathias de Lobel (Matthaeus Lobelius) (1538-1616), a Flemish botanist and physician, attempting to group plants by specific characteristics, observed that the majority of the plants he examined had broad leaves with a net-like venation, and a smaller group had long grass-like leaves with long straight parallel veins. Consequently, he decided to use the form and venation of leaves as the dividing factors in his classification [Sloan: 1972].

Formal description dates from John Ray's studies of seed structure in the 17th century. Ray, who is sometimes referred to as the first botanical systematist, [Pavord: 2005] whilst appreciating Lobelius' distinction, did not consider it to be sufficient for accurate classification. He introduced further sets of divisions, classifying plants by the form of the flower, the corolla and calyx. In his observations of the structure of the seed and the embryo, he distinguished between plants which produce seedlings with one leaf, and those that produce two. Having observed this dichotomy of cotyledon structure, he reported his findings in a paper read to the Royal Society in December 1674, entitled "*A Discourse on the Seeds of Plants"* [Birch: 1757 p162].

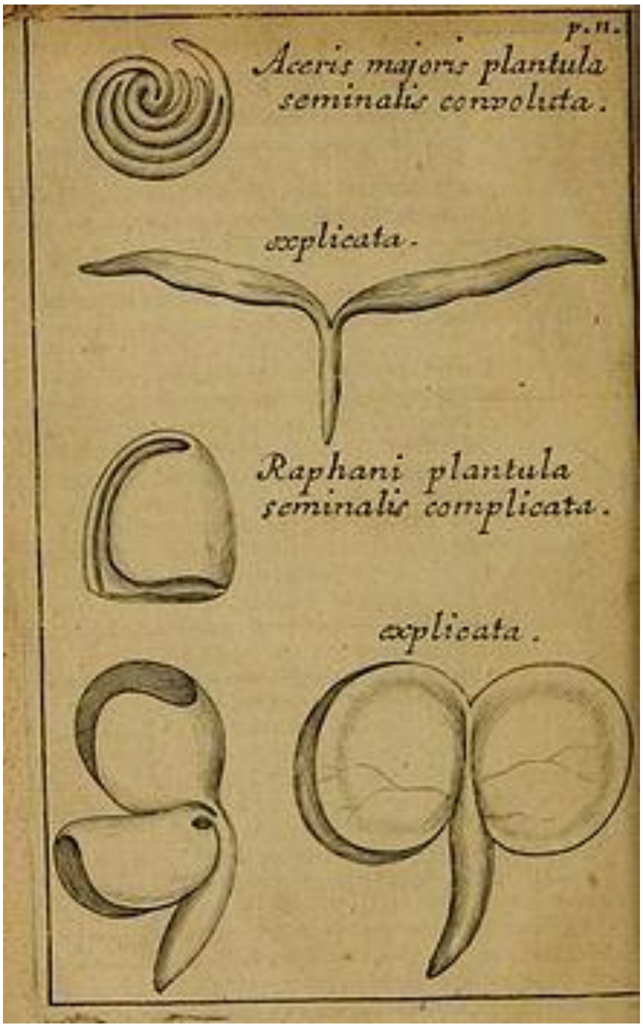


Fig. 3. Illustrations of cotyledons by John Ray

These illustrations (Fig 3) are from the *Methodus plantarum nova (1682)*, reproduced from drawings by Marcello Malpighi (1628-1694) for his *Anatome Plantarum* (1679) [attribution: John Ray [Public domain].

Modern Classification:

Monocotyledon	***Dicotyledon***
Single cotyledon (embryonic leaf)	Two cotyledons
Long narrow leaf	Broad leaf
Parallel veins	Network of veins
Vascular bundles scattered	Vascular bundles in a ring
Floral parts in multiples of 3	Floral parts in multiples of 4 or 5

The validity of the distinction has remained useful even to the present day, although recently the appreciation of the diversity of the external morphology of monocotyledons has made comparisons with dicotyledons less clear-cut [Tillich: 1998].

Ray's *Historia Plantarum,* was followed bytreatises on European flora and fauna. Most classifications to date had been based on a single feature; but Ray's innovative concept was to include data on all the structural characteristics, including anatomy. By insisting on the importance of the lungs and the cardiac structure, he effectively established the class of mammals. Westfall describes his establishment of species as a unit of taxonomy was undoubtably a significant contribution to the later taxonomical system of Carolus Linnaeus in the eighteenth century [Westfall: 2019].

3.6.8 *Natural kinds and the Wary Chymist*

To what extent did naturalists believe that they were picking out natural kinds? Kornblith [1993] adds an interesting slant to some of Locke's discussions on real and nominal essences, suggesting that his position might not be as sceptical as previously thought. Locke's intention[14] is to show that people use ideas to determine kinds rather than discovering real

[14] "…we find many of the Individuals that are ranked into one sort, called by one common Name, and so received as being of one Species, have yet Qualities depending upon their real Constitutions, as far as different from one another, as from others, from ways in which they accounted to differ *specifically*. This, as it is easy to observe by all, who have to do with natural bodies; so Chymists especially are often, by sad experience, convinced of it, when they, sometimes in vain, seek for the same Qualities in one parcel of Sulphur, Antimony, or Vitriol, which they have found in others. For though they are Bodies of the same *Species*, having the same nominal *Essence*, under the same Name; yet do they often, upon severe examination, betray qualities so different from one another, as to frustrate the Expectation and Labour of very wary Chymists" [Locke: 1689 (III, vi, 8)].

kinds in nature, and furthermore, members of the same natural kind all have the same properties. Locke states: "it is…. Impossible, that two Things, partaking of exactly the same Essence, should have different Properties…" (Locke: 1669, III, iii 17). But Kornblith points out that it is easy to find out if two substances do not belong to the same kind; if they differ in even one property, they cannot belong to the same kind. For example, if there are two samples, one of which is malleable and one which is not, then they do not belong to the same natural kind. It is immaterial whether they belong to the same nominal kind; clearly, they cannot be of the same real kind. It gives us some information of the boundaries of real kinds, albeit minimal knowledge [Kornblith: 1993 pp26-27].

Kornblith quotes Locke who says that the 'very wary Chymists' are often frustrated when they find, upon examination, that different samples of substances which are supposed to be the same thing, nevertheless exhibit different properties. Kornblith suggests that their frustrations would only be evident if they had expectations of the samples being all alike. There is a presupposition by the chemists that their nominal kinds pick out a class of objects which are all alike in their properties. When they find they are not, said chemists are frustrated. And the reason for such frustration is clear: they have discovered that their kind terms do not pick out a real kind in nature [Kornblith: p27]. It is possible that the differences are due simply to impurities. Even minute impurities can have significant effects on the properties (Chapter 6.2). Boyle and Du Clos had different views on the problems of spotting impurities. Du Clos thought that such contaminants were quite easy to identify. Boyle thought that the effects of impurities in a sample were a serious threat to the reproducibility of experiments [Boyle: 1661]. Boyle cautions that even when conducting experiments with supposedly unadulterated, genuine materials, there may be a considerable disparity between substances supposedly the same. Even experienced chymists sometimes failed to reproduce experiments, usually because of the presence of impurities. Boyle of course gives no credence to those who blame the position of the stars or planets. It seems clear that there is an expectation that the metals, at the very least, form natural kinds, though that is not explicitly stated. He expects that pure gold and silver etc are obtainable, albeit with some difficulty in many cases. He writes of the goldbeaters, who need the purest gold obtainable to hammer it to the greatest area and thinness, yet the mint-masters are not above adding a little silver or copper to stiffen the coin thereby making it less susceptible to attrition. In all these discussions there seems to be an assumption that there exist natural kinds; there are clear and exact divisions between, for example, the various metals. They are aware of what to expect from a natural kind, or at least the ones with which they have great familiarity. There is no suggestion that there may be a merging of kinds (as opposed to an alloy). Such kinds exhibit stable properties which enable them to be identified.

Even if the cause of the difference is not clear, it does seem that the chymists were intent on picking out natural kinds, though their terminology was different from that of the modern age. The identification (and reliable availability of unadulterated product) of natural kinds was highly significant in the pursuit of reliable, repeatable experimental procedures and concomitant ability to predict behaviours accurately. Boyle voices his concerns regarding repeatability in *Of Un-succeeding Experiments* (Chapter 6) [Boyle: 1661].

The concept the chymists have of a nominal essence are not formed haphazardly. “They are carefully thought out with the purpose in mind of bounding a kind so as to pick out a class of individuals which do not differ at all in their properties – in short, with the purpose of picking out a real kind” [Kornblith: 1993, pp26-27]. They will not always be successful in this endeavour. For example, if two samples of antimony failed to have all the same properties this would indicate that the term the chymist associates with antimony does not pick out a real kind in nature. The chymists would want their terms to pick out real kinds, and would therefore have to modify the nominal essence associated with that term. By an iterative process of this kind, including ‘severe examination’ it would be possible to get closer and closer to the real kinds in nature[15] [*ibid* p28].

The thought of “severe examination” brings to mind the efforts of the *Académie Royale* in their endeavours to extract the essences of plants for medicinal purposes. By systematically distilling hundreds of plants they hoped to isolate the active ingredients, determining which plant was effective in curing what diseases or ailments. For a pharmacist isolating the powers of specific plants was a recognised, important goal. Despite all their concerted efforts, the project was deemed a failure (Chapter 6).

[15] “On the view presupposed in the wary chemist passage, we may have highly non-trivial knowledge of the boundaries of real kinds, so long as we are both careful and fortunate.” Locke accepts that the knowledge of the boundaries of real kinds may be had with “much time, pains, skill, strict enquiry, and long examinations” [Kornblith: 1993 p29].

Natural Kinds as Homeostatic property clusters

Kornblith puts forward an argument for natural kinds which is predicated on an internal 'real' structure, of which we may have some knowledge. "It is precisely because the world has the causal structure required for the existence of natural kinds that inductive knowledge is even possible" [*ibid*, p35].

In support of this stance, Kornblith [1993 p35] invokes Boyd's (1988, 1991) account of natural kinds as homeostatic property clusters.[16] He also argues against Locke's insistence that there are no chasms or gaps in nature. "Organism are structured as to maintain themselves in certain states. For example, many animals have systems to maintain their body temperature within certain limits; plant cells have cell walls which are designed to maintain the pressure in equilibrium with the pressure from outside. In general what we see in these cases of homeostasis is a cluster of properties which work together so as to maintain reinforce themselves, even in the face of change in the environment" [*ibid,* p 35].

Kornblith notes that Boyd suggests that this account of self-regulating in organisms may provide a model for all natural kinds. This necessitates that only certain combinations and types of properties are viable; this in turn imposes a world in which there are 'gaps and chasms', contrary to Locke's belief. Certain combinations of properties would be impossible to realise [*ibid* pp35-36].

Locke also insists that it is impossible that two things, having the same real Essence, should have different properties [Locke: 1689 III, iii p17]. "It is clear, however, that samples of the same natural kind do not, indeed could not, have all of their properties in common". This raises the question of what properties are intrinsically necessary and which are extraneous, or accidental. Two samples of gold, for instance, may differ in size, shape and weight, yet still be gold. In the biological realm, the differences among members of the same natural kind become even more salient [Kornblith: 1993 p37]. There are hairless cats and furry cats; they are all cats, yet they have dramatic and obvious differences. Clearly members of the same natural kind must be alike in important respects. But how do we determine which ones are relevant? In the case of the gold samples, the answer is intuitive. For other, more complex situations we need a workable hypothesis. Kornblith claims that Boyd's account of natural kinds as homeostatic cluster properties may be effective in answering this question.

[16] Boyd's theory is considered more applicable to biological natural kinds than chemical natural kinds.

"When certain unobservable properties reside in a homeostatic relationship a collection of observable properties inevitably flow from that unobservable base. For example, when molecules of hydrogen and oxygen combine to form the stable compound H_2O, the observable properties of being colourless, odourless, tasteless and so on, are an inevitable product of that base. Certain other properties, however, are not thereby determined. The weight and shape of a sample of H_2O, for example, are not determined by the fact of its chemical composition, nor its temperature. Although the chemical bond between hydrogen and oxygen makes H_2O a homeostatic unit, features such as weight, shape and temperature are neither a part of, nor by-product of, that homeostatic relationship. Only the properties which reside in the homeostatic relationship are definitive of natural kinds. It is these properties, together with those which inevitably flow from them, which members of the same natural kind must have in common" [*ibid*, p37].

Kornblith notes that members of the same natural kind cannot have all their properties in common [*ibid*, p37]. It follows that the procedures applied in order to differentiate one kind from another must be quite subtle. In many cases the depth of experience of the chymists undertaking such analyses will be of great importance in detecting the more fine-grained distinctions. In others the differences will be obvious. Seventeenth-century chymists had many techniques at their disposal. Some were not reliable guides, and it became clear that differentiation by colour, for example, although used extensively, was not a fundamental property. Many substances were identified by the method of preparation.

Having given his suggested proof that there are natural kinds (only certain combinations of properties are stable) Kornblith says that there is good reason to believe that the unobservables mooted can be best explained by homeostatic property clusters. "There is indeed reason to believe that we may revise our nominal kinds so as to correspond to something deeper than just a convenient classificatory scheme of observable characteristics" [*ibid* p41]. The justification for this statement is that a system which explains observable characteristic by postulating the underlying properties has been "astoundingly successful." He continues with a very strong realist statement; "… in the light of the intimate relationship between the postulation of unobservable structure and the various successes of science, one can no longer reasonably doubt the real existence of such structure" [*ibid* p41].

Kornblith has given a strong argument that it is possible to know something of real essences. And the postulation of such underlying properties and relationships led to predictive, explanatory and technological applications. From what can be seen of the efforts of the chymists, botanists and other natural historians of the seventeenth century it seems clear that they were making concerted efforts to discover natural kinds, and had a degree of success in the taxonomical classification systems that they developed. Some of these systems are still relevant today; others laid the groundwork for future developments.

Induction and Natural Kinds

Kornblith develops an account of natural kinds that has its origins in John Locke's work on real and nominal essences. In Kornblith's view, a natural kind is a stable cluster of properties that are bound together in nature. Only certain clusters of properties are viable. The existence of such kinds serves as a natural ground of inductive inference. How knowledge of natural kinds is attained can be explained by human psychology. Firstly, our concepts are structured innately in a way that presupposes the existence of natural kinds [Kornblith: 1993, p 28]. Secondly, our native inferential tendencies tend to provide us with accurate beliefs about the world when applied to environments that are populated by natural kinds. It is not possible to give a detailed description of Kornblith’s exposition here, but the evidence drawn from the examples in this chapter does seem to support the notion that the concept of natural kinds is inherent in our psychological makeup. There is a kind of ‘fit’ between the world and ourselves. The default assumptions by chymists throughout the period favours the acceptance of natural kinds whether explicitly expressed or simply implicit in assumptions, and endeavours are made to pick them out. We expect nature to be carved at its joints [*ibid* pp44-45].

3.7 RESEARCH COMMUNITY

3.7.1 *Introduction*

Republic of Letters

Erasmus (ca.1467-1536) was probably the first to use the term *respublica litteraria*, (republic of letters), an international scholarly community operating in the Latin West. In these humanist roots we can see the formation of a strong international commonwealth of letters [Burke: 1999]. Writing in Latin, his works were accessible to the scholarly elite of a wide geographical area. Translations into the vernacular increased the availability to a more socially diverse group. *Litterae* in the humanist context mean ‘learning’ but in terms of literature and linguistics. A [*respublica*] might be construed as an invisible or imaginary community [*ibid* p8]. Although natural philosophy was not considered part of the original definition of fifteenth-century humanism, by the mid sixteenth century there were links between humanism and astronomy and medicine. In the seventeenth-century polymaths such as Leibniz bridge the gap between the disciplines of humanities and natural philosophy. Mersenne for example, discussed subjects such as chronology and music as well as mathematics with Descartes and chymistry with Van Helmont [*ibid* p13]. Communications between learned societies such as the Royal Society and humanists were not uncommon. The phrase 'republic of letters' dropped out of common use, declining possibly around the end of the eighteenth century. It is likely that the cause was the decline in the use of Latin, plus other socio-political reasons [*ibid*, p13]. But if the phrase has been lost to common usage, the spirit has not. It has its embodiment in the thriving international scientific community of the twenty-first century.

The Hartlib Circle

Samuel Hartlib's Circle (active 1630-1660) promoted and facilitated international connexions between natural philosophers in no small scale. The network extended to the intellectual community of Europe and the Americas. In excess of 4,250 letters either written to or (mostly) from some four hundred correspondents or exchanged between third parties have been catalogued [Greengrass: 1994]. Hartlib corresponded with alchemists, iatrochemists, educational reformers, natural philosophers and inventors. His network included Boyle, Starkey, and Comenius. The communications included discussions on chrysopoeia.

3.7.2 *Learned Societies*

Several learned societies sprang up in the seventeenth century. These included the Royal Society (1660) in England, the *Académie Royale des Sciences* (1666) of France; in Italy there was the *Accademia del Cimento* (1657) Florence, and *Accademia dei Lincei* of Rome (1603). The *Academia Naturae Curiosorum* of founded in January 1652 in Schweinfurt, then Halle, Germany. Many societies issued reports and scientific journals.

3.7.3 *Royal Society*

Founded in 1660 and initially meeting at Gresham College, the Royal Society was preceded by the 'Invisible College' which dates to 1640. Boyle was a founder fellow [Hunter: 2007] and Robert Hooke was the First Curator of Experiments. The motto of the newly formed

Royal Society was '*nullius in verba*'- 'nothing in words' or 'nothing on authority', more commonly taken to mean 'take nobody's word for it'.[17] Whatever the correct translation is, the intention is clear, i.e. not to accept the word of ancient authorities unless confirmed by observation and experiment; scepticism over ancient texts, the avoidance of verbose rhetoric and the requirement for collection of data [Sutton: 1994].

Five hundred and fifty-one fellows were elected to the society in the first forty years of its existence [Hunter: 1982; 1994]. A number of the founding fellows of the Royal Society are known to have attended lectures on the practice and theory of chymistry. Sir Robert Moray and William Petty attended the lectures of William Davisson in Paris in the 1640s. John Evelyn and Sir Kenelm Digby were present at those of his successors, Annibal Barlet and Nicaise Le Fèvre, in the late 1640s and 1650s. Attendees included Robert Boyle, Robert Hooke, John Mayow, Thomas Willis, Richard Lower and John Locke [Golinski: 1989].

Golinski (1989) discusses the social influences upon the society, and the attempts to extend the influence and increase the prestige of the new experimental philosophy in the first few decades of the society's existence.[18] The Society's activities can be described under two groups: experimental demonstrations and written transcripts [Golinski 1989]. The aim was to have a membership that was socially inclusive, though in the words of Margaret 'Espinasse, it was "to have been open to all classes rather in the same way as the law courts and the Ritz." [Shapin: 1988]. Shapin notes that the annual subscription may have effectively excluded many craftsmen, applied mathematicians, seamen and others who may have been interested in the any technological spin-off that might result from the Society's research. The fees were waived in some cases. But the Society drew the majority of its fellowship from the elite class, with or without philosophical credentials [*ibid*].

The publication of the *Philosophical Transactions of the Royal Society* began in 1665, edited by Henry Oldenburg. *Académie Royale des Sciences* (1666) seems to be more organised, with written objectives, whereas the Royal Society seems to be quite haphazard and unstructured in the early days.

---

[17] Nothing in words" has been described by Stephen Jay Gould as the "canonical mistranslation" of this famous motto.

[18] Golinski [1989] notes "the legacy of Paracelsianism still remained strong after 1650. Spratt and Glanville were at pains to distance the new chymistry from the chymical practices which had a philosophical or religious component. This would have included alchemy practiced as a magical or mystical art. But others defended Paracelsianism as a type of natural magic as a legitimate manipulation of nature for human goal".

Philosophical Transactions of the Royal Society

Boyle writes of the benefit of those engaging in natural histories of writing their observations, and that such virtuosi and their societies keep correspondence with each other so everyone can be aware of the work that is being done, and what is still to be attempted. He notes that these correspondences would be particularly useful to inform people who live in remote parts; and the input from people in remote locations may add to the variety (and he claims certainty) of the observations. Anstey and Hunter (2008) note the Baconian influence on Boyle. Boyle, writing to Oldenburg, stresses the benefit of publication of treatises to show the necessity of Natural History "for building up a real & solid Philosophy" [Anstey & Hunter: 2008]. The *Philosophical Transactions of the Royal Society* seems to satisfy those requirements. *Phil Trans* was initiated in 1665, edited by Oldenburg. Volumes 1 to 5 appeared between April and July; there was a short gap, with the next issue being in November of 1665. This hiatus was due to 'the great mortality in London;' a poignant reference to the Black Death.

Boyle's 'Heads' on *Cold* was one of the first entries in the first publication of March, 1665. This edition included a wide range of subjects, the majority not relating to chymistry, such as Hooke's observations, using his telescope, on a spot on one of the belts of Jupiter, an account of the improvement in optical glass, the motion of a comet, a 'peculiar' lead ore of Germany, whale fishing in the Bermudas, and an obituary of the French mathematician Pierre de Fermat. In the following months, letters begin to appear commenting on previous articles. A description of Hooke's *Micrographia* appears in the April edition. Experiments or 'tryals' are evident, for example Thomas Henshaw's "*Observations and Experiments on the May Dew"* (1667). Also there are anonymous reviews of books, which are predominantly descriptive rather than analytical.

Technê informing epistêmê

The Royal Society states its aim clearly; it is "for the better attaining the End of their Institution, to study Nature rather than books, and form their Observations, to compose such a History of Her, as may hereafter serve to build upon a Solid and Useful Philosophy upon;" [Oldenburg: 1666, Vol 8]. It gives suggestions to the fellows to make observations on their several journeys to distant lands. For this purpose, lists are drawn up to guide the traveller on requirements (Chapter 3). One such list was *Directions for seamen to make observations in the East and West Indies.* This was a comprehensive list which included noting latitude and longitude, taking magnetic readings, noting the ebbing and flowing of the sea, measuring the distance between high tide and low tide, during spring and neap tides; mark the depth of coasts and ports, the type of ground at the bottom of the sea, whether it might be clay, sand, rock., etc. Last in this long list is to "carry with them good scales, and glass vials…. to be filled with sea water at different degrees of latitude, and varying depths, noting the weight, and recording the degree of latitude as well as the date. [Oldenburg: 1667]

Perhaps there was some concern over whether these measurements could be achieved as the following volume contained an *'Appendix to the Direction for Seamen, bound for far voyages.'* It would be of good use, it says, both naval and philosophical, to know how to sound depths of the sea without a line, and how to take water samples from any depth of sea. Hooke then gives directions on how this may be achieved. He gives impressively detailed instructions with careful practical notes. This is clearly a person who has tested the method and instruments carefully in order to optimise experiments as far as possible.

Peer Review

Informal review via correspondence did take place, but peer-review by journals seems to be absent in the seventeenth century. Kronick (1990) notes that formal peer review was instigated by the Royal Society of Edinburgh in 1731. In the preface to its first volume of the *Medical Essays and Observations*, it stated its process and policy for publication: "Memoirs sent by correspondence are distributed according to the subject matter to those members who are most versed in these matters. The report of their identity is not known to the author. Nothing is printed in this review which is not stamped with the mark of utility" [Kronick: 1990]. The Royal Society introduced peer review some twenty years later, in 1752. Between 1665 and 1708, the Society licensed the publication of the *Philosophical Transaction*, plus about fifty books [Moxham & Fife: 2018]. Pre-publication evaluation of the books was generally casual; for the *Philosophical Transactions* there are rarely traces of any at all [*ibid*]. The Society had been unsuccessful when it had tried to impose their views. Moxham cites their failed attempts to persuade Hooke to drop some of his more speculative claims in his *Micrographia* (1665). "At the early Royal Society, licensing represented less an endorsement or an intellectual evaluation of particular research claims, and more a judgement of how far association with a given work would redound to the Society's credit" [*ibid*].

The first secretary of the Royal Society, Henry Oldenburg had complete discretion on what was published [*ibid*]. After his death in 1677, for the next seventy-five years, the

Philosophical Transaction was edited by secretaries to the society [Moxham and Fyfe: 2016]. As the contents of the *Transactions* was derived entirely from the meetings of the Society, the situation remained broadly the same until 1752, The Society established a committee to review all articles to be published in the *Philosophical Transactions.* The regulations for this 'Committee on Papers' required five members of the committee to constitute a quorum, and allowed them to call upon any other member of the Society who was knowledgeable or skilful in the subject area under review [*ibid*].

3.7.4 *Académie Royale des Sciences (1666)*

One of the earliest academies of science, founded in 1666 by Louis XIV at the Louvre in Paris. Like the Royal Society, it had its forerunners; in Paris and the surrounding areas there were numerous private gatherings from the early decades of the seventeenth century [Hahn: 1971]. These early societies, such as the academies of Bourdelin and Thévenot were in communication with sister organisations, taking a keen interest in the Royal Society in London and the *Accademia del Ciminto* in Florence [*ibid*]. With the financial support of the King, the politician Jean-Baptiste Colbert (1619-1683) appointed Samuel Cottereau du Clos (1598-1685) and Claude Bourdelin (1621-1699) as founder members of the Académie. Du Clos was a physician and Bourdelin had trained as an apothecary.

Chymistry was one of the main foci of the academy's work, and Boyle's writing was, among others, discussed there [Holmes: 2003]. They assessed the work of various chymists, such as Glauber and Johann Kunckel (1630 or 1638-1703). They were particularly focussed on conducting actual experiments, not just hypothesising. In December 1666, Du Clos, physician to the king, proposed a plan for the discussion of the principal matters of chymistry. The meetings, held twice-weekly, were relatively informal. Du Clos lists twenty questions to be addressed. See examples in Appendix E.

Franckowiak (2011) states that Du Clos' début at the newly formed *Académie* took place only a few years after the recognition of Paracelsian chymistry as an essential ingredient in physics. As a result of this recognition, " the chemical principles - Mercury / Sulfur / Salt or Spirit / Oil / Salt / Earth / Water whose strength against those of hylemorphism lay in their demonstration in the laboratory - to be studied for themselves and no longer in their confrontation with others, thus revealing their conceptual frailty" [Franckowiak 2011]. Du Clos, who had established one of the first chemical laboratories and research programmes in France, did not subscribe to Boyle's mechanical hypothesis. He agreed with Boyle's view that the collection and accumulation of reliable observations and rigorous experiments was all-important in the attempt to understand natural phenomena. Boyle's *Skeptical Chymist* was known in France and was reviewed for the Académie in 1669 by Du Clos [Partington: 1962, p497].

Another dedicated experimenter was Claude Perrault, who with Du Clos studied the mineral waters of France. Believing that it was necessary to carry out a great number of experiments before deriving a universal law, he made many experiments with the mixtures of the juices of plants. He is said to have carried out nearly two thousand analyses. During his thirty-two years at the Académie he invented and executed many of the chemical operations.

After 1669, the Académie began publishing a volume annually giving details of the work done by its members. This publication, the *Mémoires de l'Académie des Sciences* was considered the pre-eminent academic publication in Europe [Hahn: 1971].

Peer Review at the Académie Royale des Sciences

Peer review in the eighteenth-century century appears to have been well established. At the *Académie Royale*, meetings of the *Comité de Librairie* were held to evaluate work to be published. The minutes have been preserved in their entirety for the years 1749-1780 [McClellan: 2003]. Papers from earlier years have been lost, making it difficult to ascertain the level of peer review in the seventeenth century. However, it is likely that there was at least a nominal system in place, given the sophistication of the later process in the mid-eighteenth. From the extant manuscripts available, it is clear that items submitted to the *Comité* had to meet certain unstated but definite criteria before they were even accepted for formal review. Papers had to be the work of the nominal authors, the subject had to be science, and of a suitable length. They could not be too elementary, and must contain new knowledge [*ibid* pp29-34] and must not have been published elsewhere. There also seems to have been a deal of scepticism applied. Nothing that seemed absurd had a chance of being published under their auspices. Before accepting papers for publication, papers were typically refereed; this peer review was a powerful means for controlling the publication of knowledge. McClellan [*ibid*] elucidates: "Crucially, the referees were not lay authorities…. but scientific peers in an institution devoted to science and controlled by the producers of knowledge themselves. If this was not the absolute origin of peer review in science, it was certainly an early and weighty episode."

3.8 Universities

Foundation of the Universities

The first universities include the University of Bologna, est. 1088, Oxford, est. 1167, Paris Sorbonne, est.1150 Cambridge, est. 1207, and Padua, est. 1222. After the economic decline of the fourth to ninth centuries, the economy began to improve. The universities were a product of this growing economy of the Middle Ages and the associated commercial need for artisans to establish guilds or corporations, known as *universitas* [Grant, 1996, Chp3]. The *universitas* evolved into a legally recognised, self-governing association, the university.

Grant describes the inauguration of the universities: “By 1200, universities were flourishing in Bologna, Paris and Oxford” [*ibid*]. These universities and the many others that followed them, were heavily involved in studying the newly translated Latin texts, and it was by means of the universities that this intellectual inheritance was disseminated. The earliest universities were famous and international; Paris (the Sorbonne) and Oxford were renowned as centres of philosophy and science. Many universities in northern Europe used Paris as a pattern. Philosophy was the principal subject in the Arts faculties of these universities. It was divided into moral philosophy, metaphysics and natural philosophy. Aristotelian natural philosophy formed the core of the curriculum. It would have included study and debate on Aristotle’s *Physics, On the Heavens, On Generation and Corruption, Meteorology* and others. By 1500, over seventy universities had been founded [*ibid*]. Medieval society accepted the separation of church and state, each of which was willing to recognise the existence of corporate institutions such as the university [*ibid*; Chapter 8]. By the end of the Middle Ages, nearly every principal state in Europe had a university, founded either by the Church or a secular ruler.

By modern standards, the number of students enrolled was small; for the larger institutions, such as Paris, probably between one thousand and fifteen hundred. However, looking at the whole of Europe, approximately seven hundred and fifty thousand students matriculated between 1350 and 1500. There seems to have been free movement between universities as students sought out particular masters for their studies [*ibid*]. This freedom would have added to the spread of information across Western Europe. A corpus of Greek texts, principally Aristotelian, and including Islamic and Greek commentaries was available for study; the institutions and teachers were accessible. The type of scholar is also important.

Theologians

Grant [1996] describes the development of a class of theologian- natural philosophers within the universities of Western Europe as extraordinary. There was nothing quite comparable in any other civilisation. Schools of theology expected their students to have competence in natural philosophy, and therefore a Master of Arts degree was usually a requirement for entry. Arts would have included the study of logic, exact science (mathematics, astronomy, geometry, optics) [*ibid C*hp 8]. Grant states that the part that the theologian-natural philosophers played was critical to the development of science. If they had treated Aristotle as a dangerous opponent to the faith, it is extremely unlikely that his work would have become a core part of university curricula. Instead of opposing, they embraced it. They contributed to natural philosophy in no small measure. Grant describes these three conditions – the availability of the translated Greek texts, the formation of the medieval universities and the emergence of theologian natural philosophers – as essential pre-requisites to the Scientific Revolution [Grant:1996]. There appears to be an adequate vehicle for the dissemination of Aristotelian metaphysics and natural philosophy in Europe, well-studied and intensely debated. A continuity can be shown between medieval philosophy and that of the early modern period.

3.9 SUMMARY

It can be seen that the necessary cognitive toolkit was available. Logic reasoning was taught, debated and detailed in widely available textbooks. This does not entail, of course, that it was invariably rigorously applied, but the framework was there, and powerful critical assessment was an important, commonly used tool.

Experimental chymists had metaphysical paradigms to work to, though there were several competing factions. Based on Aristotle, with influences from Neoplatonism, Islamic natural science, and Paracelsian matter theory and metaphysics, there were various interpretations, especially with respect to Aristotle. These authorities were subject to much scrutiny and opposition. Such opposition did not always sit well with the Church authorities, which had adopted the Thomist interpretation of Aristotle as orthodox. Despite the fragmentation of the paradigms, they did provide some heuristic value. The mechanical philosophy became to gradually replace Aristotelianism over the century. Boyle’s corpuscular hypothesis was simpler, more readily intelligible than the hylomorphism of Aristotle. Boyle offered experimental proof of abiding chemical species. Challenges were not limited to his doctrine of prime matter and substantial forms but on classification of minerals as well, which Agricola, with his in-depth knowledge and technical expertise, was in a good position to dispute.

Cataloguing of minerals and the enormous number of new plants was no small task, and provided the informational basis for taxonomical classification. The search for natural kinds appears to have been widespread from earlier eras (the recognition of metals as a natural kind) if not articulated as such. There seems to be an implicit expectation of chymists when acquiring chymical reagents that they should, ideally, be pure. There was debate, however on whether species could be defined (Locke and Leibniz) and the issue of real and nominal essences. Alchemical taxonomy could be confusing and ill-defined, but advances were made in classification of minerals and flora. Many of the tests used for identifying minerals are still in use today. New instrumentation, such as the microscope, enhanced the ability to define chymical species (e.g. by crystalline structure). Studying the vast number of illustrations of plants was an enabling factor in Ray’s taxonomical division between monocotyledons and dicotyledons, distinguishing major groups. It has been argued [Kornblith: 1993] that a natural kind is a stable homeostatic cluster of properties that are bound together in nature; only certain combinations are viable. “The causal structure of the world as exhibited in natural kinds thus provides the natural ground of inductive inference” [*ibid*].

4 EARLY CHYMICAL TEXTBOOKS- AGRICOLA, LIBAVIUS, BÉGUIN

4.1 INTRODUCTION

Textbooks are clearly an efficient vehicle for disseminating information. Some might be simply collections of recipes, or descriptions of apparatus. Even this is useful, an advance on the earlier practice of handing down technical information by word of mouth, being less likely to be lost, though of course losses still occurred. Some textbooks included theory as well, though some remain esoteric, and occasionally misleading. Often textbooks were a natural output of lecture notes for students at the universities, as with Béguin, for example. I have looked for evidence of *epistêmê* informing *technê* and vice versa.

4.2 CHYMISTRY AT THE UNIVERSITIES

Chymistry was normally taught as part of the medical curriculum. Indeed it was often referred to as an adjunct to the discipline of medicine. There was some reluctance in the early modern period to accord it a higher status. Until the seventeenth century, chymistry had been taught by professors of medicine, but in 1609 Johann Hartmann (1568-1631) was appointed to the chair of Chymiatria[19] at the University of Marburg to give public lectures on iatro-chymistry, or medico-chymistry [Debus: 1990]. Debus, however, suggests that describing it as the first chair may not be entirely accurate, given the likelihood of chymistry courses combined with medicine at an earlier period [Debus: 1990]. Twenty years on at the University of Jena, Werner Rolfinck (1599-1673) was teaching anatomy, surgery, botany and chymistry, and in 1639 he was appointed '*Director exerciti chymici.'* "This has repeatedly been referred to in the literature as the first university appointment in chemistry, a claim in which there is only partial truth because of the likelihood of earlier chemical instruction through medical courses elsewhere and because of the frequent confusion among historians of science between chemistry as we understand it and the chemical medicine of the Early Modern Period" [*ibid*]. "Hartmann's appointment, like Rolfinck's, has been claimed as tantamount to the foundation of a chair of chemistry. Taking Hartmann as the first chair of Chymistry, Davidson would therefore be the third professor of chymistry appointed in Europe; in his case no doubt exists about the definite character of the chair and the exact date

[19] Iatrochemistry

of its foundation.” [Read, 1961]. Davidson or Davisson [20](ca. 1593-ca. 1669) born in Aberdeen, emigrated to Paris. His ‘*Philosophia Pyrotechnica’,* (*Philosophy of the Art of Fire, or Course of Chymistry*) was a manual of chymistry published for his students in four parts, between 1633 and 1635. It was not translated from Latin into any other language except French. Davisson was succeeded by Nicolas Le Fèvre, Christopher Glaser and Moyse Charas, all of whom were to write important chymical works [Debus: 1990].

“There was, however, no official instruction in chymistry in Oxford or Cambridge until the 1680s” [*ibid*]. Interest was not lacking, however, and chymical laboratories were established in England, including Boyle’s in Oxford in 1654. Le Fèvre, Apothecary to Charles II, worked in the laboratory at St. James’s Palace [Partington: 1962]. “Elias Ashmole (1617-1692), antiquarian, alchemist and member of the Royal Society, planned the Museum at Oxford which would include a chemical laboratory” [Debus: 1990]. Dr. Robert Plot (1640-1696) was appointed the first Professor of Chymistry at Oxford in 1683. Plot was influenced by traditional alchemy and Van Helmont, but is thought possibly to have used Lémery’s *Cours de Chymie* as a textbook [*ibid*]. In the early eighteenth century the teaching of chemistry under the influence of John Friend and John Keill became more Newtonian [Debus: 1990]. Regular chymical lectures became available at Cambridge from 1683 also, though laboratory facilities were very limited [*ibid*].

In Germany, lectures on chymistry at Jena had been inaugurated by Zacharias Brendel (1553-1617) after he had been appointed Professor of Medicine in 1612. He gave lectures to medical students in 1613 and again in 1615. Debus remarks that this was a relatively early date for chymistry lectures. Brendel’s son, Zacharias Brendel Jr. (1592-1638) was appointed Professor of Medicine in 1627 and gave lectures on chymistry for medical students as well. These lectures were the basis of his textbook *Chimia in artis formam redacta* (1630) [Debus:1990]. Four further editions were published between 1641 and 1671. Chymistry still was treated as an adjunct to medicine and described as an art, but very highly rated. Brendel’s practical textbook designated four determinate heat levels: the water bath, the ash bath, flame and the blast furnace [Debus: 1990. pp184-185]. Rolfinck, who had studied under Sennert, was Brendel’s successor and the first professor of Chymistry at Jena [*ibid*]. In 1641 he was appointed the first Professor of Chymistry at Padua [*ibid,* p184]. Leiden was the principal university for chymistry in the Netherlands, due to the influence of Hermann Boerhaave

[20] Also known as Dr D’Avissone

(1668-1738) whose courses attracted an international clientele. His textbook of chymistry *Elementa Chemiae* ‘Elements of Chemistry’ (1732) was an enlarged and revised edition of his lectures, and was translated into several languages [Partington: 1961].

Rossi (2000) notes that the large body of literature available in the sixteenth century was rich in technical treatises. It includes the works of engineers, artists and master craftsmen. For example, there were two treatises by Georg Agricola on mining and mineralogy, three books on mechanics by Simon Stevin or Stevinus (1551-1617). Treatises on navigation by Thomas Hariot (1560-1621) and Robert Hues (1553-1632), were published respectively in 1594 and 1599 [Rossi:2000]. Libavius' *Alchemia* was published Frankfurt in 1597. This comprehensive tome, designed to be used as a textbook, (and often cited as the first modern-style textbook) contained instructions on apparatus, instrumentation and chemical reactions and recommendations on laboratory layout (see Chapter 1). Further details of his book are discussed below.

Tyrocinium Chymicum was a set of chymistry lecture notes collated by Jean Béguin and published in 1610 in Paris, France. Many of the preparations given were pharmaceutical, aimed principally in teaching chemical procedures to apothecaries. Another significant French publication was that of Nicolas Lémery’s *Cours de Chymie* in 1675. This was translated into English, Dutch, Italian, German, Spanish and Latin and went into many editions [Clericuzio: 2006]. These would have been available to seventeenth century readers. Nicaise Le Fèvre, in his *Traite de la chymie* (1660) describes chymistry as the art and knowledge of nature itself [*ibid*].

I have selected a limited number of these textbooks to examine in detail, from the end of the sixteenth to the close of the seventeenth century. I have looked for differences across the period. Specifically, does the theory inform the practice? Or is the theory detached from what is essentially a book of receipts? I explore whether these books include *epistêmê*, or *technê.* Parry (2014) discusses the difference between *epistêmê* and *technê* as defined and discussed by many of the ancient schools of philosophy. Epistêmê is usually understood to mean knowledge while *technê* is often translated as craft or art. It is not quite so straightforward, as *epistêmê is* closely connected to *technê* as skill or practice. *Epistêmê* may be considered as scientific knowledge, but not necessarily as scientific as in the modern term, which includes the conducting of experiments to confirm hypotheses. It is, rather, to emphasise the certainty of the knowledge [Parry: 2014].

"As the concept of *technê* develops, the role of reflective thought is emphasized. Whereas *technê* is associated with knowing how to do (*epistasthai*) certain activities, *epistêmê* sometimes indicates a theoretical component of *technê*. Then it is associated with understanding (*gnôsis*)" [*ibid*].

Many sixteenth and seventeenth century chemists, aware of the lack of recognition of chymistry as an independent discipline in its own right, sought to elevate its status. One of the ways in which this recognition might be attained was the systemisation of alchemical and chemical textbooks. Agricola's *De re Metallica*, published in Germany in 1556, was an extremely comprehensive treatise on mining and metallurgy and was recognised as such [Agricola: 1557]. Another example, described by Clericuzio, is that of Libavius who endeavoured to introduce chymistry into the university curriculum. To achieve this, he attempted to demonstrate that chymistry had both a theoretical basis and a logical method of practice. In his *Alchemia*, he reformed the chemical terminology, discarding much of the obscure (and much criticised) language of the alchemists. He was strongly opposed to the Paracelsian influences on chymistry, promoting Aristotelianism in its stead. In this aim he was not entirely successful, though he did influence some contemporary textbooks [Clericuzio: 2006]. Lang [2013] describes Vannoccio Biringuccio (1480-1539) as the first metallurgist of note. Born in Siena, his *De la Pirotechnia* (*Concerning Pyrotechnics*) was published posthumously in 1540. His work, though less sophisticated than Agricola's, emphasised careful observation practice and experimentation. It was published in Italian, French, English and German [Zietz: 1952]. These are just a few of the chymical textbooks published in the period; I have selected six of particular note.

4.3 AGRICOLA: DE RE METALLICA (1556)

Agricola's most well-known treatise, *De Re Metallica*, [Agricola: 1557] is undoubtedly a very fine and detailed textbook on all things pertaining to mining and metallurgy. Its twelve chapters cover a wealth of subjects, in great detail. To give a brief indication of its range, it covers mining law, mineralogy, tools, shafts and tunnels, surveying, assaying, and how to make and use almost everything needed for (relatively) safe and efficient mining. The breadth of material, with its attention to detail, is impressive. He takes great care to avoid the risk of misunderstanding or ambiguities in his instructions. The very many woodcuts assist the understanding of the text. These show for example, tunnels and shafts, engines for raising the excavated soils, all with appropriate labelling. It is somewhat lacking a clear exposition of his theory, however. This can be found in other works (Chapter 4.3.1).

He makes clear his approach: "I have omitted all those things which I myself have not seen, or have not read or heard about from persons upon whom I might rely" [Agricola: 1557: Hoover & Hoover: 1950, xxxi]. "That which I have neither seen, nor carefully considered after reading or hearing of, I have not written about. The same rule must be understood with regard to all my instructions...." [*ibid*, xxxi]. One has the impression of an authoritative text, earnest in its desire to teach practical subjects down to the smallest detail. Does it promote understanding as well? His theory does inform the text; and his insistence on the importance of observation is emphasised.The book itself is a very practical textbook, intended for estate owners and their administrators, to enable them to understand the working processes of the miners and ancillary workers. .

Agricola notes that there is a dearth of useful books on mining and metallurgy although these disciplines are least as old as agriculture. There is only Pliny (C. Plinius Secondus) plus very few others, such as *De la pirotechnia* by Vannucci Biringuccio (1480-*c.*1539) of Siena. [*ibid* xxvii]. Given the lack of metallurgical treatises it is "all the more wonderful" that so many alchemists claim to transmute metals. Their language is obscure and their nomenclature inconsistent. But the strongest evidence of their incompetence, deceitfulness or lack of a viable hypothesis is their distinct lack of success. If transmutation of base metals worked "they would have filled whole towns with gold and silver" [Agricola: 1557, Hoover: 1952 pp-xxviii-xxix]. A man of strong views, he adds that their fraudulent activities warrants capital punishment. He may have been sympathetic to Dante's view that fraudsters and counterfeiters belong in the eighth circle of Hell. Agricola's theoretical base was Aristotelian, but he had confidence to challenge that authority where he had good reason.

4.3.1 *Agricola's theory of the origin of ore deposits*

Agricola "rejected absolutely the Biblical view", and that of the alchemists and astrologers vigorously on the origin of ore deposits [Hoover & Hoover: 1952 III notes p.46]. That he was influenced by the Peripatetic philosophy, is clear from his writings [*ibid*]. "He accepted absolutely the four elements and their binary properties, as well as the theory that every substance had a material cause operated upon by an efficient force" [*ibid*] In *De Ortis et Causis* and *De Natura Fossilium* is Agricola's attempt to disprove Aristotle's theory of exhalations as the origin of stones and metals. Aristotle proposes this theory in the *Meteorologica III* (Chapter 3).

Agricola gives the definitions of the various geological terms.[21]

Fossils	all bodies of subterranean origin.
Earth *(terra)*	composed of clay, mud, ochre, marl and 'peculiar earths' generally. The origin of these 'earths' was from rocks, due to erosion, transportation, and deposition by water.
Solidified juices (*succi concreti or succi congelati*)	comprised salt, soda, bitumen, etc. being generally those substances which he conceived to be soluble in, and deposited from, water.
Stones (*lapides*)	comprised precious, semi-precious and unusual stones, for example quartz, feldspar etc., as opposed to country rock. These originate mainly deposits from ordinary mineral juice and 'stone juice' (*succus lapidescens*), but also in lesser proportion by transportation of fragments of rock.
Metals (*metalla*)	comprised the seven traditional metals; the compounds comprised the metallic minerals; both were due to deposition from juices, the compounds being from a mixture of juices.

Table 2 Agricola's definition of geological terms

4.3.2 *Naturalism and Scepticism*

Can Agricola be considered a methodological naturalist? He does not invoke the supernatural or occult in his chymical explanation. He is generally sceptical, but occasionally inconsistent; he accepts some statements which seem to have very little support. In *De Re Metallica* [Agricola: 1556], he talks of "demons of ferocious aspect" [Agricola: 1557. In: Hoover 1952, p217] in the mines, which can be put to flight by prayer and fasting. A reason given for pits being abandoned is "fierce and murderous demons, for if they cannot be expelled, no one can escape from them." [*ibid*]. This sits somewhat uncomfortably with the more prosaic reasons to abandon a mine such as insufficient yield or noxious air. But belief in demons or gnomes in mines was a very general belief at that time, and Agricola seems to have accepted it without question [Hoover, p.217, note 26]. However, in general Agricola's commitment to a naturalist methodology supported by observation seems strong. For example, he uses the colour of fumes from heated substances to gain knowledge of the type of solidified juices mixed with it. Generally, blue fumes indicate that it contains azure; yellow, orpiment; red,

[21] This has been tablated from data in Hoover & Hoover (1952) [footnote p46]

realgar and so on. He classifies minerals by their colour, taste, odour, etc., as described in *De Natura Fossilium* [Agricola: 1546].

Synopsis

Agricola was certainly responsible for progress in the systemisation of mineralogy and metallurgy. Some methods had been in use since antiquity -for example fire assay and use of the touchstone to assess purity of gold – but *De Re Metallica* is the first publication which gives such detail and can be considered the first major work on metal assaying (Chapter 7). Such comprehensive descriptions may the result of study of the (rather few) mining and metallurgy publications such as the anonymous German publication *Probierbüchlein,*[22] and Biringuccio's *De la pirotechnia.* He would have also been familiar with the Aristotelian traditional works, Theophrastus, Pliny, and those of Paracelsus, Geber, and other alchemists of the Middle Ages as well as those of his contemporaries. The identification of several hundred minerals is given in *De Natura Fossilium.* In *De Re Metallica,* aside from the methods of precious metal assaying, "the assaying lead, copper, tin, quicksilver, iron and bismuth is almost wholly new" [Hoover & Hoover: 1950, p220]. Most of these methods for these analyses were still in use in the twentieth century. Hoover describes Agricola as the author of "the first proper book on assaying" [*ibid*].

Until the publication of *De Re Metallica* works on these subjects were few, mainly collections of recipes, uncatalogued and with insufficient instructions for novices. These may have been passed down the generation as *aide memoires* [*ibid*, p220]. But apart from his undoubted contribution to the practicalities of mining and metallurgy, an importance aspect of his work is his influence on scientific methodology. This is his insistence on observation to explain natural phenomena, rather than by speculation or deference to authority. He was part of an influential intellectual circle and his major publications were translated into several European languages and went through many editions. The impact of his work including his challenge to Aristotle is likely to have played a part in the gradual rejection of the Aristotelian corpus.

---

[22] This was a collection of notes, probably master to apprentice, lacking formal arrangement.

4.4 ANDREAS LIBAVIUS

Andreas Libavius (ca. 1540-1616) was born at Halle, Saxony. He read philosophy, history and medicine at the University of Jena, later producing textbooks plus works on chymistry and philosophy. His criticism of the Paracelsians was profound and he exposed many expensive 'elixirs' as common drugs promoted as something special [Partington, 1961]. Libavius did not shrink from stating his disapproval on such matters. “Paracelsus, as in many other matters he is stupid and uncertain, so also here he writes like a madman” [*ibid*, p244].

Despite his reservations on Paracelsian methods, he defended the use of chymical remedies against the prohibition in force at the medical faculty of Paris. Although Libavius was a staunch believer in the transmutation of metals [Moran: 2007 p94], he gave strong warnings against fraudulent practices which might tempt the incautious. Partington notes that he had an independent attitude and describes him as an excellent classical scholar. His main fault is credulity and uncritical use of alchymical works [Partington: 1961].

The *Alchemia* is a comprehensive and detailed tome and is considered Libavius' most important work. The first edition was published in 1597; a second, extended version appeared in 1606. Aside from the *Alchemia*, other publications included a collection of essays: *Singularium* was in four parts between 1599 and 1601. This set probably represented Libavius' lecture notes and may have been used as a school manual [Partington: 1961, p246-7].

Contents of the Alchemia

Alchemia is split into sections or books: Book I, *Alchemiae Liber Primus*, *De Encheria*, and Book II, *Liber Secundus Alchemiae, De Chymia* which is split into Tract I, Tract II and Tract III [Libavius: 1957].

In Book I, *De Encheria* (*The first part of Alchemy*) Libavius begins with a definition of alchemy as the art of perfecting magisteries[23] and of extracting pure essences by separating bodies from mixtures. (*Alchemia est ars perficiendi magisteria, et essentias puras e mistis separato corporo, extrahendi*) [*ibid*]. Book I consists of sixty-five chapters which roughly cover the subjects shown diagrammatically in *Tabula primi* (Fig 4) These are the operational methods used to produce chemical substances.

[23] For definition of magisteries, see next section

In general, this part describes the kinds of operations which are suitable for working on each magisterium and essence. The requirement for manual dexterity, along with acuity of the senses, attention and a keen ingenuity, is emphasised. *Encheria* is supported by *ergalia*, the explanation of the tools (instruments and apparatus) and *pyronomia*, the knowledge of use of fire and the application of heat. *Ergalia* and *pyronomia* are essential pre-requisites for *encheria.* The first book is largely descriptive, including details of different types of furnace (reverberating etc) and other apparatus. The Latin edition of 1597 contains only one small diagram (of an ampulla) but the extended German edition of 1606 has in the accompanying commentary many woodcuts depicting furnaces, tools and a proposal for a chymical laboratory.

Libavius sets out his two tables. Table 1 (Figs 4 [Libavius: 1597], Fig 5[24] *Encheria*, begins by bifurcating into Operational Methods (*Elaboratione*) and elevation or raising, (*Exaltatione).* In chapters III-XIII, *De ergalia* onwards, he describes apparatus, furnaces and practical instructions on sealing etc. *De Encheria,* as well as covering apparatus, discusses *De Pyronomia* Chapter XIV, the practical aspects of controlling and applying heat. Chapters on sublimation, distillation, coagulation, corrosion, extraction etc. follow. There is little here of any theoretical underpinning; perhaps he considers this unnecessary for basic, common processes. It is a practical guide meant to equip the reader with the requisite operations and processes along with details of the relevant apparatus.

Book II *De Chymia* is split into Tract I, *De Magisteriis*, Of Magisteries, Tract II *De Extracus* Of Extraction, and a short Tract III *De species Chymicis Compositis* (Of the composition of chemical species.) Fig. 6 [Libavius: 1597] and Fig 7[25]

[24] My translation

[25] My translation

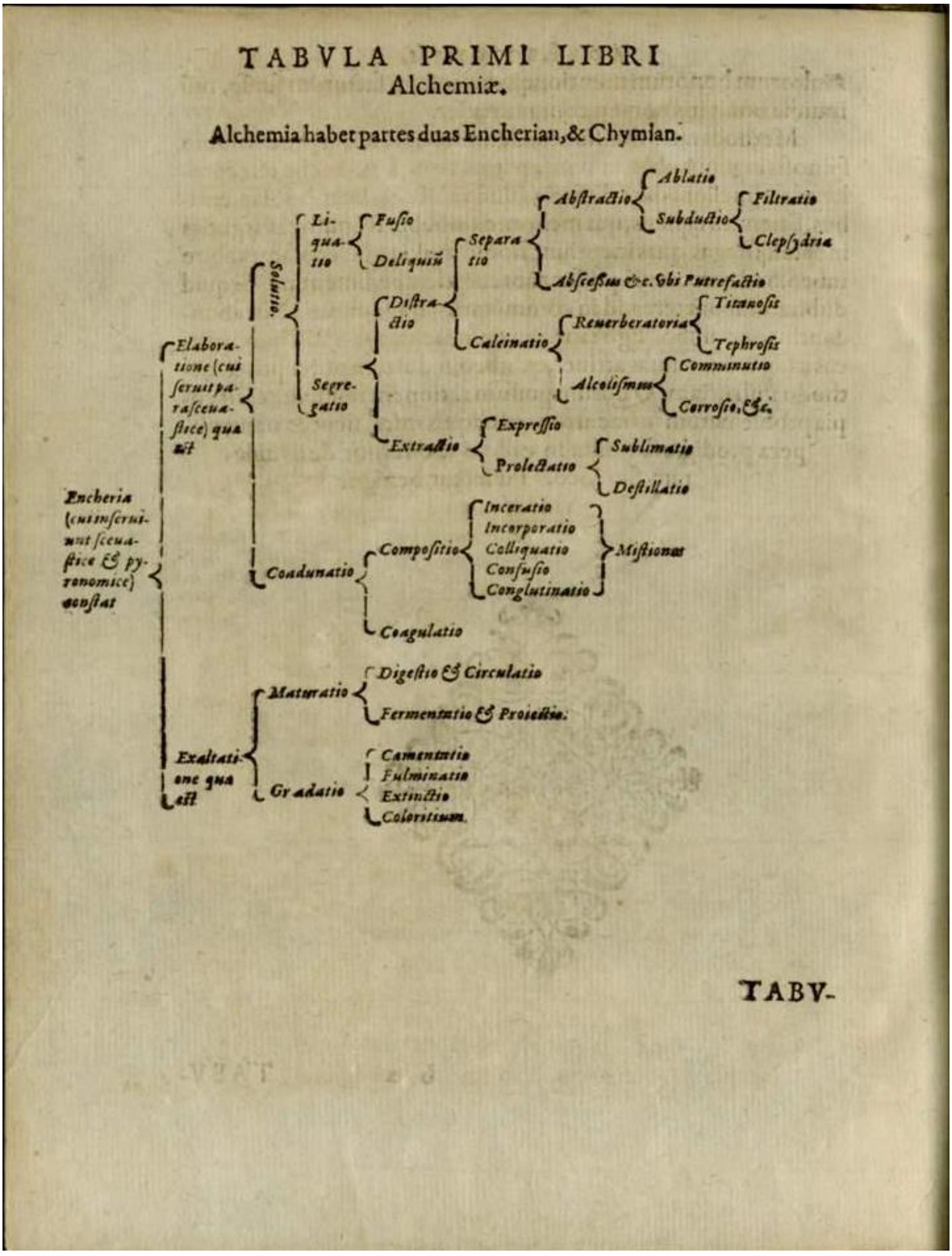


Fig. 4. Tabula Primi Libri Alchemiae

[Libavius: 1597]

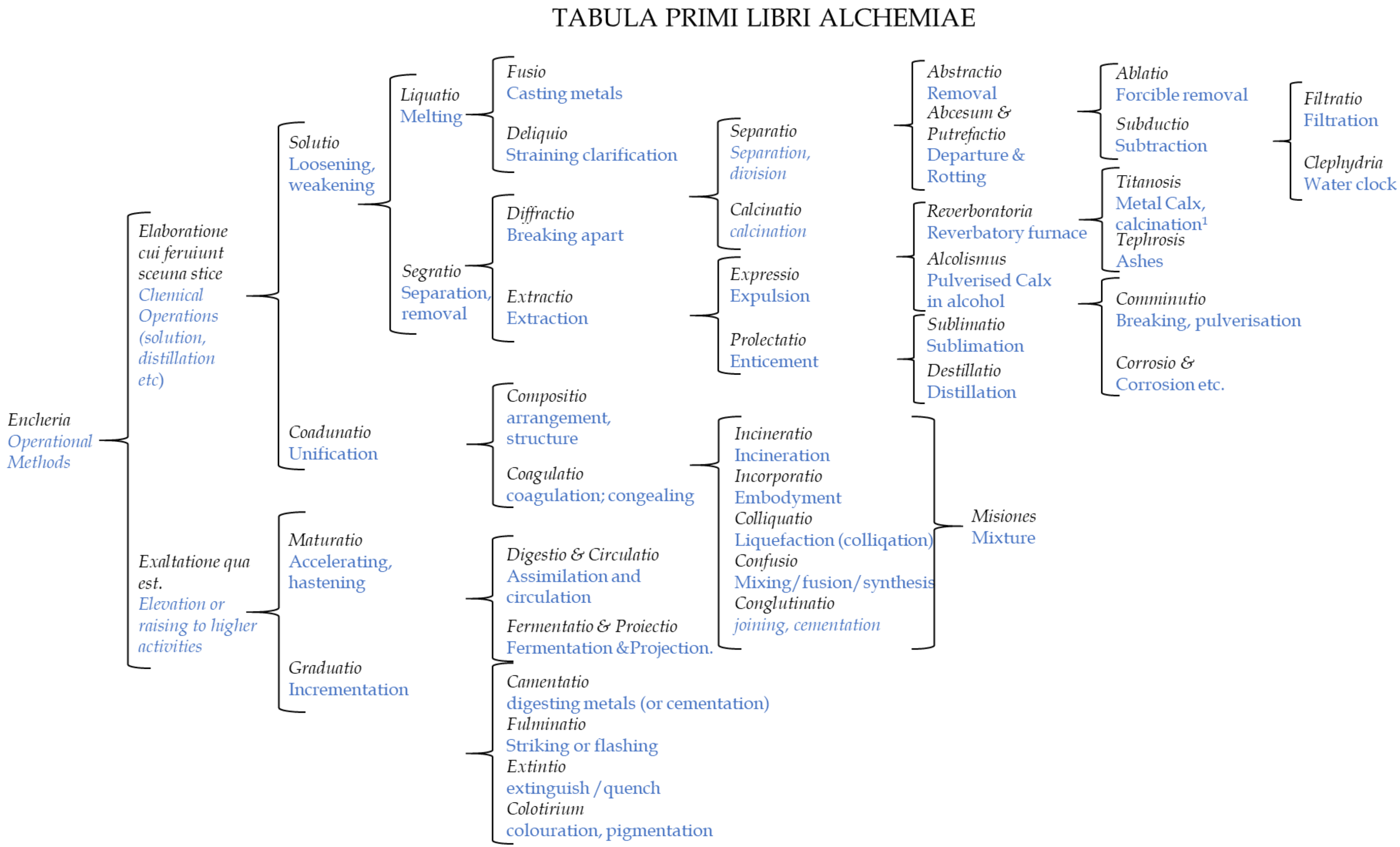


Fig. 5. First book of Alchemy - translation

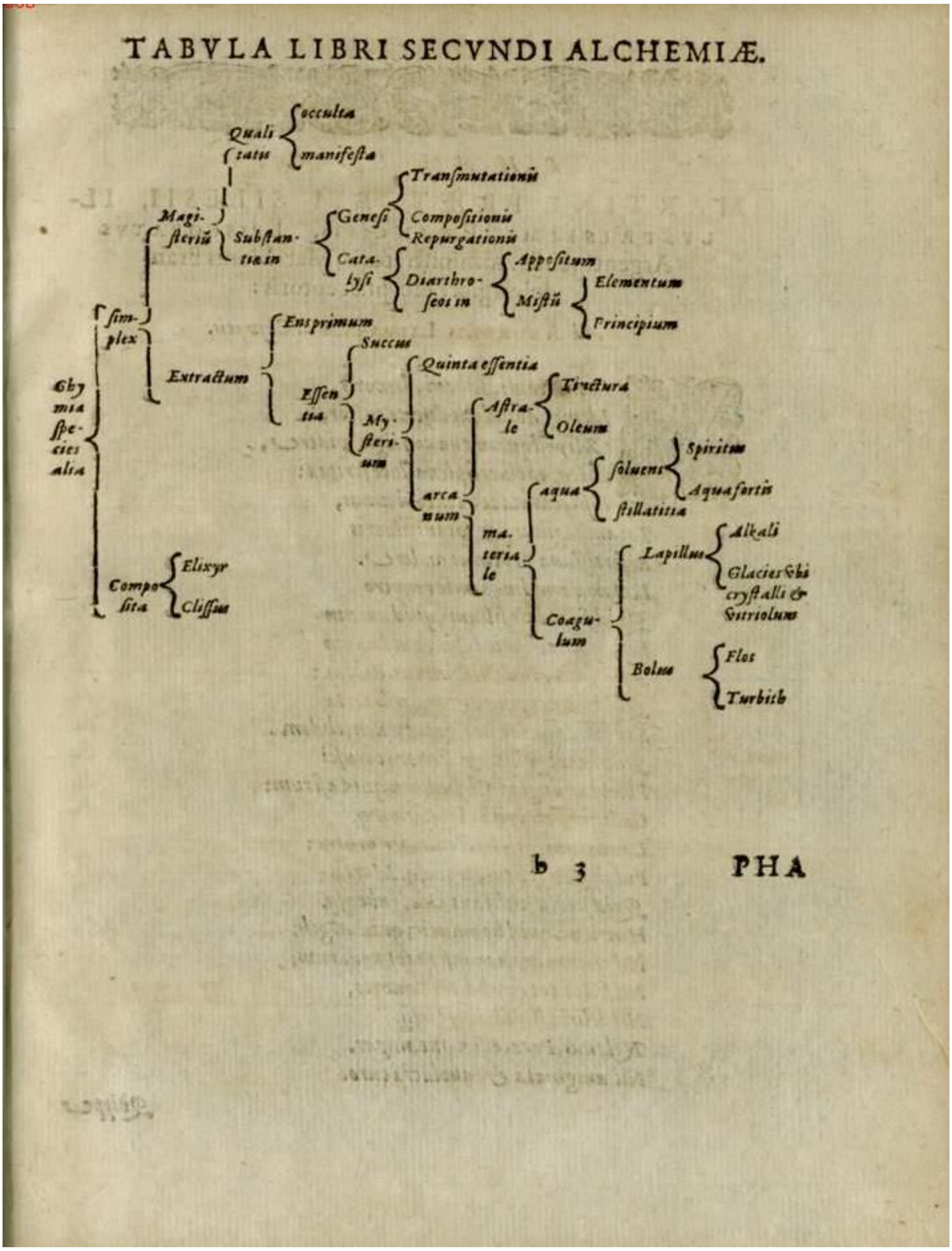


Fig. 6. Tabula Libri Secundi Alchemiae

[Libavius: 1597]

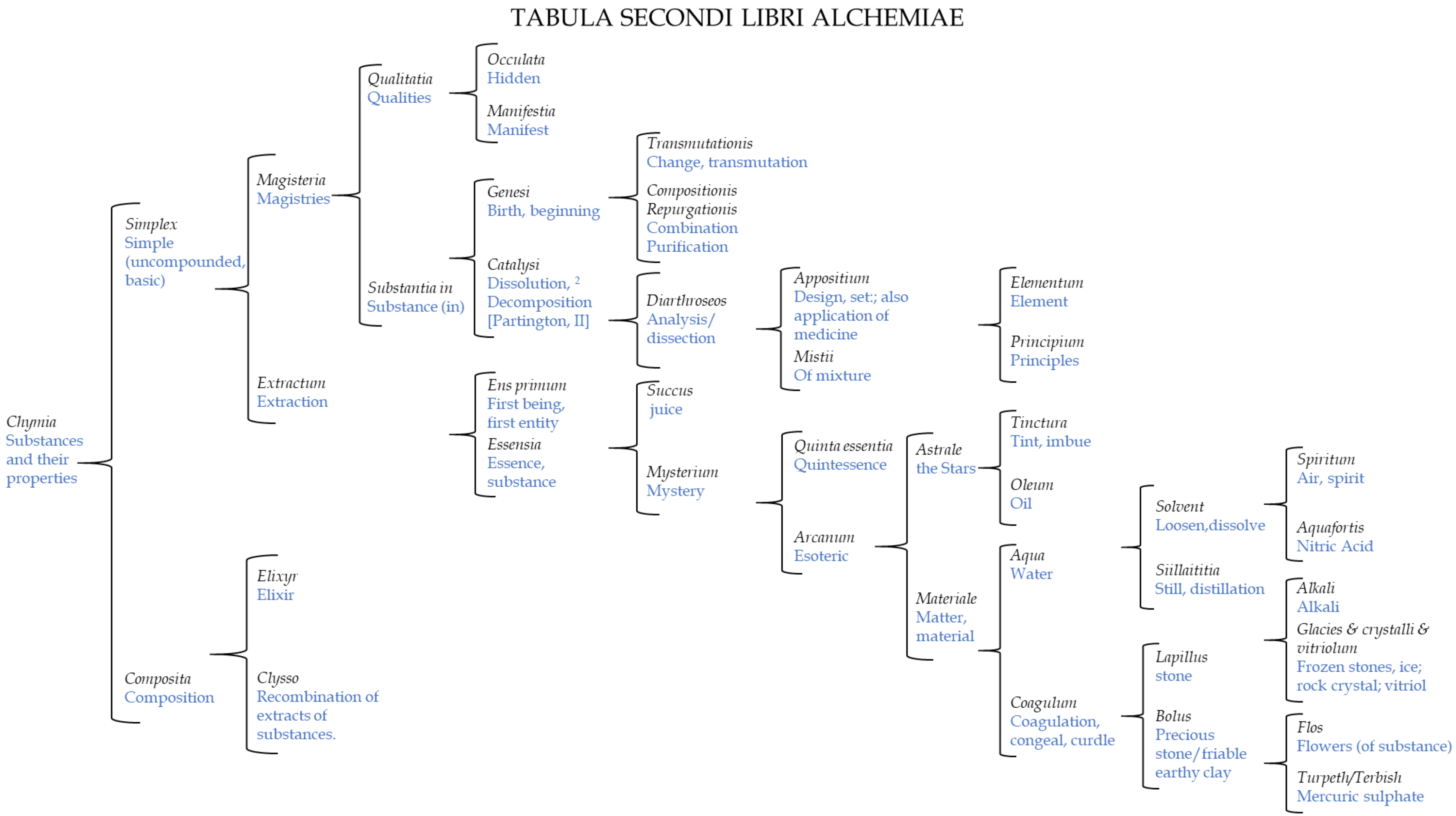


Fig. 7. Second Book of Alchemy - translation

4.4.1 *Magisteries, Transmutation and Mysteries, Quintessence and Elixirs.*

Magisteries

Whilst Book I covers basic processes, more complex chymistry can be found in Book II. In Tract I, Libavius devotes several chapters to magisteries. He defines it as the part of *chymia* which concerns itself with the “exaltation of whole things so that they arrive at some excellence of essence” [Moran: 2007, p255]. Impurities are removed but this is not the same as the operation of making a new substance from extraction.

Moran explicates that magisteries were divided into two types, the 'magistery of manifest qualities' and the ‘magistery of the occult’ [*ibid*]. The magistery of manifest qualities related to the elaboration or ennoblement of outward forms available to the senses [*ibid*]. By contrast, the magistery of occult quality was concerned in improving the effects of the material, not its outward qualities. Magnetism was well-known as an occult quality whereby the magnetic force could be transferred from a lodestone into iron, without, apparently, draining away any of its own magnetic strength. How this could happen was puzzling. Seventeenth-century natural philosophers did have a concept of the conservation of mass, dating back to Aristotle. Libavius' answer was that the magnet could renew itself in the same way as it conferred a power of magnetism on the iron. He called this mystery the ‘magistery of occult quality’. [*ibid*, p256] The magistery can be defined then as a strengthened efficacy. He wanted to know if the transference of the qualities occurred with or without material change; there seemed to be evidence of both options. Where there was no material connexion between bodies, two explanations could be offered as how the qualities of one body appeared in another. The power or magistery that existed in the source body could supply a similar quality in the target subject by means of conception (*in susceptive*). Alternatively, a spirit might pass from one body to another, providing its power *(de inventione magisterii)* [*ibid*]. The Magisterium of a substance divides into genesis (or generation) and catalysis (decomposition/dissolution); the magisterium of genesis divides into transmutation and composition. In this regard, Art follows Nature. The transmutation of the elements are the familiar ones of Aristotle, for example water to air. It seems that in this context of a mixt, Libavius is using it in an Aristotelian sense, as distinguished from a mere aggregation, which he would not consider a genuine case of coming-to-be.

Transmutation

Libavius defended transmutation, saying that nature's change of one element into another was an everyday occurrence. Iron apparently transmuted into copper; indeed springs (the Old and the New Ziment) from the copper mine at Herrengrund, lower Hungary, were known for this effect. Old iron left in the springs, deep in the mine, turn copper coloured. This precipitation of copper from the vitriolic waters was deemed evidence of transmutation. This effect had been reported to the Royal Society [Kazmer: 2004]. This apparent transmutation was generally accepted until around the middle of the seventeenth-century when chymists began to examine the phenomena more closely. Pagel (1969) describes the innovative work of the German chymist and logician Joachim Jungius (1587–1657) who suggested that blue vitriol (copper sulphate) was a combination of copper with spirit of sulphur, and that the proximity of the more imperfect metal, iron, presents the vitriolic acid with a combination for which it has a greater affinity. Hence it releases the copper. "The final proof that there is an exchange as opposed to transmutation is bound up with Jungius' observation of the colour change of the vitriol solution from blue to green" [*ibid*]. At this point the reaction ceases; no more iron can be dissolved when its equivalent amount of copper has been precipitated [Pagel: 1969, p103]. His work, published in 1642, was a significant step in seventeenth century chymistry, laying the groundwork for future developments [Multhauf: 1958].

The process of transmutation Libavius describes [Libavius: 1597 II/I/19] as one that occurs absolutely *per se*, that requires a precursor substance which is similar in nature to the final product. It makes the base material nobler or finer, both in itself and in its use, than the ordinary product. This implies that alchemical gold is superior to ordinary gold. The transmutation of metals involves a retention of a key form. It is unclear if Libavius believes in a plurality of forms or a strict Thomist approach. Is there a form for metal and another for gold? It is not the case, he says, that anything can be made from anything. Therefore, to make gold it is advisable to start with a metal. One reason is the mysterious incomparability of the materials, the other is the multiplicity of the environmental variables. To make a noble metal i.e. gold or silver from a base metal is easier to achieve because of the dualistic nature of the metals which consist of Mercury and Sulphur. Here he seems to indicate that the metals differ not so much in substance but in mere accidents. (Perhaps he thinks that all metals are fundamentally the same; in which case, how does he account for the distinctness of the species?) The job of the chemist is to identify what is missing and to add it in; any metal can in principle be made into gold or silver, fixing the 'mercurial liquor' with the 'soul' of sulphur. These two mysterious constituents cannot be ordinary quicksilver or brimstone. The 'sulphur of gold' must be extracted from gold; once extracted it can be 'exalted' into something with gold-making powers. This 'sulphur of gold' extracted from gold is possessed of a generative power, and can 'lend' this productive power to the matter it is operating on, giving it a 'movement' towards a like form.

A second method for transmutation is the 'projection' of a perfect elixir onto liquid metal. Exactly how this perfect elixir is procured is not clear. Libavius cites the philosopher Pico della Mirandola's (1463–94) account of transmutation. He claims that he has seen silver to gold transmutation without going via mercury. For silver to gold transmutation, you have to add what is missing, i.e. the colour and the weight. Is Libavius thinking, as Bacon seems to have done, that all that is necessary is to add the 'missing' qualities one by one? Something to give it the quality of yellow, for example, or malleability. Two processes of transmutation are believed possible: silver to gold (Pico) and silver to mercury to gold (mainstream alchemy). Because it is an extremely difficult process, a universal magistery, a 'perfect medicine' of metals is recommended to achieve the goal. Libavius concedes that the difficulties are so great that most of the claims to transmutation are fraudulent.

Elixirs

Up to this point he has been discussing simple chemical species, that is ones that arise from a single process. In the following section he moves on to complex chemical kinds. It is clear that Libavius considers a compound medicine a fully homogeneous material, not just a random mix of its miscellaneous parts. Libavius quotes Baptista Porta: he says that an elixir differs from an essence in that it is composed of several species [Libavius: 1597, II/III/I]. An essence is presumably chemically simple.

Libavius give us the recipes for the Elixir of Life[26]. This seems to be a straightforward recipe for a strong, aromatic brew. Distillation would presumably result firstly in an alcohol-based distillate, then a more watery one. The early fraction might well carry away most of the aromatic oils from the herbs and spices. This might give you a liquor something like Benedictine. What medicinal powers this might have is unclear. It is also odd that Libavius gives this easily concocted recipe with commonplace ingredients for what is supposed by the

[26] "You make an infusion of a number of woods, roots, vegetables, orange and lemon peel, etc. in lots of Greek wine. Add lots of herbs and spices - nutmeg, mace, mint, basil, marjoram, pepper… Digest with more wine. Filter. Give it another three days to digest, and then distil." [Libavius: 1597]

alchemists to be a mysterious, elusive elixir with almost magical powers; the ultimate reward for dedicated labours. It might well produce an aromatic liquor - but is this the fabled elixir of life? Perhaps it is meant to be simply a powerful tonic. There are numerous other examples of elixirs in the same chapter.

Synopsis

Libavius states his intention to provide a comprehensive book on chymistry, something which he believes is lacking to date. To provide a clear and evident systematic discourse of the subject, available to all and resting on secure foundations while avoiding the obscure and inaccurate is his stated aim. Does he succeed? In part, but by no means completely. Although Libavius stresses the importance of both technical competence and the application of theory, his own theoretical stance is far from clear. Presumably the intended audience of his textbook would not be expected to be novices. His metaphysics is complicated and not well defined. There are references to vital spirits, which does not preclude naturalism; Bacon believed they were just part of the natural world. He makes “little or no use of atomism as an explanatory theory” [Clericuzio: 2000, p21]. He gives dozens of recipes but does not indicate in most cases where he acquired them from, or whether they are his own original work. There seems to be little attempt at falsification. Libavius appears as a strange mixture of a polemical, argumentative person who is quick to criticise others for views he did not agree with, but seems to accept ancient authorities and formulae lacking any provenance. He seems to be a sort of Janus-faced figure, giving us a series of recipes for metallic transmutation, defending its theoretical possibility against critics, and yet accepts that most of the claims are fraudulent.

How influential was his book? It was certainly comprehensive, and in widespread use. It contains hundreds of recipes and instructions on the basic, as well as the more esoteric, operations. It however lacks the clarity of Agricola's *De Re Metallica*, which is both comprehensive and comprehensible [Agricola: 1556].

4.5 JEAN BÉGUIN

4.5.1 *Introduction*

Jean Béguin (circa 1550-1620) was born in Lorraine, then a Germanic province and studied medicine and pharmacy, possibly at Sedan [Partington: 1961]. To improve his knowledge of metals and minerals he visited the mines of Hungary (in 1604) and Schemnitz (c 1611) [Béguin: 1610]. He settled in Paris where he established a School of Pharmacy and gave public lectures on the preparation of spagyrical drugs. Patterson (1937) describes these lectures, which proved extremely popular, were well-received in most, if not all, quarters. Originally intended as a set of lecture notes for his students, he published a small book of seventy pages entitled *Tyrocinium chymicum* (*Chymical Essays*), circa 1610.An expanded version was published shortly afterwards. It was very influential, and was issued in French, Latin, and English [Patterson: 1937].[27]

It was popular enough to have been pirated and published anonymously in Cologne, much to Béguin's vexation. There were over forty (legitimate) editions, and Boas Hall [1958] notes that it was still being read in the last quarter of the seventeenth century and can be considered more influential than Libavius's *Alchemia,* which was available only in Latin. There was some criticism of the publication by those who were concerned about the accessibility of alchemical secrets and those who disapproved of his Paracelsian views. Béguin had to be cognizant of political opinions, having been censured by the Medical Faculty of the University of Paris.

The book[28] was divided into three sections. The first book starts with the definition of alchemy, followed by '*Of Solution in Genere'* then *Solutions, Calcination, Extraction, Coagulation and Lutation*. Book II covers *Waters from flowers, Aqua fortis, Spirits, Vinegar, Oils Tinctures, Balsams, Extracts, Calcination of metals, and Magisteries*. Book III deals with *Quintessence.*

In Book I, Chymistry is defined as the Art of dissolving and coagulating natural mixed bodies [Béguin: 1610, p2]. Chymistry is not involved in the acquisition of, but is engaged in the practical work, that is of making magisteries, tinctures, quintessences and so on. He emphasises the importance of visual evidence and inspection, which prevail over even well-considered reasoning [*ibid.* Chp.II, p22]. Alchemy is not just concerned with the transmutation of metals; the intention is to prepare the medicines: "most sweet, wholesome and safe medications" [*ibid* p3].

---

[27] Patterson, utilising Ferguson's notes, has made a detailed study of the dates of the various editions.

[28] The English translation dated 1669 is said to be a direct translation from the Latin edition of 1612 [Patterson: 1937].

Béguin discusses the three principles, Mercury, Sulphur and Salt. The chymical solution is an operation in which the natural mixt body, by separation of the heterogeneous parts, is resolved into its own three principles ‘truly stated’ by Aristotle, of matter, form and privation. These principles he describes as ‘rather noetic’ in contrast Galen’s ‘truly hypostatic’ (i.e. fundamental) four elements, viz. Fire, Air, Water and Earth. The alchymist claims that there are three sensible, and *most near principles of sensible bodies*, viz Mercury, Sulphur and Salt. He notes “Chymical bodies possess a nature between body and spirit” [*ibid* p21]. These principles “are neither bodies, because they are plainly Spiritual, by reason of the influx of celestial Seeds, with which they are impregnated; nor Spirits, because corporeal, but they participate of either nature; and have been insignized by Philosophers with various names.” This given in Béguin’s Table:

SALT.	SULPHUR.	MERCURY.
Common Salt.	*Salt-peter.*	*Salt armoniack.*
Unpleasant, & bitter.	*Sweet.*	*Acid.*
Body.	*Soul.*	*Spirit.*
Matter.	*Form.*	*Idea.*
Patient.	*Agent.*	*Informant, or movent.*
Art.	*Nature.*	*Intelligence*
Sense.	*Judgment.*	*Intellect.*
Material.	*Spiritual.*	*Glorious.*

Table 3 Béguin’s attributes of Salt, Sulphur and Mercury

[Béguin: 1669, p22]. See Appendix F for further details.

Clearly these three principles can be considered metaphysical. He elaborates, saying that by Mercury, Sulphur and Salt are not minerals of a kind which can be extracted from mixt bodies by chemical resolution, such as those purchased from merchants. His next sentence suggests that this notwithstanding, they are ‘more or less’ mineral, as they have an affinity with minerals, differing amongst themselves, property and actions.

Béguin describes how they can be utilised: you cannot unite volatile Mercury and a fixed salt unless you bond it using Sulphur ‘which participates of either principle.’ It tempers the dryness of Salt, the Liquidity of Mercury, by its own viscosity; the density of Salt, and the permeability of Mercury by its own soft fluidness, and the bitterness of Salt, and the sharpness of Mercury, by its own sweetness.

Every mixt body can be resolved into these three principles. His proof is given by the well-known example of the greenwood tree. It can be shown by ‘weighty reasonings,’ but that ‘ocular and evident inspection’ far outweigh theorising. He presents the standard example for the benefit of novices. If you burn green wood, there will be initially certain wateriness, which is not suitable or unlikely to enable it to catch fire. If these fumes are collected, they can be easily resolved into water. This is called Mercury. Next there will be an oleaginous, easily inflammable substance, which if resolved into vapours and will pass into oil; this is called Sulphur. After a while a dry and terrestrial substance remains. Using water to facilitate extraction, in humid and cold conditions will dissolve, and in hot congeal, is a substance that it given the name of Salt [Béguin: ca. 1610]. This is presented as proof, without any further comment. The subsequent chapters continue with calcination, extraction, coagulation, luting, the building of furnaces and so on. It’s a practical volume with simple recipes processes, a useful book intended for novices.

It is in Book II that Béguin gives us his account of how to make ‘*Burning Spirit of Saturn.*’ This has been noted as one of the first descriptions of acetone. Patterson describes the process:

Calx of Saturn or minium (lead acetate or red lead) is infused in distilled vinegar, then digested naturally for one day, and stirred often, so that it does not crystallise in the bottom of the vessel. The menstruum is poured off, and other (unspecified, presumably more vinegar) menstruum poured on until all the saltiness has been abstracted. “The crystals obtained by evaporation are digested for a month with such heat Bain, such that they continually be resolved like oil into Liquor” [Beguin:1669; Patterson: 1937]. Afterwards they are distilled by retort in sand, observing degrees of fire, (presumably he means keeping an even heat) into which a large capacious retort is annexed. If this is not very tightly luted, “so a great fragrance, filling the whole laboratory”, will be lost (i.e. the distinctive smell of acetone would be noticed. After the distillation, when it has cooled, the *caput mortuum* will be observed to be very black, and of no value. From the liquor a yellow oil is formed, supernatant, and a red oil the colour of blood settling to the bottom. The phlegm, by repeated distillations, separated from the burning water, shall keep the ‘most fragrant spirit of Saturn’ as a precious balsam for various diseases. He adds that that a fragrant spirit of this kind can be extracted not only from Saturn (lead), but also from all other metals. The process therefore produces two oils, the yellow oil supernatant (i.e. lying above a solid residue) [Patterson: 1937, pp.260-261].

Boyle repeated this experiment, as described in the *Sceptical Chymist*. There seems to be some confusion over the number of products of the chemical process. Patterson notes that Boyle does not report having two distinct oils. It is suggested that the red oil might have been due to impurities in the lead acetate, or the preliminary digestion of the lead acetate for about a month. The 'spirit' and 'yellow oil' together probably constituted one thing, acetone[29] [*ibid*]. Aside from the important one on acetone, this chapter contains dozens of recipes: calcinations, salts, essences, sublimates and magisteries.

Book III is a short treatise on Quintessences. The definition of Quintessence, which is problematic because there are various characterisations. The term may signify any chemical species which has 'put off the Elementary grossness of matter'; is opposed to a magistery; sometimes it denotes a aethereal, celestial and most subtle substance. After a gallant attempt to collect these assorted interpretations, he adds one further definition; it is taken from the three principles of any mixt body dissolved, and freed by chemical operations from their elementary, sensible, corruptible and mortal quality, and coagulated either into one spiritual body, or a 'corporeal spirit.' The Quintessence conserves the health of the human body, prolongs youth, retards Age, and expels every disease [Béguin: 1669, p127].

Synopsis

There are several points of interest about Béguin's book. After it was published, he had requests from his pupils to have it re-issued in French, and to elucidate the doctrine of the three principles more fully. He eventually agreed to both these suggestions, and to introduce some theoretical discussion [Patterson: 1937, p274]. Jeremias Barth translated it into Latin.

Firstly, it describes the three chemical principles on which the theory is based. Admittedly there is some obscurity over the metaphysical principles and the common substances, but this is not unusual in the time. He appears to be saying there is a type of indeterminate state that has properties of both.

Secondly, it shows Béguin's process to obtain acetone. He was possibly the first, or one of the first to do this, and he has been described as the discoverer. Acetone was to play a part later in Boyle's *Sceptical Chymist*, where he wished to disprove the concept that every substance separated by fire necessarily "was pre-existent in it as a principle or element of it" [Boyle:

---

[29] Incidentally, the name for acetone as 'burning spirit of Saturn' persisted until near the end of the eighteenth century

1661]. His intention was that fire might not only divide bodies into small parts, but might reassemble these parts into entirely new substances [Gorman: 1962]. Gorman describes Boyle's argument [*ibid*]: the particles of one substance, not bound together very strongly, may attach themselves more tightly to the corpuscles of another, added body. In this event the two combining corpuscles would lose their attributes, e.g. shape, size or motion, or other accidents which made them the domination of body they were. From the coalition of these there may arise a new body. Boyle uses the preparation of acetone as an example. He observed that the residue from distillation, though he describes it as 'leaden' differs from the minium, hence he believes that some of the vinegar particles must be firmly attached to the caput mortuum. It was usual in the early seventeenth century to ignore the composition of the caput mortuum, and treat it as of no consequence in the chemical reaction. Béguin ignored it; Boyle did not [*ibid*, p98].

The book demonstrates a lucidity of thought and purpose in its attempt to provide clear instructions of alchemical procedures. These are specifically for medicinal remedies. He believes that efficacious remedies are usually those in which Galenic and chemical constituents are combined. His instructions are generally clear, though some of his terminology less so.

It gives what has been described as a first form of a chemical equation (Chapter 7). Crosland notes that building on this concept, William Cullen and Joseph Black developed a system using lines and darts to represent chemical reactions. This can be seen in manuscripts of 1757-58 which show Cullen's use of diagonal lines to explain four different reactions [Crosland: 1959].

Béguin believed firmly that reason must be supported by experiment. Where he is not convinced of the validity of a chymical experiment, he attempts it himself to test the validity of claims. In his letter to Barth, he claims his proficiency in the crafting of medicinal remedies and intention to commence making these "precious and useful" things as soon as possible. He assures his friend that he will "never have anything rare and elegant" in the art which he would not communicate to him [Beguin:1613; Patterson: 1937]. For the moment, he says, he will not pass on the method, because he has not subjected it to trial. Béguin has strong views that statements alone, however convincing their source, are insufficient as evidence, and must be put to the test experimentally to confirm - or disconfirm - any putative account. He seems to have a nice appreciation of the value of testing methods. Discussing the objections to metallic and mineral remedies, the action of which could be quite vehement, he counters such objections to the supposed lack of efficacy (or outright harm) of such drugs by attacking the physicians who ordered them, or the artificers that prepared incautiously. His dedication to validation by experimentation is exemplary.[30]

Béguin's statement "Chymical principles possess a nature between bodies and spirits" [*ibid* p1] is another example of the belief in a dual nature of principles as both spiritual and corporeal. This concept may help to explain why early modern alchymists expected to be able to extract medicines with extraordinary powers (such as *aqua vitae*) from mundane chemical reagents, which must have, presumably something of the immaterial spirit within them. Similarly, 'philosophical mercury' might be expected to be isolated for use in transmutation, a process in which Béguin had a life-long belief.

4.6 Summary

Textbooks were, and are, an important vehicle for the distribution of knowledge, information and technical practice. Kuhn, discussing the use of textbooks in normal science says that "an increasing reliance on textbooks or their equivalent, was an invariable concomitant of the emergence of a first paradigm in any field of science" [Kuhn: 1962; 2012 p136]. It could be argued that the textbooks in question did not represent adherence to single stable authority ormetaphysical theory. If the textbook is more than just a collection of receipts, it must adhere to a metaphysics. In this era Aristotelianism (including different interpretations of Aristotle, such as monism and pluralism) and other factions, such as Neoplatonism and Paracelsianism, have their influence on the textbook authors.

Nevertheless, these textbooks, collating, organising and preserving past and current chymical practice and theory were an essential part of the growth of knowledge.

Agricola's comprehensive tome was impressive for its scope and detail, was very well illustrated and gave practical directions for a vast range of mining technology. Libavius fulfilled a role in disseminating standards of working, teaching chymical processes and providing prodigious numbers of recipes. The design of Béguin's *Tyrocinium chymicum* became a model for the French chymical textbook in the latter part of the century. Boyle

[30] "For it is very well known how great a number there are, who unworthily approach to this noble Art, and having learned… the use of this Science from books only and not from αυτοψία (autopsy) or proper experience, unadvisedly prepare Stibium or Hydragyry, and so prepared are not afraid to use it inwardly, either for conserving the health of Man, or for restoring the same when decayed. With such precipitates of Chymists, it is no wonder that they that use them be precipitated into the grave" [Béguin: 1669, p15].

regarded Béguin as the authoritative leader of the spagyrical or ‘chymical’ sect [Boas Hall: 1958, p53]. An important contribution was his changing the view of alchemy as simply transmutation of metals to recognition of its practical use as iatrochemistry. Alchemy, or chymistry in the service of medicine might have more credibility (and more utility) as a means of producing ‘safe and salubrious’ medications. His description of acetone and his prototype of the chemical equation, described in the 1615 edition of his book, are important, progressive contributions to modern chemistry (Chapter 7.5.2).

5 SEVENTEENTH CENTURY TEXTBOOKS - SENNERT, LE FÈVRE, LÉMERY

5.1 INTRODUCTION

This chapter examines the output of three significant textbook authors. Daniel Sennert's contribution includes his synthesis of corpuscularianism with Aristotelian substantial forms and the crucial experiment of the 'return to the pristine state'. This was offered as proof that the noble metals can apparently disappear in solution then be regained in their metallic state. Nicaise Le Fèvre's *Traité de la Chymie* is described by Partington as "important for its transmission into French and English circles of German chemistry in a systematic form" [Partington: 1962, Vol III. p19]. He held high office in both England and France and was elected fellow of the Royal Society in 1663 [ibid, p 17]. Nicolas Lémery gave experimental lectures in France which led to his international renown, and published the very well received *Cours de la chemie* (1675). He was once a colleague of Glauber. His methodology and scepticism gives him perhaps the most modern outlook of the seventeenth century chymists.

5.2 SENNERT

Professor of medicine at the University of Wittenberg from 1602, Sennert was a follower of both Galen and Paracelsus, though the latter came in for a lot of criticism. He was a prolific writer, publishing substantial works on medicine and natural science [Partington: 1962]. This analysis focuses on his chymical textbook, *De chymicorum* [31]. Sennert was responsible for introducing the teaching of chymistry into the medical curriculum at the University of Wittenberg [Moran: 2005].

Sennert is interesting for his attempt to reconcile the theories of Aristotle, Galen, Paracelsus and the corpuscular hypothesis. He insists that the prime matter of Aristotle should not be denied; indeed, he suggests that it would be impious to do so. He accepted the Paracelsian *tria prima*, though he expressed concerns about mercury as a Principle [Sennert: 1662, pp62-63] and rejected the Paracelsian belief that the Salt, Sulphur and Mercury were more

[31] *De chymicorum cum Aristotelicis et Galenicis consensu ac dissensu liber: cui accessit appendix de constitutione chymiae* (Wittenberg, 1619), translated into English in 1662.

fundamental than the four elements [*ibid* p51-63]. As a medical man he accepted Galen's theory of the four humours and the doctrine of signatures, with the caveat that signatures alone were not sufficient: "…but we must not trust only signatures…" [*ibid* p134]. The *tria prima* were composed of the four Peripatetic elements, but he also believed the Paracelsian stance that all natural bodies contain a *vis seminalis,* a seminal force which confers life. It is remarkable that he retained an Aristotelian concept of form yet is considered an atomist (or at least a corpuscularian) and accepted occult qualities such as celestial seeds, a strange admixture. Newman explains Sennert's stance: Chymical operations can be explained in terms of *diakrisis* and *synkrisis.* He uses specific terms for the particles which are separated out or conglomerated. The smallest parts are *partes minimae*, (very small parts) the next level are the *partes subtiles* (small 'particles') and the largest are called *partes grossae* (large 'particles'), the terminology of Geberian alchemy [Newman: 2006, pp91-90]. There is no mechanical explanation offered in terms of corpuscles' size, shape or configuration [*ibid* p134]. Sennert does not sign up for the mechanical philosophy.

5.2.1 *De chymicorum*

In this book, Sennert defines chymistry as an Art, not a science. Dispute over Principles is not within the Chymists remit [Sennert: 1662]. However, a significant portion of the text is taken up with theoretical discussions. The early chapters indicate the alchemical milieu in which Sennert is immersed, including a belief in the transmutation of metals. He guides us through a comprehensive account of matter theory starting with his opinion of Paracelsus, (and other authorities) the analogy of the macrocosm-microcosm, prime matter, the elements, the origin of forms, spirit, the principles of the chymists, generation and corruption. I confine this review to the above subjects; the latter part of the book is concerned primarily with medicine. I outline the above and give an account of his synthesis of hylomorphism with the corpuscular hypothesis, including an account of his 'reduction to the pristine state' experiment.

5.2.2 *Authorities*

Sennert places a great deal of reliance on authorities such as Agricola and Libavius, and gives the background to chymistry including Trismegistus, Moses, Mary the Prophetess, and the *Emerald Table.* Presumably he believed it held some truths worth studying. He has no qualms in criticising Paracelsus in no uncertain terms. Sennert does not accept the macrocosm/microcosm analogy [*ibid* Chp 6], on which he claims Paracelsus' chymistry is based. The chymists take this analogy too far, equating it with the real thing, but Sennert challenges them to prove it. Sennert insists on experimental evidence. His invective continues with an attack on his system of the *tria prima*. The Paracelsian elements are the matrices, receptacles in which something is formed [*ibid*, p31].

Transmutation must be accepted; it is wrong to deny the evidence of Arnold de Villanova, Raymund Lully, and Zabarella. He has a counter to the objection that metals are distinct species, and therefore cannot be transmuted into each other. He agrees that the form of iron and the form of lead cannot be turned into the forms of copper or gold. However, if the form of iron departs, then the form of copper may be brought in; similarly, for lead and gold [*ibid* p6]. This is easier in metals because they have one common matter; the Elements are 'transinuted' [transmuted][32] [*ibid*, p7]. He insists that such transformed gold is true gold; chymical gold has all the properties of gold (yellow, malleable etc.) therefore must be acknowledged as such. He does admit that transmutation is a very difficult process, a skill not easily attained.

5.2.3 *The Principles of the Chymists*

Sennert analyses the chymical principles as understood by various authorities. Severinus claims that the three principles are to be found in every individual body; Salt gives consistence of solidity and coagulation, Sulphur with its oiliness tempers the congelation of the Salt; and Mercury by moisturising it with a fluid substance, makes the mixture more flowing [*ibid*, p51]. Hermes says "Mercury is the Spirit, Sulphur the Soul, and Salt the body"[33]. Sennert would like to see a more definitive and clear classification. They call these Vital Principles, because they give strength, faculty and power to things, and are the causes of actions. They call them formal Principles, because they give power of action to things, and open the hidden ways of action, and supply the explication of occult qualities. "Now are there such principles? How, and of what things are they principles?" he queries. Sennert asks: By what arguments may we prove such Principles exist?

[32] For example, wheat and other plants which are perfect species in their forms, turn into chyle, and blood is turned into flesh, bones and membranes [*ibid*].

[33] This is shown in Béguin's table (Chapter 4).

1) Where there are the same effects and qualities in many things, it follows that such qualities are caused by the same thing, i.e. a common principle. "… all things are heavy by reason of the earth, and hot by reason of fire." [Sennert: 1662, p55]. But colours, scents, savours etc are in minerals, metal stones, jewels and plants "Therefore they are in them by some common principle and subject but the Elements are not such a principle because they have no power to produce such qualities. Therefore we must search for some other principles" [*ibid*].

This is not a strong argument, but was an accepted scholastic one.

2) Things can be resolved into the three principles. It is evident that Salt is in all things, though the Chymists say that metals are made only of Sulphur and Mercury. [*ibid,* Chp 11].

There is the claim that a chymist competent with metals can make crystals from them, and subsequently make salt. Though not all mixed bodies taste of salt, it does not follow that there is no salt present. We cannot deny that fire is in all mixtures, though not all things feel hot. This salt is not to be considered an earth, because salt is hot and dry and cleaning, whereas earth is cold and dry. It was a common argument.

5.2.4 *Prime matter, Forms, Generation and Corruption.*

Sennert's interpretation of Aristotle was a version of Latin pluralism. Although accepting that prime matter and substantial forms as fundamentals of the explanation of existence, his interpretation is markedly different from Thomistic monism [Michael: 1997, p275]. He accepts, as orthodoxy, that "prime matter and substantial forms are fundamental principles of what exists" [*ibid*]. Michael describes how he differs from the majority of Aristotelians, in believing that prime matter had a reality of its own, contrasting with their concept of pure potentiality. Aquinas also held that each substantial form is an "absolute and immutable actuality" which determines the nature of an individual substance, and that each substance has only "one substantial form" that inheres in prime matter. From Sennert's viewpoint, there are two kinds of substantial forms, supervening and subordinate. "Each living organism has a plurality of substantial forms and a plurality of grades of matter" [*ibid*, p275].

Prime matter, then, does have a reality. Elemental atoms are composed of prime matter and substantial form; each element has its specific substantial form. Sennert's is a "hierarchical and pluralist" system [*ibid*, p287].

Salt, Sulphur and Mercury have some additional quality, acquired at the Creation. The next (subordinate level of mixts) are formed from the Elements and the *tria prima*. Each level will have subordinate forms. Above the 'first mixts' of Salt, Sulphur and Mercury lie the forms of the metals (generally believed to consist of mercury and sulphur). At the next level up will be the very tightly bonded 'particles' consisting of a mixt of the *tria prima* and the elements, in various proportions. Sennert quotes Severinus [Sennert: 1662, p51] who shows that the three principles are found in every individual of three orders of the bodies of the lower world, animal, vegetable and mineral.

There is much dispute amongst the philosophers on the nature of mixture, and how the elements remain in the mixture. Sennert declares himself in agreement with Scaliger. He defines the mixture to be "the last motion of least bodies to a mutual contraction to make a union." He accepts that it is very hard to see how the union of the smallest thing is made, whether by breaking or by mixture, or whether they are completely lost. His opinion is that in mixture, that the things being united in small parts, should act together by their contrary qualities, *but not lose their forms wholly*. If they lost their original forms, that would result in a corruption rather than a mixture. The forms would unite under one superior form. Sennert declines to speculate whether the forms are broken, or remain whole (similar to virtual remains of elements, perhaps). But it is certain that the forms of the Elements are not abolished, otherwise in resolution or putrefaction there would be a generation of new Elements [*ibid* p74]. This notwithstanding, he denies that the specific form of anything gets its nature from the Elements only; as in every natural thing there is a more Divine Principle and Nature, that gives them their specific constitution, and defines them as a particular species. This leads us to his 'crucial' experiment (described below) designed to show that substances, in this case metals, survive.

5.2.5 *Sennert's Synthesis of Aristotle's Hylomorphism with Corpuscularianism*

Sennert was a thorough-going Aristotelian, reluctant or unable to let go of the concept of substantial forms, but could not reconcile experimental evidence with Thomistic monism. Corpuscular theories, holding that matter was made up of minute particles, had been extant in the Middle Ages [Newman: 2006 p24]. Democritean atomism offered little explanatory power. Sennert was a corpuscularian, but remained an Aristotelian as well. Insisting on proof by experimentation, he attempted to meld the theories together. Chymistry, using *diakrisis* and *synkrisis* could explain chymical reactions, to a degree. In this it had superior explanatory power to Aristotelianism. He believed that his "reduction to the pristine state" experiment would prove that a substance (a metal in this instance) could be recovered after it had apparently disappeared. In the monist view every substance has a strict unity and has only one substantial form. The form never exists without matter, and matter does not exist without a form. Every compound is composed of all four elements; consequently, all of them may be extracted from every compound. In *On Generation and Corruption,* [Aristotle: c.350 BC; Joachim:] states that the compound must be uniform., "..any part of such a compound being the same as the whole, just as any part of water is water " [*ibid* I, 10] i.e. it is homogeneous or homeomerous.

In synthesising these pluralist concepts with the corpuscular hypothesis, he attempted to show that Aristotelian substantial forms were a necessary feature of matter theory, unlike Boyle who wanted to prove that substantial forms had no place in corpuscularianism. Sennert set out to prove his theory with what has been called a crucial experiment.

The Crucial Experiment – Reduction to the Pristine State

"If gold and silver be mixed together, they are so thoroughly mixed per minima that the gold cannot in any way be detected by sight, but if *aqua fortis* is then poured on, the silver so thoroughly dissolved that no metal can be detected in the water by sight. But since it is really present, it can emerge, thence into a segregated form, and certainly in such a way that both the gold and the silver retain their own nature; and it is in this fashion collected into the subtlest calx, which is nothing other than a heap of innumerable atoms, which is again reduced into the purest gold and silver by fusion" [Sennert: 1662, Newman 2006][34].

Newman explains the process. Adding aqua fortis to an alloy of gold and silver gave a solution in which the metals were indiscernible. By adding salt of tartar (potassium carbonate) to this solution and heating it in a crucible, he was able to precipitate out the silver, demonstrating that the silver, in particulate form, remained in the mixture. This process, known as "reduction to the pristine state" enables the silver to be visually

---

[34] "*Si aurum et argentum simul liquescant, ita per minima miscentur, ut visu deprehendi aurum in argeto nullo modo possit. Si vero postea aqua fortis affundatur, ita solvitur argentum, ut ullum metallum in ea aqua deprehendi visu non possit: cum tamen revera insit & hinc segregatum emergat; & quidem ita, ut & aurum & argentum suam naturam retineat; & hoc modo in subtilissimam calcem, quae nihil aliud est, quam congeries aliqua innumerabilium atomorum, redigatur, quae in aurum et argentum purissimum fusione iterum reducitur."*[Sennert: 1619: Chp. XII].

identifiable as the original reactant. This conflicts with the Aristotelian interpretation. [Newman: 2006].

Synopsis

How successful was his synthesis? Although he used it in an attempt to retain Aristotelianism in the face of growing criticism, ultimately it failed to survive. His work was opposed by Boyle, particularly in his *Forms and Qualities.* Sennert's crucial experiment of return to the pristine state was appropriated by Boyle in support of his own version of the corpuscular theory. Sennert does seem to be attempting to optimise chymical method, delving deep into the chymical structure. His trust in authorities notwithstanding, he supports his conclusions by experiment, and is not chary of challenging received opinion when this is invalidated by experience. Although he uses the term 'atom' he is usually referring to minimal parts, the last point of analysis rather than a Democritean atoms. There is no discussion in this text of indivisibility or vacuum.

Sennert was an influential writer, with a strong classical education and an enquiring mind. His incisive commentaries demonstrate his desire for clarity and consistency in alchemical and chymical theory, and his reliance on empirical data for proofs.

5.3 Le Fèvre

The Frenchman Nicholas Le Fèvre[35] (*c.*1615–1669), son of an apothecary, was tutored in medicine and philosophy at *l'Académie de Sedan.* Le Fèvre practised as an apothecary in Sedan until 1646 when Samuel Cottereau Du Clos became his patron. Du Clos, clearly a man with connexions, was one of the founding members of the French *Académie Royale des Sciences.* Le Fèvre delivered lectures of international repute in pharmaceutical chymistry. In 1652 he was appointment royal apothecary and demonstrator of chymistry at the *Jardin du Roi,* and in 1660 moved to London to become apothecary-in-ordinary to the royal household of Charles II. He managed the laboratory at St James's Palace. Le Fèvre was elected F.R.S. in 1663 [Partington: 1962 Vol III].

In Paris in 1660 he published his *Traité de la Chymi*e (*A Compendious Body of Chymistry:* An English translation appeared in 1664 followed by a second in 1669. It was also translated

[35]Also known as Nicaise, Nicasius; Le Fevbre, Le Fèvre.

into German and Latin [*ibid*]. His metaphysics is basically Neoplatonist, with influences from Aristotle, Paracelsus, and contemporaries such as van Helmont and Glauber. Le Fèvre refers to the Universal Spirit and the World Soul frequently in his work, accepting it without questioning its veracity; it was a prevailing metaphysical theme of his milieu. There is no reference to the mechanical philosophy in the *Traite,* although it would be well known to his Royal Society colleagues. Perhaps his Neoplatonic sympathies were so far removed from a mechanistic view that he did not consider it a contender. He may have considered a mechanical explanation unnecessary.

The *Traité* is divided into two main books. Book I *Of the Body of Chymistry abbreviated* is intended to cover the theoretical groundwork, the second the practice of the art[36]. A brief look at the long history of chymistry follows: expertise in metallurgy and mineralogy; calcination known from the time of Moses; and the purification of gold was described by Hippocrates [*ibid*]. This first section describes principles and elements of natural things; this is followed by purity and impurity. Part II of the *Abridgement* covers solutions and coagulations, degrees of heat, vessels, furnaces (with illustrations) and lutations.

The Purpose of Chymistry

In the Second Book [Partington: 1961 p101] is *The Treating of Chemical Operations.* This includes operations of separation and purification of the first five substances, (Water, Spirit, Oil, Salt and Earth) extracting principles or juices of vegetation (roots, leaves, flowers, seeds) animals; of fermentation and so on. In the *Preliminary Discourse* he asks whether chymistry should be called an art or a science, and how should it be defined. His answer is the difference lies in their inferential ends or purposes. The scope of science is to contemplate, and its end is to attain knowledge by that contemplation, not by making things [Le Fèvre: 1662, Book III Part I/7]. Art on the other hand is concerned with operational practical accomplishment. Within this aspect of chymistry is iatrochemistry, the purpose of which is to attain practical goals, assisted by theory. At a lower level is pharmaceutical chymistry, in which the apothecaries practice their art, guided by the iatrochemists. Chymistry can therefore be called both science and art; it is a practical or operative science (or knowledge) of natural things. Le Fèvre insists that the practical side of chymistry must be informed by the theoretical. To practice chymistry without the benefit of the theoretical side brings it down to

[36] This theoretical part takes up about twenty percent of the whole, a substantial proportion.

the level of the empirics. But it is also necessary that the chymical philosophers appreciate that *technê* also informs the theory. He has little time for scholastic philosophers who discuss the ontology of the substance of a body *ad infinitum* without coming to any useful, practical conclusions. This he contrasts with a chymical physician or naturalist who will demonstrate the attributes of, say, a mixed body, by subjecting the senses to the smell, texture, taste etc. of the component parts. It's a very practical illustration, and displays a preference for the physically demonstrable to the "airy and notional arguments" [*ibid*, p10]. Stick close to visible and practical things. Then if we think a body is made of an acid spirit, a bitter salt, and a sweet earth, we can make these (component) parts manifest to the senses, and perceive all the conditions that we have attributed to them [*ibid*].

Chymistry is the application of theory to practice**.** How closely is this followed in his *Traité?* He expounds the metaphysics in considerable detail, not just in the theoretical section but appears within the recipes and processes throughout the text. It is not clear, however, to what extent theory informs the practice. And there seems to be little of the reverse process, with practical experience or testing to modify theory.

Theoretical Aspects

This theoretical section begins with Part 1, *Of the Principles and Elements of Natural things.* One cannot assume that the natural body is the only object of chymistry, as it is also concerned with the universal spirit. This has many designations including vital substance, spirit of life, Mercury of life and others. Chymists assign to Nature two elements, one Spiritual, the other Corporeal; the virtue of one being hidden in the bosom of the other. The *Universal Spirit* seems an integral part of chymical theory. It is also highly metaphysical, resting on a Neoplatonic world view of the universal soul or spirit. He describes this spiritual substance as the primary and sole substance of all things, consists of three distinct substances, or rather it is one essence with a 'threefold denomination' or aspects. [*ibid*, p15]. In respect of its natural heat and fire, it is called sulphur; in respect of its moisture it is known as Mercury, and in the respect of extreme dryness or drought it is called Salt. This spirit has undoubtably been created by the omnipotency of the First Cause, when it was extracted out of nothing [Le Fèvre: 1662 I/16]. He quotes Virgil[37]: "the spirit within nourishes, and the mind that is

[37] "*spiritus intus alit, totamque infusa per artus mens agitat molem et mango se corpore miscet*" [Virgil: ca 29-19 BC, Aeneid]

diffused throughout the living parts of nature activates the whole mass and mingles with the vast body of the universe" [Virgil: ca 29-19 BC].

Le Fèvre continues: "For all the parts of the Universe are in continual need of supply and presence, as we discover by the effects: and if by any accident hath been deprived thereof, he immediately returns to possess it, and taking its place, restores life by his arrival. So we see, that having extracted from the salt of Vitriol several substances contained therein, if the dead earth, or *caput mortuum*, be exposed to air, in some sheltered place free from the washings of rain, this spirit will not fail to return to it, being potently attracted by this matrix i.e. an earth, whose earnest longings is to fill itself with this spirit, which makes the principal part of all things existent; for as things are only destinated to their operation, so they cannot act, but by their efficient internal Principles. Therefore God, who ever works by the most compendious way, and will not every day busie his Omnipotency in the creation of new substances, hath once and for all created this Universal Spirit, and placed it everywhere, that he might operate in all things" [*ibid* I/16]. A further elucidation follows: The spirit is universal which is imprinted with the character of the mixes (i.e. prime matter is informed) according to the matrices. These diverse matrices receive the spirit to make it a body. Thus in a vitriolic matrix, it becomes a vitriol; in an arsenical, an arsenic. If it were a vegetable matrix it would become a plant, and so on. The Spirit is embodied in such or such a compound, according to the different Idea it has received from the particular 'ferment'; but that notwithstanding, it can be extracted, by art, out of the compound. It can be removed from the 'gross' body and given a more 'subtle' one, bringing it nearer to its universal nature. This enables it to manifest its own virtues better [*ibid* I/17, pp16-17]. He insists that there must be a reduction to the pristine state, [*ibid* p14] referencing Paracelsus' *Vexations.* But although the spirit cannot return to its universal nature without first losing the 'idea' or form from the matrix in which it was embodied, it can, for a while after becoming disembodied, still preserve a kind of imprint or character of its previous body.

Clearly Le Fèvre believes that the Universal Spirit is a 'given' and must be accepted without argument. It is the foundation of his chemical philosophy. But how his philosophy, and his exhortations that theory informs practice and vice versa is actualised, is less clear.

References to Le Fèvre's metaphysics

The *Traité* is infused with Le Fèvre's metaphysical theory. He refers to the universal spirit in the recipes, for example in Book II Chp V. *Of Dew, and Rain* he specifies the best time to collect water for the formulae. Rain for the menstruum should be collected eight days either side of the Spring equinox[38].

The Universal Spirit is a substance "voyd and divested of all Corporeity" ubiquitous, and radically contains within itself the first three substances, Sulphur, Mercury and Salt. [Le Fèvre: 1662, p 13]

Every chemical substance is therefore analysed with respect to the active Principles and the combination of properties which result in an external sensibility. Resting upon metaphysical presence, it would be many decades before this deep-rooted concept would be abandoned in favour of a more material explanation. There is no concept here of *minima naturalia* as in Boyle's philosophy. Conflation of spiritual and material (or metaphysical and 'ordinary') are frequently seen in the seventeenth century. Indeed, there are reminders in the text to be sure that you have the appropriate type for your recipes. "See therefore you do not mistake Phlegm for Pituite, Mercury for quick silver, and Sulphur for ordinary brimstone..." [*ibid* I/25]. The principles themselves have various appellations, viz., (Philosophical) Mercury is also called Spirit, or radical Moysture.

Chymical Composition

In his discussion of minerals he describes cinnabar as a mineral body, composed either of Sulphur and Mercury, or brimstone and quick-silver [*ibid* I/65]. The two components are coagulated to form a hard, stony substance. The natural substance is extracted from mines but an artificial variety can be made by sublimation of the brimstone and quick-silver. There is no assumption here that the artificial cinnabar would differ, or be substantially inferior to, the naturally-occurring variety.

Le Fèvre's discussions of compounds also demonstrates his scholastic interpretation clearly. [*ibid* V/II]. Here he defines alteration, generation, corruption, and 'mixtio;' by understanding

---

[38] "….because then the Air is all filled and impregnated with those true heavenly seeds that are destinated to the renewing of all natural productions; and when the water hath been elevated from the earth, and deprived of the several ferments wherewith the divers generations made within and without her Womb, had filled her, she doth fall again through the Air, where she is furnished anew with a pure Spirit, undetermined to all things, and fit to assume any shape. And so much shall suffice, to shew the necessity of choosing the Aequinoctial time, for gathering of the Rain-water" [*ibid* p118].

these terms we know how purity and impurity play a part in their generation. He indicates the difference between alteration and corruption, the two types of mixtion, one natural and one artificial. He defines the improperly named, artificial type as local proximity of separate bodies (what we call a mixture). The natural type is a strict union of the substances such that results in a substance which differs substantially from its component parts; a compound. The mixts are described as perfectly or imperfectly compounded depending upon the strength of the union of the principles. Animals, vegetables and minerals are examples of strong unions, while ice and snow differ from water only slightly, by the "adjunction of foreign and adventitious qualities." The imperfectly formed compounds are termed meteors; these represent an intermediate stage in the process of nature towards perfection.

Theoretical statements such as these are frequent throughout the books. Clearly Le Fèvre's objective is to propound his theory; to teach as well as provide formulae. I think he believes that he has demonstrated the correctness of his philosophy. But is there any indication of refutation of theory by experimental evidence? I have not found any. The copious number of recipes are detailed, but their provenance is not given, and it is not known how many are Le Fèvre's own and how many are simply copies. Such an aggregation of the many and varied recipes and instructions was certainly a prodigious task – no small achievement – and judging by the several editions published, in several languages, it was considered a very useful addition to a chemist's library. Whether there can be a similar claim for the theoretical part is questionable.

Classification and Measurement

In his experiment '*The Solar Calcination of Antimony'* Le Fèvre demonstrates an appreciation of weight measurement [*ibid* Chp II]. The experiment is designed to show how the purification of antimony is more effective using sunlight than with nitre. However, Goddard had tried to repeat this experiment in 1664 but found that the weight of antimony, far from increasing, reduced from twelve grains to about three or four. Boyle had no better result [Partington: 1962, p21].

Measurement of quantity in his medicaments are not precise. Quantities are sometimes given for the recipes (see below) but the level of accuracy is not high. In *CHAP. X. Of Minerals and their Chymical Preparation* where preparations of various sorts given, there is no indication of their origin or efficacy. For example, he describes the preparation of an astringent bolus (for external application only, mercifully.) The base ingredient is Bole-Armeniack (a kind of reddish earth, containing iron). This preparation can only be made in the spring, as frog's spawn, an essential ingredient, is available only around March [Le Fèvre: 1662 p87]. It calls for half a bucketful of spawn of frogs, to which half a hundred of crayfishes should be added, then bruised in a stone or marble mortar. It is placed in a linen bag and the liquid is drained off, and purified by percolation. There should be about a pound of liquid which is then mixed with an ounce of crystallised salt-peter and rock-alum. This is then mixed with the bolus until the earth has absorbed all the liquid. It is said to be good for both stopping blood, hindering inflammation, and for salves, plasters and poultices.

At the commencement of this section (*ibid*, Sect. I, *Of Earths*) he reiterates his intention that the chapter will serve as a guide and set rules for the making of these preparations. It is true that he attempts to classify different types of minerals, 'middle minerals' or marcasites, and metals. This classification rests upon the place of origin, the matrix from which they were supplied and certain characteristics. Classification is certainly useful, but this is not a very exact or deep analysis of type. It is difficult to see how his rules and guides of the preparation of the medications, useful though they may be as recipes, give much guidance for future avenues of development, other than at a very basic level. There is no suggestion that any of the medicinal preparations (some of which seem to serve quite diverse purposes) should be subject to any test of effectiveness. Testing seems limited to checking whether the preparation has the correct texture or astringency as described in the recipe.

Synopsis

It seems clear that Le Fèvre, although his book addresses the apothecaries, he expects, indeed insists, that chymistry is both an art and a science; principally it is a practical science with theory informing practice, and practical knowledge must be taken into consideration when contemplating or generating theory.

Does Le Fèvre's metaphysics guide new research? It does not appear to. Would you try to prove that the planets influence the preparations? For example, supposed added value of water collected at the time of the Spring Equinox – is this just hearsay? Some of these rituals just add to the complexity of the process without evidence of their efficacy.

Is there evidence of fruitfulness? Does anything in the theory suggest new avenues to follow? The theory should guide new research; it shouldn't be entirely hit-and-miss approach. Bacon suggests further experiments, a research programme. Boyle sets up experiments to prove a conjecture. These seem to be missing in Le Fèvre's work. There is a lack of scepticism in certain areas. Astrology is accepted without questions. On the positive side, Le Fèvre's treatise was important in the transmission into French and English circles of German chemistry in a systematic form. He was familiar with the works of Basil Valentine, Paracelsus, Van Helmont and Glauber [Partington: 1962]. Lémery's more popular work drew on that of Le Fèvre's practical recipes, but more clearly and concisely written and with much of the mystical parts removed [*ibid*].

5.4 Nicholas Lémery

Born in Rouen, France Nicolas Lémery (c1645-1715) studied with an apothecary in Rouen [Partington: 1962]. In 1666 he left for Paris to work in Glaser's laboratory at the Jardin du Roi. Subsequently he joined the pharmacist Verchant in Montpelier. Here Lémery gave lessons, reported as being excellent, in chymistry, and practised medicine. His next move, in 1672, was to Paris where he later set up his own laboratory in the Rue Grande. It was here that he gave his experimental lectures for which he was renowned. They were attended by all classes, national and international. In 1684 he became physician of Caen, and practiced in Paris. However, this came to a halt after the revocation of the Edict of Nantes (1685) and the instatement of the Edict of Fontainebleau [Partington: 1962, p28-29]. This had been preceded by a series of repressive measures against Protestants and the Reformed Church. Lémery, as a Protestant, did not fare well. His laboratory was closed, and his lectures all but ceased. In 1686 he converted to Catholicism, and resumed his lectures and laboratory work. In 1699 he was accepted into the Paris *Académie.* [*ibid*] His text book, *Cours de la chemie* (*A Course of Chymistry*), first published in 1675 was very popular. It was translated into Latin, English, Dutch, Italian and Spanish [*ibid*]. The second edition in English was published in 1685.

Lémery on the nature and role of Chymistry

Lémery begins with *Of the Principles of Chymistry,* in which he sets out his understanding of the Universal spirit plus the five Principles. He starts with a definition of 'principle'; this is taken to mean a substance which cannot be divided or separated. They may be divided theoretically perhaps, but this division is beyond human power. The first principle, the Universal Spirit, is admitted as part of the composition of the mixts, but he describes it as "a little metaphysical." As such it is insensible and Lémery seems to want to pass over this inconvenience as he is determined to present chemical processes as tangible and demonstrable. However, this metaphysical spirit, diffused through all the world, is admitted as being part for the composition of Mixts. There seems to be some tension here. If it is metaphysical then why is it being invoked as part of a sensible hypothesis; if it is active, is it corporeal, and if so, then in what manner is it metaphysical? Perhaps Lémery is aware of this in its portrayal as 'a little metaphysical' – there is something which he cannot quite explain, but cannot dismiss either. Siegfried [2002] notes that ambiguity in language is a mark of the exploratory, creative period of scientific progress, while acknowledging that it also indicates a period of confusion [Siegfried: 2002 p79].

This First Principle, the Universal Spirit, produces different things according to the different matrices, or pores of the earth in which it settles. He describes this as the universal spirit or acid trickling down from the heavens into the matrices of the earth and forming, after some time, salts. Referring to the alchemists, "We grant unto them, that the Universal Spirit does contain an *Acid* which serves towards the production of *Gold*, because the *acid waters* or *salts* which do enter into the composition of this *metal*, do proceed from the Universal Spirit" [Lémery: 1686]. It may be that the "Acid Spirit of the Air" is synonymous with his conception of the Universal Spirit, or at least it seems to act as such. He makes several references to this 'spirit of the air.' "The *Earth*, which is called *Caput Mortuum*, or *Terra Damnata*, is the last of the Passive Principles, and can no more be separated pure than the rest, but will still retain some Spirits in it; and if after you have depriv'd it of them as much as you are able, you leave it a good while exposed to the Air, it will recover new Spirits again" [Lémery: 1686, p5].

He considers chymistry a path to knowledge[39]. Philosophers, he says, come up with grand ideas, but can prove or demonstrate nothing, with a plethora of schools offering various explanations. Chymistry, however, may bring us as close as possible to the true Principles of Nature; we may obtain this knowledge by studying the division of mixts, and the figure of the first small particles which make up the composition of mixed bodies [*ibid* p278].

5.4.1 *Lémery's mechanical hypothesis*

Lémery paints a picture of a mechanical hypothesis coupled with a robust methodology to ensure the accuracy of his conclusions vis-à-vis chemical reactions. His intentions are clear, but can he justify his suppositions? For example, he attributes the sharpness of the taste of

[39] ".... because Chymistry is an Art that *demonstrates* what it does, it receives for fundamental only such things that are palpable and demonstrable. It is in truth a great advantage to us, that we have *Principles* so sensible as they are, and whereof we can have so reasonable an assurance" [Lémery: 1686 p6].

acidic liquids to their having sharply pointed corpuscles, and the size and shape of pores of various substance is correlated with their chemical reactions. He describes the nature of acids, alkalis and salts: "… the nature of a thing as obscure as that of a salt cannot be better explicated, than by admitting that the configuration of its parts is the reason for the effects it produces" [Lémery: 1686]. "I shall affirm, that the acidity of any liquor does consist in keen particles of salts, put in motion; and I hope nobody will offer to dispute whether an acid has points or no, seeing that every ones experience does demonstrate it, they need but taste an acid to be satisfied of it, for it pricks the tongue like anything keen…" [*ibid* p25]. This seems to go far beyond the evidence. He has a fixed concept of mechanical hypothesis and accepts the common notion of acidity being caused by pointed particles, but this conclusion is not justified by the sensible impression. It could be argued by analogy; a sharp pin causes a sharp pain. Perhaps it is justifiable as IBE.

Explaining the effect of acids on alkalis, he describes the violent reaction observed when the two are mixed. This is due to the acids having points that strike the pores of the alkalis, opposing their motion. Resistance is dependent on the solidity of the alkali; resulting in varying degrees of agitation or effervescence of the liquid. Different alkalis have differently shaped pores. He conjectures that this explains the varying degrees of effectiveness of alkalis (and acids) on other substances. It is apparent that he believes explanation to be well established [*ibid* p26].

He continues: with volatile salts, the 'igneous particles' breaking through the pores of an alkali salt, 'become imprisoned by calcination' and contribute substantially to the agitation, resulting in strong effervescence. Acid salts rarely cause effervescence when treated with acid liquors. This is because the pores are very small, and therefore the common acids are not able to pierce them. However, there are some acids with points so fine and of such proportion that they can enter the exceedingly small pores of the acid salts, causing an agitation or 'commotion.' [Lémery: 1686]. These salts, although called acid, may be described as alkaline, in respect of some powerful acids. Sea salt, for example, is not violently affected by spirit of nitre, or spirit of vitriol or of alum. However, if it is mixed with the strongest oil of vitriol (sulphuric acid) there will be a visible effervescence. He concludes that one acid salt can be considered alkaline in respect of another. This seems to be anticipating our modern acid-alkaline pH scale. The reasoning behind it is corpuscular.

That an acid and an alkali will destroy each other when mixed together was a commonly held hypothesis. As shown by Holmes, this disproved by the French chymists at the *Académie*

(Chapter 6). This neutralisation occurs when as much acid has been added to the alkali such that all of the alkali is penetrated. It is no longer possible to reconstitute the alkali, even by washing it to remove the acid. This is because the acid has broken and lost its points in the contest, especially when the alkali is very resistant. In a similar vein the alkali will have lost its peculiar configuration of pores; that which defined it as an alkali is lost.

Lémery refers to his mechanical theory in several places in the text book, for example, in his treatment of mercury [*ibid*, VIII, p115]. He conjectures that it is probable that the parts of this metal are all of a round nature. He bases this conclusion on the observation that however it is divided it always retains a globular shape. The fluidity of mercury is explained by the little spheres being unable to connect to, so they roll around next to each other. It is volatile because these spheres, being simply contiguous rather than connected, are more likely to be separated than other metals which enjoy strong physical connexions. To the question of why these parts, which are heavier in comparison with other bodies, yet cannot resist fire, he offers a creative explanation. The pores of mercury may be of such a texture that the igneous parts of fire, once they have found a way into the pores, may not be able to find a way out again, and fly up together [*ibid* p155]. Other metals, which are more fixed than mercury, remain unconsumed by fire, because there is no space for the igneous particles to enter and separate them. If the parts are round, it might be argued that mercury should be light, as there will be space between these little round bodies. His counter is that the balls are massive and compact, despite the vacuities. Although the parts of mercury are heavy, it does not follow that every part of mercury is heavy enough to resist fire.

Lémery’s theory does not invoke spirits to explain chemical changes, but rests upon mechanical activity. He does speculate, and mentions some of those which he seems to regard as self-evident. Any opposition is dismissed. But these speculations go beyond the evidence presented or indeed available. For example, his claims about the size of pores of gold could not be substantiated. Even with the microscopes of the time a sufficient level of granularity would not have been available.

The next section of the book consists of practical descriptions followed by furnaces and other apparatus. He includes section on degrees of heat. Next comes a section on chymical terms; fewer than thirty, so a useful but not exhaustive list.

Minerals

In the First Part, *Of Minerals,* Lémery defines mineral as “whatsoever is found petrified in the Earth or upon the Earth” [Lémery:1686]. This petrifaction may be caused by a coagulation of acid or salt waters, found in the pores of the earth. The differing conditions will give different outcomes. The growth of minerals is very different from that of animals and vegetables, the former comes about though an agglutination of congealed waters, the latter by means of juices that insinuate and spread in the vessels and fibres of which the animals and plants consist. Metals, seven in number, gold, silver, iron, tin, copper, lead and quicksilver, are the traditional metals of the ancients. Metals are described as differing from other minerals in that they are malleable, except for quicksilver which he acknowledges does not fit the definition, but is included because it is closely associated with the others, but also because it is thought (by alchymists) to be the ‘seed of metals’ [*ibid* p46]. Note that Lémery does not hold this view himself. Lémery then tells us of the astrologers' view of the metals, with their supposed correspondence with the planets, and how they have given the seven metals the names of the planets, gold being called the Sun, silver the Moon, iron for Mars, quicksilver for Mercury, tin for Jupiter, copper for Venus, and lead Saturn [*ibid*]. Astrologers maintain that the seven planets govern the principal parts of the human body, and that each planet influences our hemisphere; for example, we should work on silver on a Monday, Iron on a Tuesday etc. for optimum results. Lémery dismisses all this as groundless nonsense, easy to disprove. “I have told you what the soberest among them say; for nothing can be so absurd as what some of them would have us believe” [*ibid*, p47]. He is willing to accept that if they could prove any of these claims evidentially, we might have some reason to accept their doctrine, although their principles are false. They have nothing to confirm their opinions; it is shown every day that they are utterly false. Metals may be put to good use in medicinal remedies, but their effects may be better explicated by causes nearer to hand than the Stars [*ibid*, p48]. He regards astrologers as a set of charlatans. A healthy scepticism is apparent here.

Clearly Lémery believes strongly in the requirement for proof in the justification in any hypothesis, and that negative instances must be considered when weighing the evidence. There appears to be an awareness of the need for parsimony, a restriction of ontological entities or at least a search for simpler explanations than those offered by the astrologers, even if he were not familiar with the work of William of Occam.

I have taken some (typical) examples from various chapters on minerals to analyse the level of instruction and explanation given. These are principally from the *First Part.* The later, expanded 1698 edition includes Homberg's discussion on Bologna stone (Chapter 6 on Homberg's experimental method.)

The Criticisms of Alchemy – Ars sine arte

Lémery accuses alchemists of covertness, greed, and conceit. According to their doctrine, nature intends always to produce gold in the mines. Hindrance to this process causes the production of 'inferior metals'. The vanity of the chymists leads them to assume that they can assist nature and 'perfect' the other metals and turn them into gold. To this end they have spared no time, no cost, no pains in their attempt to exalt the inferior metals into gold. Those "most curious and delicate of all" who hunt for the "seed of Gold in the Sun and in the Dew" receive a special mention [*ibid*]. There is no ambiguity in his views on alchemy as a quest for transmutation or the Philosophers' Stone. His very strong scepticism is apparent. He writes of the tricks that charlatans use, and remarks with disgust on their "egregious knavery" [*ibid*, p52].

They had not put the supposed gold to test, for example, that it would be dissolved *by aqua regis*; nor had they checked its malleability or its specific gravity. Without these tests, Lémery insists, it is not reasonable to declare that it is gold. Regarding the purification of gold, he expands on giving various, with indications that he has performed the processes himself [*ibid* p60-64]. He notes the improbability of obtaining pure, twenty-four carat gold, because of the difficulty in removing the last, small amount of silver or copper, even with iterative processing [*ibid* p65].

He concludes that he cannot absolutely state that someone at some time may have not have been able to make gold; but his scepticism is clear: "...there is more appearance of impossibility than possibility in the case" [*ibid*]. We all have only a small knowledge relating to natural mixts. Gold as well as silver is obtained from the mines in which there is water. He conjectures that these waters carry some saline principles that congeal and are incorporated into Earths of a particular composition, which are impossible to imitate by art: "…in order to make *Gold,* a perfect knowledge of the *Salts* that the *Waters* of the *Mines* do convey, is very requisite as well as the disposition of the *Matrixes* or *Earths* in which they do congeal" [*ibid* p57]. To believe that a man, by utilising artificial fires, can concoct metals such that they can be turned into gold clearly goes against reason. He also questions whether mercury should be considered the seed of gold. Mercury which is supposedly drawn out of minerals and metals they call the seminal principle of gold. He has reservations that there is actually any mercury in these minerals, and even if there is, we have no reason to call it the seed of gold. It is impossible that mercury is able to produce gold. The alchymists claim that the seed of gold is within all bodies, and it is abundant within the Universal Spirit. Because manna, dew and honey are impregnated with this spirit, they believe that gold may be drawn out of these substances [ibid, pp57-58]. There is no reason to think that the universal spirit is especially abundant with the seed of gold than any other metal, or for that matter, any plant or animal. He accepts that the Universal Spirit does contain an acid, which might be used in the production of gold, because acid waters or salts are included in the composition of gold; but that being so, and you call it the acid a seed, it will be part of the composition of all other mixt bodies as well. He concludes that to spend time attempting to make gold is a waste of time, and quotes an apposite definition of alchemy, giving his opinion in no uncertain terms. "An Art without any art, whose beginning is lying, whose middle is nothing but labour, and whose end is beggary"[40] [*ibid*, p58].

On the medicinal properties of gold, he acknowledges that it is a good remedy for those who have taken an excess of mercury, as the two metals will bind together as an amalgam. [*ibid*, p 59]. Other claims for the benefits of gold are met with derision. The hypothesis that gold taken internally can prevent all diseases, and prolong life are built on a weak foundation, and not confirmed by experience. There is no evidence that the Sun influences gold, that the pores of gold are of such construction to have the power of retaining the influence better than any other metal or any other substance; this would be very hard to prove. He continues in the same vein, covering several supposed virtues of gold, and commenting upon the weakness, or lack of any proof. Although such proof had sometimes been attempted, Lémery is able to point out the flaws. While insisting that gold taken alone does not have any effect on health, he is prepared to accept that some preparation of gold made with spirits can be of value.

Synopsis

It is clear that this book was far more than a collection of recipes. Lémery includes theoretic discussions and plainly wishes his readers to understand the underlying theory and to apply reasoned arguments to any claims made for the chrysopoeian and iatrochemical preparations.

---

[40] "*Ars sine art, cuius principium mentiri, medium laborare & finis mendicare"* [Lémery: 1686].

He encourages a sceptical stance, especially towards some of the more outlandish claims of aspiring alchymists, demanding that any assertion be subject to proof. Astrology is mentioned, but dismissed; it seems to be included for completeness rather than any contribution it could make to theory. Lémery also offers his own mechanical hypothesis; in his discussion on solvents [*ibid* p69] he proposes a corpuscular explanation for the precipitation of gold. Lémery's sceptical theme can be appreciated throughout his treatise. He also does take note of negative instances. In summary, this book promotes chymistry as he intends, with tangible and demonstrable processes, and understanding of chymical theory. The extreme polemical stance with respect to alchemy leaves no doubt as to his views on the art. Lémery's own hypothesising lacks rigour in promoting unproven (and unprovable) statements concerning the mechanical properties of chemical substances. He does however, avoid the animistic explanations of Paracelsus or Francis Bacon. There are no exasperated spirits in his philosophy; it is a pragmatic approach with explanatory value. In addition, detailed practical instructions (with illustrations where relevant) indicates a strong familiarity with the processes described, and include useful advice to aid success carrying out procedures.

5.5 SUMMARY

Sennert's synthesis of Aristotelian substantial forms with the corpuscular hypothesis is quite different from the French chymists' approach. Both Sennert and Lémery focus strongly on the theoretical aspects, and both insist that theory must conform with experimental evidence. Sennert uses experiment to support his theory. Although Lémery expounds theory in some detail, and uses it as explanation in explaining chymical reactions (acid-alkali for example) he concentrates on the corpuscularian side of it. It is not clear that the metaphysical spirits are doing much work in the explication of the chymistry.

Comparison of Le Fèvre with Lémery

How does Le Fèvre compare with his fellow countryman Lémery? Lémery's work was published about twenty years after Le Fèvre's. Both provide theory as well as textbook recipes, but Le Fèvre does not display the scepticism that runs through Lémery's work. They both seek to raise the level of chymistry's status, and they provide a theoretical framework. Le Fèvre's matter theory is strongly metaphysical with no concessions to the mechanical philosophy. Both men provide detailed descriptions of the chymical processes. Lémery describes the astrologers' beliefs then dismisses them as arrant nonsense. Le Fèvre fails to provide similar criticism. Lémery also warns against charlatans and describes their underhand methods. Proof and justification are demanded for any scientific statement. I have not seen similar requirements from Le Fèvre.

6 EXPERIMENTATION, REPRODUCIBILITY AND NEGATIVE INSTANCES

6.1 INTRODUCTION

In this chapter I look firstly at reproducibility and experimentation. Boyle's Baconian approach, illustrated by his '*Heads' and 'Queries'* and his response to problems of reproducibility are considered. Examples of such issues are given in the Anti-Elixir Experiment, and attempts to reproduce images of plants in frozen water. Homberg's work with the Bologna stone provides a good example of the difficulties encountered in reproducing phenomena and the impressive way Homberg dealt with them, using a very sophisticated and modern approach. An interesting example of lack of repeatability and a dearth of scepticism can be seen in the issues surrounding the Sympathetic Powder.

In Section 6.3, I move on to the experimental procedures utilised by the *Académie Royale* in their efforts to extract active ingredients from plant material, a project which had very disappointing results. This extensive, collaborative programme involved hundreds of experiments using analysis by distillation. The methods were systematically applied and included colour indicators which was quite innovative at that time, plus methodological improvements and original tests. Recording and review of the results was standard procedure and can be considered an early type of peer review. Although the overall project was deemed a failure, negative results led to improved experimental methodology and the disproving of the Acid-Alkali theory, which held that acids and alkalis could not co-exist in the same solution. They also discovered that an 'occult' acidity below the sense threshold could be identified, which contradicted Aristotelian natural philosophy.

6.2 REPRODUCIBILITY AND TESTABILITY

6.2.1 *Boyle's Baconian Approach*

The Occasional Papers [Hunter: 2005] are not only a clear indication of the extensive range of Boyle's interests, but the influence of Bacon on his experimental method. In his paper are experiments to be carried out, listed under various groups.[41] It's very much a Baconian collection of data, attempting to be comprehensive, but without much direction, though it became much more systematic after 1665. The list is quite typical of Boyle's *Queries*, some of which are published in the *Philosophical Transactions.* Details of one of the *Queries* are given below.

Queries Concerning Shining Wood

A set of queries on shining wood, i.e. luminescent wood, indicates the observations and trials to be made. Boyle starts with simple experiments on the shining wood to determine what affects the luminescence. Tests are to be made with corrosive liquors, spirit of wine, burning, and the analyses of the ashes of the burnt wood, plus noting the smell and effects of the smoke. The specific gravity is to be determined. These are to be made in differing conditions; varying warmth, dryness, dampness, in ambient air and sealed from air. He conjectures that the luminescence may be due to the wood becoming rotten, and that treatment with spirit of wine might prevent putrefaction. Linked to these he suggests trials on shining fish and coal [Hunter: 2005]. It's a broad scope, although not exhaustive.

This and similar papers demonstrate that Boyle's method was influenced by Bacon, though Hunter points out that Boyle, although he recognised and respected the Baconian method, he himself was quite discursive in his approach, which could hardly be called systematic. In 1665, however, his work became more structured, as in his *New Experiments and Observations Touching Cold, or an Experimental History of Cold,* published in the *Philosophical Transactions* [Oldenburg: 1665 Vol 1]. Here he deals sequentially and systematically with each theme [Hunter: 2007, p5] and acknowledges his debt to 'the illustrious Verulam' for the manner of organising the topics and their respective inquiries. An informal kind of peer review is mentioned, by correspondence of the author with other interested (and presumably suitably qualified) parties [Hunter: 2007]. See Appendix G for an example of Boyle's '*Heads.*'

Boyle outlines some of the difficulties encountered in reproducing experiments (*The First Essay on the Unsuccessfulness of Experiments* and *The Second Essay on Un-succeeding Experiments* [Boyle: 1661, p37-39; p57-81]. Boyle notes the dissatisfaction experienced when experiments do not go as expected, either failing completely, or varying significantly

---

[41] Examples are: *Volatile Salts, Magnetic Tryals, Concerning Shining woods, Titles and Articles of Inquiry in Order to a Natural History of the Sea, Quaeries about gems* [Hunter: 2005]

from the results anticipated. Boyle acknowledges the difficulty in listing all the possible problems, but he mentions the technical skill of the experimenter, and the perennial issue of purity of materials. The materials in question may be natural or factitious (artificial), sincere or adulterate, or simple or compound. Some experiments fail because they may have once been tried with genuine materials and at another time with 'sophisticated' [*ibid*, p38] i.e. adulterated, materials[42]. It's possible that an experiment done with an adulterated material may actually perform better than one done with the pure material; the impurity may have produced the effects. Boyle remarks upon the difficulty obtaining suitable materials. He quotes van Helmont on chymical preparations "There were scare any, vulgarly sold in shops, to be relied upon as faithfully prepared" [*ibid* p39].

Boyle was aware of the problem of repeatability regarding experiments not carried out in comparable conditions or to uniform standards [Boas Hall: 1958 pp215-216][43]. Boas Hall [1958] notes that even if he had not advanced to the systematic position of the modern scientist who insists that experiments be repeated for confirmation by their originator, and be capable of being repeated by others, he was well on the way to this concept [*ibid*].

In the *Second Essay*, Boyle continues with listing the reasons why experiments fail. He relates an episode concerning a trustworthy doctor of his acquaintance who lent his laboratory, well stocked with *aqua fortis* 'of several compositions' in Amsterdam to a friend in his absence. This friend claimed to have dissolved gold in the *aqua fortis,* and by various steps, including separating out sulphur from it, made a golden tincture from which he had turned silver into 'very perfect' gold. Unsurprisingly the doctor of Amsterdam returned speedily to his laboratory to try the process himself. He was, apparently, able to make a volatile tincture of gold by which he turned silver into gold; this was repeated several times, transmuting silver by weight into the same or greater weight of gold. [Boyle: 1661, p57] Boyle did not doubt it, as his own experiments led him to accept that gold could be separated out of a yellow substance or tincture, and partly because he thought that silver, in chymical

---

[42] From medieval Latin sophisticatus 'tampered with').

[43] "For I have already noted… that there will be scare found such a uniformity in qualities, and particularly specifick weight, among bodies of the same kind or denomination, as there is generally presumed to be. There may also be some difference, though perhaps but little, betwixt the waters men employ, especially if the air be at one time (as in July) intensely hot, and another (as in January) exceeding cold. The difference also of degrees of goodness of the balances men employ about nice experiments, is not altogether considerable. But there is a thing of greater moment...the difficulty in finding an exact uniformity in weights of the same demonination." [Boyle: 1690 *Medicina Hydrostatica,* ch.16].

terms, may have a sulphur in it, which may mature to a golden substance. Bacon's observations support this idea. Alas, the Dutch doctor was unable to repeat the experiment, blaming the failure on the *aqua fortis*. He prepared some fresh, but to no avail. Boyle attributes the fruitless attempts to 'some other more abstruse cause' saying that Glauber had been able to make gold once and could not repeat the experiment with any success. Boyle offers little more in explanation, except to say that it is not uncommon for an experiment to work once, but fails to be repeatable [Boyle: 1661b p58]. He does seem wont to accept authorities, despite his claims to scepticism.

One observation he makes is that many experiments are successful using small quantities of matter, but fail when the quantity is increased substantially. The explanation offered is that a large quantity may not be evenly exposed to the right amount of heat whereas it would be easier to ensure a small quantity was heated to the correct degree.[44] This would be easy to test, surely. Perhaps the issue is that failure may be caused by a number of variables making the actual cause quite difficult to track down. By Boyle's own account failure was far from unusual.

Boyle tried repeating experiments that had been described by 'learned writers' [*ibid* p61], but this one had nothing to do with transmuting metals. In *Unsucceeding Experiments* he describes experiment of a lixivium made of the ashes or salt of a burned plant. When this liquid is frozen, it is reported that an 'idea', presumably meaning image, (in this case wormwood) of the plant appears in the ice. Despite several attempts (and varying parameters) he was unsuccessful; he could not discern anything that looked more like wormwood than any other plant. Other observers were unable to perceive any more than he did. In the test vials the ice did seem 'oddly figured' but he has seen the same effect in water in which saltpeter, sea-salt, sugar etc. has been dissolved, and even in ordinary water. Many waters that have percolated through the earths which abound in saline particles of various nature, may become impregnated with them. He concludes that the supposed images in frozen lixivium or decoction is supported by very uncertain proofs, and fears that those who claim to have seen them, "have in that discovery made as well use of their Imagination as of their Eyes." He notes that people are inclined to corroborate others' observations rather than be thought to be less able to discern the images that others pretend, or believed they see [*ibid*

[44] This might be explained by the surface to volume ratio which has an effect on diffusion rates.

p62]. Some scepticism is apparent here, as well an astute observation on the frailties of human nature.

Boyle draws two conclusions. Firstly, the building of hypotheses must rest on very carefully executed experimentation. It is unsafe to rely on one experiment alone. Even experienced experimenters may suffer variability in their results. Secondly, if writers are not fastidious about their own reputation – if they report fabulous stories and repeat mere hear-say, without adequate evidence – we are not obliged to accept their word. Where sincerity and stature of the philosopher is high, he recommends allowing the benefit of the doubt [*ibid* p78]. Unless and until one's own experiments show a clearly contrary result or there is some 'change of circumstances,' Boyle counsels caution in rejection of their experimental results. His scepticism is tuned to the perceived veracity of the source.

It does not appear that the underlying theory is considered to be refuted when trying to work out why experiments fail. Pragmatic fixes such as attempting to recreate the conditions of the successful experiments, or just assuming they have not got all parameters the same, seems to be the norm. This is fair enough as a starting point, but one would expect that if failures continued (especially if they were widespread) then that would be an indication that the theory might be unsound. There is little evidence of theorising, using any paradigm to solve the mystery. The skill, experience and reputation of the experimenter are important factors, in Boyle's view, in ascertaining the veracity (or otherwise) of the experimental results. It must be acknowledged that an expert in a particular field, whether natural philosopher or craftsman, can, through long experience see details where others cannot. For example, a non-specialist looking down a microscope or through a telescope may find it hard to distinguish bacteria or moons respectively, even when they are advised what to expect. Aberration and other defects in early lenses compound the difficulty.

6.2.2 *The Bologna Stone*

The making of the Bologna stone highlights the difficulties encountered in producing reliable, reproducible results in seventeenth century chymistry. Principe (2016b) relates the attempts of Homberg to reproduce his process of synthesising this stone. The Bologna stone (*lapis illuminabilis*) was unusual, and highly prized, because of its persistent luminescence. Its rarity added to its value to natural philosophers, possibly both for its novelty value and its perceived potential in increasing knowledge of the nature of light or the making of the Philosopher's Stone.

Luminescent materials, such as white phosphorus, were popular in demonstrations such as those held by the Royal Society [Golinski: 1989]. The Bologna[45] Stone was discovered in c.1603, in the hills south of Bologna, by Vincenzo Casciarolo. It had to be specially prepared to make it luminescent, and although there are references to the process in the early decades of the seventeenth century, by mid-century the method was described as "a lost secret" and reported as such in the *Philosophical Transactions* of 1666 [Principe: 2016b]. The luminous stone became scarce even in Italy; it had been suggested that this was because the person who used to prepare it at Bologna had died leaving insufficient details of the process to make it luminous. As the luminescence faded over time, even those who had acquired the stones previously (Boyle had received one from John Evelyn) were unable to obtain new supplies. It is this lost secret that Homberg was able to rediscover. Around 1677 or 1678 he travelled to Bologna [Principe: 2016b] and learned to prepare Bologna stones of exceptional brightness. Principe relates an anecdote by Homberg which sheds some light on the difficulties of its reproducibility.

Homberg affirms that he had made luminous (using a process of calcination) a large quantity of these stones, in more than a hundred different operations. Later, in Paris he attempted to calcinate some of the stones he had brought from Italy [Homberg, In: Principe: 2006b]. But he was unsuccessful. Repeating the process ten times, with the utmost attention to detail, he still was not able to produce the luminescence. This was rather awkward for him, as he had promised to teach a friend how to process it, and was being pressed to keep his word. Reluctantly acquiescing, he began the process at his friend's laboratory, not without misgivings. When the process was complete, he found the stones to be the "most brilliant and luminous" he has ever seen [*ibid*]. He was astonished. As far as he was aware, he had changed nothing in the operation; the stones were from the same batch as his own. After deep reflection he realised that the only difference in the whole process was the use of a bronze mortar to grind the powder used instead of his own iron one in his Paris laboratory. Homberg reran the trial at his own laboratory using a bronze mortar, and the process was a success [*ibid*]. Not satisfied with leaving the puzzle unsolved, he determined to find the root cause, and undertook a series of carefully planned experiments. Appreciating the need to change only one parameter at a time, he prepared separate batches of ground Bologna stone using mortars made of marble, porphyry, iron bronze, and lead [Principe: 2016b]. Further samples

[45] Also known as or Bolon, Bolonia. The stone is now known to be mineral baryte $BaSO_4$, barium sulphate.

of stone were made by crushing them on platters of silver and tin, and in a copper bowl. After calcinating stones which had been covered in each of these powders separately, he found that the stones which exhibited luminosity were those, and only those, which had been prepared using a bronze mortar or a copper bowl [*ibid*].

The second stage of the trial involved taking each of the prepared powders separately and grinding them for a second time, but only using a bronze mortar [*ibid*]. He found that all of them became luminescent except for those which had been initially prepared using the iron mortar. This led to his discovery that even the minutest trace of iron was sufficient to prevent luminescence. His confidence in this conclusion was strengthened by his subsequent observations that Bologna stones with brown spots or veins, indicating the presence of iron, never became luminous[46] [*ibid* p131]. Principe points out the importance of using specific materials, some of which may not be obvious such as the constituents of ancillary equipment. Homberg fortuitously had suitable apparatus in his early attempts at making the luminescent stone; if he had not, he would not have been successful. Homberg recognised not only the importance of avoiding having even the smallest particle of iron, but also observed that an equally small quantity of copper was an active ingredient in the process. He discovered that by grinding the powder in the bronze mortar for greater or lesser periods of time, a minute amount of copper enhances the luminescence while greater amounts inhibit it [*ibid*]. He attempted a chymical explanation for the phenomena but was not entirely convinced of its veracity. Homberg writes “it is not easy to give a convincing reason why copper contributes towards making the Bologna stone luminous while iron completely prevents it from becoming so” [Principe: 2016 p132]. In fact, an explanation of persistent luminescence was not forthcoming until the mid-twentieth century. The addition of tiny amounts of a specific material to change its properties is known as doping.

Homberg’s work shows the signs of a well-developed scientific methodology. He carried out experiments carefully and consistently. When first he met failure, followed by an unexpected success (as far as he could tell he had not changed any parameters) he set out to ascertain the cause of such inconsistency. He did this by designing a set of experiments which he executed in a controlled manner. Persistence, critical thinking, and attention to the fine details of his method led him to understand the cause of the failure – traces of iron. His observations led

[46] This extreme sensitivity is now known to be the effect of a luminescence poison or quencher. Traces of iron as low as 0.005% can have this effect [Shadrach & Vadivelu: 2007].

him further; he came to realise that minute traces of copper enhanced the luminescence. He attempted to explain the effect in chemical terms, but was unable to do so in a manner that satisfied him.

Homberg did not publish these findings himself, but reported his discovery to Nicholas Lémery, who published it in the 7th French edition of his *Cours de Chymie* (1690) [Lémery: 1690]. Lémery describes the process as a calcination, explaining that the operation is to purify and exalt the sulphur contained in it. The operation completed, the stones "thus calcined, are each of them a Phosphorus." [47] They should be kept in a dark place, and the light from them will diminish over the years. This can be rectified by exposing them to the open air for a short while. They may continue to glow for some years, after which they will have to be calcined anew to replenish the effect. Lémery notes that there is a problem with iron in the process; it is 'prejudicial' to the light-emitting quality, whereas brass has a positive influence. He concludes that iron has a 'bad quality' which might be due to the vitriolic acid of the metal which unites with the exalted sulphur of the stone, thereby fixing it, and hindering the light from kindling and shining [*ibid*]. He gives a corpuscular explanation to explain the experimental results. The process itself is given in detail, including drawings to support the text, showing the Bolognian stone at various stages of the process, plus a small furnace and hearth, with brief descriptions.

6.2.3 *Boyle: The Not-So-Sceptical Chymist*

Boyle was aware that negative results could prove more fruitful than positive ones. He remarks "…so in Philosophical trials, those unexpected accidents that defeat our endeavours do sometimes cast us upon new discoveries, of much greater advantage than the wonted and expected success of the attempted Experiments would have proved to us" [Boyle: 1661 In: Hunter & Davis: 1999 Vol 2 p82].

His reaction to the results of the following experiment is puzzling. Boyle's matter theory allowed the transmutation of (almost) any substance into any other substance. He does caveat this, including only inanimate substance [Boyle: 1666].

[47] 'Phosphorus' was a term used to describe any luminescent material.

On the unrepeatability of experiments: The Anti-Elixir Experiment

The acquisition of the anti-elixir is a strange and quite bizarre story, involving a Frenchman, Georges Pierre des Clozet, a secret society of alchymical adepts and the exchange of money and goods of great value, not to Boyle's advantage. This adept had inveigled himself into Boyle's society, having persuaded him of his credentials, passes Boyle a small package of powder with minimal instructions attached and disappears swiftly, avoiding further questioning. Boyle believes he has received something important; a powder able to debase gold. The reasoning and preparation are described in *Of the Degradation of Gold by an Anti-Elixir*[48] paper [Boyle: 1678, Vol 9]. He not unnaturally decides to make an experiment using it. He defines the necessary criteria for the experiment to be considered a success:

Firstly, a great change must be made by the elixir and it needs to be demonstrated on extremely stable and immutable bodies such as metals. Next the change must be rapid and must be effected using a very small portion of transmuting powder - this is the 'projection' of the alchymists. Finally, and most important there must be a notable alteration in the specific gravity of the material. This is particularly relevant because the specific gravity of gold is difficult to change, unlike other properties such as colour, malleability and stability. If it can be shown that an Anti-Elixir can make such a crucial change that through the alchymists' art and if one can debase gold via alchemical processes one would expect to be able to reverse the process; a true elixir could be made.

Boyle sets up the experiment with great care. He invites a witness, a doctor experienced in refining and assaying gold, who is only partially informed of Boyle's own expectations. He tells him only that the gold, the most malleable of materials, will be made brittle. Boyle expected more than brittleness, but declines to give further details, "having thus prepared him not to look for all that I expected" [Boyle: 1678. *In:* Hunter and Davis: 1999, Vol 9 p. 12]. Boyle, on opening the little folder paper was surprised and disappointed at the very small quantity within. He had planned two trials but there was scarcely enough material for one; by estimation less than a tenth of a grain (about 0.05gm). This was too little to risk weighing,

---

[48] Principe (1998) has suggested that Boyle's Anti-Elixir paper, *Of the Degradation of Gold by an Anti-Elixir*, published in 1678, was intended for the closing section of that paper. It was one of a pair of papers on transmutation, the other being on incalescent mercury [Principe 1998].

because of likely loss on the weighing balance. They weighed out two drams of gold obtained from English coin[49].

The gold, without addition of a flux, was placed in a new pre-heated crucible. Boyle himself added the dark reddish powder to the melted gold. It was heated for about fifteen minutes, to allow complete diffusion. He saw no change in the appearance of the gold while it was heating, or as it was poured out into another crucible apart from a slight opalescence noticed by his assistant. When the substance had cooled, it appeared not as fine gold, but a dirty-coloured lump of metal, as though it was thinly coated with a substance resembling "half-vitrified Litharge" [Boyle: 1678]. On one side of the crucible was a little globule of metal, not gold-coloured, but like "coarse silver" [*ibid*]. "..we perceived that there were stuck to one side of the Crucible a little Globule of Metal that looked not at all yellowish but like coarse Silver, and the bottom of the crucible was overlaid with a vitrified substance, whereof one part was of a transparent yellow, and the other a deep brown, inclining to red, and in this vitrified substance I could plainly perceive sticking at least five or six little Globules that look't more like impure Silver than pure Gold" [*ibid*].

Boyle expresses surprise and disappointment. Although in some points it was what he had been anticipating, in others ways it was not what he had been given to expect by the virtuoso. He wonders whether it was the virtuoso's haste or design in leaving without supplying adequate instructions. Using a touchstone to test the substance, the new mass was judged to be closer to silver than gold. Percussion testing was next. As Boyle had predicted, it was brittle, and flew into pieces under the impact of the hammer. Thirdly, they examined the interior of the pieces; they found these to be of a dirty colour, like brass, and the fragments resembled bell-metal (an alloy of copper and tin) more than silver or gold. A fourth test was made, cupelling. They weighed out one dram (reserving the remainder for further trials) and placed it in a new crucible [*ibid*]. They added about half a dozen times its own weight of lead and heated it in the fire continuing to apply heat for about an hour and a half - about twice as long as they expected. Copious fumes were given off almost to the end of the cupelling. They found the cupel "very smooth and entire" but tinged with purplish red, surprisingly and in addition to the refined gold there was some dark-coloured dross [*ibid*]. They concluded that

---

[49] This had been cupelled with lead and then quartered with silver. This process involved melting the gold with three times its own weight of silver and then dissolving the alloy in *aqua fortis,* which would remove the silver, resulting in a 'fairly pure' gold. [Principe: 1998]

this dross had come from the "deteriorated Metal, not from the Lead" [*ibid*]. When they weighed the gold they found they had fifty-three grains, so appeared to have lost seven; however, the dross made up the difference. The dross was subjected to little further examination [*ibid*].

Why the material has not been subjected to test using *aqua fortis* is curious; this would be the obvious test. Boyle claims not to have any of reliable quality. It is an odd explanation; if he considered the experiment to be of great importance, which he clearly did (he went to the trouble of inviting a witness) why did he not ensure that he had *aqua fortis* of suitable quality? It was a common enough chymical reagent at that time. He has a secondary excuse. He had heard that in some metalline mixtures, where gold was the predominant quantity, it might protect other metals (for example silver) from being dissolved in the menstruum. This does seem somewhat ad hoc, not altogether plausible. The test of great importance, that of specific gravity, is then undertaken. Weighing the 'ill-looking mass' it was found that instead of having an s.g. of 19, as would be expected of pure gold, it was about two-thirds of that value. He claims therefore to have reduced the specific gravity by a notable amount. Boyle expressed delight at this result, and thanks to the 'Obliging Virtuoso' who had supplied the wonderful power. The trial was hailed as a victory of Art over Nature.

This experiment raises a number of questions. Why was Boyle so convinced that the powder was genuine? What was the powder actually, and what chemical reaction had taken place? Pierre must have been a charismatic character, and a story-teller *par excellence*, with a deep enough knowledge of alchemy to satisfy Boyle of his credentials. His talk of a secret society of alchemical adepti must have struck Boyle as extraordinarily fortuitous. Boyle sent Pierre many presents, but there was no reciprocal exchange.

Principe [1998] suggests that the anti-elixir powder may have been antimony which would have been readily available in an alchemist's laboratory. Molten gold absorbs antimony extremely readily; 1:1920 parts of antimony is enough to render the metal brittle, and whitish in appearance. Boyle's proportion was 1:1000, so within parameters required for this reaction. However the change in specific gravity would not have been so great. Perhaps the small quantity (or the apparatus) resulted in measurement error. Boyle does mention that he did not have suitable weights for measuring very small quantities. Further investigation may shed light on this matter, but this episode raises queries over Boyle's scepticism.

6.2.4 *The Sympathetic Powder*

Lémery, in *Cours de Chymie* (1686, 1698) in his section on vitriol describes the Sympathetic Powder and salve used on wounds. This powdered version of the weapons salve was claimed by Sir Kenelm Digby as his invention. Lémery makes his opinion clear: "The *Sympathetic powder* that has made so much noise is nothing but white *Vitriol* opened, prepared divers ways according to men's different conceptions about it" [Lémery: 1686, pp 334-338; 1698, pp 414-418]. The preparation of the powder, which includes exposure to the heat of the Sun, is said by some people to be better while the Sun is in Leo, due to the particular influence of the Sun at that time. Lémery remarks that the drying is better simply because of the greater heat of the Sun in high summer. What is said of influence is merely imaginary [*ibid*].

"Many do only pulverize the ordinary *Vitriol*, in order to make the Sympathetical powder. When you would use this powder, you are to take the bloud of a wound upon a linnen cloth, and to sprinkle some of it upon the bloud. It is pretended, that though the bloudy linnen were ten miles off from the Patient, when the Sympathetical powder is applied to it, the wound would presently heal. But the experience of several persons who have tried it (and others may do the same) does evince, that men have had a great faith, when they have talked of the effects of this powder; for if it be not applied to a cloth newly blouded, and even in the chamber of the Patient, you will certainly find no effect from it. Nay where such precautions have been used, it performs no great matter, and sometimes does nothing at all" [*ibid*].

Lémery gives an explication of the supposed effect.

"Now to explicate the action of *Vitriol*, called Sympathy, you must know that there does continually exhale into the air, little bodies from this mineral salt, and to convince you of it, you need only to put the several Vitriols of different colours pretty near one another in the same place, you will find after 12 or 15 daies that they have all changed colour a little in their *superficies*. The white will become yellow, the green whitish, the blue greenish, the red grayish. These changes of colour cannot proceed but from little bodies, which being separated from each kind of *Vitriol*, and mixing in the air, some part of them do fall confusedly on the matter. And it must not be said that these changes are caused by the air, which does open and rarefie these salts; for if you put them into places separate, or distant from one another, this effect will in no wise happen" [*ibid*].

"You must also observe that the bloud, to which the Vitriolick powder is applied, retaining some heat still, may thereby increase the activity and number of the little bodies which do arise from the *Vitriol*. And these Vitriolick bodies dispersing themselves in the air are they that cause all the Sympathy, for they do mix in the wound of the patient, and because the virtue of *Vitriol* is to stop the bloud, and to dry it, you need not wonder if the volatile parts which come from it, do perform the same effect" [*ibid*].

Lémery thus claims to have given the most rational explication of an effect which had hitherto passed for something altogether inexplicable. He concludes that he would not advise any wounded person to insist or depend too much on a remedy of this nature; "for to one who ever received considerable good, there's a hundred, who never perceived any effect from it" [*ibid*]. Nevertheless, there are those who speak of it as a never-failing medicine. If someone tries to convince them by a simple experiment to the contrary, they insist such failure is because of incorrect preparation. He notes that many authors have written a great many untruths attempting to defend the powder's effectiveness. It's clear from this explication where Lémery's sympathies lie. Although he does not claim to have tried experiments himself on this subject, it seems clear that he has weighed the evidence and offered a rational explanation of the effect (or lack thereof). No resort to magical powers is deemed necessary nor desirable.

Debus [1977 p479] notes that Boyle, in the *Usefulness Of Experimental Philosophy* [Boyle: 1663] despite being doubtful, prescribes the sympathetic medicine to his friends. "I see not, why these remedies, that work, as it were, by emanation, may not deserve the name of medicines, if they sometimes unquestionably succeed, though they should not always prove successful ones; nor why they should, notwithstanding their sometimes not succeeding, be laid aside; especially since these sympathetic ways of cure are most of them safe and innocent, they though, if they be real, they may do much good, if they prove fiction they can do no harm… " [Boyle: 1663].

One might wonder if a placebo effect was taking place when the 'cure' was offered. Perhaps an unconscious recognition of the power of the mind to affect the body, or a lingering alchymical notion of astral emanations?

6.3 CHYMICAL INVESTIGATIONS AT THE ACADÉMIE ROYALE DES SCIENCES

Determining the properties of Plants

Holmes (2003) describes the types of projects which were considered for implementation at the *Académie* in 1669. Charles Perrault advocated the study of plant extracts. *The Académie* should "pursue further clarification of the two general principles of concretion and solution, which some believe to be comprised of acids and sulphurous substances. And for that purpose search for all inductions that could serve for knowledge of what an acid is, and what a sulphurous substance is, and sometimes of their general effects." He believed that the strife generated by the action of these two mutually antagonistic principles was the cause of all chymical and physiological change [Holmes: 2003 p53].

Du Clos and fellow academicians attempted to analyse plants by distillation. Their aims were to analyse the plants down to their simplest constituents to enable them to improve medicinal remedies. The project, which lasted many years and was executed at considerable expense by a group of knowledgeable people and unflagging dedication, was generally considered to be a failure. Homberg claimed that the fourteen hundred distillations gave worthless results, since cabbage and hemlock apparently gave the same products [Partington: 1962 p12].

Claude Bourdelin was responsible for most of the *Académie's* experimental chymistry programme since its foundation [Holmes: 2003 p48]. During 1668, a programme, led by the botanist Jean Marchand, was initiated to produce a *Histoire des plantes*, a collaborative project to which naturalists, chemists and *physiciens* would lend their expertise. It was not until 1670, though, that the chymistry laboratory of the *Académie* was available for use. Following a method outlined by Du Clos, Bourdelin examined forty-two types of plants during 1670/71. Regrettably, these early records have not survived; however, from January 1672 detailed descriptions of the analyses were documented in the *Académie's* records showing the step by step progression of his investigations [*ibid* p54]. The results were recorded and contributed to the *Mémoires pour servir à l'histoire des plantes* by Dodart. The first part described in details the experimental processes and results; the second section of this book contains detailed illustrations of the plants *'Descriptions de Quelque plantes nouvelles'* [*ibid*].

Holmes (2003) describes Bourdelin's experimental objectives as the determination of the specific compositions of various plant materials in order to discover the discrete virtues. Despite difficulties in the analysis and explanation of the results, (the sheer quantity of data provided by Bourdelin brought its own problems) they continued to develop and standardise their procedures with the expectation of eventual success. Anomalies occurred which prompted further investigation. Besides subjecting the plants to any chymical analysis, the plants were listed together with their descriptions and culture [*ibid*]. (See Appendix H for details of the experiments).

Holmes states, "Du Clos[50] moved beyond traditional methods of recognition of substances by their sensible qualities towards a set of analytic procedures capable of more objective and more subtle distinctions." Boyle's work may have provided motive for the academicians to utilise colour change and precipitations as a means for identifying the substances obtained from distillations [*ibid* p51]. Boyle had described many of his experiments in his *Experiments and considerations touching colour* (1664). He had noted that most acid salts turn syrup of violets red. He also showed that if oil of tartar (a fixed alkali) was added to mercury sublimate, the solution would turn deep orange, and a precipitate formed [*ibid* pp50-51]. On the other hand, a urinous salt (a volatile alkali) produced a white precipitate with the sublimate. This allowed a clear distinction to be made between the two major classes of alkali [Boyle: 1664]. Du Clos may have considered therefore that the use of colour indicators would prove useful in identifying substances derived from distillations [Holmes: 2003, p51]. Additionally, a set of experiments using tournesol was reported by the *Accademia del Cimento* [*ibid* p57]. Experiments (performed collectively and reported anonymously) prompted the claim: "The sour juice of lemons, the spirit of vitriol and the spirit of sulphur change the purple of litmus (tournesol) and that of the violet tincture of violets to scarlet, from which state oil of tartar renders it purple. Vinegar also reddens it but to a less bright colour." The substances which reddened litmus were known acids, whereas oil of tartar was a strong fixed alkali [*ibid*, p57].

The experiments

Having weighed accurately the starting materials and each of the portions collected in the receivers, Bourdelin noted (for the case of asparagus) that "all the portions together, including one ounce judged to have been lost in the neck of the retort by the moistening of the lined and paper, the volatile and fixed salts, [and] the oil, amount to 5 livres, 14 ounces, 18 grains, so that there were only about two ounces lost out of the six pounds [of starting material]" [*ibid*, p58]. Holmes makes this comment on the evidence of careful quantitative analysis: "Evidently the first chemists of the Paris Academy embraced a rigorously quantitative style of experimentation. Often thought to have been introduced by a more famous countryman exactly one century later, the 'balance sheet' reasoning illustrated here was more familiar to chymists of the seventeenth century than historians have commonly

[50] Du Clos disagreed with Boyle's contention on the repeatability of chemical experiments. Boyle's claim was that chemical experiments were often misleading because of the impurities in the materials leading to different outcomes. Du Clos thought that it was easy to determine when such occasions occurred [Holmes: 2003 p53].

noticed" [*ibid*, p58]. Many tests were carried out but they were not successful in separating plant matter into its simplest principle; they could not get to their elementary compositions. This objective seemed beyond their capabilities using these processes, but by using a standardised procedure, they could distinguish some differences in various plants by their partial decomposition.

Bourdelin compared samples of narcissus warmed gently in closed vessels. He observed also the changes made by testing with sublimate, vitriol and tournesol. These three tests were (by then) standard tests. The first and second samples of distillate were pellucid, retaining the odour of the flowers without any other savours. They showed no effect with the three standard test solutions. The third portion, resembling the first two, was "without manifest acid, did nothing with sublimate or vitriol [but] reddened the tincture of tournesol." The fourth portion, pellucid as the first three, still had a null result with sublimate and vitriol, but turned the tournesol a beautiful shade of red [*ibid* p61].The fact that the tournesol turned red, indicating acidity, despite the acidity not being sensible, and that the tournesol turned a brighter red in the samples where the acid was manifest, was an important point. It would have strengthened their convictions that the tournesol was an indicator that could detect acid that was too weak to be tasted; it could detect a non-manifest acidity [*ibid* p61]. This was a very un-Aristotelian notion, as the human senses were supposed to be sufficient to detect substances' properties.

Co-existence of Acids and Alkalis

Previous experience showed that liquors that turned tournesol red did not precipitate sublimate, and those that precipitated sublimate did not redden tournesol. This was consistent with the long experience of chemists that solutions did not taste simultaneously both acid and alkaline. But Bourdelin had a sample that exhibited indications of both acid (reddened tournesol) and at the same time precipitated sublimate, indicting an alkali. His comments were as follows: "It made one think that the sulphuré [alkali] and the acid were mixed together without being totally destroyed by one another…" [*ibid*, p62]. The idea that an acid and an alkali could exist together a was dramatic new concept for chymists of the seventeenth century. Holmes describes this realisation as "of watershed significance" [*ibid*]. It had always been thought that when an acid and an alkali were brought together, they destroyed one another. This was because of the observation of the violence of the effervesce during the reaction, but also because the resulting solution had neither the acridness of an acid nor the bitterness of an alkali. That an acid and an alkali might still be present, and recoverable, even though undetectable in the solution was considered remarkable [*ibid*, p62]. Boyle's explanation of this phenomenon was based on a corpuscular image of particles separating and re-uniting. This depiction however, opposed the intuitive notion that the properties of mixts reflected the properties of their constituent parts. Nevertheless, as Holmes notes, the academicians were coming to accept that there were indicators which could detect acids and alkalis that were too weak to be perceptible to the senses.

Attempting repeatability

Rather than dismissing the apparently anomalous result that acid and alkali could apparently co-exist, they investigated further. Initially unable to reproduce the effects they desired, an alternative strategy was implemented. In an experiment with aromatic root of elecampane Bourdelin took one eighth of each portion of distillate, mixed them together in a vial, and added the mixture to a solution of sublimate, which it whitened and turned turbid. With vitriol it formed an olive-grey colour, and with tournesol it turned strongly red [*ibid*, p63]. This was evidence that the phenomenon was repeatable. They may have inferred that either an alkali and an acid could co-exist under some conditions, or alternatively that the sublimate and tournesol could not both be reliable indicators of the presence of an acid or an alkali respectively [*ibid*, p63]. Further tests with other various liquors gave that results varied considerably, with no obvious pattern emerging. With perseverance he created tests which led to an indication of an acid and an alkali existing in solution together.

Although the chymists did not succeed in their objective to discover regular differences in plant composition by their analyses, their failure in this aim was not due to lack of experimental rigour. They developed procedures and followed new paths when the evidence warranted further investigation. They discovered some interesting phenomena along the way, though this did not lead immediately to the understanding of the processes involved.

6.3.1 *Memoires pour Servir l'Histoire des plantes*

The Memoires served as a summary of the above work undertaken. The intention was to follow it with an extended version in two books, but these never materialised.

There were a variety of aims of the *Académie* with respect to the analysis of plants. There was some disagreement between different factions on priorities and goals. The specific aim of *L'Histoire des Plantes,* published in 1667 by the *Académie* was initially to provide a comprehensive compilation of plants, an urgent and obvious requirement given the large number of plants that had been discovered in the past two centuries. “Between 1550 and 1700, the number of known plants quadrupled while the number of botanical compendia declined” [Stroup: 1990 p70] (Chapter 3).

Stroup describes Huygens’ proposal as an all-encompassing Baconian-style natural history for the *Académie,* with Perrault suggesting comprehensive descriptions, illustrations and a topographical index. Du Clos, who became director of the work, suggested that an explanative chymical analysis should be incorporated. However, control of the project passed to Dodart after he joined the Académie in 1671 [*ibid* p75]. “Dodart presented the Academy's raw findings, without hypotheses or conclusions. Duclos and Perrault, in contrast, expected the natural history to go beyond mere reports of experiment and difficulty” [*ibid* p75].

The *Histoire* included a beautifully illustrated section of the species of plants. The *Académie* commissioned the drawings from life rather than using copies of illustrations which were often not sufficiently accurate nor detailed. Microscopes were used to help the illustrators with intricate or very small plants [Stroup p79]. The areas of research established by Huygens, Perrault, Du Clos and Dodart were influenced by the traditional separation between descriptive natural histories and explanatory natural philosophy. These distinctions faded as the project progressed, with chymical analysis being part of the research objective [*ibid*, p79].

Du Clos, as initial director of the project, was able to include chymical analysis an integral part of the natural history of plants. The sensible properties of the distillates were to be recorded and subjected to analyses, including the crystalline form produced by condensed liquors [*ibid*: p73]. Dodart, taking over from Du Clos, had a fundamentally different outlook. Despite this disagreement, in the published *Memoires,* Dodart states that he hopes for some insight into the actual microstructure of the plant. He hoped to discern whether the fibrous structures are the mere fibres they appear, or alternatively if they are actually tubes which may carry a fluid [Dodart: 1676 p3]. Quite probably a microscope would have been used, as it had been for the drawing and engravings of the plants. Hooke’s *Micrographia,* published in 1665 would have been of great interest. Du Hamel purchased a microscope for the *Académie.*

Over the century the perception of how to study nature was undergoing change. Natural histories of plants, following a Baconian regime, were by and large simply descriptive. The discovery of plants that could move, *mimosa pudica* for example, challenged the Aristotelian dichotomy between plant and animal life. This perhaps prompted the search for analogies between the two, bringing, "botanical and zoological research closer in intent and method" [Stroup: 1990 p67] promoting convergence of botanical and zoological research objectives. Demonstrating analogical reasoning, in 1668 "….Perrault and Edme Mariotte defended the hypothesis that sap circulates in plants as blood does in animals" [Stroup, 1990, p131].

In the method of experimentation, Dodart insists that the obviously superstitious must be ignored. Equally, reported results that could not be replicated should not be rejected as false without due consideration. There are many legitimate reasons for failure, some of which may not be obvious. He is perhaps being a little too forgiving here. If it has not proved possible to replicate an author's observation, should he always be given benefit of the doubt? This approach might be acceptable if the experiment was not implemented precisely, or the author's interpretation was unclear. But surely there is a time when it should accept that the author's claim is mistaken. Dodart seems reluctant to suggest that authorities such as Dioscorides' or Galen's assertions are simply false.

6.3.2 *Synopsis*

In the work of the *Académie* we can see their achievements as a collaborative research community which had the benefit of good resources and funding. They considered their aims and objectives, and the means by which these aims are to be achieved. Their stated objectives were to increase knowledge (as understanding of causes) and to improve medicaments. Awareness of the 'balance sheet' of chymical reactions was a contributory part of their experimental process, a clear example of quantitative analysis long before Lavoisier. This process led them to the significant discovery that acids and alkalis could co-exist. They did not ignore negative results; instead they utilised the findings. Impressive quantities of data were collected and analysed. The *Académie* acted as peer reviewer, overseeing the experimental work and discussing outcomes. They discovered that indicators could reveal 'occult' acidity where the strength of acidity lay below the threshold of human senses, contrary to the Aristotelian view. Did all the resource and time give a good return in terms of understanding chymical philosophy? Perhaps not, but their work did increase knowledge. Their aspirations to understand the virtues of plants were not an achievable objective in the era. The chemistry is quite complex.

6.4 Testability

For a hypothesis to gain credibility it has to be testable. Experiments can be designed to demonstrate the hypothesis, though of course this does not result in certain proof. It may be in certain circumstances that the hypothesis is theoretically testable, but the means to test is not yet available, as with Einstein's predictions. These capabilities may become available, with new knowledge and improvements and developments in technology. Reproducibility relates to testability. It is essential that testing is performed, but without adequate reproducibility, test results may be of little value. Reasons given for failure may be offered that allow the hypothesis to remain extant, for example, impurities, lack of technological expertise, failure to control parameters (temperature control was still problematic), lack of appropriate equipment (dependency on furnaces for example) and the hypothesis may survive if it seems to provide some explanatory value and there is no rival hypothesis to supplant it.

6.5 Falsificationism

There were many attempts at falsification of rival theories. Béguin proved his friend's putative method for transmutation to be wrong by experiment. Boyle tried to oust Aristotelian theory to supplant it with his own corpuscular hypothesis. In the sample works analysed, I have not found any examples of Popperian falsificationism per se. Reasons for rejecting a hypothesis is complicated by the issues of reproducibility, making the specific cause difficult to assess. Adherence to one's own theory or to respected authorities also influenced the acceptance of negative results. This discussed further in Chapter 8.2.4.

6.6 Summary

Achieving reproducibility was an issue which exercised the ingenuity of the chymists. It is evident that they considered it desirable, but the factors militating against its achievement were considerable. The number of variables in each experiment may make finding the cause of failure quite difficult to track down. This is exacerbated by the difficultly in accurate measurement of each variable; heat, impurities, strength of reagents, weight, skill; each or any of these factors may be responsible. Air was not included as a chymical. However, effluvia carried by the air were accepted as existent, so the importance of experiments taking place in closed or open vessels was recognised. As instrumentation advanced, so did the potential for greater accuracy, improving repeatability. Homberg's methodology was exemplary. Bourdelin's qualitative analysis is an important indication of the explicit requirement of weight conservation in experiments.

Advances were made in the identification of chymical substances. At the *Académie,* the experiments were carried out methodically. Unexpected and negative results were assessed in a critical manner and used to devise new tests, moving beyond traditional methods of recognition of substances by their sensible qualities towards a set of analytic procedures capable of more objective and more subtle distinctions. Bourdelin's rigorously controlled experiments included quantitative analysis.

The level of scepticism was variable. Boyle in his unfortunate association with Pierre was almost certainly the victim of a confidence trick. This lack of scepticism is atypical of him, although he is reluctant to criticise respected authorities. Lémery displays a strong scepticism in all the instances reviewed.

A fine example of cataloguing can be seen in the *L'histoire des plantes* which has excellent detailed illustrations.

7 COMMON METHODOLOGY

7.1 INTRODUCTION

In this chapter I will discuss heuristics, exemplars, symbolic generalisations and their relevance to chymistry. I will give a little of the historical background as much of the methodology of the Early Modern period draws on the experimental efforts of the alchemists of the Renaissance and from assayers, whose art had been in existence for millennia. Availability of laboratory facilities and the level of sophistication of apparatus, instrumentation and chemical reagents will be relevant to the complexity and level of experimentation that can be performed. An overview of the typical processes carried out by alchemists will be given. The progressive elements will be shown, for example Béguin's proto-equation and the increased clarity attained by advances in classification and taxonomy. Heuristic paradigms and the non-epistemic values of scope, simplicity and fruitfulness will also be considered. Finally, a brief review of the improvements in quantification will be made.

7.2 EXEMPLARS & SYMBOLIC GENERALISATION

These were discussed briefly in section 1.7. There is a close relationship between heuristics (as problem solution activities), exemplars and symbolic generalisation.

7.2.1 *Exemplars*

Kuhn discusses the recognition of the cognitive function of exemplars in the *Postscript*: "By it [exemplar] I mean, initially, the concrete problem-solutions that students encounter from the start of their scientific education, whether in laboratories, on examinations, or at the ends of chapters in science texts. ... All physicists, for example, begin by learning the same exemplars: problems such as the inclined plane, the conical pendulum, and Keplerian orbits; instruments such as the Vernier, the calorimeter, and the Wheatstone bridge" [Kuhn: 1969, *Postscript*].

In Chapter 1, I suggested that these examples from physics have their parallels with chymistry. In the following sections I will give details of a sample of the processes which were used in the alchemical laboratory, such as analysis and synthesis, assaying, distillation, calcination, fermentation and similar operations typically utilised in the period, and beyond. Considered with these will be the relevant apparatus and instrumentation.

Kuhn suggests ordinary problem solving of this sort as merely the application of theory to that which has already been learnt. They are done for practice, to gain facility or reinforce what has already been learnt. He thinks that such a description is only correct after a number of problems have been done; it is not correct at the start. "Rather, doing the problems is learning the language of a theory and acquiring the knowledge of nature embedded in that language" [Kuhn: 1962; 1970,[51] p172]. Also, "...exposure to a series of exemplary problem solutions teaches them [the students] to see different physical situations as like each other..." [*ibid*, p168]. We can look therefore for similar exemplars to those of physics, where chymists absorb the theory by practice of standard processes. Examples of such exemplars are given below. Development in theoretic understanding would be disseminated via the research community, including the wide communication network of the Hartlib Circle.

Exemplars in Lime processing

There were two principal uses of lime, the first being for agriculture and secondly as a mortar and cement for masonry. These have been in use for centuries. The earliest archaeological evidence for lime burning in Britain comes from the Roman period (AD 43-410). From around the eleventh-century the building of kilns and burning of lime became wide-spread as demand grew[52] [Smith: 2018].

Limestone and chalk are forms of calcium carbonate ($CaCO_3$) naturally formed from deposits of shells and marine organisms. When calcium carbonate is heated to a temperature of 900-1100 deg. C., it is calcined, producing calcium oxide (CaO) (quicklime), and carbon dioxide gas. Quicklime reacts exothermically with water, fiercely enough to produce steam, to form calcium hydroxide ($Ca(OH)_2$), known as slaked or hydrated lime. The slow reaction of slaked lime with carbon dioxide and water in the atmosphere causes it to revert to calcium carbonate, completing the cycle. This property of reverting calcium carbonate facilitates the use of lime as a cement. Quicklime is slaked with an excess of water to form a lime putty, which is mixed with hard sand to form a mortar. The mortar sets hard as the conversion to calcium carbonate occurs. It is a slow process and the mortar, initially weak, will continue to harden for years. A harder cement may be formed if the lime contains alumina and silica,

[51] *Postscript*

[52] Rural lime-burning became more common in the seventeenth-century, and the trade of Limeburner appears documented more frequently as a specialised occupation rather than casual or general labourer [Smith: 2018].

forming calcium aluminate and silicate as the cement hardens. These insoluble compounds allow the cement to harden under water.

Chemically, the process is as follows:

i) Calcination

$CaCO_3 \rightarrow CaO + CO_2 \uparrow$

Limestone heated to 900 deg. C calcines to give quicklime plus carbon dioxide gas (fixed air)

ii) Slaking (hydration)

$CaO + H_2O \rightarrow Ca(OH)_2$

Quicklime plus water gives slaked lime

ii) Reversion

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Slaked lime plus carbon dioxide from the atmosphere results in a reversion to calcium carbonate [*ibid*].

Lime was used as a fertilizer (using chalk or marl) known in prehistoric times. Lime counteracts the acidity of the soil (making it more suitable for certain crops) and improving drainage by making heavy clays more porous. Calcium is essential for plant growth. Chalk was left to weather, the cycles breaking it down into a fine enough state to be spread. However, calcium carbonate is practically insoluble and needs to be ground to a powdered state. In pre-modern era it was necessary to calcine the lime by burning using a lime kiln. An intermittent flare kiln was described by Cato (234-149 BC) in *De Agricultura* (circa 160 BC) These two processes represent a continuity with historical practices which include a cycle of analysis and synthesis.

Stahl: theory of phlogiston.

This paradigm illustration of exemplars, phlogiston, is usually associated with eighteenth-century chemistry, with Lavoisier's overthrowing of the phlogiston theory and replacing it with his theory of oxygen. The origins of the theory, however, begins in the seventeenth-century. German chemist, physician and philosopher, Georg Ernst Stahl, introduced the theory of phlogiston, drawing on older hypotheses, including that of Johann Joachim Becher (1635-82) [Weisberg et al: 2011].

Partington's description of Stahl's experiment is given below:

"Sulphur is a compound of a volatile and combustible part with a fixed and incombustible part, the latter being an acid" [Partington: 1961, p671]. "In his earliest writings, Stahl adopts Becher's theory that sulphur, instead of being an element or principle as the alchemists taught, contains the same inflammable principle (*terra pinguis*, phlogiston) as metals, its other principle, corresponding with the calx of a metal, being oil of vitriol (*acidum vitriolicum*). This was proved by a new experiment (novum experimentum) which Stahl claims as his own… and always considered as very important.." It appears in his earliest work *Zymotechnia fundamentalis* (1697)…" "The sulphuric (vitriolic) acid is 'fixed' by combining with potash to form vitriolated tartar (tartarum vitriolatum; potassium sulphate). This is fused with salt of tartar in a crucible with charcoal dust thown in, when causing sulphur to be generated, and forms with the potash a liver of sulphur (*hepar sulphuris*). The vitriolic acid takes phlogiston from the charcoal and becomes true sulphur… When a melt of potash and sulphur giving liver of sulphur was kept (exposed to air, a condition not mentioned, as unimportant) for a quarter of an hour, it lost its red colour and became white vitriolated tartar such as is made from salt of tartar and oil of vitriol. By heating this with charcoal, liver of sulphur is again formed, from which sulphur is at once precipitated by acids" [Partington: 1961: p 671]. Stahl's famous experiment was regarded as proof that sulphuric acid (oil of vitriol) was an element and sulphur a compound of sulphuric acid and phlogiston (φ).

"Liver of sulphur can be made by heating potash with sulphur *or* by heating oil of vitriol plus potash with charcoal which is rich in phlogiston.

Hence:

(sulphur + potash) = oil of vitriol + potash + φ

Therefore, sulphur = (oil of vitriol + φ)"

[*ibid* p672].

Further developments by Henry Cavendish (1731-1810) and Joseph Priestley (1733-1804) led to the isolation of dephlogisticated air (oxygen) [Weisberg et al: 2011]. Stahl's work led eventually to the oxidation/reduction theory, said to be one of the first unifying theories in the discipline.

Sennert's Crucial Experiment

Sennert's experiment in which he proved that the metals retained their form despite apparently disappearing when treated chymically (Chapter 5.2.5) [Partington: 1961]. Sennert used this experiment in his synthesis of substantial forms with corpuscularianism, in support of Aristotelianism. He did not subscribe to Thomist monism, but supported a pluralist interpretation incorporating a hierarchical concept of substantial forms (Chapter 5). Boyle, however, drew on this experiment to challenge Aristotelian substantial forms [Boyle: 1661].

Homberg's experimental method

Homberg's exemplary experimental procedure would be a model for later work. When Homberg found serious issues of repeatability of his process with the Bologna stone, he set up a series of carefully controlled experiments to discover the cause (Chapter 6.2.1). The series of experiments he devised adhered to the Baconian directive to alter only one parameter at a time. He not only tried different mortar types, but also variations in other stages of the calcination process. His conclusion, reached by a series of carefully reasoned steps, was that even minute traces of iron prevented fluorescence occurring. Homberg's method is a beautiful example of good experimental method, still current today. As he was an associate of Boyle, it is likely that he was a vector for promulgating his techniques to continental Europe. He published articles in the *Mémoires De L'Académie des Sciences* and Lémery included some of Homberg's work in his influential *Cours de Chymie* [Boas Hall: 1958].

Experimentation at the Académie Royale

At the Académie Royale, the French chymists improved the systemisation of chymical experiments (Chapter 6.3). Bourdelin, under the direction of Du Clos, and later Dodart, Perrault and Borel, carried out a carefully planned and executed set of experiments over several years. Although they did not achieve their objective of isolating the active ingredients in plants, their work provided interesting and important discoveries. These discoveries could scarcely have been made without the meticulous attention to operating parameters, repeatability, recording and analysis. Aware of the necessity to control heat, they surmised that the best way of extracting such substances (with minimal alteration) was by gradual, controlled application of heat. Accuracy in timing would be important here. The extracts would be analysed by mixing them with various solutions to indicate the properties of the constituent parts. The scale and complexity of the project was an important step towards a set of analytical procedures capable of more objective and subtle distinctions than those from traditional methods [Holmes: 2003]. The analyses by colour indicators by Boyle [1664] may have prompted the use of indicators at the *Académie*. These experiments led to the clear identification of the two major groups of alkalis. Further experiments by Bourdelin revealed that certain indicators could detect levels of acidity that were below the threshold of detection by human senses. This was referred to as occult acidity (Chapter 6.3). This contradicted the Aristotelian position on manifest properties. Acidity should be detectable by taste.

Bourdelin made accurate note of the weight of materials both before and after completion of the experiments. Holmes describes this as a rigorous quantitative style by the *Académie* [Holmes: 2003]. The method was Baconian in its use of controlled experiments.

Further experimentation with colour indicators (in this case tournesol) led to the highly unexpected conclusion that both acids and alkalis could co-exist in the same solution. This was a seminal moment in seventeenth-century chymistry, as up until this time it was commonly thought that an acid and alkali brought together would destroy each other. The experiment was shown to be repeatable (Chapter 6).

During the whole project, the chymists had to deal with the issues of negative results. This did not deter them, but stimulated the development of new procedures and new paths of investigation. In that sense the project can be considered fruitful. The high level of experimental rigour was an enabling factor.

7.2.2 *Symbolic generalisation*

Symbolic generalisation, as defined by Kuhn is understood as easily formalisable universal propositions regarded by a scientific community as natural laws or the fundamental equations of theories [Kuhn: 1977 pp297-302]. These include such important components as “elements combine in constant proportion by weight” [Kuhn: 1962, 2012: p182]. There was a general acceptance of conservation in weight during the seventeenth century as can be shown by the many experiments by Boyle, van Helmont, Bourdelin, Béguin, Santorio – to name a few– in which weight was carefully measured and was an important part of the design and execution of the experiment; the assumption of weight conservation seems to be implicit in the design. The use of symbols was not apparent at this time, even though the concepts were understood and adhered to in general. Kuhn notes that “the power of science seems quite generally to increase with the number of symbolic generalisations the practitioners have at their disposal” but he accepts that the example of taxonomy suggests that normal science can proceed with few such expressions [*ibid*].

Taxonomic Classification, Nomenclature

The nomenclature in early alchemy was confusing and convoluted to say the least. The planetary names for metals was relatively straightforward in that there was some consistency: Mars represented Iron, Venus, copper, etc. These were based on the supposed planetary influences. There seems to be an assumption of abiding chemical species. Béguin's discussion of salt, mercury and sulphur is in *Tyrocinium chymicum* (See Chapter 4). Many plants had several synonyms resulting from Greek and Latin names and common names (Chapter 3.6.7). A similar issue arises with medieval Arabic alchemical terminology; lead can be known as *usrub, ānuk* or *abbār*, tin as *raşāş qala'ī* [El-Elwed: 2002] (Chapter 2.5). Cataloguing and ensuring consistent, standardised nomenclature would assist enormously in helping to identify natural kinds.

7.2.3 *Heuristics*

Heuristics are strategies derived from experience acquired from previous experiments or processes. Models exemplifying idealised or simplified states may be used to design further experiments.

Lavoisier has been given credit for formalising the concept of weight balance in chemistry, and rightly so. But it does appear that the concept, if not necessarily articulated, did form a type of heuristic for the design of experiments in the seventeenth century, well before Lavoisier came on the scene. Bourdelin's careful measurements of weight at the *Académie Royale's* experiments with plant materials have already been noted (Chapter 6.3). Van Helmont's willow tree experiment, published posthumously in *Ortus Medicinae* (1648) is a well-known example of the recording of weight gain and loss, with the expectation that they will balance out (Chapter 8). Santorio Santori (1561-1636), professor at Padua and Venice [Partington, 1961] was a pioneer in detailed balance studies. He designed and utilised "a moveable platform, attached to a steelyard scale" enabling changes in body weight to be quantified [Eknoyan: 1999, p230]. His *Ars de statica medicina* (*On static medicine*), 1614, presented the practical results of a series of weighing procedures [Eknoyan: 1999]. Boyle also concerned himself with weight balance in his many chymical experiments and Hooke describes experiments involving weight in his *Micrographia* [Hooke: 1665, Obs.XV].

Chymical affinities also provided heuristics used to design experiments which enabled predictions (see also Chapter 7.5.4).

The mechanical hypotheses may have offered heuristics by analogy. Size, shape and motion can be visualised by everyone. Boyle believes that explanations using these terms will be "universally intelligible, and will be preferable for that reason" [Pyle: 2002]. Whether Boyle's mechanical hypothesis informs and directs his science has been a subject of debate [Chalmers: 1993]; [Pyle: 2002].

7.3 TRADITIONAL METHODS

Many of the processes have a long history; some of the methods are still current. There were two principal types of analysis- fire analysis and distillation, including dry distillation. Ancillary to these were methods for weighing, assessing temperature, controlling heat, and timing. Oddy describes the three basic methods for gold assaying used from ancient times (fire assay, the touchstone and specific gravity measurement [Oddy: 1983] as being still in use until the end of the twentieth-century[53]. Similarly, distillation and rectification have been known at least since the Middle Ages.

7.3.1 *Metallurgy/Assaying*

Of the three main methods of assaying, fire assaying probably has the longest history, going back over two millennia. Expertise in assaying was driven largely by commercial considerations, with counterfeit coinage being a problem since the invention of coinage around the end of the seventh-century BC in Asia Minor. Forgeries exist for virtually all of the precious metal coinage from antiquity, and laws against forging are known to have been extant in Roman times. The earliest legal documents are from Athens c. 375BC [Oddy: 1983, p52]. The different methods of assaying each had their specific advantages and disadvantages. A very basic method used to check the authenticity of coins was a scratch test to reveal gold gilding of silver.

Fire Assaying

Oddy illustrates the basic process of fire analysis. For analysis by cupellation, gold alloy and a larger amount of lead are melted together in a crucible (often a cupel, made primarily of

[53] More recently, X-Ray Fluorescence has been adopted as a non-destructive method of assaying.

bone) using an oxidising flame. The elements of the alloy (excluding any silver) are oxidised; the resulting dross is absorbed into the cupel. Remaining in the cupel is the gold plus any silver contained in the alloy. In ancient times the two metals were then separated by a cementation process. This involved applying strong heat to a cupel containing a mixture of brick dust, copper and iron sulphate and salt by which the silver was converted to silver chloride. The silver chloride would be absorbed by the brick dust, allowing the gold to be recovered [Oddy: 1983]. An alternative method was to heat the gold/silver alloy with antinomy sulphide, which would convert the silver to silver sulphide, but some of the antimony alloys with the gold. Further heating is required to separate out the metals. This method of assaying was described for the first time at the beginning of the sixteenth-century. The discovery of *aqua fortis* (nitric acid) enabled silver to be dissolved out of the gold; this is the method generally used currently [*ibid*]. Theophilus (flourished 12th century) describes a method of purifying silver by cupellation, though does not mention measuring purity. The Worshipful Company of Goldsmiths of London, which existed before 1179, appointed its first full-time assayer in 1478 [*ibid*].

Specific Gravity

This method dates to Archimedes (287- 212 BC) or earlier and his (now) well-known realisation that specific gravity could be used to check if a purported gold artefact had been debased. As Oddy explains, the method depends upon the fact that the specific gravity of gold (19.3g/cm^3) is nearly twice that of silver (10.5g/cm^3) and more than twice that of copper (8.9g/cm^3). Thus it may be used to indicate the degree of debasement. More accurate methods based on specific gravity were developed over the centuries[54] [Oddy: 1983].

Boyle coined the term hydrometer and described the instrument in 1675 [Bensaude-Vincent: 2000]. In the *Philosophical Transactions* (Vol. 10) pp329-348, Boyle asserts that he can prove its theoretical credentials and describes its use. "For 'tis clearly deducible from the

---

[54] "Both Galileo and Boyle developed graduated balances to simplify the calculation of the results" [Oddy: 1983]. Galileo developed a hydrostatic balance, the *bilancetta*, but the details were not published until 1644, after his death [Mottana: 2014]. Aside from his measurements of specific gravity of metals, he tested many gemstones, precious, semiprecious and artificial, and tabulated the results. Regrettably, descriptions of the stones are not supplied, so it is not possible to identify with certainty some of the gems, though others can be inferred. The reliability of the method is supported by the readings of several of the samples. For example, *rubini 3* gave a s.g. of 4.02, which compares well with the theoretical value of 3.989g/cm^2 [*ibid*]. Van Helmont also did experiments involving specific gravity [Partington: 1961] where he determined the specific gravity of metals in ratios.

Grounds of the Hydrostatics, that any solid Body heavier than Water, looses in the Water as much of the weight it had in the Air, as Water of equal bulk to the immersed Solid would weigh in the Air ; and consequently, since Gold is by far the most ponderous of Metals, a piece of Gold and one of equal weight of Copper, Brass, or any other Metal, being proposed, the Gold must be less in bulk, than the Copper or Brass."

Boyle: 1675; *Philosophical Transactions.*p330]. It can be utilised in the testing of alloys as well single particular metal, and is especially useful for the detection of counterfeit gold coins. It has certain advantages over other methods (such as fire assaying) in that it is non-destructive and the instrument is cheap, easily portable and does not require much skill in use. The hydrometer can also be used for measurement of specific gravities of liquids such as alcoholic beverages - ale and wine are typical examples. It is still used in modern times for this purpose.

Touchstone

The "touchstone was known to the Greeks at least as early as the fifth-century BC" [Hoover & Hoover: 1950 p458]. This method of quantitative analysis has certain advantages over assaying and the specific gravity processes, which are reliant on accurate weight measurement, and therefore dependent upon the accuracy of the weighing balance. The touchstone method has the double advantage of being non-destructive and easily portable, with no heating required. It does require some skill, however. Touching involves rubbing the artefact to be assessed onto the surface of a dark, preferably black, stone and comparing the streak with those of standard alloys. Agricola (Chapter 4.1) describes the method in detail in *De Re Metallica* (Chapter VII). Briefly, different needles are made with varying proportions of gold[55]. Methods (and perhaps theory) would have been passed down from master to apprentices.

[55] For example, one set of twenty-four needles is made of gold and silver. The first needle consists of twenty-three *duellae*[55] (about 9gms) of silver and one *duellae* of gold. The second is of twenty-two *duella* silver to two of gold, and so on, with the twenty-fourth needle which is pure gold. This set of needles is suitable for testing the quantity of silver or gold in the sample, typically coinage or ore. Other sets are gold and copper, gold, silver and copper, and a fourth which is silver and copper [Agricola: 1556: Hoover: 1950, p253-265]. Experienced assayers were said to achieve very accurate results [Hoover and Hoover:1950].

7.3.2 *Distillation and Rectification*

Distillation "made up the central operation of the 17th century chemical laboratory" [Holmes: 2003]. There is lack of certainty as to when the still was invented, but it was certainly used in the Middle Ages. By the middle of the 14th century distillation was a central operation of alchemists attempting to produce essences [*ibid*]. An early work in Early Modern period was John French's book *The Art of Distillation in* 1651, published in English. This may have been derived in part at least from the German alchemist Hieronymus Braunschweig's work, the "*Liber de arte destillandi* or the Small Book of Distillation was published …1500 and this edition is famous as one of the early printed works" [Forbes:1948, p109.] A second edition was published in 1512 [*ibid*].

These processes were very well established in the period. Any craftsman, artisan, metallurgist or assayer would be expected to be familiar with them or most of them along with sublimation, calcination, fermentation, dissolution in acids. Putting into practice processes such as redox reactions not only leads to competency in execution, but may promote understanding of the theory.

7.4 Laboratories, Instruments and Apparatus

7.4.1 *Laboratories*

Better funded than its English counterpart, the French *Académie Royale des Sciences* had two chemical laboratories in its first premises in the King's Library in Paris [Crosland: 2005; Stroup: 1990]. "Within a few months of the foundation of the Académie in 1666, plans were made for the construction of a chemical laboratory and in 1668 it came into use [Crosland: 2005]. It was fitted out with several furnaces, and ancillary equipment. A second smaller laboratory was built in close proximity. One of the prime objectives was the chymical analysis of plants by distillation. The science of chymistry was formally recognised by the Académie as one of the six major branches of science in 1699 [Crosland: 2005].

In the *House of Experiment*, Shapin discusses the availability of suitable places for the accomplishment of experimental work. There were plans for the Royal Society to have custom-built sites, but none of these materialised. However the new Oxford Ashmolean Museum (1683) did have a chemical laboratory in its basement [Shapin: 1988]. Experiments, including chymical, during the mid- to-late seventeenth century were carried out in a variety of venues. In England, these included apothecaries' shops, the royal palace and the universities. Shapin notes that some of the important venues utilised were private residences where laboratories were coextensive with the private residential areas. These included the laboratory of Francis Mercury Van Helmont, Samuel Hartlib's house at Charring Cross, and Kenelm Digby's residence. Other important sites were the various residences and laboratories of Boyle, the meeting places of the Royal Society and the quarters of Robert Hooke [*ibid*].

7.4.2 *Instruments and Techniques.*

The Aristotelian concept of qualities was not conducive to the development of mathematically quantitative values which could be denoted by symbols. The replacement of the elemental properties of hot and cold by the concept of temperature indicated the loosening of the hold of the four-element theory. Thermoscopy was well-known in the ancient world but did not develop into a systematic science until the Early Modern period [Barnett: 1956]. Barnett suggests that the development of modern thermometry and the concept of temperature took place in the early seventeenth-century as a result of two specific changes. One was the move towards abstraction, with increased importance placed on quantitative aspects of phenomena rather than focusing on qualitative. "The second was the trend towards instrumentation, essential to implement the process of abstraction and to enable non-subjective quantitative readings to be taken. For example, the degree of hot and cold could be determined without reference to sensation" [*ibid*, pp273-274]. Barnett further suggests that the move towards quantification may have been stimulated by the renewed interest in the works of Democritus and Plato, which claim that the essence of reality can be expressed quantitatively or numerically. Familiarity with the thermoscopes of Philo of Byzantium and Hero of Alexandria may have been a second driving force [*ibid*]. The chymists of the seventeenth-century benefited from the significant advances in instrumentation, which, though not fully developed, paved the way for more accurate measurements and a concomitant improvement in reproducibility.

Measurement of Temperature – the development of the thermometer.

The era was pre-thermometer but the thermoscope, which indicated changes in temperature but lacked a scale, was known. The invention of the first air thermometer was circa 1592-1597 and is attributed to Galileo [Barnett: 1956]. In the development of thermometry can be seen the appreciation of the need for accurate quantitative measurements in experimental operations, particularly for repeatability. Instrumentation was necessary to isolate actual degrees of heat and cold independent of subjective bodily sensations, which the Early

Moderns were coming to accept were not accurate representations of the phenomena. Galileo challenged the Aristotelian theory that hot and cold were two distinct properties capable of separate identification [*ibid,* p272]. Cold was simply the absence of heat.

The possibility of standardisation of the making of thermoscopes was considered one way of being able to replicate results with confidence. However, standardisation in manufacture presented many difficulties, though it was attempted by the *Accademia dei Lincei* [Barnett: 1956]. The alternative approach was to be able to calibrate individual thermoscopes by having fixed reference points. Many difference ways of setting these points were attempted, with varying degrees of success. By 1615, Sagredo constructed a thermoscope which probably used fixed points determined by snow, and snow and salt. These reference points enabled him to calibrate and add graduation points on the tube. In 1644, Marin Mersenne described a minor modification of the Galilean air thermometer [*ibid,* p278].

Bacon (1620) describes the use of a thermoscope and commented on the lack of uniformity amongst the various instruments. He notes its superior sensitivity; “the sensitivity of air to cold and heat is so subtle and sensitive that it far surpasses the sensitivity of the human touch” [Bacon: 1620 in: Jardine & Silverthorne: 2000, p125]. This aspect of thermometry, the necessity to measure temperature independently of human senses, was gaining ground.

Van Helmont set a scale of temperature with fifteen fixed points[56] [Partington: 1961 p220]. The development of liquid thermoscopes was an improvement on the air type, which were neither conveniently portable nor easy to use. An additional disadvantage was the open liquid being subject to evaporation. Kircher published an account of a hybrid version in 1643, which was simpler to use, but had the drawback that the unsealed tube left it vulnerable to changes in atmospheric pressure. That the open-air thermometer readings were affected by fluctuations in the external air pressure was a serious problem for uniformity and may have influenced the development of the liquid thermometer. The first closed liquid thermoscope that has been recorded is that of the Grand Duke Ferdinand II of Tuscany. The date is uncertain but is before 1644. The bulb was filled with alcohol (sometimes coloured) and the tube hermetically sealed, eliminating the problem of evaporation [Barnett: 1956].

[56] Ranging from the greatest cold, melting ice, well water, gentle lukewarm, lukewarm, human body temperature, feverish temperature, May sun, distillatory, boiling water, sublimating sulphur, melting pyrites, dark red heat, bright red heat, reverberatory with bellows. [Partington: 1961 p220].

Torricelli's experiments demonstrated the existence of the vacuum and correctly surmised that the variations in the height of the mercury in the thermometer were due variations in air pressure. Pascal repeated and extended Torricelli's experiment beginning in 1646 [*ibid*]. Pascal's famous experiments on the variation of air pressure with altitude were extremely significant. In his treatise of 1663 *Treatise on the weight of the mass of the air* (published posthumously) he reported "that degrees of heat are not correctly marked even in the best thermometers since in them all the different heights at which the columns of water stands are ascribed to the rarefaction or condensation of the air inside the tubes, whereas from our experiments we learn that changes that take place in the outer air, that is, the mass of the air, contribute markedly to those changes" [Barnett: 1956, p282].

Thermoscope to thermometer

In *Measuring Fire*, Powers (2014) focusses on the progression towards mastering the difficult process of fixing temperature points in order to accurately calibrate thermometers. Boerhaave (1669-1738) first used a thermometer in his chemistry lectures in 1718 in Leiden [Powers: 2014]. In his early lectures Boerhaave differentiated between four general grades of heat; the first degree of heat was that of a gentle water bath equivalent to the warmth of dung; the second degree was that of a summer day or warm-water bath. The third was the point of boiling water, and the fourth included the melting point of metals and the point of combustion. Each was related to the ways of producing changes in substances during chemical operations [*ibid*, p163]. In 1717, Fahrenheit (1686-1735) moved to Amsterdam where he constructed mercury thermometers. He sent samples to Boerhaave, who had been appointed to the chair of Chemistry at Leiden. Boerhaave and Fahrenheit met and corresponded over a twelve-year period, with Boerhaave becoming Fahrenheit's most important patron, utilising his thermometers in his post-1718 lectures and textbooks.

Powers remarks "Most thermometers until the late seventeenth century were idiosyncratic devices that were not graduated according to set scales" [ibid, p164]. There were significant difficulties in obtaining consistency between various instruments, even those from the same maker. In theory, it was thought possible to calibrate against standard fixed points, produced by reliable phenomena, such as the freezing point of water. In practice this was not so easily obtained. Solid ice may get colder as it freezes, and as was already known, barometric pressure was also variable, so the boiling point of water was not a fixed point either[57]. This was used until the eighteenth-century, when the method was deemed unreliable. Fahrenheit, continuing his research, thought that the most reliable fixed point was that of human body temperature. Later he fixed on the ice-water bath brought to thermal equilibrium. He believed his mercury thermometer would prove a useful instrument for chemical analysis. It extended significantly the range of thermometric measurements. With mercury's boiling point of 600 deg. F. (315°C) it had a far greater range than spirit of wine thermometers which were functional to about 174 deg. F. (78°C) and was also suitable for many of the common chemical reagents such as oil of vitriol, and spirit of nitre; these have a boiling point higher than 78°C. He contended that each pure chemical species had a stable boiling point, specific gravity and thermal expansion. Knowing these would enable determination of composition and purity of samples [*ibid,* p167]. Fahrenheit strove for a high level of agreement between his spirit and mercury thermometers but was unable to make the two types agree at measurements above 112 deg. Despite these difficulties, Boerhaave utilised the thermometers in his chemistry lectures as they had an important function in demonstrating his theories on fire. "He aimed to promote an empirical approach which could be used to put chymical principles and methods on a firm footing, based on the appreciation of natural phenomena rather than speculative hypotheses" [*ibid,* p169].

Measurement of Time

Instruments for measuring time included clepsydra (water clocks), pulse rates, music, and calibrated candles. The accuracy of water clocks was dependent upon the viscosity of the medium used; viscosity, (and rate of flow) humidity, and different outcomes in closed or open vessels.

Although Bacon would have been able to measure time in terms of hours, smaller increments would have been problematic. Hours would have been divided up, (halves, quarters) but not into minutes and seconds before the end of the seventeenth century [Dohrn-van Rossum: 1996]. Presumably one could count one's pulse which might give the ability to make comparative estimations of time elapsed, but this will lack accuracy and is only comparative, not absolute measurement.

---

[57] The French academicians used the ambient temperature of the cellars of the Royal Observatory, endeavouring to maintain a standard point. [Powers:2014]

Given a container of water with a restricted outlet to allow the container to empty, it is a commonplace that the water flow decreases as the water level reduces. That the water flow does not remain constant is due to the reduction in pressure of the head of water. Mills (1982) relates the attempts, from as long ago as 1400BC, to mitigate this shortcoming. This was achieved by making a cone-shaped (with the bottom diameter smaller than the top) rather than a straight-sided cylindrical vessel. The angle of the cone must have been determined empirically, as the mathematical theory was not developed until the seventeenth century [Mills: 1982]. The viscosity of water also has to be taken into consideration, as water runs faster at higher temperatures.

The pendulum clock was invented in 1656 by Huygens [Lau, Plofker: 2007]. Before this date, hours could not be measured in minutes or seconds, but at best into quarters, as noted above. In 1673, Huygens published *Horologium Oscillatorium*, where he described improvements to the design. Over the next decades error reduced from under one minute per day to less than ten seconds per day [Higgins et al: 2004]. This clearly found application in design and execution of experiments.

Assaying Balance

The assaying balance was described in the *Fleta Minor* (1580) by Ercker, translated by John Pettus (FRS 1663) published 1683; and also in *Aula Subterranea* (Prague, 1574) by Lazarus Ercker. The earliest illustration of an enclosed analytical balance was in the *Theatrum Chemicum Britannicum*, ed. Elias Ashmole, (1652) [Newman: 2000 in: Holmes & Levere: 2000]. This is said to be the oldest illustration of a balance in a case [*ibid*. p40]. There is a dearth of information on the precision of the enclosed balance, but an *Ordonnace* of Philip VI of France, ca.1343, insists that the assaying must be carried out where there is neither wind nor cold, and the assayer’s breath does not affect the balance. This would indicate that it must be light, and one would assume a fair degree of accuracy [*ibid* pp40-44].

Agricola gives a woodcut showing three balances of differing sizes, and explains the weights system [Hoover: 1950 p264-265]. The largest is for weighing leads while the second is for ore or metal to be assayed. The third, most delicate balance is used for weighing beads of gold or silver after being assayed in the cupel. The smallest weight used seems to be the drachma, approximately 4.3gms.

The Microscope

The effect of water globules, and later glass spheres, had been recognised by the ancient Greeks and Romans as producing magnification [Bardell: 2004]. Islamic philosopher Ibn al-Haytham (ca. 965-ca 1039) had investigated the magnification of plano-convex glass. Roger Bacon (ca 1220-92) also experimented with lenses as an aid to vision, and discussed his eight rules for refraction of light in his *Opus majus* (1267). The first single-lense microscope is credited to Dutch spectacle makers around 1600.[58] The earliest record of the existence of a microscope is by Huygens in 1662, in a letter in which he describes it as a 'lunette do Drebbel'. The earliest recorded observations using a microscope are circa 1625 [*ibid*]. Microscopes were built by the Dutchman Antony van Leeuwenhoek (1632-1723) who was elected FRS in 1680 [Dobell: 1923]. He made minute biconvex lenses, and mounted them in silver. Regrettably most of his microscopes are lost. Magnification would have been around x300 with 'excellent resolution' [*ibid*].

Hooke's seminal work, *Micrographia* (1665), was published by the Royal Society. It is probable that usable magnification would be around x50, due to aberrations and chromatic distortions by the lenses, and the need for a useable depth of vision. Nevertheless, extremely detailed engravings were made depicting features not previously accessible to the human eye, including crystalline forms. It is likely that the Danish geologist Nicolaus Steno (1638-1686) would have been familiar with Hooke's work [Schneer: 1983]. Steno travelled widely in France, Germany and Italy, and was elected to the *Accademia del Cimento*. Hooke had done some work on crystallography [Hooke: 1665, XIII] but Steno took it further by formulating the law of constant angles, now known as the first law of crystallography (1669) [Schneer: 1983]. This law states that the "angles between corresponding faces are the same for all specimens of the same mineral" [Glazer: 2016]. The law is also called the law of constancy of interfacial angles [*ibid*] and holds for any two crystals. This clearly has benefits in terms of taxonomical classification, as crystal formations can be used for identification; for example, common salt is cubic. Crystalline formation had already been used for distinguishing substances, but the availability of the microscope enabled a greater level of detail and differentiation

[58] Though the exact person is not known, it is likely to have been Hans Janssen, his son Zacharius, or Hans Lipperman, or possibly an instrument maker, Jacob Metius [Dobell: 1923].

Furnaces

Glauber, an innovative and practical chymist, was responsible for many improvements to furnaces and stills. One invention was the installation of a chimney at the top of the furnace to improve the draft, replacing the traditional bellows [Partington: 1961]. His improvements allowed him to attain higher temperatures; this facilitated an increase in the range of distillable substances.

The blowpipe

This simple but very effective instrument had been used since antiquity. Newman [2000] calls the blowpipe and the precision balance as “two of the most important tools of the early chemist” [Newman *In*: Holmes & Levere: 2000 pp35-38]. Egyptian carvings from circa 2500BC show them being used by goldsmiths and other artisans. Easily portable, it consists of a thin tube, a few inches in length, one end thinning to give a small orifice, the other end being wider to allow air to be blown through it. The sample to be analysed is placed on a charcoal block and heated by a flame.[59] Newman states that a description of the blowpipe is given in Paul of Taranto’s *Theoretica et Practica,* probably written around the end of the thirteenth century. The action of the flame on the sample is indicative of the type of mineral (by colour) or ore. In the *Ars Alchemie* of Scotus (1266-1308) it is shown that it was possible to differentiate two chemicals which were both known as nitrium, sal nitrium (or natrium) in medieval times. These substances were soda (sodium carbonate) and salt-peter (potassium nitrate). They were differentiated by tests using burning coals, checking for vapour or smoke, saltation, crackling and a product of combustion [*ibid* pp37-38]. Newman conjectures that a blowpipe would have been a possible instrument for these tests using glowing coals.

The blowpipe was also used in glassmaking. Kunckel’s book on glassmaking *Ars vitriaria experimentalis* (1679) suggests the blowpipe as useful apparatus for the alchymist. This book included the seven books of Neri plus the notes by Merret in the first part, while the second part was by Kunckel himself. It is considered to be by far the best account of glass-making in existence until the end of the eighteenth-century [Partington: 1961]. In the seventeenth-

[59] The blowpipe facilitates the direction and concentration of a stream of air onto a small area, intensifying the heat in the area. This produces an elongated flame composed of a low–temperature inner blue cone of unburned gases, a visible flame in which gases are rapidly oxidized (the reducing flame), and an invisible outer zone of high temperature in which no gas combustion takes place (the oxidizing flame) See also Newman: 2000] in [Holmes & Levere: 2000, p36].

century the blowpipe was widely used in the glass industry and the technique became common in the laboratory for chemical analysis [Hudson: 2005 p156]. The blowpipe is still used in some glass-making processes, particularly artisanal.

7.4.3 *Other Instrumentation & analytical techniques*

A few of the other commonly used apparatus were the *Alembic*, *crucibles*, *cupels*, which had been in used by alchemists and metallurgists for centuries. The *bain-marie*, said to have been invented by Mary the Jewess between the first and third centuries AD, is still in use in modern times.

The *pneumatic trough* invented by Stephen Hales (1677-1739) was used for collection of gases. Hales was a pioneer in quantitative experimentation, especially in plant and animal physiology.

Burning lenses have been used since antiquity. More sophisticated lenses, some quite substantial, were used by many chymists, including Le Fèvre, who describes a three- or four-feet diameter lens used during an experiment calcining antimony [Partington: 1962].

7.5 GENERATION OF NEW TECHNIQUES, PROCESSES OR CHEMICALS.

Having demonstrated the continuity of the chymists' methods over time, and the gradual improvements that have been accomplished, I move on to the more progressive elements. These include the progress in understanding chemical composition and taxonomy.

7.5.1 *Prototype of the chemical equation*

Béguin's diagram shows in graphic form the reaction in the distillation of corrosive sublimate (mercuric chloride) and stibnite (antimony sulphide), where butter of antimony (antimony trichloride) and cinnabar (mercuric sulphide) are formed. "…This is a clear description of double decomposition in terms of affinity (sympathie)" [Partington: 1962, p4].

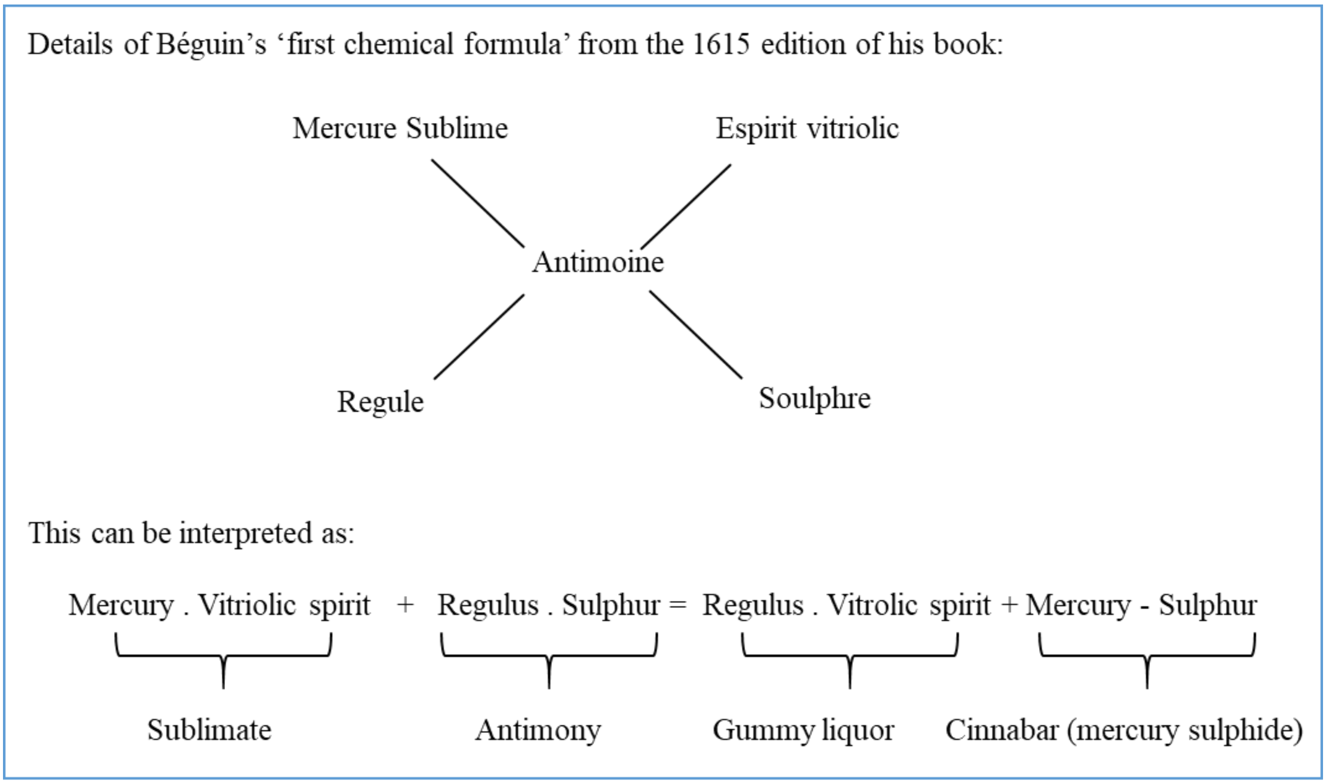


Fig. 8. Béguin's 'First Chemical Equation'

7.5.2 *Mineral acids and other chemical reagents*

Two important developments of the Middle Ages were the distillation of ethyl alcohol and the production of mineral acids. The mineral acids, nitric, sulphuric and hydrochloric, became available in the thirteenth-century, Multhauf says "The mineral acids manifest themselves clearly only about three centuries after al-Razi..." [Multhauf: 1966]. They were not unambiguously differentiated before the seventeenth.

Acids

Concentrated acetic acid was prepared by distilling verdigris; the residue contains copper. Otto Tachenius (1610-1680) a German pharmacist, iatrochemist and alchemist (and incidentally a purveyor of a dubious remedy distilled from vipers) proved by experiments, some of which were quantitative, that it was the same as common vinegar, though stronger [Partington: 1961 p296].

Glacial acetic acid was prepared by Stahl in 1697 [Partington: 1962 p685]. The preparation of oil of sulphur (*oleum sulphuris*) is described by Giambattista della Porta (1535-1615). This preparation is usually credited to Libavius.

Mineral Acids

Hydrochloric and nitric acid combined in the ratio 3:1 forms *aqua regia,* which is one of the few reagents that will dissolve gold. The discovery of these acids is often attributed to Geber. However, the Geberian corpus comprises over three thousand books and is unlikely to be the work of one person (Chapter 2). Basil Valentine was possibly the first to prepare hydrochloric acid from marine salt (sodium chloride) and sulphuric acid (oil of vitriol).

Nitric Acid

Glauber was a German-born iatrochemist who settled in Amsterdam [Partington: 1961]. He described clearly the production of concentrated mineral acids - hydrochloric, sulphuric and nitric -in his *Furni novi philosophici* (1646-1650) [Debus: 1977, p426]. The notes and practical applications made his book extremely popular; it was translated into Latin, German, French and English [*ibid*, p429].

Nitric acid (*aqua fortis*) was made by reacting sulphuric acid with a nitrate (such as potassium nitrate).

$H_2SO_4 + KNO_3 \rightarrow KHSO_4 + HNO_3$

Alternative methods were the heating one part of saltpeter with one of alum, giving *spiritus acidus nitri*, or by heating1part of saltpeter with 2 parts of green vitriol, giving *aqua fortis* [Partington: 1961, pp350-352].

Acetone

Béguin is said to have given the first description of acetone. He describes the process in his *Tyrocinium chymicum* (c. 1610) (Chapter 4.5). The distillation of a fragrant spirit and two oils (red and yellow) from sugar of lead (lead acetate) would give acetone (this had been given by Libavius.)

7.5.3 *Determining Identity*

Boyle's Colour Indicator Analysis

Boyle's work on analysis using colour indicators is considered to have played a vital role in the development of analytical chemistry. His *Experimental History of Colours* (1664) describes fifty experiments which include optical work with prisms as well as a substantial number relating to the investigation of tinctures on chymical reagents. Possibly the most well know of these is the syrup of violets trial on acid salts and on alkalis (experiment no. XX). He found that the common acids turned blue syrup of violets red, while alkalis turned it green. Similar effects were obtained using various juices such as those from *Ligustrum nephriticum*, buckthorn berries (*Rhamnus cathartica*), cornflowers (Centauris cyanis) and tournesol. Boyle describes experiment no. X in which the tincture of *Lignum nephriticum* and how (following Kircher) it may be utilised to discern whether a salt is of acid, sulphurous or alkaline nature [Boyle: 1664: Hunter and Davis:1999, vol 4].

Boyle was not the first to recognise that bases turn red cloth blue, and that acids will turn it red again. Eamon (1980), quoting Debus, notes that the observation that "bases turned scarlet cloth blue, while acids turned it red again; the colour change of tincture of violets and of rose leaves in the presence of oil of vitriol was also noticed in the early seventeenth century" [Debus:1962] [Eamon: 1980].

Eamon suggests that a possible source of Boyle's information on colour changes may have come from medieval cloth dyers or painters, who had accumulated much empirical data on the use of plants to provide a wide range of colours[60] [Eamon: 1980]. Techniques for testing for alkalis and acids in solution were developed by Boyle and also by fellows of the Académie Royale (Chapter 6.3).

Other identification tests

Boas Hall [1958] describes Boyle's methods of analysis "But in addition to....more or less physical means of determining identity, Boyle devised or adapted numerous chemical methods. Sometimes he used the fact that there was a peculiar reaction which only one substance gave. An example was the difference in solubility in aqua regia and aqua fortis of gold and silver. Boyle remarked that *saccharum saturni* (sugar of lead) must not only taste sweet, but must be capable of producing *spiritus ardens Saturni*, Béguin's burning spirit of Saturn, 'acetone.'" Only the acetate, the true sugar of lead, will give this reaction [Boas Hall: 1958, p132-134].

[60] The colours obtained varied not only with the types of plant, but the season in which they were harvested and which mordants were used. Dyers induced colour changes chymically, and almost all the vegetable extracts used on textiles would have been treated with different mordants to produce a variety of colours and intensities [Eamon:1980].

Chemical composition and taxonomy

In early attempts to categorise substances, use has been made of taste and appearance. The term ‘acid’ dates from 1626, probably borrowed through the French *acide,* or directly from the Latin *acidus,* sour, from *acere,* to be sour, related to *acer,* sharp [Barnhart: 1988, 2002].

Alkali is a term used from the late fourteenth-century, meaning any substance that had the properties of soda, such as lye or potash. Alkali morphed from the Arabic *al-qali,* the “burnt ashes of saltwort,” a plant growing on alkaline soil [*ibid*]. One of the commonest salts in use in the seventeenth-century was salt of tartar, or potash, (potassium carbonate) which gives off carbon dioxide when treated with acid.

‘Base’ seems to have been first used by the French chymist Louis Lémery (1677-1743) as a synonym for the older Paracelsian term ‘matrix’. Its modern meaning in chemical vocabulary is attributed to Rouelle (1703-1770) who used it in a memoir on salts in 1754 [Jensen: 2006].

There is a gradual transition of the term matrix from the concept of a womb of the earth, to earth and subsequently base, as Rouelle used it into the 18th century. By the 1730s the term matrix had largely disappeared, and the metaphysical notion had given way to the modern term 'base' [Siegfried: 2002, pp81-82].

Salts and spirits

Salt was a name given to a variety of substances; the metaphysical Salt of Paracelsus and many corporeal bodies. The particular use was generally inferred from the context. Potassium carbonate and sodium hydroxide were often conflated. Partington notes that Stahl’s work is only comprehensible when it is remembered that the acids, (vitriolic acid, spirit of salt, and nitric acid) and alkalis (potash, soda and ammonia) are still classified as ‘salts’ [Partington: 1961, Vol II, p678].

As noted by Siegfried, around the middle of the seventeenth century, Glauber had recognised the neutralising effect when acids and alkalis were mixed together. In 1688, Pierre Borel (c. 1620-1671), a member of the Académie, wrote an essay on the mortification of acids by alkalis, describing the characteristic effervescence found with such reactions. If a substance effervesced when treated with an acid, it was an alkali, and vice versa. This became the standard method of characterising the acidity or alkalinity of a body [Siegfried: 2002, p76]. The effervescence was not, however, recognised as the liberation of a gas. Rather it was explained as ‘strife’ between the bodies. By the early eighteenth century, neutral salts, identified by the failure to effervesce with either an acid or an alkali, became known as a separate class of salts [ibid, p78].

7.5.4 *Van Helmont's Acid-Alkali Theory*

J.B. Van Helmont, described by Boas Hall as the 'first great theoretical chemist of the century' [Boas Hall: 1958, p55] was very influential on Boyle. He was responsible for the well-known Willow tree experiment, in which weighed a sapling before planting, noted that it was five pounds (2.3 kg), potted it up with earth weighing about two hundred pounds (about 90kg) of dry earth. Over five years nothing was added to the pot except for rain water or distilled water. When five years were over, he had the tree weighed again and found that it weighed 169 pounds (about 77 kg), while the soil had lost only 2 ounces (57 grams). He concluded that "164 pounds of wood, barks, and roots arose out of water only." He was not aware of course of photosynthesis, and at that period air was considered to be chemically inert, but it was an important experiment in that he used a balance and he believed that the mass of materials had to be accounted for in chemical processes. He criticised Aristotelian theory and rejected the four-element theory and the tri prima. He believed that mercury was a simple substance and not a constituent of other metals [Partington: 1961, Vol II, p210-243].

His acid-alkali theory claimed that all substances were composed of acid and alkali. This theory came out of his experiments and explanations of the digestive systems of animals. One of van Helmont's pupils, Sylvius, extended the idea from digestion to encompass all bodily functions, claiming that all bodily fluids were either acidic or alkaline. For some years it was held in high regard (though Boyle opposed it.) Its success did, however lead to a closer connexion between chymistry and medicine [Boas Hall: 1958 p59]. The perceived importance of chemical drugs was enhanced, and proficiency in chymistry was the norm for the majority of eminent physicians. Boyle specifically rejected the acid-alkali theory and demonstrated its inadequacies by pointing out numerous and common exceptions [Siegfried: 2002 p77]. For example, the theory claimed that anything that acids attack and dissolve must contain an alkali. He illustrated the fallibility of the theory:

The solution of copper in *aqua fortis* was held by this theory to be caused by the fundamental reaction between the acid and the alkali in the copper. Boyle pointed out that this argument was unsafe, because spirit of urine (an alkaline, ammonia) would also dissolve copper filings. This work, coupled with his indicator experiments, work effectively destroyed credence in the theory.

7.5.5 *Chemical Affinities*

It was in 1718 that Geoffroy (1672-1731) presented his *Table des differents rapports observés en Chimie entre differentes substances* to the Académie Royale in Paris [Klein: 1995]. His table, which indicated explicitly the level of affinity of one chemical substance for another, became the prototype for later ones. This was an extremely important development. However, it can be shown that the concept of affinity was known implicitly in the late seventeenth century. For example, Lémery, writing in his *Cours de Chymie* describes the dissolution of mercury and its subsequent recovery:

"Cinnabar is nothing but a mixture of Acid Spirits and mercury together; thus, if you do mix it with some Alkali, and drive it upwards by fire, the Acids, for the reasons I have already spoken of concerning Silver, must leave the Bodies to which they were joined to before, for to enter the Alkali; and this is what is happening here, for the Acids finding the quicklime very porous, do leave the mercury, and adhere to the quicklime; so that this mercury, being disengaged from what held it fixed before, and driven by the fire, comes forth of the retort in form of spirit, but the coolness of the water that is in the recipient, condenses it and resolves it into quicksilver" [Lémery: 1677, p84-85;Siegfried: 2002, p63].

This indicates awareness of affinity or elective attraction; the pattern of behaviour where one substance shows a particular chemical preference by leaving its combination with one body to attach itself to another. In this case the acid has greater affinity for the quicklime than that for mercury. The concept can be seen in the mid-seventeenth century, in for example the work of Glauber. Chymists were aware of the displacement of one metal for another. This elective behaviour was used as an explanation long before the systemisation by Geoffroy [*ibid*, p94]. Siegfried describes Geoffroy's table as the most important summary of chymical behaviour at that time. The purpose was to enable chymists to predict the result when they mixed different bodies. Note that with the exception of the Sulphur principle, all the substances represented – acids, alkalis, earths, metals, neutral salts – are materially real. There is no metaphysical explanation attached (Chapter 2).

7.6 MATHEMATICS (QUANTIFICATION)

Four areas have been identified where advances have been made in the area of quantification. These are the concept of weight balance, temperature measurement, specific gravity and the measurement of time.

Weight

There appears an implicit understanding of the requirement, indeed expectation, for the total weight of chymical components prior to analysis to balance out with the weight after processing. At the *Académie*, Bourdelin performed (Chapter 6.3) his extensive and laborious experiments on plants, carefully making and recording the weight 'balance sheet.' The willow tree experiment conducted over five years by Van Helmont specially used weight measurements in an attempt to prove his hypothesis. Boyle made use of this concept repeatedly in his experiments, including that in his *Essay on Nitre.* Later more explicitly quantitative work can be seen in *Producibleness of Chemical Principles* (Part 1), 1680. Homberg was also aware of the need for conservation of weight principle [Siegfried: 2002, p87]. However, attempts at quantification would remain problematic until gases were included as part of the equation and suitable instruments and techniques were developed for isolating and measuring different kinds of air [*ibid*].

Temperature

Thermoscopes were already in use around the beginning of the century (by Galileo for example) but the invention of reliable thermometers was a difficult and daunting task, as discussed earlier. Without standard reference points, it was almost impossible to set a scale, and without having a thermometer to measure phenomena which could be used to set the fixed points, calibration was a pernicious problem. During the seventeenth-century numerous different fixed-point methods were used to gauge temperature [Chang: 2004]. Many used a two-point system, such as Sanctorius who used candle flame and snow, rather than a single point such as boiling water, but all systems suffered from a lack of certainty and a lack of uniformity which are so necessary for reproducibility of experiments. Van Helmont was unusual with his fifteen-point system, attempting greater accuracy. Nevertheless, these systems, though not very accurate, and subject to variables such as air pressure, did eventually lead to consistency in the measurement of temperature. This was an enabling factor in the experimental method and science of heat.

Specific Gravity

Although this method of analysis was known since antiquity, improvements in method were made. Van Helmont determined specific gravities of tin, iron, copper, silver, lead, mercury and gold [Partington: 1961].

Time

Huygens was responsible, with the development of his pendulum clock, for increasing the accuracy of time measurement. Whereas before the end of the seventeenth-century, time was reckoned by the quarter-hour at best [Dohrn-van Rossum: 1996]. Huygens' improvements allowed divisions into minutes during the latter decades of the century. This would have enabled much better accuracy in timing of experiments, particularly those involving heat, and would have resulted in improvements in reproducibility.

7.7 SUMMARY

Although the Early Modern alchemists faced severe problems in the practice and development of chemical processes and understanding (such as impure reagents and difficulties in measurement and regulation of parameters) they benefited from the wealth of practical experience of many generations of craftsmen, artisans, and metallurgists who had plied their trade over many centuries. This was the springboard from which seventeenth-century alchemists honed and developed traditional practices whilst also introducing new practices and instrumentation which facilitated better accuracy and reproducibility. At the same time changes in terminology and taxonomy indicated the move away from metaphysical principles and vitalism, towards materially real substances. Chymistry as analysis and synthesis of abiding chemical species, which is subversive to Aristotelianism, clearly marks a change in the prevailing deep matter theory.

Progress with classification was being made, albeit the issue of impure reagents remained a challenge. A wide range of analytical techniques were available. Fusible bodies such as gold, silver, copper, iron, lead, tin were well defined separate entities. For the metallurgists and alchemists, the manifest properties such as density, colour, hardness, sound (for example the cry of tin), flame test (colour), fusibility, ductility and ease of alloying were all regularly used methods of analysis (Chapter 2). Differentiation of substances by crystalline structure, already employed, was very much augmented by the deployment of the microscope. Progress was made by the *Académie Royale* in analytical procedures for acids and alkalis. Boyle's work on colour indicators was also an important contribution. Systemisation of chymistry had improved, with such experimental methods as those of Homberg being promulgated, certainly in France and England, possibly further across Europe.

In this chapter I have shown that exemplars which equate to those described by Kuhn in physics, were also extant in chymistry. Universal propositions can be found that were understood implicitly, though not necessarily explicitly, or in symbolic notation. The requirement for weight balance in experiments was an accepted concept, though not necessarily well articulated. It provided a heuristic with which to design, and subsequently assess, experiments. Notable also is the knowledge and manipulation of chemical affinities, in advance of Geoffroy's explicit table of 1718. Appreciation of affinities was an enabling factor in the prediction of experiments.

8 ANALYSIS AND CONCLUSIONS

8.1 INTRODUCTION

I set out to evaluate the practice of science in the seventeenth-century Latin West. This has been achieved by treating the practice of science as a Wittgensteinian cluster, identifying the essential and desirable components. By examining important literature of the era, scientific communities, common methodology, authorities etc., I have assembled representative samples of the state of scientific practice, with special reference to chymistry, in the time period. This enables me to prove my conclusion that alchemy/chymistry practised in the Early Modern period had the components necessary for it to be judged science by informed persons, and as such deserves to be recognised as having a positive, substantial contribution, as proto-chemistry, in the development of the modern discipline of chemistry. Without recourse to an ahistorical scientific method, I can now show that the chymistry being practiced by educated men, and indeed artisans, complied in many respects with good practice, and in some cases exemplified it. Gathering the disparate components together, I analyse the extent to which they can be said to be embedded (or have failed to gain hold) in the practice of natural philosophy, including the complex interactions amongst them.

8.2 ANALYSIS

8.2.1 *Cognitive Toolkit*

It seems axiomatic that it would not be possible to have an activity that can be described as science without having cognitive faculties underlying such a practice. Therefore, at the core of the discipline lies what I have described as a ‘cognitive toolkit.’ This joins critical reasoning and reflective thought with systems of analysis and methods of acquiring scientific data. Few scientists work entirely divorced from a research community and all which that entails; universities, learned societies, peer review, authorities, and the closely associated sceptical challenging of orthodoxy. The epistemic values of accuracy and coherence ought to be inherent in the teachings of a scientific community, though there may be a disjoint between normative values and actual practice. It is difficult also to see how science could proceed at an experimental level without heuristic paradigms, even if they are quite simplistic. These theory-neutral heuristic paradigms are of importance in observation, data collation, experimentation, and reproducibility. To prove or disprove a hypothesis by experiment requires decisions to be made on which data to collect, which parameters are relevant, and how to test the hypothesis. Reproducibility is vital in the corroboration of a hypothesis, and insightful handling of negative instances can prove very instructive. A high level of scepticism would ensure that the claims of authorities are tested and not just accepted based on the stature of the authority or the longevity of the assertion. Observations and data collation lead to classification and by extrapolation to the concepts of natural kinds. The understanding and manipulation of natural kinds are fundamental aspects of chemistry.

8.2.2 *Critical Thinking*

Reviewing the core requisites, I will begin with the cognitive toolkit. Did seventeenth - century natural philosophers have the cognitive tools and the appropriate education, knowledge, training, i.e. a nurturing intellectual environment and the practical sufficiencies to practice a chymistry which is creditable as proto-chemistry?

Critical or reflective thinking was appreciated and well-established in ancient Greece; from the Late Middle Ages onwards there were scholars such as Aquinas, John Colet, and Erasmus (Erasmus corresponded with Agricola and Paracelsus). In England, the Cambridge Platonists advocated reason as a divine imprint of God within Man. Bacon's *Advancement of Learning* (1605), *Novum Organum* (1620) and also Descartes' *Rules for the direction of the Mind* (1685) aimed to promote critical thinking to avoid accepting common beliefs or sophisticated rhetoric that lacked sufficient evidence or rational foundation to warrant belief [Paul et al: 1997]. The *Port Royal Logic* (1662) was "the most influential logic text from the time of its publication up to the end of nineteenth century" [Buroker: 2014]. This book contains a section on scientific method and epistemology. There were debates over the use of the old logic and the new logic, indicating that there was a strong awareness of the necessity for clear and logical arguments. The Port Royal Logic helped to update and simplify Aristotelian logic. Its concepts were carried through into later centuries, influencing, for example Mill's *A System of Logic* (1843). As the century nearer its close, logic began to centre increasingly on an analysis of cognitive faculties. This type of analysis, introduced by Descartes, was continued by Locke in *Essay concerning Human Understanding* (1690) [Capozzi: 1998]. It can be seen that seventeenth century natural philosophers had the benefits of several important and influential works on logic, to aid critical thinking on specific sciences such as chymistry (see Chapter 3.2).

Syllogism

The Aristotelian system of syllogisms was taught at the universities, but was subject to increasing criticism over the century. There was a strong move towards experimental work, and deduction from observations and results (Chapter 3.2). The syllogism was challenged by Bacon and others.

Hypothetico-deductive method

The hypothetico-deductive method can be dated to the tenth century Islamic polymath *Ibn al-Haytham* (Alhazen), 965–1039, [Gorini: 2003] who emphasised the use of experimental data and importance of reproducibility of results resulting from such experiments [*ibid*]. An Early Modern exponent was Huygens when he presented a clear and precise account of the method to the Royal Society in 1678 [Verbeek: 2015]. He subsequently published the concept in his *Treatise on Light* (1690) [Huygens: 1690].

Induction

The Baconian induction programme is evident in the *Philosophical Transactions,* as demonstrated by the frequent requests for data by the Royal Society, and by Boyle's lists, published in their journal. A typical example is given in the *'Heads'* (Appendix G). The *Académie Royale* were committed to an inductive programme (Chapter 6). They collected massive amounts of information attempting to isolate the active ingredients of plants project, but it became difficult to assess, partly because there were so much data. However, despite the disappointing results they did have positive outcomes in the improvement of their experimental technique, and standardising their processes. Important discoveries were that acids and alkalis could co-exist, and that chymical indicators could reveal the presence of acidity below the level of human sense perception – the occult acids (Chapter 6.3).

Abduction/IBE

IBE seems to have been used quite extensively to great advantage. In physics, the Copernican theory did not give a better fit with the observed phenomena than its rival Ptolemaic scheme. It was not fact-fitting but the superior explanatory power and elegance which convinced some astronomers in the late sixteenth and early seventeenth century that Copernicus had to be right. The cause of the phases of the moon is another good example of use of the method. In chymistry, Sennert, Lémery and Boyle all made use of IBE in their theorising (Chapter 3.2.4). It remains in common usage today, a powerful if fallible technique.

8.2.3 *Scepticism*

Scepticism, or the lack of, seems to be a problematic aspect of chymistry in the seventeenth century, indeed in earlier centuries also (Chapter 0.4). Agricola believed in goblins and thought their malicious activities might explain certain problems that arose in the mines. Boyle, even when he doubted the reported results of experiments, was wont to accept them if they were backed by a sufficiently high authority. Despite his sceptical inclinations, Boyle was far too credulous. He is said to have believed in witches, but this was far from uncommon in the period. Indeed, those who denied the existence of demons and evil spirits risked being considered unorthodox and perhaps even to be attacking faith and God. This was an uncomfortable position for sceptics who retained orthodox religious beliefs. Nor was it a simple divide between educated and lay people. Hunter describes how prominent members of scientific circles vehemently defended the reality of magical or spiritual phenomena [Hunter: 2012]. Disbelievers were denounced as 'Sadducees.' One such distinguished defender of the reality of witchcraft was Joseph Glanvil, a friend of Boyle, who published posthumously *Saducismus triumphatus* (1681) (*Sadducism triumphed over*) in an attempt to "provide objective truth the reality of witchcraft and other supernatural phenomena" [*ibid,* p401]. It was certainly a live issue during this period, the conflict lasting approximately until the 1720s. The laws in England were reversed in 1736 when the Witchcraft Act made it a crime for anyone to claim that any human being had magical powers or was guilty of the practice of witchcraft. This was in step with the changing religious views of the country.

Boyle himself, a profoundly devout man, was anxious to defend the Christian faith against unbelievers. Hunter states that Boyle believed he "saw empirical evidence of the reality of what he described as 'supernatural' phenomena" [*ibid,* p406]. Boyle accepts that occult qualities are hidden, below the threshold of sensory perception. He uses the inductive procedure of transdiction (Chapter 2.10.1) to allow him to explain occult qualities in mechanical terms. Boyle does regard occult qualities as intelligible, though they remain speculative in detail.

Vitalism was ubiquitous in sixteenth and early seventeenth-century chymistry, with phenomena explained by spirits' sympathies and antipathies (Chapter 2; Van Helmont's ontology). Bacon's matter theory included animal spirits. But his was an entirely naturalistic cosmology. Natural magic, by which extraordinary effects could be obtained, did not call upon the supernatural. Occult phenomena were those which had manifest effects, but the causes were unknown, and perhaps unknowable.

The *crise pyrrhonienne* served to highlight the issues of scepticism, from dogmatism to extreme scepticism to a medium way that eventually was accepted, though not completely, until the nineteenth century. Boyle played a role in the theory of limited certainty, developing it in the *Sceptical Chymist* and other works. Most of the actors profess a sceptical outlook. They challenge the authorities, pointing to incoherence in Aristotle's theories (Agricola), the explanatory weakness of the Thomist interpretation of substantial form (Sennert), the use of syllogism rather than the ampliative function of induction (Bacon) and the reliance on unproven external sources for medical and other recipes (Béguin). Bacon cautions against believing testimonies from dubious authorities, marvellous phenomena and the like (Chapter 3.4). Lémery is extremely sceptical about transmutation (Chapter 5). Every textbook examined includes dire warnings against the unscrupulous alchemists. The motto of the Royal Society, *nullius in verba*, [Sutton: 1994] indicating that nobody should accept dogma, neatly sums up the approach, widely promoting t Baconian induction and experimental philosophy.

In some cases their scepticism fails them. Nothing seems further from a healthy scepticism than Boyle's acceptance of the mysterious virtuoso Georges Pierre des Clozet, described in Boyle's paper *Of the Degradation of Gold by an Anti-Elixir* (Chapter 6.2.3). This episode raises questions over Boyle's self-proclaimed scepticism, his experimental technique and gullibility. Charitably, one might put it down to a rare aberration in judgement, as it seems to be atypical behaviour of Boyle's. However it could also represent a dichotomy between Boyle's cryptic writings in esoteric matters of putative transmutation and that of his avowed commitment to open communication in scientific affairs. Many of the natural philosophers do profess to respect and admire the authority of the ancients and of those proximate to their own time. Where chymical formulae are involved, many recipes are given that have no stated provenance - Libavius does not tell us if they are those he has tried himself or are simply copied from multifarious sources; he does not appear to exercise critical judgement. Béguin, on the other hand, is scrupulous in maintaining provenance (Chapter 4.5).

8.2.4 *Authorities and Their Challengers, Metaphysical Paradigms*

Moving on to specific challenges to authorities, the ubiquity of Aristotelian physics made it an obvious – and frequently aimed at – target. Lack of coherence, the obscurity of his concept of prime matter (*nec quid, nec quale, nec quantum)* and poor explanatory value were the usual arrows. Aristotle's antagonists are too numerous to count, but a few of the more well-known included Gassendi (challenges the concept of prime matter (Chapter 3.4)). Agricola (Chapter 3.5.1), Zabarella, Boyle (the *Sceptical Chymist* opposed both Scholasticism and Paracelsianism), Antoine de Ville and Etienne de Clave. Given the Church's authority at the time, the making of such challenges was no light matter. Etienne de Clave's broadsheet of 1624 was torn up by the Church authorities (Chapter 3.5). Questioning of the Christian mysteries such as the Eucharist, which can be explained in Aristotelian terms, was met, regrettably, with the threat of severe penalties including death.

Dissatisfaction arose with Aristotelianism in many areas because of the lack of explanation of cause. The oft-repeated quote of Molière's *Le Malade Imaginaire*, claiming that opium causes sleepiness because it has dormitive virtue, neatly exemplifies the failure of Aristotelianism to provide knowledge of cause. But Aristotle insisted that only when we have grasped its cause can we claim to have knowledge of a thing. Sennert attempted to reconcile Aristotelian matter theory with the corpuscular hypothesis. An ingenious scheme which included levels of corpuscles informed by substantial forms, it met with limited success. Sennert uses IBE in the "reduction to the pristine state" crucial experiment to demonstrate the presence of abiding chemical species [Newman: 2006] (Chapter 5.2). Boyle later used the same process to prove the corpuscular process.

Authorities had been established and had been challenged. Metaphysical paradigms are somewhat contentious, as some authorities think they are indispensable, while others believe they can be a hinderance or simply ineffectual. Methodological Naturalism is desirable such that supernatural powers should not be invoked in the explanation of phenomena; however, it does not entail that supernatural entities do not exist. This would not have been acceptable in the Early Modern period, and indeed not in the present time either.

The attempt to falsify a theory is a strong marker in defining science. Popperians would claim that it is the defining aspect of science. There are examples of attempts to falsify rival theories. Many attacks have been made with Aristotelian theory as the target. Boyle uses the nitre experiment to disprove substantial forms. Béguin performs an experiment to disprove a proposed process for transmutation. I have not found examples of Popperian falsificationism per se in the evaluated works. This may not be unreasonable if the failures of experiment can be put down to reproducibility problems. Reasons for rejecting a favoured theory may not be clear-cut. It may not even be clear whether the main theory or an auxiliary should be altered. Bacon's concept of the 'crucial experiment' requires that all the hypotheses that can account for the phenomena should be enumerated, then by experimental contradiction, eliminated, all except one. This last will no longer be a hypothesis, but a certainty [Gillies: 1998]. Gillies shows how Duhem makes the point: "Experimental contradiction does not have the power to transform a physical hypothesis into an indisputable truth. In order to confer this power on it, it would be necessary to enumerate completely all the various hypotheses which would cover a determinate group of phenomena; but the physicist is never sure he has exhausted all the imaginable assumptions" [Duhem:1954, p190] [Gillies:1998].

It would be unrealistic to expect that strong Popperianism would be practised in the seventeenth century. A weaker version where natural philosophers have attempted falsification both at the high-level theory and auxiliary hypotheses, with a certain amount of success, can be claimed. Aristotelian matter theory suffered severe and protracted attacks. It may be difficult to accept that a theory which has been current for a very long time is no longer viable. Individuals have investments in their own theories in terms of time, status, financial considerations etc. But theories that persistently were out of step with observational evidence were rejected; for example, by the early eighteenth century it was no longer accepted that the Hungarian streams produced copper by transmutation. Publishing in 1642, Jungius explained the process in terms of affinities (Chapter 4.4.1). As rector of the Hamburg gymnasium (1628-9) he lectured in Aristotelian physics, but also pointed out the defects. Hamburg was in close relations with England and Holland and was a centre of active intellectual life [Partington: 1961]. Therefore his work is expected to have been widely disseminated.

8.2.5 *Heuristics*

Heuristics were important in the planning and execution of experiments. But were these heuristics floating free from deep matter theory? For normal, standard work such as distillation or metallurgy, it does not seem that it is necessary to have strong theoretical anchorage. Provided there is cognisance of the process – which might be a very exacting one – having a theory about why it works is not essential; it is the 'knowing how,' the technical expertise, dexterity, appropriate equipment and control of conditions which will determine the success or failure of the enterprise. Progress can be made by trial and error. The miner or the goldsmith does not require deep theoretical understanding to execute the everyday or mundane parts of his work (though he might appreciate it on an intellectual level). But theoretical considerations can be of great assistance in making improvements or making cognitive leaps perhaps. Having a framework might allow the natural philosopher chymist to intuit where development can take place without the tedium of the trial and error approach (Chapter 7.2).

Metaphysical paradigms provided a level of explanatory function; Aristotle's extensive scientific corpus supplied reasons for why the natural world is the way it is. In the *Metaphysics*, Aristotle states that all men naturally desire knowledge. His theories fulfilled a need; a flawed or partial, interim explanation may be considered better than none at all. It provides a framework on which to test hypotheses. But the retention of a theoretical framework that is not proving useful, simply because of its authority, may lead to nugatory work.

8.2.6 *Observation, cataloguing and taxonomy*

Were the chymists attempting to categorise natural kinds? If so, with what success? There is good reason to believe that there is a natural inclination, and ability, to discern discrete groups. There were prolonged debates on natural kinds, for example between Locke and Leibniz (Chapter 3.6). The recognition of natural kinds is fundamentally important to chemistry. It has already been seen that there was an abundance of collections of minerals, plants, etc., but taxonomical classification is essential, tracking real boundaries in order to make sense of the natural world. The classifications given by Borges (Chapter 3.6.1) are patently absurd, but they do focus the attention on what constitutes fundamental divisions. Locke raises the question of whether there are divisions at all, or whether the difference between one genus and another is so slight as to be imperceptible, and indeed unknowable at the most basic level, its essence. This is important for questions of whether alchemical transmutation is theoretically possible. Avicenna suggests not; what we cannot know, we cannot manipulate (Chapter 2.6). Leibniz held that each individual substance has an essence, but may not necessary be known to us. Living beings and non-living matter are treated differently. In the case of non-living matter the bodies are merely disguised by chemical transformation. In contrast the species of plants and animals are defined by generation. Locke's works simulated debate (Leibniz's rebuttal was published in 1704) which continued long after his death.

Mineralogical taxonomy

Ample evidence can be given for the existence of extensive natural histories; this is not a contentious claim. Agricola provides a detailed textbook on mining, the most ambitious of its kind, well-illustrated with woodcuts, and clear instructions on all aspects of the mining process. In addition, he provides an early attempt at taxonomical classification, especially within *De Natura Fossilium* [Agricola: 1546], demonstrating the preservation of systems of classification for minerals still partially relevant in modern times. Agricola listed over four hundred minerals, giving descriptions and methods of identification by the distinctive features and physical characteristics (Chapter 3.6). Techniques of identification and analysis, many still current, are given in *De Re Metallica* [Agricola: 1556].

Plant taxonomy

The seventeenth century saw an enormous increase in the number of plants to be catalogued [Stroup: 1979]. In the latter half of the century the histories were more discerning in content than the earlier ones which had often included mythology and folklore. These were dropped, giving a more rationalised collation of data (Chapter 3.6). John Ray, a dedicated and highly competent natural historian, catalogued thousands of plants, and made important contributions to taxonomy (Chapter 3.6.7). From his extensive studies of seed structure, he developed a taxonomical classification of cotyledons, dividing this major group into two distinct groups, monocotyledons and dicotyledons, a division which is still used today. Ray's *Historia plantarum* also contained chemical analyses of plants [Stroup: 1979].

Taxonomy of chymical/chemical terms

The identification of chymical substances was by no means a mature science. Identification of most substances was primarily on physical characteristic; acid for example relates to its sour taste, the term being in use from 1626. Alkali, a term used since the fourteenth century, was derived from the Arabic *al-qali* meaning ‘of bitter taste.’ Salts and spirits were more problematic, as acids such as vitriolic, spirit of salt and nitric acid were classified as salts, as were alkalis such as potash, soda and ammonia. By the early eighteenth century, neutral salts were established as a separate class of salts. A wide range of analytical techniques were available. Aside from obvious external characteristics, substances were classified by means of chymical indicators (syrup of violets for example) and many well-established techniques, including tests for density, colour, hardness, sound, flame testing, fusibility, malleability and crystalline structure. There was a transition of the term matrix from a metaphysical concept to earth and finally to base. By the 1730s the use of the term matrix had been dropped (Chapter 7.5).

8.2.7 *Experimentation*

On the Reliability and Reproducibility of Experiments

Reproducibility of experiments was a serious issue. Boyle was very aware of this, and counselled experimenters to be mindful of where they purchase their reagents. As Golinski [1989] notes, “it was fundamentally important for the natural philosophers in the late seventeenth-century that experiments…… should be reliably replicable” [Golinski: 1989 p31]. In context, Golinski is referring to the demonstrations (especially of phosphorus) at the Royal Society, but the issue affects all experimental work across the period. The provenance of any reagent was not secure. Even if Boyle, for example, regularly bought his chymicals from an apothecary he could trust, there was no guarantee that the apothecaries’ suppliers were similarly reliable. Presumably there were some tests that could be applied, but it is unlikely qualitative testing was routinely employed. However, the same experiment routinely repeated should give consistent product quantities such as the caput mortuum, for example. A variation from the norm would indicate impurities in the sample. Setting up the experiment had its own difficulties, and the assessment of the results was also sometimes problematic. The other parameters to be taken into consideration are temperature (it would not have been possible to replicate exactly the conditions of a furnace), whether the test was under aerobic or anaerobic conditions, time measurements (the length of time for which heat was applied, as well as the degree). There might be variations in humidity. Altitude probably was not an issue, the major cities of Europe being at sea level. The phenomenon itself may be difficult to assess, and consensus sought on the results. The specifics of the experiment, including ancillary equipment and other details, would have to be accurately recorded. These are not trivial obstacles.

Homberg, having encountered difficulties in reproducing the luminosity of the Bologna stone (Chapter 6.2) devised a programme of experiments to discover the reason behind his failure to repeat his previously successful process. His experimental method was exemplary. Probably an associate of Boyle’s, in 1691 Homberg became a member of the Paris *Académie* where he reviewed Bourdelin’s work. Though ultimately unsuccessful in its original aim, Bourdelin was meticulous in his experimental method and recording of results. The experiments carried out at the *Académie Royale* demonstrated testability, experimentation and reproducibility

George Starkey (1628-1665) is known to have formalised a methodical system for experimentation, and kept detailed notes. Negative results were included in order to improve the process. He applied theory to the design of experiments, incorporating new ideas suggested by theoretical considerations [Newman & Principe: 2002]. Starkey was very influential on Boyle.

On Disappointing Results

Boyle's Anti-Elixir Experiment did not produce the results for which he had hoped (Chapter 6.2.3). In this instance Boyle did not adhere to his own rules of good experimental practice. One can conjecture that the mysterious virtuoso was a very clever, charismatic character who swayed Boyle from his self-acclaimed scepticism with the enticement of joining a secret alchemical society. Lémery proved more sceptical than Boyle. The sympathetic power was effectively refuted by Lémery (Chapter 6.2.4), who cautioned that anyone with a wound should not depend on such a remedy. It's possible the very occasional success was due to a placebo effect.

8.2.8 *Research Community*

Chymistry at the Universities, Learned Societies, Peer Review

There was a certain amount of resistance to the teaching of chymistry in the universities (Chapter 3.7). Its status was not high. The first professor of Chymistry appointed was Hartmann (1609) (Chapter 4.2). Slowly Aristotelianism gave way to the teaching of the mechanical philosophy. It has been shown that there was a vibrant intellectual scientific community, dating at least to the fifteenth century. The republic of letters, (Chapter 3.7) in which Erasmus was a strong player, was a web of written communications which in its prime transcended national boundaries, religious and political affiliations. This 'virtual' community enabled links between the humanities and natural philosophy, including alchemy, in the seventeenth century [Burke: 1999]. One of its unwritten aims or ideals was that of scholarly co-operation, of the sharing of information. The translation of works into vernacular languages helped facilitate this aim. A natural successor to this network was the Hartlib Circle, active between 1630 and 1660. Samuel Hartlib maintained an extensive web of communications throughout Europe, connecting the intellectual community. His contacts included Robert Boyle, George Starkey and Comenius (Chapter 3.7). Informal groups arose, one of which was the 'Invisible College' inaugurated in 1640 in England. This group was the precursor to the Royal Society which was founded in 1660. In Italy there was the *Accademia del Cimento* (1657) Florence, and *Accademia dei Lincei* of Rome. The Paris *Académie royale des Sciences* journal was established in 1666 [Perrault: 1733]. A review of experimental results, such as that of the reports by Bourdelin to the other fellows of the *Académie Royale*, took place regularly.

Peer review was quite informal in the early part of the seventeenth century [Kronick: 1990]. Although the Royal Society was established in 1660, the *Philosophical Transactions of the Royal Society*, were first published in 1665, and edited by Oldenburg alone. Published monthly, the first issues were a fairly random collection of letters or memoires to Oldenburg. Formal anonymous peer review did not start until 1752, though at the Royal Society of Edinburgh it began earlier, in 1731. From the mid-eighteenth century (possibly earlier) the French *Académie* had a robust peer review system in place [McClellan: 2003]. Such a sophisticated system is not likely to have appeared without earlier prototypes, good precepts which had been developed in the seventeenth century (Chapter 3.7).

Although modern-style peer review was not present in the seventeenth-century, the Royal Society did make claims pertaining to the establishment of facts. There were two accepted sources, one literary, that is the reports of phenomena or experiments. The second was the public demonstration of experiments, conducted in the presence of reliable witnesses, which was supposed to establish matters of fact [Golinski: 1989]. The results would be written up and recorded in the Society's publications. Chymical demonstrations took place, including quite dramatic effects with phosphorus [*ibid*].

8.2.9 ***Values***

Epistemic values

The epistemic values of accuracy/prediction and consistency/coherence, though difficult to adhere to, were recognised to be of great importance in experimentation and in theorising. The qualitative emphasis in Aristotelian matter theory gave way to a quantitative approach. The ancient technology of metallurgy had been strong in quantitative analysis, as essential for assaying. The seventeenth century saw significant advances in instrumentation which provided greater accuracy in the measurement of heat, time, and the analysis and identification of material substances. This in turn led to greater reproducibility, but also to greater accuracy in the prediction of results. It is implicit in the chymists' reports of their many experiments that they aspired to greater repeatability. The publication of Geoffroy's table of affinities in 1718 systemised the appreciation of affinities already noted and used by chymists in the seventeenth century (Chapter 3.6.5; 7.5.5).

One of the many criticisms directed at Aristotelianism was its lack of coherence. At its most fundamental level it is unintelligible. Aristotle's concept of prime matter was described as obscure and difficult to grasp. Chymists such as Boyle strove to develop hypotheses which were both internally coherent and were consistent with natural phenomena. The mechanical hypotheses were more easily intelligible, avoiding many of the metaphysical aspects of previous theories whilst still providing explanatory value.

Non-Epistemic values

While accuracy is highly rated, it is rarely the only criterion used to differentiate theories. Values, such as scope, parsimony, and fruitfulness would not be of immediate interest to most artisans, but if theoretic advances were made this could stimulate the adoption of new processes. Fruitfulness was an important Baconian aim, with the intention to improve the situation of mankind, though luciferous experiments took priority, as furthering new lines of enquiry. Parsimony was implicitly understood as desirable, and had been articulated by Occam (see Chapter 3.3.2).

8.2.10 *Methodological Naturalism*

Many seventeenth century natural philosophers already subscribed to the concept of explaining natural phenomena without invoking the supernatural (Chapter 2.9). In the mechanical philosophy all natural phenomena are to be explained by its two main principles, matter and motion. Occult qualities are a cause for concern. Occult meant insensible, hidden; it did not carry to supernatural or demonic overtones which are attached to its meaning today. But occult qualities such as magnetism, electricity, elasticity, gravity, and planetary influences still have to be accounted for. They are considered unintelligible because they cannot be explained in terms of the four elements. Yet the effects are manifest. Hutchison notes how Aristotelianism failed to account for these and other phenomena such as the strange effects seen in quicklime (Chapter 2.1). Augustine cites the occult characteristics of "quicklime which grows hot when mixed with the cold element water, yet remains cool when mixed with inflammable oil, is beyond man's understanding" [Hutchison: 1982, p238].

8.2.11 *Epistêmê informing technê and vice versa*

It would be expected that there would be a two-way flow between *epistêmê* and *technê* – the one informing the other (in a virtuous circle) with the object of improvements in both. Le Fèvre certainly espouses the concept, insisting on the necessity of such a flow (Chapter 5.3).

Examples of *technê* informing *epistêmê* can be seen in the data collected by the Royal Society via the *Philosophical Transactions* for that stated purpose, and the experiments conducted by the *Académie Royale* such as the co-existence of acids and alkalis (Chapter 6.3). It has proven more difficult to find examples of *epistêmê* informing *technê* within the time period, but this is likely to have been prevalent in the royal courts and in manufacturing, particularly armaments, where the designs must be tailored to the art of the possible [Henry: 1997]. Court entertainments, warfare and manufacturing are powerful drivers, promoting innovation. In the Renaissance, collaboration between scholar and craftsmen had already been established. Henry (1997) remarks “There can be little doubt that the royal courts of Europe, from the grandest courts of national sovereigns…. provided prime sites for the cross-fertilization of scholars and craftsmen” [Henry:1997, p35]. Of court architecture and engineering, he adds “It is hard to imagine a comparable site during the period for the collaboration of scholars and craftsman. Unless, of course, it was one where the arts of war demanded the collaboration of scholars and craftsmen” [*ibid*]. Commerce, politics and warfare still provide the impetus for innovation.

8.2.12 *Common Methodology*

Common methodology includes use of apparatus, instrumentation, and chymical laboratory techniques. These include processes that go back millennia, and provide the foundation of experimental chymistry. Alchemy drew upon old established practices in metallurgy. Gold assaying processes such as fire assaying and specific gravity and touchstone were known from antiquity (Chapter 7.3). Distillation was used for the separation of substances in the Middle Ages, perhaps earlier. Proficiency in application in some or all of these techniques plus calcination, sublimation etc. (Chapter 7.3) would be expected of artisans, metallurgists and assayers. Commonly used processes such as fire analysis and distillation would teach theory by practice, acting as exemplars in chymistry.

Experimental chymical laboratories, which almost always included a heat source, such as a furnace, were established in the mid to late seventeenth-century. These included the well-equipped laboratory of the Paris *Académie*, and various locations of the Royal Society including one operated by Robert Hooke, plus Arundel House. Private residences of gentlemen, such as Boyle's several laboratories, also played an important part in the development of the experimental method [Shapin: 1988] (Chapter 7.4).

8.2.13 ***Progressive elements, Mathematics, Quantification.***

Reproducibility of experimental results was negatively impacted by difficulties in obtaining accurate quantifiable values. Whilst some measurements could be made with a good degree of certitude, others, for example measurement of time and heat, lacked precision. Progress was made though, with the appreciation that heat and cold were independent of subjective bodily sensations. Attempts were made to calibrate thermoscopes – a very difficult undertaking–– with reliable fixed points of reference. This led eventually to development of the Fahrenheit thermometer in the early eighteenth century. Measurement of time was another entrenched problem. Clocks could be calibrated to the quarter-hour but it was not until Huygens invented the pendulum clock that measurements to the minute could be achieved. Although specific gravity measurements were being taken since antiquity, the hydrometer which is a non-destructive method and the instrument is easily portable is still in current use.

Aside from the numerous improvements in instrumentation that continued throughout the century, developments were being made in other fields. Béguin formed in 1615 what is described as the first chemical equation, the prototype of the current way of expressing chemical reaction (Chapter 7.5.1). Béguin is also credited with the first description of acetone – the 'burning spirit of Saturn' (Chapters 4; 7.5.2).

The earliest known date of observations by microscope is 1625. The Danish geologist Steno, who was probably aware of Hooke's *Micrographia*, determined the first law of crystallography in 1669 (Chapter 7.4.2). The ability to discern detailed crystalline structure undoubtably made an important contribution in the identification of chymical substances and their subsequent taxonomical classification.

The role of mathematics became more important in the move from the qualitative philosophy of Aristotle to the quantitative aspects of the new experimental philosophy [Henry: 1997; 2002].

8.3 Conclusions

Alchemy lacked rigour in certain areas; this conclusion cannot be doubted. However, a definite progression towards increased systemisation can be seen over the seventeenth-century. I have shown that, with a few exceptions, all of the criteria set out as existential quantifiers necessary or desirable for the execution of good science are present, to a greater or lesser degree.

To discuss the negative instances first, within the core requirements the most notable failures are the lack of falsificationism, lack of formal peer review, problems of reproducibility and a variability in the level of scepticism. I discuss Popperian falsificationism in Chapter 8.2.4 and argue that it was not reasonable to expect strict Popperian falsification in the seventeenth century.

Formal peer review was not institutionalised until the mid-eighteenth century; however, clearly this must have been based on earlier precepts developed in the seventeenth century. The *Accademia del Cimento* experiments were performed collectively and reported anonymously (Chapter 6.3). Such formal review procedures evident in the *Académie royale* and the Royal Society cannot have emerged without prior endeavour.

Reproducibility of experiments was an ongoing problem. Without reliable chymical reagents, and the ability to closely control all the parameters of an experiment, reliability was always going to be a challenge. However, substantial advances were made in instrumentation towards the latter part of the century, and there were also well-established assaying and laboratory techniques on which to call. Advances were also made in identification of substances (Chapters 3.6.6; 7.5.3).

The low level of scepticism, especially amongst those who professed themselves sceptics, is perhaps the most surprising outcome. Clearly the issues of scepticism were debated. Mitigated scepticism, advocated by Marin Mersenne, did not find general acceptance until the eighteenth century. It was a superstitious age, and one might be unreasonable in expecting scepticism to be ubiquitous.

On the positive side, we can see many of the criteria well established, and making progress through the century. Starting with Agricola in the second half of the sixteenth century, it is clear his *De Re Metallica* was a remarkable feat of workmanship. In his and Béguin's work can be seen the beginnings of a textbook tradition. Kuhn considers textbooks a paradigm example of normal science [Kuhn: 1962].

Homberg's work represented exemplary scientific practice, and there is little doubt of his influence on experimental practice both sides of the Channel. There is evidence of very good experimental method at the *Académie,* where important insights into natural phenomena were gained. The importance of observation and cataloguing, whilst seeming a simple exercise, should not be underestimated. The task was Herculean. Systematised classification, shorn of extraneous detail, provided the raw data from which naturalists like Ray could discern the boundaries of class divisions. The concepts of natural kinds and the efforts to discern them were of huge significance in the understanding of chymistry. Metals seem to have been recognised as natural kinds since antiquity; chymists did seem to be searching and recognising other natural kinds. Kornblith (Chapter 3.6) suggests that the concept of natural kinds is inherent in our psychological makeup.

The universities with their theologian-natural philosophers contributed greatly to the dissemination of the Greek texts and the subsequent, often controversial, debates as Grant indicates. Learned societies and informal societies were effective in maintaining information flow in the international intellectual community and also disseminating values and standards.

Compositionist chemistry is described by Chang (2012) as in opposition to Principlism, which is based on the concept of principles, namely fundamental substances which impart certain characteristics to other substances. This traces back to the Aristotelian notion of a mixt [Chang: 2012, p38]. A fundamental epistemic activity of the compositionist system-type was describing chemical substances as either elements, or compounds made up of those elements. Additionally, there were the more experimental activities involving decomposing compounds into their elements. The ability to do both decomposition and re-composition was regarded as the best proof of the presumed composition of a substance. These practices required the presumption that the components were stable units that are preserved through chemical reactions. That presumption also grounded the activity of explaining chemical reactions as the rearrangements of distinct and stable building blocks which retain their identity throughout even when their properties are not manifest in a state of combination [*ibid*]. Seventeenth-century chymistry saw a movement away from Principlism towards compositionist chemistry. These Early Modern chymists can be seen to assume, and indeed prove, the existence of abiding chemical species which persisted through analysis and synthesis. Whilst not describing the building blocks as elements as such, the *minima naturalia*, pragmatically the last point of analysis, serves as an equivalent. Thus in method and theory the chymists can claim to be forerunners of modern chemistry. Siegfried [1982] and Klein [1994, 1995] have shown that the origin of compositionist chemistry goes back at least to the mechanical philosophy of the seventeenth century, becoming embedded by the late eighteenth century.

While there was no universally accepted metaphysical theory across the century, Aristotelianism, in its several interpretations, had come in for concerted attack. The mechanical hypothesis was appealing in its relative simplicity and lucidity as opposed to the unintelligibility of Aristotelian forms. Boyle's mechanical hypothesis provided heuristic value but ultimately was rejected (Chapter 7.2.3). The demolition of Aristotelian metaphysics, paving the way for new philosophies, was an important consequence of seventeenth-century natural philosophy. The development and refinement of experimental method was of considerable epistemological significance. Hypotheses needed to agree with observations and experiment. An example of this can be seen in the work of Jungius (Chapter 4.4) who effectively disproved transmutation. Nature always has the final word.

The Wittgensteinian model (Chapter 1) which I have applied to the practice of alchemy allows for a positive result dependant on some, but not necessarily all, the existential quantifiers to be present in the sample evaluated. My analysis shows that seventeenth-century alchemy/chymistry did make a substantial contribution to chemistry of the later period. As Henry notes "…alchemy had always been an experimental pursuit" [Henry: 1997] as well as encompassing theoretical aspects. There is clear evidence of an increased systemisation in the experimental method through the century. The notable accomplishments of the eighteenth century were not achieved *ex nihilo.* Rather they were built on the concentrated efforts of the seventeenth century chymists and natural philosophers.

APPENDIX A – REFERENCES & BIBLIOGRAPHY

REFERENCES

BOOKS AND PAPERS

Achinstein, **P.** (2004) Science Rules – *A Historical Introduction to Scientific Methods*. John Hopkins University Press.

Adamson, P. (2016) *Philosophy in the Islamic World.* Oxford University Press.

Agricola, G. (1546) *De Natura Fossilium (Textbook of Mineralogy).* Translated by Bandy & Bandy (1955), Geological Society of America.

Agricola, G. (1556) *De Re Metallica*, in *De Re Metallica* translated by Hoover, H.C and Hoover, L.H. (1950), Dover Publications, Inc., New York.

Ainsworth, **T.** (2016) *Form vs. Matter* Stanford Encyclopedia of Philosophy.

Albury, W.R., & Oldroyd, D.R. (1977), *From Renaissance Mineral Studies to Historical Geology, in the Light of Michel Foucault's 'The Order of Things.'* The British Journal for the History of Science, Vol. 10, No. 3, pp.187-215. Published by: Cambridge University Press on behalf of The British Society for the History of Science.

Al-Hassan, A. (2004). *The Arabic Original of Liber De Compositione Alchemiae*. The Epistle of Maryānus, the Hermit and Philosopher, to Prince Khālid ibn Yazīd. Arabic Sciences and Philosophy, 14(2), 213-231.

Anderson, **H,** & **Hepburn**, **B** (2015) *Scientific Method.* Stanford Encyclopedia of Philosophy.

Anstey, **P.** (2000) *The Philosophy of Robert Boyle.* Routledge.

Anstey, P. and Hunter, M (2008) *Robert Boyle's 'Designe about Natural History'* Early Science and Medicine 13 (2008) 83-126.

Aquinas (1256) *In quatuor libros sententiarum*, p.145, col. In Newman: (1989) 47.

Ariew, R. (2014) *Pierre Duhem.* Stanford Encyclopedia of Philosophy.

Ariew, R. & Gabbey, A. (1998) *The Scholastic Background* In *The Cambridge History of Seventeenth Century Philosophy, Vol. 1,* Edited by Garber, D & Ayers, M., Cambridge University Press DOI: https://doi.org/10.1017/CHOL9780521307635.017.

Aristotle, (c350BC) *Meteorologica (Books I to IV).* Translated by E. W. Webster.

Aristotle, (c350BC) *On Generation and Corruption.* Translated by H. H. Joachim

Aristotle, (c350BC) *Posterior Analytics* Translated by Mure, G.

Aristotle, (c350BC) *Prior Analytics* Translated by Mure, G.

Arnauld, A. & **Nicole, P.** (1662) *The Port Royal Logic.* Translated from French by Baynes, Thomas Spencer, 5th Edition (1861) Hamilton, Adams and Co, London.

Bacon, F. (1620) *Novum Organum.* Jardine & Silverthorne (editors) *The New Organon* Cambridge University Press, 2000.

Bacon, F. (1670) *Sylva Sylvarum*; or*, A natural history in ten centuries*.

Banchetti-Robino M.P. (2015) *From Corpuscles to Elements: Chemical Ontologies from Van Helmont to Lavoisier*. In: Scerri, E., McIntyre L. (eds) Philosophy of Chemistry. Boston Studies in the Philosophy and History of Science, vol 306. Springer, Dordrecht**.**

Banchetti-Robino, M.P. (2016) *Van Helmont's hybrid ontology and its influence on the chemical interpretation of spirit and ferment*. In: *From Corpuscles to Elements: Chemical Ontologies from Van Helmont to Lavoisier*. Scerri E., McIntyre L. (eds) Philosophy of Chemistry.

Banchetti-Robino, M.P. (forthcoming) *The Function of Microstructure in Boyle's Chemical Philosophy: 'Chymical Atoms' and Structural Explanation*. Banchetti-Robino, M.P. Found Chem (2019) 21: 51. https://doi.org/10.1007/s10698-018-09326-z

Bandy, M. & Bandy, J. (1955), *De Natura Fossilium (Textbook of Mineralogy)* Translation of Agricola, G. (1546), Geological Society of America.

Bardell, D. (2004) *The invention of the microscope* Bios 75 (2) 78-84, Beta Beta Beta Biological Society www.jstor.org/stable/4608700.

Barnett, M (1956) *The Development of Thermometry and the Temperature Concept.* Osiris, Vol 12, (1956) pp269-341. University of Chicago Press on behalf of the History of Science Society

Barnhart, R. (1988) *Barnhart Dictionary of Etymology*, Ed. Barnhart, R. published by. H.W. Wilson Co., 1988.

Béguin, J. (1610) *Tyrocinium Chymicum: or Chymical Essays, Acquired from The Fountain of Nature, and Manual Experience*. [English Translation 1669].

Bensaude-Vincent, B. (2000) "*The Chemist's Balance for Fluids": Hydrometers and Their Multiple Identities, 1770-1810*. In: Holmes, F. L., & Levere, T. H. (ed) (2000) *Instruments and Experimentation in the History of Chemistry.* The MIT Press, Cambridge, Massachusetts; London, England.

Beretta, M. (2000) *At the Source of Western Science: The Organisation of Experimentalism at the Accademia Del Cimenti* (1657-1667). The Royal Society. Notes Rec.R.Soc.London 54 (2) 131-151.

Bertolacci. (2013) *Reception of Avicenna in Latin Medieval Culture*. In: *Intrepreting Avicenna: Crital Essays.* Adamson, P. (Ed). Cambridge University Press.

Birch, T. (1757) *The History of the Royal Society for Improving of Natural Knowledge from its First Rise*, Vol III. Printed for A. Miller, The Strand, London.

Bird, A. (2000) *Thomas Kuhn.* Acumen Publishing Ltd. Chesham, UK.

Bird, A. (2014) *When is it that a Group that Knows? Distributed Cognition, Scientific Knowledge, and the Social Epistemic Subject. Essays in Collective Epistemology.* Lackey, J. (ed.). Oxford University Press (USA), p.42-63.

Bird, A. & Tobin, E. (2008: 2017) *Natural Kinds*. Stanford Encyclopedia of Philosophy.

Black, D. (2013) *Certitute, justification and the principles of knowledge in Avicenna's epistemology* In: Interpreting Avicenna: Critical Essays. Ed Peter Adamson. Chp 7 Cambridge Core.

Bluhm, R.K. (1960) *Henry Oldenburg, FRS. (c.1615-1677)* Royal Society Publishing.

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

Boas Hall, M. (2008) *Robert Boyle.* In: *Complete Dictionary of Scientific Biography.*Ed. Gillispie, C; Holmes, F.L ; Koertge, N; Gale,T). Detroit, Mich. : Charles Scribner's Sons.

Bolyard, C. (2017) "*Medieval Skepticism*", Stanford Encyclopedia of Philosophy. [online: *The Stanford Encyclopedia of Philosophy* (Fall 2017 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/fall2017/entries/skepticism-medieval/]

Bouillier, M. F. (1883) *Éloges de Fontenelle, avec une introduction et des notes*. Garnier Freres, Libraires, Editeurs, Paris.

Boyle, R. (1661a) *Certain Physiological Essays*. In: Hunter, M. and Davis, E.B. (1999) *Works of Robert Boyle. Vol 2.* Pickering and Chatto (Publishers) Limited, London.

Boyle, R. (1661b) *The Sceptical Chymist.* In: Hunter, M. and Davis, E.B. (1999) *Works of Robert Boyle. Vol 2.* Pickering and Chatto (Publishers) Limited, London.

Boyle, R. (1663) *Usefulness Of Experimental Philosophy.* In: Hunter, M. and Davis, E.B. (1999) *Works of Robert Boyle. Vol 3.* Pickering and Chatto (Publishers) Limited, London

Boyle, R. (1664) *Experiments and Considerations Touching Colours*. In: Hunter, M. and Davis, E.B. (1999) *Works of Robert Boyle. Vol 4.* Pickering and Chatto (Publishers) Limited, London.

Boyle, R. (1666) *The Origin of Forms and Qualities,* In: Hunter, M. and Davis, E.B. (1999) *Works of Robert Boyle. Vol 5.* Pickering and Chatto (Publishers) Limited, London

Boyle, R. (1673) *Essays of Effluviums* In: Hunter, M. and Davis, E.B. (1999) *Works of Robert Boyle. Vol 7.* Pickering and Chatto (Publishers) Limited, London.

Boyle, R. (1674-6) *Suspicions about some Hidden Qualities of the Air.* In *The Works of Robert Boyle, Vol.8.* Hunter, M. and Davis, E.B. (1999). Pickering and Chatto (Publishers) Limited, London

Boyle, R (1674) *About the Excellency and Grounds of the Mechanical philosophy* . In *The Works of Robert Boyle, Vol.8.* Hunter, M. and Davis, E.B. (1999). Pickering and Chatto (Publishers) Limited, London

Boyle, R (1675) *A New Essay-Instrument invented and described by the Honourable Robert Boyle, and the uses thereof.* Philosophical Transactions of the Royal Society, no. 115, Vol 10. pp329-348

Boyle, R. (1678) *Of the Degradation of Gold by an Anti-Elixir, In: The Works of Robert Boyle Vol.9.* Hunter, M. and Davis, E.B. (1999). Pickering and Chatto (Publishers) Limited, London

Boyle, R. (1684) *Experiments and considerations about the porosity of bodies, in two essays, Vol.10*. Hunter, M. and Davis, E.B. (1999). Pickering and Chatto (Publishers) Limited, London.

Boyle, R. (1685) *An Essay of the Great Effects of Even Languid and Unheeded Motion*. In: *The Works of Robert Boyle, Vol.10* Hunter, M. and Davis, E.B. (1999) Pickering and Chatto (Publishers) Limited, London

Boyle, R. (1690) *Medicina hydrostatica: or, Hydrostaticks applyed to the materia medica*. London, Samuel Smith.

Bradbury, S. (1967) *The Evolution of the Microscope.* Pergamon press.

Bristow, W. (2010) *Enlightenment,* Stanford Encyclopaedia of Philosophy.

Brockliss, L. (1996) *Curricula*. In: *A History of the University in Europe Vol II. Universites in Early Modern Europe. (1500-1800).* De Ridder-Symoens, H. (ed.) Cambridge University Press.

Bronstein, D. (2016) *Aristotle on Knowledge and Learning: The Posterior Analytics.* Oxford Scholarship.

Borges, J: (1942) *Celestial Emporium of Benevolent Knowledge.* Unknown

Burke, P. (1999) *Erasmus and the Republic of Letters.* European Review, Vol 7, No.1 5-17.

Buroker, J. (2014) *Port Royal Logic* Stanford Encyclopedia of Philosophy (Spring 2017 Edition), Edward N. Zalta (ed.)

Buyse, F. (2013) *Boyle, Spinoza and the Hartlib Circle: The Correspondence which never took place.* Society and Politics Vol. 7, No. 2 (14).

Buyse, F. (in review) *Robert Boyle and Baruch Spinoza: The Redintegration of Saltpeter* - A reply to A. Clericuzo.

Capozzi, M. (1998) *The emergence of a logic of cognitive faculties: Logic in the 17th and 18th centuries'* Routledge Encyclopedia of Philosophy

Chalmers, A. E. (1978, 2013) *What is this thing called Science?* Open University Press.

Chalmers, A. E. (1993) *The lack of excellency of Boyle's mechanical philosophy*. Studies in History of Philosophy and Science. Volume 24, Issue 4, October Pages 541-564 doi.org/10.1016/0039-3681(93)90052-L

Chang, H. (2004) *Inventiing Temperature. Measurement and Scientific Progress.* Oxford Univerisity Press

Chang, H. (2011a*) Compositionism as a Dominant Way of Knowing in Modern Chemistry*, Science Hostroy Publication Ltd.

Chang, H. (2011b) *The Persistence of Epistemic Objects Through Scientific Change*.Erkenn (2011) 75: 413. DOI 10.1007/s10670-011-9340-9

Chang, H. (2012) *Is Water H_2O? Evidence, Realism and Pluralism.* Boston Studies in the Philosophy of Science.

Chang, H. (2018) *Is Compositionist chemistry the paradigm for reductionist science?* Presentation at the History of Science annual conference.

Chang, K. (2011) *Alchemy as Studies of Life and Matter: Reconsidering the place of Vitalism in Early Modern Chymistry*. Isis 2011, History of Science Society.

Chisholm, H. (1911) *Homberg, Wilhelm.* Encyclopædia Britannica (11th ed.). Cambridge University Press.

Craig, A. D. & **Bushnell, M. C.** (1994) *The Thermal Grill Illusion: Unmasking the Burn of Cold Pain,* Science, New Series, Vol. 265, No. 5169 (Jul. 8, 1994), pp. 252-255.

Clericuzio, A. (2000) *Elements, Principles and Corpuscules. A Study of Atomism and Chemistry in the Seventeenth Century*. Kluwer Academic Publishers

Clericuzio, A. (2006) *Teaching Chemistry and Chemical Textbook in France*. From Béguin to Lémery. Science and Education.

Clericuzio, **A.** (2010) *"Sooty Empiricks" and Natural Philosophers: The Status of Chemistry in the Seventeenth Century Science* in Context, 23 pp329-350.

Cohen, H. F. (2010) *Greek Nature-Knowledge Transplanted: The Islamic World*. In: How Modern Science Came to the World. Amsterdam University Press.

Cohen, S. M. (2012) *Alteration and Persistence: Form and Matter in the Physics and De Generatione et Corruptione* Oxford Handbook of Aristotle. Edited by Christopher Shields.

Collins (2019) *Collins English Dictionary.* HarperCollins.

Crosland, M. (2005*) Early Laboratories c.1600–c.1800 and the Location of Experimental Science,* Annals of Science, 62:2, 233-253, DOI: 10.1080/00033790410001724801

Crosland, M. (1959) *The Use of Diagrams as Chemical 'Equations'* In: *The Lecture Notes of William Cullen and Joseph Black.* Annals of Science. 15:2, 75-90.

Crosland, **M.** (1962) *Historical Studies in the Language of Chemistry*. Dover Publications.

Dawes, G. W. (2017). *Ancient and Medieval Empiricism* Stanford Enc. Philosophy.

Debus, A. G. (1962) *Solution Analyses Prior to Robert Boyle*. Chymia, 8, 41-61.

Debus, A.G. (1977) *The Chemical Philosophy*. Dover Publications Inc.

Debus, A.G. (1978) *Man and Nature in the Renaissance.* Cambridge University Press.

Debus, A.G. (1990) *Chemistry and the universities in the seventeenth century.* Estud. av. vol.4 no.10 São Paulo Sep./Dec. 1990.

Del Soldato, E. (2016) *Natural Philosophy in the Renaissance.* The Stanford Encyclopedia of Philosophy (Spring 2019 Edition), E. N. Zalta (ed.)

Deming, D (2016) *Science and Technology in World History Vol 4*. McFarland and Company Inc.

Dewey, J. (1933) *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process*. Boston, MA: D.C. Heath & Co Publishers.

Dobell, C. (1923) *A Protozoological Bicentenary: Antony van Leeuwenhoek (1632–1723) and Louis Joblot (1645–1723)*. Parasitology, 15(3), 308-319. doi:10.1017/S0031182000014797

Dod, B.G. (1982) *Aristoteles latinus*. In: *Cambridge History of Later Medieval Philosophy*. Kretzmann,N, Kenny,A & Pinborg, J . (eds) Cambridge: Cambridge University Press. pp. 45--79 (1982) Chap. 2 (pp. 45–79).

Dodart, D. (1676) *Memoires pour server a L'Histoire des Plantes*. De L'Imprimerie Royale.

Dohrn-van Rossum, G. (1996) *History of the hour: clocks and modern temporal orders.* University of Chicago Press.

Dorveaux, P. (1924) *Les grands pharmaciens: XVII. L'apothicaire Le Febvre Nicaise dit Nicolas*. Bulletin de la Société d'histoire de la pharmacie, 12e année, n°42, 1924. pp. 345-356.

Du Clos, S. (1675) *Observations sur les eaux minerales des plusieurs provinces de France, faites en l' Académie royale des sciences.*

Duffy, S. (2006) *The Difference Between Science and Philosophy: The Spinoza-Boyle Controversy Revisited*. Project Muse, Vol 29, no 2, July 2006. pp. 115-138.

Duhem, P. (1914, 1954) *The Aim and Structure of Physical Theory,* Translated by Louis De Brogie. Princetown University Press; Oxford University Press.

Dyson, F. (1919) *A Determination of the Deflection o f Light by the Sun's Gravitational, from Observations made at the Total Eclipse of May 29, 1919* Royal Society Publishing.

Eamon, W. (1980) *New Light on Boyle and the Discovery of Colour Indicators* Ambix Vol. 27. Part 3

Eaton, W. (2005) *Boyle on Fire.* Continuum Studies in British Philosophy.

El-Eswed, B. (2002). *Lead and Tin in Arabic Alchemy*. Arabic Sciences and Philosophy, 12(1), 139-153.

Eichholz, D. (1949) *Aristotle's Theory of the Formation of Metals and Minerals* Cambridge University Press.

Eknoyan, G. (1999) *Santorio Sanctorius (1561–1636) – Founding Father of Metabolic Balance Studies* Am J Nephrol 19: 226–233.

Fisk, M. (1963) *Primary Matter and Unqualified Change*, The concept of Matter in Greek and Medieval Philosophy, Ed. McMullin.

Forbes, R. J. (1948) *Short History of the Art of Distillation from the Beginnings up to the death of Cellier Blumenthal*. E.J Brill, Leiden, Holland.

Foucault, M. (1966) *The Order of Things: An Archeology of the Human Sciences.* Pantheon.

Franckowiak, R. (2011) *Mechanical and Chemical Explanations in Du Clos' Chemistry*. Ambix, Vol 58., No 1, March 2011, 13-28.

Franssen, M, Lokhorst, G-J, Van de Poel, I. (2018) *Philosophy of Technology* The Stanford Encyclopedia of Philosophy (Fall 2018 Edition), Edward N. Zalta (ed.)

Friedman, et al. (1999) *Enhancement of Clinicians' Diagnostic Reasoning by Computer-Based Consultation*. JAMA, ,1999, Vol 282, No.19.

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

Gaukroger, **S.** (2001) *Francis Bacon and the Transformation of Early-Modern Philosophy*. Cambridge University Press.

Gillies, D. (1998) *The Duhem Theory and the Quine Theory*. In*: Philosophy of Science: The Central Issues.* W.W. Norton & Co. New York; London. Ed. Curd, M & Cover, J.

Glanvill, J. (1665), *Scepsis Scientifica, or The Vanity of Dogmatizing*, Royal Society.

Glare, P. G. W. (Ed) (2015) *Oxford Latin Dictionary,* Vol I and II. Second edition. Oxford University Press.

Glazer, A (2016) Crystallography: *A Very Short Introduction.* Oxford University Press.

Golinski, J. (1989) *A Noble Spectacle -Phosphorus and the Public Cultures of Science in the Early Royal Society*. Isis Vol.80, No. 1, pp11-39.

Gorini, R. (2003) *Al-Haytham the Man of Experience, First Steps in the Science of Vision.* Journal of the International Society for the History of Islamic Medicine (ISHIM). Vol 2 No.4.

Gorman, M. (1962) *The History of Acetone, 1600-1850*. University of California Press.

Grant, E. (1996) *The Foundations of Modern Science in the Middle Ages: Their Religious, Institutional and Intellectual Contexts*. Cambridge University Press.

Grant, E. (2008) *The Fate of Ancient Greek Natural Philosophy in the Middle Ages: Islam and Western Christianity*. The Review of Metaphysics, Vol 1, No.3 (March 2008, pp503-526). Philosophical Education Society Inc.

Greengrass, M, Leslie, M, and Raylor, T. et al, (Editors) eds (1994) *Samuel Hartlib and Universal Reformation: Studies in Intellectual Communication* Cambridge University Press, 1994

Guerlac, H. (1961) *Quantification in Chemistry*. Isis. Vol. 52, No. 2, (June 1961) pp194-214 on behalf of the History of Science Society.

Gutas, D. (2012) *The Empiricism of Avicenna* Cambridge Companions, Oriens, Vol. 40, No. 2, pp. 391-436.

Hales, S. (1727) *Vegetable Staticks,* Inys Woodward, London.

Hacking, I. (1983, 1993) *Representing and Intervening* Cambridge University Press.

Hacking, I. (2006) *The Emergence of Probability*. Cambridge University Press. American Association for the Advancement of Science.

Hahn, **R.** (1971) *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666-1803*. Los Angeles: University of California Press.

Hankinson, R. J. (2005) *Sextus Empiricus: Outlines of Pyrrhonism.* In *Central Works of Philosophy*, Shand (ed.). McGill-Queen's University Press.

Hannaway, O (1975) *The Chemists and the Word. The Didactic Origins of Chemistry.* John Hopkins University Press. Baltimore and London.

Hansson, S. O. (2013) *Defining Science and Pseudoscience.* In *Philosophy of Pseudoscience.* Ed. Pigliucci, M, & Boudry, M. University of Chicago Press.

Hedesan, G. (in review) *Alchemy*. In: *The Occult World.* Taylor and Francis

Henry, J. (1986) *Occult Qualities and the Experimental Philosophy: Active Pronciples in Pre-Newtonian Matter Theory.* Science History Publications Ltd.

Henry, J. (1997, 2002) *The Scientific Revolution and the Origins of Modern Science.* Palgrave.

Henry, J. (2008) *The Fragmentation of Renaissance Occultism and the Decline of Magic*. Hist. Science Society xlvi 1-48.

Holmes, F. L. (2003) *Chemistry in the Académie Royale des Sciences.* Historical Studies in the Physical and Biological Sciences, Vol 34. no. 1. University of California Press.

Holmes, F. L., & Levere, T. H. (ed) (2000) *Instruments and Experimentation in the History of Chemistry.* The MIT Press, Cambridge, Massachusetts; London, England.

Holmyard, E.J. & Mandeville, D.C. (1927) *Âvicennæ de Congelatione et conglutinatione Lapidum being sections of the Katâb al-Shifâ*, Paul Geuthner, Paris.

Hooke, R. (1665) *Micrographia, or some physiological descriptions of minute bodies made by magnifying glasses, with observations and inquiries thereupon,* The Royal Society, London

Hooke, R. & Derham, W. (1726) *Philosophical Experiments and Observations of the Late Eminent Dr. Robert Hooke*. W. Derham (ed.) London.

Hoover, H.C. & Hoover, L.H. (1950) *Georgius Agricola: De Re Metallica* (Translation) Dover Publications, Inc., New York.

Hooykaas, R. (1949) *The Experimental Origin of Chemical Atoms and Molecular Theory before Boyle*. Chymia Vol. 2 1949 (pp65-90) University of California Press.

Hoyningen-Huene, P. (1993) *Reconstructing Scientific Revolutions.* University of Chicago Press.

Hoyt, D. V., Schatten, K. H. (1997) *The Role of the Sun in Climate Change.* Oxford University Press.

Hudson, J.A. (2005) *Chemical History: Reviews of the Recent Literature* Royal Society of Chemistry

Hunter, M. (2000) *Self-Definition through Self-Defence: Interpreting the Apologies of Robert Boyle, 1627-91*: In: *Scrupulosity and Science.* Boydell Press.

Hunter, M. (2005) *Robert Boyle's* '*Heads' and 'Inquiries' Occasional Paper no.1.* The Robert Boyle Project, School of History, Classics and Archaeology, Birkbeck, University of London.

Hunter, M. (2007) *Robert Boyle and the Early Royal Society: A Reciprocal Exchange in the Making of Baconian Science*. The British Journal for the History of Science, Vol. 40, No. 1, Cambridge University Press.

Hunter, M. (1982, 1994). *The Royal Society and its Fellows 1660-1700: the morphology of an early scientific institution.* British Society for the History of Science.

Hunter, M. (2012) *The Decline of Magic: Challenge and Response in Early Enlightenment England.* The Historical Journal, Vol 55. No2. Cambridge University Press.

Hunter, M. & Davis, E.B. (1999) *Works of Robert Boyle. Vol 2.* Pickering and Chatto (Publishers) Limited, London.

Hutchison, **K.** (1982) *What happened to Occult Qualities in the Scientific Revolution?* Isis Vol 73, no.2, pp233-253

Huygens, C. (1690) *Treatise on Light.* Chez Pierre van der Aa. Marchand Libraire, Paris. Huygesn.

Jabir Ibn Hayyan (eighth century)/Pseudo-Geber (thirteenth century): *From Of the Investigation or Search of Perfection; Of the Sum of Perfection; and His Book of*

Furnaces. (2003). In S. Linden (Ed.), *The Alchemy Reader: From Hermes Trismegistus to Isaac Newton* (pp. 80-94). Cambridge University Press. doi:10.1017/CBO9781107050846.012.

Jensen, W. (1986) *The Development of Blowpipe Analysis*. The History and Preservation of Scientific Instruments, 1986, pp. 123-149.

Jensen, W. (2006) *The Origin of the term Base.* Journal of Chem.Educ., 83, 1130.

Jones, A. (2013) *Rocks and Minerals.* HarperCollins Publishers Ltd. London.

Jones, J.-E. (2018) *Locke on Real Essence*. Stanford Encyclopedia of Philosophy.

Kazmer, M. (2004) *Dr. Edward Brown's visit to the mining towns of Lower Hungary in 1669* Natural Heritage of the Carparthian Basin.

Keas, M (2018**)** *Systematizing the theoretical virtues*. Synthese (2018) 195:2761–2793 https://doi.org/10.1007/s11229-017-1355-6

Kirschner, S. (2017) *Nicole Oresme.* The Stanford Encyclopedia of Philosophy (Fall 2017 Edition), Edward N. Zalta (ed.)

Klein, J. (2012) *Frances Bacon.* Stanford Encyclopedia of Philosophy.

Klein, U. (1994) *Origin of the Concept of Chemical Compound.* Isis Vol 00, no.4 pp769-782. History of Science Society.

Klein, U. (1995) *E.F. Geoffroy's Table of Different Rapports - A reinterpretation*. Ambix, 42:2, 79-100.

Klein, U. (2008) *The Laboratory Challenge: Some Revisions to the Standard View of Early Modern Experimentation*. History of Science Society. Isis Vol 99 No. 4 pp769-782.

Knox, D (2019) *Giordano Bruno*. The Stanford Encyclopedia of Philosophy (Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/sum2019/entries/bruno/>.

Koinm, A. (2000) *Christopher Merret's Use of Experiment*. The Royal Society.

Kornblith, H. (1993) *Inductive Inference and Its Natural Ground: An Essay in Naturalistic Epistemology.* Massachusetts Institute of Technology Press, Cambridge, Massachusetts

Kronick, D.A. (1990) *Peer Review in 18th-Century Journalism* JAMA, Vol 263, no 10.

Kuhn, H. (2017) *"Aristotelianism in the Renaissance*", The Stanford Encyclopedia of Philosophy (Summer 2017 Edition), Edward N. Zalta (ed.) https://plato.stanford.edu/archives/sum2017/entries/aristotelianism-renaissance.

Kuhn, **T.** (1952) *Robert Boyle and Structural Chemistry in the Seventeenth Century*. Isis vol. 43, April 1952.

Kuhn, T. (1962) *The Structure of Scientific Revolutions* University of Chicago Press. 4th edition 2012.

Kuhn, T. (1970) *Reflections on my Critics. In*: *Criticism and the Growth of Knowledge, Vol. 4.* Press Syndicate of the University of Cambridge.

Kuhn, T. (1977) *The Essential Tension.* University of Chicago Press.

Kuhn, T. (2000) *The Road Since Structure: Philosophical Essays 1970-1993.* University of Chicago Press. Ed. Conant & Haugeland.

Ladyman, J. (2013) *Towards a Demarcation of Science from Pseudoscience*. In Philosophy of Pseudoscience. Ed. Pigliucci, M, & Boudry, M. University of Chicago Press.

Lagerlund, H. (2016) *Medieval Theories of the Syllogism*, The Stanford Encyclopedia of Philosophy (Spring 2016 Edition).

Lakatos, I. (1969) *Criticism and the Methodology of Scientific Research Programmes Aristotelian Society* Proceedings of the Aristotelian Society, New Series, Vol. 69, pp. 149-186 Published by: Blackwell Publishing on behalf of The Aristotelian Society

Lakatos, I. (1970) *History of Science and Its Rational Reconstructions.* Proceedings of the Biennial Meeting of the Philosophy of Science Association, Vol. 1970 pp. 91-136.

Lakatos, I & Musgrave, A. (1970) *Criticism and the Growth of Knowledge*. Cambridge University Press.

Lang, E. (2013) *Alchemy and the Sixteenth Century Metallurgists*. Ambix, 13:2, 92-95.

Lau, K., & Plofker, K. (2007). The Cycloid Pendulum Clock of Christiaan Huygens. In A. Shell-Gellasch (Ed.), *Hands on History: A Resource for Teaching Mathematics* (pp. 145-152). Mathematical Association of America. doi:10.5948/UPO9780883859766.01

Lauden, L. (1981) *Science and Hypothesis*, D. Reidel Publishing Company, Netherlands.

Lauden, L. (1983) *The Demise of the Demarcation Problem in Physics, Philosophy and Psychoanalysis: Essays in Honor of Adolf Grünbaum*. Robert S. Cohen (Editor), R. Laudan (Editor).

Lazenby, E.M (1995) *The Historia Plantarum Generalis of John Ray*. University of Newcastle**.**

Le Fèvre, N. (1660) *Traicté de la Chymi*e (*A Compendious Body of Chymistry), The Ratcliffe, London.*

Leibniz, G. W. (1765**)** *New Essays on Human Understanding***.** 1981 translation Remnant and Bennett, Cambridge University Press.

Leicester, H.M. & Klickstein, H.S. (1952) *A Source Book in Chemistry 1400-1900.* McGraw-Hill Book Company Inc.

Lémery. N. (1685) *Cours de Chimie (New Curiosities in Art and Nature Extracted Out of the abinets of the Most Eminent Personages of the French Court: Together with the Choicest Secrets in Mechanicks, Communicated by the Most Approved Artists of France),* Printed for Matthew Gilliflower, London (English translation from French).

Lémery. N. (1690) *Cours de Chymie* (7th French Edition) Chez Estienne Michallet, Paris

Lewis, C and Short, C. (1879) *A Latin Dictionary.* Clarendon Press Oxford

Libavius, A. (1597), *Alchemia.* Printed by Johannes Saurius for Petri Kopffij. Frankfurt, 1597

Linden, S.J. (2003) *The Alchemical Reader,* (editor), Cambridge University Press.

Locke, J. (1689) *An Essay Concerning Human Understanding. In: The Clarendon Edition of the Works of John Locke: An Essay concerning Human Understanding Ed. Nidditch*, P.H. and Yolton, (1975), J. Clarendon Press, Oxford.

Look, B. C. (2009) *Leibniz and Locke on Natural Kinds. In Vlad Alexandrescu (ed.), Branching Off: The Early Moderns in Quest for the Unity of Knowledge*. Zeta Books.

Machamer, P (2017) *Galileo Galilei.* The Stanford Encyclopedia of Philosophy (Summer 2017 Edition), Edward N. Zalta (ed.)

Montada, J (1996) *Aristotle and Averroes on Coming-to-Be and Passing-Away* Oriens, Vol. 35 (1996), pp. 1-34. Brill

Mahner, M. (2013) *How to Demarcate after the (Alledged) Demise of the Demarcation Problem*. In Philosophy of Pseudoscience. Ed. Pigliucci, M, & Boudry, University of Chicago Press.

Malherbe, M. (1996) *Bacon's Method of Science.* In: *The Cambridge Companion to Bacon*, ed. Markku Peltonen, Cambridge University Press.

Manning, R. (2016) *Spinoza's Physical Theory*. Stanford Encyclopedia of Philosophy.

Markie, P. (2017) *Rationalism vs. Empiricism, The Stanford Encyclopedia of Philosophy* (Fall 2017 Edition), Zalta,E. (ed.).

Marrone, S.P (2010) *The Rise of the Universities*. In: *Cambridge History of Medieval Philosophy, Vol.1* pp50-62. Editors: Pasnau, R, and Van Dyke, C. Cambridge University Press.

Martinón-Torres & Rehren, (2005) *Alchemy, Chemistry and Metallurgy in Renaissance Europe: a wider context for fire-assay remains*. Historical Metallurgy 39 (1) 2005, 14-28.

Masterman, M. (1970) *The nature of a paradigm.* Criticism and the growth of knowledge, eds. I. Latakos, and A. Musgrave.

Mauck, A. (2012) *By Merit Raised to that bad eminence: Christopher Merrett, Artisanal Knowledge, and Professional Reform in Restoration London*. Medical History 56: 26-47.

McClellan, J. (2003) *Specialist Control: The Publications Committee of the Académie Royale Des Sciences (Paris) 1700-1793.* American Philosophical Society.

McGinnis, J. (2018) *Arabic and Islamic Natural Philosophy and Natural Science*, The Stanford Encyclopedia of Philosophy (Winter 2018 Edition), Edward N. Zalta (ed.)

McInery: 1999 *Saint Thomas Aquinas*, Stanford Encyclopedia of Philosophy.

McInery, R. & O'Callaghan, J. (2016) *Saint Thomas Aquinas.* The Stanford Encyclopedia of Philosophy (Winter 2016 Edition), Edward N. Zalta (ed).

McMullin, E. (1963) *The Concept of Material in Greek and Medieval Philosophy*. University of Notre Dame Press.

Medawar, P.B. (1969) *Induction and Intuition in Scientific Thought.* The American Philosophical Society.

Meinel, **C.** (1983) *Theory or Practice? The Eighteenth-Century Debate on the Scientific Status of Chemistry*. Ambix, Part 3 November 1983

Meinel, **C.** (1988) *Atomism from the 17th to the 20th Century* University of Chicago Press.

Meinel, C. (1988) *Early Seventeenth Century Atomism: Theory, Epistemology and the Insufficinecy of Experiment*. Isis Vol. 79, No. 1 March 1988, pp68-103.

Michael, E. (1997) *Daniel Sennert on Matter and Form: At the Juncture of the Old and the New*. Koninklijke Brill, Leiden. Early Science and Medicine 2,3.

Mills, A.A. (1982) *Newton's Water Clocks and the Fluid Mechanics of Clepsydrae* Royal Society Publishing, Volume 37 Issue 1. doi.org/10.1098/rsnr.1982.0004

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

Moran, B.T. (2006) *Axioms, Essences, and Mostly Clean Hands: Preparing to teach Chemistry with Libavius and Aristotle*. Science and Educations (2006) 15:173-187.

Moran, B.T. (2007) *Andreas Libavius and the Transformation of Alchemy*. Science History Publications, USA.

Morello, N. (2006) *Agricola and the Birth of the Mineralogical Sciences in Italy in the Sixteenth Century,* In book: Special Paper 411: The Origins of Geology in Italy DOI: 10.1130/2006.2411(02)

Mottana, A. (2014) *Galileo as Gemmologist: The First Attempt in Europe at Scientifically Tesing Gemstones.* The Journal of Gemmology, 34(1) 2014. Pp.24-31. The Gemmological Association of Great Britain.

Moxham, N., & Fyfe, A. (2018) *The Royal Society and The Prehistory of Peer Review, 1665–1965.* The Historical Journal, 61(4), 863-889. doi:10.1017/S0018246X17000334

Multhauf, R. (1958) *The Beginning of Mineralogical Chemistry.* Isis Vol. 49, No. 1. History of Science Society.

Multhauf, R. (1966) *The Origins of Chemistry.* Oldbourne, London.

Needham, P. & Hendry, I. (2012) *Philosophy of Chemistry.* Elsevier.

Neri, A. (1612) *Del L'arte Vetraria.* Nella stamperia de Giunti.

Neto, J. (1997) *Academic Skepticism in Early Modem Philosophy.* Journal of the History of Ideas, Vol. 58, No. 2, pp. 199-220. University of Pennsylvania.

Newman, W. (1989) *Technology and Alchemical Debate in the Late Middle Ages.* Isis, Vol. 80, No. 3 (Sep., 1989), pp. 423-445. The University of Chicago Press on behalf of The History of Science Society.

Newman, W. (2000) *Alchemy, Assaying, and Experiment* In: Holmes, F. L., & Levere, T. H. (ed) (2000) *Instruments and Experimentation in the History of Chemistry.* The MIT Press, Cambridge, Massachusetts; London, England.

Newman, W. (2001) *Corpuscular alchemy and the tradition of Aristotle's Meteorology, with special reference to Daniel Sennert*. International Studies in the Philosophy of Science. 15.2, 145-153.

Newman, W., & Principe. L. (1998) *Alchemy vs. Chemistry: The Etymological Origins of a Historiographic Mistake.* Early Science and Medicine, Vol. 3 No.1 pp32-65.

Newman, **W., & Principe. L.** (2002) *Alchemy Tried in the Fire.* University of Chicago Press

Newman, **W.** (2004) *Promethean Ambitions: Alchemy and the Quest to Perfect Nature*. Chicago University Press.

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

Newman, **W.** (2014) *Mercury and Sulphur among the High Medieval Alchemists: From Rāzī and Avicenna to Albertus Magnus and Pseudo-Roger Bacon*. Ambix, 61: 4, 327-344.

Newton, I. (1713) *General Scholium (Philosophiæ Naturalis Principia Mathematica) 2nd edtion,* Cornelius Crownfield, Cantabrigiæ.

Newton, I. (1726) *General Scholium* (Philosophiæ Naturalis Principia Mathematica) 3rd edtion. London.

Oddy, A. (1983) *Assaying in Antiquity*. Gold Bulletin, 1983, 16 (2) British Museum.

Ogilvie, B. (2000) *The Many Books of Nature: How Renaissance naturalists created and responded to information overload*. History of Science Society Annual Meeting, Vancouver, Nov. 3, 2000

Oldenburg. H. (1666) editor, Philsophical Transactions of the Royal Society, vol.8.

Oldenburg. H (1667) *Directions for Observations and Experiments to Be Made by Masters of Ships, Pilots, and Other Fit Persons in Their Sea-Voyages* Source: Philosophical Transactions (1665-1678), Vol. 2 (1666 - 1667), pp. 433-448 Published by: Royal Society. Stable URL: https://www.jstor.org/stable/101197

Oldroyd, D.R. (1974) *Some Neo-Platonic and Stoic influences on Mineralogy in the Sixteenth and Seventeenth Centuries.* Ambix, 21:2-3, 128-156. Doi: 10.1179/000269874790223614

Pagel, W (1969) *Chemistry at the Crossroads: The Ideas of Joachim Jungius*. Ambix, 16:1-2, 100-108.

Parascandola, J. & **Ihde, A.** (1969) *A History of the Pneumatic Trough* Isis, Vol. 60, No. 3 (Autumn, 1969), pp. 351-361 Published by: The University of Chicago Press on behalf of The History of Science Society

Parry, R. (2014) *Epistêmê* and *Technê*, The Stanford Encyclopedia of Philosophy (Fall 2014 Edition), Edward N. Zalta (ed.), [http://plato.stanford.edu/archives/fall2014/entries/episteme-techne]

Paracelsus, A. (c1527), *De Natura Rerum (Of the Nature of Things)* Strasborg/Bern.

Partington, J. R. (1937) *A Short History of Chemistry*, London: Macmillan. Reissued by Dover Publications, New York.

Partington, J. R. (1961) *A History of Chemistry, Vol II.* Macmillan & Co. Ltd. London.

Partington, J. R. (1962) *A History of Chemistry, Vol III.* Macmillan & Co. Ltd. London.

Pasnau, R. (2010) *Cambridge History of Medieval Philosophy, Vol 1.* Cambridge University Press.

Pasnau, R. (2010) *Cambridge History of Medieval Philosophy, Vol 2*. Cambridge University Press.

Pasnau, R. (2011) *Metaphysical Themes 1274-1671* Clarendon Press, Oxford.

Patterson, T.S. (1937) *Jean Béguin and his Tyrocinium Chymicum.* Annals of Science, Vol 2, No. 3.

Pavord, A. (2005) *The Naming of Names: The Search for Order in the World of Plants*. Bloomsbury Publishing USA.

Paul et al. (1997) *A Brief History of Critical Thinking* California Teacher Preparation for Instruction in Critical Thinking.

Pennock, **R.** (2011*) Can't philosophers tell the difference between science and religion? Demarcation revisited.* Synthese, Vol. 178, No, 2 Evolution and its Rivals. (January 2011) pp177-206. Published by Springer.

Pérez-Ramos, **A**. (2014) *Bacon's forms and the maker's knowledge* tradition. Cambridge Companion to Bacon chp 4. Cambridge University Press.

Perrault, C. (1733) *Mémoires de l'Académie royale des sciences depuis 1666 jusqu'en 1699.* Chez Martin, Coignard, Geulin, Paris. [http://gallica.bnf.fr/ark:/12148/bpt6k56063967/]

Pigliucci, M. (2003) *Species as family resemblance concepts: the (dis-)solution of the species problem?* BioEssays 25:596-602. Wiley Periodicals Inc.

Pigliucci, M. (2013) *The Demarcation Problem. A Belated Response to Laudan*. In Philosophy of Pseudoscience. Ed. Pigliucci, M, & Boudry, M. University of Chicago Press

Pigliucci, M. & Boudry, M. (2013) *Philosophy of Pseudoscience*:*Reconsidering the Demarcation problem*. University of Chicago Press.

Popkin, R. H. (1960, 2003) *History of Scepticism, from Savonarola to Bayle*. University of Oxford.

Popper, K. (1959) *The Logic of Scientific Discovery.* Translated by the author from 1934 German original, titled *Logik der Forschung. Zur Erkenntnistheorie der modernen Naturwissenschaft*, "Logic of Research: On the Epistemology of Modern Natural Science.

Powers, J. (1998) *'Ars Sine Arte:' Nicholas Lemery and the End of Alchemy in Eighteenth-Century France*, Ambix, 45:3, 163-189, DOI: 10.1179/amb.1998.45.3.163

Powers, J. (2014) *Measuring Fire: Herman Boerhaave and the Introduction of Thermometry into Chemistry.* OSIRIS 2014, 29: 158–177 The History of Science Society. University of Chicago Press.

Preston, J. (2008) *Kuhn's 'The Structure of Scientific Revolutions': A Reader's Guide* Bloomsbury Publishing.

Principe L. M. (1992) *Robert Boyle's Alchemical Secrecy: Codes, Ciphers and*

Concealments, Ambix, 39:2, 63-74.

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

Principe, L. (2013) *The Secrets of Alchemy* University of Chicago Press.

Principe, L. (2016a) *Alchemy.* In: Magee (Ed.), *The Cambridge Handbook of Western Mysticism and Esotericism* (pp. 359-371). Cambridge University Press. doi:10.1017/CBO9781139027649.031.

Principe, L. (2016b) *Chemical Exotica in the Seventeenth Century, or, How to Make the Bologna Stone*. Ambix, Vol. 63 No. 2, May 2016.

Pyle, A. (1987) *Animal Generation and the Mechanical Philosophy: Some Light on the Role of Biology in the Scientific Revolution*. History of Phil. Life Sci., 9 (1987) 225-254.

Pyle, A. (1995) *Atomism and its Critics,* Thoemmes Continuum.

Pyle, A. (2002) *Boyle on Science and the Mechanical Philosophy*: *a reply to Chalmers.* Studies in History and Philosophy of Science. Elsevier Science Lt.

Pyle, A. (2013) *Locke.* Polity Press. Cambridge UK

Quine, W.V (1951) *Main Trends in Recent Philosophy: Two Dogmas of Empiricism*. The Philosophical Review, Vol. 60, No. 1. pp20-43

Quine, W.V & Ullian J.S. (1978) *The Web of Belief.* McGraw-Hill Inc.

Rampling, (2019) *More than 2000 years of elements: a pre-history of the periodic table*, Nature, 565, 563-564 doi:10.1038/d41586-019-00289-5.

Raven, C. (1947) *John Ray, Naturalist: His Life and Works.* Cambridge University Press

Read J. (1961) *William Davidson of Aberdeen The First British Professor of Chemistry*, Ambix, 9:2, 70-101, DOI: 10.1179/amb.1961.9.2.70.

Rees, G. (1996) *Bacon's Speculative Philosophy i*n M. Peltonen (Ed.), The Cambridge Companion to Bacon (Cambridge Companions to Philosophy, pp. 121-145). Cambridge: Cambridge University Press.

Rees, G. (2014) *Bacon’s Speculative Philosophy*. Cambridge Companion to Bacon, Cambridge University Press.

Rees, **G.** (2014) *Bacon’s Legacy.* Cambridge Companion to Bacon, Cambridge University Press.

Robb, L (2005) *Introduction to Ore Forming Processes* Blackwell Publishing

Rocke, **A.** (1985) *Agricola, Paracelsus, and 'Chymia'*. Ambix, 32.1 38-45.m 1666–86.

Roos, **A.M.** (2015) *Mineral waters across the Channel: matter theory and natural history from Samuel Duclos's minerallogenesis to Martin Lister's chymical magnetism, ca. 1666–86*. Notes Rec. (2015) 69, 373–394 doi:10.1098/rsnr.2014.0066. Published online 9 September 2015

Ross, D. (1923, 1995) *Aristotle*, Routledge. London and New York.

Rossi, **P.** (2000) *The Birth of Modern Science.* Blackwell Publishing.

Sankey, H. (1997) *Induction and Natural Kinds.* Principia (2) (1997) pp239-54.

Schickore, **J.** (2018) *Scientific Discovery.* Stanford Encyclopedia of Philosophy.

Schneer, C. (1983) *The Renaissance Background to Crystallography* American Scientist, Vol 71, No. 3 (May-June 1983) pp254-263.

Sennert, D. (1619, 1662) *De Chymicorum Cum Aristotelicis et Galenicis, Consensu et Dissenu. Chymistry made easie and useful. Or, The agreement and disagreement of the chymists and galenists*. Wittenburg. Translated by Nicholas. Culpeper, and Abdiah Cole. (1662) London.

Sennert, D. (1662) *Thirteen Books of Natural Philosophy.* Translated from *Epitome naturalis scientiae*, (1632) by Culpper, N and Cole, A. London 1661.

Shadrach, C. & Vadivelu, S. (2007) Engineering Physics for Anna University. Dorling Kindersley (India.) Pvt. Ltd

Shapin, S. (1988) *The House of Experiment in Seventeenth Century England.* Isis, Vol. 79, No. 3, pp. 373-404.

Siegfried, R. & Dobbs, B. J. (1968) *Composition, a neglected aspect of the chemical revolution*, Annals of Science, 24:4, 275-293.

Siegfried, R. (1982) *Lavoisier's Table of Simple Substances: Its Origin and Interpretation.* Ambix, 29:1, 29-48, DOI: 10.1179/amb.1982.29.1.29.

Siegfried, R. (2002) *From Elements to Atoms: A history of Chemical Composition.* American Philosophical Society, Philadelphia, PA.

Sloan, P. (1972) *John Locke, John Ray, and the Problem of the Natural System*. Journal of the History of Biology, Vol. 5, No. 1 (Spring, 1972), pp. 1-53.

Smith, G.E. (2002) *The Methodology of the Principia* in G.E. Smith and I.B. Cohen (eds), *The Cambridge Companion to Newton*, Cambridge: Cambridge University Press, 138–73.

Smith, N (2018) *Pre-Industrial Lime Kilns: Introduction to Heritage Assets***.** Historic England, Swindon

Sober, E. (2012) *Core Questions in Philosophy: A Text with Readings.* Pearson Education

Spade, P.V. (2009) *Medieval Philosophy*, Stanford Encyclopedia of Philosophy.

Stanford, K. (2017) *Underdetermination of Scientific Theory,* Stanford Encyclopedia of Philosophy.

Stroup, A. (1990) *A Company of Scientists; Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences*. University of California Press.

Sutton, C. (1994) '*Nullius in Verba' and nihil in verbis': Public Understanding of the role of language in science*. BJHS, 27, 55-64.

Tarrant, N. (2018) *Between Aquinas and Eymerich: The Roman Inquisition's Use of Dominican Thought* Censorship of Alchemy, Ambix, 65:3, 210-231.

Tahko, T.E., (2015) *Natural Kind Essentialism Revisited*, Mind, Vol 124, 495, 795-797 doi:101093/mind/fzv027

Taylor, P., Hoyler, M., & Evans, D. (2008) *A Geohistorical Study of 'The Rise of Modern Science': Mapping Scientific Practice Through Urban Networks, 1500-1900*. Minerva 46:391-410.

Teeter Dobbs, Betty Jo (1975) *The Foundations of Newton's Alchemy or The Hunting of the Greene Lyon.* Cambridge University Press.

Teeter Dobbs, Betty Jo (1974) *Studies in the Natural Philosophy of Sir Kenelm Digby* Part III. Digby's Experimental Alchemy - The Book of Secrets, Ambix, 21:1, 1-28, DOI: 10.1179/ amb.1974.21.1.1.

Thagard, P. (2007) *Coherence, Truth, and the Development of Scientific Knowledge.* Philosophy of Science, Vol. 74, No. 1, pp. 28-47. The University of Chicago Press on behalf of the Philosophy of Science Association Stable doi:10.1086/520941.

Thornton, S. (2018) *Karl Popper,* Stanford Encyclopedia of Philosophy. Ed Zalta,,E.N

Tiles, J. E. (1993) *Experiment as Intervention* British Journal for the Philosophy of Science, Vol. 44, No. 3, pp. 463-475 Published by: Oxford University Press on behalf of The British Society for the Philosophy of Science.

Tillich, H. (1998) *Ancestral and Derived Character States in Seedlings of Monocotyledons*. In: *Monocots: Systematics and Evolution*, Ed. Wilson and Morrison. Csiro Publishing, Australia.

Tiwari, M.and **Mishra**, **B.** (2011) *Application of Cluster Analysis In Expert Systems – A Brief Survey.* IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 5, No 1, 1694-0814.

Van Melsen, A. (1952) *Atomos to Atoms.* Duquesne University, The Ad Press Ltd, New York, N.Y.

Virgil (ca 29-19 BC) *The Aeneid.* West, D (Translator). 1999, 2003 Penguin Books

Verbeek, T. (2015). *Huygens, Christiaan (1629–1695)* In: Nolan (Ed.), The Cambridge Descartes Lexicon (pp. 379-380).Cambridge University Press

Warner, H.R et al., (1988) ILIAD *As An Expert Consultant to Teach Differential Diagnosis*. AMIA Proceedings of Annual Symposium. Nov 9:71–376.

Webster, E.W. (1923) *Webster's translation of the Meteorlogica Works of Aristotle translated into English*. Oxford Clarendon Press.

Weisberg, Needham, & Hendry (2011) *History of Chemistry*. Stanford Encyclopedia of Philosophy.

Westfall, R (2019) *John Ray English Naturalist.* Encyclopaedia Britannica.
https://www.britannica.com/biography/John-Ray-English-naturalist#ref235647

Wildberg, C. (2016) *Neoplatonism.* Stanford Encyclopedia of Philosophy.

Wittgenstein, L. (1953) *Philosophical Investigations.* Blackwell Publishing Ltd. Translated by Anscombe et al. ; 4th ed. 2009, Hacker and Schulte

Zabarella, G. (1590) *De rebus naturalibus.* In: Valverde, J.M.G. (2006) *De rebus naturalibus.* Koninklijke Brill, NV Leiden, The Netherlands.

Zietz, J.R. (1952) *"The Pirotechnia" of Vannoccio Biringuccio,* Journal of Chemical Education 507-510

Zupko, J. (2018) *John Buridan.* The Stanford Encyclopedia of Philosophy (Fall 2018 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/fall2018/entries/buridan/>.

INTERNET SOURCES AND SOFTWARE TOOLS

1. *Early English Modern Books* (EEBO) http://eebo.chadwyck.com/search/
2. **Libavius** (1597) *Alchemia.* Digital images of original uploaded by Bayerishe Staats Biblithek http://bildsuche.digitale-sammlungen.de/index.html?c=viewer&lv=1&bandnummer=bsb00015654&pimage=00001&suchbegriff=&l=en
3. *Oxford Dictionaryof National Biography* http://www.oxforddnb.com/view/article/16342?docPos=2
4. *Philosophical Transactions of the Royal Society of London* (The Online Books page) http://onlinebooks.library.upenn.edu/webbin/serial?id=philtransactions
    a. The Royal Society Library Services List of Fellows of the Royal Society 1660 – 2007 A-J
    b. The Royal Society Library Services List of Fellows of the Royal Society 1660 – 2007 K-Z
5. *Académie des Sciences* (Members List) https://fr.wikipedia.org/wiki/Catégorie:Membre_de_l'Académie_des_sciences_(France)
6. *Mémoires de l'Académie royale des sciences depuis 1666, jusqu'a 1686.* Tome 1 (1733) http://gallica.bnf.fr/ark:/12148/bpt6k56063967/
7. **Bouiller, F**. *Éloges de Fontenelle*, Garnier Frères Librairies-Editors. Paris. https://archive.org/stream/logesdefontene00font#page/n7/mode/2up
8. **Dodart** (1676) *Memoires de 'Histoire des plantes* http://gallica.bnf.fr/ark:/12148/bpt6k5773311c/f71.double
9. *Philosophical Transactions of the Royal Society* (1666) vol 8. https://babel.hathitrust.org/cgi/pt?id=ucm.5324351222&view=1up&seq=90
10. **Higgins, K., Miner, D., Smith, C.N., Sullivan, D**. (2004), *A Walk Through Time* (version 1.2.1). Available: http://physics.nist.gov/time [2010, July 12]. National Institute of Standards and Technology, Gaithersburg, MD.
11. **Shea, B (2016)** *Karl Popper: Philosophy of Science* In: James Fieser & Bradley Dowden (eds.), Internet Encyclopedia of Philosophy
12. **Bennett, J**. (2017). (Notes on) *The Origin of forms and Qualities. Boyle,R.* https://www.earlymoderntexts.com/assets/pdfs/boyle1666.pdf

APPENDIX B – GLOSSARY OF TERMS

NOTE: Definitions are from Hunter and Davis [1999] unless otherwise stated.

Acre	sharp (spirits)
acetum minerale	Mineral acid, i.e. one of the three so considered -sulphuric acid, nitric, and hydrochloric (muriatic); also generally any sour or acidic liquid prepared from a mineral body.
ad siccitatem	to the point of dryness
aeolophile	A pneumatic instrument illustrating the force with which vapour generated by heat in a sphere rushes out of a narrow aperture (similar to the 'engine ' of Hero of Alexandria.
Affection	a state, property or quality, or attribute of a thing.
Affusion	a pouring on or into
alexipharmacon	An antidote against poison. [Lewis and Short: 1879]
alga marina	Sea algae, i.e seaweed
allum/roch allum	double sulphate of aluminium and potassium, found effervescent on the surface of bituminous schist (medium-grade metamorphic rock)
antimony, butter of	white antimony trichloride, made by dissolving antimony trisulphide with saltpeter in a red-hot crucible
antimony, crocus of	impure antimony oxysulphide, a bright yellow powder, also known as crocus metallorum
aqua ardente	alcohol [Moran:2006]
aqua fortis	'strong water,' a corrosive acid, usually nitric acid
aqua regia	'Royal water' a mixture of nitric and hydrochloric (muriatic) acids; one of the few solvents which can dissolve gold.
archeus	The vital, immaterial principle which Paracelsus and his followers claimed ruled over all animal and vegetable life and natural processes.
Athanore	A kind of furnace (from the Greek athanatos, undying) which is kept burning continuously to provide long-term heating [Principe: 2013].

aurific	producing or making gold
aurum potabile	'Potable gold,' a widely-sought medicament made from gold.
argentum vivum	Quick-silver, or philosophical Mercury
Arsenick	May be either Natural or Artificial; the natural is of three kinds: Auripigment or Litharge of Gold, so called for its golden colour; Sandarak, which is red; and Realgar, which is yellow: the artificial is prepared by a sublimation of the natural, with Salt. [Le Fèvre, 1660]
Azoth	Mercury; essential agent of transmutation; also panacea postulated by Paracelsus [Collins: 2019].
Base	This term was first used in 1717 by the French chemist Louis Lémery (1672-1743), son of Nicholas Lémery (1645 –1715), as a synonym for the older Paracelsian term 'matrix'. This referred to the naturally occurring salts which he postulated grew within the earth as a result of a universal acid or seminal principle having impregnated an earthly matrix, or womb. The definition for this term changed by the early 1730s to allow for an extended concept of the formation of salt. Guillaume-François Rouelle (1703-1770) redefined a neutral salt as the product of a union of an acid with any substance, whether it was a water-soluble alkali, a volatile alkali, and absorbance earth, a metal or an oil, a substance which served as a 'base' for the salt, giving it a concrete or solid form [Jenson, 2006]. The modern definition is expanded but includes 'a substance that reacts with acids to form salts.'
balneum arenae	'bath of sand,' a method of heating a substance by placing it in a container in sand and heating it from below.

Bolonian /Bologna stone	This seems to be the 'diamond' Boyle claims glowed in the dark after being rubbed, but it is likely to have been the mineral barite $BaSO_4$, consisting of made up a mix of barium, sulphur, and oxygen. The Bologna or Bolon Stone was discovered in 1603 by Vincenzo Casciarolo, {described as a kind of phosphorus in Phil Trans 1768}. Also known as the Bologna phosphorus [Partington: 1961. Vol 2, p334]
Bolus	earthy, friable stone
Burning spirit of Saturn	Acetone
calx viva	quick-lime (calcium oxide)
catalyseos	decomposition [Partington: 1961 (Vol II) p254]
coagulation	recombination [Patterson: 1937]
cohobation	reiteration of distillations [Patterson:1937]
Cucurbit	the gourd-shaped portion of an alembic, a vessel used in distilling
crocus ferri	**(**also called Crocus Martis) calcined iron
Hassian retorts, crucibles.	Stoneware capable of withstanding high temperatures for long periods of time.
Juice	There are two types defined by Agricola 'Solidified juices' (succi concreti) comprised salt, soda, vitriol, bitumen, etc. generally those substances conceived to be soluble in and deposited from water. 'Stone juice' (succus lapidescens) were generated by their own particular substance, or the combination of earths with water. [Hoover & Hoover: 1950. P46-47] [see also Le Fèvre p. 60]. Mixture of potash and sulphuric acid, made by heating. [Partington:1961, Vol II, p62]
lixivium	Water impregnated with alkaline salts, made by percolating water through ashes or other materials.
lixiviation	To wash or percolate soluble matter from solid material.

lythargrium auri	litharge of gold
magistery	A chemical species extracted from a compound body with separation of the inessential impurities. [Partington1961, Vol II., pp253-254]
matrix	A receptacle, such as an earth, which may be informed by spirit
minerals, metals and stones	Are differentiated: metals are malleable “extendable under the hammer” and can be melted. Stones are hard bodies, neither extensible under the hammer, nor meltable in the fire. Minerals fall between the two; they are fusible as are metals, but are brittle like stones.
Minium	The naturally occurring form of lead tetroxide; also known as red lead.
mistio (also mistia, mixi, mixt)	Compound
oculus mundi	'eye of the world' hydrophane, a type of milky white opal which becomes translucent when immersed in water, and was considered to be a general antidote to illness.
Orpiment	a rare orange to lemon-* mineral consisting of trisulphide of arsenic [Merriam- Webster]
principle	(i) In the early modern period ‘principle’ may mean a proposition that has a privileged or certain position (ii) a source, cause, generating factor. (Boyle uses ‘principle’ in each of those senses: he speaks of the chemists’ ‘three principles’, referring (old sense) to three kinds of matter—salt, sulphur and mercury—which the chemists credited with having special causal powers. He also speaks of ‘a system of theoretical principles of philosophy’. [Bennett:2017]
property	Quality, affection or attribute
Realgar	Yellow arsenic
Reduction	This term often meant the ‘leading back’ to a material’s original state after it had undergone significant form. Reduction often meant the

	isolation or extraction of a metal from a compound, especially an ore. This is a much more general sense than the modern determination of oxidation states or redox reactions. [Newman: 2006. xiii]
Regulus	A piece of metallic material produced by the reduction of mineral ores in the fire, and usually referring specifically to metallic antimony. [Hunter]. Lémery [1685] refers to it as the name given to the most fixt and hardest matters of many minerals and metals.
Reverberium	Reverberatory furnace, used for obtaining high temperatures
Sal armoniak	sal ammoniac, a mixture of ammonium salts, predominantly ammonium chloride
sal gem	Rock salt, sodium chloride in its natural mineral form, found as crystals in the earth.
Saxum calcis	Limestone
Spagyria	The practice of separating a material into its component parts, and then recombining them to form an ‘exalted’ form of the original substance, purified and more powerfully active. [Principe:1998]
Spirit of wine	Alcohol
Stibium	Antimony
Stibnite	antimony sulphide
Sublime	To ‘raise on high’ i.e. to raise by fire any volatile matter to the top of the cucurbit, or into its head [Lémery: 8th ed.]. This is distinct from modern usage which is limited to the direct transformation from the solid to the vapour state.
Sulphureous Salts	This includes ‘the Urinous and Volatile Salts of Animal Substances, and the Alcalisate or fixed Salts that are made by Incineration’ [Boyle:1664]
Sulphur, Liver of	Sulphur with potash
terra damnata	also known as caput mortuum, the dead earth; the residue left at the bottom of the retort after distillation

tincal	a mineral ($Na2B4O_7.10H_2O$) consisting of a native borax formerly imported from Tibet and once the chief source of boric compounds [Merriam-Webster]
transudation	Passage of a fluid or solute through a membrane by a hydrostatic or osmotic pressure gradient.
Universal Spirit	(1) aerial nitre (Glauber)
	(2) a mysterious (or metaphysical) salt which is the cause of all germination. Endowed with all the essential and central virtues of sublunary mixts; vital spirit. (Lefevre:1670, p251)
Turpeth (turbith)	(1) archaic, the mineral mercuric sulphate obtained by the action of water on mercuric sulphate.
	(2) Defined by Libavius as a specific fixed precipitate (*turpethum est coagulum specificum fixum*) [Partington II]
Vitriol, oil of	Concentrated sulphuric acid
Vitriol, spirit of	Sulphuric acid made by distilling one of the vitriols (either iron or copper sulphate)
Vitrum calendare	An early form of thermometer used by Bacon. A "heat-glass," styled "which bore "attached to the stem a long narrow strip of paper marked off with degrees at pleasure."
Zaffer/Zaffre	Oxide of cobalt

APPENDIX C – AGRICOLA'S CHALLENGE ON CLASSIFICATION

Agricola quotes Aristotle's *Meteorologica:*

"Just as its twofold nature gives rise to various effects in the upper region, so here it causes two varieties of bodies. We maintain that there are two exhalations, one vaporous and the other smoky, and there correspond two kinds of body that originate in the earth, 'fossiles' (*orycta*) and metals (*metalleuta*). The heat of the dry exhalation is the cause of all 'fossiles'. Such is the kinds of stones that cannot be melted, and realgar, and ochre, and ruddle, and sulphur, and other things of that kind, most 'fossiles' being either coloured lye or, like cinnabar, a stone compounded of it. The vaporous exhalation is the cause of all metals, those bodies which are either fusible or malleable such as iron, copper, and gold. All these originate from the imprisonment of the vaporous exhalation in the earth, and especially in stones. Their dryness compresses it, and it congeals just as the dew or hoar-frost does when it has been separated off, though in the present case the metals are generated before that segregation occurs. Hence, they are water in a sense, and in a sense not. Their matter was that which might have become water, but it can no longer do so: nor are they, like savours, due to a qualitative change in actual water. Copper and gold are not formed like that, but in every case the evaporation congealed before water was formed. Hence they all (except gold) are affected by fire, and they possess an admixture of earth, for they still contain the dry exhalation. This is the general theory of all these bodies, but we must take up each kind of them and discuss it separately" [Aristotle: c350BC, *III*].

Agricola [1546, pp15-17] notes the following:

"Minerals vary greatly in quantity. Some occur in large masses as do marbles and rocks; others in small units, as certain stones and gems. Although Nature has given all genera of minerals a small and discrete body, nevertheless rocks, marble and earths often occur as great masses and it is necessary to separate portions from the parent body."

"Thus minerals have differences which we observe by colour, taste, odour, place of origin, natural strength and weakness, shape, form and size. In order to made this knowledge clearer and more obvious, I shall explain which genera are outstanding and most important and which, in general, embrace all minerals."

"Writers do not agree on how many and which these may be. Aristotle states that there are only two classes of bodies that form within the earth, namely minerals.... and those substances from which metals are extracted...."

"Others believe that there are three classes, stones, metals and earths, which we cultivate. Avicenna mentions four classes, stones, stones that melt in fire... sulphurous stones, and saline stones. Albertus places minerals in three classes, stones, metals and an intermediate class. Aristotle has classified subterranean substances in accordance with usage of the common people of Greece. He split them into two groups, one that that just had to be dug up to be ready for use (όρυτά), and the other he called metallic minerals (μετλλευτά) because it was necessary to smelt them. Irrespective of this, Aristotle fails to recognise that metals are obtained from well-known earths and stones as well as from minerals. Since it is commonly recognised that this is true, the genus, 'mineral substance' embraces earth, stone, and metal. Even if we say, in order to please some critics, that these substances are named 'μετλλευτά' because they are searched for, we are not able to defend and support his classification even with this interpretation. Since each is dug up the genus is 'mineral substance.'"

"These interpretations of his (Aristotle's) opinion have led us to the next theory. It is said that we search for metals deep within the earth with little or no hope of finding them while stones and well-known earths are dug up without careful search. For this reason the former are called μεταλλεντά and the latter όρνκτά. Such reasoning is weak and unsupported because we do not prospect for metals alone or at all times" [*ibid*, p16]. We prospect for gems, veins of well-known earths, and even marbles, while metals sometimes occur as if they were offering themselves to us.

"Aristotle is wrong; he classifies those stones that do not melt in the fire as minerals and those stones that do melt and contain a metal as 'minerals from which metals are obtained' and therefore he cannot place those stones that do melt and yet contain no metal in either of these groups" [this must refer to bitumen and the like].

"Actually some of the stones do melt in the fire and can correctly be called μεταλλεντά (metallic) since metals are recovered from them. Other stones contain no metal but having been formed from exhalations melt in the fire and can be poured. These cannot be called μεταλλεντά. Therefore if all 'mineral substances' are formed from vapour, as he himself says, and among all these the ones which have formed from exhalations contain no metal, it follows that there must be three genera of bodies formed within the earth although only two may be formed from exhalations" [*ibid* p16].

He continues in the same vein, with a discussion on the classifications used by Albertus Magnus [*ibid* p17]. He challenges Albertus's classifications, noting: "…if we call intermediate only those minerals formed from water and earth, we will have in the intermediate class stones and metals which are composed of these elements. Since, however, some stones melt in the fire and some do not, resistance to melting is not characteristic of stones, for if it is, then stones that melt would not be stones but intermediate minerals. No one has dared to say this, not even Albertus himself. Similarly, Avicenna is not able to classify earths in any correct genus" [ibid p17].

APPENDIX D – IDENTIFICATION OF MINERALS (AGRICOLA)

Colour Expertise using the various properties was a commonly used guide to the type. For example, the streak test is given: silver, although white, makes a black line on wood; eretria wood rubbed on copper gives it a violet colour [Agricola: 1546 p12]. By the end of the seventeenth-century it was being to be realised that colour was not a reliable guide to composition. However, as an indicator for metals and metal alloys, the touchstone has been remarkably accurate.

Lustre and iridescence are described "several minerals such as the mineral *paederos* (a type of opal) which he describes as displaying a range of colours similar to that seen on the neck feathers of certain African fowl…" [*ibid* p6]. He differentiates between lustre which occurs throughout the mineral and that which is surface only [*ibid*].

Taste*:* Some minerals have a sweet taste; these include *melitites* (possibly borate or alum) and *galactites* (calcites and possibly nitrates). Current wisdom acknowledges alum as having a sweet or astringent taste. Others have bitter, salty or acrid tastes. Red ochre tastes astringent, and certain earths which have absorbed an acidic juice, exhibit an acidulous taste. Testing for the taste of congealed juices is done by placing them on the tongue. This is suitable for salt, alum, soda, iron sulphates and related species. Astringent earths adhere to the tongue.

Odour**.** The odour which is given off is considered next [*ibid* p8]. That of sory (iron sulphates) is so foul it causes nausea.

Transparency*:* Of the mixed minerals only proustite is transparent, a deep red. Four congealed juices are transparent, *halite, nitrum*, *alum* and *atramentum sutorium*

Hardness and Tenacity are treated by Agricola under strength or weakness, demonstrating how they resist destruction.

Tenacity. Tenacity is the resistance that a mineral offers to breaking, crushing, bending, cutting, or other destructive activities.

Hardness Some gems can be scratched with a file. All gems can be engraved with emery except diamond which can only be scratched by its own fragments [*ibid* p11].

Cleavage A very few [minerals] are cleavable, i.e. capable of being split into two parts, such as talc [*ibid* p10]. Talc, a hydrous magnesium silicate, has perfect cleavage.

Shape, Form, Size. Minerals have various shapes and forms, except for the earths which are amorphous or tabular. Examples of minerals of different shapes are: turquoise (hexagonal), thyrites, (spherical), beryl (cylindrical). Certain gems are triangular, or quadratic or cubic as in diamond, pyrite; spindles, geodes, convex on the inner side; smaragdus, concave. Quartz has six angles and pangonius is twelve sided.

[Agricola: 1546]

APPENDIX E – AGENDA OF THE ACADEMIE ROYALE (DU CLOS)

Du Clos sets out the questions to be considered at the *Académie*

i) Whether the principles constituting natural mixts can be distinguished by their resolution into certain parts separable through the artifices of chymistry?

ii) Whether by these artificial resolutions forms of the different parts of these mixts can be discovered without introducing new forms?

iii) Whether the external fire of the furnace in separating some of these parts of the mixts can give them forms that they had not previously had? (i and ii above were part of the debate pluralist and monist views on substantial forms, and resolution to the pristine state).

iv) Whether the external fire is a suitable and adequate method for the ultimate resolutions of mixts into the simple parts that are last in the order of resolution and first in the order of natural composition?

Appendix F *Béguin's principles*

APPENDIX F – BÉGUIN'S PRINCIPLES

Mercury. It is "that acid, permeable, penetrable, aethereal, and most pure liquor, whence all nutrition, sense, motion, colour and the retardation of over-hast age. It is made of the Element of Air, and Water: and indeed, to the first, as far as it is altered by approaching heat, it vanishes into air; but as to the other, so far as it is difficulty bounded in its own proper limits, it is easily contained in another *Terminum."*

Sulphur is a sweet, oleaginous and viscid Balsam, conserving the native heat of the parts, the instrument of all vegetation, increase, and transmutation, and the fountain, and origin of all odours, grateful and ungrateful. It is assimilated to fire, by reason of the flame which it easily conceives, as all other resinous and oleaginous things. It has a peculiar property, a power of pacifying and conglutinating extreme contraries.

Salt is a dry body, saline and has the property of preserving mixts from going bad. It is endowed with the faculties of dissolving, coagulation, cleansing and evacuating; and from it every solidity, determination, taste, and other infinites virtues. It is analogous to the Earth; not as it is cold and dry, but as an Element firm, fixed and the subject of generation of all bodies.

Appendix G *Boyle's 'Heads'*

APPENDIX G – ROBERT BOYLE PROJECT OCCASIONAL PAPERS NO. 1

EXCERPT FROM 'HEADS' AND 'INQUIRIES' CONCERNING SHINING WOOD

1. Observations to be made. Tryalls to be made.
2. Try what severall degrees of warmth and heat will doe towards the Increase diminution or Extinction of shining Wood.
3. Try what <operation> Cold either naturall, or artificially procurd by snow & salt, will have upon it. Try also the operation of a very moist aire as a Cellar; & likewise very dry, or an Easterly or northerly wind, or the Blast of a pair of Bellows.
4. Try whether a peice of clear <& also> & thin colourd glasse being layd on it the light cast by the wood thrô the glasse will be ting'd.
5. Try whether corrosive Liquors, especially clear oyle of vitrioll by the spoyling the Texture of it, will destroy or alter the Light
6. Try whether [spirit of wine] will by preserving the wood, preserve, or by penetrating it, injure the Luminiousness & whether the same Liquor being layd on Wood that is just ready to become shining will hinder it to doe soe by checking the Putrefaction.
7. <Try whether in case the [spirit of wine] extinguist the seeming fire, upon the slow evaporation of the [spirit of wine] the wood will regain any part of its Light.>
8. Try also what Effect [oil of Tartar] per deliqium urinous spirits & [oil] of Turp[entine] &c. will have; some of, that being applyd warme as well as Cold.
9. Try, with a pendulous Experiment whether any warmth can be perceived.
10. Try whether compressing or crushing it with severall degrees of force between 2 peices of clear glasse, its Light will be diminishd, extinguishd or increasd. <Try the like with shining fish.
11. 108 Try whether shining wood will shine more or lesse in the Exhausted Receiver then when 'tis <againe> full of aire, or then it dos in the open aire.
12. Whether <shining> wood being carefully seald up in a thin Glasse soe as that it be not over-heated <in> the Operation, it will continue to shine as long or neer as long as otherwise, notwithstanding its being hinderd from any intercourse with the ambient aire. Whether a peece of shining Wood being put in the Receiver will upon the withdrawing & readmitting of the aire have the fate of a kindld coal, & loose & regain its light.
13. Whether a peece of wood seald up Hermetically as is mentiond in one of the former Experiments, will retain its Luminousnesse in the Exhausted Receiver well as before the aire is withdrawn & after its return, & soe will show that the pulse that makes light is able, thô it spring from within a Hermetically seal'd Glas, is able to propogate itself through the Glas, & <either> is made upon the æther (whether aire be mix'dwith it or noe) if it be a meer pulse, or can move freely in a Vacuum as to aire, if Light be a Corporeall Effluvium.

14. What is the specifick gravity of rotten wood in reference to water
15. Whether shineing wood being kindld will easily flame, or whether it will slowly burn away like Touchwood.
16. Whether the smoak of it being held under the face will have an acute & saline smell, & will by its acrimony make the eyes water.
17. Whether the Ashes that remain of this wood will have any fixt salt as those of other wood. And whether these Ashes will differ from those of rotten wood that has not yet shone & from those of rotten wood that has ceasd to shine.
18. What substances destillation will obtain from cours [?] wood & which will not appear that noe parts will come over luminous.

Reproduced from

Hunter [2005] *No. 1 of the Occasional Papers of the Robert Boyle Project* Published by the Robert Boyle Project, School of History, Classics and Archaeology, Birkbeck, University of London, Malet Street, London, WC1E 7HX, UK Edited by Michael Hunter.

APPENDIX H – EXPERIMENTS AT THE ACADEMIE (BOURDELIN)

Bourdelin's Experiments with plants

Protocol

Du Clos outlined a protocol to be followed, one of which was distillation. Spirits and oils were to be extracted by distillation over a vapour bath, with the distillation vessel connected to a 'refrigeratory' (a cooled section of the apparatus) to collect the 'most subtle, least terrestrial oil;' then over a fire to collect the 'acid spirit and the more terrestrial oils.' The fixed salts would then be extracted by calcination followed by washing [*ibid*, p48]. Distillers were long acquainted with the observation that various types of substances obtainable from plants passed over into the recipient vessel at different 'degrees of heat', and that the best way to extract them with the least evident alteration was to carefully control the heat, gradually increasing it [Holmes:2003 , p50].

Analysis

The product of the extraction was then analysed by mixing with selected solutions. Du Clos advocated using i) a solution of salt of lead made from distilled vinegar, ii) a solution of what was known as 'sublimate' (mercury and marine acid) iii) vitriol of Mars; iv) with silver dissolved in 'eau forte' (nitrous acid). From the results, it would be possible to recognise properties of the constituent parts, some defined by chemical properties, some by the class[61] of plants from which the substances had been extracted [*ibid*, p50]. Classifications had not been standardised, though they utilised those of Theophrastus (c. 371–287 BCE) in his *Historia Plantarum).* Attempting classification was a complex task. For example, liquid distilled from cold moist herbs (containing sulphurous salt) turned the salt of lead or salt of silver milky and turbid [*ibid*, p50]. The fixed or alkaline salts extracted from the plants turned solution of vitriol of Mars (ferric sulphate) various colours indicating the difference between various salts. In addition to oil, the sulphurous and acid spirits contained salt that was recognisable by its savour and by its action. These constituent salts of a given plant could be recombined to give a single salt, which would have the virtue of the plant.

[61] This was well before Linnaeus' system of classification had been published; in 1735

Bourdelin performed dozens more experiments on various plants, examining the products of distillations and separations [*ibid*, p57]. He appears to have been trying to discover which of the three solutions – sublimate, vitriol and tournesol – were the most effective indicators. They were capable of discerning strengths that were too low to be detected by human sense of smell or taste – there were non-manifest. It was later described as an 'occult acidity' [*ibid* p61].

Bourdelin made a set of trials with a modified method. After a lengthy process involving repeated distillations and an extended heating process, the receivers were 'clear and full of volatile salt.' The residues remaining in the retorts were treated in the usual way, calcinating the solid matter and washing out the soluble fixed salt.

Inclusion of the Salt of Saturn test

In 1673 Dodart and Borel, two newly appointed members of the *Académie*, became closely involved with the plant analysis project. In early April 1673, Bourdelin focused his attention on herbs and flowers. He began distilling the leaves of wild narcissus. Of the eight samples he treated the first seven as usual, but for the eighth, collected after the fire had been augmented gradually over six hours, he added an extra test; adding salt of Saturn to the liquor. This test, consisting of "seven gros of a reddish liquor charged with volatile salt, precipitated the sublimate and the salt of Saturn, as it did with the vitriol". Adding tournesol had no effect, though it effervesced moderately with spirit of salt. It is unclear what prompted him to add the test with the spirit of Saturn as a test for sulphurous salts, i.e. alkalis. Du Clos had suggested this test in 1669, but it had never been actuated. The first test with the salt of Saturn gave results consistent with the usual effect on sublimate and acid of salt, as well as the expected effect from tournesol, i.e. no effect. The effect of the precipitation of the vitriol, on the other hand, was probably uncertain. Bourdelin added a footnote, saying that this liquor precipitated the sublimate as an orange colour, and precipitated a solution of salt of Saturn in common water. It is possible that they were following Boyle or had discovered independently that the orange colour indicated that the alkali present was fixed. In this case, however, that knew that the liquor contained a volatile alkali. It is possible that they were not clear about the meaning of the combination of tests carried out. In any event, it was decided that for all future distillations the test with salt of Saturn would be added to the three other tests already prescribed [Holmes: 2003, p61].

Co-existence of Acids and Alkalis

On the same day, Bourdelin distilled the flowers and leaves of the grand celandine. He took especial care in his efforts to characterise the fixed salt obtained from the residue. "…the fixed salt, dissolved in four times as much water, was mixed with sublimate [with which] it formed an orange colour, with vitriol of alum and that of Mars (vitriol of iron) with which it precipitated, with salt of Saturn, with which it formed a white precipitate" [*ibid*, p61]. He did not comment on what these tests revealed, but reported them to the *Académie*. This distillation of the roots of the celandine plant produced a paradoxical result [*ibid*, p61]. The first three portions of the liquor collected did not contain any acid. In contrast, the fifth was "very bitter, acid and a little saline [in taste and] precipitated sublimate, turned the vitriol brown, and reddened tournesol."

Bourdelin conducted further tests with celandine liquors and solutions of salt of Saturn, German vitriol (containing copper and iron) and various other reagents. His focus turned from the search for new solutions to the comparison of the precipitations and colour changes produced by various plant juices with sublimate and Salt of Saturn. The results varied considerably, with no obvious pattern emerging. Bourdelin persevered with his experiments with plant juices; during these trials he encountered, twice, indications of acidity and alkalinity in the same sample of distillate. One, on coriander, had the searched-for combination of precipitate and a weak red colour. The second, on Ranunculus, precipitated sublimate, turned the vitriol brownish -green and strongly reddened tournesol. Bourdelin may have believed that this was clear indication of an acid and an alkali existing in solution together, although not everyone was convinced.