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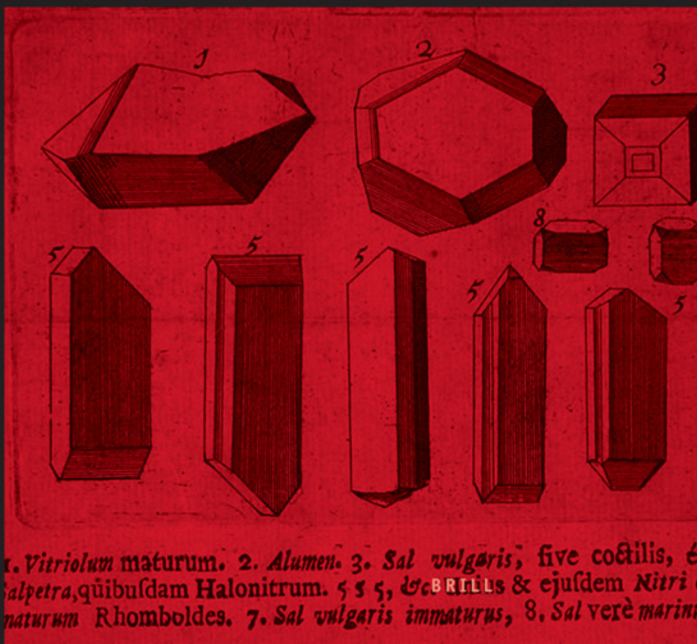
The Salt of the Earth

Natural Philosophy, Medicine, and Chymistry in England, 1650-1750

ANNA MARIE ROOS



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The Salt of the Earth

Natural Philosophy, Medicine, and Chymistry in England, 1650–1750

By
Anna Marie Roos

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Cover illustration: crystalline shapes of salts from Martin Lister, *De Fontibus medicates Anglicae*. London: Walter Kettilby, 1684, between pages 32 and 33. Osler Library of the History of Medicine, McGill University, Montreal, Quebec, Canada.

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To my father Gordon and my brother David for being my champions

To my colleague Mark Harrison for his friendship and scholarly excellence

To my husband Ian for showing me in his stubbornly Lincolnshire way that there is love in this world

The cure for anything is salt water: sweat, tears or the sea.
Isak Dinesen

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CHAPTER ONE

THE CONTEXT OF SALTS

Fifteen years ago, I was a student in Florence, studying quattrocento and cinquecento Renaissance paintings and sculpture. In the mornings, I went to lectures, visited the Uffizi, or the Bargello to marvel at Duccio's zigzagged crucifixions, the Christ's almond-shaped eyes closed in furrowed pain. I sketched and made notes. In the hot afternoons, I wandered around the city when everyone took their *reposo* or siesta. Strolling past the cheese shops that smelled of the "feet of the gods," into the artisans' quarter where the paper of tempting marbleized journals sparkled with painted copper tips adorning scrolls, flowers and foliage, I ambled past the Orsanmichele. Here Donatello's statues, suspended in time, instructed passers-by about civil duty, Florentine pride, and moral rectitude. But walking up to the San Miniato del Monte, a solid church with thick brick walls decorated with frescoes on the inside and geometric marble mosaics on the outside, was a special excursion. It was on as much of a mountain as one would find outside of Florence, affording a view of Brunelleschi's dome and the red-tiled roofs of the city below.

One July day, after an ample lunch of pasta, olives, and salty tomato sauce to maintain my perpetually hungry adolescent metabolism, I walked to San Minato, looking forward to the cool sanctuary and salubrious perfume of the rose garden. Perspiring heavily in the hot Tuscan sun as I ascended the hill, I began to feel odd. White dots appeared before my eyes, my stomach felt heavy, and the bright colors of the landscape turned faint and grey. I stumbled to a wall to rest, and I subsequently awoke to an elderly and ample Italian lady clad in black wafting a bottle that smelled piercing and sharp under my nose. "Sal volatile, sal volatile," she kept repeating, and then "bene, bene" as my eyes fluttered open. I was befuddled, yet gradually aware I had fainted, my shirt ripped and a long scrape down my side indicating my fall against the wall. The awareness of pain from the scrape and the contents of the bottle rapidly propelled me to consciousness. "Sal volatile? Sal volatile? what is that?" I thought. Then I realized, "Volatile salts . . . oh, smelling salts! Grazie, grazie, signora."

After returning to my pensione, I thought about the restorative I had been offered. Smelling salts were something I had previously thought only existed in Victorian novels, but then I also thought only tightly corseted heroines were capable of fainting, not an American student who was suffering from dehydration and heat stroke. From that day, I wondered what the source of the idea was that salts contained a vital principle that would restore consciousness. That thought led to the writing of this book, which delineates the important cultural and scientific origins and effects of salt chymistry in early modern England, and among other purposes, demonstrates the source of the idea of salt as a source of life and restoration.

In this work, I will

1. Demonstrate the centrality of salt and salt chymistry to early chymistry and matter theory generally, and ask to what extent natural philosophers and physicians in the seventeenth and eighteenth century considered salt fundamental to science and medicine.[1] The term "salt" in the early modern period was a vague one, but usually encompassed a group of "solid soluble, inflammable substances with characteristic tastes"[2] and a crystalline structure. In the early modern period, as the historian Norma Emerton has commented "as the instrument of the form, as embodiment of the generative seed and spirit, and as the transmitter of mineral qualities including crystallinity, salt became the formative principle par excellence."[3] Some chymists, such as Joseph Duchesne (1544–1609), Johann Glauber (1604–70), and Nicaise La Febvre (1610–1669) claimed there was a "hermaphroditical" or formative salt believed to be responsible for minerallogenesis and the formation of matter, or perhaps a source of the alkahest or universal dissolvent.[4] I will delineate

[1] My use of the term chymical and chymistry throughout this book is quite deliberate, as it is anachronistic practice to make clear distinctions between alchemy and chemistry in the seventeenth century. Early modern "chymists" attempted to transmute metals into gold, considered an alchemical practice, yet also performed other experiments involving mass balance or crystallographic analysis that would be considered "chemical." For further analysis of this historiographic problem, see L.M. Principe and W.R. Newman, "Alchemy vs. Chymistry: The Etymological Origins of a Historiographic Mistake," *Early Science and Medicine*, 3 (1998), pp. 32–65.

[2] Jon Eckland, "Salt", in *The Incomplete Chymist: Being an Essay on the Eighteenth-Century Chemist in His Laboratory with a Dictionary of Obsolete Chemical Terms of the Period*, Smithsonian Studies in History and Technology, Number 33 (Washington, D.C.: Smithsonian Institute Press, 1975).

[3] Norma Emerton, *The Scientific Interpretation of Form* (Ithaca: Cornell University Press, 1984), p. 214.

[4] Joseph Duchesne, *The practise of chymicall, and hermeticall physicke, for the preservation of*

these debates about salts' role in matter theory amongst the Paracelsian School as well as chymists such as Glauber, who were influenced by the work of Johann Baptista Van Helmont (1577–1634).

2. Assert that salt chymistry provides a nexus for studying the interrelationships between chymistry, natural history, physiology, and medical sciences in the early modern period. My exploration of natural history's intersection with chemical investigation in early modern England, particularly amongst early Royal Society members, proved a ripe area to explore the growing importance of the senses and experience as causes of intellectual change in the seventeenth and eighteenth centuries. While the concept of the Paracelsian *tria prima* of salt, sulphur, and mercury is important to consider in tracing the source of these ideas, I argue the work of the physician Johann Van Helmont was at their base.

3. Argue that analyzing to what extent the alchemical understanding of salts was modified in the seventeenth and eighteenth centuries is crucial to our understanding of the transition between alchemy and chymistry. To accomplish this task, I will determine to what extent conceptions of volatile salts were modified by a diminishing of interest in the salt principle, and increasing emphasis upon acidic saline spirits as the fundamental movers in chymistry, natural processes and medicine in the first half of the eighteenth century. As Ecklund commented, "in the eighteenth century salts gradually became to be thought of in terms of process, as, for example, the product of the reaction between acids and bases, acids and other salts, or between two salts, etc. Some chemists regarded acids . . . themselves as salts or at least some saline substances."[5] Indeed, Chambers *Cyclopaedia* (1728) defined salt as a "simple acid substance."[6] In the early eighteenth century, the formative qualities of volatile salts were also thought to be an aid to longevity. Before oxygen was "discovered," acidic saline spirits were perceived to be the source of life's breath, revealing not only the origins of the idea of smelling salts, but early theories of respiratory physiology.

health . . . Translated into English, by Thomas Tymme (London: T. Creede, 1605); Nicaise La Febvre, *Traicté de la chymie*. (Paris: T. Jolly, 1660); *A Compleat Body of Chemistry* (London: T. Ratcliffe, 1664).

[5] Ecklund, "Salt," in *The Incompleat Chymist*.

[6] Ephraim Chambers, "Salt," in the *Cyclopædia, or, An universal dictionary of arts and sciences* . . . in two Volumes (London: James and John Knapton, et al., 1728), volume 2, p. 12.

Historiography and chapter outline

Previous histories of salt chymistry such as Robert Multhauf's *Neptune's Gift* have focused on common salt as an industrial and commercial material, concentrating on its production, consumption and trade, particularly in the Germanies; Multhauf admitted that his work began as a project for a history of industrial chymistry.[7] Other treatments of early modern English salt chymistry, such as Robert Frank's analysis of the Oxford physiologists from William Harvey (1578–1657) to John Mayow (1640–79), have been dominated by a concentrated study of nitre and respiration in medical works; scholars Noel Coley and Matthew Eddy have analyzed salt chymistry in the context of early modern spa waters.[8] In a refinement of the magisterial analyses of Paracelsus by Walter Pagel and Allen Debus, work by Larry Principe and William Newman has indirectly indicated the importance of salt chymistry to conceptions of the alchemical Paracelsian "elemental" *tria prima* of salt, sulphur, and mercury.[9] Chapter two will more directly analyze the significance of salts to the English Paracelsian School, with a focus on the works of Joseph Duchesne (1544–1609), a French physician whose treatise

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[7] Robert P. Multhauf, *Neptune's Gift: A History of Common Salt* (Baltimore: John Hopkins University Press, 1978).

[8] Robert G. Frank Jr., *Harvey and the Oxford Physiologists: A Study of Scientific Ideas* (Berkeley: University of California Press, 1980); Noel G. Coley, "Cures without Care: 'Chymical Physicians' and Mineral Water in Seventeenth-Century England," *Medical History* 23 (1979), pp. 191–214; Matthew D. Eddy, "The 'Doctrine of Salts' and Rev. John Walker's Analysis of a Scottish Spa (1749–1761)," *Ambix* 48, 3 (November 2001), pp. 137–160; Anne Borsay, *Medicine and Charity in Georgian Bath: A Social History of the General Infirmary, c. 1739–1830* (Aldershot: Ashgate, 1999); Christopher Hamlin, "Chymistry, medicine, and the legitimization of English spas, 1740–1840," in *The medical history of waters and spas*, Medical History Supplement no. 10 (London: Wellcome Institute for the History of Medicine, 1990), pp. 67–81; Phyllis Hembry, *The English spa, 1560–1815: a social history* (London: Athlone Press, 1990); A. Sakula, "Doctor Nehemiah Grew (1641–1712) and the Epsom Salts," *Clio Medica* [Netherlands] 19, 1–2 (1984), pp. 1–22. Noel G. Coley, "The preparation and uses of artificial mineral waters (ca. 1680–1825)," *Ambix* 31 (1984), 32–48; Charles F. Mullet, *Public baths and health in England, 16th–18th century* (Baltimore: John Hopkins Press, 1946). For nineteenth-century therapeutic mineral cures, please see George Weisz, "Water Cures and Science: The French Academy of Medicine and Mineral Waters in the nineteenth century," *Bulletin of the History of Medicine* 64, 3 (1990): 393–416. For the economic impact of mineral waters, please see Sylvia McIntyre, "The Mineral Water Trade in the Eighteenth Century," *Journal of Transport History* 2,1 (1973), pp. 1–19.

[9] William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago and London: University of Chicago Press, 2002).

modified by Thomas Tymme was one of the first Paracelsian chymical treatises published in England. The chapter will also analyze Thomas Sherley's (1638–1678) translation of Duchesne's contemporary Turquet de Mayerne, as well as the work of Johann Glauber which influenced the intellectual circle of Samuel Hartlib and Robert Boyle.

Frederic Holmes' collection of essays investigates primarily eighteenth-century French salt chymistry in another light, as an experimental enterprise in its own terms, not as a mere "preparation" for the theories of Lavoisier.[10] In contrast to Owen Hannaway's view of the origins of modern chymistry, Holmes claimed that eighteenth-century salt chymistry was "investigative rather than didactic, concerned more with research and discovery than teaching and dissemination."[11] Holmes also claimed that because the experimental activity concerning salt chymistry displayed principles of specialization and the division of labor, it was to be distinguished from the "more familiar categories of natural philosophy," in which virtuosi dabble in several areas of investigation.[12] Holmes' work however primarily investigated French salt chymistry in the Académie Royale which was an organized activity sponsored by the French state. In contrast, in England, chapter three of this book will show that chymistry was rather more intimately connected to the "virtuosic dabblings," of the more loosely-organized Royal Society, largely in natural history. Salt was seen by natural philosophers such as Martin Lister (1638–1711), Robert Moray (1609–73), Thomas Philipot (d. 1682), Nehemiah Grew (d. 1682), and Robert Boyle (1627–91) to be a primeval principle or fundamental mover in processes usually described in natural history accounts, such as tides, volcanoes, meteorological effects, and plant respiration.

The effects of volatile salts (in early modern chymistry, those that have an odor and were reactive to heat), particularly of vitriol (ferrous sulphate) and saltpeter (potassium nitrate also known as nitre) were at the center of these studies in natural history.[13] This may have been because the crystals of the salts of vitriol are large and prominent, and because sulphuric and nitric acids produced spectacular and often

[10] Frederic L. Holmes, *Eighteenth-Century Chymistry as an Investigative Enterprise* (Berkeley Papers in the History of Science: University of California at Berkeley, 1989).

[11] J.G. McEvoy, "Review of Frederic Lawrence Holmes Eighteenth-Century Chymistry as an Investigative Enterprise," *Isis*, 82, 2 (1991), p. 312.

[12] McEvoy, "Review of Eighteenth-Century Chymistry," *Isis*, p. 312.

[13] Multhauf, *Neptune's Gift*, p. 130.

exothermic chemical reactions. To indicate the pervasiveness of these beliefs, appendix one provides a translation of Martin Lister's work *De Fontibus medicatis Angliae Exercitatio* (1684) [Exercises on the healing springs of England], which contains an extensive discussion of vitriol and early beliefs about volatile salts.

Further, as Dear has noted, the early Royal Society's "style of presentation" of natural philosophy with its wealth of circumstantial evidence and empirical detail "allowed no clear distinction to be made between a 'natural historical'... and an 'experimental report.'"[14] True to this fashion, English experimental works of salt chymistry in the seventeenth century, not only in form, but in their content, were "natural historical." Detailed reports of the phenomena of natural history were accompanied by theories of salt chymistry as underlying explanations for observed events. Ursula Klein's work has analyzed to what extent the chemical experiments in Herman Boerhaave's (1668–1738) *Elementae Chemiae* related not only to experimental philosophy, but to experimental history and natural history.[15] In a similar manner, an exploration of natural history's intersection with chemical investigation in early modern England is a ripe area to explore the growing importance of the senses and experience as causes of intellectual change in the seventeenth and eighteenth centuries.

The salt principle was also a fundamental alchemical tenet, and in chapter four I analyze to what extent the alchemical understanding of salts was modified in the seventeenth and eighteenth centuries to contribute to our comprehension of the early modern transition between alchemy and chymistry. As Principe has noted,

> in the Paracelsian triad [of salt, sulphur, and mercury] the largely analogical, relative, and fluid categories of the Mercury and Sulphur of the dyad are made more rigid so that the tria prima becomes universal, constant, primary, elemental bodies. For example, Quercetanus, one of the most important early expositors of the Paracelsian tria prima, insists in his *liber de priscorum philosophorum varae medicinae materia* that Mercury,

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[14] Peter Dear, "*Totius en Verba*: Rhetoric and Authority in the Early Royal Society," *Isis* 76, 2 (June 1985), pp. 144–61, on p. 154.

[15] Ursula Klein, "Experimental history and Herman Boerhaave's chemistry of plants," *Studies in History and Philosophy of Biological and Biomedical Sciences* 34, (2003), pp. 533–567. For the intersections of other early modern scientific disciplines with natural history see: *Cultures of Natural History*, eds. N. Jardine, J. Secord, E.A. Spery (Cambridge: Cambridge University Press, 1996).

> Sulphur, and Salt are present in all bodies, and that the scope of chymical philosophy includes not only minerals and metals, but also plants and animals, weather, and even celestial bodies.[16]

Seventeenth-century writers, particular those of chemical textbooks, as well as the iatrochymists, chemical physicians, and apothecaries who followed Paracelsus (1493–1541) also recognized the expansion of the *tria prima*'s principles to include all bodies.

However, Principe also argues that Paracelsus was not the chief of the alchemists, and did not inform "all of alchemy or even a major part of it," and that understanding diverse schools of thought among early modern alchemists is important.[17] His point is well taken in the case of theories of salt chymistry and natural history, which I also show in chapter three were more dominated by the thought of physician Johannes Baptista Van Helmont (1579–1644) rather than the theories of Paracelsus. Van Helmont believed that volatile salts composed the vital spirit or the breath of both animals and plants which was "resolved in the heart by fermentation into a salt air and enlightened by life."[18] In other words, volatile salts were thought to compose a vital spirit made of arterial blood transformed in the heart by fermentation into a salt air that was expelled by breathing.[19] Just as van Helmont thought that heated blood discharged its volatile salts into the air, Robert Boyle and his colleague Daniel Coxe (1640–1730) believed that volatile salts "being received into the vast subtile fluid [atmosphere] . . . becomes the Instrument of sundry remarkable effects and operations, not only in Natural, but also [in] Artificial productions."[20]

At the end of the seventeenth century, interest in the salt principle began to decline. Belief in the salt principle diminished, "as did interest in elements in general, in favor of a notion of a primeval or universal acid as a fundamental mover in natural processes, usually equated with

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[16] Lawrence M. Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (Princeton: Princeton University Press, 1998), pp. 39–40.

[17] Principe, *The Aspiring Adept*, p. 41.

[18] Allen G. Debus, "The Paracelsian Aerial Niter," *Isis* 55, 1 (March 1964), pp. 43–61, on p. 58.

[19] Robert Boyle, *Suspicions about some Hidden Qualities of the Air with an Appendix touching Celestial Magnets* (London: W.G., 1674), pp. 59–60.

[20] Daniel Coxe, "A Continuation of Dr. Daniel Coxe's Discourse . . . touching the Identity of all Volatile Salts," *Philosophical Transactions of the Royal Society* 108 (November 23, 1674), pp. 169–82, on p. 172.

sulphuric acid."[21] As Emerton has noted, in the seventeenth century, there was "recognition that the most powerful chemical agents were acids or "saline spirits," which were currently gaining increased importance in the laboratory as chemical reactions in solution gradually predominated over the old distillation processes."[22] Natural philosophers such as Descartes, Boyle, and Newton identified the seminal power and vitalist generator of matter as a universal saline or acid spirit, a tradition bolstered by Boerhaave.

To examine this intellectual transition from a salt to an acidic "saline spirit" as a vitalist generator of matter in England, in chapter four, I will examine the works of William Simpson, a Van Helmontian physician whose work on aerial acids has striking parallels with Newton's later work on acids in the *Opticks* (1704–22) and *De Natura Acidorum* (1710). I also will analyze the writings of Newtonian physicians such as Bryan Robinson (1680–1754), Archibald Pitcairne (1652–1713), George Cheyne (1671–1743) and Richard Mead (1673–1754) who posited a "Newtonian physiology" based on the premises in the *Principia*, as well as queries in Newton's *Opticks* and the *De Natura Acidorum*. Although Anita Guerrini pioneered the studies of "Newton-struck" physicians in the late seventeenth and early eighteenth century, her emphasis was primarily in the application of Newtonian physics to medicine; I will concentrate upon Newton's chymical works and their influence in the medical community.[23] Chapter five will examine the spread of these medical concepts of salt chymistry in larger society, looking at their role in patent medicines, in satire, and in medical treatments to promote longevity.

By the eighteenth century, we will see that suggestions for the identity of this universal acid reflected the "novel preoccupations... of the phlogiston theory, the nature of combustion, pneumatic chymistry, and respiration;" Lavoisier, for example, "fastened upon the elementary gas, which he named oxygen (literally acid generator) as his acidifying principle."[24] In the concluding chapter, I will briefly demonstrate this

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[21] Multhauf, *Neptune's Gift*, p. 130.

[22] Emerton, *Scientific Reinterpretation*, p. 184.

[23] Anita Guerrini, "The Tory Newtonians: Gregory, Pitcairne, and their Circle," *Journal of British Studies*, 25 (1986), pp. 288–311; Anita Guerrini, "Archibald Pitcairne and Newtonian Medicine," *Medical History*, 31 (1987), pp. 70–83; Anita Guerrini, *Obesity and Depression in the Enlightenment: The Life and Times of George Cheyne* (Norman: University of Oklahoma Press, 2000).

[24] Emerton, *Scientific Reinterpretation*, p. 227.

theoretical progression, my analysis of this progression used to elucidate the staggered and incomplete development of chymistry from alchemical beliefs, one of the key historiographic issues in the study of early modern chymistry.[25] Finally I hope that I will have answered my question, formulated a long time ago in Tuscany, about why salt was thought to be a vital element.

[25] Newman and Principe, "Alchemy vs. chymistry: The etymological origins of a historiographic mistake," *passim.*

CHAPTER TWO

PARACELSIAN CONCEPTS OF SALTS

Aristotelian analyses of the elements in his *On the Heavens* and *Of Meteorology* dominated conceptions of matter in late medieval natural philosophy. The heavens above the moon were created of the ether, a perfect shining element whose natural motion was circular and perfect. Below the moon, there were the corruptible earth, air, fire and water elements composing the material world. Each element was classified as either being hot or cold, and wet or dry. The heavy earth element had a natural motion downwards towards the center of the earth, as Aristotle postulated elements teleologically strove to be in their natural place with their identical components of matter. Water also went down towards the oceans, just as rain fell down out of the sky. Fire strove upwards to be towards the ring of fire thought to be surrounding the earth above its atmosphere; the upward motion of a burning candle illustrated this principle. Elemental air also went up towards the atmosphere. Each of these elements was paired with its opposite element which had a natural motion in a direction contrary to its own. Water, which was heavy and wet, was paired with fire, which was light and dry; the heavy and dry earth found its opposite in the light and wet air.

The sun was also responsible for the generative properties of the four elements, aiding them by its heat and light to mix and create minerals, plant and animal life. Aristotle postulated in his geocentric astronomical system that the sun was not in the center of the universe, but rather in the midst of all the other planets. The sun could radiate light in all directions, essential because Aristotle believed that the generation and corruption, or becoming and passing-away, of all sublunar creatures and elements was dependent on the Sun.[1] Robert Grosseteste, the late medieval scholar and Bishop of Lincoln, expressed a common opinion when he stated that if the Sun were elevated to the region of the

[1] Aristotle, "On Generation and Corruption," in *The Complete Works of Aristotle.* 2 vols. ed Jonathan Barnes (Princeton: Princeton University Press, 1984), 2.10.336b, lines 16–24; quoted in Edward Grant, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200–1687* (Cambridge: Cambridge University Press, 1996), p. 453.

primum mobile, the elements and compounds around the earth would be destroyed because the earth's heat would be reduced.[2] If the Sun descended to the region of the Moon, its proximity to the elements of earth, water, air, and fire would also destroy them. As it was, when near the earth, the sun caused the waters surrounding the earth to evaporate, but when it receded those waters condensed and fell.

As has been well documented by Debus and Pagel, Auroleus Phillipus Theostratus Bombastus von Hohenheim or Paracelsus (1493–1541) challenged these Aristotelian conceptions of the elements in the sixteenth century. Hellenistic alchemical texts posited that mercury and sulphur were the basic elemental principles, and Paracelsus added salt to this, creating the *tria prima* or three principles.[3] While Paracelsus had no desire to dispose of the Aristotelian schema of earth, air, water, and fire, he did feel that they were purely "spiritual in nature and only crude approximations of the objects by which we call these names."[4] And, when Paracelsus added the *tria prima* of salt, sulphur, and mercury, this second elementary system of matter, he failed to

> make clear the relationship of the new triad to the traditional elements. Varying between spiritual and material interpretations, the elements and principles were often pictured as often indefinable aspects of a primal stuff that had to exist as a basis for the more complex things of this world.[5]

This state of affairs meant that sixteenth- and seventeenth-century English chymists integrated the Aristotelian and Paracelsian schemas as they saw necessary, coming up with different numbers of elements and principles to suit their needs. This chapter will explore how coexistence of elements and principles influenced conceptions of the salt principle among Paracelsian chymists in England in the first half of the seventeenth century.

In this contextual chapter for our study of early modern saline chymistry, not only will we explore to what extent the material conception

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[2] Robert Grosseteste, *Hexaëmeron*, ed. Richard C. Dales and Servus Gieben (London: Oxford University Press for British Academy, 1982), 5.21.2, lines 20–22; quoted in Grant, *Planets, Stars, and Orbs*, p. 452.

[3] Pagel however questions if there were medieval precedents to the Paracelsian addition of salts to the *tria prima*, postulating that *terra* or *faex*, a solid residue, was introduced to provide the material basis for metals. See Walter Pagel, *The Smiling Spleen: Paracelsianism in Storm and Stress* (Basel: Karger, 1985), pp. 40–41.

[4] Allen G. Debus, "Fire Analysis and the Elements in the Sixteenth and Seventeenth Centuries," *Annals of Science* 23, 2 (June 1967), pp. 127–147, on p. 129.

[5] Debus, "Fire Analysis," p. 129.

of salt affected traditional Aristotelian conceptions of matter, but we will also analyze the debates about the identity of a Paracelsian "philosophical" or spiritual salt, and the role of salts in Paracelsian medicine. We will first examine Thomas Tymme's translation of Joseph Duchesne's *Practice of Chymicall and Hermeticall Physick* (1605), the first work in England to explore such debates, as well as the significance of salt in the Paracelsian system to an English audience. We will then also compare Duchesne's ideas about the medical use of salts to those of Turquet de Mayerne, a French Paracelsian, who bound up in the antimony wars in France, emigrated to become a physician to Charles I of England. Finally, we will analyze the role of salt in the work of Johann Glauber (1604–70), the German chymist whose ideas were influential in the intellectual circle in England centered about scientific reformer Samuel Hartlib (1600–1662) in the 1640s until the Restoration.[6]

Joseph Duchesne and Thomas Tymme's Practice of Chymicall Physick

Joseph Duchesne (1544–1609, known as Quercetanus) was a French court physician to Henry IV, and was considered "as one of the leading authorities on the new chemical medicines in Europe."[7] Renowned and rebuffed for his chymical remedies, Duchesne was involved in public controversy within and without the French court, including successfully defending Louise Robot, the Mademoiselle de Martinville, and her mother-in-law involving charges of incest.[8] Duchesne's notoriety as well as his chymical theories caused English minister Thomas Tymme to translate his *Libert de Priscorum Philosophorum verae medicinae material* (1603) and the *Ad Veritatem Hermeticae Medicinae ex Hippocratis vertumque decretis ac Therapeusi* (1604) to create the *Practice of Chymicall and Hermeticall Physick*

[6] J.T. Young's work, *Faith, Medical Alchemy, and Natural Philosophy: Johann Moriaen, Reformed Intelligencer, and the Hartlib Circle* (Aldershot and Brookfield, USA: Ashgate, 1998), discusses Morian's interactions with Glauber and the reception of some of Glauber's chymical ideas among the Hartlib circle.

[7] Allen Debus, "The Pharmaceutical Revolution of the Renaissance," *Clio Medica* 11, 4 (1976), pp. 307–317, on p. 312.

[8] Didier Kahn, "Inceste, Assassinat, Persecutions et Alchemie en France et a Geneve (1576–1596): Joseph Du Chesne et Mlle de Martinville [Incest, assassination, persecutions, and alchemy in France and Geneva, 1576–96: Joseph Du Chesne and Mademoiselle de Martinville]," *Bibliotheque d'Humanisme et Renaissance* 63, 2 (2001), pp. 227–259.

(1605). In doing so, Tymme produced the first treatise in England that was devoted to Paracelsian theory since Richard Bostocke's Paracelsian apology, the *Difference between the auncient Phisicke . . . and the latter Phisicke* (1585).[9] *The Practice* was not only one of the first seventeenth-century treatises in English to have a complete explanation of Aristotelian and Paracelsian elements, but it was the first to have an extended discussion of the Paracelsian salt principle. Duchesne's work also was popularized in the first half of the seventeenth century, influencing more practical works of Paracelsian medicine and chymistry such as John Woodall's *Surgeon's Mate* (1617).

Considering the muddied state of affairs created by the overlay of the *tria prima* unto the Aristotelian elemental system, it is not surprising that Duchesne created his own theoretical system, using a matrix of five principles with both Paracelsian and Aristotelian elements.[10] In *Le Grand miroir de Monde* (1584) and the *Defensio* (1605), Duchesne had eliminated air as an element as he believed it was rarified water, and disregarded fire as well because it was not mentioned in Genesis, leaving earth, water, salt, sulphur and mercury as his five principles.[11] To confuse the issue further, Tymme in his translation modified Duchesne's ideas, instead emphasizing a Trinitarian correspondence between the "passive" Aristotelian elements of earth, fire, and water (which included terrestrial water and the upper waters of air), with the chymically "active" Paracelsian elements of salt, sulphur, and mercury. Debus is correct to surmise that Tymme's emphasis on the trinity of matter was because of his vocation as a minister—he attributed mystical properties to the trinities of chemistry and religion.

However, despite Tymme's Trinitarian thrust, one which will extend to the classification of saline substances themselves, it cannot be overlooked that salt emerges as an overwhelmingly predominant principle in his translation. Part one of the *Practice* is devoted to "chymicall" physick, and contains three chapters about the material nature of salts. The entire second part and most of the third concerns the "hermeticall" or spiritual nature of the "hermaphroditical" salt, an "ideal Platonic form of salt." Chemists like Duchesne, as well as Johann Glauber (1604–70), and Nicaise La Febvre (1610–1669) claimed that there was a "hermaphroditical"

[9] Allen G. Debus, *The English Paracelsians* (New York: F. Watts, 1966), p. 87.
[10] See R. Hooykaas, "Die Elementenlehre der Iatrochemiker," *Janus* 41 (1937), pp. 1–28 for an analysis of Duchesne's theories of elements and principles.
[11] Debus, *English Paracelsians*, p. 90.

or formative salt believed to be responsible for the minerallogenesis, reproduction, and the generation of matter. There were several contenders for the identity of this formative salt principle including nitre, antinomy, and vitriol, the debates about which we shall analyze.

Part one of the Practice: *Salts, material substance, and the secondary qualities of taste and color*

Part one of the Practice devoted to chymical analysis began by describing the material nature of salt. It was seen as a "dry body, merely earthy... endowed with wonderfull virtues of dissolving, congealing, cleansing," and as the substantive body in the trinity of spirit (mercury) and soul (sulphur); this concept was taken from Duchesne's *Ad veritatem*.[12] And, Tymme's classification was in keeping with the Paracelsian *tria prima*, in which "salt is the directive for matter to assume solidity and bodily shape."[13] Continuing the tripartite theme, all salts were believed to contain *within themselves* salty, sulphureous, and mercurial qualities "jointly together." Common earthy salt, "fixed and firme," nitrous salt, "partly fixed and partly volatile," participating in the "sulphureous beginnings of things," and sal ammoniac, which was "of the Mercuriall beginning spiritual and airie" could all be extracted from any saline substance by a "wittie" saltmaker with the "force of fire."[14]

Tymme also claimed that salts also were responsible for secondary qualities of matter, such as color or taste. It was also possible to discern which type of salt in a sample was predominant, whether sulphureous, fixed, or mercurious, by taste. Earthy fixed salt had a simple salt taste, nitrous or sulphureous salt a sweet and oily one, and mercurial salt was sour. In fact, a substance without any salt, such as water, was described by Tymme as "utterly unsavory."[15] This belief that water was tasteless was ultimately derived from Aristotle's *On Sense and the Sensible*,[16] in which

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[12] Joseph Duchesne, (1605) *The practice of chymicall and hermeticall physicke*, trans. Thomas Tymme. (Amsterdam: Theatrum Orbis Terrarum; Norwood, N.J.: W.J. Johnson. [London: T. Creede: 1975 reprint]) fol. D1 verso.; Joseph Duchesne, *Ad veritatem hermeticae medicinae ex Hippocratis veterumque decretis ac therapeusi* (Paris: Abraham Saugrain, 1604), book xiv, p. 167. [*Haec tria principia, ab Hermete olim antiquissimo Philosopho dicta sunt spiritus, anima, corpus, ut Mercurious sit spiritus, sulphur anima, sal corpus.*]

[13] Walter Pagel, *The Smiling Spleen*, p. 37.

[14] Duchesne, *Practice of Chymicall Physicke*, fol. D2 verso.

[15] Duchesne, *Practice of Chymicall Physicke*, fol. D4 verso.

[16] Aristotle, *On Sense and the Sensible* (Whitefish, MT: Kessinger Publishing, 2004), I.4.c., line 1.

water was without savor unless it received "some affection from an external agent," such as a salt. These predominant salt, sweet, or sour tastes which derived from salty, sulphureous, or mercurial salts in any substance, the *Practice* argued, are attenuated by mixture with the "passive" Aristotelian qualities of earth, fire, and water.[17] Tymme wrote:

> for the sharpe is mixed with a mercurial liquor; the sower is mixed with a phlegmatique, or watery humour, and the eger, with a terrestrial driness: the which, the more they have of the Elementary qualities, and the same passive, so much the more weake they are and impaired.[18]

However, by chymical art, the active salts could be separated from the passive elements, and "obtaine their full force," for medicinal purposes.[19]

In a simpler vein, "cookery" could also be used to change tastes of substances, as heat would volatilize the differing salts in the food. For instance,

> So if thou shalt drawe out of onions and garlicke a Volatile and aiery sharpe Mercurial Salt, which ariseth in the superficies & uppermost of their bodies: thou shalt make them more sweet and pleasing, and to put off their sharpenesse, by which they bite the tongue.[20]

In other words, the sweetness of the cooked onions and garlic was because the marine salt and sulphureous salt were left behind after heating, lending their qualities of taste to the cooked food.

This premise that taste arises from a proportion of salts mixed with passive elements was a Paracelsian challenge to the Aristotelian-scholastic, and hence Galenic idea that taste was due to the hot, cold, moist, and dry qualities of the substance in question. Aristotle believed heat and cold were among the most fundamental features of matter in the secondary realm, including that of taste, digestive savor in the mouth, and nutritional value. In the *On Sense and the Sensible*, taste and savor increased in direct proportion with heat, whereas "coldness and freezing render Savors dull, and abolish odours altogether; for cooling and freezing tend to annul the kinetic heat which helps to fabricate sapidity." In the Aristotelian scheme, moistness also increased strength of taste. But for Tymme and Duchesne, the proportion of salts was behind the sensory appreciation of food.

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[17] Duchesne, *Practice of Chymical Physicke*, fol. D4 recto.
[18] Duchesne, *Practice of Chymical Physicke*, fol. D4 recto.
[19] Duchesne, *Practice of Chymical Physicke*, fol. D4 verso.
[20] Duchesne, *Practice of Chymical Physicke*, fol. D4 verso.

Another challenge to scholastic assumptions was the *Practice's* argument that saline spirits were behind the diversity of color in mineral, vegetable and animal matter, a belief we shall see in chapter three that fifty years later will influence theories in the Royal Society about plant pigments. Scholastics believed that color was related to the material's hot and cold qualities. This stemmed from Aristotle's belief that hotness and coldness were among the most fundamental characteristics of matter in the sublunary area, something later mechanists would deny.[21] Aristotle also promoted a causal thesis of perception, or that "the capacity of a sensible quality to produce perception has as its basis the intrinsic nature of the quality;" when applied to color, this meant that the inherent quality of a red object makes us perceive it as red.[22] And, the object's inherent quality of redness also meant the object had an inherent quality of hotness as well. Whiteness usually meant the object also had an inherent quality of coldness, like snow. Thus, as Tymme noted, the scholastic

> Physitians . . . have . . . noted certain frivolous and light observations: as when they say, that in a white onion, or in white wine, a man may judge by the color a great coldnesse, than in a red onion or in red wine.[23]

In contrast, Paracelsians argued that "solidity and often color were due to salt."[24] Tymme noted that arsenic, which is a white sublimate, and thus should be cold, instead was very biting to the taste (a hot quality). Further, white sugar when heated, revealed "its innermost spirits," and became sharp in taste, its "waters" dissolving metal, also symptomatic of hot qualities. This refutation of Aristotelian principles meant that color proceeded from "the spirits . . . or aery vapours, which lye hid in the Salt," and was not related to heat or cold at all.[25] As an example of this, Tymme utilized Saltpeter or Nitre. Nitre was also white, but when heated, dyed the body of the alembic colors "of no less variety, then are flowers of the earth in the time of the Spring."[26]

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[21] Todd Stuart Ganson, "What's Wrong with the Aristotelian Theory of Sensible Qualities," *Phronesis* XLII, 3, (1997), pp. 263–282, on p. 264.
[22] Ganson, "What's Wrong," p. 276.
[23] Duchesne, *Practice of Chymical Physicke*, fol. E1 verso.
[24] Debus, "Fire Analysis," p. 131.
[25] Duchesne, *Practice of Chymical Physicke*, fol. E1 verso.
[26] Duchesne, *Practice of Chymical Physicke*, fol. E1 verso.

Just as salts were behind colors and tastes of substances, Tymme argued in the *Practice* that the very substance of matter could be reduced to salts, and he utilized experiments with wine and its vinegar to do so. It was first postulated that salts could be volatilized by exposing the substances in which they were contained to "celestial influences," such as sunlight. Via an elaborate system of astral parallels, Paracelsus had taught that celestial influences at the macrocosmic level influenced the microcosm of the body, as well as causing chemical change in the inanimate world. Taking Paracelsus' idea in consideration, Tymme wrote that the celestial influence of the sun could reveal hidden salts that made up matter, as in the case of wine exposed to sunlight turning to vinegar. He claimed that sun "vaporeth" away the wine's quintessence, and

> this eternal and celestial essence being gone, which was the cause of the wines sweetnes (which sweetnes hath alwaeies joined with it neverthelesse, a certain pricking very acceptable to the palate, by reason of a singular temper of sharpnesse Vitriolated by sweete and Sulphurus spirits, put by the instinct of nature into wine) at the length it waxeth sower.[27]

The sourness and sharpness of vinegar had nothing to do with its supposed cold qualities, but to the "hidden . . . spirits of Salt," whose sourness was revealed when sulphureous salts were volatilized away by sunlight.

Tymme would further test the saline constitution of vinegar using distillation. Distilling three pints of vinegar revealed first watery phlegm without taste. After this phlegm was drawn away, sharp liquor remained, which Tymme identified as containing sal ammoniac, or ammonium chloride. Tymme may have obtained this observation from Duchesne's *Ad Veritatem Hermeticae Medicinae* (1604) in which he had argued sal ammoniac was closely linked to the mercurial element, and that distilling substances that contained sal ammoniac would result in a mercurial water that was sharp and biting in taste.[28] Whatever the source of this

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[27] Duchesne, *Practice of Chymical Physicke*, fol. E2 recto.

[28] Duchesne, *Ad veritatem* book IV, p. 169. as quoted in Hiroshi Harai, "Paracelsisme, Neoplatonism, et Medecine Hermetique Dans La Theorie De La Matiere De Joseph Du Chesne a Travers Son *Ad Veritatem Hermeticae Medicinae* (1604)," *Archives Internationales d'Histoire des Sciences* 51, 146 (2001), pp. 9–37, on p. 28. [*artifex peritissimus novit, mercurium, seu salem armonicum volatilem, cum aere seu aerea parte ita conjunctum esse, ut simul cum aere etiam expiret, et cum eo in aquam spiritualem reducatur, quae agnoscitur mercurialis esse aqua, ex sapore admodum acuto, aeri et vehementi, qui ex mercurio aut sale armoniaco naturae spirituali, (ut vocant Philosophi) promanat.*]

information, most likely what was being identified as sal ammoniac was some acetic acid resulting from the distillation of the vinegar, as acetic acid is a clear, colorless liquid with a sharp, irritating odor. However, because sal ammoniac also has a strong smell (it is the component in smelling salts), and acetic acid had not yet been identified by chymists, one can understand Tymme's logic. Then, Tymme remarked that it was possible to confirm the amount of sal ammoniac in vinegar by distilling three pints vinegar with an ounce of salt of tartar, a fixed salt (potassium carbonate). He claimed that the volatile sal ammoniac would conjoin with the salt of tartar, resulting in a substance that was tasteless,

> the volatile sal ammoniac being gone through passage in the fixed salt. So that the said ounce of Salt Tartar, is increased by one scruple or more of volatile Salt, increasing the quantitie of the other fixed.[29]

Indeed, a chemical reaction of the acetic acid in vinegar and potassium carbonate forms potassium acetate, a deliquescent salt with an acetic odor; the strong odor would have led to the belief that the ammoniac was within the potassium acetate. In an early attempt at mass balance, Tymme thus attempted to identify and to find the proportion of the sal ammoniac in vinegar.

Tymme then concluded:

> Nowe, as we have shewed that the sower and mercuriall liquor of things, doth borrow that tartnesse, from a certaine Armoniac salt, and volatile, which ariseth from the fixed; even so the sulphurus and oylie liquor, doth receive and taketh his virtue from no other things, than from that sweete Nitreous sulphurus salt, which borroweth the same from fixed salt: so that in the fixed salt, and out of that salt, that mercuriall sowernesses and sulphurous virtue doe spring, and doe received their fruits therefrom, as from the roote and first originall. As also it is to be noted, and to be wondered at, that a tryple substance is severally to be extracted out of one and the same Essence: from which all things created, do sucke and draw their faculties, virtues and properties: and that the same doe subsist in one and the same subject.[30]

In other words, in the physical world, the sulphureous, mercurial, and simple saline salts had their origins from fixed salts. As salts provided material body, and fixed salts were earthy, Tymme's claim was analogically

[29] Duchesne, *Practice of Chymical Physicke*, fol. E3 recto.
[30] Duchesne, *Practice of Chymical Physicke*, fol. E3 verso.

consistent with both Aristotelian and Paracelsian schemes. As Tymme commented, "from this fixed Marine salt, as from the Father and first original, all other sates [saltes] are derived."[31]

Part two of the Practice: *Salts, fire analysis and the existence of the philosophical salt*

The idea that distillation would separate a salt into its own constituent properties of fixed, sulphureous, and mercuric qualities was not only was a reflection of the Paracelsian idea that substances cannot be divided into more than three substances, but that distillation itself would reveal the base principles of matter. The efficacy of fire analysis or distillation was an idea in some dispute in the sixteenth and seventeenth centuries.[32] Paracelsians believed that vaporous fumes in distillation revealed mercury, flame sulphur, and ashes salt.[33] However, as Debus and Shakelford have shown, opponents of Paracelsus such as Erastus believed that fire changed bodies into material that was not part of original bodies, and that heat created new compounds, rather than revealing the building blocks of a substance.[34]

In chapter 10 of the *Practice*, the Paracelsian Tymme railed against thinkers like Erastus, stating that in the case of the calcinations of salts, "the naturall and original moysture in Saltes is not consumed."[35] His proof lay in the results of palingenesis, in which one took a plant, bruised and burnt it, and then calcinated its ashes, extracting from it a volatile salt. One then made a compound with the salt, and submitted it to a gentle heat; arising from the ashes were salt crystals which resembled a stem, leaves and flowers, an apparition of the plant which had been submitted to combustion.[36] Although the salt had been reduced

[31] Duchesne, *Practice of Chymicall Physicke*, fol. H2 verso.

[32] Frederic Holmes, "Analysis by Fire and Solvent Extractions: The Metamorphosis of a Tradition," *Isis* 62, 2 (1971), pp. 128–148.

[33] Paracelsus, *Die 9 Bücher de Natura rerum in the Sämitliche Werke*, ed. Karl Sudhoof and Wilhelm Matthiessen, 15 vols. (Munich and Berline, 1922–33), vol. xi, p. 348, as quoted in Debus, *Fire Analysis*, p. 131.

[34] Debus, *Fire Analysis*, p. 133.

[35] Duchesne, *Practice of Chymicall Physicke*, fols. F3 recto and verso.

[36] Lewis Spence, *Encyclopedia of Occultism* (New Hyde Park, NY: University Books, 1968), s.v. "palingenics." See William R. Newman, *Promethean Ambitions: Alchemy and the Quest to Perfect Nature* (Chicago and London: University of Chicago Press, 2004), pp. 226–232 for a discussion of palingenics. See also Francois Secret, "Palingenesis,

to ashes by heat, it still contained the original bodily structure of the plant, proving to Tymme that fire did not modify essential principles of matter. Tymme's interest in plant ashes also symbolized a general trend in chymistry. As Ahonen has remarked, although early iatrochymists

> had a bias towards distillates, the later Paracelsians [such as Duchesne, Tymme] . . . and Glauber . . . were slowly overcoming the entrenched distaste for residues and extending their chymistry to the appreciation as well of the fixed salts that remained behind in the ashes. This was to open up a whole new field of salts (e.g., the nitrates and sulphates).[37]

Tymme also utilized the example of experiments done by Sieur de Luynes or de Formentieres to extract salt from metals via calcination to show that salts were not changed in their composition by the heat of the fire. These metallic salts were

> mixed with lye made with ashes of burnt metals, by often powring warme water upon the same, & drawing it through too and againe shewing a proofe of his essence, included in the lye after this manner.[38]

The lye was strained through a filter, cleansed with water, and then placed in a vessel and exposed to the air, whereupon "there appeared a thousand forms of mettalls, with all the parts thereto belonging, as leaves, stalks, and rootes . . . in such sort as no man could be acknowledge them to be mettals."[39] The precipitation of salts from the lye which resembled metallic shapes confirmed to Tymme that the essence of metallic forms was inherent in the salty ashes, and fire did not destroy this essence. Inspired by biblical text, he then commented, "Remember man, that thou art Ashes, and to Ashes againe shalt returne."[40] This reasoning was not unique. As Newman has shown, the sixteenth-century artist and chymist Bernard Palissy, also influenced by Paracelsian ideas, believed salt's crystallizing activity showed that it was behind the production of minerals and metals.[41]

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alchemy and metempsychosis in renaissance medicine," *Ambix* 26, 2 (July 1979), pp. 81–99; A.G. Debus, *The French Paracelsians* (Cambridge, Cambridge University Press, 1991), pp. 159–61.

[37] Kathlenn Winnifred Fowler Ahonen, "Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry," (Ph.D. Diss. University of Michigan, 1971), p. 91.

[38] Duchesne, *Practice of Chymicall Physicke*, fol. F4 recto.

[39] Duchesne, *Practice of Chymicall Physicke*, fol. F4 recto.

[40] Duchesne, *Practice of Chymicall Physicke*, fol. F4 verso.

[41] Newman, *Promethean Ambitions*, pp. 154–155.

These discussions about salts' ability to be inherently generative revealed Tymme's perceptions about their dual nature. As Renaissance Neo-Platonism proposed there was an imperfect physical, and a perfect spiritual reality, Tymme also believed that while there were imperfect material salts that contributed tastes and color to material objects, there was also a philosophical or spiritual salt which was animate, hermaphroditical and thus inherently reproductive. In promoting this dualism, Tymme was reflecting the entirely typical nature of alchemists to make vague distinctions between material principles and their more exalted spiritual realities. There had also been a long medieval alchemical tradition "concerning the exalted dignity of salt as the basic operational force in Nature," and Duchesne and his translator expressed that tradition stemming from Raymond Lull's corpus of *sal in rebus omnibus.*[42]

Tymme wrote that within the plant ash there was also a spiritual salt, a spiritual "Idea, indued with a spirituall essence: which served for no other purpose, but to be matched with his fitting earth, that so it might take unto it a more solid body."[43] This existence of this spiritual salt was also shown by the fact that salt was a "balsam of nature." Tymme wrote, "all creatures by a certain natural instinct, doe desire [salt] as a Balsam, by which they are preserved, conserved, & doe grow and increase."[44] Birds and doves sought it out "with their beaks," deer gravitated to salt licks, and fish were "bred and nourished" in the sea.[45] Spiritual salts also were generative; salt was said to awake the power of semen, and Venus "the mother and first beginner of generation, is begotten of the Salt spume or froath of the male;" salt was also thought to be responsible for the generation of pearls and corals in the sea as the branching nature of the coral suggested salt crystals.[46] Fertilizing salts in marl "animateth, fortifieth, and giveth power" to the earth; as the sun caused the volatile salts in wine to vaporize and manifest chymical change, the sun in the springtime elevated and sublimated "the spirits of the said Salt, and of the balsam of Nature."[47] Salts in the air released by sunbeams fell again in the form of dew which contained "the spirit

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[42] Pagel, *Smiling Spleen*, p. 41.
[43] Duchesne, *Practice of Chymicall Physicke*, fol. F3 verso.
[44] Duchesne, *Practice of Chymicall Physicke*, fol. O3 recto.
[45] Duchesne, *Practice of Chymicall Physicke*, fol. O3 recto.
[46] Duchesne, *Practice of Chymicall Physicke*, fol. O3 verso.
[47] Duchesne, *Practice of Chymicall Physicke*, fol. O3 recto.

of the foresaid Salt," and from which Tymme asserted chymists could extract a powerful substance which could dissolve gold and silver.

Not only did Paracelsus believe salt was generative, but some of these ideas connecting the sun, salts, and the generative principle of spiritual salts stemmed from the Aristotelian corpus. Aristotle's "works involved pairs of opposing qualities, especially hot and cold, moist and dry," and these qualities were analogically connected to solar and lunar influences on the earth and the human body.[48] In *On Generation and Corruption*, he wrote that the sun releases heat which effects generation of life on earth.[49] However, because the sun was made of a perfect and immutable fifth element or aether, the sun's heat was attributed to its motion only, because the heat and light which it emitted were "engendered as the air was chafed by . . . its movement."[50] In the body, Aristotle associated the "hot" motive quality of the sun with the masculine vital heat or active "soul-principle" of the semen. The source of the vital heat of the semen was the *pneuma*, which was "analogous to the element which belongs to the stars," or the divine fifth element or aether; the pneuma was analogous to aether is that it was generative, because the Sun, which was also made of aether, was a means of creation.[51] Aristotle thus concluded that

> the heat of the sun does effect generation, and so does the heat of animals . . . which operates through the semen. The physical part of the semen, which . . . is accompanied by the portion of soul-principle and acts as its vehicle . . . [enters] the uterus . . . [and] it sets the residue produced by the female and imports to it the same movement with which it is itself endowed.[52]

Other English Paracelsian physicians such as Thomas Moffet also connected salts to lusty behavior. Thomas Moffett (1553–1604) studied medicine at Basel, wrote a manuscript on entomology which was pub-

[48] Joan Cadden, *Meanings of Sex Difference in the Middle Ages* (Cambridge: Cambridge University Press, 1996), p. 21.

[49] Aristotle, "On Generation and Corruption," in *The Complete Works of Aristotle.* 2 vols. ed Jonathan Barnest (Princeton: Princeton University Press, 1984), 2.10.336b, lines 16–24.

[50] Aristotle, *On the Heavens*, trans. W.K.C. Guthrie, The Loeb Classical Library (Cambridge: Harvard University Press, 1960), II.7.289a, lines 20–21, 31–33.

[51] Aristotle, *Generation of Animals*, trans. A.L. Peck, The Loeb Classical Library (Cambridge: Harvard University Press, 1963), II.3.736b, lines 35–40.

[52] Aristotle, *Generation of Animals*, II.3.737a, lines 1–4, 14–18. See Cadden, *Meanings of Sex Difference in the Middle Ages*, pp. 21–26 for Aristotelian conceptions of gender difference and the four elements.

lished by the court physician to James I, Turquet de Mayerne in 1634, and was a friend of Peter Severinus. Moffett had also written the preface of the official pharmacopoeia of the London College of Physicians that was devoted to Paracelsian chymical remedies.[53] If we examine Moffet's works on diet—the *Health's Improvements or Rules Comprising and Discovering the Nature, Method, and Manner of Preparing all Sorts of Food Used in this Nation*—we see that he claimed:

> Experience teacheth, that Mice lying in Holes laden . . . with Salt, breed thrice faster there, then if they were laden with other Merchandize. Huntsmen likewise and shepherds seeing a slowness of lust in their Dogs and Cattle, feed them with Salt means to hasten coupling; and what maketh Doves and Goats so lusty and lascivious that they desire to feed upon salt things. Finally remember, that lechery (in Latin) is not idlely or at adventure termed Salaritus, Saltishness, or every man knows that the salter our humours be, the more prone and inclinable we are to lechery. Wherefore whosoever coveteth to be freed of that fire . . . let them altogether abstaine from Salt.[54]

After establishing that salt was inherently generative, Tymme then went on to postulate which salt in particular exemplified this formative and spiritual salt principle, and decided that nitre, particularly an aerial nitre (in modern terms, potassium nitrate), was the best candidate. Paracelsus said that nitre arose "from the union of urine and the universal natural balsam," that nitre was uniquely able to bring about many of the Arcana of alchemy.[55] While Paracelsus' followers such as Peter Severinus, English chymist Robert Bostocke, and Gerard Dorn associated nitre with the vital sulphur, *ens astrale* or *summa vitalis*, any sixteenth-century references to an aerial nitre were confined to plague miasmas or to a theory of thunder and lightening involving the explosive force of gunpowder. As Parthington, Guerlac, and Debus have illustrated, it was not until the seventeenth century that the belief in a

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[53] Allen Debus, "Paracelsus: Five Hundred Years, Three American Exhibits at the National Library of Medicine," http://www.nlm.nih.gov/exhibition/paracelsus/paracelsus_2.html. Accessed 15 October 2006. See also Harry Weiss, "Thomas Moffett: Elizabethan Physican and Entomologist," *The Scientific Monthly* 24, 6 (1927), pp. 559–566.

[54] Thomas Muffet, *Health's Improvements or Rules Comprising and Discovering the Nature, Method, and Manner of Preparing all Sorts of Food Used* (London: Thomas Newcomb, 1655), p. 247.

[55] Allen G. Debus, "The Paracelsian Aerial Nitre," *Isis* 55, 1 (1964), pp. 43–61, on p. 46.

generative aerial nitre was widespread, and these ideas were diffused by the writings and translations of Duchesne.[56]

As a salt, nitre was inherently balsamic, but it particularly seemed to be potentially generative because it encompassed three qualities at the same time—mineral, vegetable, and animal—another nod to Tymme's Trinitarian mysticism.[57] Before industrialization, a major source of nitre was the deposits crystallizing from cave walls or privies, or other organic matter that was decomposing. Ammonia from the decomposition of urea in dung heaps would produce nitrate, and nitre-beds were cultivated in the early modern period by mixing manure and ashes, along with straw to create a compost pile; the compost pile was periodically kept moist with urine and leached with water. The liquid containing the nitrates was then converted with ashes to potassium nitrates which were refined into gunpowder. Tymme postulated that since nitre was partially extracted from of earth, usually taken out of old stables, it had a mineral quality. Because it also came from "hints of grounds which have been replenished with salt liquor," nitre also had animal origins. Finally, since "urines are nothing else, but a superfluous separation of the Salt of vegetables, by which living creatures are nourished," nitre had a vegetable nature.[58] Because vegetables absorbed nitre from the soil, especially in their roots, medicines distilled from vegetable matter would also contain a gentler saline medicament and purge; the salts "were not altogether so violent, and of so homogenous a spirit, as they were in their . . . original."[59]

Tymme also claimed that nitre was hermaphroditical, "male and female: fixed and volatile, Agent and Patient, and which is more, hot and cold: fier and Ice, but mutual friendship and sympathie joined in one."[60] Very fine gold and silver will dissolve in solutions of nitric acid containing chlorine, and virtually all soil contains significant quantities of chloride salts; since alchemists attributed male and female qualities to gold and silver, a substance that could dissolve both also seemed to contain a unity of opposites. Like all other salts, nitre also had within itself fixed, as well as volatile, sulphureous and mercurial qualities. It

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[56] Debus, "The Paracelsian Aerial Nitre"; Henry Guerlac, "The Poet's Nitre," *Isis* 45, 3 (September 1954), pp. 243–255.

[57] Debus, "The Paracelsian Aerial Nitre," p. 53.

[58] Duchesne, *Practice of Chymicall Physick*, fol. P2 recto. Debus also makes this point in "The Paracelsian Aerial Nitre," pp. 52–53.

[59] Duchesne, *Practice of Chymicall Physick*, fol. M3 recto.

[60] Duchesne, *Practice of Chymicall Physick*, fol. Q1 recto.

could exhibit hot qualities when made into gunpowder and burned; nitre dissolved in water will also produce an endothermic reaction in which the solvent will cool down. Tymme thus claimed, "Plato writeth, that this Salt, is a friend and familiar to divine things."[61]

Indeed, this philosophical salt not only was behind the structure of the sublunary world, but postulated to be part of the fabric of heaven. In Chapter XII of the *Practice*, which was devoted to Genesis, Tymme claimed that out of the Chaos, the *tria prima* was formed. Tymme wrote,

> This was the worke of God, that he might separate and pure from the impure; that is to say, that he might reduce the more pure and ethereal Mercury, the more pure and inextinguible Sulphur, the more pure, and more fixed salte, into shyning and inextinguible Starres and Lights, into a Christalline and Dyamantine Substance.[62]

In other words, the "fixed Heavens, or Vitriall and Chrystallyne circles, is a salt body," which had was so shining and pure that a "Diamond, which partaketh of the nature of fixed salt, is not of more puritie, continuance, and perpetuitie than they are."[63] This is another example of the integration of the Aristotelian system with the Paracelsian; the Aristotelian fifth element or ether, described by a fifteenth-century English encyclopedia as "resplendour perpetual... so clear and shining" which composed the crystalline orbital spheres of the planets, has been transformed into the philosophical salt principle.[64] As salt was the "foundation of the whole frame" of the microcosm of man, his very "bones, sinews, and ligaments" composed of saline substance, so was salt the framework of the macrocosm of the heavens.[65]

Salts and Disease in Paracelsian Medicine

These concepts of physical and spiritual salts were not confined to theoretical chymical tracts, but appeared in works devoted to practical Paracelsian medicine. Woodall's *Surgeon's Mate* which appeared in

[61] Duchesne, *Practice of Chymicall Physick*, fol. Q1 verso.
[62] Duchesne, *Practice of Chymicall Physick*, fol. H1 recto.
[63] Duchesne, *Practice of Chymicall Physick*, fol. H2 recto.
[64] Quoted in E.M.W. Tillyard, *The Elizabethan World Picture* (New York: Vintage Books, n.d.), p. 39. Tillyard does not give the original reference.
[65] Duchesne, *Practice of Chymicall Physick*, fols. H3 verso, L3 verso.

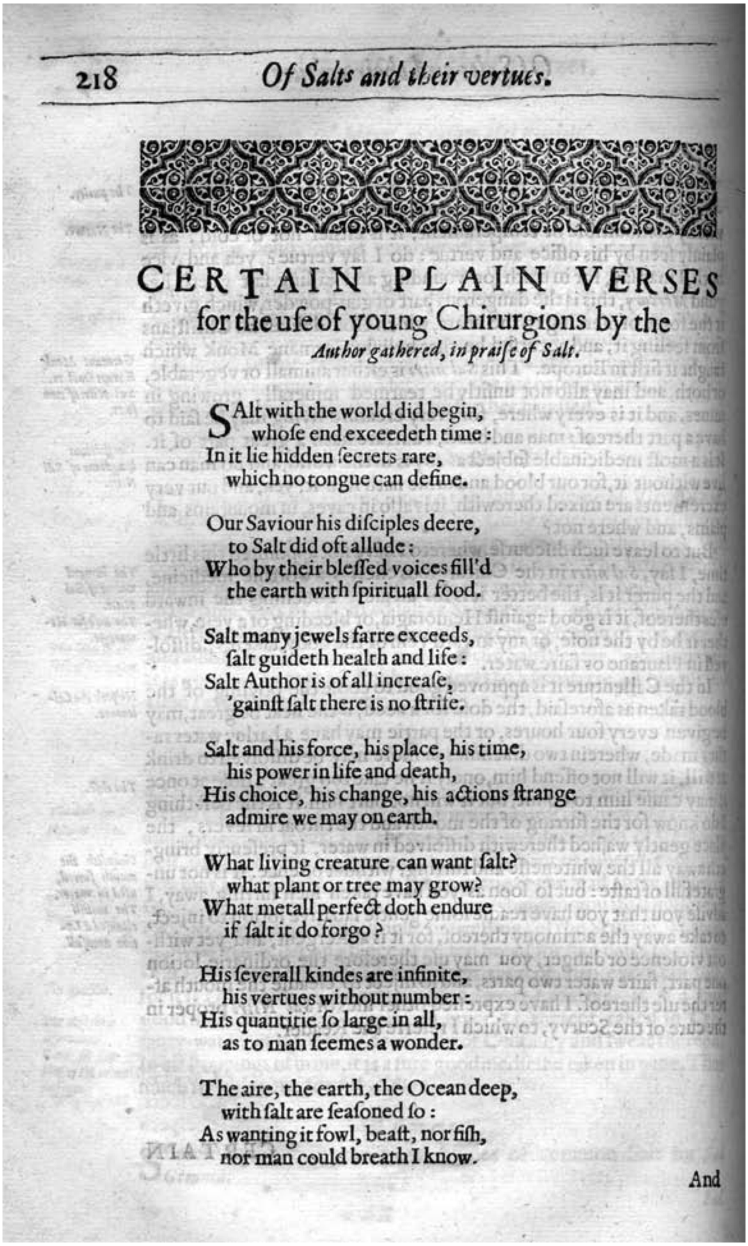
three editions in the seventeenth century, and which was one of the first works to advocate the efficacy of oranges and lemons for treating scurvy in the English navy, contained "plain Verses for the use of Young Chirurgions by the Author gathered, in praise of Salt" [Figure 1]. Not only did Woodall give practical advice in the use of salt for the preparation of medicaments, but the philosophical salt was also a subject considered necessary for naval surgeons to learn. In one verse, the philosophical salt was "both hot and cold, yea moist and dry, is salt in temperament: Yea volatile and fix also observing each intent." Woodall also claimed, all "colors strange in salt are seen," the earth "produceth salt in all," and mentioned that "spirit of Salt makes liquid Sol [gold], and Luna [silver] at thy will."[66]

In Paracelsian medicine, salt, sulphur, and mercury in the body had to be kept in unified balance. If a foreign agent, which could be food or a planetary influence, disturbed the union of the *tria prima*, as Pagel stated:

> sulphur could be released from its union with the other principles . . . and devour the mercury. If [mercury] becomes too strong it will coagulate salt and sulphur or else dissolve the salt. All such disorder and imbalance spells interference by an outside force . . . By contrast, ancient humoralism had concentrated on inside components such as this or that humour acquiring destructive qualities and thus causing disease. Instead it is abnormal ignition of sulphur that consumes the radical moisture in man; it dissipates the mercury which was to be separated in the stomach for nutrition of the whole of the body with the result of emaciation . . . and hectic fever. The agent disturbing the union of the principles introduced with the food; it is of 'excremental' nature and thus indigestible. Moreover—unlike normal excrement—it does not leave the body again, but forms local [salt] deposits—tartar—that obstruct the preformed anatomical channels causing diseases by obstruction.[67]

The most common disease which manifested these obstructions of salty tartar was gout. The coagulation of Salts into tartar caused, according to Tymme, "swelling, stones, and knots of the sinews," manifested in gout. Tartar in the stomach caused "inward gnawings" of extreme hunger because stomach acid is attracted by the chalky tartar; as the

[66] John Woodall, *The Surgeon's Mate: or Military or Domestique Surgery* (London: John Legate, 1655), p. 219.
[67] Pagel, *Smiling Spleen*, p. 30.



218 *Of Salts and their vertues.*

CERTAIN PLAIN VERSES
for the uſe of young Chirurgions by the
Author gathered, in praiſe of Salt.

SAlt with the world did begin,
whoſe end exceedeth time:
In it lie hidden ſecrets rare,
which no tongue can define.

Our Saviour his diſciples deere,
to Salt did oft allude:
Who by their bleſſed voices fill'd
the earth with ſpirituall food.

Salt many jewels farre exceeds,
ſalt guideth health and life:
Salt Author is of all increaſe,
'gainſt ſalt there is no ſtriſe.

Salt and his force, his place, his time,
his power in life and death,
His choice, his change, his actions ſtrange
admire we may on earth.

What living creature can want ſalt?
what plant or tree may grow?
What metall perfect doth endure
if ſalt it do forgo?

His ſeverall kindes are infinite,
his vertues without number:
His quantitie ſo large in all,
as to man ſeemes a wonder.

The aire, the earth, the Ocean deep,
with ſalt are ſeaſoned ſo:
As wanting it fowl, beaſt, nor fiſh,
nor man could breath I know.

And

Figure 1. A poem on salts in John Woodall, *The Surgeon's Mate or Military and Domestique Surgery*. London: John Legate, 1655, pp. 218–219. By permission of the Harden Library for the Health Sciences, University of Iowa.

tartar dissolved and putrefied, pain resulted, as well as "impostums and ulcers."[68] Excess tartar in the urine caused burning.

As Paracelsian theory advocated treating like with like (in opposition to the Galenic system, which postulated that opposites would heal), tartarous diseases could be cured by a salt because saline medicines would act as a purge, and rid the body of the tartarous obstruction. As an early English Paracelsian text stated

> Without Salt therefore, no excretion, or casting out of superfluities can be done. . . . For every voiding of Ordure is caused by the Salt, both in sound men, and sick; One is the Salt of Nature, (viz. the sound mans). The other is a corrupted and resolved Salt [Tartar]: From hence tis to be gathered, that even by Salts the Cure of it is to be perfected, in such wise, that the Salt may again rectified and separate the resolved Salt from the Sound.[69]

In his discussion of purges for tartarous disease, Tymme concentrated particularly upon antimony, and in Chapter XVI of the *Practice*, described a triad of medicines—mercurial, antimonial, and arsenicals that would respectively cure mercurious, saline, and sulphureous diseases.[70] Thought to be "sweet as Cassia," antimony was considered "a separated Salt." Paracelsus commented

> Of all minerals antimony contains the highest and strongest Arcanum [remedy]. It purifies itself and at the same time everything else that is impure. Furthermore, if there is nothing healthy at all inside the body, it transforms the impure body into a pure one which was proved in cases of leprosy.[71]

In doing so, Tymme was using inorganic materials like "mercurials, antimonials, and the mineral acids in internal medicines" in the nascent period of medical chemistry prior to 1600.[72] As McCallum has demon-

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[68] Duchesne, *Practice of Chymicall Physicke*, fol. L3 recto.

[69] *Paracelsus His Archidoxes Comprised in Ten Books, Englished and Published by J.H. Oxon* (London, W.S., 1661), book two, p. 81, p. 83. This is a likely a reprint of an late sixteenth-century translation of Paracelsus by John Hester, a distiller who published translations of Paracelsus from the 1570s until his death in 1593. See Debus, *The English Paracelsians*, pp. 66–69 for a discussion of Hester.

[70] "Wherein is shewed, that the whole force of purging in Medicines, in the *Antimonial*, *Mercurial*, and *Arsenical* Spirits according to every of their severall natures," Duchesne, *Practice of Chymical Physick*, fols. L3 verso to M3 verso.

[71] Paracelsus, *Sämtliche Werke. Nach der 10 Bändigen huserschen Gesamtausgabe (1589–1591) zum erstenmal in neuzeitliches deutsch übersetz.* trans. Bernhard Aschner, 14 vols. (Jena: Fischer, 1922–33), vol. 3, p. 151.

[72] Robert P. Multhauf, "John of Rupescissa and the Origin of Medical Chemistry," *Isis* 45, 4 (Dec., 1954), pp. 359–367, on p. 359.

strated, the use of antimony for medical purposes had a long tradition.[73] Hippocrates utilized it as a sudorific and cordial to induce sweating in fevers and cases of syphilis, "Roman doctors used it against "wild flesh" and ulcers, and in the Middle Ages it was additionally recommended to treat haemorrhoids, wounds, fistulas, skin cancer, leprosy and other sufferings."[74] Debus has indicated that in France that antimony was used as a purge by the 1560s, much to the dismay of the medical faculty of Paris who charged

> that antimony in any form was a dangerous poison that should not be taken internally (1566). In a series of decrees and court cases this powerful body tried to forbid any use of chemistry in medicine. Nevertheless, publishers continued to print books favoring medical chemistry, and by the early years of the new century courses in the preparation of pharmaceutical chemicals were available in Paris.[75]

Even before such controversies, Paracelsus himself recognized that its toxic nature meant that antimony had to be alchemically purified. As Arndt has described, Paracelsus believed that antimony had to be "free of its toxicity" before medical usage, and as Paracelsus wrote, "In the same way and form that antimony finishes in gold (in the sense of cleansing), it will perfect the body as well. It namely contains the *Essentia*, which does not allow anything impure to come together with the pure." Historian of chemistry David Schein has indicated in a course of modern experiments that when antimony is added to a combination of melted metals, it "will associate with those containing gold and part from the 'impure' metals. Because antimony seemingly 'eats' and 'extracts' the precious metals, it was also called 'wolf of metals' or 'the magnet of the wise.' "[76]

This ability of antimony was thus thought by Tymme to have a similar effect in man as well, purging toxins and obstructions such as

[73] Ian McCallum, *Antimony in Medical History: An Account of the Medical Uses of Antimony and Its Compounds since Early Times to the Present* (Bishop Auckland, England: Pentland Press, 1999).

[74] Kate Frost, "Prescription and Devotion: The reverend Doctor Donne the Learned Doctor Mayerne—Two Seventeenth-Century Records of Epidemic Typhoid Fever," *Medical History*, 22 (1978), pp. 408–419, on p. 413; Ulrich Arndt, "The Philosopher's Magnet: Alchemical Transmutation of Antimony," *Paracelsus*, (November 2005), pp. 12–17.

[75] Allen Debus, Paracelsus: Five Hundred Years, Three American Exhibits at the National Library of Medicine, http://www.nlm.nih.gov/exhibition/paracelsus/paracelsus_2.html. Accessed 15 October 2006.

[76] Arndt, "The Philosopher's Magnet," p. 15.

tartar out of the body. And, Tymme in the *Practice* indeed associated antimony with a magnetic loadstone, not only because of its ability like a magnet to attract other metals, but because like salt and like iron, antimony "was more corpulent like other things." In other words, just like salt, antimony gave bodily substance to matter, and like nitrous salt, it had ability to dissolve metals, and was called by Paracelsus, "the true bath of gold." Like other saline substances, antimony could also be melted into a glass-like substance, and was thought to contain all bodily characteristics of matter within itself. At the University of Munich, Schein performed a series of modern experiments according to a formula of the alchemist Basilius Valentinus in the *Triumph-Waggon of Antimony* (1604). Schein slowly and gently heated antimony-ore, which consists of a mixture of different antimony-oxides and especially of sulphides, until there were no more toxic fumes, and everything was melted to glass.[77] Because the glass can adopt any color of the spectrum, just as nitre heated in an alembic displayed all colors, this was proof to Valentinus and Paracelsian chemists like Duchesne that antimony was like a salt that contained all qualities within it.[78]

Duchesne's contemporary, Turquet de Mayerne, also theorized about the uses of saline medicaments. Educated at Heidelberg, Montpellier, and Paris, he became one of the physicians-in-ordinary to Henry IV, much like Duchesne. In 1603, Mayerne became involved in the antimony wars and with Duchesne was condemned in the *Apologia Medicine per Hippocratis et Galeni, contra Mayernium et Quercetanum.* In 1607, Mayerne came to England and formed intellectual connections with the English court, and after the assassination of Henry IV, became a court physician to James I.[79]

In his treatise of gout translated from the French by English court physician Thomas Sherley (1638–1678), Mayerne explicated his doc-

[77] Arndt, "The Philosopher's Magnet," p. 14.

[78] For a description of Paracelsus' preparation of antimonial medicine, see chapter 14 in *Paracelsus his Aurora, & Treasure of the Philosophers. As also The Water-Stone of The Wise Men; Describing the matter of, and manner how to attain the universal Tincture. Faithfully Englished. And Published by J.H. Oxon* (London: Giles Calvert, 1659).

[79] John Aiken, *Biographical Memoirs of Medicine in Great Britain* (London: Joseph Johnson, 1780), pp. 249–252. Also see the more recent Brian Nance, *Turquet de Mayerne as Baroque Physician: The Art of Medical Portraiture* (Amsterdam and New York, Rodopi, 2001), which offers an excellent analysis of de Mayerne's case books. My thanks to Matthew Eddy at Durham University for alerting me to this reference. Because this chapter discusses the wider reach of Paracelsian concepts of the salt principle, I am confining my analysis to de Mayerne's printed works.

trine of salts, which had both Paracelsian and Galenic influences.[80] Unlike Duchesne however, Mayerne avoided antimonial treatments, and instead recommended saline purges. As a Paracelsian, Mayerne disregards any primary causative role of the Galenic humors in gout, proclaiming that it arose when salt "exceeds and abounds" the ability of the body to absorb it. In normal digestion, the aliment is "dissolv'd into the Chyle," which is separated into the salt, sulphur and mercury. Salts are communicated to the blood, forming a Balsam for the body, and excess salts were excreted first in the urine, and then "sent off by Sweat," where they degenerate into thick "scurse and foulness, sticking to the skin."[81] When the body was unable to process excess salts in bodily liquids, salt would "inflame the parts, and vacillates and gnaws them," causing the pain of arthritis.[82] Hence the "Erratick Gout" which "shifteth placed, sparing no joint, but invading all of them successively," and which had as its root cause a salty flood of humors, was best cured by "hydragogol," or water-purging humors like syrup of the salt of hartshorn (ammonium carbonate).[83] If there were such a quantity of salt that could not be absorbed by bodily liquors, then of necessity "it will be stopt in its passages and Vessells . . . and be coagulated into different sort of Stones, according to the nature of predominant Salts."

Here the crystalline shapes of gouty tartarous concretions could be analyzed to see if what types of salts were responsible, and Mayerne noted the similarity of the growth of nodules in the body to salts made by chymical processes, as well as to minerals in the earth,

> Nay, he that shall remove his contemplations from the Coagulations of Salts, to those which happen to Stones and Marcasit[e]s, he shall find several of them so elaborately form'd according to Geometrical Rules, that he will be forced to acknowledge that Art is out-done by Nature.[84]

(We shall see in the next chapter that microscopic analyses of salt crystals for the purposes of classification became a common practice in the late seventeenth century.)

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[80] Theodor Turquet De Mayerne, *A Treatise of the Gout. Written Originally in the French Tongue* (London: D. Newman, 1676). Nance briefly discusses this treatise in *Turquet de Mayerne as Baroque Physician*, pp. 158–162. For an analysis of Sherley's chymical writings, please see Allen G. Debus, "Thomas Sherley's Philosophical Essay (1672): Helmontian Mechanism as the Basis of a New Philosophy," *Ambix* 27, 2 (1980), pp. 124–135.

[81] De Mayerne, *Treatise of the Gout*, p. 10.

[82] De Mayerne, *Treatise of the Gout*, p. 11.

[83] De Mayerne, *Treatise of the Gout*, p. 18.

[84] De Mayerne, *Treatise of the Gout*, p. 13.

Identifying which salts were behind the disease, as well as the temperament of the patient would aid treatment; the patient's hereditary history might also give clues. If the salts responsible for gouty pains were volatile, they would be diffused throughout the body, and best treated by internal medicines which would also diffuse readily, like salt of tartar dissolved in water; so although here Mayerne is following the "like cures like" Paracelsian principle, he is also taking into account the chymical composition of the salt responsible.[85] Purges like the salt of tartar, or spirit of salt (hydrochloric acid) would also rid the body of the tartarous deposits and "slime stuck to the sides of the stomach," relieving the disease's symptoms, and it "could lead salt matter away through the urine."[86]

Mayerne also thought that nitre in particular could also be a good purge, but only if taken in the wane of the moon, which showed a curious mix of Galenic and Paracelsian principles in his treatments. Paracelsian medicine, again in a "like cures like" manner, predicted the nitrous salt would dissolve kidney and bladder stones. The stricture to take the medicine at the wane of the moon was an old Hippocratic and Galenic belief in astronodia, the belief attributed to Hippocrates that the presence of the moon in different signs of the zodiac influenced the humoral content of various parts of the body.[87] The moon was thought to be "cold and moist, of the nature of Water," and hence "prognosticateth such as proceed of watry humours, citrine water, and salt flegm, for the most part with swellings and breakings out . . . retention of menstrua, and all other excrements, as . . . urine and Sweat, and the inordinate evacuation of them" as well as lymphatic diseases such as scrofula.[88] Because the moon had to do with the retention and evacuation of bodily fluids, its position in the zodiac dictated the best time for administering the humoral therapy of phlebotomy, which purged

[85] Nance also notes that Mayerne did not slavishly adhere to "like cures like," but limits his analysis to de Mayerne's use of chymical contraries, such as a sweet salt balancing a sour one. See Nance, *Turquet de Mayerne as Baroque Physician*, pp. 161–162.

[86] De Mayerne, *Treatise of Gout*, pp. 36–37. Nance, *Turquet de Mayerne*, p. 161.

[87] French suggests beginning in the twelfth century, astronodial medical texts were written around the remark by Hippocrates that the physician "should look at the moon when it is full because the blood and the medulla increase and all things grow on earth and the sea increases." Roger French, "Astrology in medical practice," in *Practical medicine from Salerno to the Black Death*, ed. Luis García-Ballester, Roger French, Jon Arrizabalaga, and Andrew Cunningham (Cambridge: Cambridge University Press, 1994), p. 39.

[88] French, "Astrology in medical practice," p. 68, p. 21.

the excess humors.[89] The moon caused the sea to swell at high tide, it was believed there was a corresponding monthly periodicity in the amount of humors. In the wane of the moon, the bodily fluids were at lower levels, and a purge such as nitre would therefore be less dilute in the body, effecting more purgation.

Mayerne also rather typically implicated the stomach in most gouty diseases, postulating that the stomach failed to separate excremental matter which was intrinsic to food. Thus, he also prescribed the usual dietary cautions of avoiding salted meats and strong wines with their excess tartar; wine could be watered down, or sugar of lead (lead acetate) could be added to wines that abounded with a "vitrioline tartar, sharp and pricking," resulting in its precipitating out (likely the precipitate was acetic acid).[90]

He also told patients to avoid venery, which "stirred up salt humors" and made the patient weak, again emphasizing the connection between salt and generative principles.[91] A sweet salt such as sugar of lead, which he believed mitigated and sweetened the humors, could also abate venereal desires by tempering the humors' saltiness.[92]

Glauber, the nitrous alkahest, and the vitrioline sal mirabile

In the first half of the seventeenth century, Paracelsian physicians and chemists thus utilized different combinations of Aristotelian elements and Paracelsian principles to suit their practical and philosophical beliefs about saline chemistry. We have thus seen so far that salt was thought to be a primary component of physical matter, its chymical composition affected secondary qualities of matter such as taste and color. Its balance in the body was important; if too prevalent, salt would coalesce into tarterous obstructions that could cause gout, arthritis, and kidney and bladder stones. In a philosophical and spiritual sense, salt was thought to be inherently generative, reproductive, and connected

[89] See Charles W. Clark, "The Zodiac Man in medieval medical astrology" (Ph.D. diss., University of Colorado, 1979) for a discussion of the figure that indicated where to let blood in the lunar cycle.
[90] Mayerne, *Treatise of Gout*, pp. 26–27.
[91] Mayerne, *Treatise of Gout*, p. 31.
[92] Mayerne, *Treatise of Gout*, p. 46.

to the fertility of sunbeams; nitre played a particular role in the work of Duchesne as the philosophical salt.

In the writings of Johann Glauber, called the "Paracelsus of the seventeenth century" all of these ideas coalesced, and his work was influential among chymical circles in England, particularly the Hartlib circle.[93] Correspondents of Samuel Hartlib (ca. 1600–1662), created a virtual Solomon's house as delineated in Francis Bacon's *New Atlantis*, concerning themselves with practical applications of natural philosophy, particularly agriculture, medicine, and chymistry. "Several extracts of Glauber's works are to be found among the papers of Samuel Hartlib," and Hartlib had nearly all of the Glauberian corpus in his possession, promoting the "international dissemination of his writings and equipment."[94] As Young has shown, Glauber's ideas about utilizing nitre to improve agriculture as well as his ideas about it serving as an alkahest or universal dissolvent were also of great interest to the Hartlib circle. Glauber's work on nitre influenced figures such as Benjamin Worsley, a chief figure of the Invisible College, a geographically separated group of natural philosophers pledged to social action whose peak of activity was 1646–47 and which included Robert Boyle.[95] Worsely, an inventor whose project in 1646 to manufacture

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[93] "Paracelsus des 17. Jahrhundert" in Wolfgang Schneider, *Geschichte der Pharmazeutischen Chemie* (Weinheim: Verlag Chemie, 1972), p. 130.

[94] J.T. Young, *Faith, Medical Alchemy and Natural Philosophy*, p. 198. I am utilizing Christopher Packe's edition of Glauber's work translated in the seventeenth century: *The Works of the Highly Experienced and Famous Chymist Johann Glauber* (London: Thomas Milburn, 1689).

[95] For Glauber's influence on Worsley, see Copy Tract on Saltpetre in Hartlib's Hand, Benjamin Worsley undated 39/1/16A–20B: 21A, 21B blank 39/1/16A in the Hartlib Papers. Glauber's influence even spread to minor figures of the Hartlib circle, such as Robert Child, who wrote to Hartlib on 2 February 1652, "as for Glaubers works in Latine I thanke you, I vnderstand them as well in High dutch, for perhaps the translatour may more faile than I shall: as for your freinds thriving by Glaubers 2. 3. book of minerals I haue read them lately I suppose, that it is easy to vnderstand his meaning, & I suppose it is but one only way. viz by bringing metals to Slag or Cinders as Concerning those 4 things about Alkahest, I suppose that neither do Come nigh the Alkahest for the first, I do not well vnderstand, what aqua pluuialis sub [putrefacta?] salificata meaneth, I know that water will putrefy & [altered] leaue Eartly feces at the botome, & grow sweet againe, as in Sea voyage, & that out of this Earth a salt may be drawne, & that ther is a kind of volatile salt euen in fresh water, salt also may be mixed with water but what this question meaneth I know not. the 2nd & 3d are fixt, the Alkahest is volatile: the 4th is volatile <[metalline?]> which I suppose the Alkahest is not, & I Cannot beleeve that Glauber will reveall it to any one, though perhaps they may get some [left margin:] particulars from him, which may sufficiently Enrich a moderate spirit:" Page [15/5/18A] of the *Hartlib Papers.*

saltpetre met with Parliamentary approval, was the focus of the Invisible College. His project, *De Nitro Theses quaedam*, a brief tract containing a synopsis of current chemical theory about saltpetre, and miscellaneous experimental evidence was based on Paracelsian chemistry.[96] The Kincardine Papers of Sir Robert Moray, an early Royal Society figure, also illustrated that he consulted Glauber's medical works extensively.[97] Glauber's work was also translated and published in England throughout the seventeenth century; it thus seems Glauber's ideas on salts are important to consider in our analysis of the context of English salt chymistry.

Glauber, born in Karlstadt, Bavaria, was one of the first industrial chymists and best known for the stomach remedy—Glauber's salt—sodium sulphate. He was self-taught, and in the upheaval of the Thirty Year's War, traveled to Vienna when he was 21 years old.[98] As Colin Russell related, Glauber became ill with a stomach bug known as 'the Hungarian disease.' As he was unable to keep down solid food, he was "recommended to try drinking water from a spring near Neustadt. Improvising a cup by hollowing out part of a loaf he imbibed some of the fluid and was cured with astonishing rapidity."[99] Curious to know the cause of his recovery, he evaporated the water and obtained long thin crystals that seemed similar to nitre. Glauber however subsequently showed that the salt in question was not nitre. Glauber wrote, "for it could not be the water of Saltpetre seeing that in no wise conduceth to the stomach, but rather occasioneth nauseousness and loathing."[100] Rather, Glauber concluded it "the same compound as that obtained when vitriol (sulphuric acid) acted on common salt" or sodium sulphate.[101] Since sodium sulphate has laxative qualities, it well could have effected his cure. The sodium sulphate was termed by Glauber as *sal mirabile* or miraculous salt. Though Ahonen makes the claim

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[96] Charles Webster, *The Great Instauration: Science, Medicine, and Reform, 1626–1660* (New York: Holmes & Meier Publishers, 1976).

[97] David Stevenson, *The Kincardine Papers of Sir Robert Moray*, forthcoming, 2007, Ashgate-Variorum press.

[98] For biographical information on Glauber, see K. Ahonen, *Dictionary of Scientific Biography*, article on 'Glauber.' J.R. Partington, *A History of Chemistry*, vol. ii, (New York: Macmillan, 1961).

[99] Colin Russell, "Furnaces for Philosophers," in "Chemistry World," September 2004, the Royal Society of Chemistry website. http://www.rsc.org/chemistryworld/restricted/2004/September/philosophers.asp. Accessed 15 October 2006.

[100] *The Works of Glauber*, part one, p. 260.

[101] Russell, "Furnaces for Philosophers."

that Glauber held "two different theories of the vital salt that are difficult to reconcile: one emphasizing . . . nitrous salt and the other the role . . . of *sal mirabile*," it seems the reason that the theories could not be reconciled was because Glauber postulated two different roles for nitre and *sal mirabile*.[102]

Nitre, rather than serving as a philosophical salt as in Duchesne, instead was Glauber's alkahest, or a universal dissolvent capable of producing medicines of great power. As Porto has demonstrated, the alkahest began as an "obscure invention of Paracelsus," and became widely known in the early modern era as one of physician Johann van Helmont's most important secrets.[103] Glauber thought the alkahest was nitre or potassium nitrate because its products could be both very acidic and very basic, both of which were corrosive.[104] For instance, nitre could be distilled with fuller's earth or vitriol to make nitric acid (spirit of nitre or volatile nitre), a strong acid or, it could be "fixed" by burning it with charcoal, producing potassium carbonate, a very powerful base. Because products from nitre could be very acidic, or very basic, Glauber first published in 1633 that it was a universal solvent. Porto claims correctly that Glauber believed the alkahest stemmed from but a family of substances that included "nitre itself, nitric acid (produced by the distillation of saltpeter), and potassium carbonate (produced by adding charcoal to fused nitre)."[105] In Glauber's *Apology against Farner*, published in 1652, which was largely a diatribe against his former research partner whom he accused of stealing his chymical secrets, he gives fairly detailed instructions for preparing his nitrous alkahest. Glauber first argues that

> what moved Helmont to call it Alkahest, we shall not here dispute: In indeed believe he did it, thereby to demonstrate its Nature and Essence; in the Brabantick Idiom, which was the Mother Tongue of the Authors it sounds Althohees, that is very hot; and so the name answers to the

[102] Ahonen, "Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry," p. 95.

[103] Paolo A. Porto, "*Summus atque felicissimus salium*: The Medical Relevance of the Liquor Alkahest," *Bulletin of the History of Medicine* 76, 1 (2002), pp. 1–29, on p. 1.

[104] Ahonen, 'Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry', p. 107, n. 59, as cited in Newman and Principe, *Alchemy Tried in the Fire*, p. 242.

[105] Porto, "*Summus atque felicssimus salium*," p. 22. Boerhaave was also of the opinion that Glauber's alkahest consisted of potassium carbonate. See Herman Boerhaave, *Elementa chemiae* (Leyden, 1732), vol. I, pp. 848–868.

> Essence, for this Liquor is nothing but a meer fiery Water, by whose immense and secret heat Vegetables, Animals, and Minerals, if they are put in to fire a certain time, are forthwith purged, preened and made better. This Menstruum then, is nothing but igneous Liquor, prepared of urinous Salts.[106]

This alkahest was from related nitrous salts for

> Nature is copious, and sets before our eyes many various Ingredients, from which, by the help of Arts, divers things may be effected . . . for the genuine Sal terra, or Salt-Petre, may be made of Salt of Tartar; and of Sal terra, or Nitre, a fixed Salt, like Salt of Tartar; of spirit of Wine, Salt of Tartar, and of Salt of Tartar spirit of Wine; of Wine-Vinegar, Nitre, and of Nitre, corrosive Vinegar. So those Salts partake of either nature and will be managed at pleasure.[107]

Just as Tymme in the *Practice* utilized the heating of wine and its vinegar to show that a triad of fixed, sulphureous, and mercurious salts all stemmed from one material salt which was responsible for bodily substance, colors and tastes, Glauber argued that calcining wine produced a variety of interchangeable saline products that were all alkahests capable of refining matter. For instance, salt of tartar, often found as a crustlike deposit on wine casks, was a traditional raw material for the preparation of potassium carbonate after calcination.[108]

It was no accident that Glauber's alkahest came from products of wine. Some of this state of affairs may have been due to the influence of Van Helmont. In Van Helmont's *Arcana Paracelsi*, he claimed "*Eminentior est ejus liquor Alkahest immortalis, immutabilis aqua solvens, et sal circulatus ejus, qui reducit omne corpus tangibile, in liquorem sui concreti*."[109] In other words, there was a liquor alkahest and its sal circulatus; the *sal circulatus* as Darnstaedter illustrated was an alcoholic solution.[110]

The spirit of wine (ethanol) was also the prime solvent for preparing Glauber's *aurum potabile*, a drinkable tincture of gold. Previous attempts

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[106] *Works of Glauber*, Part one, p. 152.

[107] *Works of Glauber*, Part one, p. 153.

[108] Ladislao Reti, "Van Helmont, Boyle and the Alkahest," *Some Aspects of Seventeenth-Century Medicine and Science: Papers Read at a Clark Library Seminar October 12, 1968* (Los Angeles: University of California, 1969), p. 10.

[109] J.B. van Helmont, "Arcana Paracelsi," *Ortus medicinae* (Lyons: Ant. Huguetan, 1667), p. 481.

[110] Ernst Darmstaedter, "Liber claritatis totis alkimicae Artis-Bologna, Cod. Lat. 164 (153)," *Archeion*, VI (1925), pp. 319–330, as quoted in Reti, "Van, Helmont, Boyle, and the Alkahest," p. 10.

at creating this tincture, such as those by Francis Anthony (1550–1623), a scholar of chymistry from Cambridge University, had been largely unsuccessful. Anthony's *aurum potabile* was a potent emetic and cathartic that was as likely to cure his patients as kill them.[111] Anthony, like Glauber, wished to find a means to dissolve an insoluble substance like gold and make its healing properties digestable.[112] Hence Glauber used his alkahest to achieve that aim. Glauber believed that this "tincture, which they have radically joyned with the spirit of Wine," was a "heating and living spirit, communicating its strength and faculties to man's body."[113] The *aurum potabile* contained the vivifying power of the sun; taking the spirit of wine chymically combined with gold would cure the body by engendering in a chymically concentrated increase of the "humidum radicale" or vital spirits that one would attain in lesser concentrations by basking in the sun.[114] The potency of the *aurum potabile* also demonstrated the "greatest harmony of all things, betwixt the Sun, Gold, man and wine."[115] Behind this harmony were the nitrous salts of the alkahest—the aerial nitre Glauber postulated was in sunbeams made vines grow to produce wine, engendered the growth of minerals like gold in the bowels of the earth, and nitre was also in human urine, furthering the macrocosm, microcosm analogy. As Glauber stated,

> there is nothing can be brought forth in the nature of things, without the medium of salt; yea man himself is not born without the Sun, Man, and Salt. . . . The sun and salt are the Parents of all things, which procreate all things and without nothing is procreated. . . . Salt being added to Wine in its fermentation, rendereth it stronger and sweeter.[116]

Because the alkahest of nitre broke down matter to its most basic level, and because salts were thought responsible for color, Glauber produced a comprehensive list of how nitre could be used to create artist's paints and differently hued glazes. Copper or lead dissolved in nitric acid

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[111] Hereward Tilton, *The Quest for the Phoenix: Spiritual Alchemy and Rosicrucianism in the Work of Count Michael Maier (1569–1622)* (Berlin and New York: Walter de Gruyter, 2003), p. 103.

[112] Tilton, *The Quest for the Phoenix*, p. 103.

[113] "Of the Tincture of Gold, or the *Aurum Potabile*," *Works of Glauber*, Part one, p. 97.

[114] *Works of Glauber*, Part one, p. 191.

[115] *Works of Glauber*, Part one, p. 96.

[116] *Works of Glauber*, Part one, p. 256. It is also possible that wine, important in Eucharistic ceremonies as it was believed by Catholics to be capable of transmutation, carried mystical significance for Glauber. Ahonen has discussed the Christological symbolism of Glauber's chymistry extensively in her dissertation. See her chapter "The Redemption of Nature," pp. 152–186.

produced a green color.[117] Salt peter could also whiten yellow wax, and could color glass. Glauber also knew that nitric acid would stain nails, feathers, or quills gold, and it could be utilized as a purple glaze in pottery. The acid's affinity with precious metals also meant that when it was mixed and heated with gold, silver, or copper along with some antimony, a "vitrified" pottery glaze could be made that would "far exceed in beauty or splendour those vessels which are gilt with those Metals."[118]

Some contemporaries of Glauber, such as Sir Robert Moray, a founder of the Royal Society, had great regard for Glauber's alkahest, as well as his other medicaments, such as Glauber's *panacea antimonialis*. This was probably antimony pentasulphide as described in Glauber's *Miraculum Mundi*, though Moray stated that "I guess by the color (red) it is rather some preparation of vitriol."[119] In a letter to his friend and protégé Alexander Bruce, Moray wrote, "Put your doctor to a further enquiry about that powder of Glauberus, I beseech you, for if he hold all he heights there is not two remedies in the world preferable to it."[120] He warned Bruce however to get the powder of Glauber's "own making," as if it was not, the medicinal results would likely "blast" Glauber's "reputation when everybody that meddles in his trade thinks him one of the noblest chimists now living."[121]

Moray put his finger on a problem that Glauber had among his fellow natural philosophers. Glauber's work was not always considered clearly expressed by his contemporaries. Not only was Glauber fairly vague about the exact nature of his alkahest in an attempt to shield its identity from all but alchemical adepti, but his use of chymical terms could be inconsistent. The Leiden physician Herman Boerhaave, who was thorough enough in his devotion to chymistry to read the works of Van Helmont seven times over, was quite convinced that Glauber's alkahest consisted only of potassium carbonate; members of the Hartlib

[117] *Works of Glauber*, Part one, p. 179.

[118] *Works of Glauber*, Part one, p. 181.

[119] 7/17 November 1657. Mastricht. From Moray to Alexander Bruce, (ff. 17–18) in Stevenson, *The Kincardine Papers of Sir Robert Moray.*

[120] 4/14 December 1657. Mastricht. A Monsieur, Monsieur Alexander Bruce, Gelorgeert in de Witte Swan tot Bremen. Franche par Münster (ff. 25–8) in Stevenson, *Kincardine Papers.*

[121] 8/18 January 1658. Mastricht. A Monsieur, Monsieur Alexander Bruce, in de Witte Swan tot Bremen (ff. 48–9), in Stevenson, *Kincardine Papers*.

circle were even more confused.[122] Robert Child, a gentleman dabbling in natural philosophy and minor luminary, wrote Samuel Hartlib on 2 February 1652,

> as for Glaubers works in Latine I thanke you, I vnderstand them as well in High dutch, for perhaps the translatour may more faile than I shall: . . . Concerning those 4 things about Alkahest, I suppose that neither do Come nigh the Alkahest for the first, I do not well vnderstand, what aqua pluuialis sub [putrefacta?] salificata meaneth, I know that water will putrefy & [altered] leaue Earthly feces at the botome, & grow sweet againe, as in Sea voyage, & that out of this Earth a salt may be drawne, & that ther is a kind of volatile salt euen in fresh water, salt also may be mixed with water but what this question meaneth I know not the 2nd & 3d are fixt, the Alkahest is volatile: the 4th is volatile <[metalline?]> which I suppose the Alkahest is not, & I Cannot beleeve that Glauber will reveall it to any one, though perhaps they may get some [left margin:] particulars from him, which may sufficiently Enrich a moderate spirit.[123]

Hartlib himself, after taking notes from Glauber's work on the alkahest in 1650, concluded that Glauber's wide span of chymical activity may have been behind some of the confusion or inconsistency in his works. Hartlib wrote,

> it is most certain that others finde more in Mr Glaubers Book's, which are already published then hee knoweth himself or is able to performe <put in practise>. For one man cannot trie or experiment all things <particulars> and besides this Glauber [altered] is naturally somwhat inconstant that cannot dwell long vpon any thing, but being so fanciful or rich in apprehensions <Inventions> and aiming alwaies at a Plus Vltra, hee bend's all his studies and endeauors to reach this end. This j confesse is may bee prejudicial to himself but the Publick fares the better for it.[124]

Unfortunately for Glauber, his problems with nitre as an alkahest extended beyond audience misunderstanding. Glauber recombined his volatile nitric acid and his fixed potassium carbonate and recognized he produced simple nitre reconstituted, so he found that nitre was obviously not a universal dissolvent.[125] (This was also a result that Robert Boyle published in his *Essay on Nitre* (1661)). Glauber's failures to find

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[122] Herman Boerhaave, *Elementa chemiae* (Leyden: Isaac Severinus, 1732), I, 848–868, as quoted in Reti, "Van Helmont, Boyle, and the Alkahest," p. 11.

[123] The Hartlib Papers, Robert Child to Samuel Hartlib, 2 February 1652, Ref: 15/1/18A.

[124] The Hartlib Papers, 2 extracts & notes on Glauber's Alkahest, in Hartlib's hand, 30 December 1650, Ref: 31/8/6B.

[125] Newman and Principe, *Alchemy Tried in the Fire*, p. 242.

an alkahest by 1660 led Hartlib to write in a letter to John Winthrop "our german adepti with whom I shall be better acquainted ere long, count no better of Glauber then a mountebank, one that continues to cheat all sorts of people by his specious artifices and one that knows nothing in the true Philos. work Alkahest Elixir.[126] J.T. Young has also commented on how Glauber's reputation declined severely in England at the time of the Restoration.[127]

Glauber's failure with nitre led him to turn his attention to his *sal mirabile*, which was of a fundamentally different nature than his alkahest. His philosophical salt was not a mere dissolvent, but was behind the creation of matter, such as minerals and metals. As revealed in his *Treatise of the Nature of Salts*, Glauber's philosophical salt was sodium sulphate, ($Na_2SO_4 \cdot 10H_2O$; this decahydrate became known as Glauber's salt), a combination of common salt and spirit of vitriol (sulphuric acid). In this reaction, hydrochloric acid is also produced from sodium chloride and sulphuric acid in which case the Na_2SO_4 is known as salt cake:

$$2\ NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2\ HCl$$

Sodium sulphate may have been Glauber's choice for his *sal mirabile* because one of its reactants—vitriol—had the advantage of being "conveniently assimilable" to some of the principles of to the Paracelsian *tria prima* of salt, sulphur, mercury.[128] Vitriol was a salt in the form of iron II sulphate produced when pyrites were exposed to moist air, and the vitriolic liquid or sulphureous spirit of vitriol (sulphuric acid) called 'gur' or 'bur' was believed by Glauber and other early modern mining authors such as Agricola to be a sign of the presence of metals as well as the petrifaction of wood.[129] Glauber in his *Philosophical Furnaces* wrote extensively of the production of sulphuric acid from the mixture of pyrites—iron or copper sulphates, with water, and called vitriol a "metallical seed."[130] He also commented that "no sulphur is destitute of vitriol, nor vitriol of sulphur . . . and every sulphur is by its

[126] The Hartlib Papers, Hartlib to John Winthrop the younger, 16 March 1660, Ref: 7/7/3B.

[127] J.T. Young, *Faith, Medical Alchemy, and Philosophy: Johann Moriaen, Reformed Intelligencer, and the Hartlib Circle* (Aldershot: Ashgate Variorum, 1998).

[128] Norma Emerton, *The Scientific Reinterpretation of Form* (Ithaca: Cornell University Press, 1984), p. 217.

[129] Emerton, *Scientific Reinterpretation*, p. 217.

[130] Johann Glauber, *A Description of New Philosophical Furnaces* (London: Richard Coats, 1651), p. 73.

own proper agent or vitriolated salt, which it hath in its possession by nature. . . . excocted or boiled up more and more into a metal . . ."[131] Indeed, vitriol itself was "sometimes identified" by seventeenth-century natural philosophers analyzing spa waters with a "universal salt which could take on different forms according to the metals and minerals with which it came into contact."[132] Glauber indeed wrote that his *sal mirabile*, "addeth an encrease to . . . all things, especially of the metals, which it renders manifest . . ."[133] He also indicated,

> before I enter upon the description of the Virtues lying hid in my *Sal Mirabile*, I thing [sic] it necessary to indicate, That Salts of this sort do every where occur in the Earth, and begin dissolved by Water, are carried to the superficies, and such Fountains are enumberated by Georgius Agricola, shewing in what places they may be found, and that all things put into them are in a short time converted into a stony matter; which many other Writers also testified, and especially Celsus in his Book *De Rebus metallicis*.[134]

The *sal mirabile* activated by the "soul, spirit, and life from the Starrs, as from an universal seed, and the body from the Water as a universal mother" generated metals, where "they become partakers of a certain saltish Nature."[135] The *sal mirabile* was found not only in the earth and in fountains, but had a sulphurous nature communicated it to it by burning stars which was crucial to metalline development. This "sulphureous salt . . . holds stubbornly" to the metal "until full maturation has been achieved, at which time it separates from the metal as no longer needed."[136] Typical to most mining authors such as Agricola, Glauber believed that minerals and metals were found at various stages of maturity—immature minerals were bismuth or arsenic, those of middling maturity, the base metals like lead, and finally when a metal was fully

[131] Ahonen, "Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry," p. 138.

[132] N.G. Coley, "Cures without Care: 'Chymical Physicians' and Mineral Water in Seventeenth-Century England," *Medical History* 23 (1979), pp. 191–214, on p. 197.

[133] *Works of Glauber*, Part one, p. 264.

[134] *Works of Glauber*, Part one, p. 259.

[135] *Works of Glauber*, Part one, p. 124.

[136] Ahonen, "Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry," p. 105. Van Helmont also noted that vitriol was merely a hungry hermaphroditical and sulphureous salt which had eaten into a metal like brass, until it matured. See Glauber, *A Third Paradox*, p. 695.

mature, it would become gold.[137] The *sal mirabile* was thus most prevalent in immature metals, and not present in the fully mature gold.[138] But the generation of hard metals from the delicate *sal mirabile* was a ticklish business. If not brought to maturity, and exposed to air too soon by impatient miners, "their life consisting in a Volatile Salt, is elevated and drawn back by the stars."[139] If exposed too soon to water, Glauber also claimed the tender salts of the embryonic metals would dissolve. And, when metals were removed prematurely from the earth,

> from which they have no more nutriment, their sulphureous covering being laid aside, the defense and safeguard of their Nature being banished, they rightly resemble a decrepit Old Man, whose Radical moisture is dried up and are dissolved and eaten up by the same Astral Salt, or Vehement Corruscation, from which they did spring.[140]

When exposed to air, metallic sulfides, like copper and iron pyrites (fools' gold or iron sulfides—(FeS_2), obtain a green sulphureous or vitriolic tarnish (iron II sulphate), which may have led to Glauber's idea that the "sulphureous coat" was protecting growing metals.

Glauber then discussed the medicinal virtues of his *sal mirabile*. He claimed that when *sal mirabile* was heated with gold producing a green salt and a phlegm, and the green salt was extracted with Spirit of Wine (ethanol), he obtained his "green lyon," or his "vitriol of Sol [gold]."[141] As a product of the philosophical "salt, gold, and wine," the medicine's green liquor renewed the body, as the "greenness of the Trees half dead . . . in the Spring time," caused the "blood in the body to be renewed and revived."[142] It is not entirely clear what the chymical composition was of this "vitriol of Sol." Glauber also vehemently denied

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[137] See Ahonen, "Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry," p. 135, as well as Carolyn Merchant, *The Death of Nature: Women, Ecology and the Scientific Revolution* (San Francisco: Harper San Francisco, 1990), pp. 25–41 for a discussion of the maturation of metals. In other places Glauber claimed that an acid spirit within the sulphureous *sal mirabile* protected the "tender salt" of the embryonic metal from destruction, allowing it to mature to its final form. He wrote, "That mineral acid which is plentifully found in vitriol and sulphur is the only Agent whereby Nature Maturates the yet volatile and unripe Minerals in the earth," and in another tract that the ripening agent in the earth was the sulphureous salt of vitriol.

[138] Ahonen, "Johann Rudolph Glauber: A Study of Animism in Seventeenth-Century Chemistry," p. 105.

[139] *Works of Glauber*, Part one, p. 124.

[140] *Works of Glauber*, Part one, p. 124.

[141] *Works of Glauber*, Part one, p. 265.

[142] *Works of Glauber*, Part one, p. 266.

its green color was the result of any copper compounds; he also claimed he was not merely dissolving gold in *aqua regia* (nitric and hydrochloric acid) to get his green lyon, claiming such a mixture would be gold in color (it is actually yellowish-green and a method still utilized by jewelers to purify gold).[143] It is possible that Glauber may have utilized a mixture of real and fool's gold, as the salt of green vitriol, produced by the exposure of pyrites to moist air, dissolved in ethanol would make a green solution. His description of the oil of vitriol produced from pyrites in his *Philosophical Furnaces* is also remarkably similar to that of the vitriol of sol; both solutions resulted from dissolving green salts in water or alcohol, were bright green in color, and produced similar medical cures.[144] Further he indicates in the *Philosophical Furnaces* that both the "gold Marcasites" of pyrites as well as "gold ore" can produce the oil of vitriol, which he calls as a medicine the "gold of physicians," suggesting he saw marcasites and gold as functionally equivalent in the production of medicines.[145]

Glauber's vitriol of sol also defended humanity from putrefaction and corruption, as it was made from the "most noble part of Salt," and the purest metal of Gold; though Glauber does not specifically claim it was the philosopher's stone, he may have had in his mind this association. Some chymists postulated vitriol itself was the philosopher's stone; common until the eighteenth century was the "vitriol acrostic": *Visita Interiora Terrae Rectificando Invenies Occultum Lapidem* (visit the interior of the earth; by rectifying you will find the hidden stone.)[146] Glauber himself mentions this acrostic in his *Philosophical Furnaces* and stated the ancients by this verse "would give us to understand that a true medicine is to be found in it."[147]

Glauber also emphasized water as an important medium of transport for the *sal mirabile*. He asked,

[143] *Works of Glauber*, Part one, p. 267.

[144] Glauber, *A Description of New Philosophical Furnaces*, pp. 70–73. In the *Furnaces*, he describes this oil of vitriol as a "sweet oil" of vitriol, usually known as ether, made from distilling ethanol and sulphuric acid. However, the process in which he describes making his oil of vitriol does not involve ethanol, but the exposure of pyrites to moist air, and the collection of the green crystals. The green salts were mixed with water, and evaporated several times until a "sweet oil or juyce" resulted.

[145] Glauber, *A Description of New Philosophical Furnaces*, p. 70.

[146] See Emerton, *Scientific Reinterpretation*, p. 210, footnote 2.

[147] Glauber, *A Description of New Philosophical Furnaces*, p. 73.

> wherefore did the ancient Philosopher and Poets worship Venus, the Goddess of . . . Generation, and attribute to her a beautiful green, generated of the spume or foam of the sea. What is the foam or froth which the sea casteth out upon the shore, but salt, which being dried up by the heat of the sun, is reduced to salt. . . . The Ocean, the Mother of all fertility, sheweth also its Greeness, especially in those places where it is rich in salt . . . without the sea noting would encrease in the Earth, but on the contrary, all things live, and are encreased by it.[148]

Observing the seeming generation of metals and minerals in subterranean mines fed by springs, Glauber claimed that this also showed that water was the "principium or beginning of all the elements; which thing is sufficiently manifest, and may be seen daily," and that water was "as the universal Mother" of matter. Though Glauber does not mention Van Helmont as a factor in these conclusions, it is possible Glauber's speculations may have been partially fueled by Helmont's belief that water consisted of corpuscles made up of the *tria prima* and thus was the source of transformations of matter.[149] Van Helmont himself identified his universal salt, termed the "hungry hermaphroditical salt" as a sulphureous acidic salt present in fountains, and described how when it was reacted with metals like brass, it created vitriol.[150] As Pagel has noted, Van Helmont believed that

> salty sea water percolating into the earth, loses its salt . . . the water then assumes at appropriate places the semina of indigenous salt, mineral or metal. Thus, out of water grow saltpeter, alum, vitriol and sea-salt. These form a primitive mineral juice, the bur, which is the germ-cell of individual metals and minerals. The latter grow to maturity when there is not further influx of water.[151]

Whether it was due to his belief that metals grew in mines fed by water, or to Van Helmont's ideas, *sal mirabile*'s watry medium of transport rather than air (as nitre was transmitted) may have made it an attractive choice for Glauber when deciding upon the identity of his philosophical salt.

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148 *Works of Glauber*, Part one, p. 266.

149 William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago and London: University of Chicago Press, 2002), p. 64. *Works of Glauber*, Part one, p. 282.

150 Johann Van Helmont, *Van Helmont's Works, Made English by J.C.* (London: Lodowick Lloyd, 1664), p. 695.

151 Walter Pagel, *Joan Baptista Van Helmont: Reformer of Science and Medicine* (Cambridge: Cambridge University Press, 1982), pp. 57–58.

Glauber thus seems a transitional figure in saline chymistry. While he acknowledges the important of nitre as expressed in earlier authors like Duchesne and Paracelsus, he postulates its power was expressed for new purposes—namely the Helmontian alkahest. Whereas Duchesne acknowledges the role of salts in color and taste, it is via its ability as an alkahest that nitre is able to manifest these physical changes in Glauber's works. Glauber's use of a sulphuric compound as his universal salt brings together influences from mining authors like Agricola and the 'gur' or 'bur,' as well as the new emphasis on water in the work of Van Helmont, who as we will see in the next chapter, also had great influence in forming conceptions of salts among English chymists in the early Royal Society.

CHAPTER THREE

VAN HELMONT, SALTS, AND NATURAL HISTORY IN EARLY MODERN ENGLAND

We have seen in the last chapter that the influence of Paracelsian ideas in salt chymistry in English works was profound in the first half of the seventeenth century, as the *tria prima* of Paracelsus gave salt a central role in matter theory. However, we have also demonstrated that Johann Glauber, whose work was known to members of the Hartlib circle, was influenced by the work of Van Helmont, most specifically in his concept of the alkahest and in water as a method of transport for his *sal mirabile*. Certainly, the realization that Van Helmont was crucial to the development of early modern chymistry in the latter half of the seventeenth century, particularly in the work of Robert Boyle, has been cogently demonstrated by Principe and Newman.[1] In the case of saline chymistry in the early Royal Society however, it would be a mistake to limit ourselves to a story of Van Helmont as interpreted by Boyle; nor were all of Van Helmont's ideas utilized for purely chymical or iatrochymical studies. Royal Society figures such as Martin Lister, Robert Moray, and Nehemiah Grew interpreted Van Helmont's chymical work quite independently of Boyle for the purposes of their own work in natural history, a topic to which this chapter will be devoted after a brief contextual analysis of the role of salts in Helmontian chymistry.

Van Helmont's theories of the elements and of salt differed greatly from those of Paracelsus. First, Van Helmont believed that water and air were the only true elements. In his *Paradoxes*, Van Helmont explained his theory of the interrelationship of elements and principles. "there are Originally two onely Elements in the Universe, to wit, the Air, and the Water; which are sufficiently insinuated from the sacred Text, by the Spirit swimming upon the Abysse or greet Deep or Waters, in the first

[1] William R. Newman, *Gehennical Fire: The Lives of George Starkey, an American Alchemist in the Scientific Revolution*. (Cambridge: Harvard University Press, 1994); Lawrence Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest.* (Princeton: Princeton University Press, 1998).

beginnings of the world."[2] "Water was the matrix of all other matter through the power of specific seeds implanted in it by God."[3] Earth and Fire "if they are called Elements . . . are secondary ones proceeding from the former."[4] Because fire was merely a secondary element, Van Helmont disagreed with the efficacy of fire analysis. Like Erastus, he believed that heat created new compounds rather than revealing the building blocks of a substance; "salt, sulphur and mercury were thus not true principles, but were produced by the heat of analysis."[5]

For Van Helmont, salts in particular were "offspring of the waters," and if exposed to the Sun, "are made aiery and vapoury Effluxes, rushing into water with a hastened Violence."[6] In other words, some salts could be powerfully volatile. Volatile salts referred to salts that gave off an aeriform component (such as an odor), but also to salts that decomposed easily on heating. Boyle's definition of volatile was even more specific; he believed the corpuscular bits of volatile matter had to be "very small" so they are more "easily put into motion by the action of the Fire and other agents."[7] The specific volatile salts that van Helmont, and subsequently Boyle had in mind were most likely ammonium carbonate, and ammonium chloride known as sal ammoniac or a volatile alkali.[8] Fixed salts referred to salts with a degree of solidity of a substance as measured by the ability of that substance to resist the action of fire, those which were nonvolatile; an example is potassium carbonate which is noncombustible. Not surprisingly, Boyle classified fixed substances as being composed of large or "gross" particles which would be "too unwieldy and unapt to be carried up into the Air by

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[2] J.B. Van Helmont, "Another paradox," in *Van Helmont's Works, Made English by J.C.* (London: Lodowick Lloyd, 1664), p. 691.

[3] Allen Debus, "Thomas Sherley's Philosophical Essay (1672): Helmontian Mechanism as the Basis of a New Philosophy," *Ambix* 27, 2 (1980), pp. 124–135, on p. 124.

[4] Van Helmont, "Another paradox," p. 691.

[5] Debus, "Thomas Sherley," p. 125.

[6] Van Helmont, "Another paradox", p. 692.

[7] Robert Boyle, *Experiments and Notes, About The Mechanical Origin and Production of Volatility* (Oxford: E. Flesher, 1675), p. 5.

[8] Jon Ecklund, *The Incompleat Chymist: Being an Essay on the Eighteenth-Century Chemist in His Laboratory, with a Dictionary of Obsolete Chemical Terms of the Period*, Smithsonian Studies in History and Technology, Number 33 (Washington D.C.: Smithsonian Institute Press, 1975), online http://dbhs.wvusd.k12.ca.us/Chem-History/Obsolete-Chem-Terms TOC.html. Accessed 20 September 2006. For a discussion of obsolete chemical nomenclature, see Maurice P. Crosland, *Historical Studies in the Language of Chymistry* (London: Heinemann; Cambridge: Harvard University Press, 1962.) Boyle also specifically cited the corpuscles of sal armoniac as volatile in the *Experiments and Notes . . . of Volatility*, p. 4.

the action of the Fire . . . or to be buoyed up by the weight of the Air [atmospheric pressure.]"[9]

Van Helmont postulated a role for volatile salts in the atmosphere and in respiratory physiology that drew upon older conceptions of salts as vital, as well as Paracelsian concepts of the aerial nitre, but which had entirely new implications for iatrochymistry and medicine. In his analysis of the chymistry of the blood, he claimed that venous blood, having given nourishment to the organs of the body, was made volatile and converted into gas which was breathed out.[10] This conversion of the venous blood into breath was thus done chemically, and concerned with the production of fixed and volatile salts. The historian Walter Pagel further explains van Helmont's theories of blood chymistry:

> Fixed salt is alkali; its particles are stable and form a deposit when a substance containing it is liquefied by heat. In settling down, it "snatches" particles of less subtle nature—so called sulphurous particles—which are incorporated in the deposit. The fixed salt being unable to fix all the sulphur particles, the rest, which have escaped being snatched, follow their natural tendency to become volatile and in their turn force some of the salt to evaporate with them. Thus, volatile salt is generated. When heated in an open vessel all salt contained in the substance evaporates. This is what happens to the . . . [venous] blood in the . . . lung, that is where it is in contact with the air. All its salt has become volatile whereby it is disposable by the breath.[11]

Clericuzio has in turn shown that "English Helmontians based their physiological theories on the notion of vital spirits, which they conceived as a volatile alkaline salt."[12] Physicians such as Francis Glisson (1597–1677), Walter Charleton (1619–1707), and Thomas Willis (1621–1675) all believed this spirit was particulate, having "specific chemical properties;" Willis for instance saw a "volatile salt, produced by the action of a local ferment situated in the brain, as the actual matter of animal spirits."[13] Frank has also demonstrated that William Harvey and

[9] Robert Boyle, *Experimental Notes of the Mechanical Origins or Production of Fixtness* (Oxford: E. Flesher, 1675), p. 4.

[10] Walter Pagel, *Joan Baptista van Helmont: Reformer of Science and Medicine* (Cambridge: Cambridge University Press, 1982), pp. 88–90.

[11] Pagel, *Joan Baptista van Helmont*, pp. 89–90.

[12] Antonio Clericuzio, "The Internal Laboratory: The Chemical Reinterpretation of Medical Spirits in England, 1650–1680," *Alchemy and Chemistry in the 16th and 17th Centuries*, ed. P. Rattansi and A. Clericuzio (Dordrecht: Kluwer, 1994), pp. 51–83, on p. 63.

[13] Clericuzio, "The Internal Laboratory," p. 68.

the Oxford physiologists, such as William Croone (1633–1684), had a chemical notion of muscular motion based on saline chymistry.[14]

Influenced by van Helmont's belief that the breath of man and animals contained volatile salts, Robert Boyle himself wrote in his *Suspicions about some Hidden Qualities of the Air* (1674) that the atmospheric air was likewise impregnated with such salts, and that volatile salts could draw water.[15] Daniel Coxe (1640–1790), a London physician and Royal Society Fellow, wrote several articles in the *Transactions* about atmospheric volatile salts which were inspired by Robert Boyle's ideas. Coxe claimed: ". . . the Air, which is as I could fully demonstrate, [is] impregnated with a Volatil Salt . . . partly expired from Animals during their life."[16] Just as van Helmont thought that heated blood discharged its volatile salts into the air, Coxe also believed that the release of volatile salt in the air was due to "Subterraneous . . . and Coelestial Fires" and that these Salts, "being received into the vast subtile fluid Expanse . . . become the Instrument of sundry remarkable effects and operations, not only in Natural, but also Artificial productions."[17]

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[14] R.G. Frank, Jr., *Harvey and the Oxford Physiologists: A Study of Scientific Ideas.* (Berkeley: University of California Press, 1980). For a reprint of Croone's work see also William Croone, ed Paul J.G. Maquet, *On the Reason of the Movement of the Muscles* (Philadelphia: American Philosophical Society, 2000). On Croone, see also: L.M. Payne, Leonard G. Wilson, and Harold Hartley, "William Croone, F.R.S.," *Notes and Records of the Royal Society of London*, 15, (1960), pp. 211–19. Leonard G. Wilson, "William Croone's Theory of Muscle Contraction," *Notes and Records of the Royal Society of London*, 16 (1961), pp. 158–78. Thomas Birch, *History of the Royal Society* (London: A. Millar, 1756–7), vol. 4, pp. 339–340. *Dictionary of National Biography* (repr., London: Oxford University Press, 1949–1950), vol. 5, pp. 207–8. William Munk, *The Roll of the Royal College of Physicians of London*, 2nd ed., 3 vols. (London, 1878), vol. 1, pp. 369–71. F.J. Cole, "Dr. William Croone on Generation," in M.F. Ashley Montague, ed. *Studies and Essays in the History of Science and Learning Offered in Homage to George Sarton* (New York: Schuman, 1947), pp. 113–35.

[15] Robert Boyle, *Suspicions about some Hidden Qualities of the Air with an Appendix touching Celestial Magnets* (London: W.G., 1674), pp. 59–60.

[16] Daniel Coxe, "A Continuation of Dr. Daniel Coxe's Discourse . . . touching the Identity of all Volatile Salts," *Philosophical Transactions of the Royal Society* 108 (November 23, 1674), pp. 169–82, on p. 172. Most of Coxe's experiments had to do with palingenics, or the "resurrection of plants, and the chemical method of achieving their astral appearance after destruction." Coxe took a plant, bruised it, burnt it, collected its ashes, and, in the process of calcination, extracted from it a volatile salt. He then made a compound with the salt, and submitted it to a gentle heat, and there gradually arose from the ashes, salt crystals which resembled a stem, leaves and flowers; or, in other words, an apparition of the plant which had been submitted to combustion. Information on palingenics for this note was taken from Lewis Spence, *Encyclopedia of Occultism* (New Hyde Park, NY: University Books, 1968), s.v. "palingenics."

[17] Coxe, "A Continuation of Dr. Daniel Coxe's Discourse," p. 172.

Many of these remarkable effects that salt produced in the atmosphere were relevant to fields of natural history, as well as meteorology, both predominant fields of study for the early Royal Society. Natural history was a disciplinal mainstay of the Baconian program of deductive empiricism from which the Royal Society claimed was its methodological basis. Michael Hunter, as well as scholars studying early museums, including the Royal Society's own collections and the Ashmolean, has illustrated the importance of natural history to the early modern scientific program.[18] Figures such Nehemiah Grew contributed work in botany, and Martin Lister wrote about spa waters and conchology. Robert Boyle and his protégé Daniel Coxe, described as "having the role of Boyle's *alter ego*" were also heavily involved in researching salt chymistry in the latter part of the seventeenth century, analyzing role of the salts in spa waters, as well as physiology, and iatrochymistry.[19] As evidenced by the *Royal Society Transactions*, weather keeping was also a pursuit that occupied many fellows such as Robert Moray (1608–1673) and Edmond Halley (1656–1742), and Jankovic has shown how meteorology was crucial to the society's Baconian research program.[20] Because Harold Cook has characterized chemistry as the "basic analytical tool" for seventeenth-century investigators of anatomy and natural history, it seems an understanding of his chemical theories and their intellectual context will shed further light on their natural history work.[21] In all of these pursuits, salt chymistry played a significant role.

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[18] Peter Dear, "*Totius en Verba*: Rhetoric and Authority in the Early Royal Society," *Isis* 76, 2 (June 1985), pp. 144–61; Michael Hunter, *Science and Society in Restoration England* (Cambridge: Cambridge University Press, 1981); Arthur Macgregor, *The Ashmolean Museum: A History of the Museum and its collection* (Oxford: Ashmolean Museum, 2001); Marjorie Swann, *Curiosities and Texts: The Culture of Collecting in Early Modern England* (Philadelphia: University of Pennsylvania Press, 2001).

[19] Antonio Clericuzio, *Elements, Principles, and Corpuscles: A Study of Atomism and Chymistry in the Seventeenth Century* (Dordrecht and Boston: Kluwer Academic Publishers, 2001), p. 161. For Boyle's works, see Robert Boyle. *Works of Robert Boyle.* ed. M. Hunter and E.B. Davis, 14 vols. (London: Pickering and Chatto, 1999–2000). Correspondence between Boyle and Coxe on saline chymistry can be found in Robert Boyle, *The Correspondence of Robert Boyle*, eds. M. Hunter, A. Clericuzio, and L.M. Principe (London: Pickering and Chatto, 2001), 6 vols., especially Coxe's letter to Boyle in vol. 3, 19 January 1666, pp. 30–43 concerning vegetable salts.

[20] Vladimir Jankovic, *Reading the Skies: A Cultural History of English Weather, 1650–1820*. (Chicago, University of Chicago Press; Co-published with Manchester University Press, 2001).

[21] Harold Cook, "Natural History and Seventeenth-Century Dutch and English Medicine," in *The Task of Healing: Medicine, Religion and Gender in England and the Netherlands,*

Salt Chymistry, Meteorology, and Tidal Motion

Before the publication of the *Principia*, one of the most important puzzles in meteorology for the natural philosophers of the early Royal Society was the cause of the tides. In seventeenth-century England, the causes of planetary beams were considered "occult," an Aristotelian and early modern term utilized when distinguishing "qualities which were evident to the senses from those which were hidden."[22] After the Restoration, natural philosophers attempted to "rid the world of occult causes and to explain invisible forces like solar and lunar emanations" via the mechanical philosophy, matter-theory, and chemical systems.[23] This examination of occult causes extended to the tides, or the effects of the sunshine and moonbeams upon the seas.

Scholarly analysis of seventeenth-century tidal theories has primarily focused on Galilean, Cartesian, and Keplerian ideas, or upon the origins of Wallis' and Newton's gravitational models.[24] Tidal theory in

1450–1800, ed. Hilary Marland and Margaret Pelling (Rotterdam: Erasmus Publishing, 1996), pp. 253–270, on p. 261.

[22] Keith Hutchinson, "What Happened to Occult Qualities in the Scientific Revolution?," *Isis*, 73 (1982), pp. 231–53, on p. 234.

[23] Anna Marie Roos, "Luminaries in Medicine: Richard Mead, James Gibbs, and Solar and Lunar Effects on the Human Body in Early Modern England," *Bulletin of the History of Medicine*, 74 (2000), pp. 433–57, on p. 433. For an article that analyzes English solar and lunar medicine in the nineteenth century, see Mark Harrison, "From medical astrology to medical astronomy: sol-lunar and planetary theories of disease in British medicine, c. 1700–1850" *British Journal for the History of Science*, 73 (2000), pp. 25–48. My thanks to Professor Harrison for discussing his article with me.

[24] David E. Cartwright, *Tides: A Scientific History* (Cambridge: Cambridge University Press, 1999); Federico Bonelli and Lucio Russo, "The Origin of Modern Astronomical Theories of Tides: Chrisogono, *De Dominis* and their Sources," *British Journal for the History of Science* 29, 4 (1996), pp. 385–401. For an older work that is an excellent survey of the history of the tides from the ancient world to Newton, see Rollin Harris, "Tidal Work and Knowledge Before the Time of Newton," in *Manual of Tides*, Part 1, Treasury Department, U.S. Coast and Geodesic Survey (Washington D.C., Government Printing Office, 1898), pp. 386–409. There is also a virtual academic industry on Galileo and the tides. See Eric J. Aiton, "Galileo's Theory of the Tides," *Annals of Science* 10 (1954), pp. 44–57; Eric J. Aiton, "On Galileo and the Earth-Moon System," *Isis* 54 (1963), pp. 265–66; Eric J. Aiton, "Galileo and the Theory of the Tides," *Isis* 56 (1965), pp. 56–61; Harold L. Burstyn, "Galileo's Attempt to Prove that the Earth Moves," *Isis* 53 (1962), pp. 161–85; Harold L. Burstyn, "Galileo and the Earth-Moon System," *Isis* 54 (1963), pp. 400–401; Harold L. Burstyn, "Galileo and the Theory of the Tides," *Isis* 56 (1965), pp. 61–63; Stillman Drake, *Galileo Studies: Personality, Tradition, and Revolution* (Ann Arbor: University of Michigan Press, 1970), pp. 200–213; Stillman Drake, "History of Science and the Tide Theories," *Physis* 21 (1979), pp. 61–69; Stillman Drake, *Telescopes, Tides, and Tactics* (Chicago: University of Chicago Press, 1983),

early modern England thus was in a pre-paradigmatic state, evincing a multiplicity of conflicting arguments.[25] Even after the publication of Newton's *Principia* (1687), in 1692 the periodical *The Gentleman's Journal* listed ten different explanations of the tides, and complained that competing ideas caused "the learned . . . [to be] much puzzled about . . . the Flux and Reflux of the Sea."[26] Part of the reason for this state of affairs may have been because the lunar influence on the tides was a phenomenon "odd enough to count as magical and bearing properties that eluded the matter-theory that prevailed in Europe from Aristotle to Descartes."[27] Matter theory for instance did not explain why all bodies of water do not exhibit tidal behavior. Despite the multiplicity of explanations about the occult causes of the tides that existed, no scholarly research has been done analyzing chemical models of the sea's flux and reflux, in particular those proposed by poet and miscellaneous writer Thomas Philipot (d. 1682) and Robert Moray.

Thomas Philipot was the son of John Philipot (1589?–1645); John was a Somerset herald, friend of William Camden, and a historian

pp. 171–86; Maurice A. Finocchiaro, *Galileo and the Art of Reasoning* (Dordrecht: Reidel, 1980), pp. 74–79; Harold I. Brown, "Galileo, the Elements, and the Tides," *Studies in History and Philosophy of Science*, 7 (1976), pp. 337–51; Joseph C. Pitt, "The Untrodden Road: Rationality and Galileo's Theory of the Tides," *Nature and System*, 4 (1982), pp. 87–99; Joseph C. Pitt, "Galileo and Rationality: The Case of the Tides," in J.C. Pitt and M. Pera ed., *Rational Change in Science: Essays on Scientific Reasoning*, (Dordrecht, Boston: Reidel, 1987), pp. 235–53; Joseph C. Pitt, "Galileo, Copernicus and the Tides," *Theoria et Historia Scientiarum*, 1 (1991), pp. 83–94; William R. Shea, "Galileo's Claim to Fame: The Proof that the Earth Moves from the Evidence of the Tides," *British Journal for the History of Science*, 5 (1970), pp. 111–27. For a philosophical treatment of Galileo's rhetoric about the tides, see Donald Mertz, "The Conception of Structure in Galileo: Its Role in the Methods of Proportionality and *Ex Suppositione* as Applied to the Tides," *Studies in History and Philosophy of Science*, 13, 2 (1982), pp. 111–131. For Newton and the Tides, see Eric J. Aiton, "The contributions of Newton, Bernoulli and Euler to the theory of the tides," *Annals of Science*, 11 (1956), pp. 206–223, and for Cartesian theories, see Eric J. Aiton, "Descartes's theory of the tides," *Annals of Science* 11 (1955), pp. 337–348.

[25] For a discussion of the multiplicity of theories which compete when a scientific speciality is in a pre-paradigmatic state, see Thomas Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago: University of Chicago Press, 1996), pp. 10–22.

[26] *The Gentleman's Journal: Or the Monthly Miscellany*, ed. Pierre Motteaux, April 1692, (London: R. Baldwin, 1692), p. 17; Anna Marie Roos, *Luminaries in the Natural World: Perceptions of the Sun and the Moon in England, 1400–1720*, Worcester Polytechnic Institute Studies, vol. 20 (New York: Peter Lang Publishing, 2001), p. 242.

[27] Brian P. Copenhaver, "A Tale of Two Fishes: Magical Objects in Natural History from Antiquity through the Scientific Revolution," *Journal of the History of Ideas*, 53, 3 (July–September 1991), pp. 373–398, on pp. 373–4.

and archaeologist of Kent.[28] Thomas followed some of John's interests closely, to the point of even plagiarizing some of his father's antiquarian histories. However, Thomas was best known as a "tolerable poet" while a student at Cambridge University and as an author of tracts on a variety of subjects ranging from suicide, *Aesop's Fables*, to the history of heraldry.[29]

By the 1670s, Thomas Philipot's interests had shifted to natural philosophy, and in 1673, he published *A Phylosophical Essay, Treating of the most Probable Cause of that Grand Mystery of Nature, the Flux and Reflux: or Flowing and Ebbing of the Sea.*[30] Through an extended chain of logical deduction, the majority of his treatise was devoted to a systematic consideration and rejection of the myriad of pre-Newtonian theories of the tides, including those of Galileo and Kepler, and a synopsis of the state of tidal research that included both English and continental works. Philipot defended his choice to spend so much time summarizing theories, explaining that tidal models were so "entwin'd and complicated . . . that it is a greater Difficulty to trace out and unravell them, than to Subvert, or Dismantle them."[31] In the last pages of this work, however, Philipot made his own contribution, and proposed a theory of the tides based on chymical reactions of sea salts and atmospheric pressure caused by the emanations of the sun and the moon on the seas.[32] As Antonio Clericuzio and Allen Debus have illustrated, by the 1670s and 1680s, English scientists such as John Webster, Thomas Sherley, and William Simpson blended the iatrochymistry of physician Joan Baptista van Helmont with chemist Robert Boyle's corpuscularianism and the mechanical philosophy, applying the results to

[28] *Dictionary of National Biography*, 1937–39 ed., s.v. "Thomas Philipot," and s.v. "John Philipot."

[29] For an analysis of Thomas Philipot's meditative poems, see Wolfgang Lottes, " 'On this Couch of tears': *Meditationen in schwerer Krankheit von Donne, Wotton, Latewar, Isham und Philipot*," *Literatur in Wissenschaft und Unterricht*, 8 (1975), pp. 56–71; According to the *DNB* entry, Thomas Philipot plagiarized his father's *Villare cantianum, or, Kent surveyed and illustrated* (London: William Godbid, 1659); Thomas Philipot, *Poems* (London: R.A., 1646); Thomas Philipot, *Aesop's fables, with his life: in English, French & Latin* (London: William Godbid, 1666); Thomas Philipot, *Self-homicide-murther, or, Some antidotes and arguments* (London: W. Downing, 1674); Thomas Philipot, *A brief historical discourse of the original and growth of heraldry* (London: E. Tyler and R. Holt, 1672).

[30] Thomas Philipot, *A Phylosophical Essay, Treating of the most Probable Cause of that Grand Mystery of Nature, the Flux and Reflux: or Flowing and Ebbing of the Sea* (London: T.M., 1673).

[31] Philipot, *Phylosophical Essay*, p. 1.

[32] Philipot, *Phylosophical Essay*, pp. 11–14.

medicine.[33] Philipot similarly applied such models, with a focus upon fixed and volatile salts, to the sea's flux and reflux.

Before writing his work on tides, Philipot demonstrated an interest in exploration and navigation, writing a history of the Spanish monarchy which contained extensive summaries of the then-known facts concerning the Spanish possessions in the New World, as well as a history of navigation that contained his theories upon the causes of the variation of the compass.[34] In his tract on the compass, he showed familiarity with the work of van Helmont and William Gilbert; for example, Philipot mentioned that van Helmont claimed, in accordance with his belief in the connection of the macrocosm of the animistic earth to the microcosm of the human body, that "if a man [sic] in framing the Needles, shall stand with his Back plac'd to the North, and place one point of the Needle (which he intends for the North) directly Towards himself, the needle so made, shall always point regularly and infallibly toward the North without variation."[35] Although Philipot wished that "some person of exalted imagination" would produce needles "for experiment after [Helmont's] direction," he subsequently dismissed the idea as "infirme and crazy," as the "variation of the Needle proceed from the attractive vigour . . . of the Earth, which by irrefugable demonstrations [by Gilbert] "may be evinc'd to be one continued magnet."[36]

Despite his dismissal of van Helmont's ideas about magnetic variation, Philipot would later evince interest in the study of other occult forces, and be influenced by Helmontian theories of volatile and fixed salts in his work on the tides.[37] And one of these natural productions

[33] Philipot, *Phylosophical Essay*, pp. 11–14; Debus, "Thomas Sherley's *Philosophical Essay* (1672)" pp. 124–35. Antonio Clericuzio, "From van Helmont to Boyle. A study of the transmission of Helmontian chemical and medical theories in seventeenth-century England," *British Journal of the History of Science* 26 (1993), pp. 303–334, on p. 330. Iatrochymistry is a medical theory, first associated with Paracelsus, that disease results from a chemical reaction and that it can be both defined and treated chemically. Corpuscularianism was Boyle's physical theory that supposed all matter to be composed of minute particles.

[34] Thomas Philipot, *The original and growth of the Spanish monarchy united with the House of Austria* (London: W.G., 1664); Thomas Philipot, *A Historical discourse of the first invention of navigation and the additional improvements of it with the probable causes of the variation of the compasse* (London: W. Godbid, 1661).

[35] Philipot, *Navigation*, p. 11.

[36] Philipot, *Navigation*, p. 11.

[37] Gilbert in his *De Mundo Nostro Sublunari* did however differ from Philipot's conclusion that the tides were caused by both the sun and the moon; Gilbert believed that tides were produced by the magnetic force between the earth and the moon, and not by its rays or light. He also "did not understand how the ebbing of the tide followed

was the tides. If we now turn to Philipot's *Phylosophical Essay*, we see Philipot believed the flux of the sea was due to the fact:

> there is a vitriolated, volatile or armoniack salt or spirit, that is wrap'd up in the Bowels of the Sea and lies there clasped up and Imprison'd in the Embraces of the fixed . . . Salt, which upon its Excitation, by the Agitation of the Superficies of the Sea, and the opening of it by the combined and complicated Impressions of the Sun and Moon, dislodges from its Inclose, and shoots it self up to the watry Margent, and drags along with it, that Heap of Waters we stile the *Flux.*[38]

Just as van Helmont believed heated blood in contact with air discharged its volatile salts and became breath or gas that was released into the atmosphere, Philipot may have analogized that volatile salts were freed from the fixed sea salt via motion of the waves and the heated emanations of the sun and moon. The volatile salts were subsequently released into the air, and their motion and expansion caused the flux of the tides.[39]

To explain the reflux of the waters, Philipot also utilized the explanation of what he called the "spring of the air" which was Boyle's term for atmospheric pressure. A connection between atmospheric pressure and planetary effluviums was indeed proposed by Boyle, who speculated that the Gravity of the Atmosphere

> may be alter'd by unseen Effluviums . . . [as] we have often perceived by the Mercurial Baroscope the Weight of the Air to be noticably increased, when we could not perceive in the Air . . . any cause to which we could ascribe so noticeable a change.[40]

Boyle thought perhaps that even "the Sun it self may not now and then alter the Gravity of the Atmosphere otherwise than by its Beams

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from the direct attraction unless the interior of the earth contained humors which retreated into the earth when the tidal forces ceased, and so caused the surface of the sea to descend. He also did not understand why the earth and moon did not fall together." See Harris, *Manual of Tides*, 398; William Gilbert, *De Mundo nostro Sublunari* (Amsterdam: Elzevir, 1651), pp. 298–99.

[38] Philipot, *Phylosophical Essay*, p. 11.

[39] The expansion of the volatile salts to cause the flux of the sea was similar in mechanism to the ability of volatile salts to agitate the animal spirits of the body. English Helmontians in fact often "administered volatile alkaline salts distilled from blood to agitate restore the weakened vital spirits or archaeus of the body" by their expansion. Boyle himself attempted to distill the spirit of blood, which he believed was "fully satiated with saline and spiritous parts," and thus had the therapeutic ability to restore the vital spirits. See Roos, "Luminaries in Medicine," pp. 453–54.

[40] Boyle, *Suspicions about some hidden qualities in the air*, p. 45.

or heat."[41] Via a similar mechanism, Philipot proposed that the air "ascended up" with the sea's flux, and "upon closing and contracting its Face upon the Recess of those two great Luminaries, shrinks back again, and with it pulls along, that mass of waters it before had elevated, and this produces the Reflux."[42] In other words the atmospheric pressure of the sun and moon "pushed back" the air that had risen with the flow of the tides, leading to the tides' ebb.

To further support his hypotheses, Philipot cited Jesuit authors such as Libertus Froidmont (1587–1653) and the polymath Athanasius Kircher (1601/2–1680). Froidmont was a professor at Leuven, and a Latin edition of his *Six Books of Meteors* was published at Oxford in 1639.[43] A good proportion of the fifth book was devoted to considering systematically hypotheses of the tides, each submitted to *questiones* and *disputationes* in scholastic fashion. Philipot in fact seems to have utilized Froidmont's structure of argumentation and some of his content in the beginning of this *Phylosophical Essay* when he considered other tidal models. To support his idea of chemical reactions in the air causing the motion of fluids, Philipot in particular cited Froidmont's observation of an experiment done by the Swiss physician and philologist Jacob Zwinger (1569–1610). Zwinger noticed that oil of vitriol ascended and descended with the flux and reflux of the sea.[44] Because oil of vitriol is extremely reactive and hygroscopic (it absorbs water), it is likely Zwinger was noticing water absorption during periods of higher humidity.[45] Philipot then connected lunar action to saline chymistry by

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[41] Boyle, *Suspicions about some hidden qualities in the air*, p. 45.

[42] Philipot, *Phylosophical Essay*, p. 12.

[43] Liberti Fromondi, *Meteorologicorum Libri Sex* (Oxford: William Turner, 1639).

[44] Liberti Fromondi, *Meteorologicorum Libri Sex* (Oxford: William Turner, 1639), p. 321. *Scribit alibudi Swingerus, oleum quoddam vitreoli esse, quod tumescit cum Luna & detumescit: quid si igitur similis substantaie, aut qualitatis, id est, vitriolatae, ut loquuntur nostri Chymici, spritium marini alvei fundus obtineat?* [Swingerus writes somewhere of the oil of vitriol which exists, that swells and shrinks with the moon. Therefore, what is this quality of vitriol, of which our chemists speak, which is similar to the spirit of the sea and tides? (my translation)]. Froidmont's source was Jacob Zwinger, *Principiorum chymicorum examen ad generalem Hippocratis, Galeni, caeterorumque . . .* (Basil: Sebastian Henricpetri, 1620). Jacob Zwinger was interested in salts, like his father, Theodore Zwinger, and "sought to find the elements that were valuable in Paracelsian doctrine and extract them" including Paracelsus' doctrine of the *tria prima* of salt, sulphur, and mercury. See Jole Shackelford, "Lutheran Orthodoxy, and the Rejection of Paracelsianism in Early Seventeenth-Century Denmark," *Bulletin of the History of Medicine* 70 (1996), pp. 181–204, on p. 182. My thanks to Dr. Shackelford for providing me with information about Jacob Zwinger.

[45] Boyle also noted that vitriolic substances were particularly susceptible to atmospheric moisture; adding water to oil of vitriol or sulphuric acid in fact will result in

citing Kircher's *Mundus Subterraneus* (1665). Kircher recorded that an infusion of the volatile salt, sal armoniack, "placed obliquely to receive the Influence of the Moon . . . did Increase and Decrease as it held of an equal Correspondence, by an uninterrupted Chain of Atoms, with the Flowings and Ebings of the Marine waters."[46] (Sal ammoniac or ammonium chloride is similarly hydroscopic and reacts to atmospheric humidity, which may have been behind Kircher's observations of its increase and decrease with the tides).[47]

Philipot also seemed to be unaware of the fact that in 1665, members of the Royal Society were privately testing Kircher's hypotheses. In a letter from Henry Oldenburg, the secretary of the Society, to the writer, chemist, and mathematician Robert Moray, Oldenburg stated:

> Kircher produces severall Experiments to evince, yt ye Moon is ye sole cause of those Sea-reciprocations, by a Nitrous quality and Dilating faculty. . . . etc. it be experimented, if it hath not been by any of our Oxonian friends, whether Nitrous water, mixed with common salt, exposed in a bason to ye Beams of ye Moon in a free open place and a cleer Moonshiny night, will boyle and bubble up, and ye more vehemently, ye neerer the two Luminaries are to ye places of their Conjunction and Opposition.[48]

Four days later, Robert Boyle commented that Moray "has been here to watch ye successe of ye Expt of Kerker yt you sent him concerning ye Ebbing and flowing of ye sea."[49] As Stevenson has shown, Moray had in fact written a series of letters to Kircher about magnetism and tides from 1643 to 1646, as well as in 1653, one of which about the tides of the Hebrides that Kircher reprinted in the *Mundus Subterraneous* and

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a dangerous explosive reaction. See Robert Boyle, *A New Experiment And other Instances of the Efficacy of the Air's Moisture* (Oxford: E.F., 1673), p. 7.

[46] Philipot, *Phylosophical Essay*, p. 12. Philipot is referring to Athanasius Kircher, *Mundus Subterraneus, in XII libros digestus* (Amsterdam: J. Janson, 1665). The original work was published in 1665, and a partial English translation was published in London in 1669 which Philipot may have used. See Athanasius Kircher, *The vulcano's, or Burning and fire-vomiting mountains . . . collected for the most part out of Kircher's Subterraneous world* (London: J. Darby, 1669).

[47] Robert Boyle also noted how a solution of sal ammoniac and water gained weight when exposed to the air "amounting to near a dram." See Robert Boyle, *A New Experiment . . . of the Efficacy of the Air's Moisture*, pp. 6–7.

[48] Henry Oldenburg to Sir Robert Moray. 7 November 1665, in *The Correspondence of Henry Oldenburg*, ed. and trans. A. Rupert Hall and Marie Boas Hall, 12 vols. (Madison: The University of Wisconsin Press, 1966), vol. 2, p. 592.

[49] Robert Boyle to Henry Oldenburg. 11 November 1665, in *The Correspondence of Henry Oldenburg*, vol. 2, p. 604.

which Moray published in the *Philosophical Transactions*.[50] In 1658, Moray wrote to his protégé and friend Alexander Bruce,

> But whatever your skill in water works be I think I may venture to say you are not well enough acquainted with the duration of ebbs and floods. Yet I will not now begin to indoctrinate you. The trueth is, that is one of the sciences I find most imperfect. I have lent a list to Kircherus, whom I have encouraged to labour to perfect it. And when all other more necessary and serious conversation is almost reaped and we have clattered our bellyfulls at meeting, a fitt of that science may take us up an afternoon or two.[51]

But Moray was to be disappointed with these "fitts" of science in a number of ways.

As Stevenson wrote,

> In 1665 [Moray] heard that long-awaited work on tides by Athanasius Kircher had been published. From Oxford he wrote to Henry Oldenburg, (1618–1677) the secretary of the Royal Society, asking to check in the book to see 'to see if the irregular tides in the West Isles of Scotland be there.' Oldenburg's reply brought good news and bad. Yes, Kircher had published Moray's letter. But he had dismissed his observations to

[50] Lettere di Sir Robert Moray nel Carteggio A. Kircher Nell'Archivio della Archives de Pontificia Universita Gregoriana, 28 Jan 1656, Number 568. Colonia Agrippina [Cologne]. Sir Robert Moray to Kircher. The letter, also printed in Kircher's *Mundus Subterraneous* (Amsterdam: Elzevir, 1665), vol. i, p. 143, is as follows:

> *Rei nautica, inquit, perutile esse historiam justam maris aestus & motus omnes tam regulares, quam anonalosubivis occurentes fuse explicantem condere. Quidquid hueusquede hac re videre contigit, maneum puto. Te dignum sane facinus esset, hoc muneris suscipere. "Mirae sunt in quibusdam locis fluxus & refluxus alternationes." Ego hic narrabo, quod in Insulis Hebridum partim propriis oculis observavi, partim as incolis fide dignis didici. Est locus in freto Insulis minisculis, rupibus &syrtibus frequentibus consperso in majores "vulgo Eust & Herres" insulis sito. Aestus maximi, id ist, tempore conjunctionis & oppositionis Solis & Linae quo plemmyra fit ora sexta ordinatete procedunt; fluxus Orientem in Occidentem horarum spacio, sicuti & refluxus ab Occidente in Orientem persiciter . Hoc duobus diebus ante Pleniluniumejusque oppositum, ac totidem post ea semper sic se habet; Tertia autem die & deinceps longe aliter, toto enim tempore diurno sive fluat, sive refluat Occidentem versus dirigitur, nocte vero on Orientem vergit. Hoc ego ipse deprehendit; sed ferunt insuper Indignae, aliud adhuc magis miramhic accidere. Tota scilicet die, dum Sol signa Borealia perlustrar, cursus aquae dictos in Occidentem tendere, tota autem hyeme in contratium; quorum causam mihi non est concessumpenetrare. Hactanus verba supra citati Equitis.*

Moray's account of these Hebridean tides were published in the *Philosophical Transactions*, Monday June 5, 1665 as well. My gratitude to David Stevenson of St. Andrew's University for providing me with this information. His transcription of Moray's letters from the Kincardine manuscript in the Royal Society Library is forthcoming from Ashgate Variorum Press.

[51] 8/18 January 1658. Mastricht a Monsieur, Monsieur Alexander Bruce, in de Witte Swan tot Bremen (ff. 48–9), in Stevenson, *The Kincardine Papers of Sir Robert Moray.*

> incomplete to be of value. Oldenburg added soothingly that doubtless Kircher dismissed Moray's evidence because it was incompatible with his own theories.[52]

Moray's recreation of Kircher's experiment with salts and tides was also apparently inconclusive, as Moray commented "it is not lyke gain credit here."[53] After several hours and trials where Moray and "Mr. Boiles' man" or laboratory assistant observed a basin filled with water, bay salt, and nitrous salt, no agitation of the water appeared, "onely some litel bubles of air raised by the not fully dissolved Salts."[54] Moray informed Oldenburg that he should probably not transcribe such negative experimental results for the *Philosophical Transactions*, "knowing your moments may be better employed."[55] Indeed, these experiments were not published, which is why Philipot apparently was unaware of them. Indeed by 1674, an anonymous *Philosophical Transactions* paper commented that

> divers eminent Chymists have delivered several Preparations of Vitriol, which derive Moisture from the Moon more or less, according to her several Phases; which I am perswaded is a meer Dream, having seen little hitherto that should perswade me any of the Planets do influence otherwise than by Heat and Light.[56]

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[52] Oldenburg, *Correspondence*, vol. 2, p. 590, p. 592. Athanasius Kircher, *Mundus Subterraneous*. 2 vols. (Amsterdam: J. Janssonius 1665), vol. 1, p. 143; as quoted in Stevenson, "Introduction: The Life of Sir Robert Moray," *The Kincardine Papers of Sir Robert Moray*.

[53] Moray to Oldenburg. 12 November 1665, in *The Correspondence of Henry Oldenburg*, vol. 2, p. 606.

[54] Moray to Oldenburg. 12 November 1665, in *The Correspondence of Henry Oldenburg*, vol. 2, p. 606.

[55] Moray to Oldenburg. 12 November 1665, in *The Correspondence of Henry Oldenburg*, vol. 2, p. 606.

[56] *Philosophical Transactions*, 103 (May 25, 1674), p. 46. Here we also see the gradual separation of astrology and astronomy. Whereas astrology and astronomy had been part and parcel of the same discipline in the late Middle Ages, they were increasingly separated into two types of study. Among elites in the seventeenth century, the pursuit of judicial or Ptolemaic "genethialogical" astrology [based on the geniture or time of birth], which posited that human fate could be predicted or controlled by occult effects of the planets, became more carefully separated from that of astronomy, which was the study of planetary systems. In the latter half of the seventeenth century, the discipline of astronomy also came to include the study of previously astrological effects of the planets, particularly the sun and moon, on weather and health. See A.M. Roos, "Astrology, the Academy, and the Early Modern Newspaper," *Astrology and the Academy*, ed. Michael York, Patrick Curry and Nick Campion (Bristol: Cinnabar Books, 2004), pp. 131–146 for an extended discussion of this growing distinction.

Philipot's final support for his tidal chymistry was the phenomenon of Prince Rupert's drops, otherwise known as "chymical glasses."[57] These objects were introduced to England in the 1640s by Prince Rupert of Bavaria (1619–1682), and were teardrop shaped glass beads, made by dropping molten glass into cold water [Figure 2]. The solid glass object had a bulbous end which tapered into a curved glass tail, and these objects exhibited unusual properties of strength and fragility. The formation of the drops created tremendous stress between the outside layer, cooled by the water, and the inside which was warm; due to the tremendous surface tension of the glass, the head withstood hammering on an anvil.[58] However, breaking the tail resulted in the shattering of the entire drop into fine powder because the glass released the internal stress with such power.[59] These drops were utilized in practical jokes by Charles II; the King would have a subject hold the bulb end in the palm of his hand, and then break off the top, giving the victim a small but harmless explosion in a closed hand.[60] Indeed, Philipot referred to these drops as "Greatricks [great-tricks] glasses."[61]

As with the tides, there was a multiplicity of interpretations of the phenomenon, already correctly grasped in principle by Robert Hooke in his *Micrographia*.[62] Philipot however believed the drops shattered because of a chemical reaction. When the tail was snapped off,

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[57] The diarist Samuel Pepys stated he was first shown the drops or "chymical glasses," which he had "heard talk of" by Peter Honywood on 13 January 1662. He wrote the glasses "break all to dust by breaking off a little small end, which is a "great mystery." See the *Diary of Samuel Pepys*, ed. John Warrington, 3 vols. (London: Dent; New York: Dunton, Everyman's Library, vol. 53), vol. 1, p. 224. See also Laurel Brodsley, Sir Charles Frank, F.R.S., and John W. Steeds, "Prince Rupert's Drops," *Notes and Records of the Royal Society of London* 41 (1986), pp. 1–26, on p. 9. John Beckman, *A History of Inventions, Discoveries, and Origins*, 4th ed. of the English translation, edited by W. Francis and J.W. Griffith, 2 vols. (London, Bohn, 1846), vol. 2, pp. 241–245. I wish to acknowledge Dr. David Zuck for his aid in identifying the reference to these glass drops in Philipot's work.

[58] "Prince Rupert's Drop and Glass Stress," Corning Museum of Glass, http://www.cmog.org/ page.cfm?page=281&originalsearchtext=prince%20rupert%27s%20drop, p. 1.

[59] For a more detailed scientific explanation of the drops' explosion, see S. Chandrasekar and M.M. Chaudhri, "The explosive disintegration of Prince Rupert's drops," *Philosophical Magazine*, B70 (1994), pp. 1195–1218.

[60] "Prince Rupert's Drop and Glass Stress," Corning Museum of Glass, p. 1.

[61] Philipot, *Phylosophical Essay*, p. 12. Much research has revealed there is no connection between "Greatricks" glasses and the seventeenth-century Irish healer Valentine Greatrakes.

[62] Robert Hooke, "Observation vii of some Phaenomena of Glass Drops," in *Micrographia* (London: John Martyn and James Allestry, 1665), pp. 33–44.

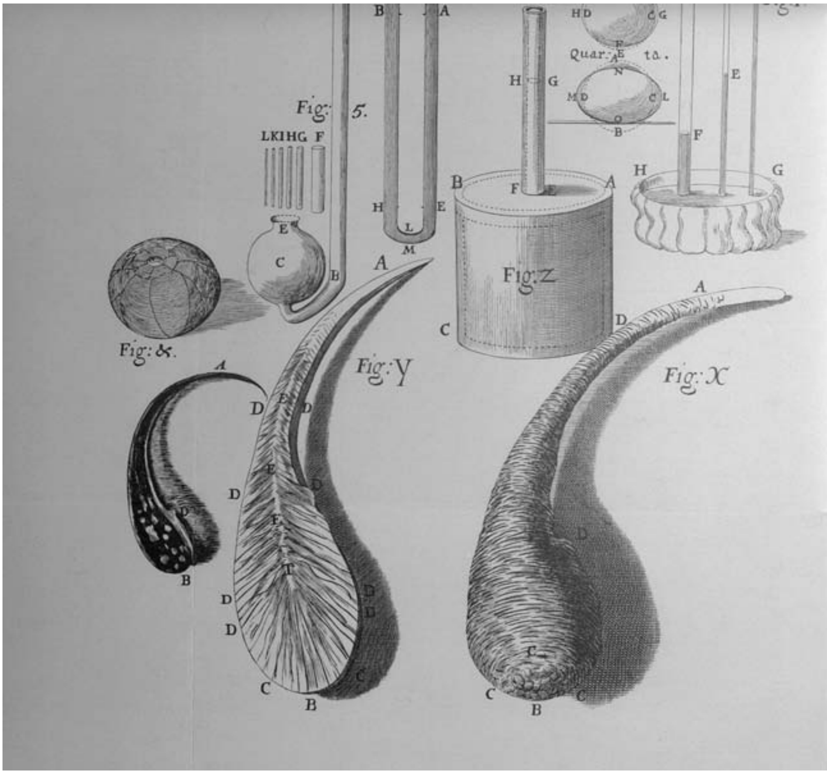

Figure 2. Prince Rupert's Drops or the "Glass Drops" in Robert Hooke, *Micrographia*. London: John Martyn and James Allestry, 1665, p. 10. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

> the volatile salt, that lay imprison'd, and cloister'd up, in the claspings, and Circumscription of the . . . fixed Salt, finding it self enfranchis'd and redeem'd from the strict Enclosures of those two rigid Adversaries sallied out, with an impetuous Eagerness, and that Eruption occasions that disorder and concussion.[63]

In other words, just as the waves of the sea released the volatile salts from the fixed salts, causing the fluxing of the sea, the breaking of the drop's stem also released its volatile salts, whose expansion caused the drop's explosion.

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[63] Philipot, *Phylosophical Essay*, p. 13.

After presenting his theory and supports for tidal chymistry, Philipot addressed his opposition. He realized that one of the major obstacles to the formulation of mechanical or chemical tidal theories was to find an explanation for the fact that smaller bodies of water such as the "Euxine, Baltick, and Caspian Seas" do not exhibit tidal behavior.[64] (Many inland seas are virtually tideless because the entering strait is too narrow to allow the influx or outflow of sufficient tidal waters).[65] Philipot's explanation was that rivers "perpetually disgorge themselves into those Seas above said," emptying fixed salts from underground caverns and mines, where minerals and salts were generated by mother earth.[66] As a result, the volatile salts in these seas were "check'd and depress'd" by fixed salts of sulphur, nitre, and bitumen.[67] And, so "benumb'd" were the volatile salts that it was "impossible for the united Influence of the Sun and Moon, to excite their so stupified vigour."[68] Philipot may have been influenced in his ideas again by Froidmont, who immediately

[64] Philipot, *Phylosophical Essay*, p. 13. "Euxine" or "Euxinic" refers to areas in which limited circulation of water has produced stagnant conditions, leading to deposit of black oil shale. Philipot likely is referring to the Black Sea, known for its oil deposits in the seventeenth century. See Oxford English Dictionary. 2nd ed. 1989 (ed. J.A. Simpson and E.S.C. Weiner), *OED Online*. Oxford University Press. <http://oed.com>, s.v. "Euxinic." The Caspian Sea, the largest lake in the world, receives water from several rivers, such as the Volga, Ural, and Emba in the northern and central parts of the sea, but it has no outlet. It actually has, contrary to Philipot, some tides, ranging from 70 cm. to 3 m. See Ramiz Mamedov, "On the Level: The continuing problem of the Caspian," in *The Caspian Times*, www.caspiantimes.com, p. 4. Philipot was however mostly correct in thinking the Baltic has not tides; it actually has a very small tidal variation. "It is greatest in the inner part of the Gulf of Finland, where the difference between high and low tide is 20 cm." See *The Encyclopedia of Oceanography*, ed. Rhodes W. Fairbridge, Encyclopedia of Earth Sciences Series, vol. 1 (New York: Reinhold Publishing Corporation, 1966), s.v. "Baltic Sea."

[65] Richard Ellis, *The Encyclopedia of the Sea* (New York: Alfred A. Knopf, 2000), s.v. "Tides."

[66] Philipot, *Phylosophical Essay*, p. 13. This explanation for the origins of sea salt was apparently shared by Robert Boyle. Boyle wrote "the Sea derives its saltness from the Salt that is dissolved in it . . .; But I take that Saltness to be supplied, not only from Rocks, and other Masses of Salt . . . but Also from the Salt, which the Rains, Rivers and other Waters dissolve in their passage through divers parts of the Earth, and at length carry along with them into the Sea." See Robert Boyle, *Tracts Consisting of Observations About the Saltness of the Sea* (Oxford: E. Flesher, 1674), p. 15. The idea that underground mines constantly generated minerals, serving as the womb of the Earth Mother, is a common conceit in Paracelsian and Helmontian thinking. See Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution* (San Francisco: Harper, 1990), pp. 20–41.

[67] Philipot, *Phylosophical Essay*, p. 13.

[68] Philipot, *Phylosophical Essay*, p. 13.

before his discussion of vitriolic oil mentioned the lack of tides in the Dead Sea, termed by the Roman Naturalist Pliny as well as the Book of Genesis as the *Lacus Aphaltites* or "Lake of Asphalt," for its tremendous quantity of bitumen and fixed salts.[69]

As he concluded his treatise, described as a "faint result of my pen," Philipot evinced a gentlemanly desire to use his work to serve his fellow citizens, proclaiming he was certain that "new Discoveries" would improve his "theories to greater advantage of the public."[70] In the interim, he advised his readers with a maxim from Horace: "*Si quid novisti rectius istis candidus imperti; si non, his utere mecum*," or "If you have ideas better than these of mine, share them openly; if not, use these as I do."[71] His systematic consideration and rejection of nine other tidal theories—ranging from Homer's view they were caused by whirlpools to Kepler's idea that the tides occurred because the sea was as a breathing animal (which Philipot dismisses because could not see on "which coast these prodigious lungs are located" (!)—illustrated the multiplicity of ideas about the waters' flux and reflux.[72] Philipot was thus a transitional figure, providing an explanation for the tides during the height of iatrochymistry's popularity, only to see such theories over-

[69] Froidmont, *Meteorologicorum*, p. 321. *Hoc tamen me retinet quod Asphalities sive mare mortuum, bitumine stans et plenissimum, aestum tamen non sentit. Oportet ergo aliter temperatum esse bitumen, ut ad Lunam se moveat.* [Nevertheless a dead sea like the Asphalities does not experience the tides, standing still and full, held back by the bitumen. Therefore, it is necessary for the bitumen to be tempered in order that the moon moves [the sea.] (My translation.) "From time to time large quantities of bitumen rise to the surface from the bottom Bitumen is also found along the shores of the Dead Sea and is referred to in Genesis (xiv, 10) where it speaks of the *puteos multos bituminis*—"many pits of slime." See Joseph Malloy, "Dead Sea," *The Catholic Encyclopedia*, vol. iv. (New York: Robert Appleton Company, 1908), online at: http://www.newadvent.org/cathen/04658a.htm. William Gilbert in his *De Mundo* mentions the role of bitumen and fixed salts in suppressing the tides. William Gilbert, *De Mundo Nostro Sublunari*, pp. 297–298.

[70] Philipot, *Phylosophical Essay*, p. 14.

[71] Philipot, *Phylosophical Essay*, p. 14.

[72] The idea that the tides were caused by whirlpools was promoted by Richard Hakluyt's *Collection of the Early Voyages, Travels, and Discoveries of the English Nation*. 5 vols. (London: H.R. Evans, 1809–12; London, 1598–1600) vol. 1, pp. 134–135. Hakluyt used the examples of whirlpools near the Hebrides, stating it was but one of four in "opposite quarters of the world, from whence many does coniecture that as well the flowing of the sea, as the blasts of the winde, haue their first originall." In the fourth book of his *Harmonics* (1619), Kepler states that the tides are akin to the breathing of terrestrial animals and fishes. See Johannes Kepler, *Opera Omnia*, ed. Christian Frisch. 8 vols. (Frankfurt and Erlangen: Heyder et Zimmer, 1865–71), vol. 5, p. 255. However, in his earlier *Introduction to the Motions of the Planet Mars* (1609) Kepler noted that the attractive forces exercised by earth and moon upon each other are proportional to their masses. Kepler, *Opera Omnia*, vol. 3, p. 151.

come by Newton's *Principia* fifteen years later. In his method of rejecting and combining elements from this kaleidoscope of theories, Philipot blended interests in occult forces, chymistry, and natural philosophy to explain the mechanism of tides, which he termed this "Grand Mistery of Nature."[73]

Martin Lister, the salts of pyrites, and natural history

Van Helmont's assertion of the presence of salts in the atmosphere also affected work done by Martin Lister, another early Royal Society member, on meteorology, minerallogenesis, and theories about the formation of fossils. Born in Yorkshire, Martin Lister was educated at St. John's College, Cambridge (M.A. 1655), subsequently studied medicine at Montpellier from 1663–1666, and when on the continent became "an avid natural historian" and physician.[74] Elected a Royal Society Fellow in 1670–1, Lister devoted himself to a variety of biological studies, including botany, fossil classification and conchology, forging a friendship and lengthy correspondence with John Ray (1628–1705).[75] Lister's works ranged from a well-known treatise on spiders, to a recollection of a voyage to Paris, to an annotated edition of the Roman cookbook of Apicius (1705) that was publicly ridiculed by satirists, especially with its references to contemporary English cuisine.[76] Scholarly work

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73 Philipot, *Phylosophical Essay*, p. 14.

74 Cook, "Natural History and seventeenth-century Dutch and English Medicine," p. 257.

75 "Martin Lister," s.v. *D.N.B.* (Oxford: Oxford University Press, 1937–38 ed.) See also "Martin Lister," s.v. *Biographia Britannica*, 1st ed. (London, 1747–66), vol. 5, pp. 2974–5; William Munk, *The Roll of the Royal College of Physicians of London*, 2nd ed., 3 vols. (London, 1878), vol. 1, pp. 442–5. For Lister's correspondence with Ray, please see John Ray, *The Correspondence of John Ray*, ed. Edwin Lankester (New York: Arno Press, 1975, reprint of London: The Ray Society, 1848). Some of Lister's letters to and from Ray are also present in MS Lister 2 and 3, Duke Humfrey Library, Bodleian, University of Oxford.

76 William King (1683–1712), the satirist and miscellaneous writer, lampooned both Lister's *Apicius*, as well as Lister's *Journey to Paris.* See William King, *The Art of Cookery, In Imitation of Horace's Art of Poetry. With some Letters to Dr. Lister, and Others: Occasion'd principally by the Title of a book publish'd by the Doctor, being the Works of Apicius Ceolius,... Humbly inscrib'd to the Honourable Beef Steak Club* (London: Bernard Lintott, 1706); Martin Lister, *A journey to Paris in 1698* (New York: Arno Press, 1974); John Lough, "Martin Lister's travels in France," *Durham University Journal* 76 (1983), pp. 37–41; Martin Lister, *Martin Lister's English Spiders: 1678*, trans. John Parker and Basil Harley (Colchester, Essex: Harley Books, 1992); See Geoffrey Keynes, "Dr. Martin Lister, F.R.S., Some Uncollected

about Lister has therefore primarily concentrated upon analysis of his investigations in natural history.[77] Other authors have noted his contributions to geographical cartography, particularly his stratigraphic utilization of fossils.[78]

Little attention has been focused upon Lister's work in chemistry, the most salient examples being his analysis of pyrites or "fools' gold" (iron sulfides (FeS_2), in mineral springs contained in his *De Fontibus medicatis Angliae Exercitatio* (1684) [Exercises on the healing springs of England], in his contributions to the *Philosophical Transactions* in the 1670s and 1680s, and in his unpublished manuscript "Method for the History of Iron."[79] (A translation of *De Fontibus* is provided in appendix one). In

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Authors," *The Book Collector* 28 (1979), pp. 501–520. S. Wood, "Martin Lister, Zoologist and Physician," *Annals of Medical History*, n.s. 1 (1929), pp. 87–104. For a focus on the work of Martin Lister and Jan Swammerdam, see Cook, "Natural history and 17th-Century Dutch and English medicine," pp. 253–270.

[77] Robert W. Unwin, "A Provincial Man of Science at Work: Martin Lister, F.R.S., and his illustrators 1670–1683," in *Notes and Records of the Royal Society of London* 49, 2 (1995), pp. 209–30; David E. Allen, "Spider Man at Work," review of John Parker and Basil Harley, eds., *Martin Lister's English Spiders 1678* in *Notes and Records of the Royal Society of London* 47, 1 (1993), pp. 144–45; J.D Woodley, "Anne Lister, Illustrator of Martin Lister's *Historiae Conchyliorum* (1685–1692)," *Archives of Natural History* [Great Britain] 21, 2 (1994), pp. 225–229. For a recent analysis of Lister's cabinets of curiosities, see P. Fontes da Costa, "The Culture of Curiosity at the Royal Society in the first half of the eighteenth century," *Notes and Records of the Royal Society of London* 56 (2002), pp. 147–166; Lister is also mentioned in Michael Hunter, "The Social Bias and Changing Fortunes of an Early Scientific Institution: An Analysis of the Membership of the Royal Society, 1660–1685," *Notes and Records of the Royal Society of London* 31 (1976–7), pp. 9–114.

[78] For a discussion of Lister's contributions to geological cartography, see Cecil Schneer, "The Rise of Historical Geology in the Seventeenth Century," *Isis* 45, 3 (1954), pp. 256–268, on pp. 261–263.

[79] Martin Lister, *De Fontibus medicates Angliae* (London: Walter Kettilby, 1684); "Three Papers of Dr. Martin Lyster, the first of the Nature of Earth-quakes . . . from the Pyrites alone," *Philosophical Transactions* 14 (1684), pp. 512–515; Martin Lister, "Certain Observations of the Midland Salt-Springs of Worcester-Shire, Stafford Shire and Cheshire," *Philosophical Transactions* 14 (1684), pp. 489–495; Martin Lister, "Method for the History of Iron, Imperfect," MS Lister 1, Duke Humfrey Library, Bodleian Library, University of Oxford. Although there have been no analyses of Lister's works on spas, there have been many studies of early modern English debates concerning the chemistry of hot springs as well as their economic impact. For instance, the most famous seventeenth-century medical debate was that engendered by Dr. Robert Wittie's (1613?–1684) *Scarborough spaw* (1660) a work in which he advocated the mineral waters at Scarborough as a cure-all; his claim was challenged by other physicians such as William Simpson (fl. 1665–1677) and after a series of dueling pamphlets, the controversy, which essentially centered around Galenic vs. Paracelsian medical cures, was carried out in the *Philosophical Transactions.* See Noel G. Coley, "Cures without Care: 'Chymical Physicians' and Mineral Water in Seventeenth-Century England," *Medical History* 23 (1979), pp. 191–214. Robert Wittie, *Scarborough spaw; or, A description of the nature*

the seventeenth and eighteenth centuries, the term "pyrites" referred to any mineral that could strike sparks from iron. According to Lister, the "hardest" of pyrites was "formerly polished and used instead of flints in ye Spanish wheele lockes."[80] He defined pyrites more specifically as "ironstone marcasites" or "brassie lumps" which were "nothing else but a body of iron disguised under a vitriolic varnish" found "all over ye Yorkshire Woldes; we have seen in the last chapter that "vitriol" referred to Iron II sulphate which occurred as a weathering product of pyrites.[81] Lister, in common with other early modern English chemists, specifically claimed vitriol consisted of an "insipid" earth he called ocher, some iron metal, mineral sulphur, the acid salt, and some small portion of the volatile aerial salt.[82]

An understanding of Lister's work on pyrites and vitriol is best attained by placing him in the intellectual context of the seventeenth-century

and vertues of the spaw at Scarbrough Also a treatise of the nature and use of water (London: Charles Tyus and Richard Lambert, 1660); William Simpson, *Hydrologia chymica, or, The chymical anatomy of the Scarbrough, and other spaws in York-Shire: wherein are interspersed, some animadversions upon Dr. Wittie's lately published treatise of the Scarbrough Spaw* . . . (London: W.G., 1669). For analyses of medicinal effects of early modern English spas, see Anne Borsay, *Medicine and Charity in Georgian Bath: A Social History of the General Infirmary, c. 1739–1830* (Aldershot: Ashgate, 1999); Christopher Hamlin, "Chemistry, medicine, and the legitimization of English spas, 1740–1840," in *The medical history of waters and spas*, Medical history Supplement no. 10 (London: Wellcome Institute for the History of Medicine, 1990), pp. 67–81; Phyllis Hembry, *The English spa, 1560–1815: a social history* (London: Athlone Press, 1990); Alex Sakula, "Doctor Nehemiah Grew (1641–1712) and the Epsom Salts," *Clio Medica* [Netherlands] 19, 1–2 (1984), pp. 1–22. Noel Coley, "The preparation and uses of artificial mineral waters (ca. 1680–1825)," *Ambix* 31 (1984), pp. 32–48; Charles Mullet, *Public baths and health in England, 16th–18th century* (Baltimore: John Hopkins Press, 1946). For nineteenth-century therapeutic mineral cures, please see George Weisz, "Water Cures and Science: The French Academy of Medicine and Mineral Waters in the nineteenth century," *Bulletin of the History of Medicine* 64, 3 (1990), pp. 393–416. For the economic impact of mineral waters, please see Sylvia McIntyre, "The Mineral Water Trade in the Eighteenth Century," *Journal of Transport History* 2,1 (1973), pp. 1–19. See also Ronald and Ann Cowell, *Essex Spas and Mineral Waters* (Romford, Essex: Ian Henry Publications Ltd, 2002).

[80] Lister, "Method for the History of Iron," p. 5. Pliny's *Natural History*, which Lister cited extensively in the *De Fontibus*, stated, "When struck with a nail or another stone they [pyrites] give off a spark, and if this is caught on sulphur or else on dry fungi or leaves it produces a flame instantaneously." Pliny, *Natural History*, 36.29, line 138.

[81] Lister, "Method for the History of Iron," p. 18.

[82] Lister, *De Fontibus, passim*; "Some observations and Experiments about Vitriol, Tending to Find out the Nature of that Substance, and to Give Further Light in the Inquiry after the Principles and Properties of Other Minerals: Communicated by a Fellow of the Royal Society, Who Maketh Use of Chymistry Chiefly as Subservient to Physiology," *Philosophical Transactions* (1665–78), Vol. 9, no. 103 (1674), pp. 41–47, on p. 41.

chemical debate about the formation of minerals. As we have seen in the last chapter, some chymists claimed that there was a "hermaphroditical" or formative salt believed to be responsible for minerallogenesis and other types of matter formation, and there were contenders for the identity of this salt including nitre and vitriol. The vitriolic liquid or spirit of vitriol (sulphuric acid) called 'gur' or 'bur' was believed by Glauber and other early modern mining authors to be a sign of the presence of mineral ores, "with which sulphurous exhalations were also associated."[83]

While Lister agreed with his colleagues about the composition of vitriol, we will see that he dismissed the idea that vitriol was the universal acid salt responsible for mineral formation. Lister also disagreed that there was any particular sole active element responsible for mineral formation, arguing in particular against Van Helmont who assigned water that role. To support his assertions against Van Helmont, we will see that Lister incorporated the empirical work of early modern chemists in the Académie Royale des Sciences, specifically utilizing the *Observations on the Mineral Waters of France* (1684) written by their chief chemist Samuel Du Clos (d. 1715).

As these Helmontian aqueous theories of mineral formation arose in the seventeenth century, other chemical authors held "mineral exhalations as an explanation for the generation of . . . minerals and of the vaporous effluxes thought to issue from ore-deposits."[84] Lister was one of these authors, believing that the volatile exhalations of pyrites and its vitriol in the *air* were important in the transformation of matter, and he subscribed to the sixteenth and seventeenth-century theory of *witterung* or ore exhalations as an explanation for the formation of minerals.[85] Scratching or crushing pyrites does result in a sulphurous smell, and Lister claimed pyrites and its vitriol gave off a "warm vapour" that was "largely sulphurous, pungent, and inflammable," identifying vitriol as volatile.[86] Despite his allegiance to the theories of *witterung*, we will illustrate that Lister made use of his interests in natural history to go one step beyond them, postulating that the sulphurous exhalations from pyrites were responsible for the heating of hot springs, and meteorological and geological effects.

[83] Emerton, *Scientific Reinterpretation*, p. 217.
[84] John A. Norris, "The Mineral Exhalation Theory of Metallogenesis in Pre-Modern Mineral Science," *Ambix*, 53, 1 (March 2006), pp. 43–66.
[85] See David Oldroyd, "Some Phlogistic Mineral Schemes," *Annals of Science* 31 (1974): 269–305, on p. 276 for an explanation of *witterung*.
[86] Lister, *De Fontibus*, p. 77.

The chemical context of salts, pyrites and vitriol in the De Fontibus

Lister's *De Fontibus* was a work that met some public acclaim and was given an extensive and favorable notice in the review journal, *The Weekly Memorials for the Ingenious*, a publication in the "same format as the French *Journal des Scavans*."[87] The reviewer praised the "inquisitive and curious" naturalist for his "piercing industry" in creating a history of "English Spaws," and in "the Discovery of such things as relate to the natural Improvement of his own Country."[88] To begin his chemical analysis of spa waters, in the first chapter of the *De Fontibus*, Lister described and classified common salts, including nitre or saltpetre, common salt, alum, salt derived from limestone or "*nitrum calcarium*," and vitriol "born from iron pyrites." He did his classification primarily by a detailed examination of salt crystals, a common practice among late seventeenth-century chemists who considered the macroscopic and microscopic examination of crystalline structures important, as their regularity seemed to suggest their innate formative power in chemical transformation. Lister may have taken his cue from Bath physician Edward Jorden (1569–1632) who "strongly advocated the examination of their crystals" to identify dissolved minerals in spas; Dr. Tancred Robinson (1657–1748) and John Ray, Lister's colleagues, also remarked in correspondence that Anton von Leeuwenhoek also "hath observed a great variety of figures" in microscopic examination of salts.[89] Tancred Robinson wrote to Lister concerning the *De Fontibus*:

> This afternoon I spent some hours with Mr. Boyle, who gives you his most humble service, and is as proud of your good opinion, as you can possibly bee of his; hee hath try'd most of the experiments of your last book, and tells me that hee finds you a very faithfull and Authentick writer, hee shew'd mee this day the severall crystallizations of those salts, which

[87] *Weekly Memorials for the Ingenious* (London: Henry Faithorne and John Kersey, 1683/4), no. 50, Jan 15, pp. 376–82. James Fieser, "The Eighteenth-Century Reviews of Hume's Writings," *Journal for the History of Ideas* 57 (Fall 1996), pp. 645–657, on p. 646.

[88] *Weekly Memorials for the Ingenious*, pp. 376 and 382.

[89] Edward Jorden, *A discourse of natural bathes and mineral waters wherein the original or fountains in general is declared* . . . (London: Thomas Harper, 1631; reprint, New York: Da Capo Press, 1971), p. 45 as quoted in Coley, "Cure without Care," p. 198. Leeuwenhoek's work was described in Robinson's letter to John Ray on 9 May 1685, in the *Correspondence of John Ray*, pp. 167–8. Tancred Robinson served as secretary to the Royal Society in November 1685. Descartes also postulated that the "differences in salts arise from their different figures of their particles." See Parthington, *History of Chemistry*, vol. 2, p. 438.

> you have describ'd and figur'd; and hee says that hee is very fearfull to propound anything to a person of your piercing sagacity.[90]

Lister's studies in natural history also revealed him to be a consummate empiricist. As he concentrated on utilizing structure to classify animals and insects in his other treatises, it is not surprising he would utilize the same methods in his chemical work [Figure 3]. Because Lister primarily used detailed visual observation of crystal structure to classify salts, he cautioned chemists who were deceived by impure water samples in which there was "conjunction of several pure primary salts, from which confusion arises regarding the true and natural shape of crystals."[91]

After his classification of common salts, Lister turned to an analysis of salts in English mineral waters, and concluded from isolation by dehydration and crystal analysis that only two types were present: *nitrum calcarium* derived from limestone (calcium carbonate) and common sea salt. Lister thought that the presence of sea salts in English mineral springs was easily explained via the runoff of sea water inland. But nitre of lime or what he called *nitrum calcarium* was a different case. Lister commented that *nitrum calcarium* was produced by the exposure of limestone to air. This was first because "where there is nitre of lime, there is always limestone to be found," and because Lister observed that

> no salt whatever grows from limestone immediately after it has been slaked by the application of heat, but the same stone produces an abundance of salt, whether it [*i.e. the stone*] has been untreated or heated, whilst forming the walls or roof of some house; it then grows together to form crystals of its own kind.[92]

Most likely Lister was observing the formation of potassium carbonate or saltpetre crystals on walls that had been whitened by limestone, similar to the formation of nitre crystals in limestone saltpeter caves. Lister noted that *nitrum calcarium* could also not be formed by steeping limestone in water, and indeed nitrate crystals will not form in areas of excess humidity.

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[90] MS Lister 34, Bodleian Library, Oxford University, London April 12, 1683. From Tancred Robinson to Martin Lister, Lendall Street York, fol. 99 recto.

[91] Lister, *De Fontibus*, p. 4.

[92] Lister, *De Fontibus*, p. 50. [*At ubi Nitrum Calcarium, ibib perpetuo Lapis Calcarius adest*] Lister, *De Fontibus*, p. 54. [*Idem quoque identidem confirmatur; cum e lapide calcario, statim ab ipsa conctione macerato, omnino nihil salis concrescit, iden tamen lapis, sive crudus, sive coctus in Parietibus aedis alicujus, aut tectoriis usurpatus, abunde Salem suum edit, & qui in crystallos sui generis, ut supra descriptum est, concrescit.*]

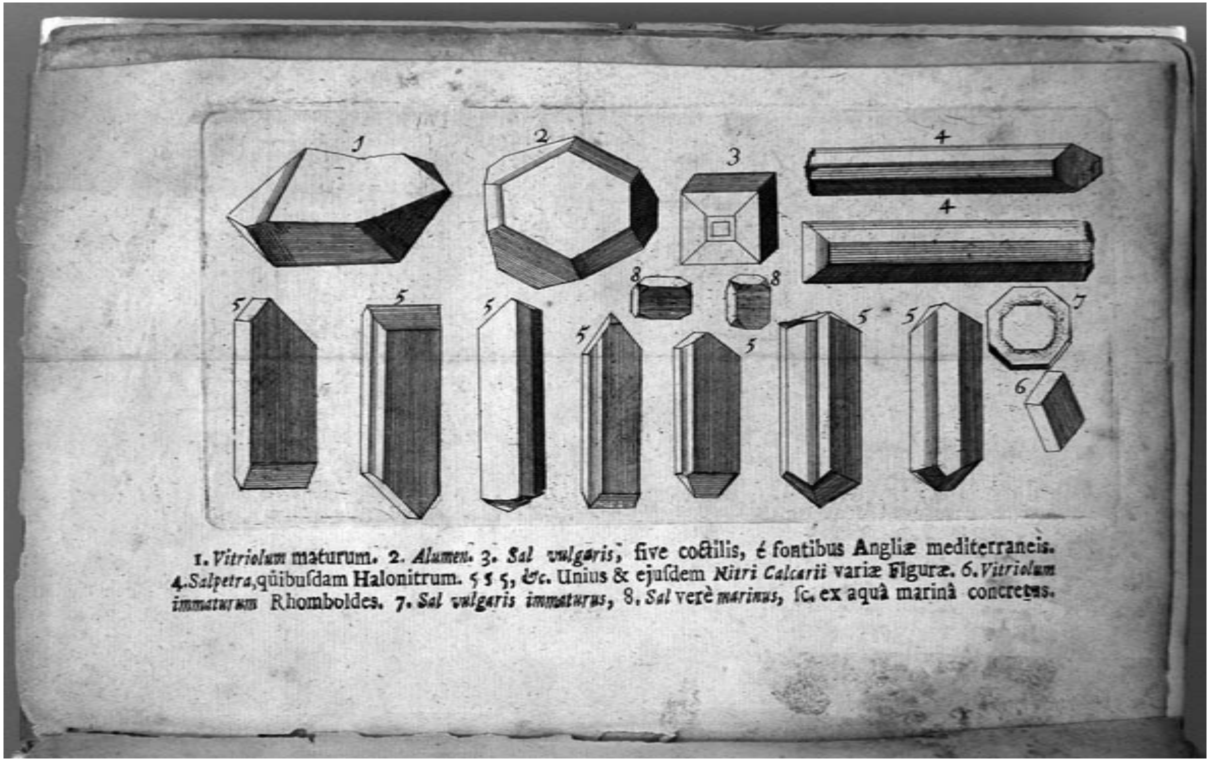

Figure 3. Crystalline shapes of salts from Martin Lister, *De Fontibus medicates Anglicae*. London: Walter Kettilby, 1684, between pages 32 and 33. Osler Library of the History of Medicine, McGill University, Montreal, Quebec, Canada.

Lister was not only interested in delineating the chemistry of English mineral waters for its own sake and for medical applications, but he wished to utilize the formation of *nitrum calcarium* as a model for the formation of vitriol from pyrites. Unlike his predecessor Van Helmont, or Johann Glauber, Lister was particularly keen to demonstrate, that like limestone salts, vitriol could only form via the exposure of pyrites to air—that nitre of lime was produced "one and the same way as vitriol."[93] Lister wrote:

> The creation of vitriol makes the whole matter clear. Its first eruption from pyrites is exceedingly premature, if it occurs in contact with air; but, as time proceeds, it becomes a little more mature. And yet fully-formed vitriol is not produced from any ferrous stone until after its due maturity which it finally reaches after a continuous period of development. If however it [a pyrite] kept perpetually under water I am not yet convinced that it will be productive of any salt. Certainly no vitriol whatever will be generated.[94]

In his assertion, Lister wished to not only to prove the efficacy of *air* or exhalations as the source of chemical reactions and effects for reasons which will be enumerated below, but argued against the Helmontian belief that vitriol and its acid, the "hungry" or "hermaphroditical salt" was the "seminal constituent of mineral waters and metal ores."[95] Lister first cited Helmont's *Oriatricke or Physick Refined* which stated that "the most excellent Vitriol, grows naturally in Mines, wherein Nature hath brought forth that hungry Salt, corroding a fertile vein [of brassy marcasite] and being dissolved in the liquor of a licking Fountain, which afterward Cauldrons do boyl into Vitriol."[96] Lister then continued, "I am unhappy with Helmontius' explanation of the generation of vitriol. He would have it that salt is formed naturally in water itself, this salt being variously known as 'juice,' 'a certain universal spirit,' 'the embryonate,' 'the corrosive,' 'the hermaphroditic' (for it is by these and other

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[93] Lister, *De Fontibus*, p. 51. [*Cum autem uno eodemque modo Nitrum calcrium nascatur, atque Vitriolum*].

[94] Lister, *De Fontibus*, p. 51. [*Rem itaque totam Vitrioli nativitas illustrat. Eius autem a Pyrita prima eruptio, si in aere sit, admodum Immatura est; procedente vero tempore, paulo perfectius est; At e nullo lapide Ferreo Consummatum Vitriolum gigantur, nisi post debitam maturitatem, ad quam, continentur quidem germinando, tandem pervenit.*]

[95] Emerton, *Scientific Reinterpretation of Form*, p. 218.

[96] Johann Van Helmont, *Oriatricke or Physick Refined: The Common Errors Therein refuted, and the Whole Art Reformed and Rectified*, trans. John Chandler (London: Lodowick Lloyd, 1662), p. 695.

names that he calls it)."[97] Lister countered Van Helmont's claims with purely empirical evidence. First, he believed it was "pointless to state that corrosive salt exist[ed] anywhere" since "up to this point it has no characteristics and is not even recognizable."[98] His observations of pyrites indicated that no vitriol was produced when marcasites were in water.[99] Further, Lister did a series of experiments in which he failed to see corrosion when he subjected many types of iron, including hematite, the "softest" form of iron, to corrosive saline or acidic solutions such as *aqua fortis* or spirit of nitre.[100]

His refutation of Helmont's theory that vitriol was formed in water was also influenced by the work of French physician-in-ordinary Samuel Cotreau Du Clos, the *Observations on the Mineral Waters of France*, which was translated into English in 1684.[101] Du Clos' work was a systematic evaluation of the chemical content of all spa waters in France under the auspices of the French Académie Royale des Sciences, part of a larger project of chemical research which began in 1666 to "determine rigorously the 'true principles of mixts [chemical compound]' by analyzing such bodies and by generating them and observing their properties."[102] Lister had been to France four times; his first voyage was

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[97] Lister, *De Fontibus*, p. 57. [*Vitrioli auem generatio, ut ab Helmontio explicata est, mihi quidem non arridet. Is vero vult, ipsis aquis naturaliter duci Salem, sive Succum, sive Spiritum quondam universalem, Embryonatum, esurinum, Hermaphroditicum (nam his & aliis nominibus ipsum idem appellat.)*]

[98] Lister, *De Fontibus*, p. 58. [*Ipsum ejus salem surinum, (ut pote nullius adhuc qualitatis participem, atque adeo non cognoscibilem) uspiam existere, esse gratis dictum*]

[99] Lister, *De Fontibus*, p. 58. [*Pyriten Vitriolum suum sub aquis persicere minime posse, ex rationibus supra positis manifestum est.*]

[100] Lister, *De Fontibus*, p. 58. [*Ferri venam ab illo sale suo esurino corrodi vix credibile est, siquidem vel mollissimum nostrum Haematiten, luti cuiusvis aemuilum, aut ipsam Ocram, vel valentissimis menstruis dectis (puta ab Aqua forti dicta, aut spiritu Nitri) minime corrodi posse experti summus.*]

[101] For Lister's mention of "Parisian Philosophers," see *De Fontibus*, 81. The full citation for Du Clos' work is: Sieur Du Clos, *Observations on the Mineral Waters of France: Made in the Royal Academy of Sciences* (London: Henry Faithorne, 1684). The review of Lister's *De Fontibus* in the *Weekly Memorials for the Ingenious* also mentioned the influence of the Royal Parisian Academy and Samuel Du Clos on Lister's *De Fontibus. Weekly Memorials for the Ingenious* (London: Henry Faithorne and John Kersey, 1683/4), no. 50, Jan. 15th, p. 380.

[102] Frederic L. Holmes, "Analysis by Fire and Solvent Extractions: The Metamorphosis of a Tradition," *Isis* 62, 212 (Summer 1971), pp. 130–148, on p. 133. Du Clos explained to his readers in his *Observations* that "the Royal Academy of the Sciences have determined to employ themselves in the Enquiry of the Qualities of those [waters] in this Kingdom, which are most considerable. And till favourable occasion may offer to make Observations at their Springs, they have caused these Waters to be brought from several Provinces, with much care, to examine them in the usual Assemblies of the Naturalists of this Academy" (p. 2).

to study for his M.A. in medicine at Montpellier (1663–66), and he published his last 1698 travel journal to Paris. It is thus not surprising that Lister would have been influenced by Du Clos' pamphlet, as his study in Montpellier coincided with the beginning of the Academy's chemical trials. Lister's *De Fontibus* was also advertised in the endpapers of the English edition of Du Clos' work, leading to the possibility that Lister was the translator; in the opinion of Lister's biographer Raymond Stearns, Lister's French would have certainly been up to the task, although he had trouble at the French Opera, "not being so Good a Frenchman, as to understand them when Sung."[103] Lister remarked in the *De Fontibus* that:

> it is not stated that mature vitriol can be drawn from any of our mineral springs as far as I know. The Philosophers of Paris [the French Academy] quite rightly marvel at this after a careful examination of about one hundred mineral springs in France. This has partly been the reason why my fellow-countrymen have quarreled in such a rude manner . . . [about metallogenesis].[104]

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[103] See Martin Lister, *A Journey to Paris in the Year 1698*, ed. Raymond Phineas Stearns (Urbana and Chicago: University of Illinois Press, 1967), pp. ix, 174 (Lister's ability in French and the opera), p. 80 (visit to Royal Academy of Sciences).

[104] Lister, *De Fontibus*, p. 65. [*Vitriolum autum maturum ab ullis aquis nostris medicatis, quod scio, elici non perhibetur. Id quod etiam jure mirantur Philosophi Parisienses, post diligens examen centum fere Fontium medicatorum Galliae. Idem ex parte in causa suit, cur nostri homines tam inurbanas lites inter se moverunt.*]

This "quarrel" was not only about the formation of minerals, but a debate among English physicians in the latter part of the seventeenth century about which particular salt was the most effective active ingredient in healing. As a practicing physician himself, Lister would have been interested in such arguments. In 1668–69, physician William Simpson wrote the *Hydrologia Chymica*, a work which "sought to identify the 'cures' associated with a plethora of 'Sanative Waters' in England and Europe" and which also sparked a number of publications about spa waters in the *Philosophical Transactions* by other doctors such as Robert Wittie, Daniel Foot, and Nathaniel Highmore. Simpson believed the active ingredient in the waters was alum, and while Wittie believed vitriol was "useful in moist diseases," its hot and biting nature drying superfluous humidity, he also thought nitre was the principal mineral in the water. (William Simpson, *Hydrologia chymica or, The chymical anatomy of the Scarbrough, and other spaws in York-Shire: wherein are interspersed, some animadversions upon Dr. Wittie's lately published treatise of the Scarbrough Spaw* . . . (London: W.G., 1669), p. 12; Robert Wittie, *Scarborough Spaw: Or a description of the nature and virtues of the spaw at Scarborough, Yorkshire* (York and London, 1667), p. 148. Nathaniel Highmore in a 1669 publication in the *Philosophical Transactions* did however suggest the healing properties of spa waters were primarily due to pyrite salts, the spring "impregnated principally from the Vitriol or Salt of Iron, which is very volatile." For these debates, see M.D. Eddy, "The 'Doctrine of Salts' and Rev. John Walker's Analysis of a Scottish Spa (1749–1761)," *Ambix* 48, 3 (November 2001), pp. 137–160, and Noel G. Coley, "Cures without Care: 'Chymical Physicians' and Mineral Water in

Volatile exhalations of vitriol and natural effects

Lister was also concerned to claim the "a continual and slow process of germination" in the air of vitriol from pyrites for not just experimental, but theoretical reasons.[105] Lister believed the atmospheric exhalations of vitriol's volatile salts were connected with chemical, geological, and meteorological reactions, and in his hypotheses we have seen he was in good company among early modern chemists and physicians. One of the fellows of the Royal Society, Daniel Coxe, was especially interested in palingenesis, and the production of volatile salts from plants via their calcinations. Given Lister's interest in botany and chemistry, Oldenburg made special mention of Coxe's work to Lister in correspondence in 1674. In a 1673 letter to Oldenburg, Lister himself already was "confident from a passage in Mr. Boile, yt he & others are masters of ye way of Extracting ye volatile salts out of all plants"; Lister also mentioned he had been performing such chemical extractions "here this 12 yeares."[106] Coxe's work on palingenics and the "plentifull" nature of pyrite salts in particular also convinced Tancred Robinson that "their fermentations, breathings, emanations, and changes . . . send[ing] forth their secret effluviums" could produce many "fruitful" effects.[107]

For Lister, one of these effects of these volatile salts in the atmosphere was the production of fossils. Past scholarship has noted the debate that Lister had with John Ray about the nature of fossils, Ray believing they were remnants of past animal and plant life, and Lister convinced that fossils were not always mineralized remains of living creatures, but could be minerals created spontaneously by nature; as he put it, some little fossilized shells could "spring from rocks and others are actual

Seventeenth-Century England," *Medical History* 23 (1979): 191–214. For Lister's distrust of Simpson, see Oldenburg to Lister, 4 September 1675, in *The Correspondence of Henry Oldenburg*, vol. 11, pp. 486–7.

105 Lister, *De Fontibus*, p. 59. [*Vitriolum assidua & lenta germinatione persici, experimenta supra posita appello, ergo non ulla corrosione momento nasci.*]

106 "Oldenburg to Lister, 20 June 1674," *The Correspondence of Henry Oldenburg*, vol. 11, pp. 35–36. "I believe, you have seen ere this, what Dr. Daniel Coxe . . . hath published in n. 101 and n. 103 of ye Transactions, concerning this way of Extracting a Volatil Salt and Spirit out of all sorts of vegetables . . ." "Lister to Oldenburg 12 March 1673/4," in *The Correspondence of Henry Oldenburg*, vol. 11, p. 303.

107 Robinson, "Some Observations on Boyling Fountains," p. 925.

living shelled creatures."[108] But there has been little discussion of the mechanism by which the mineralized fossils were created.

In his "Method for the History of Iron," Lister mentioned that pyrites not only were found near mineral baths, but often occurred in Yorkshire limestone and were mineralized with fossils. He thus believed all fossils contained iron marcasites, proven by running a magnet over them, and that pyrites could be detected in a like manner. Further, in *De Fontibus*, Lister claimed that "calcarious nitre, both when it is springing into being and when it is mature, and likewise of . . . imperfectly formed vitriol," is the "unique cause of petrification in every case."[109] Van Helmont argued that in the case of fossils, a petrifying and germinating seed in mineral waters produced shells "clothed in a crust as a result of rancid material from the depths."[110] But as we have seen, Lister denied Van Helmont's belief that water was the source of all other matter through the seminal power of specific seeds implanted in it. Instead, Lister claimed that the seed of fossils, is

> propagated not so much by sexual union [of the seeds] as by the actual rancidity from the depths. . . . The layers of rock are produced under the earth from rancid stink arising from the rocks. I am not here enquiring how layers of rock are produced, but if we suppose that they have existed from the creation of the world the question is posed as to the source of the petrification of plants, animals and now even the rocks themselves. I declare that we are generally deceived by what has a similar appearance to certain germinating rocks, as though all other kinds of rocks were produced today from one and the same cause as was once the case. Yet as far as I have been able to observe everything that petrifies is either pyrites or some kind of limestone and nothing else. These two petrifiers produced by the continual germination of salt are after their own fashion volatile, and when admitted into intermediary substances, dead as well as alive, they combine and are compacted of their own nature, and generally even preserve the shapes of the animals, and their qualities, at least to some extent.[111]

In other words, the "stink" coming from the rocks was the sulphureous vapour arising from the "continual germination" of salts of vitriol from the pyrites and calcarious nitre arising from the limestone. These vola-

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[108] Lister, *De Fontibus*, part two, p. 78. Each of the two parts of Lister's work is separately paginated. I will indicate if part two is providing the quotation in subsequent endnotes.

[109] Lister, *De Fontibus*, part II, p. 71.

[110] Lister, *De Fontibus*, part II, p. 77.

[111] Lister, *De Fontibus*, part II, p. 76.

tile salts combined with intermediary substances, which could be dead plants or animals, or just dead neighboring substances to form different petrified shapes. Just as Glauber believed his *sal mirabile*, sodium sulphate, was involved in the petrification of wood, Lister thought that "what the vitriol does to the iron is pure petrification."[112] Another sulphurous compound was responsible for petrification of all inorganic and organic matter.

Lister also apparently thought there were other "fruitful effects" of the emanations of the vitriolic salts from pyrites, in his *De Fontibus* claiming these salty emanations were the cause of the heating of mineral springs, and the production of rainstorms, earthquakes, and volcanoes. In chapter nine of the *De Fontibus*, Lister hypothesized first that the cause of heat of hot springs was "derived from salts produced by pyrites . . . or activated by pyrites itself."[113] As *nitrum calcarium* was also produced from limestone via exposure to the air, much in the same way as vitriolic salts from pyrites, he thought lime salts could also contribute heating vapours to hot springs. The abundance of limestone around pyrite minerals, as well as mists around the springs also led him to this conclusion.[114]

In asserting the centrality of pyrites in heating mineral springs, Lister first claimed that the warm sulphurous gases produced by vitriolic salts from pyrites was evidenced by mine explosions in which gases would accumulate, and the fact that mineshafts and underground tunnels of hot springs were "very warm" in the "whole of winter."[115] There was also no other substance prevalent around mineral springs that he knew of apart from volatile salts from pyrites and limestone that gave off a

[112] Lister, *De Fontibus*, part II, p. 72.

[113] Lister, *De Fontibus*, p. 76. [*Thermarum ratio, e salibus Pyritae et lapidis Calcarii nascentibus, sive ipsae Pyritis et lapide Calcario vegetantibus deducitur*.]

[114] On page 79 of the *De Fontibus*, Lister wrote: "I can prove that a warm gas is produced in like manner from active limestone in the following way. Almost all springs and wells (for most of them are considered medicinal to the extent to which they contain this or that salt) are especially warm at times of fairly severe frost, and are particularly noticeable for the way in which they give off an exhalation consisting of a very dense moist vapour, just like hot springs." [*Halitum quoque calidum a lapide calcario Vegetante, similiter ferri, sic probo. Universos fere Fontes, puteosque (nam plerique, eatenus medicati existimati sunt, quatenus hoc vel ille sale, copiosius imbuuntur) praecipue vehementioris gelu tempore tepidos esse, atque admodum copiose etiam conspicuos, densissimo vapore humido, Thermarum instar, halitus emittere.*]

[115] Lister, *De Fontibus*, p. 77. [*Item illud universo consensus testantur Metallarii, puteos subterraneos, tota hyeme, geluque praecipue tempore, admodum tepidos esse.*]

gaseous vapour.[116] Lister also believed that in "wet, moist and chilly places," the activation of pyrite salts was "particularly promoted," probably due to his observation of the increased oxidation of pyrites in humid and oxygen-rich air.[117] Lister was likely influenced by the early modern concept of "witterung," described by Christian Berward in his *Interpres Phraseologiae Metullarugicae* (Frankfurt 1684) as the "vapour or exhalation which at times rises out of the earth from rich [ore] veins," especially at the time of rain storms, and as we have seen, it was associated by Glauber with sulphurous vapors.[118] As has been well-established, the early modern period saw an influx of German mining engineers and entrepreneurs into England; Lister himself referred to Glauber and Georg Agricola extensively in his manuscript and published works.[119]

Lister's connection of volatile salts from pyrites and limestone with the heating of mineral waters was also influenced by the Du Clos' *Observations*. In speculating about the effects of spa waters, Du Clos had written that "it may be that some Mineral Vapours or Exhalations do mix with common Waters . . . and that these Waters are impregnated with their Qualities, and of some other Volatile Salts not Concrete, elevated in these dry Exhalations of humid Vapours."[120] Du Clos also argued that

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[116] Lister, *De Fontibus*, p. 80. [*At praeter Pyriten et lapidem Calcarium nihil, quod scio, halituosum emittit vaporem: atque adeo vel ambobus, vel eorum altero iste halitus calefactionis attribuendus est.*]

[117] Lister, *De Fontibus*, p. 83. "In order to prove that the activation of pyrites . . . involves vapour I shall add to these arguments that in wet, moist and chilly places the activation of those salts is particularly promoted." [*His addo, ut Pyritae & lapidis Calcarii vegitationem halituosam esse probem: nimirum, in udis & humidis, algidisque locis Salium eorum vegitationem maxime promoveri.*]

[118] Christian Berward, *Interpres phraseologiææ metallurgicææ. Oder, Erkläärung der füürnembsten Terminorum und Redearten, welche bey den Bergleuten, Puchern, Schmetlzern, Probirern und Müüntzmeistern, &c. in Benennung ihrer Profession Sachen, Gezeugs, Gebääude, Werckschafft, und Jnstrumenten gebrääuchlich sind, wie nemlich solche nach gemeinem Deutschen zu verstehn* . . . (Frankfurt, 1684), as quoted in Adams, *Birth and Development*, p. 301.

[119] Roger Burt, "The international diffusion of technology in the early modern period: the case of the British non ferrous mining industry," *Economic History Review*, XLIV, 2 (1991), pp. 249–271, on pp. 249–251. Burt actually takes issue with traditional historiography that argues that German experts introduced any unknown or radically improved techniques for the mining of non-ferrous metallic ores, but he does acknowledge they were "world leaders in the arts of the industry," and had extensive technological influence in the copper industry. In chapter six of his manuscript, "On the Method of the History of Iron," which is devoted to pyrites (pp. 43–47), Lister refers repeatedly to Glauber's *A description of new philosophical furnaces, or, A new art of distilling divided into five parts: whereunto is added a description of the Tincture of gold or The true aurum potabile: also the first part of the Mineral work, set forth and published for the sakes of them that are studious of the truth* (London: T. Williams, 1651).

[120] Du Clos, *Observations on the Mineral Waters of France*, p. 4.

hot springs grew warm specifically from hot moist vapours volatilizing from substances like pyritic vitriol, and not from the substances being combusted themselves.[121] Paraphrasing Du Clos, Lister continued in the *De Fontibus*: "The water of the hot springs, when placed on a fire, also required the same time to boil as ordinary cold water: from this it is clear that the hot springs were not heated by some underground fire."[122] Additionally, Lister also cited Du Clos' conclusion that when water from hot springs was

> taken into the mouth they do not burn it as much as ordinary water which has been heated over a stove to the same degree of heat. This seems to be due to the thinness of the substance [the exhalations] by which hot springs are heated; just as the flame produced by brandy does not burn the hand as much as a burning coal placed on it.[123]

Lister then turned to proving the activation of pyrites in the presence of moisture by analyzing their role in the cause of rainstorms. According to the *De Fontibus*, thunderstorms occurred not only because of the evaporation of the waters by sunlight, but primarily because of a partnership between moist vapours engendered by animal and plant breath and sulphurous exhalations from the volatile salts of pyrites and limestone.

To understand this mechanism of thunderstorms more thoroughly, it is necessary to examine what Lister believed about the breath of plants and animals. Although the writings of Aristotle and Theophrastus claimed that plants only had an insensitive Vegetative soul, and thus only

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[121] Du Clos, *Observations on the Mineral Waters of France*, pp. 115–116; Lister, *De Fontibus*, p. 80.

[122] Lister, *De Fontibus*, p. 81. [*Quod Thermarum aqua in ignem imposita, idem temporis spatium ad effvescendum requiret, ac ipsa aqua communi frigida: unde liquet Thermas ab igne aliquo subterraneo non callefactas fuisse.*] Du Clos, *Observations on the mineral waters of France*, pp. 118–119. Du Clos writes "That Hot Mineral Waters have no more Disposition to Boyl on the Fire than Common Cold Waters, there being as much time requir'd to cause the one to boyl as the other. Which clearly shews that the Heat which Mineral Waters contract in the Earth, proceeds not from a Motion of their Particles excited by any Subterraneous Fire."

[123] Lister, *De Fontibus*, 81. [*Quod in os sumptae, haud aeque id adurunt, ac aqua communis, ad eundem claoris gradum igne culinari calefacta: Id quod a materiae tenuitate, a qua Thermae incalescunt, oriri videtur; Siquidem Spiritus Vini dicti flamma, manum haud aeque adurit, ac pruna ei imposita.*] Du Clos writes in the *Observations*: "That these hot Mineral waters burn not the Mouth and tongue of those who drink of them at their coming forth from their Springs, as Common Water heated by Fire to a like Degree would do. Which seems to proceed from the Subtilty of the Subtances which produceth this Heat in the Water" (p. 117).

exhibited passive responses of nutrition and reproduction, Lister, like other investigators of plant sensitivity, believed that plants were more analogous to animals physiologically.[124] Inspired by the work on the circulation of the blood by William Harvey (1578–1657) and Marcello Malphigi's (1628–1694) experiments with capillaries, in a series of articles for the *Philosophical Transactions*, Lister hypothesized that plants shared a similar circulatory system, complete with veins and arteries.[125] While natural philosophers "had not yet here discover(ed) any uniting of veins into one common trunk," Lister was sure that further anatomical research would mean that "the analogie betwixt plants and animals be in all things else, as well as the motion of their juice, fully cleared."[126] As plants and animals both had similar circulatory systems, Lister speculated that they both bled and breathed; in an article in the *Philosophical Transactions*, Lister wrote in an article about grafting, it was "indeed true, there are many sorts of English Plants, which will bleed in Winter; but not also, that such Plants never refuse to do so at any time of the year, not more than a Man, who many bleed a vein when he pleaseth."[127]

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[124] Charles Webster, "The Recognition of Plant Sensitivity by English Botanists in the Seventeenth Century," *Isis* 57,1 (1966), pp. 5–23, on p. 6.

[125] Martin Lister, "A Letter of Mr. Martyn Lister, Written to the Publisher from York, January 10 1671/2, Containing an Ingenious Account of Veins by Him Observ'd in Plants, Analogous to Human Veins," *Philosophical Transactions*, 6 (1671), pp. 3052–3055, on p. 3052.

[126] Martin Lister, "A Further Account Concerning the Existence of Veins in All Kinds of Plants; together with a Discovery of the Membranous Substance of those Veins, and of Some Acts in Plants Resembling Those of Sense . . ." *Philosophical Transactions*, 7 (1672), pp. 5132–5137, on pp. 5136–7, quoted by Miles Barker, "The Motion of their Juice": Science, History, and Learning about Plants and Water," paper presented at the Australasian Science Education Research Association, Darwin Australia, 9–12 July 1998, p. 1, online http://www.fed.qut.edu.au/projects/asera/PAPERS/barker.htm. Accessed 9 August 2002. See also "Lister to Oldenburg, 15 February 1670/1," in *The Correspondence of Henry Oldenburg*, vol. 7, pp. 457–462 for a discussion of the circulation of fluids in plants, especially p. 459.

[127] Martin Lister, "Letter Written by Mr. Martin Lister to the Publisher, January 25. 1670/71 . . . Partly to the Bleeding of the Sycamore" *Philosophical Transactions* 5 (1670), pp. 2067–69, on p. 2069. Lister also writes to Ray of his "bleeding" experiments on trees in an undated letter. See "Dr. Lister to Mr. Wray," *Correspondence of John* Ray, p. 74. According to John Evelyn's *Sylva*, it was advisable to graft trees according to the phases of the moon, just as one bled humans paying attention to the lunar phases. Evelyn cited Pliny's *Natural History* for his information. See John Evelyn, *Sylva: Or a Discourse of Forest Trees* (London: Doubleday, n.d.), vol. 2, pp. 67–68.

In the *De Fontibus*, Lister then mentioned, "as plants live they breathe just like animals."[128] As support, he cited a June 1669 experiment on plant transpiration performed by John Wills, a fellow of Trinity College, Oxford in which botanical specimens were placed in glass vials "in order to find in what measure Herbs might perspire."[129] Convinced that plants "expired" a good deal of moist breath, Lister then went on to claim their breath was also responsible for wind. In an essay in the *Philosophical Transactions*, Lister wrote,

> Among the known Sea Plants the Sargosse or *Lenticula Marina* [Sea Lentil] is not to be forgot; this grows in vast quantities from 36 to 18 degrees Northern Latitude, and elsewhere upon the deepest Seas. And I

[128] Lister, *De Fontibus*, p. 88.

[129] Lister specifically cited Dr. Robert Plot's *The Natural History of Oxfordshire, Being an Essay toward the natural History of England* (Oxford: The Theater, 1677), pp. 254–5. Plot (1640–96), of Magdalen College, Oxford, and Secretary of the Royal Society in 1682, described it as follows: "He [Wills] took two glass Vials with narrow necks, each holding one pound 8 ounces, and 2 drachms or water . . . into one of these glasses filled with water, he put a sprig of flourishing Mint (which before had grown in the water) weighing one ounce: the other glass he also fill'd with water, and exposed them both in a window to the Sun. After ten days time, he found in the bottle where the mint was, only five ounces and four drachms of water remaining, and no more so that there was one pound two ounces and six drachms spent, the mint weighting scarce two drachms more than at first. From the other Glass, where water was put of the same weight, and no mint, he found the Sun had exhaled near one ounce of water, and therefore concluded it drew but so much out of the first glass, at least no more: So that allowing one ounce for what the Sun had exhaled, there was in those ten days spent by the mint, one pound one ounce six drachms of water; and the mint being increased in weight only two drachms, 'twas plain the mint had purely expired in those two days, one pound one ounce and four drachms, that is, each day above an ounce and half, which is more than the weight of the whole mint. Whence he concluded that what Malphigius so wonders at in his Book *De Bombyce*, viz. that those Animals will sometimes eat in one day, more than the weight of their bodies, is out-done by every sprig of mint, and most other Herbs in the Field, which every summers day attract more nourishment than their own weight amounts too. Which the same ingenious person at least questions not (and therefore wishes trials may be made) of the *Tithymali, Esulae*, and especially of *Pinguicula and Ros Solis*, which last sucks up moisture faster than the Sun can exhale it, and is bedewed all over at Noon-day, notwithstanding its power: Nor doubts he but that Wormwood, and all other Plants that are very hot, and of strong smells, expire as much, if not more than the Mint." All of the plants (except Wormwood) mentioned by Plot produce liquids that could be interpreted as dew. *Ros Solis* was *Drosera rotundifolia*, or Sun-Dew, a carnivorous plant noted for its dew on its leaves that intensified with the sun; *Pinguicula* was known as butterwort, another carnivorous plant with mucilage drops on its leaves to catch insects, apparently interpreted by Plot as dew. *Tithymali* and *esulae* are species of spurge that produces a milky latex from roots and stems when injured. For descriptions of these plants, see John Gerard, *Herball or General Historie of Plantes* (1613) (New York: Dover Publications, 1975).

> think . . . from the daily and constant breath of that Plant, the Trade or Tropic Winds do in great part arise.[130]

He also hypothesized that plant breath was also primarily moist; Lister used as evidence that night dews and mists from springs, rivers, and the sea also arose "largely from the condensed breath of plants."[131] And the moisture of plant breath combined with Pyrites created rain. Although Lister acknowledged that rains were "exhaled as a result of the heat of the Sun" on the ocean, he considered the condensations of the moist "vapour both of Pyrites and limestone" found underground in mines as well as that from "especially the vegetation growing on Pyrites and limestone" to be the "greatest material for rain."[132] Lister further commented that violent rain occurred when the vapour of pyrites and their vitriolic salts were mixed

[130] Lister, "Certain Observations," p. 494. Sea Lentil or Sargasso weed, is a prolific brown seaweed of the genus *Sargassum*, and was described in the *Philosophical Transactions* by Hans Sloane (1660–1753). This lush plant covers an area of Sargasso Sea that is at the heart of the Bermuda Triangle, often having floating layers 1–2 feet thick. The plant has small bladders in the form of empty sea pods that allow it to float on the sea surface "Sargasso Sea," Bermuda-Triangle.org, p. 1, online. http://www.bermuda-triangle.org/500_Leagues_of_Sea/Sargasso_Sea /sargasso_sea.html, accessed 9 August 2002. For a seventeenth-century description of the plant, please see Gerard, *Herball or General Historie of Plantes*, 1614–15. Hans Sloane, "An Account of Four Sorts of Strange Beans, Frequently Cast on Shoar on the Orkney Isles, with Some Conjectures about the Way of Their Being Brought Thither from Jamaica, where Three Sorts of Them Grow," *Philosophical Transactions*, 19 (1695–1697), pp. 298–300, on p. 300. The mounted specimens of the Sargasso weed or the *Lenticula Marina* that Hans Sloane collected during his voyages to Jamaica (1687–1689) can be seen in the Sir Hans Sloane Jamaican Botanical Collection, Natural History Museum London, online http://internt.nhm.ac.uk/cgi-bin/botany/sloane/detail.dsml?ID=1046, accessed 9 August 2002. Although Lister seems to be saying the physical breathing of plants causes the trade winds, it may be possible that he thought the volatile salts contained in plant breath may have been behind the production of winds. Sargasso weed was very salty in taste, which also may have some bearing on Lister's theory.

[131] Lister, *De Fontibus*, pp. 87, pp. 89–90. In these pages, Lister's idea that plant breath was responsible for dews led him to consider the use of it for water purification at sea, a much-debated problem in the seventeenth-century English navy. Because Lister believed the condensation of plant breath produced water, he did an experiment in which he placed sea weed, some with roots, some adhering to stones, in a "glass bodie"; the "glass bodie being full, I put thereon a head with a Beck, and adapted a Receiver thereto . . . from these Plants did distill dayly . . . a fresh, very sweet and potable water." After urging further experimentation and how his discovery "may well prove most desirable and useful for sailors," Lister then went on to speculate that sea water was the only "element of water created" in Genesis before any Animal or Vegetable was created, or the Sun itself;" over time the "vapours of Plants and the Breath of Animals and the Exhalations raised by the Sun" created the fresh water in Rivers."

[132] Lister, *De Fontibus*, p. 90. [*At forte longe maxima pluviarum material a salibus Metallorum subterraneis, & praecipue Pyritae & lapidis Calcarii vegetantibus oritur.*]

> in tiny amounts with some moist vapour, then if at any time and for any reason it happens to be set on fire [by lightening or friction] little droplets of water are necessarily forced together and thrown down, when the draught by whose movement and stirring alone they are borne up into the atmosphere is driven away.[133]

In other words, the force of sparked vapor pushed water droplets together and downwards.

Lister also believed thunder and lightning "owed their matter from the sole [sulphurous] breath of the Pyrites."[134] In the *De Fontibus*, as support for his assertions, Lister cited Pliny's *Natural History*: "Pliny says that thunder and lightening burn with sulphur, and the actual light they produce is sulphurous."[135] Lightning does small of sulphur, sulphur is in fact an excellent insulator, and static electricity accumulated on it discharges in electrical sparks towards proximate objects, effects which may have given Lister his idea. Further, in early modern German mining literature, ore exhalations due to *witterung* were implicated in meteorological effects such as thunder and lightening.[136] Referring to an article he wrote in the *Philosophical Transactions*, Lister also enumerated several recorded instances by Aristotelian scholar Julius Scaliger (1484–1558) and author of "books of secrets" Giordano Cardano (1501–76) of "Iron to have fallen in great masses, and also in powder after the manner of rain, out of the Air" indicating by analogy that because iron pyrites were involved in meteor showers, they would be involved in rain showers as well.[137] Lister then remarked that according to William Gilbert's *De Magnete* (1600) that presumably these pyrite-rich meteors, which were

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[133] Lister, *De Fontibus*, p. 83. [*Cum autem id vapore aliquo humido per minia miscetur, si quando quacunque de causa, incendi contingat aqueas particulas simul cogi, dejicique necesse est; scilicet Spiritu, cuius solius motu & agitatione in aura feruntur, exploso.*]

[134] Martin Lyster [Lister], "The Third Paper of the Same Person, Concerning Thunder and Lightening being from the Pyrites," *Philosophical Transactions*, 14 (1684), pp. 517–19, on p. 518.

[135] Lister, *De Fontibus*, p. 79. Pliny, *Natural History*, 35.50, *passim.* Lister had high regard for Pliny; in a letter to John Ray, he wrote: "I remember you once took away the prejudice I had against Pliny, and I have ever since looked upon him as a great treasure of learning." See Ray, "Mr. Lister to Mr. Wray, 22 December, 1669," in *The Correspondence of John Ray*, pp. 48–9.

[136] Olaus Magnus, *Historia Oali Magni Gothi Archiepiscopi Upsalensis de Gentium Septentrionalium varris conditionibus &c* (Basel, 1567), book 6, chapter 11, as quoted in Adams, *Birth and Development*, p. 303.

[137] Martin Lyster [Lister], "The Third Paper," p. 518. For information about Giordano Cardano and Julius Scalinger, please see William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton: Princeton University Press, 1994), pp. 278–81.

"very hard and of the color of iron," were never accompanied by showers of "gold or silver ore, or tin or Lead"; therefore this "ferrum were composed of the breath of pyrites."[138] His interest in the effects of the emanations of iron pyrites also led him to do a systematic survey of iron deposits in England and magnetism, contained in both the *De Fontibus* and in his "Method of the History of Iron."[139]

Lister claimed iron pyrites were involved in rainstorms because "lightening was magnetic."[140] He again cited an article in the *Philosophical Transactions*, in which an Irish sea-captain on a voyage to Bermuda found himself caught in a storm in which a "terrible clap of Thunder tore his sayles, and did some damage to his rigging."[141] The lightening apparently magnetized his compass, "the North and South points having changed positions . . . which strange and sudden accident he could impute to nothing else but the operation of the Lightning or Thunder newly mentioned."[142] Lister's opinion about lightening and thunder was apparently somewhat influential, as fifty years later, Benjamin Franklin wrote about it in the *Pennsylvania Gazette* in December 1737: "Dr. Lister is of the opinion, that the material cause of thunder, lightening, and earthquakes, is one and the same. Viz. the inflammable breath of the pyrites, which is a substantial sulphur, and takes fire in itself."[143]

In the *De Fontibus*, Lister also briefly mentioned that earthquakes were primarily due to the firing of the "inflammable breath of Pyrites . . . underground," and earthquakes could occur "if by chance the fire [from pyrites] is contained in subterranean hollows, and hot springs" or "if it is transported in abundance among water channels, even if it is not

[138] Lister, "The Third Paper," pp. 518–19.

[139] Lister's connection of magnetism and chemistry will be the subject of a future paper.

[140] Lister, "The Third Paper," p. 519. In fact, Lister is correct that lightening can magnetize a ship; a lightning strike can magnetize a keel or other metal fittings, rendering one's compass useless.

[141] Anonymous, "An extract of a Letter written from Dublin to the Publisher . . . viz. A narrative of a strange effect of Thunder upon a Magnetick Sea-card," *Philosophical Transactions*, 11 (1676), pp. 647–653, on p. 648.

[142] "An extract of a Letter," p. 648.

[143] See Alfred Owen Aldridge, "Benjamin Franklin and Jonathan Edwards on Lightening and Earthquakes," *Isis* 41 (1950): 162–4, on p. 162. Franklin may also have seen Lister's "Three Papers of Martyn Lister, the first of the Nature of Earth-quakes; more particularly of the Origine of the matter of them, from the Pyrites alone," *Philosophical Transactions* 14 (1684), pp. 517–19, in which Lister states in the first paragraph on p. 517: "The material cause of Thunder and Lightening, and of Earthquakes is one and the same; viz, The inflammable breath of the Pyrites, the difference is, that one is fired in the Air; the other under ground."

set on fire."[144] The possible involvement of pyrites in earthquakes also continued to provide fodder for Royal Society experiments by Stephen Hales (1677–1761) into the 1750s. Hales wrote *Vegetable Staticks* (1727) in which he measured the rate of plant transpiration, so it would not be surprising if he were familiar with Lister's works.[145] As Cohen has noted, the antiquarian and biographer of Newton, Reverend William Stuckley (1687–1785) took notes on some papers presented in the Royal Society in 1752, in which Hales:

> gives an experiment of putting some pyrites stone, with some *aqua fortis* [concentrated nitric acid (HNO_3)], into a vessel set in water, and covered with a large glass, whose mouth must be immersed in the water. A brisk fermentation arises, a black cloud, and a destruction of some quantity of air . . . Then suddenly taking up the glass out of the water, and letting in fresh air, a new ebullition arises . . . From this experiment the doctor apprehends that the cause of earthquakes is much illustrated. He says sulphureous vapour arises out of the earth generated probably by the pyrites abounding therein . . . through cracks and chinks of the gaping earth. The vapours fly into the upper regions of the air, where they meet with pure and uncorrupted air, clouds intervening like as in the glass receiver, they ingage with violence . . . through the clouds, and cause a prodigious tumult above . . . These concussions in the air act upon the surface of the earth and cause earthquakes.[146]

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[144] Lister, *De Fontibus*, pp. 78–9. [*Pyritae autem halitus effectus sunt Fulmina et Fulgura, si in caelo accendatur; Terrae motus, si forte cavis subterraneis accensus contineatur: Thermae si per aquarum ductus subterraneos copiose feratur, etiamsi non accendatur.*]

[145] *D.N.B.*, c.v. "Stephen Hales," 1937–9 ed. Stuckley and Hales became friends when Hales was a fellow at Corpus Christi, Cambridge; according to Hales' entry in D.N.B., "both 'perambulated' Cambridgeshire in search of [John] Ray's plants." Since Lister also contributed specimens to Ray's plant catalogue, it is most likely that Hales knew of Lister's work. Please also see D.G.C. Allan and Robert E. Schofield, *Stephen Hales: Scientist and Philanthropist* (London: Scolar Press, 1980); Peter J. James, "Stephen Hales' "Statical way," *Pubblicazioni della Stazione zoologica di Napoli. II, History and philosophy of the life sciences* 7, 2 (1985), pp. 287–299.

[146] *Family memoirs of the Rev. William Stuckley* (Publications of the Surtees Society, 1882–7) vol. 2, pp. 378–9, as quoted in I. Bernard Cohen, "Neglected Sources for the Life of Stephen Gray (1666 of 1667–1736)" *Isis* 45, 1 (May 1954), pp. 41–50, on pp. 44–5. Hales indeed would have observed an exothermic reaction (brisk fermentation). The sulphurous vapours he reported were most likely sulphur dioxide produced from the reaction of pyrites with oxygen: $4\ FeS_2 + 110_2 \rightarrow 2Fe_2O_3 + 8\ SO_2$, or just the production of free sulphur, as enumerated below. The reaction that Hale described was likely (assuming some pyrites were iron-copper pyrites, as he does not distinguish):

$CuFeS_2 + 4\ HNO_3 = Cu(NO_3)_2 + Fe(NO_3)_2 + 2\ H^+ + 2\ S(solid)$ OR in word form:

Iron-copper pyrites + nitric acid = Copper nitrate and iron nitrate and hydrogen ions with solid sulphur.

In a like fashion, Lister also mentioned in an article in the *Philosophical Transactions* that volcanoes were "Mountains made up in great part of Pyrites" because of the "quantities of Sulphure thence sublimed, and the Application of the Load-stone to the ejected Cinder."[147] He may have received this notion from *The Vulcanoes* (1669), which was an English summary of Athanasius Kircher's *Mundus Subterraneous.* Kircher explained, "sulphureous . . . spirits, which lodged there [in subterranean caves] . . . at length ends in a new food and nourishment of the fire."[148] Kircher also claimed that "sulphur . . . insinuated into the pores of the Calx [limestone] or Calcined Lime" where it "administers that perpetual and everlasting fuel and food of Fire"; he also speculated that vitriol and sal ammoniac might play a role in the production of lava.[149] We have seen earlier that Lister thought limestone might play a role in concert with pyrites in producing the heat of hot springs; his concern with "caukestone," which he termed "a very odd mineral," may have been suggested by Kircher's speculations.[150] Finally, to answer objections that England had a good quantity of pyrites, but little volcanic activity, Lister claimed that in areas such as Mount Vesuvius experienced more volcanic eruptions because "the Pyrites of the Vulcano's or burning Mountains may be more Sulphurious then ours. And indeed it is plain, that some of ours in England are very lean."[151]

In the frontispiece of his *De Fontibus*, Lister included a quote from Pliny's *Natural History: Tales sunt aquae, qualis terra per quam fluunt*, or waters take their nature from the strata through which they flow. Understanding the chemical nature of the waters subject to the chemical influence of pyrites was indeed crucial for Lister, and subsequent natural philosophers to comprehend meteorological and geological change. Despite the "very lean" nature of English pyrites, Lister himself seemed to regard their investigation as particularly important. Not only did the production of

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Some metallic copper impurities in the pyrite could have reacted further with nitric acid to create nitrogen dioxide, a brownish gas which may have been the "black gas" that Hales observed:

$Cu(s) + 4\ H + (aq) + 2\ NO_3{}^{-}(aq) \rightarrow Cu_2 + (aq) + 2\ NO_2(g) + 2\ H_2O(l)$

[147] Lister, "The Second Paper of the Same Person Concerning the Spontaneous Firing of the Pyrites," *Philosophical Transactions*, 14 (1684), pp. 515–517, on p. 516.

[148] *The Vulcano's: Or, Burning and Fire-vomiting Mountains, famous in the World . . . Collected for the Most Part out of Kircher's Subterraneous World* (London: J. Darby, 1669), p. 56.

[149] *The Vulcano's*, p. 57, p. 60.

[150] For Lister's description of limestone, please see "Lister to Oldenburg, 20 November 1674," *Correspondence of Henry Oldenburg*, vol. 11, pp. 132–3.

[151] Lister, "The Second Paper," p. 514.

the vitriolic varnish of pyrites convince him of the superiority of exhalation theory over aqueous mechanisms for the formation of minerals, but these minerals' sulphurous vapours provided a fertile explanation for many natural phenomena.

Plants and Salts: The Work of Nehemiah Grew

In chapter two, we saw that salts were thought to provide an elemental structure to living things. This belief, informed by a reaction to Helmontian chymistry within the Royal Society, characterized the botanical work of Nehemiah Grew (1641–1712). Grew was botanist and secretary to the Royal Society, has been subject to extensive scholarly analysis, ranging from the patronage required for the publication of his magisterial *Anatomy of Plants* (1682), to his cataloguing of the Royal Society collections, to his philosophy of vitalism.[152] However, other than his role in the discovery of Epsom salts and his promotion of nitre for fertilizer, his contributions to chymistry have received less scholarly attention. After receiving his B.A. from Cambridge in 1661–1662, Grew went onto receive his medical degree from Leiden, studying under Sylvius and writing a dissertation on the liquors of the nervous system, utilizing Sylvius' well-known acid-alkali iatrochymistry as the basis for his analysis.[153] Grew's continued devotion to chemical research was applied to his botanical work. As Bolan has shown, in his *Anatomy*, Grew thought it was necessary to perform "a chemical analysis of the contents of plants

[152] Brian Garrett, "Vitalism and teleology in the natural philosophy of Nehemiah Grew (1641–1712)," *British Journal of the History of Science* 36, 1 (March 2003), pp. 63–81; Michael Hunter, "Early Problems in Professionalizing Scientific Research: Nethemiah Grew (1641–1712) and the Royal Society, with an unpublished Letter to Henry Oldenburg," *Notes and Records of the Royal Society of London* 36, 2 (February 1982), pp. 189–209; Jeanne Bolam, "The Botanical Works of Nehemiah Grew, F.R.S. (1641–1712)," *Notes and Records of the Royal Society of London* 27, 2 (February 1973), pp. 219–231; Conrad Zirtle, "Introduction," in Nehemiah Grew, *The Anatomy of Plants*. Sources of Science, no. 2 (New York: Johnson Reprint Corporation, 1965); A. Sakula, "Doctor Nehemiah Grew (1641–1712) and the Epsom salts," *Clio Medica* 19, 1–2 (1984), pp. 1–21; William Lefanu, *Nehemiah Grew: a Study and Bibliography of his Writings* (Detroit 1990); J.R. Parthington, *A History of Chemistry*, 4 vols. (London, Macmillan, 1961–1970), vol. 2, pp. 567–8 on Grew.

[153] Nehemiah Grew, *Disputatio Medico-Physica, inauguralis, de liquore nervosa . . . pro gradu doctorates . . . subjicit Nehemiah Grew, e. com Warwickensi, die 14 Julii*. Ph.D. diss (University of Leiden, 6 July 1671). This work was published by Elsevir in 1671, and the original can be found in the National Library of Medicine and the British Library. The author plans to issue a translation with commentary in future.

both air and liquid, their colors, tastes, smells... all to be examined by agitation, frigifaction, infusion, digestion, decoction, distillation, calcination, and all the armoury of seventeenth-century analysis."[154] Grew attempted such analyses in a series of lectures appended to the *Anatomy*; like the *Anatomy*, the chemical papers were subsidized by the Royal Society's general fund.[155]

In his work, Grew concentrated particularly on the salt chymistry of plants, following an established tradition in early modern chymistry. As we have seen, there was a running controversy over fire analysis in the early modern period, with Van Helmont claiming salt was not a true chymical principle, but rather produced by the heat of analysis. Therefore, Van Helmont questioned earlier alchemical claims of palingenics that authors such as Duchesne made in his *Ad veritatem hermeticae medicinae* (1604)—in the case of burning plants to ash, Van Helmont denied that fixed salts pre-existed in plants, and believed they were produced, not extracted, by the fire. The idea of preformation of salts continued to be a prevalent topic in seventeenth-century chymistry.[156] Nicholas Lémery (1645–1715), a French corpuscularian and writer of the popular French chemistry textbook, translated into English as the *Course of Chymistry* (1698), wrote:

> Several modern philosophers want to persuade us that it is uncertain whether the substances we obtain from the mixts and which we have called Principles of Chemistry are present effectively and naturally in the mixts; they say that in rarifying matter in the distillations, fire is capable of imparting to matter subsequently an arrangement that is quite different from the one it had previously and to form the salt, oil and other things obtained.[157]

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[154] Bolam, "The Botanical Works of Nehemiah Grew, F.R.S. (1641–1712)," p. 225.

[155] Hunter, "Early Problems in Professionalizing Scientific Research: Nethemiah Grew (1641–1712) and the Royal Society, with an unpublished Letter to Henry Oldenburg," p. 201.

[156] For an overview of preformation theory, see Eduard Farber, "Variants of Preformation Theory in the History of Chemistry," *Isis* 54,4 (December 1963): pp. 443–460.

[157] Nicolas Lémery, *A Course of Chymistry Containing an easie Method of Preparing those Chymical Medicines Which are Used in Physik* (London: W. Kettilby, 1698), p. 7. According to the *Dictionary of Scientific Biography* (p. 1329), "Lémery introduced his explanations of chemical reactions in terms of particle shape and movement on an ad hoc basis. Thus the best way to explain the nature of salts is to attribute shapes to their constituent particles. Acid salts must have sharp pointed particles because of their sharp taste and, even more convincingly, because they solidify in the form of sharp pointed crystals. Contrariwise, alkalis are composed of earthy solid particles whose interstitial pores are

For his part, Lémery argued that for volatile alkali salts (primarily ammonia), "it is obvious that fire has done something to this salt, because when it was in the plant it had not odor similar to that acquired by the distillation."[158]

Boyle's protégé, Daniel Coxe, also engaged in this debate in his publications in the *Royal Society Transactions*, publications that apparently reached a wide audience. Herman Boerhaave cited Coxe's papers in which Coxe described that he took a plant, bruised and burnt it, and then calcinated its ashes, extracting from it a volatile salt. He then made a compound with the salt, and submitted it to a gentle heat; arising from the ashes were salt crystals which resembled a stem, leaves and flowers, an apparition of the plant which had been submitted to combustion.[159] Coxe also burned plants to ash, and percolated water through the ashes to obtain the lixivial or alkaline salts in an attempt to classify vegetative salts and to illustrate a Van Helmontian principle. As these "alkalies were also salts, questions regarding their production led directly to the question of whether or not they preexisted in combustible bodies."[160] Antonio Clericuzio has noted that Coxe denied that "fixed salts praeexisted in vegetables," thinking they were "produced, not extracted, by the fire. The salts alkali result from the combination of combination or union of the saline and of the sulphureous principles."[161] We not only see this assertion in Coxe's published works in the *Philosophical Transactions*, but in a letter he wrote in 1666 to Boyle, when he states "That Alcalies, or fixd salts made by incineration or Calcination seem not to have been Such ea forma[c] in the Concretes which afforded them by as

so shaped as to admit entry of the spike particles of acid. Lémery postulated that, for reaction to take place between a particular acid and alkali, there must be an appropriate relationship between the size of the acid spikes and alkaline pores."

[158] Lémery, *Course of Chymistry*, p. 20.

[159] Daniel Coxe, "A Continuation of Dr. Daniel Coxe's Discourse, Begun Numb. 107. Touching the Identity of All Volatile Salts" *Philosophical Transactions* 9 (1674): 169–182, on pp. 174–175. Boerhaave cited Coxe's work when describing the putrefaction of vegetables in his *Elements of Chemistry*. See *Dr. Boerhaave's Elements of Chemistry, Faithfully Abridg'd . . . by Edward Strother, M.D.*, second edition (London: C. Rivington, 1737), part II, p. 95. Lémery and Stahl also supported the idea that the fixed alkali in the vegetable is produced by burning. See Parthington, *History of Chemistry*, vol. II, p. 539.

[160] William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago and London: University of Chicago Press, 2002), p. 84.

[161] Antonio Clericuzio, *Elements, Principles, and Corpuscles: A Study of Atomism and Chymistry in the Seventeenth Century* (Dordrecht and Boston: Kluwer Academic Publishers, 2001), p. 161.

Alcalies borne to bee the product of the Fire they not being Pruducible but by Calcination."[162] Hence, by denying an inherent salt principle, Coxe was challenging the Paracelsian *tria prima*. While admitting that he did get palingenic apparitions of plants via isolating salts, after consulting with Royal Society fellow Robert Moray, who as we have seen had his own interests in salt chymistry, Coxe also argued that his results were a "meer Phantasme, or a fortuitous Colation of Salt to such pretty figures" to show that there was no saline principle that could recreate the essence of a vegetable.[163] Much for the same reason, Coxe also concluded from his researches that the "fixed salts extracted from the ashes of plants do not differ from one another" again denying there was any essential salt unique to each plant.[164]

Although Grew followed a similar chemical procedure, he utilized his botanical chymistry and microscopic expertise honed researching his *Anatomy of Plants* to elaborate and question some of Coxe's, Boyle's, and hence Van Helmont's ideas about principles of matter.[165] In his work with plants, Grew believed first that "no principle was made by the fire: all Principles being unalterable," and it was necessary to distinguish between elemental salt, or salt in its substantial form, which he did believe existed, and its "mixture with other principles; from whence it may receive different Shapes and Names."[166] Grew acknowledged that calcinations of a body, or its fermentation "after the manner shewed by the curious Improver of chemical knowledge, Dr. Daniel Cox . . . yieldeth some kind of Salt," and a "Lixivial Salt, qua Lixivial" could be made by combustion. But, he then stressed: "All which Salts are made, not by making the Saline principle, but only by its being differently mixed, by those several ways of the Solution of Bodies with other Principles; from which its different mixture, it receives the different denominations of Marine, Nitrous, Volatile, or

[162] Daniel Coxe to Robert Boyle 19 January 1666, in Robert Boyle, *The Correspondence of Robert Boyle*, vol. 3, pp. 30–43, on p. 34.

[163] Coxe, "A Continuation of Dr. Daniel Coxe's Discourse, Begun Numb. 107. Touching the Identity of All Volatile Salts" p. 178.

[164] Clericuzio, *Elements, Principles and Corpuscles*, p. 161.

[165] Nehemiah Grew, *The Anatomy of Plants. With an Idea of a Philosophical History of Plants, and Several other Lectures Read before the Royal Society* (London: W. Rawlins, 1682). This is the edition that will be used throughout.

[166] Grew, "A Discourse Read before the Royal Society December 10, 1674 Concerning the Nature, Causes, and Power of Mixture," in *Anatomy of Plants*, p. 227. Clericuzio also briefly notes Grew disagreed with Coxe in *Elements, Principles, and Corpuscles*, p. 162, but does not elaborate the basis of Grew's logic.

Lixivial."[167] For Grew, though mixtures of different salts interacted in a unique manner to produce various plant species, salts made by the fire did not contain elemental salt. However, he did allow for the possibility that salts created by the *air* were elemental salts containing the vital essence of a plant, and he believed he had created a process to extract such salts from vegetables. Grew took as his inspiration work done by contemporaries that indicated volatile salts in the air, such as aerial nitre, possessed vitalizing and elemental principles. He also utilized the results of his chemical research to draw conclusions about plant structure and color, and like Lister, applied his results to other areas in natural history such as meteorology.

Salts and Plant Structure

Grew's extensive macroscopic and microscopic researches and the series of plates he drew in the *Anatomy* revealed to him that plants had a fundamental geometrical structure. In his studies, Grew concluded that the "leaves of most Plants, have a Regular Figure, and this Regularity, both in Length and Circuit," is always definable in terms of the arcs of circles.[168] At the microscopic level, leaves also had a mathematical pattern of fibres that underlay its structure, leading Grew to ask what was the fundamental principle from which "Nature seems to draw her first Strokes."[169] For him, the key to the plant's regular structure lay in the Saline Principle "under which divers species were comprehended"; "whether Alkaline, Acid, or of any other Kind . . . the Salts are, as it were, the Bones" of the plant.[170] Grew's statement was likely influenced by Paracelsian chemistry, as we have seen in chapter two that in the "Paracelsian scheme of the *tria prima* salt is the directive for matter to assume solidity and bodily shape."[171]

Grew sought to prove this principle by first noting that fertilizers that nourished plants contained salt. This suggested by analogy that plants

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[167] Grew, "A Discourse Read before the Royal Society December 10, 1674 Concerning the Nature, Causes, and Power of Mixture," in *Anatomy of Plants*, p. 227.

[168] Grew, *Anatomy of Plants*, p. 150.

[169] Grew, *Anatomy of Plants*, p. 157.

[170] Grew, *Anatomy of Plants*, p. 158.

[171] Walter Pagel, *The Smiling Spleen: Paracelsianism in Storm and Stress* (Basel and Munich: Karger, 1984), p. 37.

were also made of saline substances.[172] In order to better understand how salts combined to form the leaf structure, he then sought to classify the types of vegetative salts. In the *Producibleness of Chemical Principles* (1681), Boyle had replaced the usual division of salts into acid and alkali with a tripartite division of salts into acid, alkaline, and urinous or volatile, (the latter category including nitre), a classification that Coxe would also follow.[173] However, Grew argued instead that vegetative salts should be classified into four types—nitrous, acid, alkaline, and marine—claiming "all the four salts have a share in the formation of a leaf, or other part of a plant."[174] Grew did acknowledge that lixiviating plants via fire revealed that they contained a fixed as well as a volatile alkali; "the former in the ashes, the latter in the Soot"; because plants yielded acid juices in distillation in a sand furnace, this testified to the presence of an acidic salt within them.[175] But where did the fourth marine salt come from? Grew claimed he could produce a salt quite outside of the tripartite classification, "another kind of salt . . . an essential salt," via the action of the air upon lixivial alkaline plant salts. This essential salt would in turn, shoot another marine salt, showing the air was "nature's grand menstruum, which goes sometimes greater than the Fire itself."[176]

Though Grew does not specifically state from where his idea of the air being a creative principle stemmed, it is likely his assertion may have been a modified expression of a prevalent early modern belief in *witterung*. Another stronger possibility is the work of William Harvey's student, Francis Glisson (1599–1677). Grew's microscopic work on plants began after his half-brother Henry Sampson mentioned a passage in

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[172] Grew, *Anatomy of Plants*, p. 158.

[173] Newman and Principe, *Alchemy Tried in the Fire*, p. 275. See also Antonio Clericuzio, "A redefinition of Boyle's chemistry and corpuscular philosophy," *Annals of Science*, 47 (1990), pp. 561–589, esp. pp. 588–589. Robert Boyle, *The Producibleness of Chymical Principles* published as an appendix to *The Skeptical Chymist*, second edition (London, 1681), pp. 9–10. As Clericuzio has indicated, Boyle was dissatisfied by the information given by using the color indicators syrup of violets or *lignum nephriticum* to determine alkalinity or acidity. This was because these tests only indicated if a salt was acid or not, but one would not know if it was urinous or alkaline. Thus, "Boyle suggested a trail by the color non-acid salts showed when they were combined with sublimate dissolved in fair water." Lixivial salts, produced an "orange tawny precipitate, and urinous ones white and milky." See Clericuzio, "A redefinition," p. 588.

[174] Grew, *Anatomy of Plants*, p. 159.

[175] Grew, *Anatomy of Plants*, p. 158.

[176] Grew, "A Discourse Concerning the Essential and Marine Salts of Plants, Read Before the Royal Society, December 21, 1676," *Anatomy of Plants*, p. 261.

Glisson's *Anatome Hepatis*, that drew comparisons between plant and animal anatomy, something which Grew developed.[177] Later in the *Hepatis*, Glisson also wrote that "every plant has his peculiar spirit," which were made by "eminent impressions" of the atmosphere; Glisson also claimed these plant spirits were physico-chemical going on to note that they may "be mixed with salt or subtle sulphur."[178] And of course, the long-established tradition voiced by Paracelsus about a vital nitrous salt in the air, subsequently modified by Van Helmont in his theory of human breath, may have also played a role.

In the case of plant salts, followers of Helmont and Boyle, like Daniel Coxe would argue that the salts in the air would interact with fixed salts extracted from the ashes of plants, which Coxe believed were all uniform irregardless of plant species. The air would make "corrupted" compound salts that would fool the unwary chymist into thinking they were different chemical species.[179] This claim of Coxe's was the one that Grew desired to challenge, as he believed each plant had a unique essential salt.

Grew performed chemical experiments to prove his assertions. He took an alkaline lixivial solution of the salt of Fern (likely chosen as Coxe often utilized it), placed it an earthen pan, and exposed it to the air on a windowsill. He noted in nine days that amongst a cremor that formed on the service, an essential salt began to shoot that was amber-colored, mild-tasting, and neither sour nor sharp; this result indicated to Grew that it was not acidic or alkali [see Figure 4].

The fact that this essential salt also did not react with alkalis or acids meant it was clearly not "tartar or tartareous salt" which "makes a [e]bullition with alkaline salts."[180] Grew was particularly interested in demonstrating this salt was not tartar (potassium bitartrate) for a few reasons. First, Coxe had claimed tartars were formed by the fire, stating "most Vegetables, whether Woods or Herbs, if burnt whilst they are green, and with a smothering fire, yield Salts which are far enough from Alcalisate; being either Neutral or Acid; or to speak more properly,

[177] Bolam, "Botanical Works," p. 220; Garret, "Vitalism and teleology," p. 68.

[178] Francis Glisson, *Anatome Hepatis (The Anatomy of the Liver), 1654*, ed. Andrew Cunningham. Cambridge Wellcome Texts and Documents, number 3 (Cambridge: Wellcome Unit for the History of Medicine, 1993), p. 32, as quoted in Garrett, "Vitalism and teleology," p. 68.

[179] Coxe, "A Continuation of Dr. Daniel Coxe's Discourse, Begun Numb. 107. Touching the Identity of All Volatile Salts" pp. 172–3.

[180] Grew, "Essential and Marine Salts of Plants," p. 263.

Tartareous."[181] Secondly, the calcination of tartar by heat was a crucial experiment that Van Helmont used to produce an alkaline salt of tartar (potassium carbonate). Not only did Van Helmont demonstrate in his experiment that alkali salts were made by fire, but he showed that in an open vessel, a smaller amount of tartar was produced than in a closed vessel.[182] Grew however stressed that the crystals he produced were "no sort of *Tartar*, or *Tartareous Salt*. As is plain, from the manner of their *Generation*; *Tartar* being still bred in close *Vessels*; these never, but by exposing the Liquor to the Aer."[183] He therefore thought the salt he had discovered was a unique essential salt of the plant, "different in Nature from all other Salts hitherto known, or a new Species added to the inventory of Nature."[184]

This essential salt of Fern was then allowed to continue to crystallize, and after two weeks, began to shoot another salt that in its microscopic shape and taste led Grew to conclude it was a "marine salt produced by art in the imitation of nature."[185] This Marine Salt, cuboidal and "of greater Bulk," was considered by Grew to be the foundation of the leaves' skeleton; here Grew alluded to the idea that the cube among the Platonic solids was considered the most stable, and thus it was appropriate to be the basis of a structure.[186] The fibers which determined the shape of the leaf were, as Grew's microscopic observations showed, "governed by air vessels;" the generation of these vessells was "determined by the . . . Salts according to their several Angles."[187] Marine salts produced right angles, and alkaline salts were square at one end, and pointed at the other; placed ended to end, alkaline salts would form oblique angles. Acid salts had a more crooked nature, and by "applying the lesser Side of one to the greater Side of another," would form circular or Spiral lines.[188] Combinations of the various salts would thus produce a variety of differently-shaped air vessels and shapes of leaves [Figure 5].

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[181] Coxe, "A Discourse Denying the Prae-Existence of Alcalizate or Fixed Salt in any subject, before it were exposed to the Fire." *Philosophical Transactions*, 9 (1674), pp. 150–158, on p. 151.

[182] Newman and Principe, *Alchemy tried in the Fire*, p. 87.

[183] Grew, "Essential and Marine Salts of Plants," p. 263.

[184] Grew, "Essential and Marine Salts of Plants," p. 263.

[185] Grew, "Essential and Marine Salts of Plants," p. 263.

[186] Grew, *Anatomy of Plants*, p. 159.

[187] Grew, *Anatomy of Plants*, p. 159.

[188] Grew, *Anatomy of Plants*, p. 159.

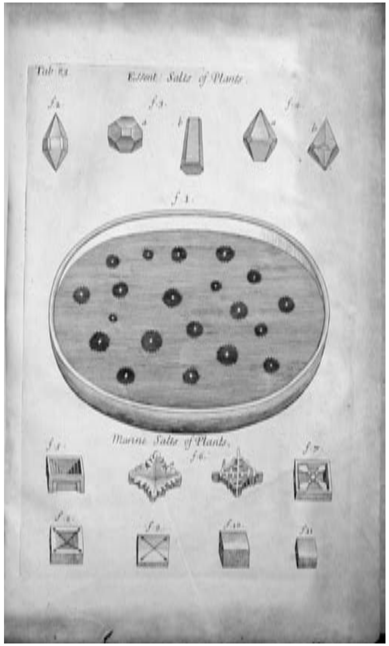

Figure 4. Nehemiah Grew, “Table LXXXIII,” in *The Anatomy of Plants. With an Idea of a Philosophical History of Plants, and Several other Lectures Read before the Royal Society.* London: W. Rawlins, 1682, p. 270. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

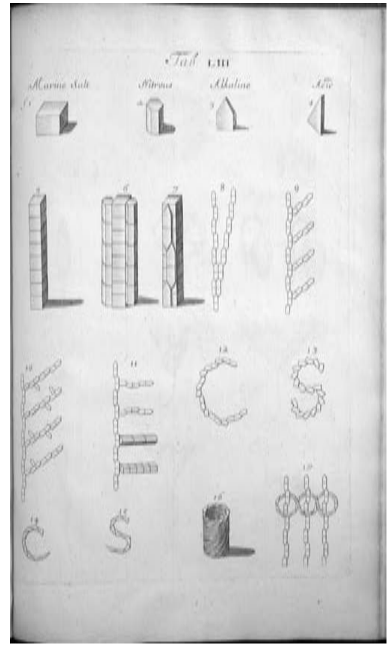

Figure 5. Nehemiah Grew, “Table LIII,” in *The Anatomy of Plants. With an Idea of a Philosophical History of Plants, and Several other Lectures Read before the Royal Society*. London: W. Rawlins, 1682, p. 240. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

And, as each species of plant had it own unique shape and structure, it would seem that the marine and essential salts produced from exposure of lixivial salts to the air were unique to each species of plant. To prove his assertion, Grew of course first had to "remove an Opinion standing in my way," namely the assertion that all alkaline salts from plants were the same as they were uniformly created by the fire, as "some Learned men have thought," an oblique reference to Boyle and Coxe.[189] To allow the largest degree of impartiality possible, Grew had salts prepared "with great care herein" by an outside apothecary, one John Blackstone, who stated in print that "all the lixivial salts mentioned in this and foregoing Discourse except that of Firne, were faithfully prepared by me" signing his name underneath his statement; Blackstone's more lowly social status as an apothecary would mean he had to commit to a printed oath so his assertion would be accepted as true.[190] Grew dissolved these lixivial alkaline salts from different plants into water, and he argued that each solution had a distinctive and unique taste. In an earlier 1674 paper for the *Philosophical Transactions* Coxe had intimated that the different tastes for the salts were due to some of the plant's oils contaminating the salts, so having Blackstone make the careful preparations was important for Grew to assure saline purity.[191] Then Grew let each solution be exposed to the air to produce the different essential salts of each plant. Microscopic observation also illustrated that each essential salt had a unique structure and color, arguing for their species-specific nature [Figure 4]. Grew therefore accomplished what was in his eyes a truer type of plant palingenesis via the medium of air rather than Coxe's use of fire, and he thought that he recreated the plant's essential saline structure.

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[189] Grew, "Essential and Marine Salts of Plants," p. 264.

[190] As Steven Shapin has illustrated in *A Social History of Truth*, standards for epistemological truth in seventeenth-century science had their origin in gentlemen's codes of honor. There was an equation between gentility, honor, and truth-telling that extended to empirical observation; the observations of Robert Boyle would be trusted more than those by an artisan. Gentlemen, by virtue of their social status, were considered more competent sensory agents, and hence they were more likely to be leaders of opinion in the scientific community. Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England* (Chicago and London: University of Chicago Press, 1994).

[191] Coxe, "A Discourse Denying the Prae-Existence of Alcalizate or Fixed Salt in any subject, before it were exposed to the Fire." *Philosophical Transactions*, 9 (1674), pp. 150–158, on p. 155.

"Nature's Art of Painting," Salts and the colors of plants and flowers

In addition to his studies of crystalline structure, Grew's theory of plant and flower color also drew from the idea that specific salts in the air caused a myriad of effects in the natural world. In a paper, "A Discourse of the Colors of Plants," read before the Royal Society in 1677, Grew stated that the green color of leaves was a chemical precipitate that formed when the acidic salts and sulphurs that plants contained mixed with volatile alkali salts in the air.[192] Similar chemical reactions controlled the colors of flowers. Like early Paracelsian chymists, Grew was attributing color to salts.

Grew first isolated the chemical substances within plants that he believed caused the green color of leaves. He poured sulphuric and nitric acid on "several parts of vegetables," finding they made less of a chemical reaction than acids poured on parts of animals. This led him to conclude that in "most Plants, the Preadominant Principle is an Acid," particularly in the parenchyma, whereas animal substances contained more alkalis.[193] Grew also argued that plants contained sulphur, especially in the wood, as there was a large amount of resinous sap in the wood's lympheducts, the sap having the same oily and flammable properties of sulphureous substances. He then performed a series of experiments in which he dropped the alkali spirit of hartshorn (aqueous solution of ammonia) or sal ammoniac on tinctures of flowers and on leaves. Spirit of Hartshorn on tinctures of borage flower turned them "verdigreese Green," and when it was dropped on green leaves, the color did not change at all, leading him to postulate that there was some alkaline "or like salt in the Air, which is predominant in the production of Green in the Leavs of Plants."[194] According to his reasoning, roots of most plants were white because they were not exposed to the volatile alkaline salts in the air, noting that the upper parts of roots, "when they happen to stand naked about the Ground," were colored by the air, such as in red sorrel roots or purple radish tops.[195] Transverse cuts of plant stalks showed a white bark parenchyma,

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[192] Grew, "A Discourse of the Colors of Plants," *Anatomy of Plants*, p. 271.

[193] Grew, "Experiments in Consort of the Luctation Arising from the Affusion of Several Menstruums upon all Sorts of Bodies, Exhibited to the Royal Society, April 13, and June 1, 1676," in *Anatomy of Plants*, p. 240.

[194] Grew, "The Colors of Plants," p. 276.

[195] Grew, "The Colors of Plants," p. 270.

but sap vessels which admitted the aerial volatile salts were as "green as the skin itself because they stand close to the Aer-Vessels."[196] Flowers in bud also tended to be whitish until exposed to the alkaline salts in the air.

The colors of flowers were produced by differing combinations of volatile alkaline salts and substances within the plant. Grew tested putting spirit of sulphur (sulphuric acid) on plant leaves, finding that dropped on green leaves, it turned the leaves yellow, but had no effect when dropped on yellow flowers. He concluded therefore that "in all yellow [flowers] the sulphureous acids and the alkaline parts are all more equal."[197] Spirit of Sulphur dropped into tincture of violets turned this Ph indicator from blue to crimson, and likewise when spirit of sulphur was dropped onto a tincture of clove-july flowers it made them bright blood red, and also heightened the red of roses. Thus, as "alkalis are predominant in Greens," acids dominated in red flowering plants.[198] From these and other chemical experiments, Grew formulated the following rules:

1. When sulphur and aerial saline principles "only swam together" but were not united chemically, no color was produced, as was the case in roots.
2. When sulphur and alkaline salts were united, they produced green colors.
3. When sulphur, alkaline, and acid salts were in equal proportions and reacting with each other, a yellow flower was produced.
4. When the sulphur predominated, and the acid and alkaline were equal, there "was a blew."
5. If the sulphur was most predominant to the "alkaline and acid," flowers were scarlet.
6. Variegated colors were the "over proportion of the Lympheducts to the Aer-Vessels," [in different parts of the flower and leaves], and therefore the dominion of the Sulphure over the Air therein."[199]

Grew postulated that yellow and green flowers and leaves suffered less loss of color when dried because the volatile salts in "the Aer being

[196] Grew, "The Colors of Plants," p. 270.
[197] Grew, "The Colors of Plants," p. 276.
[198] Grew, "The Colors of Plants," p. 276.
[199] Grew, "The Colors of Plants," p. 272. All of his scheme for color and proportions of different chemicals are on this page.

predominant in their Production, they are the less liable to suffer from it afterwards."[200] Red plants, however, no longer had the production of sulphur in their lympheducts to counter the effects of the salts in the air, so they would fade to purples and blues.

He did anticipate objection from other chemists on this point, as it was known for some time that blood on exposure to air deepened rather than faded in its color, turning bright red. For example, in 1674, John Mayow (1640–1679) in his *Tractatus Quinque Medico-Physici*, claimed that air was composed of a "small proportion of highly reactive particles which he identified as a nitro-aerial spirit"; like oxygen, "these particles alone made air suitable for respiration, and when absorbed through the lungs they imparted the bright red color to arterial blood."[201] As we have seen in the work of Lister, many early modern natural philosophers thought that respiration and anatomy in plants and animals was directly analogous. Marcello Malphigi (1628–1694), who submitted his own manuscript on plant anatomy to the Royal Society approximately at the same time as it had agreed to publish Grew's work *The Anatomy of Vegetables* (1671), asserted that the venation of leaves was analogous to the system of capillaries in animals.[202] Because the pith of plant stems was enclosed, Malphigi also compared it with the heart and brain of animals, and wood with animal bones and teeth.[203] Grew himself thought the root was similar to mouth into which entered a solution of nutrients and water, as well as air.[204] However, Grew also realized that animal circulation of the blood required valves, whereas no such valves could be found when he traced the movement of plant sap.[205] Thus, despite the arguments of his peers that circulation in plants and animals, and thus chemical reactions in blood and sap were directly

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200 Grew, "The Colors of Plants," p. 272.

201 Henry Guerlac, "The Poet's Nitre," *Isis* 45, 3 (September 1954): pp. 243–255, on p. 243.

202 Agnes Arber, "Nehemiah Grew (1641–1712) and Marcello Malpighi (1628–1694): An Essay in Comparison," *Isis*, 34, 1 (Summer 1942), pp. 7–16, on p. 13.

203 Arber, "Nehemiah Grew (1641–1712) and Marcello Malpighi (1628–1694): An Essay in Comparison," p. 13.

204 C.A. Browne, "A Source Book of Agricultural Chymistry," *Chronica Botanica* 8, 1 (1943), pp. 1–290, on p. 101.

205 Brian Garrett, "Vitalism and teleology in the natural philosophy of Nehemiah Grew," p. 72. The details of their disagreement may be examined in the British Library, Sloane 1929, "Mr. Lister's Animadversions upon my [Dr. N. Grew] last book considered," ff. 1–3. and "Dr. Grew's Answer to Mr. Lister's 2d paper, directed to Mr. Oldenburg," 1673. ff. 4–11.

analogous, Grew claimed a distinction between plant and animal substances, stating "I am not now speaking of Animal, but of Vegetable bodies; the same Aer which hightens the Color of Blood one way, may deepen that of a Flower another."[206]

Grew also thought such knowledge of the salt chymistry of plants could be used to control plant coloration. His suggestion was to start with the "tender and Virgin seed," which because of its small size and would be more affected by the tinctures of the soil, claiming all the "strange varieties in... Tulips" were made this way; in Holland in the 1630s, "tulip fever" arose for striped or variegated blooms in which scandalous sums were paid for a prized bulb, making this topic one of timely concern for the Royal Society's efforts.[207] Changing the soil, or transplanting seeds from one bed to another would also lead the plant to be "superimpregnated with several Tinctures."[208] Lastly, mixing soil with differing salts that "would concur with the Aer, to strike or precipitate their Sulphur into so many several colors," would "bring even Natures Art of Painting, in a great part, into our own power."[209] Early chymistry had "long preserved the very recipes for pigments that were the daily bread of those who composed their own painting media"; Grew's methods were another means for the chemist to be an artist of nature.[210]

Along with color, Grew believed the tastes of plants were also based upon saline chymistry, and could also be manipulated. Grew first postulated that plants that had a pungent taste did so because after the saliva dissolved their juices, their biting or nitrous salts remained on the tongue.[211] He hence concluded that Arum, which had a bitter nitrous taste, would thus grow best under a hedge, as the ground was not

[206] Grew, "The Colors of Plants," p. 272.

[207] Grew, "The Colors of Plants," p. 278. For the tulip craze, see Mike Dash, *Tulipomania: The Story of the World's Most Coveted Flower & the Extraordinary Passions It Aroused.* (New York: Three Rivers Press, 1999). The reason for the striping is the tulip bulb becomes infected with Mosaic Virus; the striping is thus not hereditary, leading to the crash in prices for these bulbs in the 1630s. The Dutch government declared it would not honor tulip contracts created before 1636, considering them gambling debts.

[208] Grew, "The Colors of Plants," p. 278.

[209] Grew, "The Colors of Plants," p. 278.

[210] Newman, *Promethean Ambitions*, p. 119.

[211] Grew, "A Discourse of the Diversities and Causes of Tasts Chiefly in Plants: Read before the Royal Society, March 25, 1675," *Anatomy of Plants*, pp. 279–295, on p. 287.

exposed to sun, but only to the air, "like those rooms in houses, which are covered is impregnated with a greater quantity of Nitrous salt."[212] Grew here was likely observing the formation of potassium carbonate or saltpetre crystals on walls that had been whitened by limestone, similar to the formation of nitre crystals in limestone saltpeter caves. The pure nitre of Arum entered into the concavity of the nervous fibers of the tongue, and "so being lodged there, is little affected or stirred, by the Motion of the Blood, but only when the Tongue itself is moved, at which time it contains a kind of pricking Taste."[213] Aquatic plants also tended to be biting, because "water being, though it self cold, yet the Menstruum by which all Salts are imbibed most easily, and in later states of Commixture with other Principles."[214] If the plant was hot in taste, it was because the flammable sulphur in the lympheducts of the plant, the particles of which "being spherick and bored with holes," contained salts.[215] Grew resorted to the mechanical action of matter to explain the sense of taste, explaining that the salt's angular structure within the sulphur meant that they "tore" the fibres of the tongue as they interacted with them, and in sufficient quality would raise a blister.

Salts, their solubility, and barometric pressure

The structure of plant salts, as well as the varieties of lixivial salts that Grew "discovered," led him to be interested in their relative degree of solubility. In a paper entitled, "Experiments in Consort upon the Solution of Salts in Water" read before the Royal Society in January 1676/7, Grew wrote,

> it was mentioned, as a thing asserted by some Phylosophers, That Water having been fully impregnated with one kind of Salt, so as to bear no more of that kind; it would yet bear, or dissolve some portion of another,

[212] Grew, "A Discourse of the Diversities and Causes of Tasts Chiefly in Plants: Read before the Royal Society, March 25, 1675," *Anatomy of Plants*, p. 287.
[213] Grew, "A Discourse of the Diversities and Causes of Tasts Chiefly in Plants: Read before the Royal Society, March 25, 1675," *Anatomy of Plants*, p. 287.
[214] Grew, "A Discourse of the Diversities and Causes of Tasts Chiefly in Plants: Read before the Royal Society, March 25, 1675," *Anatomy of Plants*, p. 287.
[215] Grew, "A Discourse of the Diversities and Causes of Tasts Chiefly in Plants: Read before the Royal Society, March 25, 1675," *Anatomy of Plants*, p. 287.

> and so of a third. And it was referred to Me by this Honourable Chair, to examine and produce the Experiment. The doing whereof brought into my mind divers other Experiments hereunto relating.[216]

When performing experiments where he supersaturated water with three salts at once—common salt, nitre and sal ammoniac—Grew noted that the different salts had different solubility. This led him to conclude that not only the "visible crystals, but the very Atomes of the Salt . . . have a different Figure one from another . . . because if they were all of one Figure, there would be no Superimpregnation."[217] The differing "superimpregnation" of salts in water also had medical implications, as although compounded infusions could be prepared, the physician could not "infuse all manner of Ingredients in any proportion," as some would precipitate out; adding more of a solute than a solution could bear would be unnecessary to the efficacy of its healing properties.[218]

Grew then wondered if "by dissolving of a Salt in Water, there by any space gained, or not;" in other words, would the level of the water in a flask be greater before or after the salt in it was fully dissolved?[219] After a series of experiments in which Grew filled a bolt head (globular flask with a long cylindrical neck, used in distillation) with a pint of water, marked the level on the stem, and then put in salt, Grew found the water level decreased. This led him to speculate that there were vacuities in water in which the salts lodged, but much to his surprise, there was not always a direct relationship between the "spaces gained by the several Salts" and their solubility. He concluded that there were different vacuities in water: "some salts, more dissoluble, increasing the Bulk of the Water less, and others less dissoluble," increasing it more.[220] He continued, "I say, that this difference dependeth not only on the different Figures of the Atomes of Salts: because then every Salt which is more dissoluble, would quantity for quantity take less room in the

[216] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 296.
[217] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 297.
[218] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 299.
[219] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 300.
[220] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 300.

Water, which is contrary to the experiment."[221] Grew also thought that although salts he tested were all different "figures," water was a fluid, its atoms were hard and consistent, and unalterable. Just as Grew believed that the elemental saline principle could not be altered by the fire, so it seems he believed that elemental water itself was unchangeable. This may have been a challenge to Boyle's corpuscular beliefs which were against "the idea of fixed chemical species" and that promoted substances "like alkali salts could be made by various agents into anything and converted by various agents into anything."[222]

Grew then asked, "what that just space might be, which any Salt gaineth upon Dissolution, with respect to its own Bulk, or the Bulk of the Water?"[223] Because water and spirit of wine dissolved salts so completely "whereby the observation of the true Bulk of the Salt," and "consequently of the just space it gaineth by the Dissolution is lost," Grew did not use these substances as his solvents, but rather utilized oil of turpentine.[224] Placing the oil in a bolt head, he then put in different salts to measure the oil's ascent, claiming that the space in which the oil ascended was a true measure of the salt's bulk. Taking that figure of the ascent of oil, and subtracting from it the level which the salts attained in being dissolved in water, would leave him "the space which the same Salts take up upon Dissolution."[225] From this technique, Grew claimed one could find the specific gravity of salts, and noted their gravity was directly proportional to their fixity, and inversely to their volatility; in his experimental trials, common salt was revealed to be the heaviest and also the most chemically inert, followed by nitre "somewhat less fixed . . . [and] somewhat lighter," alum, and then sal ammoniac which was wholly volatile and the "lightest of all Salts mentioned."[226]

From these conclusions, Grew ended his paper with a practical application of his results—namely with an argument that barometric variations were not due "not so much with the meer Weight of the air," but

[221] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 301.

[222] Newman and Principe, *Alchemy Tried in the Fire*, p. 278.

[223] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 300.

[224] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 301.

[225] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 301.

[226] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 302.

were affected by the changing concentrations of saline bodies which affected atmospheric pressure.[227] Mercury rose in the barometer for several days before a snowstorm or rainstorm, and this was because "the Aer is crowded with more and more Saline parts, which by the Winds, or otherwise, are carried into it; and so causeth it to press upon the Mercury in the Box."[228] But a day or so before the storm, the mercury fell; if the weight of the air were the only explanation for the barometer's behavior, Grew thought the mercury would fall as the storm actually occurred. Instead it fell before the front passed through. To explain this phenomenon, Grew argued that more volatile salts in the atmosphere would take up less space in the air when dissolved in the watery parts of the atmosphere than when they were undissolved. Thus, as the storm approached, the

> Salts are dissolved or incorporated into the Aqueous Parts of the Aer, as in Rain or Snow; so soon as that is done, there is some Space gained; and so before any Weather falleth, the Aer is less crowded, and presseth less upon the Mercury in the Box, which gives way to its descent in the cylinder.[229]

Grew therefore posited an entirely chemical explanation for Boyle's "spring of the air." This was something which Boyle was hesitant to do via his corpuscularian philosophy as he often displayed ambivalence between chemical and mechanical explanations for natural phenomena.[230]

Grew also believed that nitre's ability to chill substances meant that it was more prevalent in cold winds than warm, explaining why the mercury rose higher with cold winds as the nitre took up more space in the air and increased barometric pressure. The same mechanism explained while the mercury rose higher before a snowstorm than a rainstorm, as in the production of snow, "the Aer is crowded with a greater quantity of Nitre, or some other like Salts; which before they

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[227] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 303.

[228] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 303.

[229] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 304.

[230] For Boyle's reticence to explain the "spring of the air," see Steven Shapin and Simon Schaffer. *Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life, Including a Translation of Thomas Hobbes, Dialogus Physicus De Natura Aeris* (Princeton, N.J.: Princeton University Press, 1985). Also see Antonio Clericuzio, "A redefinition of Boyle's chemistry and corpuscular philosophy," *Annals of Science*, 47 (1990), pp. 561–589 for Boyle's ambivalence between chemical and mechanical explanations.

are dissolved, take up so much the more space; and afterwards so much the less, even before the snow falls."[231]

Grew's fundamental belief that the crystalline nature of salts underlay natural structures also extended to his analysis of snow. As mentioned earlier, increasing emphasis on microscopic analysis of salts to demonstrate their status as exemplars of form, was carried to many objects in the natural world. Microscopic examination of snow was a focus of much research in the Royal Society in the latter part of the seventeenth century; John Beale, Robert Hooke, and Grew all did observations in reaction to the initial findings of René Descartes about ice crystallization. The crystalline form of snow was compared by Grew to "regular figures as we see in divers other bodies."[232] In particularly, the single shoots of snow, "as so many short slender Cylinders" were "like those of Nitre . . . Nitre is formed, as is commonly known into long Cylindrical shoots, as also all Lixivial Salts for the most part; resembling, though not perfectly, the several points of each Starry Icicle of Snow."[233] Some of their ideas may have been suggested by Paracelsus who "repeatedly explained thunder and lightening in terms of an aerial nitre" and who also claimed that as "snow grows in the heavens, so salniter and other things grow out of the fire;" Glauber and Duchesne and John Mayow also expressed such ideas, and we saw Lister believed vitriolic salts had the same effect.[234] Though Grew acknowledged that other volatile salts such as sal ammoniac or salts of hartshorn, "besides their main and longer shoots, have others, shorte branched out from them; resembling as those the main, so these the Collateral points of Snow," the "icicles of Urine [Nitre] are still more near."[235] Grew believed that every drop of rain had spirituous particles, their presence evident as rain was thought to volatilize faster than water. The spirits in the rain combined with the saline elements in the air, "partly nitrous, but chiefly urinous, or of an acido-salinous nature" which fixed the snowflake.[236] The regular shape of the flake was due to the energy of spirit of the rain which acted as

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[231] Grew, "Experiments in Consort Upon the Salts in Water," in *Anatomy of Plants*, p. 304.

[232] Grew, "Some Observations Touching the Nature of Snow, Presented to the Royal Society," *Philosophical Transactions* 8 (1673): pp. 5193–5196, on p. 5195.

[233] Grew, "Some Observations Touching the Nature of Snow," p. 5195.

[234] A.G. Debus, "The Paracelsian Aerial Niter," *Isis* 55, 1 (March 1964), pp. 43–61, on p. 46.

[235] Grew, "Some Observations Touching the Nature of Snow," p. 5195.

[236] Grew, "Some Observations Touching the Nature of Snow," p. 5196.

the "pencil," and the saline parts as the "ruler," figuring it "into a little Star."[237] Nitre could also act as a pencil to "draw" other substances, as Grew then went onto comment that the structure of Feathers was also like nitre crystals because birds had no organ for the evacuation of urine, so "the urinous parts of their blood were evacuated by the habit or skin, where they produce and nourish feathers."[238]

In later publications, Grew continued to assert that alkaline salts were not made by the fire and elemental salts existed. In his 1695 treatise concerning his discovery of Epsom or "purging salts," which was based on unpublished lectures he gave at the Royal Society in 1679, he argued that the "being" or essential nature of the salts, and their ability to change the color of syrup of violets were "not wholly and altogether depend[ant] on the Fire."[239] The bitter taste of the Epsom salts was also not created by the fire, but rather augmented by it, which showed the "fixedness of its principles."[240] Further, before the Purging salt had "felt the Fire," it was alkaline, "but when it was well burnt, it was in some sort Lixivial albeit we may not so properly call it Lixivial, nor perhaps by any other Name which Use hath approved: for the Furniture of Words is in nothing more scanty."[241] Grew's comment not only have reflected the traditional "*nullius in verbo*" thrust of the Royal Society, but also may have illustrated the growing primacy of saline chymistry as conceptualized by Van Helmont, and subsequently Boyle whose use of chemical names would become more and more "approved."

If words proved unsatisfactory to describe his chemical research, Grew's admiration for nature's ability to "draw" or "paint" the varieties of plants and flowers was not, showing his commitment to "the identification of nature with art."[242] Nature used salts to "draw" and form the beauty and intricacy he saw in his observations of plants at the macroscopic and microscopic levels as well as to "paint" flowers and leaves with chemical pigments; in 82 plates in the *Anatomy of Plants* he

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[237] Grew, "Some Observations Touching the Nature of Snow," p. 5196.

[238] Grew, "Some Observations Touching the Nature of Snow," p. 5196.

[239] Grew, *A Treatise of the Nature and Use of the Bitter Purging Salt. Easily known from all Counterfeits by its Bitter Taste* (London: John Darby, 1697), p. 13. See Sakula, "Dr. Nehemiah Grew and the Epson Salts," p. 10, and pp. 17–18 for the chronology of Grew's papers and publications concerning the Epsom Salts.

[240] Grew, *A Treatise of the Nature and Use of the Bitter Purging Salt*, p. 11.

[241] Grew, *A Treatise of the Nature and Use of the Bitter Purging Salt*, p. 14.

[242] Brian Garrett, "Vitalism and teleology in the natural philosophy of Nehemiah Grew," p. 66.

himself imitated nature and directed other chemical practitioners how to use salt chymistry in soils to make their own horticultural creations. It was little wonder then that in a 1775 Harveian Oration at the Royal College of Physicians, Grew was described as discussing "in the best possible way the nature of juices and salts in plants and their taste and color."[243] One could certainly agree that his combination of chemical mechanism with a belief in essential salts of plants, used to control botanical characteristics, was a unique contribution to early modern chymistry. Grew's work, as well as the natural philosophy of Philipot, Moray, and Lister demonstrated chymistry's status as both creative art and science, the tensions between early modern conceptions of matter that stressed chemical mechanism as well as vital principles, and the differing conceptions of elemental principles.

[243] D. Munro, *Praelectiones Medicae, contains Harveian Oration of Royal College of Physicians 1775* (London, 1776), pp. 183–4, quoted in Sakula, "Nehemiah Grew and the Epsom Salts," p. 6.

CHAPTER FOUR

FROM SALTS TO SALINE SPIRITS—THE RISE OF ACIDS

In the last chapter, it was demonstrated that Van Helmont's notion of a volatile salt comprising a vitalizing spirit was influential among English Helmontians in studies of meteorology and natural history. This chapter will demonstrate that at the end of the seventeenth century however, interest in the salt principle began to decline. Belief in the salt principle diminished, and there was growing interest in the idea of a universal acid as the basic mover in processes of nature; it was usually identified as sulphuric acid.[1] As Emerton has noted, in the seventeenth century, it was believed that acids or "saline spirits" were the most powerful chemical agents, and they were increasingly important in the chemical laboratory as chemical reactions in solution predominated over older distillation processes.[2] The use of acids and alkalis in iatrochymical treatments of Boerhaave and Franciscus Dele Boë Sylvius (1614–1672), as well as Boyle's refinement of colored indicators in detecting acidity led to this shift in emphasis.

After a brief contextual discussion of the rise of acids and alkalis in chemical and iatrochymical theory, we will start this chapter with a discussion of William Simpson. Simpson was a physician from York who settled in Chapel Street in London, a chymist and an English Helmontian who was representative of this shift from salts to saline spirits. Simpson's father was a brewer, and he himself has been described as an experimentalist more comfortable in the laboratory than the study.[3] Simpson's concept of the fermentation of saline spirits or acids in the atmosphere and the body, discussed in his *Zymologia Physica* (1675) owed some of its premises to Van Helmont, some to the Iatrochymical School, particularly the works of Dele Boë Sylvius and Tachenius, and some

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[1] Robert P. Multhauf, *Neptune's Gift: A History of Common Salt*. John Hopkins Studies in the History of Technology (Baltimore: Johns Hopkins University Press, 1978), p. 130.

[2] Norma Emerton, *Scientific Reinterpretation of Form* (Ithaca: Cornell University Press, 1984), p. 184.

[3] Noel Coley, "Cures without Care: Chymical Physicians and Mineral Waters in Seventeenth Century English Medicine," *Medical History* 23 (1979), pp. 191–214, on p. 201.

to the chymistry of Isaac Newton [Figure 6]. The nature of Simpson's theories of fermentation has been largely neglected in scholarly analysis, a state of affairs likely due to focus upon his disagreement with both Martin Lister (see chapter three) and Robert Wittie, another chymist and analyst of spa waters. The dispute centered upon about the role of salts and saline spirits in the spa waters and metallogenesis. Dr. Robert Wittie published *Scarborough Spaw* in 1660 which advocated the waters as a cure for all ills, recommending that the waters were best drunk mid-May to mid-September and inadvertently initiating the summer season in spa towns. In his *Hydrologica Chymica* (1669) Simpson refuted Wittie's claims made for the mineral spring waters, and the medical debate spread beyond local boundaries to the Royal Society in London.[4] But there was more to Simpson than his role in this debate. When we turn to Simpson's tracts on fermentation, we will also see that although it is generally true Newtonianism caused the decline of Van Helmontian medicine and chemistry in England, that Simpson was an important transitional figure combining Newtonian ideas about acidic fermentation with Helmontian ideas about volatile salts.[5]

We will then subsequently analyze the role of saline chymistry in the treatises of early eighteenth-century Newtonian physicians after Simpson. It has been well documented by Guerrini that Newtonian physicians such as Bryan Robinson (1680–1754), Archibald Pitcairne (1652–1713), George Cheyne (1671–1743) and Richard Mead (1673–1754) posited a "Newtonian physiology" based on the premises in the *Principia*, as well as queries in Newton's *Opticks* (1704–22) and the *De Natura Acidorum* (1710).[6] Her emphasis however was primarily in the application of Newtonian physics and conceptions of the aether to medicine; I will concentrate in this chapter instead upon Newton's chemical works about salts and acids and their influence in the medical community in Britain and Ireland.

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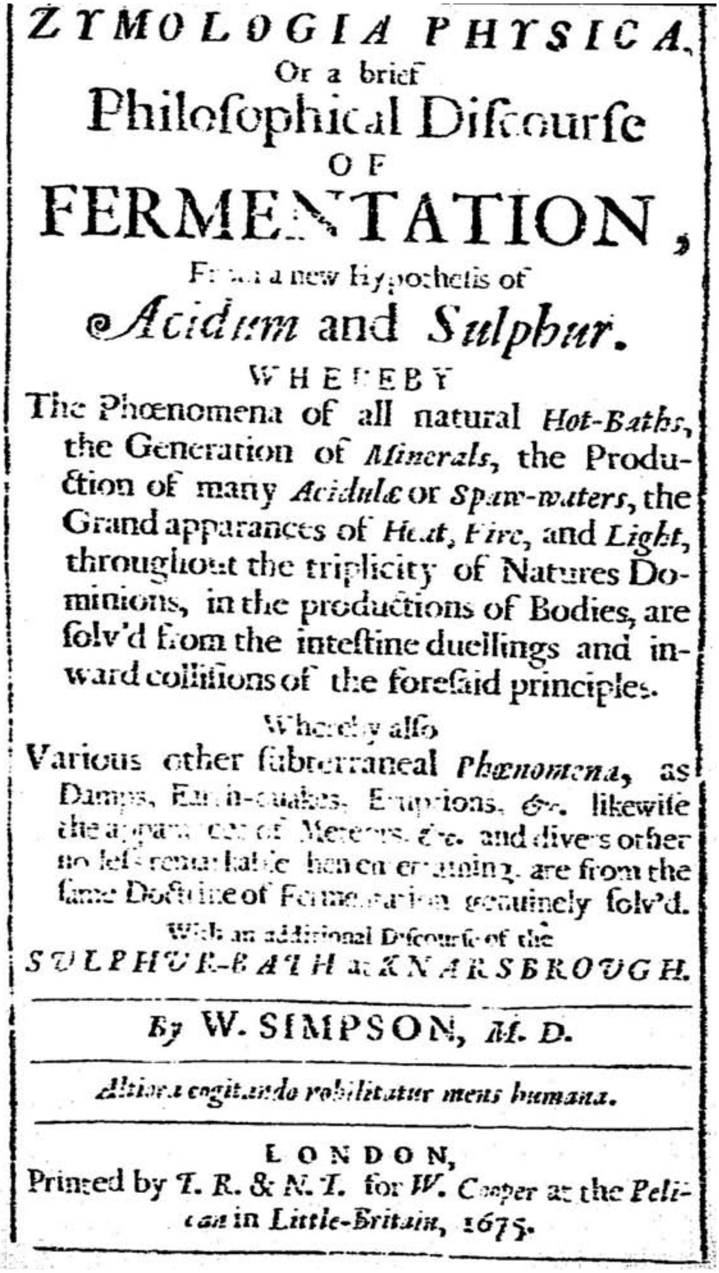
[4] William Simpson, *Hydrologia chymica, or, The chymical anatomy of the Scarbrough, and other spaws in York-Shire: wherein are interspersed, some animadversions upon Dr. Wittie's lately published treatise of the Scarbrough Spaw*... (London: W.G., 1669). See Coley, "Cures without Care," pp. 201–204.

[5] Antonio Clericuzio, "From Van Helmont to Boyle: A Study of the Transmission of Helmontian Chemical and Medical Theories in Seventeenth-Century England," *British Journal of the History of Science* 26 (1993), pp. 303–34, on p. 334.

[6] Anita Guerrini, "The Tory Newtonians: Gregory, Pitcairne, and their Circle," *Journal of British Studies*, 25 (1986), pp. 288–311; Anita Guerrini, "Archibald Pitcairne and Newtonian Medicine," *Medical History*, 31 (1987), pp. 70–83; *Obesity and Depression in the Enlightenment: The Life and Times of George Cheyne* (Norman: University of Oklahoma Press, 2000).



ZYMOLOGIA PHYSICA,
Or a brief
Philosophical Discourse
OF
FERMENTATION,
From a new Hypothesis of
Acidum and Sulphur.
WHEREBY
The Phœnomena of all natural *Hot-Baths*, the Generation of *Minerals*, the Production of many *Acidulæ* or *Spaw-waters*, the Grand apparances of *Heat*, *Fire*, and *Light*, throughout the triplicity of Natures Dominions, in the productions of Bodies, are solv'd from the intestine duellings and inward collisions of the foresaid principles.
Whereby also
Various other subterraneal *Phænomena*, as Damps, Earth-quakes, Eruptions, &c. likewise the apparances of Meteors, &c. and divers other no less remarkable hence emanating, are from the same Doctrine of Fermentation genuinely solv'd.
With an additional Discourse of the
SULPHUR-BATH at KNARESBROUGH.

By W. SIMPSON, M. D.

Altiora cogitando nobilitatur mens humana.

LONDON,
Printed by T. R. & N. T. for W. Cooper at the Pelican in Little-Britain, 1675.

Figure 6. The title page to William Simpson's work on fermentation. William Simpson, *Zymologia Physica*. London: T.R. and N.T., 1675. Courtesy of the Thomas Fisher Rare Book Library, University of Toronto.

Acids and Alkalies: The work of Dele Boë Sylvius, Tachenius, and its influence on William Simpson

Much of the work on acids and alkalis stemmed from investigations into salt chymistry. We have seen that, under the influence of Van Helmont, the nature of fixed alkaline salts created by calcining plants was a research preoccupation of the Royal Society. Boyle also was involved in the classification of salts. As has been documented by Clericuzio, in his *Usefulness of Experimental Naturall Philosophy* (1663) Boyle classified salts comprehensively and distinguished three types: acid, alkalizate or lixivial, and urinous or volatile. Principe and Newman have also demonstrated that Boyle drew a contrast between the Helmontian alkahest and "common corrosive saline liquors" or acids and alkalis.[7] The liquors, derived from salts via distillation, deliquescence, lixiviation, and solution were of three types: acid (such as nitric acid), urinous (ammonia and its salts), and alkalizates (fixed alkalies such as potassium and sodium carbonates). Boyle further derived a set of early "Ph" indicators, such as syrup of violets to classify salts and their liquors into acid, urinous or lixivial types.

Van Helmont's work also influenced theories on acids and alkalis by Franciscus Dele Boë Sylvius or Sylvius. Sylvius, a professor at Leiden, had students from a number of countries, including England, and several of his tracts were translated into English in the second half of the seventeenth century, or modified in chymical textbooks. Some of these works included his treatise on children's diseases and rickets, as well as excerpts in William Salmon's *Systema Medicinale* (1684), and Nicolas Lémery's popular *A Course of Chymistry (1686)* was based on Sylvius' iatrochymistry.[8] Sylvius believed that the functions of an organism were determined by ferments or effervescences arising from the acidic or alkali character of bodily fluids; Like Van Helmont, Sylvius used

[7] William Newman and Lawrence Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago: University of Chicago Press, 2005), pp. 275–6.

[8] Franciscus Dele Boë Sylvius, *Of Children's Diseases . . . As Also a Treatise of the Rickets*, trans. by R.G. (London: George Downs, 1684); William Salmon, *Systema Medicinale* (London: T. Passinger, 1686); Nicolas Lémery, *A Course of Chymistry. Containing an easy Method of Preparing those Chymical Medicines which are Used in Physick . . .* trans. W. Harris (London, 1686); See Rina Knoeff, *Herman Boerhaave (1668–1738) Calvinist chemist and physician* (Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen, 2002), pp. 14–15 for a brief discussion of Lémery.

the concepts of fermentation to explain physiological processes in the body, but differed in his applications. Van Helmont believed matter was created by water and ferment, or seminal origin; "the ferment is an indwelling formative energy which disposes . . . water so that a seed is produced and life, and the mass develops into a stone, plant, or animal."[9] In the body, the "internal efficient cause" or life force was called the Archeus, and Van Helmont believed its seat was in the stomach, though archei also existed in the liver and other parts of the body. In these organs, ferments via chemical processes occurred to bring about digestion and other changes in physiology. Though Sylvius believed that ferments occurred, he generally rejected the Archeus in favor of explanations that relied on a purely chymical basis such as fermentations of the neutral saliva, acid pancreatic juice and alkaline bile.[10] Bile had alkaline lixivial salt, pancreatic juice had acid and a volatile spirit, and chyle had lixivial salt, water and some acid.[11] Alkalis and acids mixed together would effervesce and usually produced heat, just as oil of vitriol (sulphuric acid) reacts with volatile alkali (ammonium carbonate); unnatural effervescence resulting from too much acidity or alkalinity (which he termed acridity) caused disease.[12] The cure was providing a medicament of the opposite Ph.[13] As Parthington stated, Sylvius believed that most disease was caused by corrosive acids, fever by an excess of alkalinity, and plague was due to volatile salts in the blood which gave it "an abnormal fluidity opposing its coagulation; this is proved by injecting a solution of the volatile salt into the veins, when the symptoms of plague are produced and hence an acid is used as a remedy."[14] The atmosphere itself could also influence bodily processes such as respiration; Sylvius wrote,

> By what power, or in what manner and way the inspired air so alters the blood is not equally clear. I for my part think that it is brought about by reason of there being dispersed in the air nitrous and subacid particles

[9] J.B. Van Helmont, *Ortus Medicinae* . . . (Amsterdam; Elzevir, 1648), pp. 29, 86, 90, 428, as quoted in J.R. Partington, *A History of Chemistry*, 4 vols. (London: Macmillan, 1961), vol. 2, p. 236.
[10] Partington, *A History of Chemistry*, vol. 2, p. 285.
[11] Partington, *A History of Chemistry*, vol. 2, p. 285.
[12] Partington, *A History of Chemistry*, vol. 2, p. 284.
[13] Partington, *A History of Chemistry*, vol. 2, p. 284.
[14] Partington, *A History of Chemistry*, vol. 2, p. 287.

> able to condense the rarefied and boiling blood and so gently to restrain its ebullition.[15]

Sylvius also believed that the atmosphere had nitric acid (*acidum nitrosum*) and volatile alkali (ammonia). The nitric acid was brought

> by the north wind from the north, where it is expelled into the air from subterranean fires; the second is brought by the south wind. When the two mix, cold is produced, as when sal ammoniac dissolves in water; greater cold is produced when the north wind carries common salt, and very intense cold when it brings volatile alkaline salt.[16]

The heat of the heart resulted from the fermentation of the acid chyle and the alkaline blood, and that the vapours emitted "in this effervescence are expelled with the expired air."[17]

As Frank has shown, Sylvius' idea of acid-alkaline fermentation and ebullition was extremely influential among English iatrochymists and physicians of the seventeenth century, particularly the Oxford physiologists in the 1650s.[18] Their inquiries were given impetus by Thomas Willis's idea of fermentation in the *Diatribae duae medico-philosophicae* (1658). The *Diatribae* was the English work responsible for introducing iatromechanism to medicine, and had been readily accepted by the College of Physicians because it successfully combined an innovative explanation of fever as due to mechanical action and reaction between corpuscles of chemical matter with traditional Galenic treatments of vomits and purges that members of the college favored and the patients anticipated.[19] Willis's theory of fermentation was thus likewise influential. Willis believed that there was a nitro-sulphurous ferment in the heart which caused bodily heat and propelled the blood throughout the body. This ferment represented the vital flame responsible for animal

[15] Dele Boë Sylvius, *Disputationum Medicarum Decas Primarias Corporis Humani Functiones Naturalise Nec non Febrium Naturam* (Amsterdam, 1663), p. 69 as quoted in Partington, p. 288.

[16] Dele Böe Sylvius, *De Affectus Epidemii Anno 1669 Leidensem Civitem depopulantia* in *Opera Medica*, ed J. Merian (Geneva: de Tournes, 1698), pp. 56–58 as quoted in Partington, p. 289.

[17] Partington, *History of Chemistry*, vol. 2, p. 287.

[18] Robert G. Frank Jr., *Harvey and the Oxford Physiologists: A Study of Scientific Ideas* (Berkeley: University of California Press, 1980).

[19] Theodore Brown, "The College of Physicians and the Acceptance of Iatromechanism in England, 1665–1695," *Bulletin of the History of Medicine*, 44 (1970), pp. 12–30, on p. 21.

life, and it was "continually nourished by sulphur from food and nitre from the air."[20]

Another thinker influenced by this work on fermentation was William Simpson, a self-described chemical physician. One of Simpson's *Two Small Treatises* made an analogy between blood and wine that was quite reminiscent of Willis' discourse on the "inkindling of the blood," which also drew a comparison between blood circulation and "Wine and other liquors agitated into Fermentation."[21] Simpson was also an author of several treatises on spa waters and one of the main adversaries in one of the most famous seventeenth-century medical debates engendered by Dr. Robert Wittie's (1613–1684) *Scarbrough spaw* (1660) a work in which he advocated the mineral waters at Scarborough as a cure-all.[22] This "quarrel" was not only about the formation of minerals, but a debate among English physicians in the latter part of the seventeenth century about which particular salt was the most effective active ingredient in healing. Simpson believed the main active ingredients in the waters was nitre; Wittie proposed that along with alum, vitriol was a major component of the waters, along with nitre and iron.

As the result of these debates prompted by Simpson's publications, Martin Lister himself apparently took a personal dislike to Simpson and related his qualms about Simpson's character to Henry Oldenburg in a 1675 letter. Though Simpson was nominated as a Royal Society fellow that year, he dedicated his *Zymologia Physica* to that scientific body, and it was reviewed extensively and sympathetically in the *Philosophical Transactions*, he was never elected.[23]

Lister's dislike of Simpson may have been related to Simpson's contrary theories about the role of fermentation in blood, as well as Simpson's thoughts about spa waters. In his *De Humoribus*, Lister denied there was fermentation in the blood, as nitre or any other acid was not sufficiently volatile to exist in the air to engender fermentation. Lister also

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[20] Jan Golinski, "A Noble Spectacle: Phosphorus and the Public Cultures of Science in the Early Royal Society," *Isis* 80, 1 (March 1989), pp. 11–39.

[21] William Simpson, *Two Small Treatises* (London: E. Wyer, 1678); Thomas Willis, *Dr. Willis's Practice of Physick*, trans. S.P. (London: T. Dring, et al., 1681), p. 25.

[22] Robert Wittie, *Scarbrough spaw; or, A description of the nature and vertues of the spaw at Scarbrough Also a treatise of the nature and use of water* (London: Charles Tyus and Richard Lambert, 1660).

[23] For Lister's distrust of Simpson, see Oldenburg to Lister, 4 September 1675, in *The Correspondence of Henry Oldenburg*, ed. Marie and Rupert Hall (Madison: University of Wisconsin Press, 1965–77), 11 vols, vol. 11, pp. 486–7. For the review of Simpson's work, see *Philosophical Transactions*, 10, 117 (1675–76), pp. 410–416.

thought a violent ferment in the body would be felt; digestive function was perceptible, yet the circulatory system was relatively quiescent, the heartbeat alone enough to propel the animal spirits throughout the body.[24] Chapter 12 of Lister's *De Fontibus* (see chapter three) also strongly argued against the influence of alum in mineral waters, which Simpson promoted as a key ingredient. Simpson also rejected others of Lister's and Wittie's hypotheses in his *Hydrologica Chymica* (1669). First, Simpson declared, contrary to Lister, that it was impossible for any metal or salt to release vapors to water and heat it. Only the sun could "resolve the Vitriol into a vapour," and "that Vitriol may dissolve in simple Water, we have before granted, but that it should give a vapour to the Water, I understand not."[25] Rejecting the principle of *witterung*, another major hypothesis in Lister's *De Fontibus*, Simpson also thought that an acid essurine or universal salt dissolved in water, met with *copper not iron*, producing vitriol in its reaction. Given Lister's emphasis on the role of iron in natural phenomena, this was a major challenge.

As a Helmontian, Simpson generally thought that water was the source of metallogenesis and general matter formation. Specifically, after the acidity of the salt was "coagulated on the metalline dissolv'd parts . . . and so both together become dissolv'd in the solitary Spring Water, in an almost indissolvable texture, then, and not till then, is the action of that Essurine acidity terminated."[26] The acidity of the essurine saline spirit thus exhausted, if it met with a vein of iron, no further reaction or production of vitriol would occur. As Simpson stated, "Mars cannot be dissolved and appear in the form of a liquor, without a dissolvent; but this dissolvent . . . the Essurine acidity, being already . . . turned into a Vitriol . . . is not at leisure to make another of them."[27] He speculated in the epilogue that this "essurine Salt, which I call the Essence of Scarborough Spaw, is a kind of alumino-nitrous Salt, or Sal hermeticum."[28] Much in the tradition of the past tradition of the aerial nitre, Simpson proclaimed his salt was not common nitre, but "truly Magnetical of the Universal spirit" a universal nitric acid.

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[24] Martin Lister, *Dissertatio de Humoribus* (London, 1709), Chapter XXVI, "An Sanguis Fermentescit? Negatur. [Does the blood ferment?, no], pp. 278–289.

[25] Simpson, *Hydrologia Chymica*, p. 8.

[26] Simpson, *Hydrologia Chymica*, p. 3.

[27] Simpson, *Hydrologia Chymica*, p. 4.

[28] Simpson, *Hydrologia Chymica*, p. 365.

Simpson's belief that ferment between this acid nitrous salt and the metal caused the production of vitriol however also pointed to his general interest in fermentation as a basis of natural and physiological processes. The basic conception of fermentation in chymistry was a broad and common one, from the Latin *fervere*, to boil or ferment, referring to a substance changing its properties via an internal process as well as to the action of leavening; the *OED* cites many examples from the seventeenth century, in context with generation, vegetation, or putrefaction.[29] Simpson's conception of fermentation however was more precisely stated. In his *Zymologia Physica* (1675), Simpson took some of his ideas about fermentation from one of Sylvius's followers, Otto Tachenius (still living in Venice in 1699). Tachenius, born in Westphalia, introduced the principles of the Sylvius' acids and alkalis to Italy, and he professed to find these acid-alkali principles in Hippocratic and Galenic writings "in which, he said, fire=acid and water=alkali."[30] Tachenius extended this theory to cover all natural phenomena. Simpson wrote in the preface to the *Zymologia*,

> . . . I began to look about me, and to consider on which of the Philosophers side I was . . . I could not tell of a good while, till at length I considered, that the great Hypocrates himself has given touches thereof . . . viz . . . All things are made of Fire and Water; and that these two are sufficient for all generations: so he adds, that Fire gives motion, and Water nutrition.[31]

In the margins next to this statement, both Tachenius and Hippocrates were cited. For Simpson, Tachenius' and Hippocrates' ideas suggested to him that the fire "hid in bodies" in the form of sulphur fermented with acidic saline spirits in water. Because Simpson was also a Helmontian, he also believed that water was the source of all matter and material change, and that

> Fermentation in our sense, is the same with [Helmont's] Spiritus impetum faciens . . . Fire hid in bodies, its also the same with that Aetherial matter, the Panspermion of other abstruse Philosophers, that *divinioris aurae particula* implanted by God in Water; which from seminal originals, produce, by a genuine expansion, all concrete bodies; its likewise the same which the noble Helmont calles *semina rerum*.[32]

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[29] Betty Jo Teeter Dobbs, "Newton's Alchemy and His Theory of Matter," *Isis* 73, 4 (Dec. 1982), pp. 511–528, on p. 525.

[30] Partington, *History of Chemistry*, vol II, p. 292.

[31] Simpson, "Preface," to *Zymologia Physica* (London: W. Cooper, 1675), fol. A4.

[32] Simpson, "Preface," to *Zymologia Physica*, fol. A5.

Simpson therefore combined Tachenius and Helmont to produce his unique idea that acidic spirits in water reacted with sulphureous and fiery components of matter to ferment and produce "the formations and transformations of Bodies."[33] Simpson proposed there "were no concretions of Bodies, as they assume their birth from the legitimate broodings of nature in all seeds and seminal offsprings, without the concurrent efficients and principles of Fermentation."[34] As Clericuzio has noted, Simpson saw the Helmontian *semina* as "corpuscles containing a spiritual formative principle."[35]

Fermentation and its manifestations in nature

Simpson then analyzed how all natural phenomena could occur due to fermentation, postulating that:

1. Hot baths get their heat from fermentation of mineral juices, and "there is no hot bath without Sulphur." Hot baths differ in their qualities because of differences in their sulphurs.
2. An acid colliding with sulphurs is required in all "mineral fermentations" or metallogenesis.
3. Fire and light were due to the collision of acid and sulphur set into motion by the air, which imbibes moisture. Volcanoes, earthquakes and lightening resulted from these collisions as well.
4. The matter of animals, vegetables, and minerals differed due to a variety of saline acids.

In discussing how spa waters were heated, Simpson began his analysis by addressing his inspiration, and to some degree, his opposition, namely Tachenius. Though Simpson acknowledged that acids and alkalies mixed together could product ebullition and heat, he claimed it was due primarily to acids meeting with "the Sulphur close bound up with the Acid and Urinous Spirit or Salt in the Compages of the Alcali."[36] Simpson also claimed there was a greater variety and proportion of

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[33] Simpson, *Zymologia Physica*, p. 3.

[34] Simpson, *Zymologia Physica*, p. 5.

[35] Antonio Clericuzio, *Elements, Principles and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century* (International Archives of the History of Ideas/*Archives internationales d'histoire des idées*) (Dordrecht: Kluwer, 2000), p. 154.

[36] Review of *Zymologia Chymica* in *Philosophical Transactions*, 10, 117 (1675–76), pp. 410–416, on p. 414.

corrosive acids within material bodies then lixivial alkalies, which he saw as primarily created by the fire rather than inherent to matter; here, Simpson agreed with Van Helmont. Therefore,

> Tachenius his Hypothesis of acids and alcalies, will not do our work, as being too narrow in the foundation to raise so large a structure of Philosophy upon, as genuinely to solve the various Phaenomena of nature, and particularly in this appearance of hot Baths.[37]

Simpson first argued that hot baths are sulphureous in nature by listing observations of natural philosophers about its presence in spas. He included Fallopius' accounts of baths in Padua, and the observations of Dr. Edward Browne, a fellow of the Royal Society, whose silver coat buttons turned yellow near the baths at Baden due to its sulphureous emanations. Browne decided to do an experiment "hanging money over the Bath at a distance, or at a greater, and found it colored in a minutes time, and that which was nearer in half a minute."[38] Simpson then discoursed upon the different sorts of Sulphurs that baths could contain, such as antimony, bitumen, or vitriol, and he suggested that the differences in their fermentative power produced "different degrees of heat in Baths."[39] The location of the fermentation involving sulphur and acid also was important. The deeper in the earth it occurred, the more precipitated the Sulphur became, "left in the colander or filter of Sand, through which its passeth, and the acidum thereby so dinted as to become very Languid."[40] Surface baths were thus more chemically potent and hotter then those below ground.

The fermentation process producing heat in the baths of course required spring water, and the transformation of sulphurous vitriol into oil of vitriol (sulphuric acid) via artificial distillation or the natural mixture of vitriol and sulphur in spring water to produce oil of vitriol illustrated this principle. If water was added again to oil of vitriol, a violent Fermentation occurred, the exothermic reaction producing violent heat.[41] Cognizant of past work which made extensive claims for the generative power of salts alone, Simpson was quite firm in denying that dry salts alone or those "mixed and sublimed together" would produce any fer-

[37] Simpson, *Zymologia Physica*, p. 8.
[38] Simpson, *Zymologia Physica*, p. 11.
[39] Simpson, *Zymologia Physica*, p. 13.
[40] Simpson, *Zymologia Physica*, p. 14.
[41] Simpson, *Zymologia Physica*, p. 18.

mentation or generative processes without moisture. Salts had to be in the form of saline spirits or acids to have fermentative effect; powerful chemistry took place in solution whether in nature or in the laboratory, not merely by the application of fire.

Having showed that acid and sulphur were the chief ingredients of hot baths, Simpson then further wished to prove that their fermentation produced the heat in the baths by performing a series of experiments in which he prepared the sulphur of antimony, a common chymical operation. The Paracelsian *tria prima* postulated that sulphur was one of the elemental substances. By isolating it, chymical physicians believed that it could serve as a potent medicine, and with proper chymical processing, sulphur could be free of side effects that often occurred in uncompounded substances.[42] Isolating the sulphurs also was a means for chymists such as Simpson to attain insights into elemental chymical reactions. Simpson did experiments mixing an infusion of *aqua regia* upon antimony, apparently following a method advocated by Angelus Sala in his *Anatomia antimonii* (1617). As Principe has noted, Sala's method treated antimony with a strong acid. The acid was prepared by dissolving sal ammoniac and saltpeter in nitric acid, and distilling it. When antimony was combined with this strong acid, the chymist would see a "vigorous effervescence" which left an "antimonial residue that is then to be extracted with a boiling solution (or lixivium) of salt of tartar. . . . This extract is then evaporated to dryness, and the antimonial Sulphur sublimed thereupon."[43] Indeed, in the *Zymologia*, Simpson wrote:

> in the affusion of *Aqua Regis* upon Antimony . . . where the acidum of the menstruum acting upon and struggling with the crude sulphur of crude solitary Antimony . . . doth cause a very strong Fermentation, where the Sulphur by the assaults of those corrosive acid Spirits grows so high in its Fermentation, as that is almost takes flame, passing off with a strong stifling and incoracible arsenical vapour, by the former of which prepared with common Salt, my ingenious Friend Mr. Wilkinson and my self have after Fermentation separated a Sulphur out of Antimony.[44]

Simpson then went on to claim that the fermentation in this experiment is not "from the salts in the sublimate (as some might urge), mixing with the acidum in the menstruum," because "the same menstruum poured upon the same salts, while incorporated in the Mercury in the form

[42] Newman and Principe, *Alchemy Tried in the Fire*, p. 101.
[43] Newman and Principe, *Alchemy Tried in the Fire*, p. 102.
[44] Simpson, *Zymologia Physica*, p. 30.

of Sublimate" caused no fermentation.[45] In other words, he is again denying that salts alone are reactive enough to engender fermentation. In his claim, Simpson also shows himself a true Helmontian. Helmont claimed in his "Progymnasma meteori," in his *Ortus Humanum* that acidic corrosives, like the *aqua regia* in Sala's process, acted upon the sulphur present in metals, driving it outward and freeing it from the Mercurial part "with which it had been associated and allowing the lixivium then to extract it."[46] In Simpson's words, "but is it not rather the Sulphur in the metal, and the acidum of the menstruum, for the sake of which Sulphur the mercurial part is also broken into pieces, and the whole by that Fermentative motion dissolv'd."[47]

The incessant nature of metallogenesis via the fermentation of seeds in underground springs and caverns and the resultant heat that existed within the mines also was proof to Simpson that the heat of baths was due to fermentation: "for where once begun, they [the minerals] cease not to perpetuate their offspring . . . the constant efflux of waters keeping the fermentative principles in constant motion"[48] Just as metals grew in the mines via fermentative processes producing "mines so hot, they [the miners] can hardly touch them," so was the heat of the springs produced.[49] Simpson's idea was in direct contrast to Martin Lister who as we saw in the last chapter, believed the vitriolic salt exposed to the air produced heat. Not surprisingly, Simpson postulated that earthquakes and volcanoes resulted from the interaction of sulphur with "a fermenting acidum in the bowels of the Earth, in some narrow passages, where, when that elasticity and explosiveness of Sulphur by a supervening acid is excited . . . forceth and presseth on all hand upon the adjacent bulkes."[50] Simpson's experiments mixing brimstone and *aqua regia* were a close approximation to the processes he saw occurring under the earth's surface. Simpson's idea that metallogenesis involved acids was also determined in the laboratory, as metals could be chymically analyzed and shown to have acids within them. Simpson not only separated acid from Brimstone, but from Lead, Antimony, and Alum, and he distilled nitric acid and hydrochloric acids from Salt and Nitre.

[45] Simpson, *Zymologia Physica*, p. 31.
[46] Newman and Principe, *Alchemy Tried in the Fire*, p. 102.
[47] Simpson, *Zymologia Physica*, p. 29.
[48] Simpson, *Zymologia Physica*, p. 38.
[49] Simpson, *Zymologia Physica*, p. 39.
[50] Simpson, *Zymologia Physica*, p. 41.

A research collaborator by the name of Mr. Fisher separated acid out of bitumen (a term referring to an amorphous grouping of resinous and petroleum products such as crude oil, amber, asphaltum, and coal), taken from lead mines in the Peak District in Derbyshire.[51]

The resulting fermentation between the acids and sulphurs accounted for the continual generation of minerals and metals; the earth was a vital womb due to the operations of chemical fermentation, which meant that salt peter mines replenished themselves, as did the tin in Cornwall "breed" after it was mined.

Simpson's ideas about metallogenesis also informed his thought about the production of heat and light. Simpson first was hesitant to postulate about the causes of "heat and light in that great and inexhaustible Fountain thereof, the Sun," as it may have a "particular Fermentation of its own, set a work by the divine Fiat."[52] Aiming for more humble ends, he decided to analyze "that which is most obvious, viz. culinary fire and then examine how Light is produced therefrom."[53] He believed that acid and sulphur inherent in any combustible substance were worked upon by the air. Much as Simpson claimed dry salts mixed together would not chemically react with each other without the addition of water, he claimed the moisture of the Air was necessary for "ignition and flagration" of substances.[54] Here, Simpson may have been influenced by Boyle, whom he cited in several instances in the *Zymologia*, particularly Boyle's discussion of light in the case of a diamond that shone in the dark. Boyle speculated that "all shining substances depended upon air to some extent and speculated that the air had a role in producing the agitation that generates light."[55] Due to its "spongy nature," Simpson speculated that air imbibed moisture,

> wheeling off from other bodies in their incessant Fermentation, and thereby becomes qualified for keeping other Fermentations afoot, and then by its other quality of penetration . . . it becomes truly capable of assisting the principles of Acidum and Sulphur in their furious combating.[56]

After the moisture insinuated itself in the acid and sulphur particles and combustion occurred, there would be left some ashes in which there

[51] Simpson, *Zymologia Physica*, p. 25.
[52] Simpson, *Zymologia Physica*, p. 48.
[53] Simpson, *Zymologia Physica*, p. 108.
[54] Simpson, *Zymologia Physica*, p. 109.
[55] Golinski, "Phosphorus and the Royal Society," *Isis*, p. 22.
[56] Simpson, *Zymologia Physica*, p. 109.

was some salt, but eventually all things combusted were reduced to water. Simpson wrote,

> And although Fire moistens no bodies put thereto, yet doth it really go off, not only in a liquid, but humid form, witness the condenc'd steam of mineral Sulphur, or Brimstone, burning under a Glass campane (distillation apparatus) is sav'd in an acid Liquor, also Spirit of Wine, fired and condensed by such an artifice, appears in an insipid water.[57]

Again, in his return to a water principle, Simpson shows the basis of his work is Van Helmontian.

From these observations, Simpson concluded that rapid fermentation between acid and sulphur, with air, produced fire, and "fire of ignition gives Light by a continual winding off in luminous rays."[58] His study of optics convinced Simpson that light makes its exit in right lines from "the source of their Fermentative motion."[59] According to his scheme, the light then would collide with water atoms in the atmosphere. This collision between light and atmospheric moisture meant the light was taken from its 90 degree path, and became refracted, reflected, and multiplied which produced the diaphanous quality of fire and accounted for the illuminating property of flames. The acid of steel and the sulphur in flints or pyrites when struck also "set into a rapid Fermentation whence ariseth fire."[60] Just as flint struck steel to make sparks, lightening was caused by the falling of one cloud upon another, each cloud containing acids and sulphurs which collided and produced the sudden flash. Simpson's theory was a modification of Martin Lister's mechanism which solely involved the volatile and sulphureous exhalations of pyrites; in Simpson's theory, acids were a necessity.

Simpson believed a similar mechanism was behind a variety of other natural phenomena, including static electricity (due to fermentation of the acids and "highly volatilized" sulphurs in the animal spirits interacting with the moisture in the atmosphere), the shining light arising from rotting wood or fish, and the production of luminous meteors. Meteors occurred due to the acid and sulphureous particles that emanated from underground generation of minerals and metals into the "fluid

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57 Simpson, *Zymologia Physica*, p. 110.
58 Simpson, *Zymologia Physica*, p. 113.
59 Simpson, *Zymologia Physica*, p. 111.
60 Simpson, *Zymologia Physica*, p. 115.

menstruum" of the earth's atmosphere producing these "short-lived luminous textures."[61]

In the last chapter of the *Zymologia*, Simpson then analyzed how the principles of acid and sulphur

> "contracted into seedlings" are interspers'd in the seminals of all things, when by such kind of Fermentation . . . all things vegetate, come to their acme and decline; yea from which the whole Scene of visible concretions are by a certain struggling form their central fires, brought into action.[62]

To support his assertion, Simpson first cited a number of authorities, including Tachenius and Oleus Borrichius. Tachenius in his *Hippocrates Chimicus* (1666) claimed that no fermentation, creation or decay of animals and plants could occur without acids.[63] Olaus Borrichius in his *De Hermetica Aegyptiorum vetere et Paracelsiorum Nova Medicina* (Helmstadt, 1648), likewise stated that acids and sulphurs formed an intrinsic part of all animals.

Acids were thus claimed to be differently composed to make up the modifications of bodies, and classified as actively fermenting and fluid, or passive and consistent of matter: "From which succlency of Acids together with intermediate coagulations and hardenings, perform'd at due seasons, all concrete bodies in the threefold Kingdoms of nature are produc'd."[64] As an example, Simpson showed how acids and sulphurs accounted for plant growth. Though as Van Helmont postulated, the bulk of all living creatures including plants was ultimately water,

> that water should be form'd coagulated, and put on the shape of an Oak, Ash, etc., that is wholly ascribable to the intrinsick agents or intestine principles of Acid and Sulphur, set in the seedling into a Fermentative motion, displayed into that figure by the manuduction and evolution of the contracted and shut up Seed, carried up and conveyed by their proper Vessels, whether by the names of veins, arteries, etc., with their accompanying Air Vessels according to . . . our countryman Dr. Grew.[65]

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[61] Simpson, *Zymologia Physica*, p. 121.

[62] Simpson, *Zymologia Physica*, p. 134.

[63] Otto Tachenius, *Hippocrates Chimicus* (Venice, 1666), 90–91, as cited by Simpson, *Zymologia Chimicus*, p. 135. Tachenius wrote, "it is agreed, that as animals and plants move towards decay, nothing is able to be begat of the new, unless it precedes acids." (*sponte accessit, sicut et reliqui succi tum vegitabilium quam animalium, cum in putrifactionem tendunt: imo nil putrere neq; generari potest novi, nisi praecedat aciditas*.)

[64] Simpson, *Zymologia Physica*, p. 136.

[65] Simpson, *Zymologia Physica*, p. 138.

Acids "woven and condensed" together formed stalks, leaves, and husks of plants, and fruit was "coagulations of acids, sweetened by their sulphurs, thereby brought on to maturity, and thence made fit for other Fermentations, in order to [create] potable liquors."[66]

Therefore, though Grew believed salts were the "bones of the plants," Simpson thought acids were at the heart of living structures, making not only vegetation, but flesh and muscular parts. Acids were also the cause of tumors, which were "swellings from acids of some badly cured Disease" producing "spurious ferment" as well as gall stones, "sulphureous parts bound up by the vinculum of an acid."[67] Again, Simpson was departing from Paracelsian chymistry which postulated gall stones were concreted salts. Rather all salts such as "sal marine, vitriol, alum" were "concreted acid juices."[68]

Simpson and Newton

Simpson's search for a vital agent in the process of fermentation, as well as his assertions about acids and sulphurs in the *Zymologia* has some striking parallels with Newton's thought.[69] In his early 1670s manuscript, "On the Vegetation of Metals," Newton discoursed about the role of a subtle active matter and the fermentation of vital processes in nature: "This is the subtle spirit. This is Natures universall agent, her secret fire, ye onely ferment & principle of all vegetation. The material soule of all matter . . ."[70] Newton echoed this premise again in the Portsmouth manuscripts, where he claimed that ferments were "the true parents of all forms."[71] When discussing the forces that moved matter in the last Query in the *Opticks*, Newton classified them as inertia, gravity, cohesion of bodies, and "active principles" which "causes Fermentation" ranking them all as "occult qualities" who principles should be discovered "to

[66] Simpson, *Zymologia Physica*, p. 139.
[67] Simpson, *Zymologia Physica*, p. 140.
[68] Simpson, *Zymologia Physica*, p. 140.
[69] Partington in his entry on Simpson also notes the similarities. See Partington, *History of Chemistry*, vol. 2, p. 484.
[70] "Of Natures obvious laws & processes in vegetation," Burndy MS 16, fol. 5r, Smithsonian Institution, as quoted in John Henry, "Occult Qualities and the Experimental Philosophy," *History of Science* xxiv (1986), pp. 335–81, on p. 343.
[71] Isaac Newton, Portsmouth Collection Add. MS. 3975, Cambridge University Library, Cambridge University, fol. 110r.

the Improvement of Natural Philosophy."[72] Newton's *Index chemicus*, a topical index of his readings in alchemy, also contains references to works by Michael Sendivogius, George Starkey, and John Mayow that discuss fermentation, atmospheric acids and aerial nitre.[73] In the 1690s, Newton also acted as a patron to William Y-worth, a distillation chemist from Rotterdam, and Newton took notes between December 1692 and June 1693 on a series of experiments in fermentation he was carrying out. As Mandelbrote has stated, Newton's annotations drew on his wide reading in alchemy, which would have made Newton realize the analogy between chemical reactions and distillations to make wine and beer. In December 1692, Newton's notes began with an account of the production and virtue of barm, which was a fermenting malt liquor. Newton subsequently noted that via the process of fermentation, "metals could be made ready for transmutation."[74] Debus has also remarked upon Newton's preoccupation with fermentation, postulating

[72] Sir Isaac Newton, *Opticks, or a Treatise of the Reflections, Refractions, Inflections and Colors of Light based on the Fourth Edition London, 1730* (New York: Dover Publications, Inc., 1979), Book III, Part One, p. 401.

[73] Richard Westfall, "Isaac Newton's *Index Chemicus*," *Ambix* 22 (1975), pp. 174–85. The author recognizes the historiographic controversy surrounding the sources of Newton's chymical musings, as well as the exact nature of his debt to alchemy, but Newton's belief in the importance of atmospheric acids is self-evident. Michael Sendivogius' (1566–1636) *Novum Lumen Chymicum* (1604), which had over thirty editions printed until the end of the eighteenth century, identified the importance of nitre and nitric acid's presence in the air for respiration and its use as a universal fertilizer and principle of life. Sendivogius believed that nitre acted "like calcined tartar (anhydrous potassium carbonate) in attracting fertilizing humidity" into the soil from the heavens celestial rays; In 1674, John Mayow (1640–1679) in his *Tractatus Quinque Medico-Physici*, claimed that air was composed of a "small proportion of highly reactive particles which he identified as a nitro-aerial spirit." Like oxygen, "these particles alone made air suitable for respiration, and when absorbed through the lungs they imparted the bright red color to arterial blood; the nitro-aerial particles explained the necessity of air for combustion." See Henry Guerlac, "The Poet's Nitre," *Isis* 45, 3 (September 1954), pp. 243–255, on p. 243.

[74] Scott Mandelbrote, "Making Sense of Motion," in *Footprints of the Lion*, exhibition at Cambridge University Library, http://www.lib.cam.ac.uk/Exhibitions/Footprints_of_the_Lion/ p. 40. Accessed 20 November 2006. Figala and Petzold have also noted that in 1701/2 Newton purchased a wide variety of French alchemical works, including works by Duchesne which concerned fermentation. Newton also was in correspondence with Y-Worth, including helping him with the writing of the *Processus mysterii magni philosophicus*, which later became published as *Mercury's Caducean Rod*. See Karin Figala and Ulrich Petzold, "Alchemy in the Newtonian Circle," *Renaissance and Revolution: Humanists, Scholars, Craftsmen, and Natural Philosophers in Early Modern Europe* ed. J.V. Field and Frank A.J.L. James (Cambridge: Cambridge University Press, 1993), pp. 173–192.

that it stemmed from Van Helmont's concept of the *Blas*, or a universal motive power, as Newton had taken notes on Helmont's *Opera omnia.*[75] The *Blas* (more specifically the *blas meteoron*) was responsible not only for meteorological effects, but also the motive power governing organic life (*blas humanum*).

As Simpson was a Helmontian, his work may thus have been appealing to Newton as he speculated about the source of the motion of matter and its natural effects. Certainly in query 31 of the 1717 *Opticks*, Newton "linked active principles with the 'great and violent' processes of chymistry, questioning the reducibility of chemistry to the passive Laws of Motion."[76] In query 31, Newton claimed in a mechanism quite reminiscent of Simpson's discussion of meteorology in the *Zymologia* that

> some sulphureous steams . . . ascending into the air, ferment there with nitrous acids, and sometimes taking fire cause lightening and thunder, and fiery meteors. For the air abounds with acid vapours fit to promote fermentation. . . . in Fermentations the Particles of Bodies which almost rest, are put into new Motions by a very potent Principle, which acts upon them only when they approach one another, and causes them to meet and clash with great violence, and grow hot with the motion, and dash one another to pieces, and vanish into Air, and Vapour, and Flame.[77]

Query 8 in the *Opticks* also asked, "and do not all Bodies which abound with terrestrial parts, and especially with sulphureous ones, emit Light as often as those parts are sufficiently agitated?"[78]

Newton also wrote the *De Natura acidorum* in 1692, which was sent to the physician Archibald Pitcairne and published by John Harris in the *Lexicon Technicum: A Universal Dictionary of Arts and Sciences* (1704–10). Acids in Newton's scheme were in size larger than water molecules, but smaller than earthy ones, and were endowed with a "great attractive force."[79] As the acids rushed "towards the Particles of bodies," they

[75] Allen Debus, "Motion in Renaissance Chemistry," *Isis* 64, 1 (March 1973), pp. 4–17, on p. 15.

[76] P.M. Heimann, "Ether and imponderables," *Conceptions of ether: Studies in the history of ether theories*, eds. G.N. Cantor and M.J.S. Hodge (Cambridge: Cambridge University Press, 1981), pp. 61–85, on p. 66.

[77] Newton, *Opticks*, Book III, Query 31, p. 380.

[78] Newton, *Opticks*, Book III, Query 8, p. 340.

[79] Isaac Newton, "De Natura Acidorum" *Lexicon Technicum: Or, an Universal English Dictionary of Arts and Sciences*, ed. John Harris (London: D. Brown, et al. 1736), vol. 1, fol. E2 recto.

"excite Heat; and they shake asunder some Particles," which was the "reason for all violent Fermentation, and in all Fermentation there is an Acid latent or suppressed."[80] Acids attracted water as much as they did particles of bodies, putting matter into solution. Newton also postulated that acids were also crucial components of sulphurs and fats; because acids were of such attractive qualities, they were "closely retain'd" by other particles when mixed with them, "quite suppressed and hidden as it were by them; so that they neither stimulate the organ of sense, nor attract water, but compose Bodies which are not Acid ie Fat and Fusible Bodies."[81] The attractive force in these suppressed acid particles "in sulphureous bodies" accounted for their inflammable nature; when sulphurs met with other materials, the acids within it "by more strongly attracting the Particles of other Bodies (earthly ones for Instance) than its own, promotes a gentle Fermentation, produces and cherishes Natural Heat, and carries it on . . ."[82] Clearly for Newton and for Simpson, acids and sulphurs were behind fermentation.

Newton then postulated that if the fermentation progressed to its ultimate end, the compound putrefied, and a new mixture or compound was created; as he expressed in the *Opticks*, nature "seems delighted with transmutations."[83] In the Propositions in the Burndy MS 16, Newton also asserted that "Nothing can be changed from what it is without putrefaction . . . nothing can be generated or nourished (but of putrified matter)."[84] Newton therefore believed that acids with their sulphurs were behind organic creation and decay. Simpson likewise when discussing the putrefaction of animals in the *Zymologia* stated that when the principles of acid and sulphur in the animal tissue interacted with the air and underwent a

> putrefactive Fermentation, the sulphur by those retrograde motions, become more volatilized and by gentle touches from its inbred Acid, winds off in a luminous flame . . . to which may be added, that in their putrefactive reductions, a mucilage be made to appear, which is the receptacle, as it were sperme . . .[85]

[80] Newton, "De Natura Acidorum," p. E2 verso.
[81] Newton, "De Natura Acidorum," p. F1 recto.
[82] Newton, "De Natura Acidorum," p. F1 recto.
[83] Newton, *Opticks*, Book III, Query 30, p. 375.
[84] Newton, Burndy MS 16, fol. 5r, as quoted in Dobbs, "Newton's Alchemy," p. 519.
[85] Simpson, *Zymologia*, p. 119.

This "sperme" would then generate new substances. Van Helmont had also suggested that bird's eggs putrified before the formation of a chick and "life is in those putrified things."[86]

Simpson postulated that the putrefying matter could also emit light, as in the case of rotting fish. This is also reminiscent of Newtonian thought. As Dobbs stated, Newton believed:

> In rarefaction . . . fermentation worked against the force of cohesion, agitating the particles so violently that they broke away from the control of the cohesive force and came under the influence of the force of repulsion. In processes of solution, for example, when particles rush together so violently that they grow hot, the . . . large composite particles of "air, vapours, and exhalations" may be expelled, or very small particles given off as light. Putrid vapours may likewise "shine from the agitation due to putrefaction."[87]

In the only surviving letter Newton wrote to Robert Boyle, composed on 28 February 1679, Newton further speculated the role that acids had in the density and affinity of matter.[88] The letter opens with Newton's speculations on the aether, a rarified substance like air. The aether was more subtle than air, was "capable of contraction and dilation" and "strongly elastic." Not only did the "intermingling of rarer with denser aether at the edges of opaque bodies" allow Newton to explain the refraction of light, but he also thought it "might explain the attraction and repulsion between bodies," as well as chemical reactions.[89]

The aether pervaded all bodies, "but yet so as to land rare in their pores then in free spaces, and so much the rarer, as their pores are less."[90] His evidence for this assertion was that when objects were placed in a vacuum, only the aether remained, accounting for such phenomena as the cohesion of two pieces of metals or marble discs in a vacuum; the fine aether in the pores of the metals or marble produced an attractive force. And, the further one went to the interior of bodies, the rarer the aether became, as it was more and more difficult for the aether to

[86] Van Helmont, "Image of Ferments," *Van Helmont's Works*, p. 113.

[87] Dobbs, "Newton's Alchemy," p. 525.

[88] Isaac Newton, "Correspondence with Robert Boyle, 1679," *Isaac Newton: Philosophical Writings*, ed. Andrew Janiak, Cambridge Texts in the History of Philosophy (Cambridge: Cambridge University Press, 2004). http://www.cup.cam.ac.uk/us/catalogue/catalogue.asp?isbn=9780521831222 &ss=exc. Accessed 20 Feburary 2007.

[89] Scott Mandelbrote, "Making Sense of Motion," in *Footprints of the Lion*, p. 98.

[90] Isaac Newton, "Correspondence with Robert Boyle, 1679," p. 1.

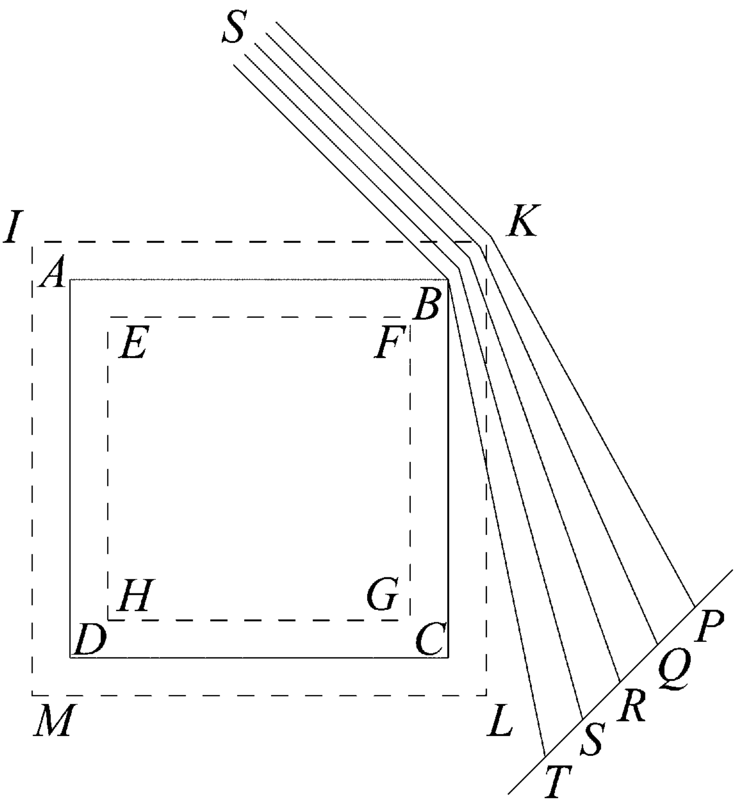

Figure 7. Newton's explanation of Grimaldi's theory of refraction using the aether model. Newton to Robert Boyle, Cambridge, 28 February 1678/9 in *Isaac Newton: Philosophical Writings*, ed Andrew Janiak (Cambridge: Cambridge University Press, 2004), p. 2. With permission from Cambridge University Press.

penetrate the inside of bodies. That conclusion explained to Newton Francesca Maria Grimaldi's light diffraction experiment, in which light "passing by the edge of a knife, or other opaque body, is turned aside and refracted, and by that refraction makes several colors."[91] [Figure 7]. As one can see, dependent on the aether gradient, the light is diffracted at different angles.

[91] Grimaldi's *Physico-Mathesis de Lumine* (Bologna 1665) is discussed at length in A. Rupert Hall's "Beyond the Fringe: Diffraction as seen by Grimaldi, Fabri, Hooke, and Newton" *Notes and Records of the. Royal Society of London* 44 (1990), pp. 13–23.

Newton then postulated that when two bodies came near each other, the aether between them grew "rarer" then before as the distance decreased. As the aether became rarer as the two bodies were almost touching, they began to repel each other, "because thereby they cause the interjacent aether to rarefy more and more."[92] As Newton explained,

> But at length when they come so near together that the excess of pressure of the external aether which surrounds the bodies, above that of the rarefied aether, which is between them, is so great as to overcome the reluctance which the bodies have from being brought together, then will that excess of pressure drive them with violence together, and make them adhere stronger to each other.[93]

The rate of cohesion or repulsion, or chymically, the relative volatility and fixedness of material bodies depended on a few other factors. First, the sizes of matter particles determined their volatility, as greater heat or force would be necessary to dissolve larger particles than smaller ones. Second, the degree which the aether in the particles was rarified determined volatility. If one had a really small particle, aether on its outside could get in from all sides more easily, so there was not as much aether gradient between the interior and exterior of the particle. Larger particles had a more pronounced aether gradient, as aether on the exterior of the particle could not get to its interior as easily; the interior of large particles were therefore more rarified.

From these speculations, Newton concluded

> this may be the reason they why the small particles of vapours easily come together and are reduced back into water unless that which keeps them in agitation be so great as to dissipate them as fast they come together: but the grosser particles of exhalations raised by fermentation keep their aerial form more obstinately, because the aether within them is rarer.[94]

In the *Hypotheses of Light*, Newton asserted an "aetherial spirit may be condensed in fermenting bodies."[95] He also speculated that "true permanent air" or the heavier air in the atmosphere may be due to the

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[92] Newton, "Correspondence with Robert Boyle, 1679," *Isaac Newton: Philosophical Writings*, pp. 1–10, on p. 4.
[93] Newton, "Correspondence with Robert Boyle, 1679," *Isaac Newton: Philosophical Writings*, pp. 1–10, on p. 4.
[94] Newton, "Correspondence with Robert Boyle, 1679," *Isaac Newton: Philosophical Writings*, pp. 1–10, on p. 9.
[95] Newton, "An Hypothesis explaining the Properties of Light," *The History of the Royal Society* by Thomas Birch (London, 1757), vol. 3, pp. 247–305, on p. 251.

"metallic exhalations raised in the bowels of the earth by the action of acid menstruums," as metals were the densest of substances.[96] The heavy air released by metallic fermentation "betrayed its ponderosity by making vapours ascend readily in it, but sustaining mist and clouds of snow, and buoying up gross and ponderous smoke."[97] Simpson in the *Zymologia* also had postulated that the more brisk fermentation occurred, the more dense the aerial products they produced; the variability of fermentation thus accounted for the different components of and effects in the atmosphere. Some of these acid-sulphur fermentations he believed were visible as "steams" a little after sun rise, "the eye being somewhat elevated above the level of the ground."[98] Both natural philosophers certainly agreed that fermentation in the atmosphere produced components of the air with different densities.

Newtonian physicians and saline spirits

Simpson's and hence Newton's emphases on the role of saline spirits or acids in chymical processes also affected early modern medical and physiological theories and applications. This was particularly the case among the Newtonian Physicians, a group of medical practitioners identified by Theodore Brown and Anita Guerrini. These physicians were primarily active between 1687 (publication of Newton's *Principia*) and 1713, though there were still doctors utilizing Newtonian theory, such as Irish physician Bryan Robinson, until the mid-eighteenth century.[99] Scottish physicians David Gregory (1659–1708), who became the Savilian chair of astronomy of Oxford, and Archibald Pitcairne (1652–1713), who was the chair of medicine at Leyden, sought Newton's patronage and utilized his work to interpret human physiology. Pitcairne's students included Richard Mead (1673–1754) and George Cheyne (1671–1743), and Gregory's pupils James and John Keill and the English physician

[96] Newton, "Correspondence with Robert Boyle, 1679," *Isaac Newton: Philosophical Writings*, pp. 1–10, on p. 10.
[97] Newton, "Correspondence with Robert Boyle, 1679," *Isaac Newton: Philosophical Writings*, pp. 1–10, on p. 10.
[98] Simpson, *Zymologia Physica*, p. 122.
[99] Guerrini, "Archibald Pitcairne and Newtonian Medicine"; Guerrini, "The Tory Newtonians: Gregory, Pitcairne, and their Circle"; Theodore Brown, "Medicine in the Shadow of the Principia." *Journal of the History of Ideas*, 48 (1987), pp. 629–48.

John Friend. These doctors also applied Newtonian theory to the effects of gravity on the body, or used calculus or geometry to interpret the mechanics of fluids through bodily vessels, along with analysis of attractions between matter.

Some of the Newtonian physicians, such as Pitcairne, concentrated on Newtonian "iatromathematics" applying purely mechanistic explanations from Newton's theory of matter in the *Principia* and *De natura acidorum* to human physiology. Pitcairne in particular concentrated upon "the analogy of the microcosm to the macrocosm, the possibility of limitless transmutation, and the inertness of matter, which was independent of force and activity."[100] As Guerrini has shown, Pitcairne discounted any explanation of the Helmontian iatrochymists, particularly any explanation which involved chemical ferments or short-range attractions between particles.[101] Pitcairne thought that the size of particles, not their shapes, was the important consideration in a theory of secretion and medical treatments; "bodily secretions were classified into grosser and thinner fluids which passed through appropriately sized bodily orifices."[102] Proper circulation, and the pressure and secretion of fluids in the vessels—all "mechanical, mathematizable . . . observable entities"—were the bases of health.[103]

As he wished to concentrate on observable entities, Pitcairne rejected Newton's explanation for heat of the blood involving fermentation. In the *Opticks*, Newton noted, "the cause of fermentation . . . is an acid, by which the heart and blood of Animals are kept in Perpetual Motion and Heat."[104] In a letter to the iatromechanical physician Archibald Pitcairne (1652–1713), Newton also noted that that "sulphur seems to be what is deposited on the lungs from the air, and what is supplied from the air to maintain fire seems to be the same."[105] In the *de Natura Acidorum*, Newton then remarked that when alchemists said "sulphur," "by sulphur they

[100] Anita Guerrini, "Archibald Pitcairne," p. 74.

[101] Guerrini, "Isaac Newton, George Cheyne and the "Principia Medicinae," *The medical revolution of the seventeenth century*, ed. Roger French and Andrew Wear (Cambridge: Cambridge University Press, 1989), pp. 222–245, on, pp. 224–5.

[102] Guerrini, "Archibald Pitcairne," p. 77.

[103] Theodore Brown, "Medicine in the Shadow of the *Principia*," p. 632.

[104] Newton, *Opticks*, Book III, Query 30, p. 399.

[105] "Pitcairne with Newton at Cambridge," March 2, 1691/2 in *The Correspondence of Isaac Newton*, ed. H.W. Turnbull (Cambridge: Cambridge University Press, 1961), vol. 3, p. 210.

mean acid."[106] As Guerrini indicated, Pitcairne thought "innate heat" was caused not by a ferment but rather collision of blood particles with each other and with vascular walls. Animal heat was also

> . . . dependent upon the motion of the heart. As in much of Pitcairne's work, the underlying metaphor came from astronomy: the heart causes life . . . by its beat, as the sun causes motion in the universe via its gravity. He drew an analogy between gravity and the heartbeat, not as Newton had in *De natura acidorum*, between gravity and local short-range attractions.[107]

Pitcairne in his rigidly mechanistic account however was an exception in the circle of the Newtonian physicians, most of who were interested in fermentations of acidic saline spirits in bodily processes and did consider the shapes of saline particles and their reactions in the body. The Newtonian physician George Cheyne in his treatise of gout (1720) traditionally attributed this malady to "the abundance of tartarous, urinous, or other salts, introduced into the Blood by the Food."[108] Treatment could be by modifying diet to lessen the quantity of the salts, increased exercise to expel salts in perspiration, or taking sulphureous medicine. The sulphur which was "small and active" would unite and dulcify the salts, "especially those of the acid kind," destroying their efficacy.[109] Newton had discoursed in the *Opticks* about the permanency of salts, and in the *De Natura Acidorum* how the "Acid that lies suppress'd in sulphureous Bodies, by more strongly attracting the Particles of other Bodies . . . promotes a gentle Fermentation . . . and carries on . . . to the Putrefaction of the Compound."[110]

Newton also noted in the *De Natura Acidorum* how saline spirits or acids "tore" into the tongue or any "excoriated Part of the Body" causing a painful Sensation.[111] Cheyne's *The English Malady* (1753) concerning nervous disorders likewise devoted an entire chapter to the "effects of

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[106] Newton, *De Natura Acidorum*, fol E2 verso. For a discussion of the possible influence the alchemist George Starkey's *Pyrotechny* had on the *De Natura Acidorum* see Newmann, *Gehennical Fire*, 228–243, *passim*.

[107] Guerrini, "Archibald Pitcairne," pp. 79–80.

[108] George Cheyne, *Observations Concerning the Nature and Due Method of Treating the Gout* (London: G. Strahan, 1720), p. 3.

[109] Cheyne, *Treatise of the Gout*, p. 9 (for lessening quantity of salts); 14–15 (for perspiration); p. 13, for lessing salts via diet; p. 17 for diluting salts via spa waters; pp. 32–37 for treatment of gout via sulphur.

[110] Newton, *De Natura Acidorum*, fol. F1 recto.

[111] Newton, *De Natura Acidorum*, fol. F1 verso.

Salts" upon "human bodies and constitutions." Cheyne stated how "corrosive animal salts," particularly acid caustics "form themselves into regular, and sharp, or angular Figures whereby they become more piercing and penetrating."[112] The salts according to Cheyne became congealed together via "the Actions of little Bodies," and to prove his assertions, he then referred the reader to Newton's *Opticks*, Keill's explanation of Newtonian physiology and the "explication of chymical appearances of Dr. Freind" and the work of Richard Mead.[113]

Richard Mead, who began as a dissenting physician in Stepney and ended up physician to George II via Newtonian patronage, wrote several works inspired by the *Principia* and *Opticks*. In his first iatromechanical work, *A Mechanical Account of Poisons* (1702), he argued that the nervous spirits or animal fluids of the body that were the most susceptible to poison were made of a "universal elastic matter" first postulated by "our great philosopher, Sir Isaac Newton," referring the reader to queries 23 and 24 or the *Optics*.[114]

In a separate essay on "Venomous Exhalations" in the *Mechanical Account*, Mead speculated upon a "vivifying matter from the air, which passes into the blood by the breath," and the effects upon this substance of subterranean emanations from "la Grotta de Cani," a Neopolitan cave which emanated a "thin, subtile warm fume" which asphyxiated passers-by.[115] The fume was a greenish color, leading Mead to postulate that it was the "phlegm of vitriol" or sulphuric acid "raised by a subterraneous heat."[116] He clamed that the acidic particles, quite in contrast to Newton's role for acids, had a "counteraction or repulsive force to the elastic matter" of the animal spirits causing it to lose its force in the body. Mead continued:

> Neither must it seem strange, that the animal spirits should be so suddenly interrupted in their action by the interposition of a ponderous fluid, since we see every day how instantaneously, on the other hand, their motion is quickened and revived by the application, to the nostrils of volatile salts, and it may be observed, that these are always alkaline, that is, of a

[112] George Cheyne, *The English Malady*, ed. Roy Porter (London and New York: Tavistock/Routledge, 1991), pp. 35–44.
[113] Cheyne, *The English Malady*, pp. 43–44.
[114] Richard Mead, "Preface" to *A Mechanical Account of Poisons in Several Essays* in *The Medical Worlds of Richard Mead, M.D.* (Edinburgh: Alexander Donaldson and Charles Elliot, 1775; New York: AMS Press, 1978), p. 7.
[115] Mead, *A Mechanical Account of Poisons*, pp. 101–103.
[116] Mead, *A Mechanical Account of Poisons*, p. 103.

> nature quite opposite to vitriolic or acid spirits, so as readily to fall into a conflict or fermentation with them.[117]

Just as Pitcairne modified Newton's works to suit his own theories, Mead followed suit, combining Newtonian aether with Sylvius's acid-alkali iatrochymistry. The basic tenets of Sylvius' theories were that effervescence was typical of physiology, and everything, including the bodily humors, had acidic and basic qualities in addition to their cold, hot, moist, and dry attributes.[118] For instance, Sylvius compared the blood's effervescence with the reaction between acids and alkalis, and claimed that "[i]nspiration serves to temper this process by giving access" to a volatile salt in the air into the blood.[119] Sylvius in particular believed that "acrimonious influences were ascribed to specific fluids," including the lymph and that "characteristic diseases resulted from their acidic or alkaline natures."[120] Too acidic conditions or alkaline conditions in bodily fluids caused disease, a state to be countered with appropriate basic or acidic medicaments to restore the balance of the humors.[121] Harold Cook has shown the simplistic division of all chymical substances into acids and alkalis made this theory an extremely popular and often misused medical treatment among the populace in the United Kingdom in the seventeenth and early eighteenth centuries.[122]

Mead also was not above using trendy vocabulary to boost his medical practice. As he later rather cynically advised another young physician, Timothy Vanbustle:

> Should you have an itching to make your name known by writing a book on physic, yet so customary, I will advise you to choose the subject by which you think you will get most money, or that will bring you the most general business . . . The method of writing, if in your frontispiece you address not your book to some great man, is to club with some other physicians; and thus by way of letters to commend each other's good

[117] Mead, *A Mechanical Account of Poisons*, p. 103.

[118] Marie Boas Hall, "Acid and Alkali in Seventeenth-Century Chemistry," *Archives internationales d'historie des sciences*, 1956, 34: 13–28; Harold Cook, *Trials of an Ordinary Doctor: Joannes Groenevelt in Seventeenth-Century London* (Baltimore: John Hopkins University Press, 1994), p. 66.

[119] Sylvius [Franciscus de la Böe], *Sylvii Opera medica tam hactenus inedita* (A,sterdam: D. Elsevir and A. Wolfgang, 1679), 32; quoted in Walter Pagel, *William Harvey's Biological Ideas: Selected Aspects and Historical Background* (Basel and New York: S. Karger, 1967), p. 194.

[120] Debus, *The Chymical Philosophy*, vol. 2, p. 530.

[121] Cook, *Trials of an Ordinary Doctor*, p. 66.

[122] Cook, *Trials of an Ordinary Doctor*, p. 66.

> practice and to support and make each other favour. But above all things, take particular care, let the subject be what it will, that the words be well chosen, so to make up an elegant and fervid speech; since you have ten to one that mind the language more than the ideas.[123]

Indeed, the prestige of the "elegant and fervid speech" of Newtonianism along with acid-alkali iatrochymistry made the *Mechanical Account* a successful publication, enough to gain Mead a position at St. Thomas Hospital in Southwark and election to the Royal Society.[124]

In his *English Malady*, Cheyne also directed his audience to the "late ingenious Performance of Dr. Bryan Robinson," an Irish Newtonian physician who extensively and more faithfully utilized Newtonian chymistry in his work than Pitcairne or Mead. In 1732, Robinson (1680–1754) wrote his *Treatise of the Animal Oeconomy*, a work of physiological mechanism.[125] Past scholarly analysis of the *Oeconomy* has portrayed Robinson's work in the context of two intellectual influences—first, Leiden physician Herman Boerhaave's (1668–1738) emphasis on the hydraulics of bodily fluids through the veins and arteries, as well his study of solids and their fibers whose faults caused distempers, and second, a "Newtonian physiology" based on the queries on ether in Newton's Opticks.[126] Robinson particularly attributed the "motion of muscles to the vibration of an ethereal fluid pervading the animal body."[127] Heimann also noted how Robinson's *Dissertation on the aether of Sir Isaac*

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[123] John Nichols, *Literary Anecdotes of the Eighteenth Century* . . . (London: Nichols, Son, and Bentley, 1812), 4:219 quoted in Kenneth Dewhurst, *The Quicksilver Doctor: The Life and Times of Thomas Dover, Physician and Adventurer* (Bristol: Wright, 1957), p. 123.

[124] Guerrini, "Isaac Newton, George Cheyne, and the *Principia Medicinae*," p. 230.

[125] Bryan Robinson, *A Treatise of the Animal Oeconomy* (Dublin: George Ewing, 1734). This is the second edition of the work, to which I will refer throughout this paper. Robinson's book was reprinted in 1734, 1735, 1737 and 1738. The 1737 edition was re-titled *A Continuation of a Treatise of the Animal Oeconomy*.

[126] For Boerhaave's influence, see Theodore Browne, "The Mechanical Philosophy and the 'Animal Oeconomy'—A Study in the Development of English Physiology in the Seventeenth and Early Eighteenth Century." Ph.D. diss., Princeton University, 1968, pp. 351–53. For Robinson and ether, see Arnold Thackray, *Atoms and Powers: An Essay on Newtonian Matter Theory and the Development of Chemistry* (Cambridge: Harvard University Press, 1970), pp. 135–41; J.R.R. Christie, "Ether and the Science of Chemistry: 1740–1790," in *Conceptions of Ether: Studies in the History of Ether Theories, 1740–1900* (Cambridge: Cambridge University Press, 1981), pp. 86–110, on pp. 96–98. Christie sees Robinson primarily as an influence on the Scottish chemist William Cullen.

[127] *D.N.B.* s.v. "Bryan Robinson." For more on the identification of ether with nervous fluid and muscular motion, see Anita Guerrini, "Ether Madness: Newtonianism, Religion, and Insanity in Eighteenth-Century England," in *Action and Reaction: Proceedings of a Symposium to Commemorate the Tercentenary of Newton's Principia*, ed. Paul Theerman and Adele F. Seeff (Newark: University of Delaware Press, 1993), p. 238.

Newton (1732) had a "considerable impact on the work of the electrical theorists of the 1740's," particularly on Benjamin Wilson's (1721–88) identification of ether with an electrical substance in 1746. There however has been little work analyzing Robinson's work on a universal acid or Newtonian chymistry in the context of respiratory physiology[128]

Robinson graduated M.D. in 1711 from Trinity College, Dublin, where he later served as an anatomical lecturer in 1716–17, and as Regius Professor of Physic from 1745[129] [Figure 8]. He also was thrice president of the Kings and Queen's College of Physicians in Ireland, and of the Irish Royal College of Surgeons. He was the editor of his colleague Richard Helsham's *Course of Lectures in Natural Philosophy* (1739) printed at Trinity College; Helsham's work simplified and popularized the discoveries and innovations in methodology of Bacon, Boyle, Descartes and Newton to university students, and parts of the work were reprinted until 1834.[130] Robinson also authored an essay on money and coins that contained Newton's "representation to the treasury as Warden of the Mint," and in fact was best known as a mathematical author before he wrote his medical treatises.[131] Robinson's first published work was a translation of Philippe de la Hire's *New Elements on Conic Sections* in 1704, which "was dedicated to his 'best friend' John

[128] P.M. Heimann, "Ether and Imponderables," in *Conceptions of Ether*, 61–83, quoted on 70. Wilson was an English portrait painter and electrician who favored Newton's gravitational-optical ether theory of electricity over Benjamin Franklin's idea of positive and negative electricity. For an older discussion of eighteenth-century British theories of electricity, Robinson, and Wilson, see R.W. Home, "Aepinus and the British Electricians: The Dissemination of a Scientific Theory," *Isis* 63, 2 (June 1972), pp. 190–204.

[129] *D.N.B.*, s.v. "Bryan Robinson." The website of the Medical School of Trinity College Dublin website lists all the Regius Professors of Physics, equivalent to the Headship of the Department of Clinical Medicine. The Regius Professors included Robinson and his teacher Richard Helsham as well; Helsham was appointed in 1733. See http://www.tcd.ie/ClinicalMedicine/people/cmhead.html, p. 1. Accessed 25 July 2004.

[130] J.L. Heilbron, "Review of Richard Helsham, *A Course of Lectures in Natural Philosophy*, published by Bryan Robinson, reprint of the fourth edition, 1767. With an introduction by D. Wearie, P. Kelly, and D.A. Addis," *History of Physics Newsletter* 8 (2001), p. 8. This reprint was published in Bristol by the Institute of Physics Publishing for the Physics Department of Trinity College Dublin.

[131] *D.N.B.*, s.v. "Bryan Robinson;" *The Dictionary of Eighteenth-Century British Philosophers*, s.v. "Robinson Bryan (1680–1754), ed. John Yolton, John Price and John Stephens (London: Thoemmes Press, 1999); [Philippe de la Hire], *New Elements of Conick Sections*, trans. Bryan Robinson (London: Dan Midwinter, 1704). Bryan Robinson, *Essay upon Coin* (London: W. Johnston, 1758). The first edition of the *Essay upon Money and Coins* was published posthumously in 1758 by Robinson's sons.

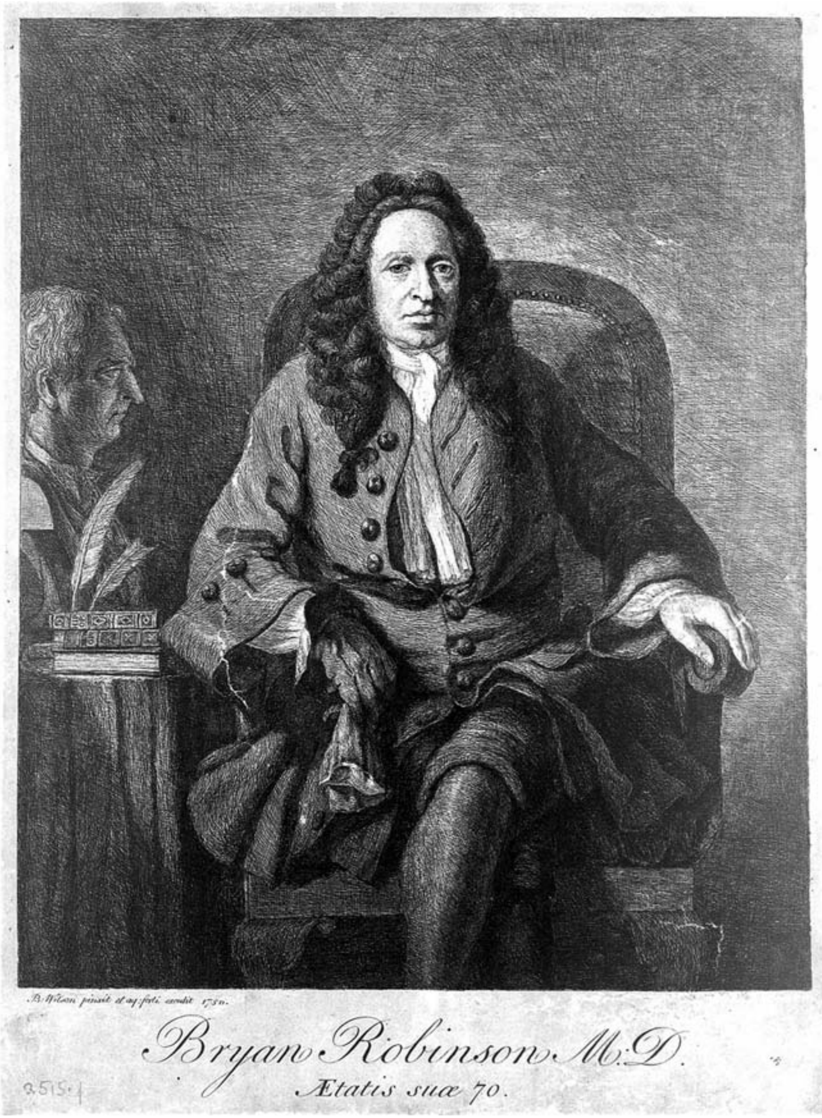

Figure 8. Bryan Robinson (1680–94), etching by Benjamin Wilson (1721–1788). Wellcome Library, London.

Harris."[132] Harris gave public lectures on mathematics, and may have tutored Robinson; Harris also later translated and published Newton's *De Natura acidorum* (1710) which likely was the reason for Robinson's emphasis upon Newtonian chymistry in the *Animal Oeconomy*.[133]

In the *Animal Oeconomy*, Robinson was particularly concerned with Newton's discussion of the effects of atmospheric acids and acidic salts upon the natural world, particularly on the bodily constitution. Robinson postulated that Newton's aether was permeated with "acidic parts of the air."[134] These acids were necessary to respiration, "preserved the life of animals," and his discussion demonstrated that Robinson had a "glimmering of the nature" of oxygen's role in respiration.[135] Robinson stated in the twenty-fourth proposition of his *Animal Oeconomy* that "[t]he life of animals is preserved by acid Parts of the Air, mixing with the Blood in the Lungs: which parts dissolve or attenuate the Blood, and preserve its Heat; and by both these, keep up the Motion of the Heart."[136] Robinson first noted from the results of Robert Hooke's (1635–1703) air pump experiments that a constant supply of fresh air is necessary to preserve the Life of Animals, as well as to preserve "sulphureous and unctuous Substances when once they are kindled."[137] He then referred to a chymical experiment done by physician Olaus Borrichius (1626–1690) in which spirit of nitre (nitric acid or HNO_3) was added to the unctuous oil of cloves (mostly eugenol $C_{10}H_{12}O_2$), an exothermic reaction that results in the production of oxalic acid and "in a burning flame" that remained present even in a vacuum. Similar experiments in which sulphur and nitric acid were mixed together and kindled, resulted in them burning "under Water, or in vacuo, as well as in the open Air."[138] Robinson then concluded that fire and flame "may both be produced and preserved in sulphureous and unctuous Substances by acid Particles even without Air," and thus, "that Air

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[132] The *Dictionary of Eighteenth-Century British Philosophers*, s.v. "Robinson Bryan (1680–1754)." Thackeray notes how Harris even "corrected the sheets" to the *Conic Sections*. See Thackray, *Atoms and Powers*, p. 136.

[133] Isaac Newton, *De Natura acidorum*, fol. B2 recto.

[134] Robinson, *Animal Oeconomy*, p. 190.

[135] *D.N.B.* s.v. "Bryan Robinson."

[136] Robinson, *Animal Oeconomy*, p. 190.

[137] Robinson, *Animal Oeconomy*, p. 194.

[138] Robinson, *Animal Oeconomy*, p. 195. A similar experiment was done by Boyle and Mayow in which they burned gunpowder under water. For a short discussion of Robinson's intellectual sources, see J.R. Parthington, "Some Early Appraisals of the Work of John Mayow," *Isis* 50 (1959), pp. 211–26, esp. pp. 224–25.

preserves Fire and Flame by means of acid Particles."[139] Therefore, in a neat syllogism, acid particles preserved the life of animals, as they preserved flame in vacuo.

But how would Robinson prove his Proposition that acid particles in the air were the chymical source of respiration? Noting past experiments by Dr. Richard Lower (1631–1691), Robinson realized that venal blood was deeper purple, and when exposed to air would turn bright red.[140] Robinson concluded that the acid parts of the air caused this change, and therefore there must be a "like contact of these acid parts with the blood in the lung."[141] Ergo, "the life of animals is preserved by acid parts of the air mixing with the blood in the lungs."[142]

Robinson then turned to Newton's *Opticks* to explain in more detail the chymical interaction of the acid in the air with the blood, drawing upon Newton's work on color and chymistry. Robinson noted that:

> the bright red Color acquired by the Blood in the Lungs, from its Purity and Intenseness, is the Red of the second Order of Colors in the Table of Sir Isaac Newton's *Opticks*, p. 206. But the blackish or deep purple Color of Venal Blood turns into this bright Red, without passing through the Colors of Blue, Green, Yellow, and Orange; and therefore, must arise from the indigo and Purple of the third Order, and not from the Indigo and Violet of the second. And consequently by that Table, the tinging Corpuscles of the Blood are lessened in the Lungs. Hence it appears, that the acid parts of the Air dissolve or attenuate the Blood in the Lungs.[143]

What was this table referred to in the *Opticks*, and how did Robinson come to this conclusion?

In the *Opticks*, Newton attempted to find the sizes of the corpuscles of light that made up different colors in the spectrum with his experiments placing a plano-convex lens on a flat glass surface, producing "Newton's rings" or colored and concentric interference rings seen when illuminated from above with monochromatic light. Although Newton believed in a corpuscular theory of light, Newton's rings result from the interference between rays reflected by the top and bottom surfaces of

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[139] Robinson, *Animal Oeconomy*, p. 195.

[140] Richard Lower, *Tractatus de corde item de motu et colore sanguinis et chyli in eum transitu* (London: J. Allestry, 1669), pp. 164–65. For an older, but still useful overview of respiratory theory, see Leonard G. Wilson, "The Transformation of Ancient Theories of Respiration in the Seventeenth Century," *Isis* 51 (1960), pp. 161–72.

[141] Robinson, *Animal Oeconomy*, p. 198.

[142] Robinson, *Animal Oeconomy*, p. 198.

[143] Robinson, *Animal Oeconomy*, pp. 198–99.

the air gap between the two pieces of glass. Because the gap (equivalent to a thin film) increases in width from the central contact point out to the edges, the extra path length of the lower ray varies, and corresponds to constructive and destructive interference, which gives rise to the series of bright and dark rings of color. After carefully measuring, Newton realized the thickness of this film of air between the lens and the glass corresponded to the spacing of the rings.[144] He also realized that the quantity of light reflected from the rings was "most copious from the first or inmost, and in the exterior Rings became gradually less and less;" in other words as Alan Shapiro has observed, Newton realized there was a periodicity in the intensity of the several colors into which he divided visible light.[145] Newton subsequently ordered the intensity of the colored rings he saw, composing a table, "wherein the thickness of Air, Water, and Glass, at which each Color is most intense and specific, is expressed in parts of an Inch divided into ten hundred thousand equal parts."[146] This is the table to which Robinson referred [Figure 9].

As Shapiro has noted, Newton also believed that the "corpuscles of bodies produce colors just as a thin film or air gap of the same thickness and density does."[147] Newton wrote,

> The transparent part of bodies according to their several sizes must reflect rays of one color and transmit those of another, on the same grounds that thin plates does reflect or transmit those rays. And this I take to be the ground of all their colors. The parts of Bodies on which their colors depend are denser than the Medium wch pervades their interstices.[148]

As Newton concluded in the *Opticks*, "the bigness of the parts of natural Bodies may be conjectured by their Colors."[149] In other words, as Shapiro has commented,

> all bodies are composed of invisible, transparent corpuscles that are in effect tiny fragments of a thin film that produces the identical color in

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[144] See Alan Shapiro, *Fits, Passions, and Paroxysms: Physics, Method, and Chemistry and Newton's Theories of Colored Bodies and Fits of Easy Reflection* (Cambridge: Cambridge University Press, 1993), esp. ch. 2, "Newton's Rings," for details on Newton's method.

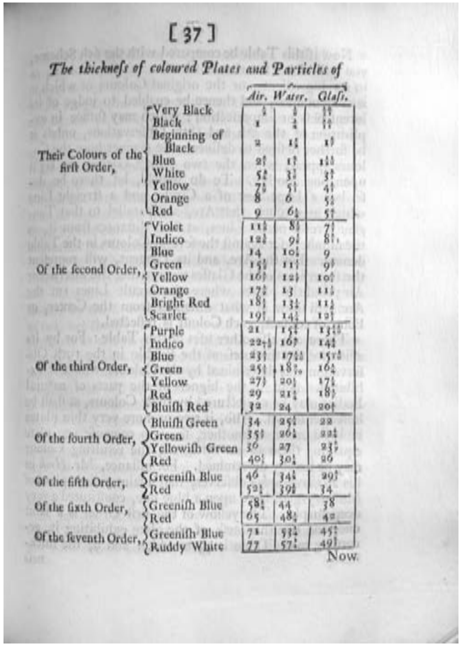
[145] Newton, *Opticks*, Book II, Part I, p. 222; Shapiro, *Fits, Passions, and Paroxysms*, p. 117.

[146] Newton, *Opticks*, Book II, Part II, p. 232.

[147] Shapiro, *Fits, Passions, and Paroxysms*, p. 117.

[148] Thomas Birch, *The History of the Royal Society of London for Improving of Natural Knowledge*. 4 vols. (London: A. Millar, 1756–1757), 3: pp. 299 and 300, as quoted in Shapiro, *Fits, Passions, and Paroxysms*, p. 118.

[149] Newton, *Opticks*, Book II, Part II, p. 232.



[37]

The thickneſs of coloured Plates and Particles of

		Air.	Water.	Glaſs.
Their Colours of the firſt Order,	Very Black	1/2	3/8	10/31
	Black	1	3/4	20/31
	Beginning of Black	2	1 1/2	1 2/7
	Blue	2 2/5	1 4/5	1 11/22
	White	5 1/4	3 7/8	3 2/5
	Yellow	7 1/9	5 1/3	4 3/5
	Orange	8	6	5 1/6
	Red	9	6 3/4	5 4/5
Of the ſecond Order,	Violet	11 1/6	8 3/8	7 1/5
	Indico	12 5/6	9 5/8	8 2/11
	Blue	14	10 1/2	9
	Green	15 1/8	11 2/3	9 5/7
	Yellow	16 2/7	12 1/5	10 2/5
	Orange	17 2/9	13	11 1/9
	Bright Red	18 1/3	13 3/4	11 5/6
	Scarlet	19 2/3	14 3/4	12 2/3
Of the third Order,	Purple	21	15 3/4	13 11/20
	Indico	22 1/10	16 4/7	14 1/4
	Blue	23 2/5	17 11/20	15 1/10
	Green	25 1/5	18 9/10	16 1/4
	Yellow	27 1/7	20 1/3	17 1/2
	Red	29	21 3/4	18 5/7
	Bluiſh Red	32	24	20 2/3
Of the fourth Order,	Bluiſh Green	34	25 1/2	22
	Green	35 2/7	26 1/2	22 3/4
	Yellowiſh Green	36	27	23 2/9
	Red	40 1/3	30 1/4	26
Of the fifth Order,	Greeniſh Blue	46	34 1/2	29 2/3
	Red	52 1/2	39 3/8	34
Of the ſixth Order,	Greeniſh Blue	58 3/4	44	38
	Red	65	48 3/4	42
Of the ſeventh Order,	Greeniſh Blue	71	53 1/4	45 4/5
	Ruddy White	77	57 3/4	49 2/3

Now

Figure 9. Table of Colors of Newton's Rings, Sir Isaac Newton, *Opticks: or, A Treatise of the Reflections, Refractions, Inflections and Colors of Light.* London: Samuel Smith and Benjamin Walford, 1704, p. 37. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

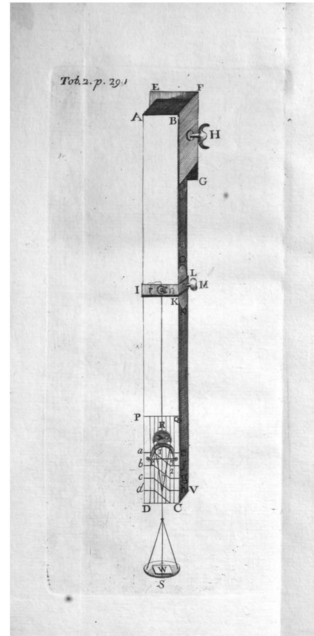


Figure 10. Bryan Robinson's device for measuring the effects of medicaments on the "animal fibres" of hair. Bryan Robinson, *A Treatise of the Animal Oeconomy. The Second Edition, with additions*. Dublin: S. Powell, 1734, p. 291. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

> Newton's rings. . . . If the corpuscles were of the same optical density as water or glass . . . their size was found from the color of the body by the table he composed that gives the thickness of a film producing that color.[150]

But Newton found it was difficult to know of what order the color of any body was, and it had to be done by comparing the color of the body with those observed in Newton's rings. Newton subsequently analyzed the qualities of the various orders of each color, concluding from his table for example that blues and violets are the "best" or most intense in the third order.[151] As Shapiro remarked, Newton supported his evidence with chymical experiments, using a chymical indicator test for acids and alkalis that he had learned from Boyle using the syrup of violets.[152] Newton wrote

> Thus the color of violets seems to be of that [third] order, because their Syrup by acid liquors turnes red and by . . . alcalizate turns green. For since it is the nature of acids to dissolve or attenuate . . . if the purple color of ye Syrup was of the second order, a acid liquor by attenuating its tinging corpuscles would change it to a red of the first order.[153]

Shapiro continued,

> Newton's argument has a testable consequence. If it is assumed as he does that chymical reactions involve only a change in the size of the corpuscles, and the colors of bodies are produced by those corpuscles just as in thin films, then the sequence of color changes in a chymical reaction should follow the order of the colors in Newton's Rings.[154]

As Newton explained in a published letter to Boyle:

> For the colors of all natural bodies whatever seem to depend on nothing but the various sizes and densities of their particles. . . . If the particles be very small (a are those of salts, vitriols, and gums) they are transparent; and as they are supposed bigger and bigger, they put on these colors in order, black, white, yellow, red; violet, blue, pale green, yellow, orange, red; purple, blue green, yellow, orange, red, &c. as is discerned by the colors, which appear at the several thicknesses of very thin plates of transparent bodies. Whence, to know the causes of the changes of colors, which

[150] Shapiro, *Fits, Passions, and Paroxysms*, p. 119.
[151] As Newton remarked, "So the Colors of the third Series all succeed in order; first, the violet . . . then the blue and green which are less mix'd with other Colors, and consequently more lively than before." *Opticks*, Book II, Part II, pp. 229–30.
[152] Shapiro, *Fits, Passions, and Paroxysms*, p. 119.
[153] Birch, *History of the Royal Society*, 3: 301, as quoted in Shapiro, *Fits, Passions, and Paroxysms*, p. 120.
[154] Shapiro, *Fits, Passions, and Paroxysms*, pp. 120–121.

> are often made by the mixtures of several liquors, it is to be considered, how the particles of any tincture may have their size or density altered by the infusion of another liquor.[155]

Hence, using Newton's logic, Robinson believed it was possible to argue from the color change observed by the exposure of blood to the air that acid was involved. An atmospheric acid attenuated the color of the blood, changing it to the smaller corpuscles of red versus the larger violet corpuscles of venous blood, just as acid liquors turned the indicator syrup of violets a red color. And, because color changes in a chymical reaction must follow the order of colors in Newton's rings, Robinson could demonstrate the degree of the attenuation of the color as well as size of blood corpuscles by observing the order of color that the blood displayed in a chymical reaction.

In response to critics of his chymical theories of physiology, Robinson further utilized Newton's ideas in the *De Natura acidorum* to prove the existence of acids in the air.[156] In his discussion of short-range attraction between corpuscles of matter, Newton postulated acids were "endued with a great Attractive Force... in which their Activity consists," and that they "were of a middle Nature between [a more volatile Water] and Terrestrial Bodies" attracting both. Salts were also supposed to be composed of acids and earth elements "united by attraction." Robinson believed that the formation of nitre in the mortar of walls was the result of the union of atmospheric acids and earthy elements. Robinson wrote:

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[155] Newton, "Newton's Letter to Boyle," February 28, 1678–9, in *Isaac Newton's Papers and Letters On Natural Philosophy*, p. 251.

[156] These critics included Dr. Thomas Morgan, who in the *Mechanical Practice of Physick* objected to Robinson's hydraulic applications of Newtonian physics, and who was skeptical of Robinson's identification of acid as the life-giving principle of respiration, noting that acid extinguished fire and therefore could hardly preserve the heat of the heart. See Thomas Morgan, *The Mechanical Practice of Physick* (London: T. Woodward, 1735). Since Morgan was a deist, writing tracts such as *The Moral Philosopher (1737–1741)* that questioned the veracity of scripture, he was not disturbed by Robinson's heavy emphasis on iatromechamism and seeming deism. However, several authors in the 1730s felt that the theories of "Newton-struck" physicians and Newtonian views on aether could lead to deism or atheism, such as John Hutchinson (1674–1737). See John C. English, "John Hutchinson's Critique of Newtonian Heterodoxy," *Church History* 68, 3 (September 1999), pp. 581–98; For other philosophers critical of Robinson and Newton see Geoffrey Cantor, "Anti-Newton," in John Fauvel et al., *Let Newton Be!* (Oxford: Oxford University Press, 1988), pp. 203–221; Schofield, *Mechanism and Materialism*, pp. 122–28; Thackray, *Atoms and Powers*, pp. 244–52.

> Whence it follows, that the Formation of Nitre on the Sides of plaistered Walls and on the Mortar of Brick Walls defended from Rain and Sun, must be owing to acid Parts of the Air uniting with the earthy alcalious parts of the Lime, by the strong Attractions which intercedes them: And therefore the Air abounds with Acid Particles.[157]

Most likely Robinson was observing the formation of potassium carbonate or saltpetre crystals on walls that had been whitened by limestone, similar to the formation of nitre crystals in limestone saltpeter caves; because nitre will not form in areas of excess humidity, we have seen that many early modern chemists believed something in the air was the source of a generative power to create nitre.[158]

Robinson also utilized chymical examples from query 31 of Newton's *Opticks* to demonstrate that "it is the Nature of Acids to dissolve Bodies with Heat," and that atmospheric acids were ultimately responsible for maintaining the motion of the heart. In his speculations about the source of attractive powers of magnetism, electricity, and gravity, Newton speculated upon close-range forces between individual corpuscles of matter, and utilized several chymical examples involving vitriol. Just as the formation of nitre was believed by early modern English chemists such as Lister (see chapter three) to be evidence of a formative power in the air, so was the formation of vitriol from the exposure of iron or copper pyrites to the atmosphere. Vitriol was thought to be consisted of an "insipid" earth called ocher, some iron metal, mineral sulphur, an acid salt, and some small portion of a volatile aerial salt, and was sometimes identified as a "universal salt" responsible for generating other minerals.[159] Spirit of vitriol was vitriolic acid (likely sulphuric acid). Robinson quoted from the *Opticks:*

[157] Bryan Robinson, *A Letter to Dr. Cheyne, containing an account of the motion of Water through Orifices and Pipes; and an Answer to Dr. Morgan's Remarks on Dr. Robinson's Treatise of the Animal Oeconomy* (Dublin: S. Powell, 1735), p. 50. This treatise was appended to the *Oeconomy.*

[158] Roos, "Martin Lister and Fool's Gold," 28–29. A. Rupert Hall has analyzed Newton's ideas about the role of nitre in the composition and effects of "subtile matter" in "Isaac Newton and the Aerial Nitre," *Notes and Records of the Royal Society of London* 52 (1998), pp. 51–61.

[159] [Anonymous], "Some observations and Experiments about Vitriol, Tending to Find out the Nature of that Substance, and to Give Further Light in the Inquiry after the Principles and Properties of Other Minerals: Communicated by a Fellow of the Royal Society, Who Maketh Use of Chymistry Chiefly as Subservient to Physiology," *Philosophical Transactions* 9, no. 103 (1674), pp. 41–47, on p. 41.

> And when . . . spirit of vitriol poured upon filings of iron dissolves the filings with a great heat and ebullition, is not this heat and ebullition effect by a violent motion of the parts, and does not that motion argue that the acid particles of the liquor rush towards the parts of the filings with a violence . . . And when the acid particles, which alone would distill with an easy heat, will not separate from the particles of the metal without a very violent heat, does not this confirm the attraction between them?[160]

On the basis of these queries, Robinson speculated that the acid of the air applied to "sulphureous" or "unctuous" substances continued to dissolve them with heat.[161] Since it was therefore "the nature of acids to dissolve bodies with heat" and the color changes in blood when exposed to atmospheric acids demonstrated the "acid of the air dissolves the blood," acidic acids must warm the blood at the same time they dissolved it.[162] Robinson also noted that by emptying his lungs of air and stopping his breath, his pulse grew small and quick; he concluded that the motion of his heart lessened immediately after being deprived of the Acid of the Air and (in a bit of circular reasoning) concluded it was acid in the atmosphere that preserved the motion of the heart, proving his Proposition 24.

Robinson's practical medicine: climate, splitting hairs, and acid-alkali Iatrochymistry

From his studies of respiration, Robinson then moved into their applications to understanding the nature of disease, first concentrating on the effects of temperature and climate on the body. Robinson began his speculations by doing a series of experiments in which he measured the body temperature of different subjects, and found it to be constant "at all seasons of the year, and in all Climates."[163] However, the heat being generated in the blood by the acid of the air "was lost by being communicated to the Air in the Lungs and at the Skin," and in colder weather,

[160] Robinson, *Animal Oeconomy*, 199; Newton, *Opticks*, Book III, Part I, pp. 377–8.

[161] In *De Natura acidorum*, Newton also wrote that "spirit of sulphur shakes and corrodes all liquids such as water, spirit of wine, spirit of nitre, etc and all . . . solids such as clayey earths, nitre, iron, bronze, etc. . . . and effervesces with them because of its acid being attracted by them. By virtue of this acid it feeds a flame." Newton, *De Natura acidorum*, fol. B2 verso.

[162] Robinson, *Animal Oeconomy*, p. 200.

[163] Robinson, *Animal Oeconomy*, p. 213.

more heat was lost. To maintain temperature equilibrium in the body, Robinson concluded that "Air when it is cold abounds more with . . . Acid, than when it is hot. And that it is does so, appears from Fire burning best when the Air is coldest, and worst when it is hottest."[164]

This meant that in the winter with more acid in the air, that blood was more dissolved or attenuated than in summer; the same was true for cold countries versus hotter climes. Robinson then concluded that since in hotter countries there was more malignant disease, an ancient proposition based on Galenic medicine and to be later bolstered by Enlightenment principles of geographic determinism, malignant disease was due to a "want of a sufficient Dissolution or Attenuation of the Blood."[165] To explain why the body experienced hypothermia in excessive cold, Robinson proposed that when the air was very cold and saturated with acid, "the mutual attraction of its [acidic] particles, arising from their closeness to one another, may hinder them from being drawn into the Blood in as great a Quantity."[166] This ensuing lack of acid in the blood would destroy its heat and fluidity, which would eventually stop the heart. As support for his assertions, Robinson again used examples of chymical reactions involving oil of vitriol, noting that strong oil of vitriol would not dissolve metals as quickly as when it was weaker due to its higher concentrations of acid.

If want of acid in the blood caused disease, Robinson wished to know the effects of the effects of acidic particles on the fibers of the body in order to formulate practical medicaments to treat disease. Boerhaave believed that muscles, bones, blood, circulatory vessels, and nerves were made of fibers that could become either too elastic or too rigid and therefore cause disease. Lack of motion of bodily fluids could also cause ailments.[167] Under the influence of the theories of Boerhaave,

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[164] Robinson, *Animal Oeconomy*, p. 213.

[165] Robinson, *Animal Oeconomy*, p. 213.

[166] Robinson, *Animal Oeconomy*, p. 215.

[167] Robinson in fact devoted his *Letter to Dr. Cheyne* to a study of the hydraulics of bodily fluids and disease. See Robinson, *A Letter to Dr. Cheyne Containing an Account of the Motion of Water Through Orifices and Pipes* . . . (Dublin: S. Powell, 1735). Boerhaave is also known for Boerhaave's syndrome, a spontaneous rupture of the esophagus following vomiting, as well as for his revival of the Hippocratic method of bedside instruction. See Herman Boerhaave, *A method of studying physick.* 1st. English edition, London 1719, the first authorized "Englished" version of his most famous treatise; R. Knoeff, *Herman Boerhaave (1668–1738). Calvinist Chemist and Physician* (London, 2002). For a surprisingly thorough biography of Boerhaave online see his entry on whonamedit.com, accessed 25 July 2004.

Robinson assumed that these atmospheric acids chymically affected the "spring" of nervous fibers—as Roy Porter commented, "the nerves were fine filaments and when healthy, they possessed a proper degree of elasticity—if out of condition, they became brittle."[168] Robinson then devised an elaborate experimental procedure to test the effects of "various fluids, of age, of different Kinds of Weather, and of Exercise" on the elasticity of nervous fibers characterized by careful measurement and mathematical proof.

Since nerves were in short supply for experiments, Robinson chose another type of "animal fiber" to work upon—namely human hair. Taking the hair of a "healthful young Woman 22 years of Age," he wet samples down with different types of chymical medicaments, and saw how far the hair could be extended or stretched; the more the hair could be stretched, the more elastic or healthy it was, and the more strengthening the chymical medicament was of the animal fibers.[169] He measured the extensions of hairs via an apparatus he invented [Figure 10], and explained,

> Having pass'd one End of an Hair thro' the small Hole at R, and fasten'd it by running the Screw o, I drew the other End by help of a small bearded Wire through the Hole in the Cylinder r, and fixed it by the Screw N, so as always to have an Interval of 10 Inches between those Screws. Then on the Groove of the Brass pRq I hung a Scale with a Weight W, and observed the encreased Length or Extension of the Hair when dry in two Minutes of Time, caused by the uniform Action of the given Weight of 300 Grains, which was the sum of the Weights of the Scale, or W, and of the little Brass pRq.[170]

Then he took the hair off the scale, "rub'd with the given Fluid," and placed it back on to measure its Extension, formulating elaborate tables of his results of the hair's extension and its corresponding strength and health [Figures 11 and 12].

Robinson first concluded that table two demonstrated

1. Salt of Tartar per deliquium (anhydrous potassium carbonate—deliquescence was a property some crystalline substances had of dissolving spontaneously in liquid absorbed from air) strengthened

[168] Roy Porter, "Introduction," in *George Cheyne: The English Malady (1733)* (London and New York: Tavistock and Routledge, 1991), p. xxi.
[169] Robinson, *Animal Oeconomy*, p. 290.
[170] Robinson, *Animal Oeconomy*, p. 293.

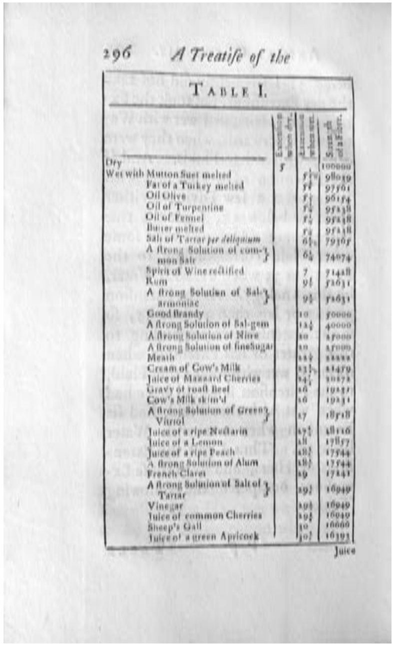

Figure 11. A portion of Robinson's Table One of the elasticity of the animal fibers. Bryan Robinson, *A Treatise of the Animal Oeconomy. The Second Edition, with additions*. Dublin: S. Powell, 1734, p. 296. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

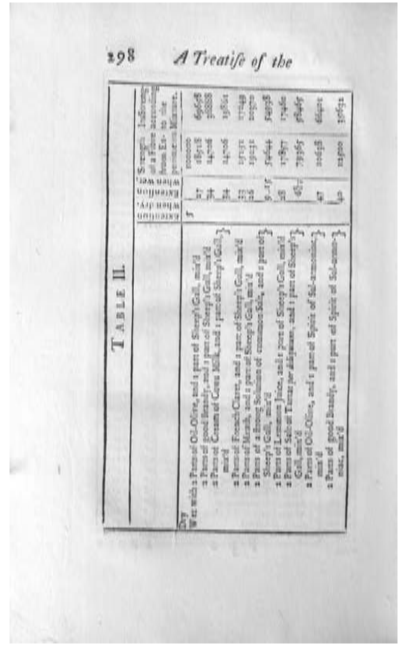

Figure 12. A portion of Robinson's Table Two of the elasticity of the animal fibers. Bryan Robinson, *A Treatise of the Animal Oeconomy. The Second Edition, with additions*. Dublin: S. Powell, 1734, p. 296. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

the hairs more than a solution of that salt in water. This meant that this salt drew something out of air besides water giving it its strengthening quality.[171]

2. Experiments by Newton in the *Opticks* demonstrated that salt of tartar per deliquium attracted Acids more strongly than any Metal.[172]
3. By Robinson's proposition 24, the air abounded with acid particles, so the "watry Moisture imbibed from the air by this Salt when it deliquates, must be strongly impregnated with acid particles."[173]
4. Therefore, "if the Acid of the Air be the sole Cause of the great Excess of the Strengthening Power of Salt of Tartar per deliquium above that of the strongest Solution of the same Salt in Water," such as receive most of the Acid into their Blood will have the strongest fibers.[174] Animal fibers would be strongest in "frosty weather," since the air abounded more with acid particles then.
5. Robinson concluded that animal fibers and fluids had their strengthening powers from the acid of the Air, "united with their component particles by virtue of its strong attraction."[175]

Robinson then turned to the effects of oils and alkalis on animal fibers, noting from his experiments that the data in table one revealed that "Oils, ardent Spirits, and all Liquors abounding with oily Parts strengthen Animal Fibres, and warm Water and alcalious Spirits weaken them."[176] He observed that alkalious intestinal gall mixed with animal oils lessened the strength of hairs, concluding that gall in the intestines "lessens the strengthening power of the oil part of the aliment in its passage thro them."[177] Yet, the fats of animals were more strengthening to animal fibers than olive oil, which showed that the oily part of the animal fats regains "in the blood that part of its strengthening power which it loses in the Intestines by being mixed with the Gall."[178] Robinson postulated that animal fat regained that strengthening power by being exposed to the acid of the air, as the blood of animals has

[171] Robinson, *Animal Oeconomy*, p. 301; Ecklund, *Incomplete Chymist*, s.v. "deliquescence."
[172] Robinson, *Animal Oeconomy*, pp. 302–303.
[173] Robinson, *Animal Oeconomy*, pp. 303–304.
[174] Robinson, *Animal Oeconomy*, p. 304.
[175] Robinson, *Animal Oeconomy*, p. 304.
[176] Robinson, *Animal Oeconomy*, p. 343.
[177] Robinson, *Animal Oeconomy*, p. 305.
[178] Robinson, *Animal Oeconomy*, pp. 305–306.

a constant supply of this acid by means of respiration. Therefore the atmospheric acids also seemed to be the immediate cause of the strengthening power of oils and all fluids abounding with oily parts.

On the other hand if an alkali like sal ammoniac (likely ammonium chloride or NH_4Cl though the term was sometimes used for other ammonium salts) was applied to hair continuously, the fiber grew less and less elastic or "weaker" over time.[179] Robinson then noted that animal fibers like hair contained an "acid in their composition, forasmuch as they contained salt"; according to Newton's *Opticks*, salt was composed of acid and earth united by attraction.[180] Therefore, alkalis like sal ammoniac lessened the strength of animal fibers by drawing off their acids from their earthy parts, "upon which acid the strength of fibres depends."[181] To further support his assertion, Robinson referred to the work of Stephen Hales, particularly his *Vegetable Staticks* (1727). Hales was a "disciple of Boyle, Mayow and Newton," and his *Staticks* was "self consciously" written in the "style of Newton's Opticks."[182] "Influenced by some of Newton's ideas on the chymical role of air," Hales demonstrated that air could unite with other substances such as sal ammoniac.[183] Hales postulated that upon such union air lost elasticity, and thought this decrease was due to the air's "fixation by acid . . . fumes raised with that air."[184] In other words, just as air lost elasticity by having sal ammoniac drawing off its acid, sal ammoniac applied to animal fibers also weakened them by the same mechanism.

In Section V of the *Animal Oeconomy*, Robinson then did a series of experiments in which he demonstrated that the same chymical substances that strengthened and weakened animal fibers had the same effects upon the blood by increasing or decreasing its viscosity. For instance, spirit of hartshorn (a strong solution of ammonia produced by the distillation of hartshorn [NH_4O_4]) as an alkali weakened the blood "when taken in too large a quantity," causing blood thinness and hemorrhaging, whereas blood coagulated by animal venom became fluid

[179] Robinson, *Animal Oeconomy*, pp. 307–308.
[180] Robinson, *Animal Oeconomy*, p. 309.
[181] Robinson, *Animal Oeconomy*, p. 309.
[182] Milton Kerker, "Herman Boerhaave and the Development of Pneumatic Chemistry," *Isis* 46 (1955), pp. 36–49, on 39; Brown, "Medicine in the Shadow of the *Principia*," p. 645.
[183] Kerker, "Herman Boerhaave," p. 39.
[184] Kerker, "Herman Boerhaave," p. 39.

by "large doses of alcalious spirits."[185] To explain blood chymistry and its interaction with the acids of the air, Robinson wrote:

> the acid of the air, after it is taken into the blood, unites with its Salts, and thereby renders them grosser and less volatile . . . in like Manner as Spirit of Sea-salt which is an acid spirit [most likely hydrochloric acid] and Spirit of Soot which is a volatile alcalious spirit, being mixed together unite and compose the Particles of Sal Ammoniac, which are grosser and less volatile than before: But volatile alcalious Spirits, which are composed of volatile alcalious Salts and Water, attenuate and thin the Blood. . . . And therefore the Acid of the Air, by channeling the Salts of the Blood and become volatile by Heat or Putrefaction in to a Kind of Sal-armoniac . . . keeps up a Tenacity in the Blood. Hence the blood will be apt to abound with volatile Salt, when it is not sufficiently impregnated with this Acid.[186]

Robinson then explained that a lack of acid in the blood was most likely to happen in hot weather, when the air contained less acid. This was because there were more sulphureous steams and volatile salts in the atmosphere that were raised from the earth in hot weather. Salts also arose from putrid substances of vegetables and animals in warmer climes, and the heat meant people were likely more inactive or had more putrid fevers, and their blood and breath tended to abound with volatile salts.

Robinson's theory at its basis had its origin in the work of van Helmont, who we have seen originated the study of volatile salts in a primarily iatrochymical and medical context. In his analysis of the chemistry of the blood, van Helmont claimed that venous blood, having given nourishment to the organs of the body, was made volatile and converted into gas that was breathed out.[187] It thus seems that Robinson again dovetailed older Helmontian beliefs in a vital volatile salt, fit them into a Newtonian chymical construct which emphasized

[185] Robinson, *Animal Oeconomy*, 344. It is possible here that Robinson was affected by his contemporary Dr. Richard Mead's work on poisons, which advised much the same type of medicaments. See Richard Mead, *A Mechanical Account of Poisons in Several Essays* in *The Medical Works of Richard Mead, M.D.* (Edinburgh: Alexander Donaldson and Charles Elliot, 1775; rpt. New York: AMS Press, 1978).

[186] Robinson, *Animal Oeconomy*, pp. 344–45.

[187] Walter Pagel, *Joan Baptista van Helmont: Reformer of Science and Medicine* (Cambridge: Cambridge University Press, 1982), pp. 88–90. The material about acids, alkalis and van Helmont and Sylvius is taken from Anna Marie Roos, "Luminaries in Medicine: Richard Mead, James Gibbs and Solar and Lunar Effects on the Human Body in Early Modern England," *Bulletin of the History of Medicine* 74 (2000), pp. 433–57, on pp. 452–53.

the importance of atmospheric acids, yet drew from Boerhaave in his emphasis on fibers in diagnosing disease.

From these principles, Robinson developed a series of acidic and alkali medicaments to affect the elasticity and health of the animal fibers. As we have seen, the basis for his treatments was an extension of the acids-alkali theory of the humors which had its origin in the 1660s among iatrochymists on the Continent influenced by van Helmont and Sylvius.[188]

Instead of using acids or alkalis to "restore the balance of the humors," Robinson utilized these popular medicaments to appropriately strengthen or weaken the animal fibers and blood to attain bodily balance and treat disease. To treat fevers in "which the Salts of the Blood are rendered too volatile by Heat or Putrefaction," such as child-bed fever, Robinson prescribed "sweating with acidulated Drinks," as sweating would carry off part of the volatile Salts and the acids would restore balance in a over-alcalious blood.[189] Drinks impregnated with acids were also more cooling, and treatment would continue until there were signs of "concoction" in the urine, signaling a growing tenacity of the blood and bodily fibers.[190] (Concoction referred to the ripening of morbific matter to perfection, making it fit for elimination from the body; by concoction, noxious humors were separated from sound ones).[191] In other ailments, such as in an "phthisis" (tuberculosis), where there was an putrid fever and the blood abounded with volatile salts, Robinson prescribed riding, particularly in cold air by which the blood was "plentifully" supplied with atmospheric acids.[192] The pulmonary lesions in tuberculosis were likely evidence to Robinson of hemorrhaging, which was a signal of the "dissolution" and acrimony of the blood due to its high concentration of alkali salts. On the other hand, inflammatory Fevers, frequent "in cold frosty Weather in which the Air abounds most with acid Particles,"

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[188] Allen G. Debus, *The Chymical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries*. 2 vols. (New York: Science History Publications, 1977), vol. 2, pp. 519–31. Other authors have illustrated that Sylvius's theory of acids and alkalis may have had its origins in the theories of van Helmont. See Antonio Clericuzio, "From van Helmont to Boyle: A Study of the Transmission of Helmontian Chymical and Medical Theories in Seventeenth-Century England," *British Journal for the History of Science*, 26 (1993), pp. 303–334 on p. 330.

[189] Robinson, *Animal Oeconomy*, p. 466.

[190] Robinson, *Animal Oeconomy*, p. 474.

[191] Online *OED*, s.v. "concoction," accessed 25 July 2004. Concoction could also refer to bodily digestion and secretion in a more general sense.

[192] Robinson, *Animal Oeconomy*, p. 346.

and caused by blood saturated with acid, were more frequent among "Persons who used much Exercise."[193] They were treated by "alcalious Powders and Spirits" to weaken the bodily fibers and to attenuate the blood by their warmth.[194]

In a general Scholium concluding the *Animal Oeconomy*, Robinson concluded, probably much to his satisfaction, that he knew "how to increase or lessen the Strength of the Fibres, and Tenacity of the Fluids," resulting in a "proper Method of conducting chronical Diseases."[195] Taking his cue from Newton's *non fingo hypotheses*, he believed he had "Avoided Hypotheses," explaining "the Laws which obtain in Human Bodies by Reason and Experiment," and acknowledged that to Newton he was "chiefly indebted for what... [he] had delivered."[196] Ironically, in his reliance upon Newton in formulating his medical principles, Robinson relied heavily on the hypothetical queries in the *Opticks* and the *De Natura acidorum*. As Brown has commented, in the *Oeconomy* it was "experimental method, not mathematical reasoning, which dominated the work, and experiment steadily gave way to speculation."[197] Although Robinson's hypotheses were dressed in the guise of Newtonian physiology, his work ultimately had its basis in an older and more empirical chymical tradition of atmospheric salts composing a life-giving principle, a tradition that contributed to the early modern understanding of respiratory physiology.

[193] Robinson, *Animal Oeconomy*, p. 349.
[194] Robinson, *Animal Oeconomy*, p. 349.
[195] Robinson, *Animal Oeconomy*, p. 489 and p. 491.
[196] Robinson, "Preface" to the *Animal Oeconomy*, pp. iii–iv.
[197] Brown, "Medicine in the Shadow of the *Principia*," p. 645.

CHAPTER FIVE

SALTS AND SALINE SPIRITS IN THE MEDICAL MARKETPLACE AND LITERATURE: PATENT MEDICINES AND CHYMICAL SATIRE

In the last chapter, we observed that by the beginning of the eighteenth century, saline spirits or acids had largely replaced purely saline substances as the vital element in human physiology and natural history among natural philosophers and elite physicians. The advent of acid-alkali iatrochymistry and the influence of Newtonianism lessened the influence of Helmontian chymistry with its emphasis on vital salts. This chapter, in contrast, will analyze the continuing influence that salt chymistry had in wider society. We will concentrate on two areas, both having to do with the perceived "legitimacy" of salt iatrochymistry in medical treatment. First we will analyze the use of salts in patent medicines and popular medicaments, and secondly, we will examine the role that salt chymistry played in popular literature, primarily that which satirized alchemy and chymical medicine. Though much has been written by Rattansi, Webster, and Cook about chymical medicine among elites, including the attempt at the formation of a Society of Chymical Physicians in 1665, iatrochymistry at the popular medical level is something which necessitates more analysis.[1] Likewise, there has been work about satire leveled at alchemists in general, but little about literature that took its inspiration from Helmontian salt chymistry, despite its pervasive influence among natural philosophers and physicians. As the work of Nummedal on chymists of the Holy Roman

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[1] Harold Cook, *The Decline of the Old Medical Regime in Stuart London* (Ithaca: Cornell University Press, 1986); *Trials of an Ordinary Doctor: Johannes Groenevelt in Seventeenth-Century London* (Baltimore: Johns Hopkins University Press, 1994); P.M. Rattansi, "The Helmontian-Galenist Controversy in Restoration England," *Ambix* 12 (1964), pp. 1–23; "Paracelsus and the Puritan Revolution," *Ambix* 11 (1963), pp. 24–32; Charles Webster, "English Medical Reformers of the Puritan Revolution: A Background to the "Society of Chymical Physitians," *Ambix* 14 (1967), pp. 16–41; Charles Webster, *From Paracelsus to Newton: Magic and the Making of Modern Science* (New York: Dover, 2005); Charles Webster, *The Great Instauration: Science, Medicine and Reform 1626–1660* (London: Duckworth, 1975); Charles Webster, ed. *Utopian Planning and the Puritan Revolution: Gabriel Plattes, Samuel Hartlib and Macaria* (Oxford: Wellcome Unit for the History of Medicine, 1979).

Empire has shown, the question of legitimacy in chymical practice is also something of current historiographic interest.[2]

Salts, Patent Medicine and Astrology

As many studies of early modern history of medicine have demonstrated, the medical marketplace in England was a diverse one, with apothecaries, barber-surgeons, licensed and unlicensed physicians, and chymical empirics competing for business. The general lack of effectiveness of most remedies, as well as the high cost of licensed medical care meant that patients were likely to seek several alternatives. From the housewife making herbal remedies to treat her children, to the valetudinarian Robert Boyle's preoccupation with various nostrums, medical knowledge was of great concern to the larger population.[3]

By the mid seventeenth century, proprietary medicines or mass-marketed "quack remedies" emerged in the English medical marketplace. As one of the editors of the early eighteenth-century London newspaper *The British Apollo* opined, any "Nostrum of some Never-born Doctor... if expos'd to Sale at Tower-Hill, Lincolns-Inn or Moore-Fields, twill yield a Summ of Money as soon as any other valuable commodity."[4] Previously, as Cook has mentioned, more "orthodox" physicians, beginning in the seventeenth century, avoided charges of quackery and flogging their wares by refraining from using broadsheets; rather they would write short pamphlets about their medicaments which were more respectable.[5] Advertisements in the late-seventeenth and early eighteenth-century

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[2] Tara E. Nummedal, "Alchemical Reproduction and the Career of Anna Maria Zieglerin," *Ambix*, 48 (2001), pp. 56–68; Tara E. Nummedal, "The Problem with Fraud in Early Modern Alchemy," in *Shell Games: Studies in Scams, Frauds, and Deceits (1300–1650)*, ed. Mark Crane, Richard Raiswell, and Margaret Reeves (Essays and Studies, number 4) (Toronto: University of Toronto Press, Centre for Reformation and Renaissance Studies. 2004), pp. 1–23. See also Pamela H. Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton: Princeton University Press, 1994).

[3] Barbara Beigun Kaplan, *'Divulging of Useful Truths in Physick.' The Medical. Agenda of Robert Boyle* (Baltimore: The Johns Hopkins Press, 1993); For information on the medical marketplace, see Roy Porter, "The patient in England, 1660–1800," *Medicine in Society: Historical Essays*, ed. Andrew Wear (Cambridge: Cambridge University Press, 1992), pp. 91–118.

[4] *British Apollo, or curious amusements for the ingenious*, Vol. III, no. 42, Friday June 30th to Monday July 3, 1710, p. 2.

[5] William Newman, *Gehennical Fire*, p. 196; Harold Cook, *The Decline of the Old Medical Regime in Stuart London* (Ithaca: Cornell University Press, 1986), p. 43.

"question-and-answer" newspapers *The Athenian Mercury* and the *British Apollo* also were a means to reach an audience without resorting to hawking ones wares on the street. The *Apollo* for instance carried notices of Dr. Tyson's Apoplectick Snuff whose tendency to induce sneezing was credited with clearing any extra mercury taken for venereal disease that was lodged in the body, as well as clearing sight and removing drowsiness.[6] Some of these "more respectable" medical pamphlets and advertisements which specifically described iatrochymical medicines, particularly those by George Starkey and his rival Richard Matthew, have been analyzed by Newman.[7] Pamphlet wars and rivalries to corner the market in artificial spa waters which involved saline chymistry have also been delineated by Coley.[8]

The connection however between medicaments involving salt chymistry and popular medical beliefs in astrological medicine in the work of both orthodox and "quack" physicians is still a relatively unexplored area. Though it is true, as I have shown in other publications, that elites largely disavowed most astrological medicine by the end of the seventeenth century, at the popular level, there was still a pervasive belief that the planets affected and caused bodily illness.[9] Physicians looking for a means to sell medicaments were apparently well aware of this, and as this chapter will show, used the language of saline iatrochymistry as a marketing tool to promote "innovative" medicines within a framework of medical theory which was entirely traditional. In this chapter, I will present two case studies to analyze the interactions between saline chymistry and popular astrological medicine. First, we shall analyze the work of James Gibbs, a provincial "orthodox" physician who published

[6] For Dr. Tyson's snuff, see *British Apollo, or Curious Amusements for the Ingenious*, Friday July 28th to Monday July 31st, 1710, p. 4. For more information on science and medicine in the these newspapers, please see, Helen Berry, *Gender, Society and Print Culture in Late-Stuart England. The Cultural World of the Athenian Mercury*. (Aldershot: Ashgate, 2003); Anna Marie Roos, "Polite Society and Perceptions of the Sun and the Moon in the Athenian Mercury and the British Apollo, 1691–1711," *Didactic Literature in England, 1500–1800: Expertise Constructed* (Aldershot: Ashgate, 2003), pp. 79–98.

[7] William Newman, *Gehennical Fire: The Lives of George Starkey, an American Alchemist in the Scientific Revolution* (Cambridge: Harvard University Press, 1994).

[8] Noel G. Coley, "Cures without Care: 'Chymical Physicians' and Mineral Water in Seventeenth-Century England," *Medical History* 23 (1979), pp. 191–214.

[9] Anna Marie Roos, "Luminaries in Medicine: Richard Mead, James Gibbs, and Solar and Lunar Effects on the Human Body in Early Modern England," *Bulletin of the History of Medicine*, 74, 3, (Fall 2000), pp. 433–457; see also "Astrology, the Academy and the Early Modern English Newspaper," in *Astrology and the Academy*, ed. Patrick Curry, Nick Campion, and Michael York (Bristol: Cinnabar Books, 2004).

a tract about scrofula, salt chymistry, and solar and lunar influences. Secondly, we will examine the work of seventeenth-century London and Dublin "quacks" Lionel Lockyer and Timothy Byfield, and their connections between salts and sunlight.

Saline chymistry, solar and lunar astrological medicine, and scrofula

James Gibbs was the son of the vicar of Gorran in Cornwall, and a student of Exeter College, Oxford. Although he spent part of his professional career as a poet, attempting to promote a new metrical version of the Psalms (published in 1701), he became better known for his work as a physician.[10] In 1712, he wrote a treatise on scrofula, or the king's evil, which is the "tubercular inflammation of the lymph glands of the neck," although the term was "employed more loosely to comprehend a wide variety of complaints affecting the heat, neck and eyes, particularly swollen lips, tumors, sores and blisters" as well as cataracts.[11] Gibbs was motivated to publish for legal and commercial reasons. He had apparently cured a youth from Plymouth of scrofula in 1706 that had been unsuccessfully treated with mercury. However, Gibbs had not been paid for his pains and thus "commenced an [legal] action against [the boy's] Father, for the sum he promised" at Launceston and subsequently received his fee.[12] Because the father continued to maintain that Gibbs had not truly healed his son, which resulted in some other unspecified "various discourses concernying this Tryal," Gibbs "thought fit to publish" his treatise in vindication of the court's judgment and his course of treatment, and his reputation as a physician.[13] Gibbs' medicament, based on acid-alkali iatrochymistry and mechanism combined with older beliefs about astrological medicine was also sufficiently different from the usual cures for scrofula via

[10] *DNB*, 1937–39 ed., s.v. "Gibbs, James."; James Gibbs, *The First Fifteen Psalms of David, translated into Lyric Verse, propos'd as an essay, supplying the Perspicuity and Coherence according to the Modern Art of Poetry* (London: J. Matthews, 1701).

[11] Keith Thomas, *Religion and the Decline of Magic* (New York: Charles Scribner's Sons, 1971), p. 192.

[12] Gibbs, "Preface," in *Observations of various eminent cures of scrophulous distempers, commonly called the king's evil:... To which is added. An essay, concerning the animal spirits, and the cure of convulsions* (London: Ralph Simpson, and W. Innys; Exeter: Philip Yeo, 1712), pp. 1–2.

[13] Gibbs, "Preface," in *Observations of various eminent cures*, p. 2.

mercury or the royal touch to be advertised as an innovative cure in the medical marketplace.

Traditionally, the moon's control over watery humors made it the morbificant planet in scrofula, which as seventeenth-century astrological physician Richard Saunders claimed, "comes under the chin like a swelling, and it doth increase and decrease with the moon."[14] Cures were usually effected by the king's touch; Charles II gave a specially-stamped piece of gold to the sufferer to be worn about the neck, which was "widely regarded as a talisman in which the curative power was deposited."[15] While it is likely, as Thomas has claimed, that the monarch's innate personal power and consecration as king was an important reason that people felt his touch was effective, the cure may have to do with even more basic associations. Anne Geneva has illustrated that the analogy of the monarch with the sun was pervasive in early modern England.[16] Further, astrological physicians often prescribed solar astrological amulets made of gold, which via antipathy would protect against lunar diseases, like scrofula. Therefore, it is possible the amulet given by the monarch to the sufferer was associated at some level as an antipathetic astrological preventative. Indeed, if it was not possible to visit the king or afford a gold talisman, one astrological physician of the late seventeenth century recommended "three solary herbs to wear... haveing a vertue agreeing with the nature of Gold, and serveth instead of Gold, as Gold is under the dominion of the Sun as being a Metal."[17]

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[14] Richard Saunders, *The astrological judgment and practice of physick* (London: Langely Curtis, 1677), p. 198.

[15] Thomas, *Religion and the Decline of Magic*, p. 196. In the iconographic collection of the Wellcome Institute in London, there are pictures of these amulets issued by Charles II. Although before the Restoration, the scrofula talisman was a real gold coin, called an 'angel' with the impression of St. George slaying the dragon, the medal issued by Charles illustrates a hand coming out of the illuminated heavens touching the heads of a group of sufferers. The slogan reads: "He toucheth them, and they weare healed," a clear and politically astute allusion to the divinity of the monarch and perhaps to the healing powers of the heavens themselves. See *Front and reverse of four coin-like objects known as 'royal touch pieces' which were given by royal personages to people suffering from the king's evil (scrofula)* (London: John Churchill, n.p.d., Wellcome Institute for the History of Medicine, London, BRN number 18475, ICV number 51428).

[16] Anne Geneva, *Astrology and the Seventeenth-Century Mind: William Lilly and the Language of the Stars* (New York: St. Martin's Press, 1995), p. 267.

[17] Joseph Blagrave, *Blagrave's astrological practice of physick* (London: S.G. and B.G., 1671), pp. 114–5.

Though Gibbs did not use amulets in treatment, as he found previous "notions of [scrofula] to be of little use, and very few accounts of their success in curing disorders of this nature," he did believe that scrofula was due to lunar influence.[18] First, Gibbs explained that the full moon reflected all the light which it received from the sun to the earth, and he believed that these

> reflected rays of the Moon, passing by the earth on all sides of it, tho' not equally, cannot but obstruct the Beams in some Measure, which are directed from the Sun to the Earth; and consequently the influence of the Sun on the Earth is diminished.[19]

The lunar beams thus met and obstructed the sunbeams, and "consequently the Motion and Heat which the Sun communicates to the Earth will be lessen'd, and the natural Effect hereof will manifest it self in some Constitutions."[20]

The source of the subsequent effect of the lack of sunlight on the body was explained by the traditional connection between the vital animal spirits and the sun. Aristotle's linkage of life with the generative sun and motion inherent in the soul-principle—the *pneuma*—also meant that he considered the motion of the heart as indicative that it was the seat of the soul.[21] The sun was thus often associated by early modern English writers with the animal spirits and the circulatory system.[22] In the *Anatomy of Melancholy*, Robert Burton said of the middle region of the body that "the principal part is the heart, which is the seat and fountain of life, or heat, of spirits, of pulse and respiration, the sun of our body, the king and sole commander of it, the seat and organ of all passions and affections."[23] William Harvey thought the blood was the best example of the animal spirits, writing that "for us physicians, spirit is…namely that whatsoever attempts anything by its own endeavour

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[18] Gibbs, *Observations of various eminent cures*, p. 3.
[19] Gibbs, *Observations of various eminent cures*, p. 58.
[20] Gibbs, *Observations of various eminent cures*, p. 59.
[21] Specifically, Aristotle said that the heart produced the pneuma "which is continually created and renewed inside the body so long as there is heat and life. It is the vehicle of the soul, and as such is responsible for reproduction and movement." Galen, *Galen on Respiration and the Arteries*, trans. David J. Furley and J.S. Wilkie (Princeton: Princeton University Press, 1984), p. 19.
[22] Walter Pagel, "Medieval and Renaissance Contributions to Knowledge of the Brain and its Functions," in *The History of the Brain and its Functions*, ed. F.N.L. Poynter (Oxford: Oxford University Press, 1958), p. 108.
[23] Robert Burton, *The Anatomy of Melancholy*, ed. Holbrook Jackson, 3 vols. (London: J.M. Dent, 1932), vol. 1, p. 153.

and arouses any motion with agility and vehemence, or initiates any action."[24] Harvey also believed that the blood had a celestial nature as it was "analogous to the element of the stars," and the heart in the body was as the sun was in the solar system, in the midst of the body and giving life.[25] Further, although the works of Paracelsus that influenced many seventeenth-century English astrological physicians were anti-Aristotelian, they expressly placed the central soul in the heart, and stated that the heart corresponded to the Sun.[26] As a medical treatise published at about the same time as Mead's indicated,

> a [celestial] Body or its particles are said to Warm, when by their motion they greatly, move, stir, or agitate the Animal tactile Spirits...coldness is caused by diminishing, retarding, or putting a stop to the natural motion of the animal Spirits. Thus some bodies cause a coldness by repelling, baiting back, or crowding together the said Spirits.[27]

Gibbs then put a mechanical gloss on this traditional explanation. Like Mead, in his discussion of how his treatments affected the body, he wanted to avoid "Philosophical Cant." Gibbs, disavowing the "occult Notions of Expression" of the Peripatetics demonstrated "Mechanically the Operation of such Medicines...explaining their Forms and Qualities by which they are dispos'd and enabled to perform such effects."[28] Specifically, Gibbs utilized the acids-alkali theory of the humours and saline iatrochymistry.

Gibbs' work may have been more directly influenced by the well-known treatise by English physician John Browne, entitled *Adenochoiradelogia* (1684) in which the acid-alkali theory is a basis for treatment, and in which Browne speculates about lunar influences in scrofula.[29] Browne felt that the "Tydes... [were]...the presages of Sickness as well as of Health, of Recovery or Death"; therefore "proper Conjectures" were necessary to explain how the cycles of the "Plenilunaries" regulated

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[24] William Harvey, *Disputations Touching the Generation of Animals*, trans. G. Whitteridge (Oxford and Boston: Oxford University Press, 1981), pp. 374, 378–9.

[25] Harvey, *Disputations Touching the Generation of Animals*, p. 379.

[26] Pagel, "Medieval and Renaissance Contributions to Knowledge of the Brain," p. 108.

[27] Gideon Harvey, *The Third Edition of the Vanities of Philosophy and Physick Enlarged to more than double the number of sheets* (London: A. Roper and R. Bassett, 1702), pp. 129–30.

[28] Gibbs, "An Essay Concerning the Animal Spirits and the Cure of Convulsions," in *Observations of various eminent cures*, p. 1.

[29] John Browne, *Adenochoiradelogia or, an Anatomick-Chirurgical Treatise of Glandules & Strumaes, or Kings Evil Swellings. Together with the Royal gift of Healing, Or Cure thereof by Contact or Impression of Hands, performed for above 640 Years by our Kings of England* (London: T.N., 1684).

the amount of the acidic substances which ran "by the loose fibrous Contextures" of the lymphatic glands, and hence controlled the severity of the scrofular outbreak.[30]

In his application of acid-alkali theory to scrofula and discussion of lunar influences, Gibbs provides these "proper Conjectures." Gibbs asserted that because the sunshine would mechanically cause the particles of the spirits to expand or "elastically ferment," a loss of sunshine during a full moon would cause the spirits to be sluggish, leading to "turgescence in the humours."[31] The excessive influence of the moon compounded this humoral turgidity, as the lunar influences cooled, compressed, and restrained the spirituous particles.[32] Usually the solution to humoral turgidity was evacuation of the excess humours, but Gibbs believed that the suppression of the animal spirits caused an decrease in alkalinity and thus an excessively acid condition in the lymphatic ducts. The lymph as a result coagulated much as "milk is coagulable by vinegar"; the acid's coagulative effects were produced by particles

> which are long and sharp pointed, and can be no otherwise dispos'd for Coagulation, which is a transfixing, and it were a Nailing together; and by that means accumulating the sulphurs of the lymph into a curd-like mass.[33]

And, it was this turgescence and coagulation of the lymph in the lymphatic ducts caused the glandular swellings of scrofula, and the blockage of the optic nerve by these excess scrophulous humours caused the sore eyes and blindness associated with the "king's evil."

Gibbs' remedy was administration of volatile salts or alkalis that would decoagulate the tumors and cure the disease by acting as a chemical substitution for the traditional vitalizing influence of sunshine on the body. In this course of treatment, Gibbs displays some influence from English Helmontians who, making the traditional associations between the vital spirits and the heart, would administer volatile alkaline salts distilled from blood to restore the weakened vital spirits or *archaeus* of the body. Robert Boyle himself also attempted to distill the spirit of

[30] Browne, 'Preface', in *Adenochoiradelogia*, fol. D4 verso.
[31] Gibbs, *Observations of various eminent cures*, p. 59.
[32] Gibbs, *Observations of various eminent cures*, p. 61.
[33] Gibbs, *Observations of various eminent cures*, p. 34.

blood which he believed was "fully satiated with saline and spirituous parts," and thus had the therapeutic quality of a restorative.[34]

If Gibbs would not have written well after Newton's work, his combination of Helmontianism with iatrochymistry would have been typical of natural philosophy, chymistry and medicine that were immediately pre-Newtonian, paralleling the ideas of many chemical physicians in London right after the Restoration.[35] Indeed, because Gibbs was educated at Oxford during the heyday of iatrochymistry and van Helmont, he may have adhered to that medical tradition, and seemingly was not yet affected by the "establishment of Newtonianism which brought about the decline of van Helmont's chymistry and medicine in England."[36] After all, Gibbs was from more conservative Cornwall, far removed from the College of Physicians, the Royal Society, and the latest penchant for medical applications of Newtonian theory. Indeed, the manner in which Gibbs used the tides to support his idea of sunshine causing ferment in the body and in the air indicates that he either did not know of, or did not believe in gravitational forces. Rather, in a manner reminiscent of Philipot (see chapter three), Gibbs believed that the sunbeam's "elastic ferment" of the particles of the air was the cause of the tides. When the moon passed over a part of the sea, she obstructed and damped the elastic ferment of the atmosphere, causing the waters to ebb. However, when the moon passed and the sun took over again, the renewed elasticity of the atmosphere upon the waters caused them to flow.[37]

Timothy Byfield, the Sal Volatile Oleosum, and Lockyer's Pill

Timothy Byfield was less isolated geographically than Gibbs, but more marginally placed in the profession. An Irishman and a former dissenting minister, Byfield had his practice in London; although he claimed to be an MD and a fellow of the College of Physicians in Dublin, he apparently did not graduate from an English university.[38] He primarily

[34] Clericuzio, "From Van Helmont to Boyle," p. 333.

[35] See Clericuzio, "From Van Helmont to Boyle," pp. 326–334 for further information on how English chemical physicians combined Helmontian chymistry with corpuscular theories.

[36] Clericuzio, "From van Helmont to Boyle," p. 334.

[37] Gibbs, *Observations of various eminent cures*, pp. 63–4.

[38] William Berkin, "The Dissenting Tradition in English Medicine of the Seventeenth and Eighteenth Centuries," *Medical History* 39 (1995), 197–218, on p. 217. David Haycock,

assayed spa waters for their saline contents and sold artificial waters that imitated those that came out of the springs, publishing his achievements in works such as *The Artificial Spaw or Mineral Waters to Drink: Imitating the German Spaw-Waters in its Delightful and Medicinal Operations on Humane Bodies* (1684).[39] In 1711, his "true Sal Volatile Oleosum" was the first compound medicine to receive a letter patent under the act of 1624.[40]

In his *Horae Subjectivae, or Some Long-Vacation House Redeem'd for the Discovery of the True Sal Volatile Oleosum* (1715), Byfield asserted that sunlight was made of sulphureo-saline exhalations. These lightbeams "incircled with radical Moisture" from cloud vapours were "Spiritual Nourishment." Along with this spiritual essence, we also needed food so

> that the natural Spirits may be recruited, which do continually slide forth thro' the Pores; for thus we must maintain a successive repair of the loss of Nature. Our nourishing Juices are made by the more succulent substance of our Meat, whereby the Parts and Humours of the Body are reinforc'd. The radical Moisture is renewed out of the purer Particles of Blood, with the celestial Influences intermingling with 'em by Respiration. Thus the natural ferment of Man's Body, as well from his spiritual as his corporeal Diet, seems to consist in a Sulphuro-Saline Temperament, which Vital Union becomes more imbodied in oleose Salts, and then assumes a greater Corporeity.[41]

Byfield believed that nitrous salts in the air were bound up with sulphurs, as sulphur's oily qualities were similar to oily sperm and thus near "the Principles of life'; since sulphureous oils often appeared red, so he thought they gave blood its red tincture.[42] Volatile salts were also plentiful in bodily fluids like sweat and urine, so it was evident they were important components of the humors as well. Byfield thus claimed that via chymical art he drew down "from the Sun and Air plenty of illuminated Sulphurs," combining them with volatile salts to make his medicament.

"Medicine within the Market: proprietary medicines in seventeenth-century England," London School of Economics History Seminars, http://www.lse.ac.uk/collections/economicHistory/seminars/Haycockpaper.pdf, p. 5. Accessed 18 October 2006.

[39] Noel Coley, "Cures without Care," p. 205. T. Byfield, *The Artificial Spaw or Mineral Waters to Drink: Imitating the German Spaw-Waters in its Delightful and Medicinal Operations on Humane Bodies* (London: James Rawlins, 1684).

[40] Haycock, "Medicine within the Market," p. 5.

[41] T. Byfield, *Horae Subsecivae: Or, Some Long-Vacation Hours Redeem'd for the Discovery of the True Sal Volatile Oleosum* (London: J. Whitlock, 1715), pp. 3–4.

[42] Byfield, *Horae Subsecivae*, pp. 6, 8.

Thus far, Byfield is adhering to older ideas about the aerial nitre, as well as Paracelsian followers such as Peter Severinus, English chymist Robert Bostocke, and Gerard Dorn who associated nitre with the vital sulphur, *ens astrale* or *summa vitalis*. As we have seen, the association of the sun with vitalizing qualities was also quite traditional in astrological medicine. But like Gibbs, Byfield then appended acid-alkali iatrochymistry to his medicine, claiming in typical fashion that excess acid "preyed upon" the sulphureity in the blood, fermenting it, transmuting its juices into a "vitriolick tartness," and taking away its vital force.[43] His medicine restored the sulphureous content in the blood, as well as neutralizing excess acids; the sulphureo-saline volatiles also loosened food in the stomach "precipitated and hardened by Acids." Although Byfield's medicine was a very panacea, remedying "all aguish Distempers, Rheumatisms, Dropsies, Jaundices, etc.," he was aware that if he "enumerated Diseases at this rate… 'Tis so rank Quackish."[44] He was selling a patent medicine, but he still wished to retain some sense of respectability.

Not so for his colleague Lionel Lockyer. Lockyer (1600–1672) widely publicized a secret preparation "called Pilulae Radiis Solis Extractae" purported to be a medicine of a "solar nature, dispelling of those causes in our Bodies, which continued, would not only darken the Lustre, but extinguish the Light of Our Microcosmical Sun."[45] The microcosmical sun was considered to be the heart, as it animated the body with the animal spirits, much as the sun animated the earth with its rays. Much like Gibbs or Byfield's claims for volatile salts, Lockyer's pill quickened the vital spirits. The composition of the pill was mostly glass of antimony, or *vitrum antimonii*, a transparent glass created from a preparation of antimony; glass of antimony was a common medicament and an extremely strong emetic, usually administered in wine, and popularly thought to work, according to the London newspaper the *British Apollo* due to the "saline and sulphureous particles of the antimony, who subtile effluvia thus impregnated the wine with the aforesaid virtue."[46] The

[43] Byfield, *Horae Subsecivae*, p. 10.
[44] Byfield, *Horae Subsecivae*, p. 29.
[45] Lionel Lockyer, *An Advertisement Concerning those Most Excellent Pills Called Pilulae Radiis Solis Extractae. Being an Universal Medicine* (London: s.n., 1665), fol A2r. For another analysis of Lockyer, see A.S. Hargreaves, "Lionel Lockyer (1600–72) and his Pillulae Radiis Solis Extractae, *Pharmaceutical Historian* 29, 4 (1999), pp. 55–63, and William Newman, *Gehennical Fire*, pp. 195–200.
[46] *The British Apollo, Or Curious Amusements for the Ingenious*, Volume 11 (1711), p. 489.

composition of the pill was realized by chymist George Starkey who was a rival with his own medicaments, as well as the chymist George Wilson.[47] In his *Compleat Course of Chymistry*. Wilson gave the recipe for the pill claiming, "this is what Mr. Lockyer aimed at in the Composition of his Pill, by which he got a good estate:

> Take of Antimony Six Ounces, of Nitre Ten Ounces, of Common Salt one Ounce and an half, and of Charcole an Ounce: Let them all be made into Fine Powder, and well mixt, and be put into a red-hot Crucible by half a spoonful at a time, continue the Fire a quarter of an Hour after; then either pour it into a Cone, or let it cool in the Crucible, and you will find Three Substances, viz. In the Bottom a little Regulus; above that a compact Matter, something like the Liver of Antimony, and upon the Surface, a more Spungy Mass: separate them from one from another, and put by the Regulus; Powder the other two, and wash them apart, till they have no Taste of the Salts; dry them gently, and keep for use. The uppermost Substance is counted the best, and is of a fine Golden Color, when 'tis washt.[48]

The medicament was thus prepared from volatile salts, with a fixed salt to bind it, and its golden color also implied its "solar" origins. In a handbill, Lockyer also advertised the medicament, showing him using a burning mirror to make the pills, implying its solar nature.[49] [Figure 13].

Because the pill was composed of the simple volatile salts of antimony and nitre, Haycock has estimated his mark up was 64 times; one-quarter ounce of medicament, or 100 pills which lasted 20 days, cost 4 shillings. Lockyer's will revealed he left "almost, £1900 in cash bequests . . . the leases on four properties, and a quarter share in the ship *Batchelour* of London."[50] He was careful to include in all his advertisement a recognizable effigy portrait to ensure patients were getting the "authentic" pill, as well as a coat of arms—a chevron between three boar's heads, though Lockyer had no right to arms by grant or descent.[51] One advertisement proclaimed, "The true effigy here you may behold, of him, for who avoiding others ill, hath Given a medicine far

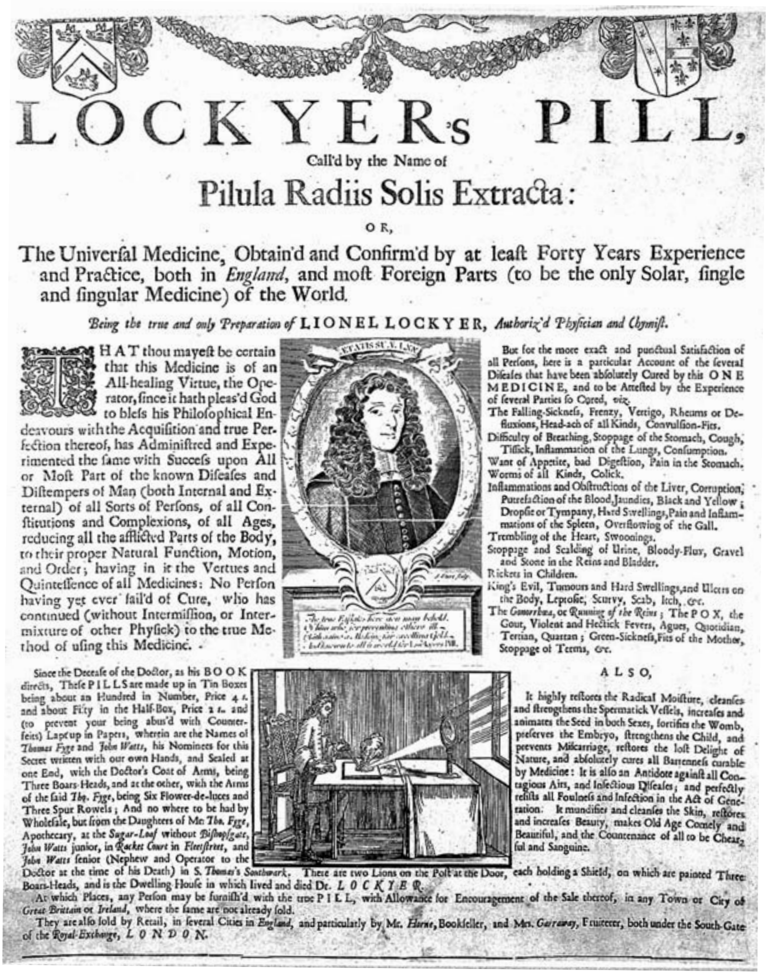
[47] Newman, *Gehennical Fire*, p. 198.

[48] George Wilson, *A Compleat Course of Chymistry* (London: W. Turner and R. Bassett, 1700), pp. 103–4, as cited by Hargreaves, "Lionel Lockyer," p. 59.

[49] Broadsheet advertising L. Lockyer's patent medicine, Historical Images Collection, #L0002420, Wellcome Library, London. Hargreaves also noted this handbill "Lionel Lockyer," p. 59.

[50] Haycock, "Medicine within the Market," p. 2.

[51] Hargreaves, "Lionel Lockyer," p. 57.



LOCKYERs PILL,

Call'd by the Name of

Pilula Radiis Solis Extracta:

OR,

The Univerſal Medicine, Obtain'd and Confirm'd by at leaſt Forty Years Experience and Practice, both in *England*, and moſt Foreign Parts (to be the only Solar, ſingle and ſingular Medicine) of the World.

Being the true and only Preparation of LIONEL LOCKYER, *Authoriz'd Phyſician and Chymiſt.*

THAT thou mayeſt be certain that this Medicine is of an All-healing Virtue, the Operator, ſince it hath pleas'd God to bleſs his Philoſophical Endeavours with the Acquiſition and true Perfection thereof, has Adminiſtred and Experimented the ſame with Succeſs upon All or Moſt Part of the known Diſeaſes and Diſtempers of Man (both Internal and External) of all Sorts of Perſons, of all Conſtitutions and Complexions, of all Ages, reducing all the afflicted Parts of the Body, to their proper Natural Function, Motion, and Order; having in it the Vertues and Quinteſſence of all Medicines: No Perſon having yet ever fail'd of Cure, who has continued (without Intermiſſion, or Intermixture of other Phyſick) to the true Method of uſing this Medicine.

But for the more exact and punctual Satisfaction of all Perſons, here is a particular Account of the ſeveral Diſeaſes that have been abſolutely Cured by this ONE MEDICINE, and to be Atteſted by the Experience of ſeveral Parties ſo Cured, *viz.*

The Falling-Sickneſs, Frenzy, Vertigo, Rheums or Defluxions, Head-ach of all Kinds, Convulſion-Fits.
Difficulty of Breathing, Stoppage of the Stomach, Cough, Tiſſick, Inflammation of the Lungs, Conſumption.
Want of Appetite, bad Digeſtion, Pain in the Stomach.
Worms of all Kinds, Colick.
Inflammations and Obſtructions of the Liver, Corruption, Putrefaction of the Blood, Jaundies, Black and Yellow; Dropſie or Tympany, Hard Swellings, Pain and Inflammations of the Spleen, Overflowing of the Gall.
Trembling of the Heart, Swoonings.
Stoppage and Scalding of Urine, Bloody-Flux, Gravel and Stone in the Reins and Bladder.
Rickets in Children.
King's Evil, Tumours and Hard Swellings, and Ulcers on the Body, Leproſie, Scurvy, Scab, Itch, &c.
The *Gonorrhea*, or *Running of the Reins*; The POX, the Gout, Violent and Hectick Fevers, Agues, Quotidian, Tertian, Quartan; Green-Sickneſs, Fits of the Mother, Stoppage of Terms, &c.

ALSO,

It highly reſtores the Radical Moiſture, cleanſes and ſtrengthens the Spermatick Veſſels, increaſes and animates the Seed in both Sexes, fortifies the Womb, preſerves the Embryo, ſtrengthens the Child, and prevents Miſcarriage, reſtores the loſt Delight of Nature, and abſolutely cures all Barrenneſs curable by Medicine: It is alſo an Antidote againſt all Contagious Airs, and Infectious Diſeaſes; and perfectly reſiſts all Foulneſs and Infection in the Act of Generation. It mundifies and cleanſes the Skin, reſtores and increaſes Beauty, makes Old Age Comely and Beautiful, and the Countenance of all to be Chearful and Sanguine.

Since the Deceaſe of the Doctor, as his BOOK directs, Theſe PILLS are made up in Tin Boxes being about an Hundred in Number, Price 4 *s.* and about Fifty in the Half-Box, Price 2 *s.* and (to prevent your being abus'd with Counterfeits) Lapt up in Papers, wherein are the Names of *Thomas Fyge* and *John Watts*, his Nominees for this Secret written with our own Hands, and Sealed at one End, with the Doctor's Coat of Arms, being Three Boars-Heads, and at the other, with the Arms of the ſaid *Tho. Fyge*, being Six Flower-de-luces and Three Spur Rowels; And no where to be had by Wholeſale, but from the Daughters of Mr. *Tho. Fyge*, Apothecary, at the *Sugar-Loaf* without *Biſhopſgate*, *John Watts* junior, in *Racket Court* in *Fleetſtreet*, and *John Watts* ſenior (Nephew and Operator to the Doctor at the time of his Death) in *S. Thomas's Southwark*. There are two Lions on the Poſt at the Door, each holding a Shield, on which are painted Three Boars-Heads, and is the Dwelling Houſe in which lived and died Dr. *LOCKYER*.

At which Places, any Perſon may be furniſh'd with the true PILL, with Allowance for Encouragement of the Sale thereof, in any Town or City of *Great Brittain* or *Ireland*, where the ſame are not already ſold.

They are alſo ſold by Retail, in ſeveral Cities in *England*, and particularly by Mr. *Horne*, Bookſeller, and Mrs. *Garraway*, Fruiterer, both under the South-Gate of the *Royal-Exchange*, *LONDON*.

Figure 13. Broadsheet advertising Lionel Lockyer's patent medicine. London. Wellcome Library, London.

exceeding Gold, and known to all the world for Lockyer's Pill."[52] His grave in Southwark Cathedral has the same effigy life size in marble, with another advertising-like rhyme as its epitaph:

> Here Lockyer: lies interr'd enough: his name
> Speakes one hath few competitors in fame:
> A name soe Great, soe Generall't may scorne
> Inscriptions whch doe vulgar tombs adorne.
> A diminution 'tis to write in verse
> His eulogies whch most mens mouths rehearse.
> His virtues & his PILLS are soe well known…
> That envy can't confine them vnder stone.
> But they'll surviue his dust and not expire
> Till all things else at th'universall fire.
> This verse is lost, his PILL Embalmes him safe
> To future times without an Epitaph

Johann Heinrich Cohausen (1665–1750), Salt Iatrochymistry, and Theories of Longevity in his Satire, Hermippus Redivivu*s (1742)*

With such predominant quackery as Lockyer's, it was little wonder that alchemy and chymical medicine became foci for satire. In his literary analysis, Linden argues that in England, Geoffrey Chaucer began a long tradition of alchemical satire that was interrupted by a new tradition of spiritual alchemy in the poetry of Donne and Herbert, and others, before a return in the work of Samuel Butler to the earlier satirical tradition at the turn of the eighteenth century.[53] One of the most prevalent writers of this revived genre was Johann Heinrich Cohausen (1665–1750) a physician and well-known author in the Germanies and France, and in England, where his works were widely translated and disseminated [Figure 14]. The *Hermippus*, as well as Cohausen's other books, were listed in a number of eighteenth-century English book and auction catalogues, indicating a reasonably wide distribution; his works were also present in the Royal College of Physician's Library, as well as in the library of Martin Folkes, who served as the President of the Royal Society.[54]

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[52] Lionel Lockyer, *An Advertisement Concerning those Most Excellent Pills Called Pilulae Radiis Solis Extractae. Being an Universal Medicine* (London: W. Nicoll, 1783), frontispiece. Wellcome Library, London.

[53] Stanton J. Linden, *Darke Hierogliphicks: Alchemy in English Literature from Chaucer to the Restoration*, (Lexington: The University of Kentucky Press, 1996).

[54] See for example, Samuel Baker, *A catalogue of the entire and valuable library of Martin Folkes… which will be sold by auction by Samuel Baker… on Monday February 2, 1756* (London:

Figure 14. Portrait of Johann Henrich Cohausen (1665–1750). Wellcome Library, London.

He was best known for medical satire such as the *Pica Nasi*, a Latin parody on snuff in which Apollo ordered Mercury to confiscate the noses of snuff takers. When the satyrs returned them, the desperate victims grabbed the wrong noses and were unrecognizable[55] [Figure 15]. Cohausen's last and most famous medical satire however was his *Hermippus Redivivus* (1742), a treatise on salt chymistry and the prolongation of life. Studies of Cohausen and the *Hermippus* have been largely antiquarian; the only scholarly works a French dissertation concerning his medical biography done in 1900 and a short German bibliographic study.[56] Because Cohausen has been primarily known for medical satire, his large numbers of serious treatises on iatrochymistry and medicine which served as the basis for his more humorous works have been largely unexamined. Cohausen's *Hermippus* and its comedic presentation of longevity had a profound reliance on earlier scholarly works he composed which analyzed the theories of van Helmont. Cohausen utilized van Helmont's belief that volatile salts composed the vital spirit or the breath of both animals and plants; it was these volatile salts in the breath, more prevalent in the young, which Cohausen argued would extend life's duration.[57] Cohausen also was influenced by Sanctorius' (1561–1636) studies of ambient air and bodily secretions to formulate his

s.n., 1756), p. 40; Thomas Egerton, *A catalogue of a general collection of books*... (London: s.n., 1798), p. 230; Thomas King, *A catalogue of books, including, among others, the library of the late Mr. Anthony Purver*... *will begin selling February 1, 1786* (London: s.n., 1786), fol. T1 recto; Thomas Lowndes, *A new catalogue of Lownd's circulating library, consisting of above ten thousand volumes* (London: s.n., 1758), p. 72; Paul Vaillant, *Catalogu librorum apud Paulum Viallant, Bibliopolam*... *or a catalogue of books in most languages and faculties* (London: s.n., 1762), p. 151; Royal College of Physicians of London. *Bibliothecae Collegii Regalis Medicorum Londinensis catalogus* (London: s.n., 1757); University of Edinburgh Library, *Catalogus librorum, ad rem medicam spectantium, in Bibliotheca Academiae Edinburgenae, secundum auctorum nomina dispositus* (Edinburgh: s.n., 1798), p. 89.

55 Johannes Henrico Cohausen, *Dissertatio satyrica physico-medico-moralis de pica nasi, sive tabaci sternutatorii* (Amsterdam, J. Oosterwyk, 1760).

56 An antiquarian study is found in S. Baring-Gould, "Hermippus Redivivus," in *Curiosities of Olden Times*, (New York, Thomas Whittaker, 1896), pp. 135–152. A scholarly dissertation about Cohausen is: A. Beauvois, '*Un practicien Allemand au XVIII^e siècle: Jean-Henri Cohausen (1665–1750)*.' ['A German Practitioner in the 18th Century: Jean-Henri Cohausen (1665–1750)'], (PhD thesis, University of Paris, April 1900). Henceforth, this dissertation shall be referred to as "Beauvois," with French and English translations provided in the notes. My thanks to Mrs. Jane Fleeson for translating this work from the French. A short bibliographical study of Cohausen can be found in: Herman Paal, *Johann Heinrich Cohausen, 1665–1750; Leben und Schriften eines bedeutenden Arztes aus der Blütezeit des Hochstiftes Münster, mit kulturhistorischen Betrachtungen* (Jena, G. Fischer, 1931).

57 Debus, "The Paracelsian Aerial Niter," p. 58.

Figure 15. Frontispiece from Johann Cohausen, *Dissertatios atyrica physico-medico-moralis de pica nasi, sive tabaci sternutatorii*. Amsterdam, J. Oosterwyk, 1760. Wellcome Library, London.

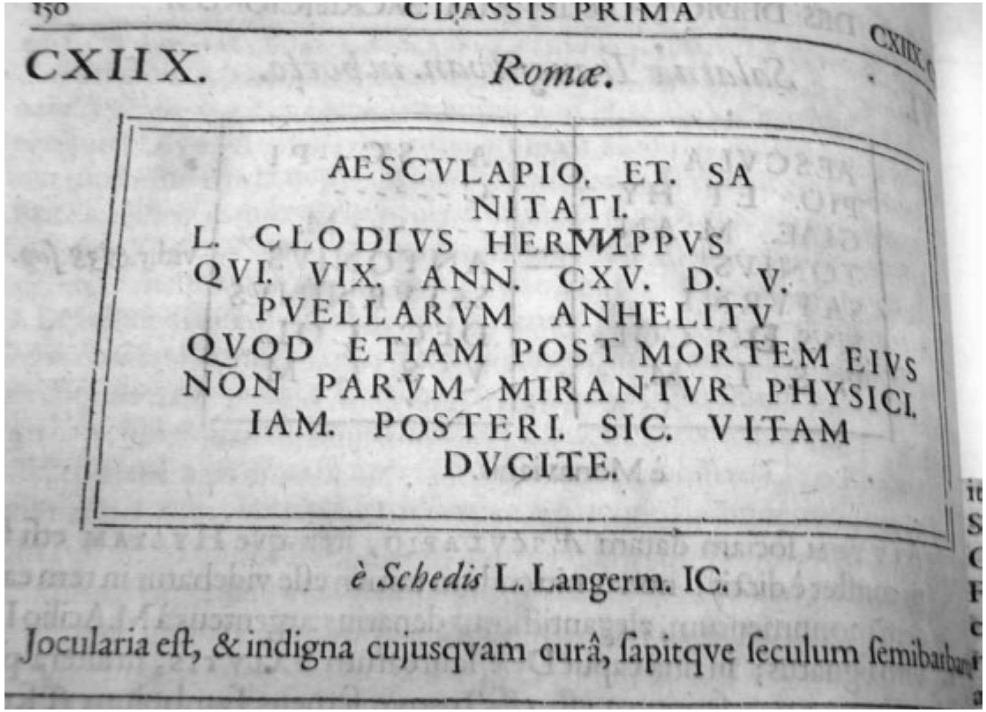
ideas in the *Hermippus*, as well as to a lesser degree by Leiden physician Herman Boerhaave (1668–1738). These theories of van Helmont and Sanctorius would have been recognizable to English natural philosophers and doctors who read Cohausen's work, and Cohausen's skillful use of their medical and chymical ideas may have contributed to the popularity of his satire in that country.

Although Cohausen's scholarly treatises demonstrated he was committed to chymical medicine in his own practice, he could still with trenchant wit poke fun at the pursuit of immortality. Cohausen admitted at the end of the *Hermippus* that he wrote it in a humorous vein for his own enjoyment (and likely in hopes of book sales), but he also knew that the basis of his work was recently-accepted medical beliefs and applications which made his satire all the more effective. Cohausen simply modified the traditional literary conceit of satirizing the search for the philosophers' stone with a humorous treatment of more current iatrochymical analyses of respiration and longevity, taking these ideas to outrageous conclusions. Ironically, because of Cohausen's skillfulness in presenting medical concepts in the *Hermippus*, further analyzing the intellectual context of his ironic treatise is also an aid to our understanding of early modern theories of longevity and iatrochymistry.

The Basis for the Hermippus

The title of the *Hermippus Redivivus* was likely based upon two references. Hermippus was an ancient one-eyed comic active during the Peloponnesian War who parodied Homer and wrote satiric verse, a genre of which Cohausen was fond.[58] In the *Hermippus*, the reader was treated to a "redivivus" or redux of such humor, so Cohausen in his title was thus indicating to his audience his satiric intent. Cohausen also claimed that the title was based upon an ancient and most certainly not genuine inscription said to have been found in the seventeenth century in Rome. Being an amateur classicist himself, the physician correctly claimed the inscription was included in Thomas Reinesius's magisterial *Syntagma Inscriptionum* (1682) [Figure 16]. But Cohausen

[58] *Wikipedia*. http://www.wikipedia.org.s.v. "Hermippus". Accessed 13 October 2005; Oskar Seyffert, *Dictionary of Classical Antiquity* (1894) http://www.ancientlibrary.com/seyffert/index.html. s.v. 'Hermippus.' Accessed 2 October 2005. An exhaustive search for sources for the name of Hermippus only revealed one other possibility—that of St. Hermippus, an obscure Christian martyr.


150 CLASSIS PRIMA

CXIIX. *Romæ.*

AESCVLAPIO. ET. SA
NITATI.
L. CLODIVS HERMIPPVS
QVI. VIX. ANN. CXV. D. V.
PVELLARVM ANHELITV
QVOD ETIAM POST MORTEM EIVS
NON PARVM MIRANTVR PHYSICI.
IAM. POSTERI. SIC. VITAM
DVCITE.

è Schedis L. Langerm. IC.

Jocularia eſt, & indigna cujusqvam curâ, ſapitqve ſeculum

Figure 16. The inscription and its subsequent disclaimer of its authenticity in Thomas Reinsius and James Gruter, *Syntagma inscriptionum antiquarum cumprimis Romæ veteris*…Leipzig and Frankfurt: Johann Fritschens Erben, 1682, p. 156. With permission from the Harris Manchester College Library, Harris Manchester College, University of Oxford.

conveniently did not mention that Reinesius commented from its philology that it was likely a fraud, and not worthy of any serious concern from classicists.[59] The inscription in question was therefore well suited for satire, and it read:

> *Oesculapio et Santitati*
> *L. Clodius Hermippus*
> *Qui vixit annos CXV. Dies V. ejus*
> *Puellarum anhelitu*
> *Quod etiam post mortem*
> *Non parum mirantur Physici*
> *Jam posteri sic vitam ducite.*[60]

Translated, it described one L. Clodius Hermippus who lived 115 years and 5 days via imbibing the breath of young women which had life-restoring qualities. In his work, Cohausen speculated about Hermippus' life, surmising that he was the prefect and teacher in an orphanage or school for girls sponsored by the Roman government.[61] He described in detail how Hermippus spent most of the day in the rooms of the orphanage with the children telling them stories designed to promote virtue and playing and joking with them. A large fire was built in the morning to rarify the air before the children arrived, so he would get the most benefit out of the little girl's breath, and in damp weather, the rooms were perfumed so malicious smells would not enter; there also was a garden surrounding the orphanage with plants which quickened

[59] Johannes Henrico Cohausen, 'Preface', to *Hermippus Redivivus, Sive Exercitatio Physico-Medica Curiosa de Methodo Rara ad CXV Annos Progoandae Senectutis per Anhelitum Puellarum, ex Veteri Monumento Deprompta, Nunc Artis Medicae Fundamentis Stabilita, Et Rationibus Atque Exemplis, Hic Non Singulari Chymiae Philosophicae Paradoxo* (Frankfurt-on-the-Oder: John Benjamin Andrae and Henry Hort, 1742), pp. 1–2. This is the original edition which will be referenced throughout this paper. Thomas Reinsius and James Gruter, *Syntagma inscriptionum antiquarum cumprimis Romæ veteris, quarum omissa est recensio in vasto Jani Gruteri opere cujus isthoc dici possit Supplementum: opus posthumum… cum commentariis absolutissimis et instructissimis indicibus nunc prim um editum* (Leipzig and Frankfurt, Johann Fritschens Erben, 1682), p. 156. Reinsius says of the inscription, "it is laughable, and unworthy of any concern, from one who understands the pagan world." *[Jocularia est, et indigna cuiusquam cura, sapitque seculum semibarbarum.]*

[60] Cohausen, 'Preface', to *Hermippus Redivivus*, p. 4. Literally, "L. Clodius Hermippus dedicates this to Aesculapius and to health, who lived 115 years and 5 days on the breath of girls, which after his death, astonishes physicians. Those of you who follow, extend your life in a similar way."

[61] Cohausen, *Hermippus Redivivus*, p. 25. *[Conjicio itaque eum in Orphanotrophio Romano puellari seu Gymasio quodem Virgineo.174…]*

the vital spirit and prolonged life with their odors.[62] In an eighteenth-century German edition of the work, the engraving on the frontispiece likewise illustrated Hermippus surrounded by a classroom of children, one little boy sitting on his right knee reading a book[63] [Figure 17].

The *Hermippus* was a commercial success, mentioned by the *Journal de Scavans*, and translated in 1743 into English by John Campbell (1708–1775), a Scottish historian and political writer. Campbell's text was re-translated into French by M. de la Place in 1789, and "it is this that is known and considered by many people as the work of the German physician"; some later readers even thought the *Hermippus* was authored by Campbell in its entirety.[64] Dr. Johnson said of it that it was a "very entertaining account of the hermetic philosophy and as furnishing a curious history of the extravagances of the human mind."[65] The *Hermippus* was also reviewed in *The World*, a popular weekly better known for essays by Lord Chesterfield acknowledging the achievement of Johnson's *Dictionary*.[66] Isaac D'Israeli described Campbell's book as a "curious banter on the hermetic philosophy and the universal medicine; the grave irony is so closely kept up, that it deceived for a

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[62] Cohausen, *Hermippus Redivivus*, pp. 47–48. *[Adjacebat Paedatrophio hortus amoenissimus, in quo florum herbarumque, quae magnam vitae longiori praestant subsidium gratissimis odoribus Spiritus vitales recreantes, et quibus etiam indies conclave exornabant puellae solertiores, uberrimus erat proventus. In hunc quotidie serenius arridente aura cum universo juvencularum grege secedebat et exspaciabatur Hermippus, comitantibus singulas suis pupis inter quas sine cura degebat, ne unam quidem hanc curam fumens, qua solicitus curaret, qua potissimum diligentia curas effugeret. Sine quo uno tanquam omnium praesidiorum vita, omnia ad producendam vitam ad hibita emori cum Platonicis indicabat. Hi cum puellis jocabatur, laudebat, saltabat, cantillabat, et ludiera puerilia exercebat vere repuerascens.]*

[63] Johannes Henrico Cohausen, 'Frontispiece', in *Der wieder lebende Hermippus, oder curioese physicalisch-medicinische Abhandlung von der seltenen Art sein Leben durch das Anhauchen Junger-MaÌgdchen bis auf 115. Jahr zu verlaÌngern…aus dem Lateinischen uÌbersetzt*, Sorau, 1753.

[64] Beauvois, pp. 89–90; William Godwin, in the preface to his novel St. Leon, believed the *Hermippus* was authored by Campbell. See William Godwin, 'Preface', to *St. Leon: a tale of the sixteenth century. By William Godwin. In two volumes…*(Dublin, P. Wogan, G. Burnet, P. Byrne, W. Porter, W. Jones, 1800), vol. 1, p. 1; J.H. Cohausen and John Campbell, *Hermippus Redivivus, or, the Sage's Triumph over Old Age and the Grave, Wherein a Method is laid down for Prolonging the Life and vigour of Man including A Commentary upon an Antient Inscription, in which this great Secret is revealed; supported by numerous Authorities* (London, J. Nourse, 1744).

[65] James Boswell, *The Life of Johnson (London, J.M. Dent and Sons, Ltd., 1933), vol. 1, p. 258.*

[66] Adam Fitz-Adam [Edward Moore] ed, *The world. By Adam Fitz-Adam…A new edition Vol. 3*, 4 vols. (London, 1772), no. 110, Saturday, 6 February 1755, p. 38. *The World* was later reprinted in *Harrison's British classicks. Vol. VII. Containing The World, and Lord Lyttelton's Dialogues of the Dead* (London: Harris and Co., 1787), Vol. 7, p. 250.

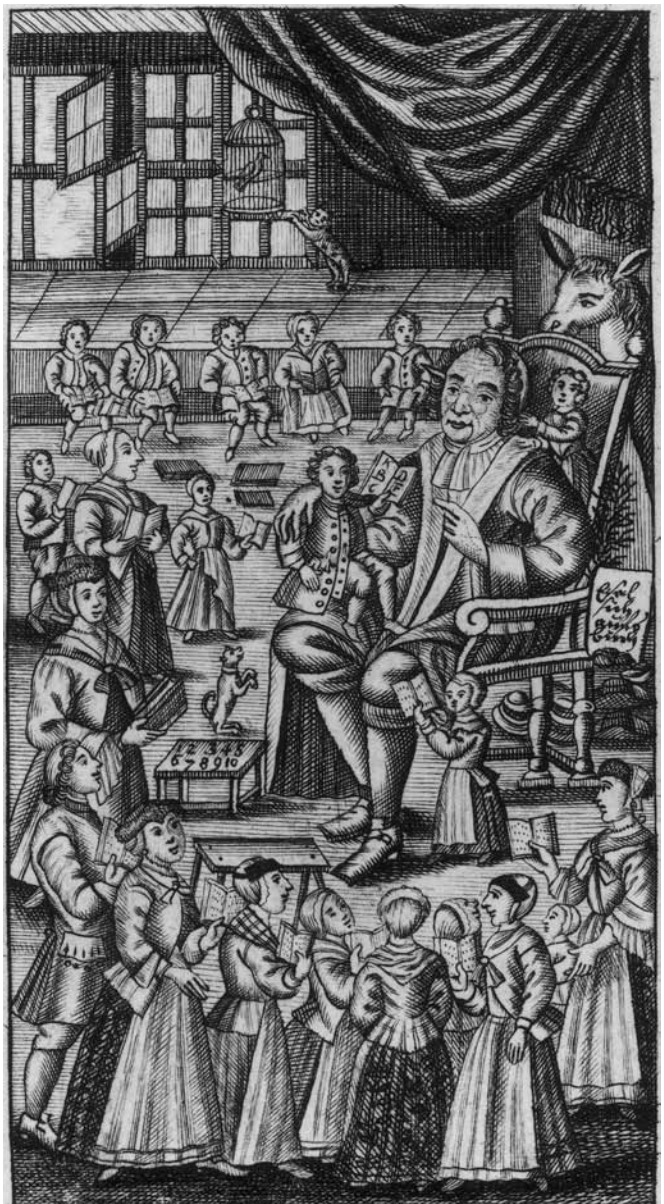

Figure 17. Frontispiece from J.H. Cohausen, *Der wieder lebende Hermippus*… Sorau, 1753. © The British Library Board. All Rights Reserved (shelfmark 1167.a.60).

length of time the most learned. Campbell assured a friend it was a mere *jeu-d'-esprit*."[67] William Godwin (1756–1836) later mentioned that the *Hermippus* was the inspiration for his novel about a count to who was revealed the secret of the philosophers' stone, the *St. Leon: a tale of the sixteenth century* (1800).[68] According to Osler, the book "had a rapid sale and induced many people to adopt the notion of prolonging life by inhaling the breath of young persons. A physician took lodgings in a boarding-school after having read the essay."[69]

However, in its attempts to be entertaining, Campbell's translation added even more ludicrous claims and content to Cohausen's original work, augmenting it with legends of longevity from the medieval period, deleting passages that may have offended the sensibilities of female readers, and embellishing it even more in a 1749 edition where it sold widely in England.[70] These additions were not surprising, for Campbell was well known to be skillful at fictitious autobiography and satire, writing for instance '*The Travels and Adventures of Edward Brown, Esq., formerly a merchant in London*', in 1739; the "description given in it by three Arab brothers . . . of a strayed camel, which they had never seen, may have suggested to Voltaire the similarly constructive description of the dog and horse of the queen and king of Babylon in 'Zadig.'"[71] Dr. Johnson also remarked that "Campbell is not always rigidly careful of truth . . . he once told me that he drank thirteen bottles of port at a sitting . . . [and] you could not entirely depend on any thing he told you in conversation."[72] Whether aided by port or not, Campbell did his translation of Cohausen's *Hermippus* quite loosely, transforming Cohausen's more

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[67] Isaac D'Israeli, *Curiosities of Literature*, 6 vols. (London, Moxon, 1834), vol. 2, p. 102. Isaac was the father of the politician Benjamin D'Israeli.

[68] William Godwin, "Preface", to *St. Leon: a tale of the sixteenth century*, vol. 1, p. 1. In Godwin's moralistic tale, the main character, the Count St. Leon, who suffers from a gambling addiction, learns the secret of the philosophers' stone from a stranger. His immortality and wealth causes him to lose his wife, suffer from a case of mistaken identity, and to be estranged from his son, nearly leading him to fight a duel against him in the end.

[69] Sir William Osler, *Bibliotheca Osleriana—A catalogue of books illustrating the history of medicine and science collected, arranged, and annotated by Sir William Osler* (Oxford, Clarendon Press, 1929), p. 215.

[70] Beauvois, pp. 89–90.

[71] *D.N.B.*, (Oxford: Oxford University Press, 1995), CD-Rom version, s.v. "John Campbell, LLD." John Campbell, *The travels and adventures of Edward Brown, esq; formerly a merchant in London*, London, 1739.

[72] Boswell, *Life of Johnson*, vol. 1, p. 176. Johnson however did say that Campbell never "lied with pen and ink," though "you could not entirely depend on any thing he told you in conversation."

subtle medical satire, which contained a number of serious examinations of theories of longevity, into a completely outrageous flight of fancy designed to maximize profits at the booksellers.[73]

Cohausen's Theories of Longevity: the Iatrochymical Influence of van Helmont

Campbell's reinvention of the *Hermippus* also overshadowed Cohausen's earlier and entirely scholarly treatises on longevity and iatrochymistry such as the *Decas Tentaminum Curiosa* (1698), written in response to the publication of a rival physician. Born in Hildesheim in Lower Saxony, Cohausen studied medicine in Frankfort-on-the-Oder, and became physician to the Bishop of Munster in 1717, retiring to private practice in Vreden.[74] In 1693, when Cohausen established his medical practice near Munster after his studies in Frankfurt-on-the-Oder, Conrad Berthod Behrens, a physician in Hildesheim and member of the Acádèmie Cesareo-Leopoldine, composed a treatise on longevity.[75] It was dedicated to the prime minister of the bishop of Munster in hopes of patronage. However, after much anticipation and excitement in the Bishop of Munster's court about the secrets that the book would reveal, there was a bit of disappointment. Behrens argued that God determined there was a fixed lifespan for humans and that prolonging life was not possible, leading to his subsequent exile from court.[76] Hoping to make a name for himself, Cohausen penned his own work on longevity, the *Decas Tentaninum curiosa*, and presented it to Frederick Christian, Bishop of Munster.[77] This opportunistic work made his career, as the bishop subsequently showed him great favor, making him his primary physician and a provincial physician for the jurisdictions of Ahaus and Horstmar.[78] Ensuring he would not have the fate of Behrens,

[73] According to his *D.N.B.* entry, Campbell was charging nearly 2 guineas a sheet to write the last of his published works, so his business strategy was successful indeed.

[74] *Allgemeine Deutsche Biographie*, http://mdz1.bib-bvb.de. s.v. "Cohausen, Johann Heinrich"; Accessed 3 October 2005, *Dictionnaire d'histoire de la medicine* (Mons, 1778), s.v. "Cohausen, Jean-Henri." The relatively few biographical resources on this physician were also noted by Beauvois, p. 1.

[75] Beauvois, p. 23.

[76] Beauvois, p. 24.

[77] Beauvois, pp. 24, 26. The work to which Beauvois referred was J.H. Cohausen, *Tentamium physico-medicorum decas de vita humana* (Cosfeld: Johann-Bartholomeus Steinii, 1699). This treatise was published at Cohausen's own expense indicating his desire for patronage.

[78] Jodocus Herman Nunning, *Commercii litterarii dissertationes epistolicæ historico-physico-curiosæ*...*J.H. Nunningii et J.H. Cohausen*...*cum utriusque historica bibliographie et præfatione*

Cohausen warned his readers "May he who is preparing to read this text not believe that I am rather presumptuous for promising him the extended age of Nestor."[79] Rather, in ten chapters Cohausen analyzed the different means of prolonging life, including animal, mineral, and vegetable preparations; his central tenet was that the tree of life was placed in the terrestrial paradise by God, and that in our postlapsarian state, it is possible to recover it via chemical medicine and the Arcanum or life elixir; as Sculakowska has demonstrated, the "tree of life" schematized "the means to obtain the philosophers' stone and its nature."[80] In his approach in the *Decas*, Cohausen directly imitated the ideas of the chymist and physician van Helmont, who in his own writings on the extension of life wrote:

> Arcanums... do exceed the Powers of Nature, even as Art doth very often overcome Nature: And that is not only true in Secrets which heal Diseases; but also in the Tree of Life, which restores defective Nature. Therefore the ordination of that Tree is the Preservation of Life, with a certain kind of renewing of Youth.[81]

As we will see in the *Hermippus*, Cohausen would claim that the breath of young women was a very Arcanum, and propose that the vapour from their breath be collected in trumpets and subsequently distilled to produce an elixir of life. The *Decas* though not initially written for purposes of satire but of patronage, would provide a useful resource when Cohausen wrote the *Hermippus* forty-four years later.

Although he would not publish another work on longevity until the *Hermippus*, (he did have an extended version of the *Decas* in manuscript form), Cohausen continued to evince a strong interest in publishing survey works based on the medicine, iatrochymistry and alchemy of van Helmont. We have seen in previous chapters that among English natural philosophers in the latter part of the seventeenth century, van Helmontian chymistry provided an influential theoretical basis. Cohausen apparently followed suit. In his work on fevers *Archeus febrium faber et medicus*, (Amsterdam 1731), Cohausen remarked of van Helmont: "*Vir*

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epicritica S.E. Cohausen, 3 vols. (Francofurti ad Moenum, 1746–54), vol. 1, p. 123 as quoted by Beauvois, p. 26.

[79] Cohausen, 'Preface', to *Tentaminum physico-medicorum*, as quoted by Beauvois, p. 24.

[80] Beauvois, pp. 24–25. Urszula Sculakowska, 'The Tree of Aristotle: Images of the Philosophers' Stone and Their Transference to Alchemy from the Fifteenth to the Twentieth Century', *Ambix*, 33, 2 (November 1986), pp. 53–77, on p. 58.

[81] J.B. Van Helmont, *Van Helmont's works: containing his most excellent philosophy, physick, chirurgery, anatomy.../Made English by J.C. [i.e. John Chandler]* (London: Lodowick Lloyd, 1664), p. 753.

ad reformanda et exornanda artis documenda a Deo electus," or that he was a man sent by God for the enhancement of reformation of medicine.[82] Indeed Cohausen supported Helmont's theory of the irritation of the archeus or the "internal efficient cause" or life force of the body as the cause of fever; the archeus was resident in the stomach, and when the archeus perceived that the body was poisoned by disease, it became agitated and attempted to drive the cause of the illness via a fever.[83] In van Helmont's words, fever was thus a "perturbation of the archeus of life," or as the historian Walter Pagel said of Helmont's position, "Fever is not a disease, but a symptom that indicates the war waged by nature against disease."[84] Thus in the *Archeus febrium*, Cohausen prescribed van Helmont's special diet regime of barley, oat, and rice gruel which was easy on the stomach and would help restore the archeus to its proper order.[85] In his work, Cohausen may have also been following the ideas of the German physician Johannes Doleaus who in his popular *Encyclopedia Medicinae Theoretico-Practicae* (1684) adopted van Helmont's notion of the Archeus and fevers.[86]

Cohausen also wrote the *Helmontius Ecstaticus*, a survey of van Helmont's remedies, and an explication of an ecstatic vision that Helmont received. This vision comprised the frontispiece which illustrated van Helmont receiving the *gemma rosae* or the "perfect ruby," the philosophers' stone, as well as the alchemical mystery of the *ignis-aquae*, the alkahest or the universal solvent from a messenger of God [Figure 18].[87]

We have seen in chapter two that salts, particularly volatile ones that were reactive when heated or possessed a distinct odor, were usually

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[82] Beauvois, pp. 58–59.

[83] Johannes Henrico Cohausen, *Archeus Febrium Faber Et Medicus* (Amsterdam: Salomon Schouten, 1681), p. 2. [*Archeum hunc in stomacho veluti throno residere credidit Helmont. In eo namque veluti peculiari suo sensario omnium ingestorum, sive alimenta sive Medicamenta, sive venena sint, utilitates atque noxas percipit et distinguit, suasque indignationes, furores, angorem, metum, varisque morborum ideas, concipit, et mediante fluidorum solidorumque mechanism regulares motus in irregulares et inordinatos commutando, varios morbos et febres ipsas concitat.]* Also see Beauvois, p. 68. As pointed out by an anonymous reviewer, Paracelsus was the first physician to discuss the archeus, a concept which Van Helmont expanded.

[84] Pagel, *Joan Baptista Van Helmont*, p. 161.

[85] To read more about the *archeus*, see *Van Helmont's Works*, p. 1009.

[86] J. Dolaeus, *Encyclopaedia Medicinae Theoretico-Practicae* (Frankfurt, 1684), quoted in Antonio Clericuzio, *Elements, Principles, and Corpuscle: a study of atomism and chemistry in the seventeenth century* (Dordrecht and Boston: Kluwer Academic, 2000) p. 197.

[87] Johannes Henrico Cohausen, *Helmontius Ecstaticus* (Amsterdam: Salomon Schouten, 1731), p. 301.

Figure 18. Frontispiece from Cohausen's *Helmontius Ecstaticus*. Amsterdam: Salomon Schouten, 1731. © The British Library Board. All Rights Reserved (shelfmark 1035.f.1).

candidates for the alkahest, a premise with which Cohausen agreed, stating: "*Liquori alkahest ex subjecto salino*."[88] Salts not only looked homogenous in their material form when visually examined, but the chemical reactivity of volatile salts made them seem candidates for the universal solvent. However, van Helmont, realizing that the search for the alkahest was difficult, offered his followers an alternative, the volatilization of fixed alkalies—particularly salt of tartar [in modern terms, likely potassium carbonate or K_2CO_3], to produce a solvent with powers akin to, though still inferior to those of the alkahest.[89] Powerful alkalis indeed can dissolve a good deal of substances via their corrosive nature, and are involved in saponification or soap-making. Cohausen again followed van Helmont's lead, and in an unpublished manuscript, the *Sal tartari volatile intricassimum extricatum... de paraeparation alis tarati volatilsati, vice-alcahestini* [The intricate extraction of the volatile salt of tartar, the vice-alkahest], he described his attempts to volatilize the rather non-evaporative potassium carbonate.[90]

Cohausen was interested in the volatilization of salts not only to produce an alkahest, but because as we have seen, volatile salts in the blood were thought by van Helmont to "be the conserver of the body."[91] Cohausen in the *Hermippus*, claiming "the most expert anatomists know for certain that out of a [young and] sound body, a lively flying salt will be breathed out, and this breath will have a vital strength and balsamic capacity or at the least a powerful mechanical elasticity which communicates vigor, according to the precepts of the philosophers...."[92] He then stated, "It is true according to the opinion of Helmont...that the breath penetrates the whole bodily system, even to the hairs, catching up volatile salts in its passage."[93] Thus, because their blood circulation

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[88] Cohausen, *Helmontius Ecstaticus*, p. 301.

[89] Cohausen, *Helmontius Ecstaticus*, p. 137.

[90] A list of Cohausen's unpublished manuscripts can be found in Jodocus Herman Nunning, *Commercii litterarii dissertationes epistolicæ historico-physico-curiosæ J.H. Nunningii et J.H. Cohausen cum utriusque historica bibliographie et præfatione epicritica S.E. Cohause*, 3 vol., (Francofurti ad Moenum, 1746–54), and a description of them is provided in Beauvois, pp. 118–133.

[91] *Van Helmont's works*, p. 744.

[92] Cohausen, *Hermippus Redivivus*, p. 12. [*Unde è contrario dilucescit, si è corpore sano, vivido sale volatili turgido remittatur, ipsamque, quo apud recentiores plerosque Anatomicos expertissimos hodie certum est, massam sanguineam ab alio rursum inspiratus ingrediatur, vel virtutem balsamico—vitalem juxta doctrinam Philosophorum, vel juxta principia mechanica saltem vim elasticam potentiorem, adeoque motum vivaciorem alterius corporis sanguinis solidisque communicare.*]

[93] Cohausen, *Hermippus Redivivus*, p. 12. [*Si vera foret Francisci Mercurii Helmontii sententia Alphabet Nat. Colloq. 4 de occulta anhelitus circulatione in abdomine ceu centro corporis,*

was vigorous, the breath of youth brimmed with salts; when inhaled by the aged, this salty breath would prolong life.[94] The breath was thus a chemical Arcanum.

In his reliance on van Helmont in his satire, Cohausen was following the theories of iatrochymical physicians and natural philosophers in England in the latter half of the seventeenth century.[95] An addendum to Lewis Cornaro's treatise on longevity (1740) which Cohausen referenced in the *Hermippus* contained excerpts from *Royal Society Transactions* written in the seventeenth century that attributed life-giving properties to salts in the breath; this same excerpt was also published in a *History of Cold Bathing* (1715), so it must have been a reasonably pervasive anecdote. The excerpt related that there was a:

> Man in the North [of England] of an extream Age; he lay on a Pad on the Ground in a dark smoaky tatter'd Cottage…with a little Cow lying by him, chewing his Cud…I ask'd him what that Cow serv'd for, with her Mouth so near him? He answer'd, for Refreshment; for, said he, the Breath of the Cow is a Cordial, and much refreshes me when I am faint. As to being comforted with the Breath of the Cow, it is highly rational to believe it; for the breath was warm and must emit with it some volatile Salts, and fragrant Particles, analogous to our own Spirits. I have heard several Shepherds…say that in rousing of their Herds from their Rest in a Morning, the Steams not only of their Bodies, but even the Effluvia and Scent of their Dung and Urine has been grateful and refreshing, from those salubrious volatile Salts that they draw in with their Breath in their Sheep Folds, and Cow-Houses, early in a morning before the Beams of Light and Heat exhale them, and rob them of the best Nose-Gay in the World.[96]

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omnibusque membris, ne capillis quidem exceptis, quis dubitet eundem de corporis universi proprietate participare.]

[94] Cohausen, *Hermippus Redivivus*, p. 12. […*et copia spirituum turgeant, sed et quod nonnulli praetendunt, adhuc initiis suis seminalibus proximiores plurimum balsami radicalis, quod tamen singulis annorum periodis magis imminuatur, obtineant patet effluvia ex illorum corpore emanantia eiusdem plane esse conditionis*.]

[95] Antonio Clericuzio for instance has illustrated the importance of a vital saline spirit to seventeenth-century English physicians in his article, "The Internal Laboratory: The Chemical Reinterpretation of Medical Spirits in England," *Alchemy and Chymistry in the Sixteenth and Seventeenth Centuries*, Ed. Piyo Rattansi and Antonio Clericuzio (Dordrecht and Boston: Kluwer Academic, 1994), pp. 51–80.

[96] Lewis Cornaro, *Sure and Certain Methods of attaining a Long and Healthful Life: With Means of Correcting a Bad Constitution, etc. Made English by W. Jones, A.B* (Dublin, Richard Gunne, 1740), pp. 58–59. This account was also published in John Floyer and Edward Baynard, ΨΥΧΡΟΛΟΥΣΙΆ· *Or, the History of Cold Bathing, Both Ancient and Modern in Two Parts* (London: William Innys, 1715), pp. 409–410.

The Role of Insensible Perspiration in Longevity and Gendered Exhalations

After his discussion of saline particles in the breath, Cohausen then explained in the *Hermippus* how the exhalations and inhalations of body played a role in prolonging life, particularly the emissions from the pores of the skin. Van Helmont claimed that volatile salts were emitted through insensible perspiration, and Cohausen argued that the pores were engaged continually in the aeration of the blood, inhaling and exhaling the surrounding atmosphere, taking up and discharging atmospheric particles from the circulatory system; if the surrounding atmosphere was healthy, the body would benefit, but if virulent, the body could become diseased.[97] Cohausen's assertion was of course a version of the miasma theory of disease, which natural philosophers such as Robert Boyle discoursed about the effects of effluvia and the salubrity of the atmosphere on health.[98] The *Elementa chemiae* of Leiden physician Herman Boerhaave also analyzed the virtue of plants diffused through

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[97] Joan Baptista van Helmont, *Ortus Medicinae* (Amsterdam: Elzevir, 1648; reprint, Brussels: Culture et Civilisation, 1966), pp. 178–192; Cohausen, *Hermippus Redivivus*, pp. 51–52. "According to Hippocrates and other the nobles of Medicine, the human body when healthy perspires through the open pores of the skin. [This is] because of the incessant motion and the continuous circular course of the blood in which small particles are incessantly emitted. Sanctorius weighed the mass of these excretions of the body which bodies previously excreted... These effluvia give out a scent through transpiration and are of the nature of the body from which they are emitted, a sickening and harmful scent from those that are unhealthy, and a vigorous and sound scent from the youthful, and but when examined this emanation is humid and unctuous, and as one sweats it likewise condenses into a damp and fatty substance. Likewise the breathing human body has pores and the absorbent vessels in the skin, through which lifeless bodies accept the outward animated corpuscles of exhalations. Undoubtedly, the pores of the skin are engaged in the aeration of the blood, inhaling the surrounding atmosphere and then exhaling it again, reinforcing vital movements, or if the air is virulent, destroying life.

[*Corpus humanum juxta Hippocratem caeterosque Medicinae procures perspirabile est, quatenus per poros cutis in sanitate patulos ob continuum liquidorum motum sanguinis perpetua cirulatione attenuati particulae sive effluvia incessatur emittuntur, quae juxta staticen Sanctorii quascunque alias corporis excretiones mole et aliquot librarum pondere... Effluvia haec transpirata, seu per transpirationem emissa corporum suorum redolent naturam; et uti ex aegrotantibus et cacochymicis insalubria et noxia, sic ex juvenilibus vegetis ac sanis non tantum vivida, sana et volatilia, sed et humido—unctuosa excernuntur, quemadmodum et ipse sudor, qui ex transpiratis condensatis constat, humidus quoque et pinguis est. Humanum corpus inspirabile quoque est, idest habet poros et vasa absorbentia in cure... Indubitatem est aërum effluviis resertum per cutis spiracula ingredi et sanguini ac succo nervosa se insinuare, motusque vitales aut roborare, aut etiam, si virulentus fit, perfumdare.*]

[98] Robert Boyle, *An Experimental Discourse of some causes of the Insalubrity or Salubrity of the Air* (London: Samuel Smith, 1690), p. 169. Though he does not explicitly give a reference to Van Helmont in this context, it is also possible Cohausen could have been influenced by Helmontian writings on the weapon salve and magnetism, which

the air and their subsequent medicinal effects; for instance postulating that the effluvia of the Poppy procured sleep, and the vapor of the yew was thought to be deadly to those who slept under it; van Helmont in his discussion of human breath, proclaimed that odors were more efficacious than liquid medicines, "seeing that the Spirit of our life, since it is a Gas, is most mightily and swiftly affected by any other gas, to wit, but reason of their immediate co-touchings."[99] Cohausen reasoned if the smells of Vegetables had such high effects, animal odors in the form of breath and sweat should even have stronger results. Therefore, one could also imbibe not only the breath of healthy young people, but also be benefited by their perspiration exhaled through the skin.

To continue the formulation of his argument, Cohausen utilized the work of Sanctorius, (1561–1636), a Paduan physician, on insensible perspiration. Sanctorius, inspired by physicians of classical periods who discoursed on suppressed or obstructed perspiration, wrote that perspiration was "absolutely necessary to the well being of a Human Body. [Its production was] occasion'd by the constant Circulations of the Animal Fluids, and the forcible Contractions and Attritions of the Solids."[100] Those parts of the fluids and solids that were not necessary for the nourishment of the body, flew out of the body through the pores of the skin and mouth, meaning that it was necessary there be a "proportionate Recruit by daily food."[101] By measuring the amount of insensible perspiration in the body and regulating one's diet, and keeping the outflowing of sweat and consumption of food at a constant level, one could regulate and preserve one's health.[102] Sanctorius then argued that as the body aged, the solids and fibres of the body grew hard, contractions in the tissues slowed and stopped, perspiration halted, and death resulted. In other words, the bodily tissues would lose their tonic motion of tissues and relevant organs. Tonus was a wide-ranging concept in early modern medicine originally postulated by the Stoics

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postulated an action-at-a-distance mechanism of disease. See Johann van Helmont, "Of the Magnetick or Attractive Curing of Wounds," *Van Helmonts Works*, pp. 756–792.

[99] *Van Helmont's works*, p. 110.

[100] Sanctorius, *Medicina Statica: Being the Aphorisms of Sanctorius, Translated into English with large Explanations* by John Quincy (London: William Newton, 1712), p. 1. For the history of insensible perspiration, including its classical origins, see E.T. Renbourn, "The Natural History of Insensible Perspiration: A Forgotten Doctrine of Health and Disease," *Medical History* 4, 2 (April 1960), pp. 135–152.

[101] Sanctorius, *Medicina Statica*, p. 1.

[102] Sanctorius, *Medicina Statica*, p. 1.

and Galen, and held not only by Sanctorius but by other physicians such as Boerhaave and George Stahl.[103] Tonic motion

> referred to the mechanism in which the blood circulation that delivered harmful matters to the excretory organs, and . . . the colatory structure of the organs that filtered out those matters. As the body's putrefaction [and aging] continued, tonic motion worked to hold it in check.[104]

Cohausen agreed, writing in the *Hermippus* that "The body . . . is made of up fluid and solid materials, and life depends on the incessant movement of the fluids, especially the systole and diastole, but if the movement of fluid stops, the body will die."[105] However, Cohausen argued that the bodily fluids were constantly agitated not only through the blood circulation, but by the operations of air currents which penetrated the body through the pores and mouth. Although old age would mean gradual stoppage of fluid movement and obstruction of the pores, if the circulation of the fluids was maintained by the infusion into the pores and mouth of fresh vital forces in the air, such as from proximal young people, then life could be extended.[106]

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[103] Jerome Bylebyl, "The Medical Side of Harvey's Discovery: The Normal and the Abnormal," in *William Harvey and his Age: The Professional and Social Context of the Discovery of the Circulation*, Henry E. Sigerist Supplements to the *Bulletin of the History of Medicine*, ed. Jerome J. Bylebyl (Baltimore: John Hopkins University Press, 1979), pp. 40–41; See also Herman Boerhaave, *Institutio in Physick . . . the Second Edition translated by J. Browne* (London: Jonas Browne, 1715), p. xvi; Boerhaave wrote "Therefore these two kinds of Motion, viz. a Pulse which exerts its Power in the Vessels and the Heart, and drives from the Centre to the Circumference, and the Tone which is seated in all the Fibres, membranous and muscular Parts . . .; if these are in a right State and in due Strength, Equality and Temperment, the Blood is received into the Parts equally and without Impediment, and from the same, a due Quantity is expell'd in due time, the Secretions naturally follow, and so the Business of *Health* is perform'd."

[104] Ku-Ming (Kevin) Chang, "'Motus Tonicus': George Ernst Stahl's Formulation of Tonic Motion and Early Modern Medical Thought", *Bulletin of the History of Medicine* 78 (2004), pp. 767–803, on p. 789.

[105] Cohausen, *Hermippus Redivivus*, p. 52. [*Notum est corpus humanum esse machinam pnevmatico-hydraulicam ex fluidis atque solidis contextam, euisque evexiam et vitam in horum continuo motu atque circulo consistere, liquidorum autem motum à solidorum motu tonico, systole atque diastole unice dependere, ita ut hisce integris ac salvis vita constet, cessantibus atque ablatis pereat.*]

[106] Cohausen, *Hermippus Redivivus*, p. 52–3. [*Certum porro fluida corporis humani in se spectata, quatenus indies renovantur et per alimenta restaurantur, quam diutissime et vel ultra aevum durare posse, eorum tamen motum tandem necessario imminui ac demum tolli duntaxat et vitio solidorum, quatenus haec tractu temporis, et longo annorum cursu paulatim indurantur, exarescunt, rigida sicque immobilia evadunt, unde tono et motu cessante confetarium quoque est fluida remorari et tandem penitus subsistere. In qua fibrarum ariditate, duritie, inflexilitate et ad vividum motum ineptitudine senectutis ratio formalis consistit, quam proin veteres in siccitate et frigiditate collocarunt . . . Ex quibus demum concludo, si quis posset solida in sua mollitie, flexilitate ac consequenter justo tono ac motu conservare,*

One way to keep the pores of the skin open and performing well to maintain tonus was via oil, a technique for longevity utilized by the ancients. Cohausen related Pliny's account of Pollio, a soldier of the emperor of Augustus—who when asked how he had managed to live over a hundred years replied: *Melle intus, foris oleo*, or "honey within, oil without."[107]

Other than anointing oneself on the outside, Cohausen felt it was possible to "oil" the pores of the body from the inside by inhaling specifically young female breath, as he claimed women were more oily or fatty than males. He utilized as his support the writings of the ancient Macrobius who claimed that in funeral piles it was important to lay one fatty female body to six male bodies in a great pyre, as the male bodies would be more speedily consumed.[108] After a facetious anecdote, where Cohausen claimed that the physician Fabricius knew of a lady who emitted sparks when she combed her hair, he more seriously refers the reader to his publication *Lumen novum phosphoris accensum* (1717) for evidence of the latent heat and fire of women.[109]

Cohausen's *Lumen* was a serious scholarly effort submitted to the Bordeaux Academy of Science (established in 1703) in competition for a prize granted by the Duke of Force of 300 livres for the best answer to a proposed question. In this case, the prize committee requested an explanation for the cause of light from phosphorus, a topic of much interest in both continental and English natural philosophy; in 1674, Brandt of Hamburg first obtained phosphorus from the "Microcosmic

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eum quoque posse avertere senectutem, et sic vitam ultra centem pluresque annos facile protrahere.] Cohausen refers the reader to his *Decas* for further discussion of *tonus.*

107 Cohausen, *Hermippus Redivivus*, pp. 53–54. [... *qui ut memorat Verulamius ad annum tricentesimum aetatem produxisse fertur seu ut alli referent Pollionis veterani militis apud Caesarem Augustum, qui centesimum annum longe excesserat. Qui rationem rogati, quomodo vigorem corporis tanto tempore conservarint, respondisse dicuntur: Melle intus, foris Oelo, Plinius 1.2. c 24.*]

108 Cohausen, *Hermippus Redivivus*, pp. 54–55. [*Corporis vero puellaris perspirabile non duntaxat humidem est, sed et unctuosum, idest ex aqua et oleo constans, ideoque naturam et vim obtinens humectandi et emolliendi siccas rigidasque corporis senilis fibras, quo diuturniori motui, contractioni dilationi, et fluidorum impulsui sufficiant.... Dixi perspirabile corporis puellaris esse unctuosum, alii vapores oleosos seu halitus sulphureos appellant, quia corpora faeminea prae virilibus, et consequenter etiam puellaria prae puerilibus majore scatent unctuositate, quod experientia antiquos quoque Romanos docuerat, quibus ut scribat Macrobius cadavera comburendi ritum recensens, solenne erat senis virorum cadaveribus mulierbre adjicere, quia persuasum erat unius adjectu quasi natura flammei ceatera virorum corpora rapidiori foco absumi*].

109 Cohausen, *Hermippus Redivivus*, pp. 55–56. [... *et apud Jo. Fabri in Palladio Chymico puella inter pectendum è capite ingremium ignis scintillas stellarum instar excutiens... Fiendi modum et causam Lumen meum novum phosophoris accensum sufficientur detexit.*] Joannes Henricus Cohausen, *Lumen Novum Phosphoris Accensum* (Amsterdam: Joannem Oosterwik, 1717).

Salt" a name given to phosphates from urine excreted from the microcosm of the body, and Robert Boyle also wrote two works about his early experiments with phosphorus, entitled *The Aerial Noctiluna* (1680) and *The Icy Noctiluna* (1682).[110] Though unsuccessful at winning the prize, Cohausen's *Lumen* was a compilation of all theories that were attempts to explain the phenomena of phosphorescence; the first part of the work analyzed natural phosphors of the air, sea, and land, and the second section compiled instances of luminescence of plants and animals, such as in glowworms, as well as artificial phosphors such as the Bolonian stone. In the third section of the *Lumen*, Cohausen praised the artificial "hermetic phosphorus" discovered in 1673 by Christolph Adolph Baldouin, a magistrate in Saxony; it was an impure calcium nitrate (perhaps containing some sulphur) made from chalk and nitric acid, believed to be a potential alkahest.[111] In his attempts to explain luminescence, Cohausen remarked in the *Lumen*, "there is in all things a certain salt, which is nothing other than potential fire," and he included observations on the development of molecules of fire that existed in the human body, including descriptions of some cases of spontaneous combustion; he believed them most prevalent in women, supposedly occurring after they imbibed large amounts of brandy or spirits.[112] From ideas such as these, Cohausen affirmed in the *Hermippus*

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[110] E. Newton Harvey, *A History of Luminescence: From the Earliest Times Until 1900*, Vol. 44 (Memoirs of the American Philosophical Society, Philadelphia: American Philosophical Society, 1957), pp. 151, 154. Beauvois, *"Les concours de Bordeaux," [The Bordeaux Contest]*, pp. 43–51, *passim*. Robert Boyle, *The Aerial Noctiluna or some New Phenomena and Process of a Factitious Self-Shining Substance* (London: Thomas Swaden, 1680).

[111] Harvey, *A History of Luminescence*, p. 155 and p. 321.

[112] Cohausen, *Lumen Novum Phosphoris Accensum*, p. 25 as quoted in Harvey, *A History of Luminescence*, p. 155; Beauvois on p. 47 of his dissertation mentioned Cohausen's anecdote about brandy and spontaneous combustion in the *Lumen novum*. Anecdotes about latent fire in the body, and speculations as to their cause were prevalent in the seventeenth and eighteenth centuries. For instance, physician Thomas Willis related in his *Practice of physick* (1681), "for we have known in some endued with a hot, and vapourous blood, when they have put off their inner garments at night going to bed near a fire of Candle, a very thin and shining flame to have shewn itself, which hath possessed the whole inferiour region of the Body. The reason of which affection seems wholly the same, as when the evaporating fume of a Torch just put out is again inflamed by a light inkindling, and manifestly argues that another flame, the root of this extrinsick one, lyes hid within the Body." Thomas Willis, *Dr. Willis's Practice of Physick, Being all the Medical Works of That Renowned and Famous Physician*… (London: T. Dring, C. Harper, and J. Leigh, 1681), p. 32. As Clericuzio has indicated, Willis believed that heat was generated "by the reaction of particles of nitre coming from the air and mixing with sulphur contained in the blood." See Clericuzio, "The Internal Laboratory," pp. 65–66. For a survey of early modern ideas of spontaneous combustion, please see Jan Bondeson, *A Cabinet of Medical Curiosities* (London: B. Tauris), 1997, pp. 1–25.

that "with these examples it is sufficiently understood that latent fire is plainly in superabundance in women's bodies bringing forth copious vital heat."[113]

Cohausen's comments were an interesting inversion of the Aristotelian premise of matter and spirit dualism between male and female. In the pre-modern era, men were typically seen as hot, spirituous, the givers of form to matter. On the other hand, Aristotle claimed that women, who were of moist and cold complexions, were shorter lived than males, and that they were merely material and closer to the animal world.[114] As Guerrini has commented, "The ideal female of Vesalius, in images which persisted for centuries, was literally more material than the male, being fleshy and voluptuous in contrast to the tautly muscled ideal man."[115] However, in Cohausen's medical work of the Enlightenment, the human body was less a vessel of Aristotelian humors than a machine fired by an internal chemical combustion engine; with this advent of iatrochymistry and Cartesianism, Cohausen turned Aristotelian gendered assumptions on their heads, a not uncommon event in satirical works which often invert accepted principles. Through their very materiality, their fatty flesh, women produced spirit, the ethereal vital breath.

Indeed, whether he knew it or not, in his treatment of gender, Cohausen was also in agreement with theories of insensible perspiration that were modified by Newtonian physicians. As Newtonian physicians such as Pitcairne argued that the body was a hydraulic machine consisting of bodily fluids, health would lie in the "unobstructed circulation of bodily fluids" and in free perspiration and discharge of excreta.[116] In the *Emmenologia*, a treatise on menstruation, John Friend asserted the women discharged excreta through menstruation rather than via

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[113] Cohausen, *Hermippus Redivivus*, p. 56. [*Hoc loco saltem scire sufficit, quod lux illa veluti calor summe attenuatus superabundantem in corporibus faemineis ignis vitalis copiam prodat.*]

[114] Lynn Thorndike, "Two Other Passages *De Complexiones*", *Isis*, 54, 2 (June 1963), pp. 268–269, on p. 269.

[115] Anita Guerrini, "The Hungry Soul: George Cheyne and the Construction of Femininity," *Eighteenth-Century Studies*, 32, 3 (1999), pp. 279–291, on p. 280; See also Londa Schiebinger, *The Mind Has No Sex?* (Cambridge: MA: Harvard University Press, 1989), chap. 6, *passim*; Maryanne Cline Horowitz, "Aristotle and Women," *Journal of the History of Biology* 9 (1976), pp. 183–213; Joan Cadden, *Meaning of Sex Differences in the Middle Ages* (Cambridge, Cambridge University Press), 1995.

[116] Luica Dacome, "Living with the Chair: Private Excreta, Collective Health and Medical Authority in the Eighteenth Century," *History of Science* xxxix (2001), pp. 468–500, on p. 471.

insensible perspiration, and that the role of insensible perspiration was less crucial in females than in males. In fact,

> in women insensible perspiration was . . . naturally obstructed. This was due to a combination of factors related to the circulation of blood and the secretion of perspirable matter. As the pulse of women was more "languid" than that of men . . . women's blood circulation was less strong and less powerful. This meant the orifices of the vessels of the female body were too small to convey substantial amounts of perspirable matter, and women skin was too skin, its pores too small, to all proper excretion of perspirable matter.[117]

In a refiguration of the Aristotelian premise that women were a defective variation of the male body, the Newtonian physicians used Friend's reasoning to argue that "women's bodies were more unbalanced than those of men." Women were less effective bodily machines.

If their bodies were more unbalanced, so were women's emotions. Guerrini has commented that over the course of the eighteenth century, "the medical definition of the female changed from being primarily physical to being primarily emotional: from body to spirit."[118] Cohausen witnessed this transition and utilized it for his medical and satiric purposes. If women were perceived as more sensitive and less emotionally balanced in their nature as the eighteenth century progressed, there was the danger that the "sensitive were also sensual, and more given to the pleasures of the flesh, conforming to the older view of women as animal-like."[119] In the *Hermippus*, Cohausen adhered to this caution, noting that it is not the breath of any woman that was ethereal and life-giving, but only those women who were healthy, young and chaste; virgins were particularly effective in their life-giving powers.[120] In answer to an objection raised in his text by his colleague Bishop Nunning, who in his own attempt to add hilarity to the *Hermippus* exhorted Cohausen to explain why Solomon with all of his wives had not lived a long life, Cohausen claimed it was because Solomon was surrounded by women

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[117] Dacome, "Living with the Chair," pp. 475–6.
[118] Guerrini, "The Hungry Soul," p. 279.
[119] Guerrini, "The Hungry Soul," p. 285.
[120] Here Cohausen may have been influenced by Roger Bacon's recommendation that the touch of girls, beautiful song, and the sight of beauty could give longevity. See Bruce Moran, *Distilling Knowledge: Alchemy, Chymistry, and the Scientific Revolution* (Cambridge and London: Harvard University Press, 2005), pp. 23–24.

in a harem, and their breath was tainted by lustful relations.[121] Cohausen also entreated his readers never to marry an old woman, as she would absorb all the vital principles from one's lungs. The young man who married a rich old spinster in hopes of gaining money would trade his life, as she would become youthful, and he prematurely aged.[122] Old women were "like cats, whose breath is poisonous to life," a reference to the age-old connection of cats to crones, witchcraft and female sexuality.[123] As Cohausen explained, as women aged and became more sere and dry, their breath and sweat became more noxious, and more representative of their supposed animalistic natures.

In the midst of Cohausen's advice to bottle female breath, to marry young wives, as well as his admonition to schoolteachers not to smoke in the classroom, as they were denying themselves the volatile salts in the breath of their charges, it would be evident to most readers that they were in the midst of an effective satire which utilized medical theories of the day to accomplish a humorous end. To continue the joke, much in the manner of Thomas More's *Utopia*, Cohausen used the satiric devise of including a series of encomiums and letters praising the *Hermippus*. One letter was from his friend Bishop Nunning, who had earlier critiqued Cohausen's work with his example of Solomon; another from

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[121] Cohausen, *Hermippus Redivivus*, chapter three, pp. 37–48 is entitled: *[Resolvuntur geminate autori ab Amico propositae Quaestiones: 1. Cur non longaevior fuerit Salomon, cui tot ex integra puellarum legione singulis horis fuerunt Nympharum Aspirationes?]* or Here some questions are solved which were proposed by a friend of the Author: 1. Why was it that Solomon did not have a long life, as every single hour he was surrounded by the breath of a legion of young women?

[122] Cohausen, *Hermippus Redivivus*, pp. 61–62. *Sic passim vetulis os oblinunt juvenes, ut aurea haereditate potiantur. Interim vetulae, quibus putridus oris halitus, et impuri, exsucei squalidique corporis nequam est Spiritus, pravo contactu faedoque commercio maritos juvenes brevi tempore emarcere faciunt, et in senium propero gradu praecipitant* [Thus everywhere young man defile [themselves] with the breath of their elderly wives to obtain a golden inheritance. Meanwhile the elderly wives, with their unclean breaths from their squalid bodies decay with their crooked touch their youthful husbands in a short time, causing their precipitous aging.]

[123] Cohausen, *Hermippus Redivivus*, pp. 63–64. [Tanta est cati domestici malignitas ex oculis et ore spirans (nam et ejus cerebrum homini toxicum habetur) ut ex ejus familiaritate & accubitu plures in tabem ac hecticam immaturamque mortem inciderint. Sed nec minus periculum est, si quis uxorem vetulam concubinam habeat, quae juvenilis vitae flamman satis reluctanem non quidem statim difflare et dissipare, paulatim tamen instar cati imminuere et extinguere potest]; Roger Chartier, "Texts, Symbols, and Frenchness," *The Journal of Modern History*, 57, 4 (December 1985), pp. 682–695 has an analysis of cat symbols in the early modern period in its analysis of Robert Darnton's "Great Cat Massacre." See Robert Darnton, "The Great Cat Massacre, 1730," *History Today*, 34 (Aug. 1984), pp. 7–15; Pierre Roudil, "Dieu ou Diable: Le Chat Dans L'Histoire [God or devil? The cat in history]," *Histoire Magazine* 36 (1983), pp. 66–73.

his eldest son, Bernard, also a physician of some note who published a work on the chyle; and there was an concluding "*epigramma votivum*" from Salentinus Ernest Eugenius Cohausen, the nephew of our author, doctor to the troops of the Elector Archbishop of Cologne, and active correspondent with scientific societies.[124]

After this extensive display of learned praise, Cohausen could not maintain the pretense any longer, and finally admitted in the last few pages that the premise of the *Hermippus* was a "*lusus satryicus*," Hermippus himself a fictional character. Cohausen launched his career by penning a work that did not promise any secrets to immortality, and ironically, he ended it in the same vein, no doubt disappointing his more gullible readers much as the work by Dr. Behrens did to the members of the Bishop of Munster's court forty years earlier. Like Behrens, Cohausen proclaimed in a concluding verse that longevity was not to be found in the breath of girls or the philosophers' stone, but rather "*Sed fato et Fortunae salutari, causis plerumque eventuum occultis*" or aging was due to the outcome of fortune, with unknown causes and outcomes.[125]

In the *Helmontius Ecstaticus*, Cohausen praised the hermetic vision of van Helmont in which Helmont received the alkahest and the "*gemma rosae*" the perfect ruby or the philosophers' stone, and in the *Decas*, the physician proclaimed it was humanity's purpose to search for the lost tree of life. Now, at the end of his own life, in his conclusion to the *Hermippus*, Cohausen continued his verse satire with a poem dedicated to the *Emerald Tablet* of Hermes Trismegistus, which alchemists claimed held the secret of the philosophers' stone and immortality.[126] Pictorial representations of the *Emerald Tablet* contained the Latin acrostic for the volatile salt vitriol, as we have seen thought to be a possible source of the philosopher's stone: *visita interiora terrae rectificando invenies occultum lapidem*—visit the interior of the earth, by rectifying you will find the hidden stone. Cohausen's satiric reference to a volatile salt which supposedly held the secret of immortality could not be a more fitting end to his work. Newman has noted that it was not until the beginning of the 1700s that alchemy was distinctly separated from chymistry,

[124] Cohausen, *Hermippus Redivivus*, p. 84. For a complete description of Cohausen's relatives, see Beauvois, pp. 134–139.

[125] Cohausen, *Hermippus Redivivus*, p. 90.

[126] Cohausen, *Hermippus Redivivus*, p. 86.

and there still remained some overlap between the two disciplines.[127] During his career which ended in the early Enlightenment, Cohausen witnessed and demonstrated in the *Hermippus* the gradual transformation of alchemical principles into chemical ones; what were formerly serious precepts became subjects for humor and derision. As John Campbell wrote in the preface to his version of the *Hermippus*,

> There is in this Dissertation such a mixture of serious Irony, as cannot but afford a very agreeable Entertainment to those who are proper Judges of Subjects of this Kind, and who are inclined to see how far the Strength of human Understanding can support philosophical Truths, against common Notions and vulgar Prejudices.[128]

We can only agree, for Cohausen's satire was worth its salt indeed.

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[127] Newman, *Promethean Ambitions*, p. xiii.

[128] John Campbell, "Preface," to Cohausen and Campbell, *Hermippus Redivivus, or the Sage's Triumph over Old Age*, 1744 ed., p. iii. This is Campbell's preface to his loose translation of Cohausen's original work published in 1742.

CONCLUSION

FROM SALINE ACIDS TO ACIDIFYING OXYGEN

In his "Observations on Respiration, and the Use of The Blood" (1776), Joseph Priestley speculated upon the atmospheric substance necessary for respiration, and provided a short summary of the history of past scientific beliefs about the process of breathing. He wrote:

> Others say, that the air itself is not admitted into the blood, but only some active, spirituous, and ethereal particles; that this vital spirit passes from the lungs to the heart and arteries, and at length become the animal spirits, which are by this means generated from the air. Others, who do not admit that the animal spirits are derived from the air, still say that some other *vital principle* comes from thence. This vital principle MALPHIGHIUS supposes to be saline vapour; LISTER, a hot, inflammable, sulphureous spirit...and BRYAN ROBINSON, the aerial acid, which preserves the blood from putrefaction; preserves also its density, and strengthens the animal fibres. For this reason he supposes it is we feel ourselves refreshed in cold air, as it abounds with a more plentiful acid quality.[1]

In his summary, Priestley was referring to a long intellectual tradition in seventeenth and eighteenth-century chymistry, analyzed in this book, which attempted to identify the vital principles in the air responsible for respiration with a particular reactive chymical substance. The purpose of this chapter is to ascertain briefly to what extent these concepts of a vital salt or saline acidic spirit survived in the Enlightenment. To accomplish this task, we will analyze the role of saline spirits or acids in the chemical revolution of Lavoisier. While Lavoisier's discoveries "revolutionized perceptions of space and caused the old theories of air to be discarded," to what extent did they stem from specifically older beliefs about salts from English iatrochymistry?[2] In other words, to what extent did the saline spirit or atmospheric acid become oxygen, the acidifying principle?

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[1] Joseph Priestley, "Observations on Respiration, and the Use of the Blood," *Philosophical Transactions of the Royal Society of London*, 66 (1676), pp. 226–248, on 229.

[2] Alain Corbin, *The Foul and the Fragrant: Odor and the French Social Imagination* (Leamington Spa, Hamburg and New York: Berg, 1986), p. 139.

Our analysis will begin with the work of dissenting minister Stephen Hales in the *Vegetable Staticks* (1727), an innovative work inspired by Newtonian chymistry on the production of airs (gases) in which he utilized a pneumatic trough or a pedestal apparatus to measure the amount of air released in a chymical reaction. Hales believed that aerial acids and volatile salts contributed to the elasticity and fixedness of the air, produced or absorbed gases, and affected human respiration. We will also examine Hales' *Philosophical Experiments*, a series of discourses about surviving long voyages at sea (1739) in which he analyzes sea salts and their exhalations in the atmosphere. In turn, we will then demonstrate to what extent Lavoisier was influenced by Hales and the Newtonian chymical tradition of acidic saline spirits in the atmosphere.

Stephen Hales, Aerial Acids and Salts

Stephen Hales (1677–1761) was a dissenting minister, physiologist and chymist who was awarded the Copley medal by the Royal Society in 1739, and as we have seen in chapter four, influenced the work of Newtonian physician Bryan Robinson. In his seminal work, *Vegetable Staticks* (1727), Hales applied Newtonian experimental method to plant physiology, further developing the chymical queries in the *Opticks*. The *Staticks* primarily included analyses to show "how great a proportion air is wrought into the composition of animal, vegetable and mineral substances."[3] As Francis Darwin realized, the foundation of Hales' views on the nutrition and presence of "airs" in plants was based upon a premise of Newton's in which he postulated if fermentation progressed to its ultimate end, the compound putrefied, and the dense bodies rarified into several sorts of Air; this Air by fermentation, and sometimes without it, was then formed into new mixtures or compounds.[4] As Hales wrote of Query 30 of the *Opticks*, Newton "observes of air that dense

[3] Stephen Hales, *Vegetable Staticks*, History of Science Library, ed. Michael Hoskin (London and New York: MacDonald and American Elsevier Inc., 1969; London, 1727), p. 6.

[4] Sir Francis Darwin, "Stephen Hales, A Reply to Criticism," 14 (1915) *New Phytologist*, pp. 27–29, on p. 27. Hales also adheres to this premise in his *Philosophical Experiments Containing Useful, and Necessary Institutions for such as undertake long voyages at Sea* (London: W. Innys and R. Manby, 1739). On p. 34, he wrote, "But Putrefaction, that most subtile of all Dissolvents, effectually disjoins and separates all the component parts of putrifying Bodies... after the Putrefaction ceases, [the bodies] are formed into new combinations."

bodies by fermentation rarity into several sorts of air, and this air, by fermentation, and sometimes without, returns into dense bodies."[5] On this basis Hales formed his theory of vegetable nutrition, concluding "that particles of air in a fixt state" adhere to and "are wrought into the substance" of plants.[6] Hales thought of fixed air as a unifying and binding principle "greatly contributing in fixed state to the union and firm connection of the several constituent parts" of living and non-living matter.[7] Non-fixed air, or free air however was inherently elastic.

Although in modern terms, Hales did prepare a wide variety of gases in his experimentation, he did not think that the differences in the properties of the free or fixed "airs" he collected were due to chemical identities. As Ecklund has noted, Hales

> viewed the differences he found in the air obtained from different substances as being due to the presence of impurities, which he referred to as "fumes" or "vapours."... Hales was led by his faith in Newtonian atomism to explain the differences of properties in terms of an intermixing of particles of the impurities with those of the one true elastic substance—air.[8]

As air was capable of union with other substances, Hales believed that upon such union, the fixed air lost that elastic property associated with its free state.

To accomplish his analyses of airs and their fixation into plants and animals, as well as their impurities, Hales used an apparatus to collect gases over water in vessels separate from those in which they were generated. The substance that Hales studied was placed in a retort and heated; the retort was connected to a receiver suspended in water. If air was driven off on heating the retort, then the water level in the receiver would drop. If air was absorbed by the water, the water level would rise, so the change in water level was a measure of the amount of gases produced or absorbed [See Figure 19].

Hales however had a different explanation for the rise and fall of levels. In experiment 76 in *Vegetable Staticks*, Hales concluded,

> A good part of the air thus raised from several bodies by the force of fire, was apt gradually to lose its elasticity, in standing several days; the

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[5] Hales, *Vegetable Staticks*, p. 177.

[6] Darwin, "Steven Hales", pp. 28.

[7] Milton Kerker, "Herman Boerhaave and the Development of Pneumatic Chemistry," *Isis* 46, 1 (March 1955), pp. 36–49, on p. 39.

[8] Jon Ecklund, "Of a Spirit in the Water: Some Early Ideas on the Aerial Dimension," *Isis* 67,4 (December 1976), pp. 527–550, on p. 540.

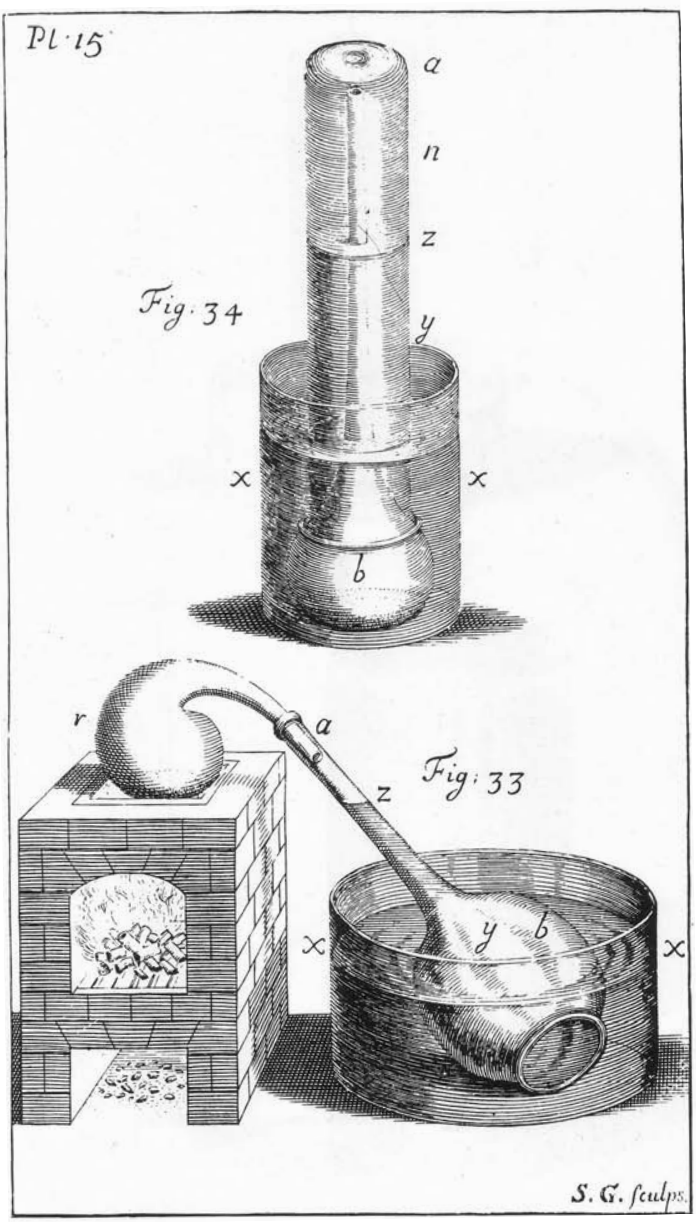

Figure 19. Hales' initial apparatus for estimating the quantity of Air that arose from a material "by distillation or fusion." Stephen Hales, *Vegetable Staticks*. London: J. and W. Innys, 1727, opposite p. 260. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

> reason of which...that the acid sulphureous fumes raised with the air, did resorb and fix the elastic particles.[9]

In other words the elastic pure air, in which the repulsive force dominates, was fixed in bodies by combining with acids and sulphurs whose attractive particles destroyed its elasticity. To some extent, Hales here was adhering to the chymistry of Newton in the *Opticks*, in which the air was "impregnated with subtle sulphur," as well as with acids; in the *De Natura Acidorum*, Newton also discoursed about the extreme attractive qualities and chymical reactivity of acids. As Heinemann stated,

> Hales considered that chemical processes were maintained by the production and absorption of gases by chemical substances, which he supposed brought about by attractive and repulsive forces. Associating [free] "air" with the alkali principle, he interpreted the interaction between acidic and alkaline substances in terms of the interactions between opposing [Newtonian] forces.[10]

Hales believed that the air lost its elasticity (decreased in volume) as the elastic particles of pure air were reabsorbed by the acid sulphureous fumes generated in the process. In other words, though "mixtures do in fermentation generate elastick air...those which emit thick fumes, charged with sulphur, resorb more than was generated in proportion to the [acidulous] and sulphureousness and thickness of those fumes."[11] Therefore removing these acidic and sulphureous fumes would mean his air would not lose its elasticity.[12] In their analyses of Hales' apparatus, Parascandola and Ihde noted that Hales invented a method for solving the problem of the loss of elasticity of the air:

> In his attempting to remove the unwanted [acid and sulphureous fumes] from his air, Hales separated the generator from the collector and gave us the pneumatic trough. He was incidentally, successful to a large extent in his purpose of preventing the air generated from losing its elasticity, undoubtedly because in passing the air through water, most of the soluble fraction would be dissolved in the process. In Hale's previous device, the

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[9] Hales, *Vegetable Staticks*, p. 162.

[10] P. Heimann, "Ether and Imponderables," *Conceptions of Ether: Studies in the history of ether theories, 1740–1900*, eds. G.N. Cantor and M.J.S. Hodge (Cambridge: Cambridge University Press, 1981), pp. 61–84, on p. 66.

[11] Hales, *Vegetable Staticks*, p. 176.

[12] John Parascandola and Aaron J. Ihde, "History of the Pneumatic Trough," *Isis* 60, 3 (Autumn 1969), pp. 351–361, on p. 355.

> "air" was generated over water, and then the soluble fraction slowly dissolved, causing the decrease in volume[13] [See Figure 20].

In addition to his invention of the trough, Hales also improvised upon Newton's chymistry and postulated his own role for the role of acids in respiration. Unlike Robinson who believed in the efficacy of aerial saline acids for breathing, Hales believed that elastic free air necessary for respiration was inherently alkali. In fact, the result of his pneumatic trough experiments demonstrated to him that acids, and in particular, too large a presence of acid sulphureous fumes in the atmosphere, could be fatal to animal respiration. Burning sulphur (brimstone) in particular flaming brimstone absorbed "much air," and when he reflected

> on the great quantities of elastic air, which are destroyed by burning sulphur; it seems to me not improbably, that when an animal is killed by lightening... it may be done by the air's elasticity, being instantly destroyed by the sulphureous lightening near the animal, whereby the lungs will fall flat, and cause sudden death.[14]

On the other hand, experiments with volatile alkali salts such as vitriolic growths on pyrites and sal tartar generated a good deal of air.[15] So, alkali salts would be beneficial to aiding respiration as they seemed to drive off air in the heating of the retort.

These conclusions led Hales to experiment with breathing apparatus coated with salts that would aid respiration in places abounding with acid sulphureous fumes, such as in mines or grottos. Hales

> bored a hole in the side of a large wooden fosset, and glewed into it the great end of another fosset... covering the orifice with a bladder valve. Then I fitted a valve *b i*, to the orifice of the iron siphon *s s*, fixing the end of the siphon fast at B into the fosset *a b*: Then by means of narrow hoops I placed four diaphragms of flannel at half an inch distance from each other, into the broad rim of a sieve, which was about 7 inches diameter. The Sieve was fixed to, and had a free communication with both orifices of the siphon, by means of two large bladders *i i n n o*."

In his instrument, expired air had to pass though the diaphragms before being inhaled. Hales then dipped the diaphragms in strong solutions of salt tartar, noting he could breathe through the apparatus twice to four times as long with the salty diaphragms as with uncoated ones, sal

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13 Parascandola and Ihde, "History of the Pneumatic Trough," p. 356.
14 Hales, *Vegetable Staticks*, p. 147.
15 Hales, *Vegetable Staticks*, pp. 101–103.

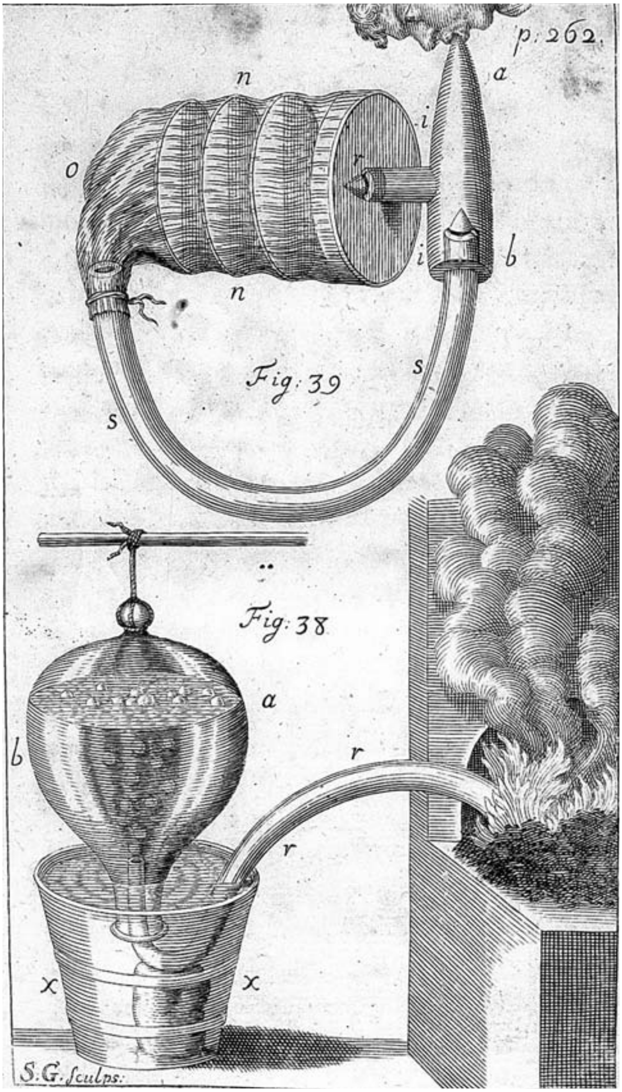

Figure 20. Hales' Breathing Device. Stephen Hales, *Vegetable Staticks*. London: W. and J. Innys, 1721, opposite p. 262. Wellcome Library, London.

tartar being particularly effective.[16] He speculated that it was the salt's chymical power of attraction to sulphureous and acid particles which allowed for longer respiration; salt would remove such particles from the fixed air, making it more elastic and wholesome for breathing. He also believed that

> in several unwholesome trades, as the smelters of metals, the ceruss-makers, the plumbers, etc it might not unlikely be of good service to them in preserving them…from the noxious fumes of the materials they deal in by the use of such a salt-coated device.[17]

The power of air and its particulate components in "chymical operations" as well as in respiratory processes led Hales to conclude

> the air is very instrumental in the production and growth of animals and vegetables, both by invigorating their several juices while in an elastic state, and also by greatly contributing in a fix'd state to the union and firm connection of the several constituent parts of those bodies, viz, their water, salt, sulphur and earth. This band of union, in conjunction with the external air, is also a very powerful agent in the dissolution and corruption of the same bodies, for it makes one in every fermenting mixture…elasticity is also not an essential immutable property of air particles; but they are, we see, easily changed from an elastick to a fixt state, but the strong attraction of the acid, sulphureous, and saline particles which abound in the air.[18]

Hales continued,

> since this is the case, may we not with good reason adopt this now fixt, now volatile Proteus among the chymical principles, and that a very active one, as well as acid sulphur; notwithstanding it has hitherto been overlooked and rejected by Chymists, as no way intitled to that denomination?[19]

Air, as well as the chymical fermentations between its atmospheric acids, sulphurs, and salts, was thus important to understand respiration as well as material change.

Hales' experiments with air in the *Staticks* and adherence to Newtonian principles led him to speculations about the source of the interactions between salts and the acidic sulphureous particles in the air in a later work, *Philosophical Experiments Containing Useful, and Necessary*

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[16] Hales, *Vegetable Staticks*, p. 150.
[17] Hales, *Vegetable Staticks*, pp. 153–54.
[18] Hales, *Vegetable Staticks*, p. 179.
[19] Hales, *Vegetable Staticks*, p. 180.

Institutions for such as undertake long voyages at Sea (1739). Along with his invention of a ventilators and breathing apparatus which improved survival rates when employed on ships, in hospitals and in prisons, Hales was also concerned with water supplies on naval voyages. The desalination of water was also a predominant concern among the fellows of the early Royal Society, a research question expressed in Hales' work.

First, in his analysis of the purification of sea water, Hales came to the conclusion that sea water consisted of common sea salt of a fixed nature, and volatile salts, namely "more imperfect bittern salt and sulphureous bittern which last Principles promote Putrefaction, and are thereby Disjointed."[20] Bittern traditionally was the mother water or lye which remains after the crystallization of common salt from sea water; it contains sulphate and chloride of magnesium, bromine and iodine. Distilling bittern salt resulted in the "saline spirit" of salt, in other words the saline acid. Hales' assertion that sea water consisted of fixed and volatile salts is reminiscent of Thomas Philipot's theories of chymical models of tides (chapter three). Hales then speculated that from the bittern salts that the "universal salt arises, which as it happens to fall on different earths, concretes and corrodes them, and thereby produces different types of salts... vitriol, alum, nitre... and sal ammoniac."[21] One of his supports for his assertion about bittern salts was the fact that "Chymists observed that Nitre consists of an Oily Saline and Volatile Substance," so it was "no wonder that Nitrous Salt should be formed in the Bittern Salt and oily Bitumen of Sea-Water."[22] He then concluded that because sea water had a good deal of nitrous salts arising from bittern, seawater could not extinguish ships in fires as well as fresh water, as nitre was exothermic and used in gunpowder. And, it was from the "the sulphurous Bitumen of the Sea, as raised by the warmth of the sun, that subtle Sulphur form which the air, and its Waters, viz Dew and Rain are impregnated."[23] He then concluded that interactions between nitric acid arising from Bittern sea salts, and sulphur in the air from sea bitumen caused violent ferments in the atmosphere resulting in thunder and lightening, the acid-sulphur fermentation again taken directly out of Newtonian chymistry. Hales concluded from his analyses that purification of sea water was best

[20] Hales, *Philosophical Experiments*, p. 34.
[21] Hales, *Philosophical Experiments*, p. 46.
[22] Hales, *Philosophical Experiments*, pp. 45–46.
[23] Hales, *Philosophical Experiments*, pp. 47.

done by letting it putrefy, releasing the more disjoined bittern and sulphureous salts into the atmosphere, and then distilling it, whereby the fixed salt left over would be left as a *caput mortuum* (dead head) or as a distillation dreg.[24]

Acids in the air and Lavoisier

Hales' work on the pneumatic trough and the chemical role of air and its saline acids was influential in Britain and in the continent, and as Guerlac has shown, he was cited by most pneumatic chemists including Joseph Black and Lavoisier.[25] The idea of a universal atmospheric acid was also still common even until the 1770s; George Stahl, the inventor of the concept of phlogiston, mentioned the subject of acidification in his treatise on salts. Stahl thought that vitriolic acid [sulphuric acid] was the fundamental or "universal acid" and widespread in the atmosphere, an opinion shared by many eighteenth-century chemists.[26] As Crosland has noted, the discovery of carbon dioxide or "fixed air" by Joseph Black in 1754 provided the "possibility of a new direction to the tradition—the Swedish chemist Torbern Bergman suggested that "fixed air" be called the "aerial acid."[27] J.F. Meyer also postulated a universal *acidum pingue* a single acid, of which the other acids were later modifications, providing "an alternative explanation to that of Black of the difference between mild and caustic (acidic) agents."[28]

Lavoisier himself was familiar with French translation of Meyer's book, being impressed by his explanation that the gain in weight when metals were calcined was due to the absorption of *acidum pingue* from the fire.[29] Lavoisier also knew of J.F. Rozier's *Observations sur la physique*, in which Rozier postulated that air behaved in some ways like an acid. Rozier in 1772 wrote a treatise on wine in which experiments on fermentation were described; he suggested that the acidity of soured

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[24] Hales, *Philosophical Experiments*, p. 33.

[25] Henry Guerlac, "The Continental Reputation of Stephen Hales," *Archives Internationales d'Histoire des Sciences* 15 (1951), pp. 393–404.

[26] Maurice Crosland, "Lavoisier's Theory of Acidity," *Isis* 64, 3 (September 1973), pp. 306–325, on p. 309. Stahl believed nitric acid was a compound of this with phlogiston. See George Stahl, *Fundamenta Chymiae Dogmaticae et experimentalis* (Nurnberg: Wolfgange Mauritius, 1723), p. 10 as quoted in Parthington, *History of Chemistry*, Volume 2, p. 679.

[27] Crosland, "Lavoisier's Theory of Acidity," p. 309.

[28] Crosland, "Lavoisier's Theory of Acidity," p. 309.

[29] Crosland, "Lavoisier's Theory of Acidity," pp. 309–10.

wine was not due the presence of tartar as traditionally described, but rather due to absorbed air.[30] Rozier of course was following Newton and Hales, who proposed that air contained acids, and thus that air gave them their corrosive qualities.[31] When doing experiments with the fixation of air in the formation of phosphoric acid from phosphorus, in an unpublished manuscript (1773), Lavoisier noted,

> The absorption of surplus air is the same in the formation of all the acids. In the fermentation of beer wort…it is observed that a very great abundance of air is released as soon as the spirituous fermentation begins. But when in the progress of fermentation the liquor begins to turn to acid, soon all the air that was released is re-absorbed to enter into the composition of this acid. M. Abbe Rosier in his treatise on wine was the first to be struck by this phenomenon…it is easy to sense that these experiments must inevitably lead to a completely new theory of fermentation.[32]

Lavoisier thus was thinking at this point about a connection between air and acidification, a connection made more manifest as he became aware of Joseph Priestley's work on airs in 1773. As Crosland noted, Lavoisier read Priestley's observations on the "acid air" obtained from muriatic acid, and upon doing his own investigations in 1774 speculated that

> marine acid [hydrochloric acid] is nothing but water impregnated with marine air. It is roughly the same kind of thing with nitrous acid.… There is every likelihood that fixed air is nothing else but an acid in the state of a vapour.[33]

Lavoisier then did his famous experiment on nitric acid in 1776, in which he brought together fractions of "nitrous air" (obtained by dissolving mercury in nitric acid, heating the residue, and collecting the gases) and oxygen, reforming nitric acid. Lavoisier also claimed that in the *Memoir* of his work that the air of the atmosphere is an acid composite of nitre and pure air. He stated,

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[30] Robert E. Kohler, "Lavoisier's First Experiments on Combustion," *Isis* 63, 3 (September 1972), pp. 349–355, on p. 351.

[31] Kohler, "Lavoisier's First Experiments," p. 351.

[32] F. Rozier, *Memoire sur la meilleure manière de faire et de gouverner des vins de Provence…* (Paris: Chez Le Vey, 1772), pp. 149–150, as quoted in Kohler, "Lavoisier's First Experiments," p. 351.

[33] M. Bertholet, *La revolution chimique. Lavoisier* (Paris: F. Alcan, 1890), p. 259, as quoted in Crosland, "Lavoisier's Theory of Acidity," p. 313.

> I am now in a position to advance affirmatively that not only the air but he purest part of the air enters into the composition of all acids without exception; that it is this substance which constitutes their acidity.[34]

Hence "pure air" was christened "oxygen" or the acidifying principle, and Lavoisier would believe each acid was an oxygen compound.

His assumptions also influenced the chemical nomenclature, published in the *Methode de nomenclature chimique* (1787), a joint effort between Lavoisier, Francois de Fourcroy, Claude-Louis Bertholett, and Pierre Joseph Macquer. Lavoisier claimed that oxygen was an appropriate name for his pure air, as it suggested a fundamental relationship between it and acids. These etymologies in his words were to "relive the memories of beginners, who retain with difficulty a new word when it is absolutely empty of meaning."[35] In his schema, salts were named in terms of the acids that they could become, and in his system he confidently named "twenty-two simple substances... not yet isolated, forming names from an individuating simple substance or radical and the relevant acid—for example—"citric radical."[36] The undiscovered bases of the undecomposed acids, he was sure would be readily uncovered now that the chemistry of oxygen was better understood. As he asserted,

> That the number of the acids that one can form is again absolutely indeterminate, since one does not know all the substances that are likely to combine itself with the acidifying principle, and that one knows again less the means that one can employ to succeed in the combination.[37]

In this way, Lavoisier's nomenclature created a conceptual map to guide chemists through a *terra incognita*, a map that represented a new paradigm of the chemical revolution.

And, even when oxygen was shown not to be a universal acidifier by Berthollet, Lavoisier's terminology stuck. As Weininger remarked, "The

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[34] Lavoisier, "Memoire sur l'existence de l'air dans l'acide nitreux, et sur les moyens de décomposer et de recomposer cet acide," *Oeuvres*, vol. II, pp. 129–138, as quoted in Croland, "Lavoisier's Theory of Acidity," p. 314.

[35] Lavoisier, "Nécessité de perfectionner la nomenclature de la chimie," in Guyton de Morveau, Lavoisier, Claude-Louis Berthollet, and Antoine François de Fourcroy, *Méthode de nomenclature chimique* (Paris: Chez Cuchet, 1787), pp. 18–19.

[36] Jessica Riskin, "Rival Idioms for a Revolutionized Science and a Republican Citizenry," *Isis* 89,2 (June 1998), pp. 203–232, on pp. 215–216.

[37] Lavoisier, "Considérations générales sur la nature des acides et sur les principes dont ils sont composés," *Oeuvres d'Antoine Laurent Lavoisier (1743–1794)* (Paris: Imprimerie impériale, 1862), vol. 1, p. 251. http://histsciences.univ-paris1.fr/i-corpus/lavoisier/index.php. Accessed: 14 January 2007.

Lavoisian nomenclature has similarly been amended, revised, excused; yet its fundamental core is still with us."[38]

Lavoisier himself in creating his nomenclature also amended, revised, and excused a tradition of saline chemistry that lay behind it, whose "core is still with us." In other words, oxygen was not only a word that triggered the "memory of beginners," but I would argue triggered the memory of a much older chemical, chymical, and alchemical tradition of which Lavoisier, in his references to Newton and Hales was aware.

In seventeenth and eighteenth-century England, we have seen that the vitalist element in respiratory physiology and in natural history was transformed from a volatile salt into a saline spirit or acid acting in the atmosphere. From tidal motion to animal spirits, from metallogenesis to the perceived key to longevity, salts and their acids played a persistent and predominant role in early modern natural philosophy and medicine. We have seen that the study of saline spirits in the air and how they affected the animal oeconomy was a significant preoccupation for early modern physiologists, leading them to regard salts as intrinsic to bodily processes. It seems that this tradition of chymistry also played a role in the chemical revolution where the saline spirit became an "acidifying principle." The concept of volatile salts as the vital element of life and material change was therefore gradually modified into an understanding of respiration and combustion involving oxygen.

[38] Stephen Weininger, "Contemplating the Finger: Visuality and the Semiotics of Chemistry," *Hyle* 4, 1 (1998), pp. 3–27, on p. 19.

APPENDIX

TRANSLATION FROM LATIN OF MARTIN LISTER'S *EXERCISES ON THE HEALING SPRINGS OF ENGLAND* (1684)

Martin Lister's *Exercises on the Healing Springs of England* is translated from the second edition.[1] Lister's work met with great acclaim and was reviewed in the *Weekly Memorials for the Ingenious*, a publication in the "same format as the French *Journal des Scavans*."[2] The reviewer praised the "inquisitive and curious" naturalist for his "piercing industry" in creating a history of "English Spaws," and in "the Discovery of such things as relate to the natural Improvement of his own Country."[3] Lister's thoughts on the chymistry of spa waters also had wider influence in the Royal College of Physicians. As Lister's colleague Tancred Robinson wrote to him in 1682/3,

> some are now very busy in the College of Physicians in experimenting upon minerall waters, as those of Northhall, Acton, Dulwich, Shooter's Hill, Epsome, Tunbridge, Ashopp, etc for by chance yesterday I went into the laboratory there, where I observ'd all their furnaces, and instruments at work upon those tryalls, but I could not learn the design, though I suspect Dr. Goodall, and Dr. Tyson to be the cheife undertakers; you have laid them a good foundation to build upon.[4]

As we have seen in chapter three, Lister's crystallographic analysis of salts in the spas, his survey of iron metals in England, and his discussion of metallogenesis involving aerial exhalations are especially notable.

The salts figure to which Lister refers in his text is reproduced as Figure 3, on page 71 of this work.

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[1] I would like to thank Dr. Tom Holland (a.k.a. Quintus), Head of Classics at the Cheltenham Ladies College, Gloucestershire for his assistance in preparing this translation.

[2] *Weekly Memorials for the Ingenious* (London: Henry Faithorne and John Kersey), no. 50, 15 January 1683/4, pp. 376–82; James Fieser, "The Eighteenth-Century Reviews of Hume's Writings," *Journal for the History of Ideas* 57 (Fall 1996), pp. 645–657, on p. 646.

[3] *Weekly Memorials for the Ingenious*, p. 376 and p. 382.

[4] Tancred Robinson (London) to Martin Lister, (Lendell Street, York) 15 March 1682/3, MS Lister 35, Duke Humfrey Library, Bodleian, Oxford University, Letter 29, fol. 89r. The references are to Edward Tyson (1651–1708), also a Royal Society Fellow, who became a member of the Royal College of Physicians in 1683, and Charles Goodall (d. 1712).

Martin Lister, of the Royal Society of London, *Exercises on the Healing Springs of England, New and Prior*
Waters take their nature from the strata through which they flow—Pliny

Edition revised by the author
London: Walter Kettilby, 1684

Translator's Notes

1. Italicized items in the text contained in italicised square brackets are translator's comments.
2. "Fossilis" literally means "dug from the earth," but is applied in this treatise to salts which are not invariably dug up but found, for example, as efflorescences on walls. Fossils usually in this period refer to all minerals.
3. "Metallum" in Latin can mean "metal" in our sense, but also "anything mined," including non-metallic substances. It can also mean the "mine" itself. Lister uses it indiscriminately to mean all of these, and also "ore" and even "mineral."
4. "Vena" has been translated as "vein" (of metal, of course), but often "ore" seems to be more appropriate, and at times this word is utilized
5. The word "atramentosus" occurs regularly. It is translated as "inky-black," in line with the author's stated preference for this word over "ferruginous."
6. I have numbered the pages in the preface, pp. i, ii, iii, etc for convenience, as they are not paginated.

Preface page i
To the Reader
Greetings

Here, for what it is worth, you have my earlier treatise on the Mineral Springs of England. I have thought long and hard before publishing it, so many are the factors which have held me back. There is the very subject matter, which has been handled by the majority of my fellow-countrymen in such a way that, if I were to write about it, it seemed inevitable that I would cause disputes and quarrels with them, and I have a great dislike of such discourtesies.[5] Indeed, as in my other writings,

[5] The discovery of several mineral water springs at Scarborough and Knaresborough in 1626, and early accounts of these springs by Michael Stanhope were followed by

I have nothing further to affirm, and no intentions which go beyond giving an account of a phenomenon. For that alone is my unwavering truth: any other currently-held fixed opinions of mine may in a short time cease to have my support (even if they have it now!). To what end then should I defend them in a determined manner, if they find fail to impress some churlish fellow?

Preface page ii

Indeed this great obstinacy in debate is, in my opinion, a plague and dishonour to the Republic of Letters. In addition although I undertook this work for relaxation I have been unable to complete it in scarcely any part because of the claims of business. I have also been prevented by ill-health, as I understand it. Yet I was reluctant to allow any correct arguments or discoveries, however incomplete they may be, to be lost. Also there is the fact that my second and better treatise is hardly in the planning stage yet, and I concluded that it could not be properly understood without continual application and a long-standing experience of the places mentioned. Yet it is scarcely justifiable that anyone should reject the whole wide field of medicine and devote his life to the investigation of certain salts and their related soils. Furthermore I did not personally visit a large number of the lesser mineral springs of England, but I had their waters brought to me for examination, or else I speak using the trustworthy words of men who are experts in waters of their kind.[6] The philosophers of Paris followed the same

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those of John French and Robert Wittie. Wittie's chymical analysis of the Scarborough spa began a debate over the mineral content of the waters. One of the disputants about the gall test (to test iron) in the waters was William Simpson (see chapter three), who referred the dispute to the Royal Society. This is the controversy Lister was most likely complaining about here. For more analysis of this debate see chapter three and Allen G. Debus, *The Chemical Philosophy* (New York: Dover, 2002), pp. 496–7. See also Robert Wittie, *Scarbrough spaw; or, A description of the nature and vertues of the spaw at Scarbrough. Also a treatise of the nature and use of water* (London: Charles Tyus and Richard Lambert, 1660). An example of the debate in the *Philosophical Transactions* is: Nathaniel Highmore, "Some Confiderations Relating to D. Witties Defence of Scarborough Spaw (Abbreuiated in Numb. 51.) together with a Brief Accompt of a Less Considerable Salt-Spring in Somersetshire; And of a Medical Spring in Dorsetshire; By the Learned Dr. Highmore in a Letter to Dr J. Beale at Yeavil in Somersetshire," *Philosophical Transactions* 4, 51 (1669), pp. 1128–1131.

[6] This claim is borne out by Lister's vast correspondence about mineral waters and mineralogical specimens in MS Lister, Duke Humfrey Library, Bodleian, as well as in his publications in the *Philosophical Transactions*, which are often letters to correspondents who have sent him mineral samples. Specific examples will be enumerated in the footnotes below.

procedure, and they were also the very first to complete an investigation of this kind.[7]

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Amongst my achievements the following is the most well-known, that I have conducted an enquiry into iron and limestone (and I would certainly have done likewise in related fields if only I had had time) and acted on my own behalf in investigating their individual differences. It is my wish to distinguish between other materials found underground following the precedent set in this way.

However, in order to object to an assertion made by P. Guirius,[8] the most recent writer on certain springs in France, I am not unduly impressed by his salt of Alumen, about which he forcefully argues, after making a careful investigation of what D. Closeus had to say about the same waters before the Philosophers of Paris.[9] He should furthermore have looked carefully at the shapes formed by crystalline salts of this kind, and he could not have done this from a few grains of some salt. Likewise in that author's works the ill-considered claim is made, contrary to the belief held by everybody else, that green vitriol, or, if you will,

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[7] Here Lister refers to the work by Samuel Cotreau Du Clos, the *Observations on the Mineral Waters of France*, which was translated into English in 1684. Du Clos' work was a systematic evaluation of the chemical content of all spa waters in France under the auspices of the French Académie Royale des Sciences, part of a larger project of chemical research which began in 1666 to "determine rigorously the 'true principles of mixts [chemical compound]' by analyzing such bodies and by generating them and observing their properties." See Samuel Cottereu Du Clos, *Observations on the Mineral Waters of France, made in the Royal Academy of the Sciences…Now Made English* (London: Henry Faithorne and John Kersey, 1684).

[8] Lister refers to Pierre le Givre, most likely to his *Traité des eaux minérales de Provins Avec le régime de vivre qu'il faut observer en beuvant de ces eaux*. (Paris: Chez Charles du Mesnil, 1659). Le Givre also wrote a book on mineral acids, *Le secret des eaux minerales acides, nouvellement découvert par le moyen des principes chymiques, qui combat l'opinion commune. Avec les lettres de plusieurs doctes medecins sur ce sujet, et le réponses de l'autheur. Seconde edition. Augmentée d'une seconde partie* (Paris: Jean Ribou, 1677). According to Alice Stroup, le Givre's book on mineral acids was discussed by the Parisian Academy of Sciences in the 1670s, and since Lister had travelled to France several times to Montpellier and to the Academy, it is possible this is how he knew of le Givre's works. See Alice Stroup, *A Company of Scientists, Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences* (Berkeley: University of California Press, 1990), chapter 15, note 96. http://ark.cdlib.org/ark:/13030/ft587006gh/ Accessed on 22 September 2006.

[9] Originally, Samuel du Clos, *Observations sur les Eaux minerales de plusieurs Provinces de France, faites en l'Academie Royale des Sciences en l'Année 1670 & 1671.* (Paris: de l'Imprimerie Royale, 1675).

vitriol of Mars, is not produced, although absolutely no other kind is produced naturally from Pyrites and Pyrites itself is nothing other than iron in its pure metallic form. However an excellent response to his other claims (those, that is, which are at variance with my findings) is made in this very treatise,

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assuming that they require no fresh rebuttal.

I have named those very springs which others call ferruginous, 'inky black' [*atramentosos*], in a manner of speaking, from their appearance. They have been called by others, who follow Pliny, after their taste, but by me after the effect they have when in contact with galls.[10]

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[10] Galls are the bulbous growths formed on the leaves and twigs of trees in response to attack by parasites. Galls are collected from oak, oak-apple and pistachio trees. Their high concentration of tannic acid reacts with iron, changing from brown to black. Iron gall ink was made from crushed galls, water, and iron II sulphate (vitriol) and gum arabic to keep the pigment suspended. The reference here is of course to *Natural History*. Galls were used in the early modern period in a color-change test for the presence of iron in spa waters.

[11] Salt of lime is calcium carbonate ($CaCO_3$) precipitated from limewater (calcium hydroxide solution, $Ca(OH)_2$) by a carbonate compound.

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Page 1
(1)
Concerning
The mineral springs of England
A treatise, the new one and the earlier one
Chapter 1

The shapes and descriptions of the four better known fossil salts, namely, salt of vitriol, alumen, saltpetre, as it is called, and sea salt, and the fifth less well-known one, that is, salt of lime.

The fossil salts found in a mature state which have thus far been discovered in our country and are better known are four: namely, vitriol, from pyrites, which is green, alumen, common salt, and nitre, otherwise known as saltpetre.

To these however we must add a fifth kind, although it is one of the less well-known types;

[12] Johann van Helmont. See Chapter three for Lister's disputes with van Helmont over the generation of vitriol.

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yet because is is the most plentiful of all, it should rightly be categorized in the class of salts. It is of course salt, or nitre of lime (nitrum calcarium).[13]

Since however we have given an accurate description of all the shapes of all these salts, we shall, in my opinion, shortly establish with greater certainty some things about the salts of mineral springs, by making a comparison between the salts of each type.

A description of vitriol

To resume, green vitriol is born from iron pyrites; when its crystals are mature and perfectly formed, they are invariably sharpened or pointed at either end, and consist of ten uneven and flat sides.

One may see in the middle four flat pentagonal sides, and they possess three flat triangular surfaces at each of their pointed extremities, as represented in the first figure.

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II. *A description of alumen* (alumen or alum).[14] I have filtered lye from the metallic form of alumen after burning it and then keeping it for a long time and drying it. It produced white crystals shaped in the following manner: their shape is a little compressed; on the one side, or, as one

[13] After his classification of common salts, Lister turned to an analysis of salts in English mineral waters, and concluded from isolation by dehydration and crystal analysis that only two types were present: *nitrum calcarium* derived from limestone (calcium carbonate) and common sea salt. Lister thought that the presence of sea salts in English mineral springs was easily explained via the runoff of sea water inland. But nitre of lime, or what he called *nitrum calcarium* was a different case. Lister commented that *nitrum calcarium* was produced by the exposure of limestone to air. This was first because "where there is nitre of lime, there is always limestone to be found," and because Lister observed that "no salt whatever grows from limestone immediately after it has been slaked by the application of heat, but the same stone produces an abundance of salt, whether it [*ie. the stone*] has been untreated or heated, whilst forming the walls or roof of some house; it then grows together to form crystals of its own kind." Most likely Lister was observing the formation of potassium carbonate or saltpetre crystals on walls that had been whitened by limestone, similar to the formation of nitre crystals in limestone saltpeter caves. Lister noted that *nitrum calcarium* could also not be formed by steeping limestone in water, and indeed nitrate crystals will not form in areas of excess humidity.

[14] Most likely aluminum sulphate (alum), though it could be alumen which was a mixed double salt of aluminum sulphate with potassium sodium or ammonium sulfate. (Potassium salt, when pure, was also commonly called "Alum."). ($Al_2(SO_4)_3 \cdot K_2SO_4 \cdot 24H_2O$); ($Al_2(SO_4)_3 \cdot (NH_4)_2SO_4 \cdot 24H_2O$); ($Al_2(SO_4)_3 \cdot Na_2SO_4 \cdot 24H_2O$).

might say, at its peak, it has a flat hexagonal surface, whilst on the other opposite side it rests upon a flat base which is similarly hexagonal. Its sides are bounded by three hexagonal flat surfaces, interposed alternatively by two quandrangular flat surfaces each, and so each whole crystal of alumen is made up of eleven flat surfaces, that is, of five hexagonal flat surfaces and six quandrangular flat surfaces. The particular crystal which I have described weighed about 50 grains. See Figure 2.

N.B. The simple and basic development of all salts should be noted thoroughly and carefully. For where it is

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...advanced for a longer time, the crystals indeed appear to grow larger. But this usually happens through a certain chance conjunction of several pure primary salts, from which confusion arises regarding the true and natural shape of crystals.[15]

A description of common salt III. If salt water is boiled to dryness, and the salt is then once more dissolved in a little spring water, it produces crystals which are truly cubic. See figure 3.

Yet in the central part of the upper side, or, if you will, flat part, a sort of transparency can be observed, which is unblemished because of a lack of substance [*within that part of the crystal*], or emptiness. Yet the remaining five sides are solid and whitish.

A solution of our so-called sal gemmae has displayed the same cubic crystals to me.[16]

I obtained the same results from common salt obtained by boiling dry salt water drawn from the inland regions of our island.

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Furthermore concerning the sea-salt made from sand in the estuary of the Lune [Lancastriensi],[17] I have additionally noticed salt of this kind develop into a brilliant white fluted mass while it is still in solution before it has been brought to dryness by heat, just as can be observed

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[15] Here we see Lister's interest in crystallinity as an indicator of chemical structure, a common conceit of the time. See Norma Emerton, *The Scientific Reinterpretation of Form* (Ithaca: Cornell University Press, 1984) for an analysis of crystallinity in early modern science.

[16] Sal gemmae is sodium chloride or "common salt."

[17] *Lancastriensi* refers to Lancashire, as the Lune River flows down from the Pennines and Eastern Lane District towards Lancaster.

in the case of fused antimony or a certain kind of stone of gypsum. Yet this same mass is dissolved in spring water, and grows in its entirety into crystals of a cubic shape, like other sea salts which I have already mentioned.

Sea salt differs completely from the salt of inland springs in kind, and a clear distinction must be drawn in every respect between seawater and fresh water. For the crystals of seawater are cut short at each of the corners, to form individual flat triangles, on at least one side of the square, but the crystals formed from saltwater have undamaged corners. As far as I aware I am the first person to record this. See figure 8.

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A description of nitre. IV. Nitre, which some call saltpetre and halopetrum, develops into hexagonal crystals, which are thin, long and of unvarying width. These crystals, I say, have sides shaped like parallelograms. Furthermore they end, on one side only, in a sort of point or tip, which is sharpened in a pyramidical fashion owing of course to the varying position of the two flat sides. On the other side however the crystals do not have a polished appearance, but invariably end as though they had been broken off prematurely. I would give a warning here that nobody should be deceived about the shape of nitre, which I am the first to sketch out and make known, but which I see has recently been incorrectly described by somebody else. See figure 4.

It should further be observed that this sharpened point, which we have stated is shaped rather like a cone on the one side of each crystal of nitre, is formed from the very end of the prism,

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and that the body of the prism itself is to no extent made narrower. I am aware that many have dreamt this feature up and carelessly applied it to crystals of nitre.

I am speaking however of the simple and primary growth of these crystals: For this does appear at times to happen as a consequence of a chance combination of several crystals.

But the following difference should be noted, that those which combine in this way by chance can also be ultimately restored to a perfect shape of their own type, if they are dissolved in water once more.

Apart from hexagonal crystals formed from a solution of saltpetre, you will also find not infrequently in the same solution (if the salt is inadequately purified) other polygonal cubic crystals of some kind or other. If these are all gathered together separately and made into a fresh solution they either turn into the crystals of nitre described above or, if they are of a different source, they make their origin clear.

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Furthermore when the aforementioned saltpetre is placed on a fire, it at once catches light with a thin flame and is completely consumed with a considerable noise, and leaves behind nothing of the death's head,[18] or, as the (al)chemists love to say, the colcothar.[19]

V. There is in addition a certain kind of salt, which some call mural nitre [*nitrum murale—nitre found on walls*] and which we call nitre of lime [*nitrum calcarium*], because it usually develops from limestone, whether untreated or treated with heat on the very old walls of buildings.[20] I shall now be the first, as far as I am aware, to give the shape and description of this lesser known salt (even though, at least in England, it is the most common of the salts which can be dug from the ground.)

Well, the crystals of this salt are thin and long, and in the middle are four parallelogram-shaped sides, but these are usually of unequal size. On the one side the point itself is formed from two flat triangular sides:

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On the other opposite side it has two flat squares, which are placed so as to be constantly opposite the part described earlier. The larger of these crystals are about half a finger long. See figure 5.

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[18] The "dead head"; the nonvolatile residue left over in the bottom of a retort or alembic after distillation.

[19] The colcothar could be a "dead head" but it usually referred more specifically to residue produced by roasting copper sulfate; it is composed mostly of copper oxide. The residue from the roasting of iron vitriol (ferrous sulfate) is also called colcothar and is composed of iron oxides. Please see William Newman, "Alchemical Glossary" in "The Chymistry of Isaac Newton." http://webapp1.dlib.indiana.edu/newton/reference/glossary. Accessed 22 August 2006.

[20] Before industrialization, a major source of nitre was the deposits crystallizing from cave walls or privies, or other organic matter that was decomposing. Ammonia from the decomposition of urea in dung heaps would produce nitrate, and nitre-beds were cultivated in the early modern period by mixing manure and ashes, along with straw to create a compost pile; the compost pile was periodically kept moist with urine and leached with water. The liquid containing the nitrates was then converted with ashes to potassium nitrates which were refined into gunpowder.

There are several other varieties of this salt, because some have five sides in the middle, etc, individual examples are described with their particular shapes in the table.

This salt also grows entirely into the crystals already described when it is once more dissolved, even though you may obtain only a few undamaged and perfect crystals at each attempt.

It is also a feature of the nature of this salt of lime that if placed on a fire it clarifies without a flame and grows into bubbles, and grows hard like deep white pumice, which is clearly after the fashion of alumen.

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Chapter II

Concerning veins of iron. It is affirmed that there is only one pyrite in England, and this and this is entirely composed of pure metallic iron.

Up to this point we have described all our fossil salts, although certain soils are correctly considered as the parents, so to speak, of some of those salts. A ferrous vein is of course the parent of green vitriol, and limestone of salt of lime; it will be my intention to give a brief explanation of those underground substances. I shall however begin with ferrous underground substances.

I shall give an honest account of the accidentals and properties of iron as far as I have understood them by personal inspection.

It is particularly true, as was once suggested by Pliny, namely, that of all the underground substances an abundant vein of ferrous material certainly occurs nowhere in England

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But I do not accept that distinction drawn by my fellow-countryman Gilbert (*On the Magnet* Book 1, chapter 8) who distinguishes between a metallic vein of iron and some kind of ferrous material, and so would have it that a great part of our island of Britain is ferrous.[21] For I consider it most certain that all loamy soil, or, if you will, every vein containing stone, which, either in its raw state or heat-treated and prepared in any way whatever, is attracted by a magnet, can be

[21] A reference to William Gilbert, *On the Magnet*, first ed. (London, 1600). Duane H.D. Roller, *The De Magnete of William Gilbert* (Amsterdam: Menno Hertzberger, 1959). Not all sources of iron ore are of course magnetic.

melted down into iron. Accordingly, if some mistake is made in a furnace, either by supplying insufficient heat or otherwise, it should not immediately be blamed upon a metallic vein, as though it did not truly share in the nature of iron.

I have decided here to describe the proof of a metallic vein of iron in accordance with what Agricola says (Book 7, page 194).[22] For the individual ferrous substances to be named below have been carefully investigated in accordance with this procedure.

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We prove (he says) a vein of iron in the forge of a blacksmith. It is heated, reduced, washed and dried. A magnet is placed on the scrapings collected by washing, which attracts the iron filings to itself. These are wiped off with a feather and collected in a crucible; the magnet is continually left on the scrapings collected by washing, and the filings are wiped off, until the magnet attracts what remains to itself. This is then heated with saltpetre in the crucible until it liquefies and from it a little lump of iron melts from it. If the magnet quickly and easily attracts the filings to itself, then we conjecture that it is a rich vein of iron, but if this happens slowly, we conjecture it is a poor one. If of course the magnet appears to want to have nothing to do with it, we conjecture that it contains either little or no iron.

The magnet § 1. The magnet is a very particular vein of iron. It is, I declare, the best metallic form of iron, and attracts to itself all other ferrous substances, be they raw or heated, as has just been shown above.

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The magnet which I have obtained from land in the British county of Devon, is a blue-black color, and a little darker than polished iron itself. When it is broken up, its interior is like marble, and it attracts filings made from itself as though they were melted-down iron.[23]

[22] Lister is referring to Agricola, *De Re Metallica*. (Basel: J. Froben and N. Episopius, 1556). For a fascinating exploration of the relationship between mining and movable type, see Pamela O. Long, "Of Mining, Smelting, and Printing: Agricola's *De re metallica*," *Technology and Culture* 44, 1 (January 2003), pp. 97–101.

[23] Magnetite is often found in East Dartmoor in Devon, and pyrrotite, a slightly magnetic iron pyrite, can be found in North Dartmoor.

The vein which flashes, like sandstone § II. In the second place I submit for consideration the red-colored vein of iron, which flashes like sandstone. This, I declare, has a sort of purplish color, of a less intense blue-black. It consists of unequal and sharp particles, like iron filings, one might say. For in whatever manner you break it, it always has this appearance, and (to omit nothing of what I have observed about this substance) this is considered the exact appearance of Swedish iron ore, which has always quite deservedly been considered the best in Europe.[24] But the color of the Swedish ore is less blue-black than almost green.

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At least this is what all the examples sent to me from twelve diggings look like without exception.[25] Furthermore when it is crushed to the powder we spoke of but in a raw state and as yet untreated by fire the magnet still attracts it, but it does not follow the magnet as readily as the ore from Sweden. When this is raw and unheated obeys the magnet as if it were pure iron. This is the most certain indication of the best

[24] Magnetite is a main component of most igneous rocks and is often present as minute crystals. Large deposits are considered to be the result of magmatic segregation, as in the Urals, and Northern Sweden, in Kiruna and Gellivaare.

[25] The series of letters to and from Lister kept in the Duke Humfrey Library at the Bodleian illustrate that Lister was receiving large amounts of mineral samples from colleagues, some of which he passed onto the Royal Society Repository. MS Lister 34 in particular shows that iron samples were being sent to him by Francis Jessop. For instance in Letter 80, fol. 186r, Jessop wrote to Lister:

> ....I have gotten together some two pices of severall oares & that is all. I have some pieces of my lord devonshires copper ore, a piece of Iron ore which I call Iron mine of which they say they can make Iron with more ease than ordinary, if I be not mistaken (for it is a great while since I first received it) they told me it would melt downe into good Iron with the first heat. I have some pieces of lead ore with pebles sticking in such a manner in ye very body of the ore, that I am apt to believe that lead ore doth grow in the earth & hathe growne about these stones. As also a piece of very pure ore wch they tell me yields 3/4 lead which growes betwixt a rock of gritstone on ye one side & a bed of fullers earth, as they call it on the other which I take to be nothing but calke. The gritstone rock itselfe is mingled per minima with ore. two small pieces of Welsh ore, a little piece of northern ore, steel ore which is not easyly but they fancy it conteines much silver in it. That which you call ye ascyltos hath one quality which it may be you tooke no notice of, being bruised small it turneth red ye dust of it coloreth things red.

The result of this correspondence was published in: "An Account of Two Uncommon Mineral Substances, Found in Some Coal and Iron-Mines of England; as It Was Given by the Intelligent and Learned Mr. Jessop of Bromhal in York-Shire to the Ingenious Mr. Lister, and by Him Communicated to the Publisher in a Letter of January 7. 1673/74," *Philosophical Transactions* 8, 100 (1673), pp. 6179–6181.

type of vein. Yet our type of vein is not entirely lacking in this property. Finally this stone of ours is very heavy, as are most of the ores from which iron is smelted. This stone is found near a ridge in the chalk hills of Yorkshire,[26] not far from a little town called Warter.[27]

§ III. In the same chalk hills surrounded by this enormous border another red-colored vein of iron reveals itself in huge numbers of places.

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At times it is quite soft, rather like a kind of clay, and at other times it is harder, and also traces red lines when it is pressed on paper. Unless it is well-heated it does not attract the magnet, but in this ore too, which is only moderately rich in iron, there are what I might call kernels or roundish knots of iron, like mustard seeds, but the size of a boy's head. These are as hard as marble, and can easily be polished and smoothed so that they shine. If they are broken they reveal a smooth and flat surface, they have a reddish-black color. When held they do not stain the fingers red. When they are crushed to fine powder, even in their raw state, a good magnet attracted them.

Likewise in the same ore you will find some softer stones made up of layers, which are also red.

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Haematite. § IV. I move from cretaceous rocks to the lead-bearing limestone of Westmorland.[28] These too are productive of several kinds

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[26] The Yorkshire wolds

[27] Warter, is a parish in the wapentake of Harthill; 4 miles ENE. of Pocklington. In MS Lister 1, "A Method for the History of Iron" which served as a series of notes and a draft for the *De Fontibus*, Lister wrote on folio 5: at Lawnesborough (Londesborough) in ye Woldes of Yorkshire in ye midle of ye Towne, there is discovered neer day ye same red scar; wch is iron stone. But besides in this Vein are great quantities of certain black knotts or of a dark-iron color; ye grain of ym when new breaks is smooth as a flint. But some of ym are full of little round and very small grains, or such of the same metal; wch grains are as if wer inclosed in ye greater knots for when any of ym fall out, they leave spherical cells in ye stones. N.B. Those black knotts are ye best iron stone. I have not yet mett withal in England, for breake ym to a coarse powder and ye Loadstone doth manifestly attract ym crude and before calcination, wch cannot be said of any else. Ye same vein appears again at Wighton alsoe above Pocklington, going up to Warter. Again yr same veine is pretie broad at spitere cliffe.

[28] Westmorland, county in N. of England; bounded NW. and N. by Cumberland, NE. by Durham, E. by Yorkshire, and S. and SW. by Lancashire and Morecambe Bay. There were many hematite mines in Westmorland during the Industrial Revolution, the hematite famous for staining the miners' skins and clothing deep red. Hematite contains

of ferrous substances, but they have a particular ore, which is called haematite.

This stone too is found there with varying appearances. It therefore received various names from the ancients, and even our fellow-countrymen. At times, like fused antimony, it develops a long drop-like formations, which face some central point, at other times it resembles bunches of grapes so that it is called botrytes [*Greek for 'bunches of grapes'*].

At times it exhibits a smoothness like pure silk, an extreme smoothness which is perceived by the fingers like a piece of lard. I have observed all of these accidentals within one and the same stone; so diverse is the nature and in consequence the names of this ore.

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In addition this same haematite is at times soft, like pure loam, and can be handled just like clay. At times it is haematite of the purest kind, at other times it is mixed in very small quantities with lead-bearing limestone.

Yet all these ferrous ores, when rubbed on paper, freely trace a vivid red line, with a certain gleam, like that of some fused metal. In this respect haematite (to pass an incidental observation) resembles that unnamed underground substance, which we Britons call black-lead, which as far as I know is found nowhere else in Europe except Westmorland, where haematite also greatly abounds.

This ferrous ore has its own particular excellence, that outstanding iron is produced from it without any previous '*fusio in Regulum*.'[29] Even mere heating over a fire is sufficient to harden it into iron with blows from a hammer.

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There exists today in the aforesaid little town in Westmorland a furnace made solely of this substance. But the stone itself is mined near Furness Fell and elsewhere in the same county.

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iron (III) oxide, Fe_2O_3. A more detailed account of this type of hematite can be found in "Extracts of Some Letters from Mr. John Sturdie of Lancashire concerning Iron Ore; and more Particularly of the Haematites, Wrought into Iron at Milthrop-Forge in That County. Communicated by Dr. Martin Lister, F. R. S." *Philosophical Transactions* 17, 199 (1693), pp. 695–699.

[29] The regulus is the pure form of the metal, so Lister is saying that the pure iron could be made just by heating and condensing it, as the ore had little impurity.

But the magnet fails to attract even this ore of iron to itself, even though it is very rich, unless it is first well-heated.

§. Likewise I possess another type of haematite greatly praised by our metallurgists from Wales. This however has a noteworthy hardness and a color ranging from red to a suggestion of blue-black. With its red hue it shows a similarity to a kind of selenite,[30] and likewise it does not trace a red line, nor is it attracted by a magnet in its raw form. The turning of this stone too into iron is said to be easy.

The vein of iron in sand. § V. The following veins of iron are nowhere found in loose sand or sandstone.

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These veins have an almost light blue-black color, which at times approaches a redness. The stones are sometimes fissile, or flat; at times they resemble a concave tile; from time to time they are solid smooth stones, whilst at other times they are mixed with the sand. If they are hard, they could in some way be used as substitutes for emery. At times the same sandy veins are nothing but soft loam.

Aetite. Aetite is found in those stones which are concave, and contains within itself a whitish or yellow inner part.[31] These stones however are naturally uneven and rough, and a certain attractiveness is added to them when they are polished.

Loamy fossil ochre. In sand the metallic form of loamy ochre is not infrequently found, as at Santon Sands in Lincolnshire, where once a great quantity was mined from a vein of the same substance.[32]

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[30] Selenite (chemical formula: $CaSO_4 \cdot 2H_2O$) is a hydrous calcium sulfate, meaning it is composed of oxygen, sulphur, hydrogen, calcium and water. It is basically a glassy, well-crystallized form of gypsum and is often referred to as satin spar. From "Selenite" in *Wikipedia: The Free Encyclopedia* http://en.wikipedia.org/w/index.php?title=Selenite&oldid=69916592. Accessed 22 August 2006. Iron oxide can add red tints to selenite, which is probably the phenomenon to which Lister referred.

[31] "Aetites, also called Aquilaeus or eagle stone, is a stone said to have magical properties, particularly connected to childbirth. It is mainly composed of iron oxide, with some flint and alumina, and is hollow with a loose nodule which rattles around inside. The stone was said to be found inside the stomach or neck of an eagle, or in its nest, hence its alternative name. It was said to heal epilepsy and prevent premature birth. Worn on the arm it was said to prevent miscarriage and worn on the thigh it aided childbirth." See "Aetites," in *Wikipedia*, http://en.wikipedia.org/w/index.php?title=Aetites& oldid =44547362. Accessed 22 August 2006. For more on the eagle-stone, see A.A. Barb, "The Eagle-Stone," *Journal of the Warburg and Courtauld Institutes*, Vol. 13, No. 3/4 (1950), pp. 316–318.

[32] Here Lister was most likely referring to iron ochre, a "mixture of silica, clay, and various oxides of iron. In red ochre the oxide is simple Fe_2O_3; in yellow ochre it is

These veins also betray themselves by their weight. But unless they are well burned and subjected to much manipulation in fire they are not attracted by a magnet.

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But when this is done, they yield wholly to the magnet.

This underground substance is found almost anywhere where sand occurs naturally. I could certainly name very many such places, but I am content with a few in Yorkshire, near Kirkham and Weston, where a great many stones are to be had which resemble aetite, but are for the most part solid.[33] Likewise I found some from time to time near Wentbridge, where one vein has an outstanding purple hue, and certainly to the south of the little town on the very ridge of a hill.[34]

Metallic iron in the neighbourhood of fossil coal from pure layers of rock, both solid and widely spread. §. VI. The subterranean forms of iron, from which iron is melted down in many localities in England, are by far the most common of all. Those veins which are found in the neighbourhood of, and between, fossil coals are wide-spreading, and form actual layers of rock, as of course one layer is cast over another.

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This stone possesses the hardness of marble, and is of a kind that can be polished. And in particular if some powered shells are mixed with it is greatly sought after by our fellow-countrymen for polishing.

It has a color ranging from dark blue to blackish, or a suggestion of blue-black.

From these layers other solid subterranean types are found which extend to huge dimensions. Elsewhere there are others made of largish

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$Fe_2O_3 \cdot H_2O$." See John Ecklund, "iron ochre," in J. Ecklund, "Salt," in *The Incompleat Chymist: Being an Essay on the Eighteenth-Century Chemist in His Laboratory, with a Dictionary of Obsolete Chemical Terms of the Period*, Smithsonian Studies in History and Technology, Number 33 (Washington, D.C.: Smithsonian Institute Press, 1975).

[33] Lister was going on his geological expedition near Kirkham Abbey, Yorkshire, near what is now known as the River Derwent. The ruins of this twelfth-century Augustinian Abbey are situated close to the river. Weston is a parish town, also in Yorkshire in the West Ridings, and by the nineteenth-century was the site of an old quarry, which may have been the source of mineral wealth that Lister describes.

[34] This is Wentbridge, and Lister is describing the wearing of the Great North Road, or Watling Street, the primary Roman Road. The water is the River Went. The underlying geology of the site is Middle Coal Measures sandstone overlain with river alluvium.

squared stones, as though they were hand-made by some industrial process, which are joined together like paving stones. They are also called 'gallystones' by our well-diggers, for some reason or other.[35]

Some small examples of these squared stones can be found in great quantities on a certain little farm called Kelfield near Pockley in the neighbourhood of Helmsley in Yorkshire; at all events it is the best subterranean form of iron.[36]

Likewise there are other roundish balls, which our fellow-countrymen call 'hareballs',

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which are all sizes ranging from the common nut to a millstone.[37]

Many places in Yorkshire have gained a reputation from these veins, such as Bentley in the neighbourhood of Black Barnsley and Adderstone etc.

These ores however are smashed into tiny bits and heated before being melted, and in the melting are mixed with limestone,[38] then the ore is poured into the purified liquid and hardened into iron by many violent hammer blows.

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[35] I have not been able to trace the source of the term "gallystone."

[36] Helmsley is quite near Rievaulx Abbey, where the Cistercians made a good deal of profit mining iron and lead. The Department of Archaeology at the University of Bradford has done several site digs of bloomeries or iron furnaces in the area. According to their researchers, "Over the last eight years ironworking sites in the Rievaulx and Bilsdale area have been surveyed. Numerous early 'bloomery' sites have been identified; many of these probably date from the medieval period. These bloomeries were small furnaces, cylindrical in shape, about 0.5 m in diameter and probably less than 2m in height. These furnaces were built of clay, fuelled by charcoal, used local ore and were blown by hand or foot bellows. There is evidence of continued ironworking after the dissolution of Rievaulx Abbey at Laskill in Bilsdale using 'high' bloomery, and later charcoal blast furnace, technology. The blast furnace was built adjacent to the Abbey ruins in 1570, and was closed circa 1670." See http://www.brad.ac.uk/archsci/depart/resgrp/amrg/NYM.HTM. Accessed 22 August 2006.

[37] Also known as "ball mine" According to the *OED*, a kind of iron ore found in rounded lumps or nodules.

[38] There are many impurities present in iron ore, mainly sand (silicon dioxide, SiO_2). This is removed by the limestone. When the limestone is heated in the furnace it decomposes to lime (calcium oxide) and oxygen. This calcium oxide reacts with the sand to produce slag, calcium silicate, $CaSiO_3$, which flows away, allowing the iron to be extracted from below.

Likewise if these ores are purified by repeated melting, they produce a much more durable and excellent iron, as is proved by the iron workers near Kirkstall Abbey in Yorkshire.[39]

In the melting itself a certain green substance, which is truly glass-like, and no longer capable of being dissolved again, floats on top of the metal itself.[40]

But the magnet shows no recognition of any of these ores, unless they receive a thorough and long-lasting heating.

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§ VII. *Ferrous ores found in marl.* Ferrous ores found in Sussex,[41] from which the King's artillery is cast, are as follows:

1. The one which my fellow-countrymen call 'Ball-mine', that is, spheroid ore. It is found beneath a certain whitish clay. This stone however is like a whitish kernel covered by a red husk. These, although the best form of ferrous ore, are quite rare. When heated for a long period, they become entirely red, and only then are attracted by a magnet.
2. A red ore marked with white veins, lies about three feet under the type described in note 1.
3. A third type also reddish, lying the same depth below the second type. It is called 'pettee mine' by our fellow-countrymen, possibly

[39] Kirkham Abbey, Yorkshire, is near what is now known as the River Derwent. The ruins of this twelfth-century Augustinian Abbey are situated close to the river.

[40] Green glassy slag is typical of a furnace using limestone as a flux. See the *Mining History Pages* at http://www.people.ex.ac.uk/pfclaugh/mhinf/bp_iron.htm. See also http://iron.wlu.edu/ or *The Smelter's Art* for iron production methods done with bloomeries and a discussion of slag.

[41] Iron production in Sussex centered about the Weald, hilly county south of London that contains a band of iron ore which has high phosphorous content. The Romans began working iron there, supplying the metal for the army and northwest fleet, and iron production continued in the medieval and early modern period with iron bloomery and then blast furnaces. As Richard Cowen has noted, "in 1242 the Archbishop of Canterbury was asked to provide 8000 horseshoes and 20,000 nails from his estates in the Weald, to be delivered to Portsmouth, almost certainly for Henry III's campaign in France that year. The largest order for which we have records was in 1253, when the Sheriff of Sussex had to provide 30,000 horseshoes and 60,000 nails." With the military aggression of Henry VIII, "by 1574 there were 110 furnaces and forges in the area, producing several thousand tons of iron, including several hundred tons of cannon." By the seventeenth century, iron-production in the Weald declined due to competition from cheaper Swedish ore. See http://www-geology.ucdavis.edu/~cowen/~GEL115/115CH10.html. Accessed 23 August 2006.

because it has little whitish veins which are fewer in number and darker. It also has red layers.

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4. The fourth and lowest ore: these last three are laid down like paving stones: the two earlier ones are softer, the last two are harder, and since they melt more easily they are more productive of iron. Likewise this fourth ore has red layers, interspersed with ochre here and there as is the case in certain sandy veins of iron. In addition the last two are believed to be hot, and are more easily cast than the others, no doubt on account of the sulphurous element of vitriol.

Yet if ever these ores are found in bluish marl, they are scarcely able to be processed. It is credible that this fault arises from an excess of vitriol. But in white marl they are of excellent quality.

Ochre which is turning red arises from pyrites. § VIII. Ochre which is turning red or dark yellow is usually produced from pyrites, and is certainly found in most inky-black mild acids, is pure metallic iron.

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After the requisite heating it is wholly attracted by a magnet.

§ IX. *Pyrites*. One pyrite found in England is the very purest metallic iron, and should be considered most productive when it forms a vein of iron. It is distinguished from the other veins of iron because it is vitriolic *par excellence*, and almost gleams with a certain silver or golden shimmer. Likewise when it is struck by steel it produces sparks if it is hard. The moderns call the stone marcasite after the Moors. It is found in mines of all metals and discovered in great variety. Some is gold, and some is silver, as far as color is concerned; it may be smooth, fluted, soft, hard, of the utmost purity, and a unique ore, which is found mixed in varying proportions, now very small, now fairly sparingly, with lead, tin, bronze and alumen ore.

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Likewise it is to be found with black flint, fossil coal, limestone, chalk and many other underground substances. Some are without exception cube-shaped, others resemble layers of parchment. Some have tuberlike roots, others are like round hail-stones or balls of any size; some are polygonal, others like honeycomb.[42] It would be an endless task to describe all their individual differences. Yet I should like to add a few things about some of them which I have observed personally with careful investigation.

1. Pyrites can be found which are internally fluted, roundish, tuber-like on the outside and at times polygonal. Their flutes point inwards towards some central point, like fused antimony, or like the description we gave above about a certain haematite.

Among these however there are some which produce their own vitriol in plentiful quantities in moist places. They are found wherever cretaceous stone occurs, but usually

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in a scattered vein.

They are called 'rust balls' by our fellow-countrymen, at least in the quarries near Foulmore in Cambridgeshire, and likewise everywhere in the Yorkshire Wolds. Concerning these Glauberus tells some amazing facts in his own fashion.[43]

2. Other pyrites of a golden color are found in the same locality, and especially in lead bearing rocks and among fossil coals, which are cube-shaped and in some way full of corners.
3. At times, especially where fossil coals abound, and elsewhere, huge layers of rock are found consisting of nothing but pyrites; some are thin, but others are thick, a foot and a half and more, as I have observed amongst other places near Bentley Hall, in the aforesaid valley of Latherden, near Craven.

[42] Pyrites are a pale brass-yellow mineral, the bisulfide of iron, FeS_2. It occurs most commonly in crystals (belonging to the isometric system and usually in the form of cubes and pyritohedrons) but is also found in massive, granular, and stalactite form. As described in chapter three, it often has a vitriolic varnish, and was used in the production of sulphuric acid. Two pieces of iron pyrites, which, when struck together, throw off a shower of hot sparks that will last for at least a second. Iron pyrites and steel will also give a hot spark. Pyrites were used as well as flints in early modern wheelock arms.

[43] See chapter two for an analysis of Glauber and his "discovery" of *sal mirable* and its relationship to pyrites and vitriol.

Furthermore in these layers of pyrites some stones are soft and fragile, but others are very hard

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and clearly flint, so that they can be pierced only with much difficulty, which causes great inconvenience to metal-workers, as is the case in the coal mines near Colne in Lancashire.

4. Likewise other pyrites are found in the shape of certain tiles among the rocks in Derbyshire, where they are commonly called chertstones.[44]
5. The pyrites found in tin-mines are called mundy[45] and maxy[46] by our metal-workers, but they are none other than common pyrites, although they are a metallic iron conspicuous for its golden or silver splendour.
6. Likewise I have obtained other pyrites, which possess an elegant silver sheen, in the coalmines not far from Wakefield.
7. Likewise I have obtained golden pyrites mingled in the middle of black flint. This stone is however only very rarely found in our chalk hills.

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8. Likewise I have obtained pyrites mixed in various ways with lead ore. At times it is entirely covered with pyrites as though by a husk. At times there is very little mixing between the substances, but in such a way that at times even to the naked eye the pyrites is inserted like a knot in the other ore. At other times one can uncover this mixture only with the help of a magnet, and then only after the requisite heating.
9. The same conclusions should be drawn about copper ore, but on account of their mutual similarity it can scarcely be discerned by the eye. Yet if the stone is heated and a magnet is applied it can easily be seen.

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[44] Clearly this is not the use of chertstone in its usual sense. The *OED* notes the original meaning of chert is "resembling flint." Perhaps the tile-like shape of the stones led to the Derbyshire term.

[45] From mundic, defined by the *OED* as "Cornish miner's name for iron pyrites, or pyrites in general." The word was first put into use by Nehemiah Grew in his catalogue of the Museum of the Royal Society, *Musaeum regalis societatis*. . . . (London: W. Rawlins, 1681), vol. 3, p. 1. He also called marcasites "yellow mundick."

[46] According to the *OED*, a corruption of the word marcasite, in use in the *Philosophical Transactions* by 1671.

10. In England no pure silver ore has yet been found, as far as I am aware, but from every lead ore without exception, or at least from thirty mines at least, silver can be drawn out—and I speak from experience.[47]

I am however sufficiently convinced by very many experiments that lead ore is mixed with veins of iron in only the smallest quantities, as we have noted above.

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11. Likewise the aluminous rocks near Whitby and elsewhere in Yorkshire abound in pyrites, so that they subsequently set themselves on fire spontaneously after the application of only a little heat. The abundance of sulphur found at the tops of piles of burnt rocks gives plentiful testimony to this fact. Why, hardly any aluminous ore can be found in Britain which contains no pyrites, and this is obvious even to the naked eye in almost every case from the golden sheen.
12. I omit wood-based pyrites from Ireland[48] (and the fact that wood from an ash tree is already a magnet) since it also to be found with the hardness of marble near Harrogate in Yorkshire. Likewise conchitis of many kinds, and many other underground substances stained with pyrites.[49] This is as much as I wish to say about my observations on pyrites.

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[47] In MS Lister 37, Duke Humfrey Library, Bodleian, Lister exchanged a series of letters throughout September to December 1701 with one John Cay from Newcastle about the process of extracting silver from lead. Lister advised him that silver was richest in a lead ore called "potter's ore," which is galena (lead sulphide) a lead ore found in Cornwall, England, and used by potters to give a green glaze to their wares; Indeed, galena deposits sometimes contain significant amounts of silver as an impurity, and galena ore is often the most important source of silver in mining. Cay continued to write Lister about mineral waters, and some of his work was published in "Part of Two Letters from Dr. Cay, to Dr. Martin Lister, Fellow of the Colledge of Physicians and Royal Society; Concerning Some Mineral Waters," *Philosophical Transactions* 20, 245 (1698), pp. 365–370. Cay affirms in these letters that there was no vitriol in English spa waters, indicating the pervasive character of this debate.

[48] Here Lister is referring to petrified wood. Indeed much petrification occurs as iron dissolves in ground water when no oxygen is present. The ground water becomes re-oxygenated as it moves though the tree trunks causing oxygen to bond with the iron. The iron then precipitates to produce a solid form of iron called hematite. This hematite is incorporated into the log's cell walls. Sometimes the wood can be further affected as hydrogen sulfide from decaying organic matter interacts with iron in the cell walls, forming pyrite.

[49] Conchitis were fossilized conch shells. Lister founded the science of conchology and conches were important in his theories about the origins of fossils. As the *Dictionary of Scientific Biography* stated: "He noticed that the distribution of fossil shells

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The magnet has given me a clear demonstration that each and every one of these substances, insofar as they are pyrites, are, after then requisite heating, the ore of a single ferrous substance.

Chapter III
Concerning Limestone

In the previous chapter we described the various kinds of iron ore and now we must explain limestone in a few words.

Compared with the amount of this stone there is little iron ore in England. For I believe that limestone forms by far the largest part of its hills and soil.

But in my opinion there are very many different types of this limestone, which I do not have time to describe at greater length. There is however a common feature to all of them,

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that they can be burnt to form quicklime.

Likewise the appearance and internal features of limestone are usually smooth and tending towards a polished look.

In this category are counted white chalk, the white clay formed from this, and flints which are usually found naturally occurring in chalk hills. For when they are set on fire and they split apart because they develop out of water. The same is true of selenite and gypsum and its many different types; the same applies also to stalactites, or any stone made from water. We have now taken account of this common feature, &c.

is correlated with the distribution of rocks, and he believed that this was an argument for their geological origin. In tracing the distribution of one particular fossil through a certain rock formation across half of England, he came close to a stratigraphical use for these formed stones (being interested in the classification and distribution of rock types, Lister in 1684 made the first suggestions for the compilation of geological maps). He explained the growth of fossils in rock as a complex crystallization from lapidifying juices found naturally in the earth. Living mollusks were also able to secrete such juices, from which, by a nonvital process, their shells crystallized; in fact he tried to grow such shells from the body juices of mollusks." Jeffrey Carr, "Martin Lister," in Dictionary of Scientific Biography, ed. Charles S. Gillespie (New York: Scribner, 1970–1990), 18 vols. http://www. chlt.org/sandbox/lhl/dsb./page. 415.php. Accessed 17 October 2006. See chapter three for more discussion of pyrite's role in fossil formation.

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Chapter IV

A brief account of certain mineral springs in England: in which all the crystals of salt are related to common salt alone and nitre of lime. Soil however is related to ochre and limestone.

The mineral springs of England are almost infinite in number and found everywhere. But I have undertaken to give a description of a few in the hope that the rest may be understood following the example of these. Since however in the case of those springs of which I have had personal experience only two kinds of salt have been found, that is nitre of lime and common salt, I shall begin with those, which appeared to contain only the one of those two salts.[50]

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Stinking salt springs. 1. And so the salt spring near Harrogate,[51] which is commonly described as sulphurous and stinking, in the neighbourhood of Knaresborough in Yorkshire, contains no other mineral save common salt. The reason for this may be that salt of this kind is generally produced without any, or, at most, a very little soil, and so it can be mixed with the waters by itself. It contains two ounces of salt for every eight pounds of water, and so is that much heavier than ordinary water.

Saline springs of this kind are very frequently to be found in the northern hilly parts of Britain. I shall indicate some of those which I have seen personally. There is one in the town of Long Addingham, to the left in the high street; there is a second near Skipton in the same region, and a third near Braughton, both easy to spot while still travelling.

[50] This is another reference to Lister's insistence that vitriol salts are not found in English waters.

[51] The spa waters at Harrogate were discovered in 1571, and the waters are iron and sulphur-rich. The Tewit Well at Harrogate, named after a church, later replaced by Christ's Church in Church Square, was the discovery of Dr. Michael Stanhope and featured in his publication "Cures without Care." For more about Harrogate and Stanhope, see Noel G. Coley, "Cures Without Care: "Chymical Physicians" and Chemical Waters in Seventeenth-Century England," 23 (1979), *Medical History*, pp. 191–214. See also Michael Stanhope, *Cures without Care, Or a Summons to Those who find little to no helpe by the use of ordinary physicke to repair to the Northern Spaw*… (London: William Jones, 1632).

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There are very many other well-known ones in the meadows of Marton and a certain country house called Crickle Grounds, so many indeed that I must remain silent on the them. And almost all of them have a putrid sulphurous smell. Why, in particularly wet and cold weather the stinking smell of these springs can be perceived at quite some distance, and I shall explain the reason below.

Yet certain springs, even saline ones, are inky-black. From these common salt is usually boiled down. There is a clearly explained account of these to be found in the Acts of the Philosophical Society of London (*N.N.* 53, 54.142).[52] The following facts however have been omitted by others.

1. The water of these springs has a particularly strong smell of sulphur if the wells have been undisturbed for a little time. Indeed meat recently slaughtered and then quickly boiled in water of that kind, say, within one day, usually becomes rotten.
2. Among those springs whose waters grow inky black with the addition of gall-nuts are to be numbered the wells

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at Nantwich, Middlewich and Northwich in the county of Chester and also Weston in Staffordshire and those others at Droitwich[53] in Worcestershire. These, I say, all grow inky-black with the addition of gall-nuts.

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[52] William Jackson, "Some Inquiries Concerning the Salt Springs and the Way of Salt-Making at Nantwich in Cheshire; Answer'd by the Learned and Observing William Jackson Dr. of Physick," *Philosophical Transactions* 4, 53 (1669), pp. 1060–1067; "An Appendix to the Discourse Concerning the Salt-Work, Publisht in Numb. 53. Communicated by the Same Doctor Jackson, in a Letter of Novemb. 20. 1669," *Philosophical Transactions* 4, 53 (1669), pp. 1077–1079. Jackson indeed boiled down brine from the Nantwich springs, even testing the amount of salt he obtained during the full moon and the change of the moon, as well as comparing amounts received during rainfall and droughts. For the beliefs about the connections between the lunar phase, tides, and salts, see chapter three.

[53] Droitwich in Worcestershire continues to have an annual "salt day" to celebrate its status as a popular spa town. The natural Droitwich brine contains two and one-half pounds of salt per gallon—ten times stronger than sea water and only rivaled by the Dead Sea.

3. A sort of white sand, and likewise the white deposit which adheres to the bottom of pitchers is deposited from them, especially if the waters are boiled in iron vessels. This is also true of sea-water, whenever it is similarly boiled down to salt. Yet neither sea water itself nor the inland wells at Droitwich produce any stony sand when they dry out by themselves or are boiled in a leaden vessel.[54]

N.B. If the white sand, which is deposited from the waters described above in the course of boiling, is in some way soaked in rainwater and kept in a wet condition, after a few months it will produce new crystals for you which closely resemble alumen. I have accurately drawn a most elegant example of these of the

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correct size and shape, see figure 7. The base of this is wholly flat, and it also has a flat vertex which is much broader. The circumference which contains the whole is octagonal, but I could scarcely see the nature of the flat surfaces of which each side of it consisted. It has a salty-bitter taste. Likewise if the crystals were pressed together in the month of July, then a few months later they entirely lost their shape and turned without interference into a white powder very like the soil or white sand from which they were produced. Yet when they were again dissolved in the same water they again formed crystals, and again and again shortly afterwards turned into white sand. This happens individually only to crystals of this kind, as far as I have been able to observe.

II. *Petrifying Springs which turn to stone*. The most famous petrifying spring is near the town of Knaresborough, also in Yorkshire.[55] The crystals are of exactly the same kind as those we described above when dealing with calcarious salt.

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[54] An extended discussion of this phenomena by Lister is discussed in his *Philosophical Transactions* article: "Certain Observations of the Midland Salt-Springs of Worcester-Shire, Stafford-Shire and Cheshire. Of the Crude Salt, Which Grows from the Stone-Powder Dejected by the Said Brines in Boyling. Of the Specifick Difference betwixt Sea Salt and Common Salt. A Way (Which Seems to be the True Method of Nature) of Distilling Sweet and Fresh Water from Sea Water, by the Breath of Sea Plants Growing in It. That This Breath Probably is the Material Cause of the Trade or Tropick Winds. In a Letter to the Publisher from the Learned Martin Lister Dr. of Physick of the University of Oxon," 14, 156 (1684), pp. 489–495.

[55] Knaresborough Spa was a rival to Harrogate, and both spas were in the same region.

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Yet if the water of this spring is boiled dry by a violent heat thin layers of whitish limestone are produced in abundance. By chance this phenomenon became known to me in another way; I kept in my house some glass jars of this spring-water from the month of August right up to the mid-winter. I saw no change in them until the glass vessels had been broken by a hard ice. But then I noticed a very white stony dust in plentiful quantities had been deposited. This was a snowy white powder, more attractive than one could belief, and bereft of any salt. That is because the powder, which is deposited without any external agent, is the same as the layers formed by boiling the water dry.

From about sixty pounds of the water of this spring I obtained about two and a half ounces of powdered limestone, and about a drachm of salt, so they were in a proportion of one to twenty.

I then performed the experiment afresh with about 120 pounds of water.

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I obtained about five ounces of limestone, but at least two drachms of salt.

I tried each again in mid-summer. I drew the former water from the spring itself, but took the latter water as it fell from the rock. We were able to discern no difference whatever in either, and I obtained a small amount of salt in proportion to the lime. Some British writers loudly declare that this is not so, no doubt so that they can lend credibility to the 'Corrosion of Helmontius.'[56] But he is wrong.

Yet my good friend Frencius[57] was right when he remarked that from this water, when it is boiled dry, only some stony powder remains, and

[56] Here Lister argues against the Helmontian belief analyzed in Helmont's *Oriatrick, or Physick Refined* that vitriol and its acid, the "hungry" "corrosive" or "hermaphroditical salt" was the seminal consituent of mineral waters and metal ores. See chapter three for an extended discussion of this issue.

[57] Frencius is apparently the chymist John French, who wrote extensively on spa waters in Knaresborough. See John French, *The Yorkshire Spaw, or a treatise of four famous medicinal wells…near Knaresbrough in Yorkshire, etc.*, (London: E. Dod and N. Ekins, 1652). French also was engaged in preparing artificial mineral waters to mimic natural ones at Tunbridge and Epsom. See John French, *The art of distillation; or a treatise of the choicest spagyricall preparations performed by way of distillation…etc.* (London: E. Cotes, 1651). See also Noel G. Coley, "Cures Without Care," pp. 191–214 for a discussion of these artificial spa waters.

omitted to mention any salt, for in a moderate quantity of water there appeared to be none.

When milk is boiled it also coagulates, no doubt because of the presence of a little salt of nitre of lime. This too is heavier than common water.

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§ There is a certain spring of the same nature, and not so obscure, by the banks of the river Ouse near Clifton, one milestone from York. But its water does not become inky-black when galls are added. It does however produce salt of lime and likewise white powdered limestone.

§ I experienced the same phenomenon in some well-water from my house, when I lived in the central street of York which is called Stonegate. When it was boiled slender slivers of limestone floated on top, and produced the same crystals on the final evaporation.

§ But, note well, there are some wells within this city which produce genuine, combustible saltpetre along with the rest, but it is simply an accidental property, and is by no means a natural characteristic of water, when saltpetre is produced from animal excrement.

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III. *Cold inky-black springs, which contain only one of these two salts, that is, salt of lime*. The mineral spring at Scarborough, which is inky-black and cold, contains only one salt, and that in large quantities, namely calcarious salt.

Furthermore the water of this spring produces both ochre and whitish limestone. According to my good friend Wittius in every six pounds of water from the Scarborough spring you will find about three drachms of contained substances.[58] And in my experiment I obtained about an ounce and a half of content from sixteen pounds of boiled water.

§ The inky-black water in the neighbourhood of Knaresborough near Harrogate, which our fellow-countrymen commonly call 'the sweet spring', produces the same salt of lime, but only a few grains in very many pounds of water. In 80 pounds of water 90 grains of content

[58] Another reference to Robert Wittie, *Scarbrough spaw; or, A description of the nature and vertues of the spaw at Scarbrough Also a treatise of the nature and use of water* (London: Charles Tyus and Richard Lambert, 1660).

remained. (According to Frencius) the water is more powerful, owing to the spirit of metal ore,

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in the ice of winter, and likewise in summer more so in the morning than at noon.

§ In the inky-black spring near Malton in the same county the same salt of lime is found. The same water also produces ochre and limestone in abundance. Yet some British writers boldly assert the opposite. Yet they are wrong. Add to these *a certain feather-like alumen*.[59] It is of course the same substance as one may from burned sulphur and pounded pyrites.

From the results I obtained matters concerning the water of this spring were as follows. Ochre is of course the first thing to be deposited from water when it is warmed. Shortly afterwards scales of limestone are deposited. But when the water is finally reduced to a tiny amount, one may filter off something resembling a feather-like alumen. This is the genuine product of pyrites. Finally however crystals of nitre of lime develop.

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If your progress is retarded by the confused combination of some small crystals, then rub a little vessel with a small amount of alumen; attractive and larger crystals will then form for you to see.

The crystals of this spring may be related to these illustrations (which we have placed above in the table by N. 5) if they are counted individually, as I have taught while applying the greatest care.

Most of them have four flat sides which are long and quadrilateral; at one extremity they end in a point made up of two flat quadrilaterals, whilst at the other they end in a sharp edge, also made up two flat quadrilaterals but invariably placed the opposite way round to the earlier ones. It may be that a fifth flat surface can be seen between

[59] The italics were Lister's, and this is an explicit reference to William Simpson's *Hydrologica Chymica*...(London: W.G., 1669), which contained a description of the spas at Malton and Knarsborough. On p. 135, Simpson asserted that the Malton Spa was thoroughly impregnated with an "essurine alumenish salt" which reacted with the iron in the water. This was in direct contradiction to Lister's assertion there was no hermaphroditical or essurine salt which promoted chymical reactions in water.

them, although it is very narrow, and certainly not armed with a point, in fact it generally shrinks away.

There are other types, for which that fifth side acts as an intermediate stage although it is by far the widest of all.

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There is such great diversity regarding their extremities that some of them appear to be different crystals from the ones they really are.

I now come to those springs, in which both salts are to be found. These are generally hot springs

Inky-black springs in which both salts exist. IV. There are furthermore a few thermal springs, or hot springs, in England. By far the most famous are those inky-black ones which arise in the city of Bath in Somerset. The British writers Jordan[60] and Guidotius give the following account of these waters.

The salts of the hot springs of Bath are nitre and common salt (although, since this nitre is not combustible I have no doubt that it is calcarious). There is twice as much common salt as nitre, ochre and limestone in the water, but not even the smallest amount of the former can be obtained from boiling, whilst the same process produces twice as much of the latter as all the other salts

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It may be however that Guidotius is being over-clever is trying to distinguish between two types of limestone.

We must however listen to him in the case of what follows.

Everything around the baths, especially the stones near the springs themselves, are colored with the deep yellow of ochre. The writer collected about a pound of this genuine ochre, and adds that it is probable that a good part of it evaporates off when the water boils, as is observed in greater detail in its actual vapors.

When the waters of hot springs heat up, they grow inky-black. Likewise these waters grow very hot, and continually produce steam.

[60] Edward Jorden, *A discourse of natural bathes and mineral waters wherein the origin of fountain in general is declared* (London: George Sawbridge, 1631); Thomas Guildott, *A century of observations, containing further discoveries of the nature of the hot waters at Bath* (London: Henry Brome, 1676).

Their heat is consistent in both summer and winter, and so these hot springs must flow from deep down amid black loam.

The hot springs have a deeper color when it is freezing cold than can be produced with galls when the sky is clear. Likewise if the waters are kept for long during a freezing cold period they retain their astringent qualities

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But when the sky is clear they quickly lose this. If the same waters are kept in well-sealed vessels they dye them with galls after a few days.

When the sandy deposit of these springs is lighted, it emits a flame in the dark like that of sulphur. The same should be assumed of the muddy residue. The same result has been obtained from the residue left by the waters after they have been boiled away.

The warm waters of Derbyshire, named after Buxton Wells.[61] § There are other hot springs in England to be found in Derbyshire. Of these I have personally visited those commonly called Buxton Wells, and the waters are indeed warm. The spring itself is remarkable and flows with a large volume of water. The spring itself is enclosed in an vault of adequate size to render bathing more convenient, just as is the custom in those hottest regions which I have observed (I am speaking of Aix in Provence and other places abroad which I witnessed with my own eyes),

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but certainly not in the open air, as is done elsewhere in England at the risk of one's health. As one enters the vaulted area one feels the very warm air, and if a window on the opposite side of the building were not continually, or at least by day, kept open, then some would not easily be able to tolerate the warmth of the place; where there is an opening in the wall to permit the water to flow out one can see the steam, just like smoke, hovering over the surface of the water, even in the days around the summer solstice. It is however true that nobody finds the water very warm when they first immerse themselves; but after a few moments you would be amazed that you did not perceive

[61] Buxton Wells in Derbyshire has springs present where the local limestone rock meets the grit stone, and the water is forced up and along fissures until it arrives at the surface. Its thermal springs were known to the Romans, and it also possessed a Royal Crescent modelled on that of Bath.

the warmth previously, such is the pleasant warmth with which it flows round all your limbs. Likewise if you cast a bare foot over the bubbling water (as happens in several places in the bath) you will clearly feel the warmth. But it steams copiously for most of the year, especially in the winter.

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Besides this, the several springs surrounding the monument are also warm, as are those erupting nearby; one of these is called St. Anne's Well, which if is drunk causes vomiting, depending how much is imbibed.[62]

But here inky-black fountains gush from broken stone[63] under which there are iron fossils; And indeed in the mountains even more distant than a mile, some springs even now are dug out for use; But out of these small neighbouring streams with their sloping banks you will agree consist of clear liquids.

These Fountains are most clear and drop hardly any clay, and are not with the summer heat inky-black, and yet some people clearly taste some metallic iron in the water.

But boiling 32 pounds of the fountains towards dryness, I have not found a single scruple of salt, without the presence of the limestone. For the most part, the salt of the springs, bound up with common salt, was interposed between limestone crystals.

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Chapter 5

Concerning the origin of the substances contained in the medicinal springs of England.

Up to this point we have discussed the salts of the individual medicinal springs, which are only two, namely nitre of lime [nitrum calcarium] and common salt: likewise we have discussed their native earth, namely ochre, and equally limestone. In addition we shall now briefly discuss the origin of all of these, or,

[62] To this day, visitors to Buxton fill their bottles at St. Anne's Well.
[63] Again, a reference to the springs arising from fissures in the limestone.

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if you will, the means by which they are created.

I shall begin however with sea, or common, salt, since its creation is the simplest, and seems to be nothing other than mere melting, since pure salt itself is a purified subterranean substance.

And indeed in our native springs it is found for the most part without any, or with only a very little, residual earth.

But where there is nitre of lime, there is always limestone to be found. And it is indeed corrosive that nitre of lime develops from its own type of stone. The way in which this development occurs must now be explained.

We have explained above how salts, when dug-up, grows into crystals. But there exists a second way in which these develop. If the former occurs in an instant, the latter occurs slowly and in stages, on the analogy of the method by which plants germinate.

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Although nitre of lime is produced in one and the same way as vitriol, even if this substance is nowhere to be found in a complete and perfect state in our medicinal springs, yet, because ochre is the breeding ground, as it were, of this salt, (and we must enquire into this also in this chapter), it will not be irrelevant to explain the origin of each at one and the same time.[64]

The creation of vitriol makes the whole matter clear. Its first eruption from pyrites is exceedingly premature, if it occurs in contact with air; but, as time proceeds, it becomes a little more mature. And yet fully-formed vitriol is not produced from any ferrous stone until after its due maturity which it finally reaches after a continuous period of development.

Newly produced vitriol, I declare, is a kind of alum, that is, it is produced from pyrites like strands of hair.[65] When these strands are created, they are a whitish color, but when they are fully-formed the are green. Then these same strands

[64] This is nother example of the mechanism of *witterung*. See chapter three for more analysis of Lister's belief in the germination of salts via the air.

[65] Literally, trichites—this word derives from a Greek word meaning "hair."

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become thick and strong instead of being thin and weak. It is easy to test this phenomenon by an experiment in the following manner, and indeed to make it occur.

Let drops of spring water fall by design onto clods of ferrous pyrites. If the experiment is performed with care and attention, and without allowing the water to turn inky black with galls, (which we must investigate next), it will produce a whitish salt which grows into crystals of a cubic-rhomboid shape. See figure 6.

These crystals are formed at the first solidification. For if they are taken away and further drying takes place, it will produce salt of another kind, if any at all is to be had, one which is, of course, peculiar to its own spring; this must be carefully observed.

Yet if you were to allow the same water to drip onto the pyrites until it becomes inky black with galls, then it will reveal to you immature salt, which will next solidify into many-sided crystals,

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after the fashion of alum, and of a greenish hue.

But if you were to allow the same drops to be perfectly formed in respect of color and consistency, (I have not yet investigated how many hours and days are required to accomplish this maturity) you will eventually obtain crystals of mature vitriol as described above.

So far we have discussed only the sprinkling of pyrites in air. If however it is kept perpetually under water I am not yet convinced that it will be productive of any salt. Certainly no vitriol whatever will be generated. Meanwhile certain gases, or, if you will, a subtle, sulphurous and inflammable vapour is produced and is continually resolved into its native ochre or metallic iron [metallum]. These are of course the results of, as it were, a miscarriage in the attempt to activate or generate vitriol, or, if you will, unsuccessful attempts made under water. But I shall have more to say about this below.

In the second already mentioned process ochre is created,

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and furthermore it should be understood that it too is being particularly produced in the dissolution of the pyrites under the water.

Add to this that before the actual activation of the vitriol it cannot be elicited even by a violent chemical process [literally: 'by chemical torture']. As Borrichius says in the Doc. Met. page 44, 'If one were to follow up the first burning of the pyrites by immediately applying heat, one would collect very little, if one may believe the words of those who were in charge of this skill.'[66] One must of course wait for it to grow, and this proceeds slowly.

The same phenomenon is confirmed again and again: for no salt whatever grows from limestone immediately after it has been softened [or 'slaked'] by the application of heat, but the same stone produces an abundance of salt, whether it [i.e. the stone] has been untreated or heated, whilst forming the walls or roof of some house;[67] it then grows together to form crystals of its own kind as described above.

The same phenomenon should be supposed in the case of nitre of lime, which in like manner produces

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a snowy white powder, or, if you will, limestone, and vitriol, and ochre, for each reason suggested above.

Yet (so as not to omit what others have observed) fully formed vitriol, cleansed of its ochre, becomes whitish, and the lime of this white salt, or, if you will, the *caput mortuum* formed from the calcinated salt, does not grow red, but becomes whitish, light, and porous, as that most illustrious author our friend Coxius declares. (See Phil. Transactions of Oldenberg, number 130).[68]

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[66] Olaus Borrichius, *Docimastice metallica* (Hafniae, 1667). This was translated into many languages and described the methods of analyzing the most important metals. Borrichius (1626–90) was a Danish alchemist who extracted oxygen out of nitre. Again Lister is trying to deny that vitriol can be produced by heat, or in water in his attempt to show its production was primarily via exposure to air.

[67] Again Lister is describing the production of nitre on walls that were limed and proximate to animal excreta.

[68] Daniel Coxe, "Some Observations and Experiments about Vitriol, Tending to Find Out the Nature of That Substance, and to Give Further Light in the Inquiry after the Principles and Properties of Other Minerals: Communicated by a Fellow of the R. Society, Who Maketh Use of Chymistry Chiefly as Subservient to Physiology," *Philosophical Transactions*, 9, 103 (1674), pp. 41–47. This is in volume 103, so Lister transposed the figures. Coxe mentions on pp. 44 and 45 purifying Dantzick or Hungarian Vitriol, "having powdered it, put in into a slender Curcurbite, plac[ing] it in Water," and keeping "it under an equal Constant Fire three or Four Days. Coxe claimed the "Oker" subsided or precipitated out, and the fluid vitriol above it when it cooled down, crystallized into a pure fiery salt. Coxe noted that vitriolate Water from the Deptford Wells when distilled and evaporated repeatedly also led to a fiery white salt. Most likely what happened is that ferrous sulphate, the Hungarian vitriol ($FeSO_4 \cdot 7H_2O$) when

Yet I reply that chalk, (ibid. Number 142)[69] or limestone formed from pyrites, is used to provide an underground foundation for paving, in those places indeed where vitriol is produced in the open. Therefore one must justifiably ask whether it is the product of some lime salt rather than the dead head of pyrites. Then again pyrites is usually mixed with certain other stones in tiny quantities, and I have carefully kept.

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very many types of these mixtures at my house. Again pure unadulterated pyrites is a form of iron found underground [metallum], as I have suggested above, and when burnt in its entirety it grows red like calcinated ochre and is attracted by a magnet. Furthermore by itself it does not produce limestone. The qualities of that whitish salt are shortly to be examined to see whether or not they can be related to immature vitriol, or to true alum, or to common salt etc.

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Chapter 6

The generation of vitriol, as explained by Helmontius, is refuted, and likewise that other explanation of the Parisian philosophers. Likewise we refute the notion that vitriol may be produced artificially by any process.

I am unhappy with Helmontius' explanation of the generation of vitriol. He would have it that salt is formed naturally in water itself, this salt being variously known as 'juice,' 'a certain universal spirit,' 'the embryonate,' 'the corrosive,' 'the hermaphroditic' (for it is by these and other names that he calls it).[70]

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dessicated loses its color and becomes a white crumbly salt. According to *The Merck Index* (1983), heating $FeSO_4 \cdot 7H_2O$ to 90°C will leave ferrous sulphate monohydrate. The monohydrate will give up its last H_2O by heating to 300°C, which was likely in the range of early modern distillation equipment with constant fire.

[69] Lister refers here to Daniel Colwall, "An Account of the Way of Making English Green-Copperas, Communicated by the Same" *Philosophical Transactions* 12, 142 (1677/8), pp. 1056–1059. Colwall on p. 1057 described how the beds of Deptford to make Copperas were lined with "the rubbish of chalk."

[70] Lister wished to not only to prove the efficacy of *air* or exhalations as the source of chemical reactions and effects but argued against the Helmontian belief that vitriol and its acid, the "hungry" or "hermaphroditical salt" was the "seminal consituent of mineral waters and metal ores." For a discussion of this belief about vitriol, see Emerton, *The Scientific Reinterpretation of Form*, p. 218.

Notes in left margin of page: *The seed of corrosive salt is up to this point still free from any flavours Parad.3—It is the first essence of corrosive things: same passage. Vitriol of Mars is made up of corrosive salt, the embryonates are made up of sulphur and a vein of iron (not iron itself), which corrosive salt, when still volatile, eats away on contact. Parad.4.4.—This salt does not develop within a vein of iron Parad.4.*[71]

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This salt is furthermore able to corrode metal by passing over it, and from this corrosion he claims that vitriol is produced in an instant.

I however counter these claims with the following:

1. It is pointless to state that corrosive salt exists anywhere (since up to this point it has no characteristics, and is not even recognizable).
2. It is clear from the arguments stated above that pyrites can by no means produce its own vitriol from its own waters.
3. It is scarcely credible that a vein of iron can be eaten away by that corrosive salt of its own, since we have proved by experiment that not even haematite, that very soft substance which closely resembles mud, or ochre, can be corroded even to the least extent by even the strongest of the aforesaid solutions (such as the pure aqua fortis, or spirit of nitre, which I have mentioned).

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Perhaps the man is deceived by the fact that iron itself is very easily corroded by certain acids. Yet this is not at all true of any iron dug from the ground [metallum] that I have seen in England up to the present (and I have a collection of very many of these from most parts of England in my house). Indeed not even that excellent Suecicum, which is as good a friend of the magnet as anything else, is corroded by the aforesaid solutions insofar as it is a form of iron dug from the ground [metallum]. I can vouch for this by personal experience.

4. I call upon the experiments described above to prove that vitriol is produced by a continual and slow process of germination, and is not therefore produced in a moment by any corrosion.

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[71] These notes are references to Johann van Helmont's *Ternary of Paradoxes (Parad)*. See Johann van Helmont, *Van Helmont's Works* (London: Lodowick Lloyd, 1664), pp. 693–698 for van Helmont's comments on vitriol.

It is indeed most true that genuine mature vitriol may be elicited in a few moments from hardened iron ['chalybs' usually represents 'steel'] with plain water (and free from foreign droplets and all acid, a fact to which that most elegant writer Bataevus Pecklinus (Purg. Exer.) bears witness).[72]

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I should like you to consider that the substance of iron is dense and weighty, but in its subterranean form [metallum] rather porous. This is proved by the fact that in its cast form it resembles pumice and would be highly fragile, if it were not subsequently hardened by violent blows. Furthermore the hardened iron itself becomes one of the remaining mixed metals, (I speak with the alchemists here). That is (see Agr. On Metals[73]) when iron is hardened and belaboured with blows it is again infused with the fused metal and imbued with it to the greatest extent possible; of course, as a result of an extended period of heating it absorbs into itself a great quantity of fused metal. It must be considered that vitriol is produced in it in the same way as it is produced in pyrites, even if its production is accomplished in a hidden manner within the iron itself.

Indeed it appears that plain water can be elicited from from hardened iron, which is the only substance it contains within it, and that no vitriol whatever arises instantaneously. This can be proved as follows:

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iron filings grow warm when water is poured on them (*see Pecklin. de P. Med. Facul. page 13; likewise Letter 11 of F. Joseph Burlius to Barsbol. Phil. Trans. number 64, page 2082*)[74] just like quick lime, that is, from salt

[72] Lister was referring to Johann Nicolas Pechlin, *De purgantium medicamentorum facultatibus exercitatio nova*. (Lugd. Batav. 4 Amstelod: Apud Danielem, Abrahamum & Adrianum à Gaasbeek, 1672). Chalybeate waters were used in purges, or in weaker doses as aids to digestion.

[73] Agricola's *De Re Metallica*.

[74] "An Accompt of Some Books Dissertationes Medicae Tres: 1. De Causts fluxus Menstrui Mulierum. 2. De Sympathia variarum Corporis partium cum Utero. 3. De Usu Lactis ad tabidos reficiendos, & de immediato Corporis Alimento, Historiae Generalis Insectorum, The Creed of M. Hobbes, Epistolae duae ad Thomam Bartholinum," *Philosophical Transactions* 5 (1670), pp. 2081–2. Lister here is referring to the Danish publication by Francis Joseph Birrhi, *Epistolae duae ad Thomas Bartholinum* [Letters from Burlii to Thomas Bartholin] (Hafnaie: Daniel Pauli, 1669). In preparing an eye remedy,

produced previously and imprisoned, as it were, within it. Add to this that trichites[75] vitriol is formed from untreated pyrites, but that when it is heated vitriol is produced, but in another way which is by no means clear, since the active state which will come from the heat seems, if not to be partially destroyed, at least to be changed in some way. We think the same about iron. Again it is known that the metallic form [metallum] of alum can be heated to a very high temperature (I have no doubt that the same is true of pyrites). Finally, even if vitriol were not produced unless it germinated for some time, as we have shown above, still some hours or days would be required for it to mature, so that I fail to understand how I could deny that, in some experiment or other,

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insufficient time has been allowed for the production of perfect vitriol.

5. Ochre is the subterranean form [metallum] of iron and so contains within it at least the beginnings of vitriol: however thoroughly and carefully you wash ochre, until it no longer produces water inky black with galls, yet gradually, if you place it in some moist place, it will produce vitriol anew from that place, just as though from the greater pyrites.
6. The chemical liquids [liquores chymici] do not separate from the metals which they have eaten away voluntarily, but all the inky black acidic substances reject their ochre at once.

Furthermore these same chemical liquids are able to recommence eating away the metals which they have rejected when heat is applied. We have however witnessed the opposite in the case of acidic substances of this kind; that is, they never again reabsorb

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Birrhi reports pouring a pint of water on 10 pounds of filings of Iron, which "within the space of an hours and a half, ferment and grow hot."

[75] Lister's word for immature "hair-like" vitriol growing on pyrites. In one of his *Philosophical Transaction* publications, Lister commented that both an alum and a pyrite glebe contained in a cabinet "in process of time... shot forth tufts of long and slender fibres or threads... bended and curled like hairs... Herein these Fibres differ'd in Taste: the Alluminous very allomy and pleasantly pungent; the Virtiolick steptique and odious." See Martin Lister, "Some Observations and Experiments Made, and in a Letter Communicated to the Publisher, for the R. Society, by the Learned and Inquisitive Mr. Martin Lister," *Philosophical Transactions* 9, 110 (1674), pp. 221–226, on p. 222.

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their own ochre once they have separated from it even if heat is applied.

§ Likewise I differ from the Parisian philosophers (when they discuss the medical springs of France) in this respect: there is of course some acidic gas, existing of itself, which is as it were the first principle of this substance [vitriol]. But wherever gas, or vapour, of this kind is acidic, then, if it arises from pyrites it is truly vitriolic; if from the metal of alum, aluminous; if from limestone, nitrous in its own way. Why, I declare that there exists a subtle gas proper to all those salts as they develop or grow active, and that it truly shares in the nature and properties of each of those substances from which it emanates.

§ There are however some (Phil. Transact. Number 104) who assert that vitriol can be made from actual common salt.[76] That indeed may be partially true, that is,

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to the extent to which that salt shares in the qualities of vitriol. By chance it is not so different from vitriol in its green color and what one might call its sourness. But it is credible that this common salt is not turned into true vitriol, but has borrowed from vitriol a certain ghost-like similarity.

If however it be urged that when salts of several kinds are dissolved simultaneously in the same water and dried out by heat they each solidify separately with their own shapes and colors, then we admit, 'It is so'. But if some salt has eaten away iron or copper, (just consider, common salt, thinned into gas by the force of fire, or otherwise) then indeed we think that it may to some extent have adopted a different quality by contamination.

But perchance I am quarrelling pointlessly. For I am not convinced about the truth of an experiment which has not yet been made public.

[76] "A Continuation of the Discourse Concerning Vitriol, Begun in Numb. 103. Shewing, that Vitriol is Usually Produced by Sulphur, Acting on, and Concoagulating with, a Metal; And Then Making Out, that Allom is Likewise the Result of the Said Sulphur; As Also Evincing, that Vitriol, Sulphur, and Allom, Do Agree in the Saline Principle; And Lastly, Declaring the Nature of the Salt in Brimstone, and Whence It is Derived," *Philosophical Transactions* 9, 103 (1674), pp. 66–73. This article was likely by Dr. Daniel Coxe.

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Chapter VII

Mature vitriol is rarely or never found in our mineral springs; but pyrites is completely dissolved in inky-black springs.

It is not stated that mature vitriol can be drawn from any of our mineral springs as far as I know.[77] The Philosophers of Paris quite rightly marvel at this after a careful examination of about one hundred mineral springs in France.[78] This has partly been the reason why my fellow-countrymen have quarrelled in such a rude manner, although there are however throughout almost the whole of Britain countless springs of an inky-black nature, from which ochre is spontaneously deposited, and ochre is the authentic product of vitriol.[79]

I can in no way persuade myself that Helmontius ever encountered vitriol of iron in the Spadan Springs of Germany, which are called Pohontius and Savenerius, although he says in all seriousness that he once distilled their waters.[80]

The sum of this matter is as follows: we have pyrites which, when it is contact with air is turned completely by its particular growth into pure vitriol; the same stone, or if you will, metallic ore, when immersed into water, is as it were dissolved into spirit, or a sulphurous exhalation, or ochre. That is to say, it becomes spirit in its whole nature. As a result we are no longer surprised that so insubstantial a juice (which is the very essence of pyrites) is less capable of developing into crystals.

Many phenomena show that pyrites is in its whole substance dissolved in inky-black waters and turns to steam:

1. In the British hot springs (as has been suggested above) whatever is exposed to their steamy vapour is strongly colored with ochre.

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II. Likewise it is well-known in the case of both cold and warm inky-black springs that, when they are collected in bags which are carefully

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[77] Please see chapter three for a discussion concerning the controversy of the formation of vitriol in water.

[78] Another reference to the survey organized by Du Clos.

[79] The nature of this quarrel is evident in the *Philosophical Transactions*.

[80] Johann van Helmont, *Supplementum de spadanis fontibus* (Liege, 1624). Helmont also mentions in the *Ternary of Paradoxes* that "the Danubius, the Rherne, the River Rhoan, Saw, Po, etc." do obtain such a [vitriolic] fountain in their first spring." See Johann Van Helmont, *Van Helmont's Works* (London: Lodowick Lloyd, 1664), p. 694.

stopped up, they preserve for a long time the property they share with gall-nuts of dying, but that when they are kept in open vessels they lose the ability to dye much more quickly; this of course is due to the ochre which is not so much removed and rendered weak and clearly ineffective as a result of the movement.

The same account is true of plants. I once gave a clear example of this in respect of the Bermudan cedar wood *(Philosophical Transactions Number 110)*; I have kept it by me for many years and it has not yet ceased to exude the vapour of its resin from its whole substance.[81]

III. Ochre itself vaporizes, as has been suggested above, because it is particularly at odds with a stony nature, for chemical reasons, since it has a dense and heavy substance.

It is utterly pointless to wait for some spirit to drip out of it, which is of course the task of some kind of fermentation.

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But this spirit of ours, which flies off, is none other than the animating metallic ore.

IV. The taste and smell of waters of this kind is totally lost once the first distillation has begun, before the separation of the said spirit, whatever it is, even if the greatest care is taken, and at the same the ability to dye in conjunction gall-nuts is also lost.

V. Indeed the very property of dying finally expires spontaneously even if the water be kept in very carefully stopped-up vessels, not by reason of the loss of some vapour, but because its quickening motion becomes weak, and then clearly quiescent and dead.

VI. The separation of ochre and limestone indicates that these substances were in the liquid. For they could not be prevented for a moment from sinking down from their salts, which are either not present at all, or present in very small quantities, as has been suggested above. And yet, contrary to the nature of dense and heavy bodies, (as they indeed are), ochre itself does so slowly, especially if the water is carefully kept in

[81] Martin Lister, "Some Observations and Experiments Made, and in a Letter Communicated to the Publisher, for the R. Society, by the Learned and Inquisitive Mr. Martin Lister," *Philosophical Transactions* 9 (1674), pp. 221–226. This is a reference to Lister's belief that vaporous exhalations from materials had the power to create or change matter, a reflection of the concept of *witterung* in German mining manuals. See chapter three for a discussion of *witterung*. In his article in the *Philosophical Transactions*, Lister gives several examples of matter seemingly generated out of the air, such as the formation of vitriol on pyrites.

closed vessels or if it is left alone without the application of any heat. Limestone is separated out with difficulty only after some time, and only after a long and severe period of freezing cold.

VII. Very little salt is found in springs in which ochre and limestone are very abundant. In inky-black waters where there is an abundance of ochre there is no vitriol whatever. Likewise in petrifying waters (which are well-known in England) near Knaresborough, the salt is like a stony powder in a proportion of about 1 to 20. On the other hand in mature vitriol and nitre of lime ochre and limestone are to be found in tiny proportions compared with the saline elements. Seven ounces of nitre of lime can at once be reduced by burning to two ounces, The same should be assumed in the case of vitriol left in the caput mortuum.

VIII. It is generally agreed that pyrites is to be found in inky-black waters entirely under the appearance of liquid from the following experiment: take some freshly drawn inky-black water, from a place where there is a great deal of ochre, say Malton, and add drop by drop a tiny amount of that lye which soap manufacturers make from quicklime and so-called clavellated ashes;[82] what sinks down gleams with a golden sheen, so that you may believe that pyrites itself is being separated.

IX. Pyrites behaves in one way in air, which we discussed above, and another when it is kept continually underwater, since vitriol is produced from pyrites in air, but under water pyrites almost dissolves. This is proved by the following fact,

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that pyrites can be burnt to produce ochre and sulphur and nothing else. And very little vitriol can be drawn from it by applying fire. Similarly ochre and sulphurous vapour are always present in inky-black waters. It is by no means vitriol, at least of the mature kind.

But vitriol itself (the other way in which it is produced is described above) is resolved into three basic substances. One of these is saline, the second sulphur and the third is ochre. But the saline element is present solely owing to the development of pyrites in the air.

The more demanding thinkers have some doubt about sulphur in vitriol. But what happens in the case of the sulphur of pyrites, which,

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[82] The *OED* reveals that clavellated ashes were "ashes of burnt lees or dregs of wine; Said of potash, probably in reference to its having been obtained from billets of wood by burning."

as we have stated, can be forced into sulphur for the most part by the application of severe heat. In the end when it is exposed to the air it turns entirely into vitriol. Then again, other methods are described in the works of certain more recent writers, by which sulphur itself is drawn from oil of vitriol, which I omit in the interests of brevity.

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Yet I do not deny that certain springs are comparable in this respect, by reason of either their position, which is, as ever, some underground channel, or by reason of the inky-black essence, on account of some very obscure increase in the water, so that at least from time to time they display vitriol in one mature form or another (which we have shown above is threefold). And so if anyone wishes carefully to investigate this matter, to see whether and how vitriol is produced in inky-black springs, then, indeed, he must needs apply much diligence over a long period, and must frequently examine the waters on every noteworthy change in the weather.

Yet some may object that vitriol combines with salt of lime. This is a mere suspicion, in my opinion. Yet if some raw vitriol is present though concealed (for this cannot true of mature vitriol, since the color and appearance where it is concealed is easily discerned).

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That man will be successful who is able to dissolve this bond with the following results, so that both salts show themselves voluntarily and come into sight.

It is then not credible that calcarious salt contains vitriol concealed within it rather than common salt, where however the smell of pyrites is strong; this is the case in certain salt springs where however there is not even a hint of vitriol. But others who have the time must investigate these phenomena. I personally affirm nothing.

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Chapter VIII

An explanation of the petrifying action of certain springs.

In brief, my understanding of petrification is as follows. Pyrites and limestone (for as far as my own observations are concerned no other substances in Britain turn to stone), as I have stated just now in the last chapter, dissolve, as it were, entirely in springs of this kind because of an exceedingly subtle current of air. And so they easily penetrate even the densest wood, and wooden pyrites have for the most part stony insides.[83] This is scarcely conceivable in the case of some calcarious powder or ochre, however fine it be.

Then from these wooden pyrites vitriol is produced from the air. And so they consist entirely of pyrites.

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Pyrites changes iron which has a true admixture of copper, or, if you will, a vein of copper, into bronze in a similar way (to make an incidental observation), that is, by the very method of petrification already explained in the case of two other liquids. But in the latter case the iron is no more changed into bronze than in the former case wood is changed into iron. Nor is there need of any solution. But the copper-impregnated liquid enters deeply with its whole substance and combines peacefully by embracing the iron.

There are many factors against some sort of precipitation, or the separation of salt, as the mechanism for petrification.

1. Springs of this kind do not usually become cloudy or muddy.
2. Ochre and limestone are deposited spontaneously (as has been explained above) but without any solidification, &c.

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Chapter 9

The cause of hot springs is derived from salts produced by pyrites and limestone or activated by pyrites itself and limestone; other opinions are refuted.

It has been shown above that our hot waters of Bath are of a dark hue, and contain within them salts of two kinds, that is common salt and sodium carbonate and that likewise they exhibit Ocra and limestone. But there is much doubt as to how they grow hot.

My own opinion however is that our native hot springs borrow their heat from active pyrites and limestone.

I exclude common salt, which practically seems to be produced by mere melting.

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[83] Again Lister is claiming that *witterung* or vaporous exhalations from minerals promote material change, in this case petrification.

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Furthermore from both substances in their active state a warm vapour arises: in the case of pyrites this is largely sulphurous, pungent and inflammable; in the case of limestone however it is milder and lighter: I shall prove this in what follows. I shall however begin with pyrites.

When rocks are opened up in wells or mines, a thin gas usually arises, which, like sulphur, can very easily be set on fire and is highly dangerous to miners.

In the second place this gas is especially dangerous in older mineshafts, because in these a long time has elapsed for generating a sulphurous vapour.

Likewise miners universally agree that for the whole of the winter and especially at a time of frost underground tunnels are very warm.

Furthermore it has been proved above that pyrites produces very large quantities of sulphur, and I further affirm that in no mine whatever in England

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is sulphur to be found unless pyrites is present to the same extent, or a mixture or compound containing pyrites, but not lead, coal or the metallic form of alum, and I affirm the same fact in respect of all other mined substances whatever. I would not wish anyone to think that I make these claims in a foolhardy or rash manner, for I drew these conclusions after a long time and much practical experience.

Furthermore in order to know why and to what extent some mined substance contains pyrites, employ a magnet, after first duly pulverizing and burning the substance, and you will never be deceived by the experiment.

Rocky material poured out from the eruptions of Etna is for the most part ferrous, as the magnet demonstrates; but when the same substance is ground to a dust and burned again it furnishes abundant proof of this phenomenon, if the magnet is moved close once more. It is credible that the type of iron is none other than pyrites from the ease with which it can be burned.

Furthermore thunder and lightning are the effects of gas of pyrites, if it is set on fire in the sky,

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as also are earthquakes*, if by chance the fire is contained in subterranean hollows, and hot springs, if it is transported in abundance along water channels, even if it is not set on fire.[84]
*Pliny says that thunder and lightning burn with sulphur, and the actual light they produce is sulphurous. Pliny, Bk 35, ch. 15[85]

2. I can prove that a warm gas is produced in like manner from active limestone in the following way.

Almost all springs and wells (for most of them are considered medicinal to the extent to which they contain this or that salt) are especially warm at times of fairly severe frost, and are particularly noticeable for the way in which they give off an exhalation consisting of a very dense moist vapour, just like hot springs.

Concerning the truth of this experience there are of course several wells of water in the city of Rome which have beyond doubt proved to be warm at a time of frost. See and consult the evidence

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of John Ray*, the most learned scientist of all our fellow-countrymen.
An Account of a Journey, Written in English.[86]

Furthermore the heat of some springs is indicated in addition to the evidence of the senses by the unfailing greenness of plants which grow around them and float on them and likewise by the fact that the

[84] Lightning does smell of sulphur, sulphur is in fact an excellent insulator, and static electricity accumulated on it discharges in electrical sparks towards proximate objects, effects which may have given Lister his idea. Further, in early modern German mining literature, ore exhalations due to *witterung* were implicated in meteorological effects such as thunder and lightening. For more on this, please see chapter three.

[85] Lister had high regard for Pliny; in a letter to John Ray, he wrote: "I remember you once took away the prejudice I had against Pliny, and I have ever since looked upon him as a great treasure of learning." See Ray, "Mr. Lister to Mr. Wray, 22 December, 1669," in *The Correspondence of John Ray*, ed. Edwin Lankester (New York: Arno Press, 1975, reprint of London: The Ray Society, 1848), pp. 48–9.

[86] Lister refers to John Ray, *Observations Topographical, Moral and Physiological, Made in a Journey through Part of the Low-Countries, Germany, Italy, and France: With a Catalogue of Plants Not Native of England. To Which is Added an Account of the Travels of Francis Willughby, Esq; through Great Part of Spain* (London: John Martyn, 1673). (Willughby was employing Ray as his tutor). Ray also wrote *A collection of curious travels and voyages* (London: S. Smith and B. Walford, 1693).

water of these springs does not easily ice over even under very severe conditions.

Additionally one must certainly not think that the warmth of these springs, which is so evident to the senses, arises from the peculiar qualities of the place or the water itself (which is the same everywhere) but from a certain hot vapour which is produced in the actual underground water channels.

But apart from pyrites and limestone there is nothing of which I know that gives off a gaseous vapour: and so without doubt this warming exhalation must be attributed to one or both of these substances.

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Well, pyrites is certainly the rarer substance if it is compared with limestone, which is found almost everywhere in huge quantities and in uninterrupted rock deposits, as we have suggested above.

In addition the vapour from pyrites can usually be distinguished from steaming ocra: and so it must be concluded that this warmth of springs for the most part arises from limestone.

The teachings of the Parisian philosophers also argue that hot springs grow warm from hot gases:[87]

1. Because when taken into the mouth they do not burn it as much as ordinary water which has been heated over a stove to the same degree of heat. This seems to be due to the thinness of the substance by which hot springs are heated; just as the flame produced by brandy does not burn the hand as much as a burning coal placed on it.
2. From the manner of heating: for there are certain leaves which remain stiff and change only their color when placed in the hottest springs of France

[87] Lister's connection of volatile salts from pyrites and limestone with the heating of mineral waters was influenced by the Du Clos' *Observations*. In speculating about the effects of spa waters, Du Clos had written that "it may be that some Mineral Vapours or Exhalations do mix with common Waters…and that these Waters are impregnated with their Qualities, and of some other Volatile Salts not Concrete, elevated in these dry Exhalations of humid Vapours." Du Clos also argued that hot springs grew warm specifically from hot moist vapours volatilizing from substances like pyritic vitriol, and not from the substances being combusted themselves.

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although they become soft from a gentle heating in boiling water: from this they argue that the heat of the hot springs is a drying agent rather than a moistener.

3. Because the hot springs are hotter at night than by day; no doubt because the warm vapours are very widely spread by the night air.
4. Because when the water of the hot springs is exposed to the air it retains its heat longer than ordinary water heated over a fire, because cold air causes the motion stirred up by the fire to cease suddenly. But this same cold air prevents the warm vapours of the hot baths from being spread so quickly.
5. Because the water of the hot springs, when placed on a fire, requires the same time to boil as ordinary cold water: from this it is clear that the hot springs were not heated by some underground fire. This at least is what they argue.

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In order to prove that the activation of pyrites and limestone involves vapour: I shall add to these arguments that in wet, moist and chilly places the activation of those salts is particularly promoted.

Again violent rain usually results from thunder; which one could scarcely believe would happen if the vapour of pyrites were given off of its own accord and in a dry condition.

Yet when it is mixed in tiny amounts with some moist vapour, then if at any time and for any reason it happens to be set on fire little droplets of water are necessarily forced together and thrown down, when the draught by whose movement and stirring alone they are borne up into the atmosphere is driven away.

Up to this point I have unfolded my own opinion. Now I turn to a refutation of the opinions of others about springs.

1. Some indeed believe that the heat of hot springs arises from the ease with which certain underground substances (such as pyrites) are set on fire.

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There are many minerals, Paracelsus says*, which are set on fire by air, and in particular warm waters which are confined to their own localities. This indeed may be true in part, but in our part of the world, that

is, the environs of England, there are no volcanos naturally occurring. Nor do I think there is any need for that vapour or gas of pyrites to ignite spontaneously in order to make the waters warm: since we have shown above that that other vapour which comes from limestone, and which of its own nature is not at all flammable,(for it assumes a different nature if by chance it changes into saltpetre), nevertheless imparts a noticeable warmth to the waters of springs.
*De Thermis, Chapter 3 Jourdan. De Baln[88]

2. We have however disproved above the existence of any corrosion between some kind of salt which eats substances away and metallic iron. But let it be supposed to exist, and let even the strongest spirit of nitre [nitric acid, I think] be diluted with water and thrown onto some powder made of, say, limestone or coral,

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then, although it will produce a violent reaction, yet it will not produce heat.

3. *Others state that the conflict stirred up between different salts, or, if you will, the joining of opposites, is a cause of heat.
**Paracelsus De Baln. Na. Tome 1, ch. 3.*[89]

I answer that the salts themselves are not by nature in disharmony with each other, but mix peacefully in the same water. If however they are ever brought to the boil on making contact, this does not usually happen until they have felt fire from some chemical preparation.

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[88] Lister is likely referring the reader to Thomas Guidott's later work, *De Thermis Britannicis Tractatus accesserunt Observationes Hydrostaticæ, Chromaticæ, & Miscellanæ, uniuscujusq[ue] Balnei apud Bathoniam Naturam, Proprietatem, & Distinctionem, Curatius exhibentes…Ad Regale Collegium Medicorum Londinensium* (Londini: Excudebat Franciscus Leach, sumptibus Authoris, 1691); Edward Jorden, *A Discourse of naturall Bathes, and mineral Waters…especially of our Bathes at Bathe in Sommersetshire* (London: Thomas Salmon, 1669).

[89] Most likely this is Paracelsus' work on baths which describes the curative benefits of bathing, including mud baths. Paracelsus theorized correctly that the medicinal action of water is due to the presence of minerals in his *Baderbuchlin: Sechs kostliche Tractat, armen vnd reychen, nutzlich vnd notwendig, von Wasserbådern: Woher die selbige warm, vnd andere Wasser kalt, vnnd auss was Vrsach sy sollicher gewaltiger Kråfften, das ihr Vrsprüng mit wachsender Arth ausz der Erdtglobel, gleich wie die Kreuter vnnd Bowme von ihrem Samen, mit schonem Bericht, wie mennigklich ihrs Brauchs sich Behelffen mag…/ durch den hocherfarnen Herren Theophrastum Paracelsum; mit Fleyss vnd müe Doctor Adams von Bodenstein, zu guten neuwen jar publicirt*. (Mülhausen im Oberen Elsåsz: Peter Schmid, 1562.)

In this way so-called oil of vitriol,[90] when mixed with plain water, at once makes it boil, not because of some contrareity between the salts (there is none), but because following a violent distillation it retains its igneous nature, like quick lime. You should consider this to be the case with other salts.

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Furthermore in order to prove that this is not a peculiar quality of some water, let water be drawn from this spring, or a well, be it warm or hot; and soon it will grow cold of its own accord and freeze, and steam will cease to be produced.

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Chapter X

Concerning the origin and material of rain
In the previous chapter we declared that the vapour of pyrites itself was moist, although it is credible that all springs are produced solely by rainwater, and this has been proven by my fellow-countryman Wittius *(On the spring at Scarborough)* and others in a learned and prolix manner.[91] I might consider that the production of rainwater, and then pyrites, and limestone might for the most part be derived from this moist vapour. Here it will not be irrelevant to my purpose to treat in brief of the origin and material of rain.

1. Waters are exhaled through the action of the sun's heat, which produces much, but not all, the material for rainwater.

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2. There is in addition the breath of all living things, even insects. This is clear to the senses if they are kept under little glass vessels for a short time.
3. Likewise the breath of plants. Willsius of Oxford has demonstrated in a very successfully devised experiment that the lives of plants

[90] Sulphuric acid.
[91] Robert Wittie, *Scarbrough spaw; or, A description of the nature and vertues of the spaw at Scarbrough. Also a treatise of the nature and use of water* (London: Charles Tyus and Richard Lambert, 1660).

> depend upon breath just like those of animals. *(The Natural History of Oxfordshire, D. Plott)*.[92]

The same phenomenon was described many centuries previously by Pliny, concerning a grass from Ethiopia, although he placed its effect among the illusions of magic. In book 26, chapter 4, he says that rivers and lakes are dried up by casting into them Ethiopian grass.[93]

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[92] As support, he cited a June 1669 experiment on plant transpiration "in order to find in what measure Herbs might perspire," performed by John Wills, a fellow of Trinity College, Oxford. Lister specifically cited Dr. Robert Plot's *The Natural History of Oxfordshire, Being an Essay toward the natural History of England* (Oxford: The Theatre, 1677), pp. 254–5. Plot (1640–96) of Magdalen College, Oxford, and a Secretary of the Royal Society in 1682, described it as follows: "He [Wills] took two glass Vials with narrow necks, each holding one pound 8 ounces, and 2 drachms or water... into one of these glasses filled with water, he put a sprig of flourishing Mint (which before had grown in the water) weighing one ounce: the other glass he also fill'd with water, and exposed them both in a window to the Sun. After ten days time, he found in the bottle where the mint was, only five ounces and four drachms of water remaining, and no more so that there was one pound two ounces and six drachms spent, the mint weighting scarce two drachms more than at first. From the other Glass, where water was put of the same weight, and no mint, he found the Sun had exhaled near one ounce of water, and therefore concluded it drew but so much out of the first glass, at least no more: So that allowing one ounce for what the Sun had exhaled, there was in those ten days spent by the mint, one pound one ounce six drachms of water; and the mint being increased in weight only two drachms, 'twas plain the mint had purely expired in those two days, one pound one ounce and four drachms, that is, each day above an ounce and half, which is more than the weight of the whole mint. Whence he concluded that what Malphigius so wonders at in his Book *De Bombyce*, viz. that those Animals will sometimes eat in one day, more than the weight of their bodies, is out-done by every sprig of mint, and most other Herbs in the Field, which every summers day attract more nourishment than their own weight amounts too. Which the same ingenious person at least questions not (and therefore wishes trials may be made) of the *Tithymali, Esulae*, and especially of *Pinguicula and Ros Solis*, which last sucks up moisture faster than the Sun can exhale it, and is bedewed all over at Noon-day, notwithstanding its power: Nor doubts he but that Wormwood, and all other Plants that are very hot, and of strong smells, expire as much, if not more than the Mint." All of the plants (except Wormwood) mentioned by Plot produce liquids that could be interpreted as dew. *Ros Solis* was *Drosera rotundifolia*, or Sun-Dew, a carnivorous plant noted for its dew on its leaves that intensified with the sun; *Pinguicula* was known as butterwort, another carnivorous plant with mucilage drops on its leaves to catch insects, apparently interpreted by Plot as dew. *Tithymali* and *esulae* are species of spurge that produces a milky latex from roots and stems when injured. For descriptions of these plants, see John Gerard, *Herball or General Historie of Plantes* (1613) (New York: Dover Publications, 1975).

[93] I am not familiar with which edition of Pliny that Lister was utilizing, but his references can be found in a more modern edition. "But above all things, it was the follies of magic more particularly that contributed so essentially to his success—follies which had been carried to such a pitch as to destroy all confidence in the remedial virtues of plants. Thus, for instance, it was stoutly maintained that by the agency of the plant aethiopis rivers and standing waters could be dried up" in Pliny the Elder, *The*

But to mock the idea he adds below, 'So let the Pontine marshes be dried up today by Ethiopian grass, and so much land be added to the suburbs of Italy.'[94] And yet if one reads with care his own description of the grass, which he gives a little further on in these words (book 27, chapter 24)

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"Ethiopian* grass has many large leaves, and numerous and full roots," and compares this with the experiment quoted above, he will no longer have any grounds for doubting the veracity of the account in my opinion.
*Book 27. c. 24 (Pliny's *Natural History*)

Indeed the amount of water which plants growing in springs, rivers and lakes consume every day is scarcely credible.

In addition the amount used in the same way by woods and grasses which grow on dry land is amazing. Springs are produced, says the same Pliny, for the most part when woods are cut down; previously the trees fed from them.

Likewise nocturnal dew for the most part arises when the breath of plants is condensed. This happens in Britain by far most copiously in May, when of course the plants are most active and growing most. In the other months it is much less, and in winter there is little dew.

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I have carried out the same experiment several times on seaweed in saltwater; and in this way I have been able to draw freshwater which was drinkable by this novel method of distillation, which will prove most desirable and useful for sailors. I share this knowledge without jealously guarding it.[95]

Natural History. eds. John Bostock, M.D., F.R.S., H.T. Riley, Esq., B.A. (London: Taylor and Francis, 1855), 26.9, p. 5159. http://www.perseus.tufts.edu/cgi-bin/ptext?lookup = Plin + Nat + 26.9. Accessed 19 September 2006.

[94] "Turning to the present moment, let them, by the agency of the herb meroïs, dry up the Pomptine Marshes, if they can, [p. 5160] and by these means restore so much territory to the regions of in the neighbourhood of our city." In Pliny the Elder, *The Natural History*. eds. John Bostock, M.D., F.R.S., H.T. Riley, Esq., B.A. (London: Taylor and Francis, 1855), 26.9, pp. 5159–60. http://www.perseus.tufts.edu/cgi-bin/ptext?lookup = Plin.+Nat. + 26.9. Accessed 19 September 2006.

[95] See Martin Lister, "Certain Observations of the Midland Salt-Springs of Worcester-Shire, Stafford-Shire and Cheshire. Of the Crude Salt, Which Grows from the Stone-Powder Dejected by the Said Brines in Boyling. Of the Specifick Difference

4. But it may well be that by far the greatest amount of the material of rain water arises from the underground salts of mineral ores and especially the active salts of pyrites and limestone and of course by these the waters of springs, rivers and marshes and the sea itself are driven off to form mists. You should take what has been demonstrated above about springs and apply it to all other types of water.

In a certain mountainous region, in evening in the valleys, in summer and winter, especially when there is a hard frost, certain dense mists arise continually from the rivers and lakes. At daybreak however the same mists can be spotted climbing about half-way up the mountains. But when the sun has risen or a wind is blowing

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they are either scattered or, if on the same day they reach the mountain peaks, they continually condense into rain and fall once more into the valleys. As for the reason why this phenomenon can be seen both on summer evenings and in freezing temperatures in winter, the same explanation applies to both. It occurs because the air is in a very pure condition, and new vapour is taken into it.

For the air is thinner than usual in time of frost, because the particles of water are without exception continually turned into frost as soon as they are produced. In like manner in summer, especially in the evening, the mist from rivers, just consider, can be seen. This is because the air is purified in the daytime by the heat, and the vapour is continually seized aloft.

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Chapter XI

An explanation of springs which stink of sulphur

There is hardly any reason for doubting whether the water of some spring stinks because of its own nature, or by reason of what it contains. Mineral springs which stink of sulphur contain only one salt, as has been suggested above, and that is the common variety. There is

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betwixt Sea Salt and Common Salt. A Way (Which Seems to be the True Method of Nature) of Distilling Sweet and Fresh Water from Sea Water, by the Breath of Sea Plants Growing in It. That This Breath Probably is the Material Cause of the Trade or Tropick Winds. In a Letter to the Publisher from the Learned Martin Lister Dr. of Physick of the University of Oxon," *Philosophical Transactions*, 14, 156 (1684), pp. 489–495.

also however a vapour or exhalation of sulphur which is produced by pyrites. This seems for the most part to be precipitated at its very birth, and so that revolting smell is the effect of its separation.

The following are indications of separation:

1. There is a certain whitish flower which floats on all waters of this kind, and grows everywhere around the edges of springs of this kind. The flower moreover is pure sulphur. In addition contact with the edges stains silver first a yellowish color, and then black, which is the effect of the same sulphur.

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2. Then there is very black mud, which is also sulphurous.
3. Straws and stones in these springs are stained purple.
4. Likewise the water of these springs tends to be cloudy, at least in comparison with others.
5. All mineral waters, at least the inky-black ones, which to that extent we have shown develop from pyrites, if they are kept for some time in skins, produce the same sulphurous smell as those most famous ones in the neighbourhood of Knaresborough.
6. Salt springs, as has been suggested above, whose water is continually drawn off in large quantities do not smell rotten, and I have no doubt that this would also occur in the case of stinking springs if their waters were drawn in copious and unremitting amounts.
7. When the water is boiled a little it loses its stinking smell and property of staining silver, as its sulphurous exhalation is driven off and dies.

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The sustained rancid nature of the water may be the cause, at least in part, of the separation, and it occurs because the water first stagnates there from some chance event. And in truth all these springs are stated to be either stagnant or very sluggish.

We should also count in this group of causes the abundance of common salt.

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Chapter XII

A brief examination of the various substances which the mineral springs of England are said by our British writers to contain.

The mineral springs of England are said to contain other substances which vary with the writer, and these writers of ours are not few in number. The reason for such great diversity seems to be that they all sought to find vitriol alone, but failed. However I shall now briefly examine the individual substances which have been listed by others.

First, for some reason or other, most of our fellow-countrymen have found nitre.

But nitre has, one might almost say, been metamorphosed into the saltpetre and halonitrum of more recent writers. It is however true that it has been discovered scarcely anywhere else

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than where animals have frequented the area.[96] It is hard to imagine it being produced in the depths of the earth, beneath very mountains, through which most mineral springs flow.

It may be that saltpetre can be formed in some manner, although no nitrous stone occurs naturally so that either pyrites or limestone must provide the material for nitre.

I leave it for future generations to work out and bring to fruition the question as to whether these stones must be steeped in urine or prepared in some other way before they can develop.

Yet although no stones are naturally nitrous, yet there is a certain soil containing that fertile salt, and once it is made fertile with that salt it retains its results for some time. Of course this same nitrous soil is exhausted of its salt by the application of heat, but if it is kept in a place free from the injuries done by the winds and rain, it is said once more to abound in new nitre.

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But the winds and rain merely dissipate the immature salt. The cause of fertility lies in the soil itself.

Yet a number of writers affirm that the salts of some springs commonly develop into droplets like icicles.[97] A sure indication of nitre!

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[96] This was a reference to the fact that a major source of nitre was the deposits crystallizing from cave walls or privies, or other organic matter that was decomposing. Ammonia from the decomposition of urea in dung heaps would produce nitrate.

[97] Lister here is referring to Wittie's experiments in his work, *Scarsbrough Spaw.* William Simpson, in his *Hydrologia Chymica* remarked on Wittie's assertions that nitre was

I have also had so called oil of vitriol which has solidified into icicles in winter, and I have kept them in this condition in my house for a long time. My friend Coxius states the same in *Philosophical Transactions N.103.*[98] I have noted above how even sea salt has solidified into icicles. But these conditions arise rather from some sort of evaporation or solidification than from the nature of the salt. But grant that then salt of some springs does develop to some extent naturally into some shapeless icicles. Yet the other more significant properties of nitre are by the admission of these same authors not to be found. They can for example be made to burn suddenly with a slender colored flame while producing a bang and a flash; their crystals are hexagonal, &c.

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Concerning nitre I am of the opinion of the ancients, that it does not naturally occur anywhere in Europe, at least in our northern regions. Indeed, if you pay attention to the descriptions and accounts of the ancients, salt of this kind appears to be peculiar to Africa and Asia, and to be quite different from our spurious kind.

Others declare that sea salt is present in some of our springs, yet it is not.

In many others however I have no doubt that it is present in inky-black springs, except for the unpleasant smelling salt ones. I wish however that they would devote more attention to the cubic-rhomboid shape of raw vitriol if it has ever been found by any of those who investigate our springs.

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in spa water: "The other part of his argument, which he thinks is *instar omnium*, to confirm his opinion of Nitre the chief ingredient, is this experiment, *viz*. that upon the exposing of the Minerals (as he calls the sediment left after evaporation of the water) some while in a most and cold air, that there have been found *stories* or little Icicles among them, which is the form of Nitre, as to the veracity of the experiment we are not incredulous, but that this should evince the preexistence of Nitre in that sediment, is the thing we contend and very much question." William Simpson, *Hydrologica Chymica* (London: W.G., 1669), p. 52.

[98] Some Observations and Experiments about Vitriol, Tending to Find Out the Nature of That Substance, and to Give Further Light in the Inquiry after the Principles and Properties of Other Minerals: Communicated by a Fellow of the R. Society, Who Maketh Use of Chymistry Chiefly as Subservient to Physiology, *Philosophical Transactions*, 9, 103 (1674), pp. 41–47. The article has no author in the *Transactions*, but its subject manner makes it likely it is the work by Daniel Coxe to which Lister refers. See chapter three for a discussion of Coxe's chymical experiments in the Royal Society.

There are others who contend most enthusiastically that in some of our inky-black waters alumen is present.

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These also call on chemistry, but have little knowledge of minerals.[99] Again they are wrong, since it is certain that they have taken the stones with which they conduct their experiments from a pile of burnt aluminous rock. Even when these are only lightly burned they have still been either contaminated by the smoke or exposed for a sufficient time to the consuming of their vitriol in air. I consider it most true that every rock, insofar as it is aluminous, if it has been very recently mined and is in its raw state, is incapable of turning the water in which it has been steeped inky-black in conjunction with gall-nuts. My friend Wittius has attested this fact, and I have proved it by careful experiment. Yet the lye of aluminous stone that has been burned, or is even in its raw state, if it has been exposed sufficiently long in air, becomes inky-black to the extent that it contains pyrites.

Many authorities demonstrate that pyrites is everywhere mixed with the ore of alumen.

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Of course at the top of a pile of burned stone an abundance of sulphur, which is the genuine offspring of pyrites, can be found. But pyrites itself can also be seen in the same place from its golden sheen. And a careful investigator, if he uses a magnet appropriately, will come across it almost everywhere in the actual aluminous ore. I can testify myself that I have some extremely pure soil from Ireland which contains an abundance of alumen, which I still keep carefully in my house. Alumen however continually effloresces from this ore as vitriol does from pyrites.

When however after a development of several months I examined these aluminous hair-like excrescences, they failed completely to turn the water in which they were dissolved inky-black in conjunction with gall-nuts. Furthermore aluminous 'strands' remained ever white even

[99] The debate was published in the *Philosophical Transactions*. In "Part of two Letters from Dr. Cay. To Martin Lister…concerning some Mineral Waters," pp. 365–370. Cay criticizes an unnamed investigator for presuming that alum was present in ferruginous waters.

after growing for a year, although strands of vitriol turn green immediately after their birth.

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Likewise it is easy for anyone to discern that they were alumen either from their sweetish taste, which is very harsh. Concerning the crystals of alumen and vitriol I have explained above how they differ. Yet the pure ore of alumen, free from all pyrites, is very rarely found as far as I know, at least in Britain.

In addition there is the fact that alumen has a severely binding effect on the stomach, whilst our inky-black minerals, in which it is said to have an abundant presence, loosen the bowels, as do the waters of the spring at Scarborough and the stinking sulphur springs near Harrogate.

Others again (so that I may not omit any of the improbable claims made by others) assert that the very ochre from the spring at Scarborough is aluminous earth, or the ore of alumen. But these can hardly have trusted the evidence afforded by a magnet, which is unimpeachable. For that very ochre which is separated by the application of heat

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if it is burned in the proper way, will happily be attracted to a magnet, and if it is kept for a longish time in a damp atmosphere will even produce the green vitriol of iron. I can testify to these facts from my own experience.

But it is further objected that the contents of the waters of this last named spring, and of certain others which also have inky-black waters, like those of the hot springs at Bath, grow white even if they are calcinated for a longish time.

My reply is that in hot springs and elsewhere in cold mineral springs ochre is wont to disappear; the reason is lies in its gas-like nature, which is certainly unique, as has been explained above.

Likewise if a moderate heat is applied, it is only partially separated, since it is deposited either spontaneously or when gall-nuts are added. And so there is no doubt that it is contained in certain inky-black waters. Likewise in other waters, such as those in Malton, even the calcinated contents,

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such as burned ochre, develop a bright red color. And they grow white from a shortage of ochre. Therefore it does not follow that for that reason ochre itself was not present in those waters in which it can be shown by many other arguments that it was present. Again, even if a magnet attracts none of the contents after they have been burned, it is nevertheless credible that iron ore could have been present there.

For the magnet does not attract vitriol made from steel, even if it is thoroughly heated, as I have proven. And so it must be very carefully cleansed of the remaining parts mixed with it, especially those of a saline nature, in order that the proof afforded by a magnet may properly succeed.

Concerning the bitumen in the hot springs at Bath, I have nothing which I can affirm from my particular collections made in May, June and July. I am not yet certain that it is bitumen, for I have received from two honest men who are natives of that city a largish quantity

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of that so-called bitumen.[100] Yet I can confirm that it consisted entirely of scrapings of dirt from bodies, and nothing besides. In addition it is said to be collected only in those months when the baths are particularly crowded.

[100] I do not know who these two "honest men" were, as a search of the relevant Lister letters in the Duke Humfrey did not reveal any bitumen deliveries to Lister in the 1670s. Lister does however mention in the *Philosophical Transactions* that "I made all the Wiches or noted Salt Springs in my way home from Bath, the last Summer, and spent some few hours in the examining of them…But before I proceed I must needs bear witness to the truth of Dr. Guidots experiments, most of which I tried my self at Bath, and find him to be a most Authentic and faithful writer. I do only yet doubt of the existence of Bitrumen for I cannot find the Floating Scum when dryed to have any such thing in it." See Martin Lister, "Certain Observations of the Midland Salt-Springs of Worcester-Shire, Stafford-Shire and Cheshire," p. 489.

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