The Saline Chymistry of Color in Seventeenth-Century English Natural History

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Introduction

Nehemiah Grew (1641–1712) was a botanist and secretary to the Royal Society. His election as a fellow was proposed by Robert Hooke.[1] As well as his work with botany, Grew was also a chymist of some standing. After receiving his BA from Cambridge in 1661–1662, Grew went on to receive his medical degree from Leiden, writing a dissertation on the liquors of the nervous system, utilizing Sylvius de la Boë's well-known acid-alkali iatrochymistry (medical chymistry) as the basis for his analysis.[2] Grew's continued devotion to chymical research was applied to his botanical work. Grew thought it was necessary to perform

a chymical analysis of the contents of plants both air and liquid, their colours,

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[1]The scholarship on Grew has been extensive, but has not concentrated on his chymical work. 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), 63-81; Michael Hunter, "Early Problems in Professionalizing Scientific Research: Nehemiah Grew (1641-1712) and the Royal Society, with an unpublished Letter to Henry Oldenburg," *Notes and Records of the Royal Society* 36, 2 (February 1982), 189-209; Jeanne Bolam, "The Botanical Works of Nehemiah Grew, F.R.S. (1641-1712)," *Notes and Records of the Royal Society* 27, 2 (February 1973), 219-231; Conrad Zirtle, "Introduction," in Nehemiah Grew, *The Anatomy of Plants*, Sources of Science, no. 2, ed Charles Zirtle (New York, 1965), 3.

[2] Nehemiah Grew, *Disputatio Medico-Physica, . . . de liquore nervosa . . .* (University of Leiden, 6 July 1671).

> tastes, smells [...] all to be examined by agitation, frigifaction, infusion, digestion, decoction, distillation, calcination, and all the armoury of seventeenth century analysis.[3]

Grew attempted such analyses in a series of lectures appended to his magisterial *Anatomy of Plants* (1680).[4]

In his lecture "A Discourse of the Colours of Plants," given to the Royal Society in 1677, Grew stated that the green color of leaves was a chymical precipitate that formed when the acidic salts and sulphurs that plants contained mixed with volatile alkali salts in the air.[5] He also stated that similar chymical reactions controlled the colors of flowers. However, this paper argues that before Newton's work with the spectrum and color, and as a Paracelsian chymist, Grew was not alone among English natural philosophers in attributing the phenomenon of color in the natural world more generally to salts and saline chymistry.[6] Salt was one of the Paracelsian *tria prima* of the elements: salt, sulphur and mercury. Furthermore, Paracelsians often attributed color and solidity of matter to saline principles. We will analyze specifically to what extent natural philosophers in seventeenth-century England, including Robert Boyle, Robert Hooke, Nehemiah Grew and Robert Plot, also thought salts governed color and color changes in flora, fauna and minerals. In a

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[3] Bolam, "Botanical Works," 225.

[4] Hunter, "Early Problems," 201.

[5] Anna Marie Roos, "Nehemiah Grew (1641-1712) and the Saline Chymistry of Plants," *Ambix,* 54, 1, (2007), 51-68; Anna Marie Roos, *The Salt of the Earth: Natural Philosophy, Medicine, and Chymistry in England, 1650-1750* (Leiden, 2007), 98. In the present essay, I am significantly broadening and deepening my analysis of early modern chymical analysis of color beyond that of Grew's work to consider other natural historians.

[6] As Tawrin Baker's chapter has shown, Robert Boyle considered the role of salts in producing color.

larger sense, we will also analyze to what extent these ideas were a rejection of Aristotelian ideas about color, and characterize to what extent chymistry was a basic analytical tool for seventeenth-century English natural historians.[7]

Studies of early modern chymistry have examined the role of color in the process of alchemical transmutation, stemming from the medieval tradition, the process described as moving from *melanosis* (blackening), *leucosis* (whitening), *iosis* (reddening) and *xanthosis* (gilding) as one transformed base metals into gold.[8] There have also been several works of art history elucidating the relationship between alchemical theory and medieval and early modern pigment composition.[9] However, there has been little study of chymical concepts of color drawn from the interactions between Paracelsian saline chymistry, matter theory and the rise of the mechanical philosophy in the seventeenth century.[10] Our investigation will also demonstrate that artisanal techniques such as pigment grinding and investigations into the chymical properties of textile dyes in the Royal Society also influenced conceptions of the saline chymistry of color among seventeenth-century English virtuosi. In this manner, we argue that different 'color worlds' of disciplinal practices and concepts

[7] Harold Cook first posited this relationship in his article: "Natural History and Seventeenth-Century Dutch and English Medicine," in *The Task of Healing*, ed. Hilary Marland and Margaret Pelling (Rotterdam, 1996), 253-70.

[8] For an overview of this process, see Lawrence Principe, *The Secrets of Alchemy* (Chicago, 2013), 123-125, 238. The color stages of transmutation and the Philosophers' Stone are described in Eirenaeus Philalethes [George Starkey], *Secrets Reveal'd; or, An Open Entrance to the Shut Palace of the King* (London, 1669), 80-117.

[9] Philip Ball, *Bright Earth: The Invention of Colour* (New York, 2001); Spike Bucklow, "Paradigms and pigment recipes: vermilion, synthetic yellows and the nature of the egg," *Zeitschrift für Kunsttechnologie* 13, 1,(1999), 140-149; D. V. Thompson, *The Materials and Techniques of Medieval Painting* (New York, 1956); Anne Dunlop, "Drawing Blood," *Res: Anthropology and Aesthetics: Wet/Dry* 63, 64 (Spring/Autumn 2013), 70-79.

[10] William Newman briefly covers Robert Boyle's theories on color and corpuscularianism in his *Atoms and Alchemy: Chymistry and the Experimental Origins of the Scientific Revolution* (Chicago, 2006), 182-185.

interacted, allowing us to elucidate the boundaries and relationships between seventeenth-century art and science.

Paracelsian Chymistry, Salts, and Color: A Reaction Against Aristotle

The chymistry of color was a source of fascination and fundamental debate for early modern English natural philosophers, particularly for natural historians for whom color could serve as a classificatory principle. There was, however, a fundamental debate about the chymical source of color in early modern England. This debate stemmed from Aristotle's belief that color is something transmitted from an object to the eye through a medium called the *diaphanos* or the 'transparent', creating an intromission theory of vision. (Whether light itself needs to be transmitted to the eye, or indeed whether we can see light in addition to color, was a disputed question among medieval scholastics.)[11] Thus, the color of the object is an intrinsic property, like its weight or taste. More specifically, scholastics believed that color was related in a variety of ways to the material's hot and cold qualities.[12] Hotness and coldness were among the most fundamental characteristics of matter in the sublunary area,

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[11] My thanks to Tawrin Baker for this point. See Tawrin Baker, "Colour in Three Seventeenth-Century Scholastic Textbooks," *Colour Histories: Science, Art, and Technology in the 17th and 18th Centuries*, ed. Magdalena Bushart and Friedrich Steinle (Berlin: Walter de Gruyter, forthcoming March 2015).

[12] "Related" here can mean a number of things, and the scholastics were meticulous in their distinctions. Some, who adhered to the pseudo-Aristotelian *De coloribus* and Galen's writings connected colors directly to the elemental bodies themselves; others thought color was the elemental qualities in some way. Others held that color was fundamentally a ratio of the body's density and rarity; density and rarity were affected by hot and cold, but not reducible in any sense to a substance's intrinsic hot and cold, and indeed the condensation of surrounding cold was a significant factor in determining the color of some phenomena. In any case, the issue was quite complex. My thanks to Tawrin Baker for these points.

something later mechanists would deny.[13] As Aristotle also promoted a causal thesis of perception, that "the capacity of a sensible quality to produce perception has as its causal basis the intrinsic nature of the quality," this meant that when applied to color, the inherent quality of a red object is what makes us perceive it as red.[14] Moreover, the object's inherent quality of redness also meant it could be a sign that the object had an inherent quality of heat as well.[15] Whiteness usually meant the object may have had an inherent cold quality.

In contrast, many Paracelsian chymists found such arguments absurd, arguing that color was not due to the object's hot and cold qualities, the most prominent chymists arguing that color derived from saline principles. Joseph Duchesne's (1544–1609) *Practice of Chymicall and Hermeticall Physick* (1605), translated by the English chymist Thomas Tymme, was the "first work in England to explore such debates, as well as the significance of salt in the Paracelsian system to an English audience."[16] The term 'salt' in the early modern period was a vague one, but usually encompassed a group of "solid soluble, non-flammable substances with characteristic tastes" and a crystalline structure.[17] Tymme first defined salt as "the chiefest means by whose help Nature bringeth forth al vegetables, Minerals, and Animals."[18] It was

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[13] Todd Stuart Ganson, "What's wrong with the Aristotelian Theory of Sensible Qualities?," *Phronesis,* 42, 3 (1997), 263-282, on 264.

[14] Ganson, "What's wrong," 276.

[15] This statement is made with the proviso that many Galeno-Aristotelian physicians would agree with this only insofar as it applies to animal bodies, and this sign might not be always reliable. See: Ian Maclean, *Logic, Signs and Nature in the Renaissance: The Case of Learned Medicine.* (Cambridge: Cambridge University Press, 2007), 151-152, 256. My thanks to Tawrin Baker for this point.

[16] Roos, *The Salt of the Earth,* 12.

[17] Jon Ecklund, "Salt," in *The Incompleat Chymist* (Washington D.C., 1975).

[18] Joseph Duchesne, *The practice of chymicall and hermeticall physicke*, trans. Thomas Tymme (London, 1605), fol. A3r.

seen as a "dry body, saltish, meerely earththy [*sic*] […] endued with wonderfull vertues of dissolving, congealing, cleansing, emptying, and with other infinite faculties," and as the substantive body in the trinity of spirit (mercury) and soul (sulphur).[19] Salts, owing to their geometric nature, were thought to give organized structure and solidity to matter. As Robert Boyle stated, "By what has been hitherto discours'd, we may also be assisted to judge of the Doctrine of the Chymists, who teach that in all Bodies, Coagulation, Stability, Hardness and Brittleness depend upon Salt."[20]

Duchesne then noted that "dogmatical Physitians have observed and noticed certain frivolous and light observations: as when they say, that in a white onion, or in white wine, a man may judge by the colour a great coldnesse, than in a red onion or in red wine."[21] However, he objected that these results were extrapolated to other observations. Duchesne noted that white arsenic (arsenic trioxide, made by sublimating arsenical soot from roasting ovens) due to its color should be cold, but instead "hid a most burning and deadly fire" (a hot quality, and indeed this compound is quite toxic). Further, sugar when heated (caramelized), though, "sweet, white and pleasant, doth hide in the innermost parts thereof, a wonderful blacknesse and sharpness, from whence may bee extracted most sharp liquors and waters," also symptomatic of hot qualities.[22] Thus Duchesne refuted Aristotelian principles of color, and instead argued that color proceeded from "the most thinne and aiery

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[19] Duchesne, *Practice*, fol. D1v.

[20] Robert Boyle, *Certain physiological essays and other tracts: Written at distant times, and on several occasions.* (London, 1669), 267.

[21] Duchesne, *Practice*, fol. E1v. For an extended discussion of salts and matter theory, please see Roos, *Salt of the Earth.*

[22] Duchesne, *Practice,* fol. E1v.

vapours, which lye hid in the Salt," so color stemmed from its saline components, and was not related to heat or cold at all.[23]

As an example of this, Duchesne utilized saltpeter or nitre. Nitre though "white as snow […] from which whitenesse, may be drawen infinite sorts of colours, most excellent to beholde" dying the body of the alembic with colors "of no less varietie, then are the flowers of the earth in the time of the Spring."[24]

Another publication, the *Surgeon's Mate* (1655) by John Woodall, the first Surgeon General of the East India Company, was a practical treatise concerning Paracelsian and naval medicine; it confirmed "all colours strange in salt are seen."[25]

The multiplicity of colors within certain salts as well as their crystalline structure also seemed to confirm they were building blocks of matter. The entire second part and most of the third of Duchesne's *Practice* concerns the "hermeticall" or spiritual nature of the "hermaphroditical" salt, an "ideal Platonic form of salt." Chymists like Duchesne, as well as Johann Glauber (1604–70), and Nicaise La Febvre (1610–1669) claimed that there was a "hermaphroditical" or formative salt believed to be responsible for the minerallogenesis, reproduction and the generation of matter.[26] As Norma Emerton has indicated, in the early modern period, "as the instrument of the form, as embodiment of the generative seed and spirit, and as the

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[23] Duchesne, *Practice,* fol. E1v.

[24] Duchesne, *Practice,* fol. E1v.

[25] John Woodall, *The Surgeon's Mate: Or Military and Domestique Surgery* (London, 1655), 219. Woodall's work appeared in three editions in the seventeenth century, was one of the first to advocate the efficacy of citrus fruits to treat scurvy in the English navy, and gave advice to surgeons in the form of verses that could be committed to memory. Woodhall also created regulations for the naval surgeons of the East India Company, and compiled lists of instruments and medicaments for their chests, many of them Paracelsian and chymical in origin. See Roos, *Salt of the Earth*, 26-28; J.H. Appleby, "New light on John Woodall, surgeon and adventurer," *Medical History* 25, 3 (July 1981), 251-268.

[26] Nicaise La Febvre, *Traicté de la chymie*. (Paris, 1660); *A Compleat Body of Chemistry* (London, 1664).

transmitter of mineral qualities including crystallinity, salt became the formative principle par excellence."[27] Thus, just as nitre heated in an alembic displayed all the colors it contained, Paracelsian chymists posited that salt that contained all potential qualities of matter within it.

Robert Boyle, Salts and Color

Although several English Paracelsian chymists continued to promote the ideas of Duchesne about salts and color, Robert Boyle refined their arguments as part of a larger research program at the Royal Society. The early Royal Society had an enduring interest in dyes and colors as part of its desire to compile an encyclopedic history of trades, and one of its earliest committees concerned dyeing. Not only would the Society record procedures involving new dyestuffs imported from the New World, but the intention to compile materials and techniques of medieval dyeing and color-making "that retained their place in the workshops until the eighteenth century" was likewise an aim.[28] For example, Nehemiah Grew's *The meanes of a most ample encrease of the wealth and strength of England* (1706-7) noted:

> In Barbary, they Dye their Scarlet Leather with Chermes Berrys, which they have from Spain. And we could manage this Berry, as well for Dying of Woolen Cloth; it would be 3 parts in 4, cheaper than Cochinele, and a better

[27] Norma Emerton, *The Scientific Reinterpretation of Form* (Ithaca and London, 1984), 214. This is also a central argument throughout Roos, *Salt of the Earth*.

[28] William Eamon, "New Light on Robert Boyle and the Discovery of Colour Indicators," *Ambix* 27, 3 (November 1980), 205.

Colour.[29]

"Chermes" were kermes, the pregnant females of the scale insects *Coccus ilicis*, which are gathered from evergreen oaks in North Africa and Southern Europe; the red dye is produced from their dried bodies.[30] In 1664, William Petty wrote *An Apparatus to the History of the Common Practices of Dying*, "a report on current techniques which outlined practices similar to those recorded in fifteenth and sixteenth-century recipe books," and he was well positioned to do so as the son of a clothier.[31] Later that year, Robert Boyle presented his book *Experiments and Considerations Touching Colours* to the Society, which was reviewed in the *Philosophical Transactions*.

In this work, Boyle first addressed the idea that salt was responsible for the structure of matter and its color in his study, citing Paracelsus:

we have taken notice of so many Changes made by the Intervention of Salts in the Colours of Mix'd Bodies, that it has lessen'd our Wonder […] *Paracelsus* himself directs us in the Indagation [investigation] of Colours, to have an Eye principally

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[29] Julian Hoppit, ed., *Nehemiah Grew and England's Economic Development: The means of a most ample increase of the wealth and strength of England 1706-7*, Records of Social and Economic History New Series 47 (Oxford, 2012), 39. Cochineal was a red dye derived from alum.

[30] Chymist George Starkey also discussed cochineal and dyeing in his letters to Samuel Hartlib published in *The Reformed Common-Wealth of Bees* (London, 1655), 15–40. The context is spontaneous generation, but also the connection between the dye of the plant and that of the insect living on the plant. (My thanks to Tawrin Baker for this point) In a similar manner, Martin Lister, an English naturalist who served as vice-president of the Royal Society, also did experiments with cochineal and kermes investigating their potential for dyes and the possibility they were spontaneously generated. He published his results in the *Philosophical Transactions*. See Martin Lister, "An Extract . . . Both Enlarging and correcting his former notes upon kermes; and withal insinuating his conjectures of cochineals being a sort of kermes," *Philosophical Transactions*, 7 (1672), 5059-5060; Anna Marie Roos, *Web of Nature: Martin Lister (1639-1712), the first arachnologist* (Leiden, 2012), 65, 110; Leonard Trengrove, "Chemistry at the Royal Society of London in the Eighteenth Century—V. Dyes," *Annals of Science*, 26, 4 (1970), 331-353.

[31] Eamon, "New Light," 205-6. For analyses of early modern recipe books, see Elaine Leong and Sara Pennell, "Recipe Collections and the Currency of Medical Knowledge in the Early Modern 'Medical Marketplace,'" in. M. Jenner and P. Wallis (eds.), *The Medical Marketplace and Its Colonies c. 1450-c 1850* (New York, 2007), 133-52.

upon Salts, as we find in that passage of his, wherein he takes upon him to Oblige his Readers much by Instructing them […] *Alios* (says he) *Colorum similis ratio est…quod scilicet colores omnes ex Sale prodeant. Sal enim dat colorem, dat Balsamum.* [On other occasions (says he) that the nature of salts is similar […] because of course all colours derive from salt. For salt produces colour, and produces a healing balm].[32]

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However, as Boyle was a corpuscularian who wished to dethrone chymical elements such as the Paracelsian *tria prima* of salt, sulphur and mercury from their status as true elements or principles of nature, he did not think salt itself was responsible for color.[33] Boyle not only rejected Aristotle's conception of the form and qualities of matter (hot, dry, wet, cold), as well as the peripatetic elements of earth, air, fire and water, but he also dismissed the Paracelsian *tria prima* in favor of a purely mechanical view of nature.[34] Boyle posited that the explanation of natural occurrences on the micro- and the macro-level should be understood solely in terms of "particles of matter, their motion and interaction," terming these particles corpuscules.[35] As Domenico Bertoloni Meli has pointed out, in *The Origine of Formes and Qualities*, Boyle "argued that colours are not inherent qualities of a body due to its substantial form; rather they derive from the mechanical texture of its

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[32] Boyle, *Colours,* 260. Michael Hunter and Edward B. Davis noted in their edition of Boyle's works that Boyle referred to Paracelsus's *De mineralibus liber*, published in volume 2 of his *Opera omnia medico-chemico-chirurgica* (1658), "though Boyle uses a different edition." See, "Colours and Cold, 1664-5," in *The Works of Robert Boyle, Electronic Edition*, ed. Michael Hunter and Edward B. Davis (London, 2003), 4: 130, footnote one. My thanks to Tom Holland for his assistance with the Latin translation.

[33] For an extended discussion of corpuscularianism, see Fokko Jan Dijksterhuis's chapter concerning the wide variety of early modern corpuscular conceptions of color. See also Peter Anstey, *The Philosophy of Robert Boyle* (London, 2000), p. 29.

[34] Robert Boyle, *The Skeptical Chymist* (London, 1661), 13-17, 347-52.

[35] J.J. MacIntosh, and Peter Anstey, "Robert Boyle," *The Stanford Encyclopedia of Philosophy* (Fall 2014 Edition), http://plato.stanford.edu/archives/fall2014/entries/boyle/. Boyle did not go so far as to call these particles atoms in the sense of Gassendi or the Greek Epicureans.

minute parts and can be easily changed by changing that texture."[36] Boyle also considered a report by Sir John Finch that indicated that a blind man could tell the difference between colors by touch, suggesting the texture of the substance had a role.[37] As a result, Boyle argued that *saline menstrua* or alkalis and acids derived from salts "may change the Colour of a Body […] by Dislocating the Parts, and putting them out of their former Order into another, and perhaps also altering the Posture of the single Corpuscles as well as their Order or Situation in respect of one another."[38] (An example of a *saline menstruum* would be nitre or potassium nitrate which could be distilled with fuller's earth 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.) In this manner, these

> very Minute, Active, and Variously Figur'd Saline Corpuscles, Liquors so Qualify'd may well enough very Nimbly alter the Texture of the Body they are employ'd to Work upon, and so may change the form of Asperity, and thereby make them Remit to the Eye that Light that falls on them, after another manner than they did before, and by that means Vary the Colour.[39]

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[36] Domenico Bertoloni Meli, "The Colour of Blood: Between Sensory Experience and Epistemic Significance," in *Histories of Scientific Observation*, ed. Lorraine Daston and Elizabeth Lunbeck (Chicago, 2011), 121. Newman, *Atoms and Alchemy,* 184-5, also mentions Boyle's attribution of color to corpuscular texture, as does Tawrin Baker's chapter in this volume.

[37] Meli, "Colour of Blood," 121.

[38] Boyle, *Colours,* 60. On page 60-1, Boyle continues, "And that also such Liquors, as we have been speaking of, may greatly Discompose the Textures of many Bodies, and thereby alter the Disposition of their Superficial parts, the great Commotion made in Metalls, and several other Bodies by Aqua-fortis, Oyl of Vitiol, and other Saline Menstruums, may easily perswade us, and what such Vary'd Situations of Parts may do towards the Diversifying of the manner of their Reflecting the light, may be (p. 61) Gues'd in some Measure by . . .the Experiments . . . as the Producing and Destroying Colours by the means of subtil Saline Liquors, by whose Affusion the Parts of other Liquors are manifestly both Agitated, and likewise Dispos'd after another manner than they were before such Affusion."

[39] Boyle, *Colours,* 54.

Boyle then wrote,

> if we please to consider Colours, not as *Philosophers*, but as *Dyers*, the concurrence of Salts to the striking and change of Colours, and their Efficacy, will, I suppose, appear so considerable, that we shall not need to quarrel much with *Paracelsus*, for ascribing in this place (for I dare not affirm that he uses to be still of one Mind) the Colours of Bodies to their Salts.[40]

In other words, rather than consider salt as a philosophical substance, a hermaphroditical salt or Paracelsian element, Boyle wished to study the role of saline chymistry in accordance with the Royal Society's interests in dyeing. As William Eamon has noted, Boyle apparently learned of color changes produced in vegetable juices from John Parkinson's herbal *Theatrum Botanicum* (1640).[41] To test his hypotheses about the effects of saline menstrua upon color, Boyle reacted spirit of salt (hydrochloric acid) as well as spirit of urine (ammonium carbonate) upon red roses, buckthorn berries (*Rhamnus cathartic*a, which produced a yellow dye used by painters, leather dressers and bookbinders), as well as snowdrops and jasmine flowers.[42] Whereas the acid only deepened the red colors of flowers, the alkalis turned the white flowers deep green.

Boyle continued his experiments exploring

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[40] Boyle, *Colours,* 261.

[41] Eamon, "New Light," 206.

[42] Eamon, "New Light," 206.

> how much changes of Colours effected by Salts, depend upon the particular Texture of the / Colour'd Bodies, has been afforded me by several *Yellow* Flowers, and other Vegetables, as Mary-gold Leaves, early Primroses, fresh Madder etc.[43]

However, as only primroses displayed any substantial color change, losing their color when reacted with the saline menstrua, Boyle concluded: "the effects of a Salt upon the Juices of particular Vegetables do very much depend upon their particular Textures."[44] In experiment twenty-nine, where he continued his work with vegetable juices, he stated "something may be guess'd at about / some of the Qualities of the Juices of Vegetables, by the Resemblance or Disparity that we meet with in the Changes made of their Colours."[45] In other words, saline menstrua and their chymical reactions with flowers could be utilised as a diagnostic tool to understand the flowers' chymical composition. Moreover, Boyle was indeed the first to realize all acids turned blue vegetable juices red, and all alkalis turned them green.

In his *Essay about the Origine and Virtues of Gems* (1672), Boyle expanded his research connecting saline chymistry and color to consider the role of salts as underlying the structure of matter, using gems as a case study. The work "really has very little to do with gemstones except as they happened conveniently to provide crystals for Boyle's inquiries in to the solid state of matter."[46] Boyle, like his

[43] Boyle, *Colours,* 264-5.

[44] Boyle, *Colours,* 267.

[45] Boyle, *Colours*, 269-70.

[46] John Sinkankas, *Gemology: An Annotated Bibliography* (Metuchen, NJ, 1993), 863.

contemporary John Webster, was a "pioneer in the study of minerals based on experimentation"; and in his treatise, he was the one of the first to express the conviction that "gems must have solidified from the liquid state."[47] Boyle postulated that the crystalline form of gems resembled that of salts that crystallized from solution, something he confirmed doing experiments with crystal growth. Boyle wrote,

> The origin assigned to gems may be countenanc'd by the *External figuration* of divers of them. For we plainly see, that the corpuscles of Nitre, Allom, Vitriol, and even Common Salt, being suffer'd to coagulate in the Liquors they swam in before, will convene into Cristals of curious and determinate shapes.[48]

When nitre crystallized in a vessel where it was free to grow in the liquid, it could acquire this shape. Not only did gems evince a crystalline shape like salts, but Boyle also postulated that gems and other "medical stones" derived "various colours" and would be "imbued with Virtues by subterranean Exhalations and other steams," from adjacent metals and from mineral salts as they solidified.[49] To test his hypothesis, he did a series of experiments where he succeeded in tinging "native Crystal with different colours" from the fumes of volatile minerals and salts.[50] Clearly, for Boyle, although he did not accept salt as an element responsible for color, he did propose that

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[47] Henry Miers, *The Growth of a Crystal Being the Eighteenth Robert Boyle Lecture* (London, 1911), 8.

[48] Robert Boyle, *An Essay about the Origine and Virtues of Gems (Facsimile of the 1672 edition).* Contributions to the History of Geology, vol. 7 (New York, 1972), 7-8. As I do not have consistent access to the Davis/Hunter edition of Boyle's *Works*, I will use this edition throughout the paper.

[49] Boyle, Gems, 166, 170.

[50] Boyle, *Gems*, 170.

saline menstrua and effluvia, and their corpuscular interactions, played a key role in the creation of color and color changes in the natural world.

Robert Hooke and an Elaboration of Color and Saline Chymistry

In his *Micrographia* (1665), Robert Hooke built upon Boyle's speculations about saline menstrua and color, which was not surprising as he served as Boyle's laboratory assistant from 1658 to 1662. Whereas Boyle was more circumspect regarding the precise nature of these corpuscular interactions, Hooke advanced a number of hypotheses in his *Micrographia* about the particular mechanisms involved in the reaction between "saline liquors" and colored substances as well as about color change.

Hooke initially trained as an artist, as apprentice to Sir Peter Lely, so he was familiar with the process of mixing paint and pigments, and frequently noted the effects of pigments in his diary. For example, he observed on 4 April 1674 that "painting with Lake on Red Lead made a most orientall colour for flowers" and on 22 January 1678 or 1679, he went to Garraways coffee house expressly to "talk of Dye colours."[51] Hooke also experimented with painting colors on marble, following the processes invented by Prince Rupert of Bavaria.[52] In his *Colours*, Boyle also discussed painting techniques and what we would today think of as primary colors, writing:

[51] *The diary of Robert Hooke, M.A., M.D., F.R.S., 1672-1680,* ed. Henry W. Robinson and Walter Adams (London, 1935), 97, 394.

[52] *The diary of Robert Hooke,* 212. Hooke wrote about his attempts to paint marble on 18 January 1675/6.

> that there are but few Simple and Primary Colours (if I may so call them) from whose Various Compositions all the rest do as it were Result. For though Painters can imitate the Hues […] of those almost Numberless differing Colours that are to be met with in the Works of Nature, and of Art, I have not yet found, that to exhibit this strange Variety they need imploy any more than *White*, and *Black*, and *Red*, and *Blew*, and *Yellow*. [53]

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He then stated that "'tis of advantage to the contemplative Naturalist, to know how many and which Colours are Primitive (if I may so call them) and Simple, because it […] eases his Labour by confining his most sollicitious Enquiry to a small Number of Colours upon which the rest depend."[54] Boyle's interest in the primary or primitive colors also had some of its origins in the Flemish Anselm Boethius de Boodt's work on gems, in which De Boodt promoted the theory of the three painter's primaries—red, yellow and blue—from which secondary colors could be derived. Boyle "sang its praises," and Robert Hooke too owned a copy.[55]

De Boodt's interest in primary colors, Boyle's work with saline menstrua, chymistry and color, and Hooke's experience with artists' pigment mixing combined to form the basis of Hooke's ideas about color in his *Micrographia*. Firstly, Hooke's

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[53] Boyle, *Colours,* 219-220; Alan Shapiro, "Artists' Colors and Newton's Colors," *Isis* 85, 4 (December 1994), 600-630, on 614.

[54] Boyle, *Colours*, 232.

[55] Shapiro, "Artists' Colors," 606. Shapiro also discusses the contributions of François d'Aguilon to the discovery of the three primaries in 1613, stating the Jesuit natural philosopher formulated his color theory most clearly. See also John Gage, "Colour in History: Relative and Absolute," *Art History* 1 (1978), 104-130; and Gage, "A 'Locus Classicus' of Colour Theory: The Fortunes of Apelles," *Journal of the Warburg and Courtauld Institutes,* 44 (1981), 1-26. Gage's invaluable *Colour and Culture: Practice and Meaning from Antiquity to Abstraction* (London, 1993) should also be consulted for early modern color theory. See also Charles Parkhurst, "Aguilonius' Optics and Rubens' Color," *Nederlands Kunsthistorisch Jaarboek*, 12 (1961), 35-49; Parkhurst, "A Color Theory from Prague: Anselm de Boodt, 1609," *Allen Memorial Art Museum Bulletin*, 29 (1971), 3-10.

knowledge of pigments ground in a mortar or mixing on a palette made him realize from microscopic observation that whilst some color changes were due to physical changes in pigments, most were chymical in nature. As an example of a physical color change caused by grinding of pigments, Hooke noted that

> if you take blue smalt, you shall find, that to afford the deepest Blue, which caeteris paribus has the greatest particles or sands; and if you further divide, or grind those particles on a Grindstone, you may by comminuting the sands of it, dilute the Blue into as pale a one as you please.[56]

There was a "significant lacuna in the 17th-century painter's palette," primarily "the lack of the so-called 'strong colours'; Only a handful of bright, stable and workable colours existed."[57] And when pigments were physically mixed, the new color was usually less brilliant than original components. This was particularly the case with smalt, which was ground blue cobalt-containing glass. When poured into cold water, it disintegrated into particles, which were ground into a pigment that substituted for natural ultramarine. Because its particles were transparent, it had low covering power, so for use as a pigment, it had to be coarsely ground or the color became faded.[58]

Hooke then continued, noting there are other "Blues […] which will not be diluted by grinding" because they cannot be separated into smaller particles other than by the operation of the fire (distillation) or some other 'dissolving [saline]

Comment [NF7]: An insertion or in original text?

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56 Robert Hooke, *Micrographia* (London, 1665), 71.

57 Jonathan Janson, "Vermeer's Palette," Essential Vermeer. http://www.essentialvermeer.com

58 Janson, "Vermeer's Palette: Smalt," Essential Vermeer. http://www.essentialvermeer.com/palette/palette_smalt.html

menstruum'."[59] In other words, Hooke realized some color changes were inherently chymical. He noted that all kinds of color, "whether precipitated, sublim'd, calcin'd, or other wise prepar'd, are hardly changed by grinding […] the smallest particles which I have view'd with my greatest Magnifying-Glass […] appear very deeply ting'd with their peculiar colours."[60]

Hooke thus thought it necessary to consider chymical mechanisms underlying color changes. Clearly influenced by Boyle's work with saline chymistry and color, Hooke postulated that the alteration of hues occurred via either the saline menstrua "altering the refraction of the liquor in which the colour swims […] or the coloured particles," or "by uniting with some particular corpuscles of the tinging body […] or some other body that is already joyn'd with the tinging particles," or by "dissolving" or precipitating the particles responsible for color. [61]

Hooke's interest in these matters was also influenced by his theory, outlined in the *Micrographia*, that color resulted in the modification of white light by refraction (in contrast to Newton's theory that white light was the superposition of all colors). Hooke examined "Muscovy" glass or thin leaves of mica under the microscope. He saw little pits distributed on the glass, and the formation of colored rings, displaying prominent hues of blue and red, though other colors were formed in what would later be called Newton's rings. Chapman noted that Hooke repeated the experience with two pieces of looking-glass plate polished to permanent optical flatness, finding he obtained a similar color fringe sequence. "This suggested to him that the four optical planes of the glass and their four inner reflecting planes within the glass produced

Comment [NF8]: Reference needed if quote.

[59] Hooke, *Micrographia*, 71.

[60] Hooke, *Micrographia*, 71.

[61] Hooke, *Micrographia*, 70.

multiple refractions and reflections, causing the colours."[62]

Since the physical properties of light also seemed to originate in some sort of motion, such as combustion or rubbing, Hooke also concluded that light was vibrative in nature, travelling from its source to the eye of the beholder by pulses or waves. Hooke postulated that one side of the light wave, when striking obliquely upon any optical surface produced red light, while the other produced blue. As Alan Chapman concluded:

> Red and blue therefore were simply the products of the inevitable angles and changing planes and forces of impact which the extreme axes of a sinusoidal wave must penetrate a transparent optical surface, being thereby the result of curves and planes in collision. The intermediate yellows, greens, or oranges were in essence vibrative resonances between the two, as each individual wave pulse penetrated a medium from an ever changing angle of impact.[63]

Comment [NF9]: Possibly a word missing from the quote here? „(...) impact **from** which the extreme (...)"

From these experiments, Hooke then went on to develop his conclusion that color was "an oblique and confus'd pulse of light," and thus a mixture of projected light might only involve these two contraries of red and blue, and the rest of the intermediate colors resulted simply from these contraries being intermixed.

To demonstrate this hypothesis at the corpuscular microlevel, Hooke referred the reader to the diagram below (Fig. 7) of a vessel ABCD holding a liquor containing

[62] Allen Chapman, *England's Leonardo: Robert Hooke and the Seventeenth-Century Scientific Revolution* (Bristol and Philadelphia, 2005), 190. For a more detailed view delineating the differences between Hooke's color theories for refracted light and for thin films see Alan Shapiro, "Kinematic Optics: A study of the wave theory of light in the seventeenth century," Archive for History of Exact Sciences 11, 2/3 (1973), 134-266, particularly 189-201.

[63] Chapman, *England's Leonardo,* 190.

colored particles EE, FF, GG, HH, etc. He also noted that these corpuscles "are of such a nature as does more easily or more difficultly transmit the rays of light than the liquor; if more easily, a Blue is generated, and if more difficultly, a Red or Scarlet."[64] As Shapiro has indicated,

> to explain how colours are generated, Hooke adopted the same explanation as he used for thin films, that of a duplicated or split pulse front in which the weaker pulse either precedes the stronger one to produce blue or follows it to produced red and yellow […] if the tinging particles slow down the light pulses, then red is generated, for as a pulse proceeds through the coloured particles of the body, a weak pulse PP is gradually formed following the stronger one OO; but if light moves more swiftly through the tinging particles, then blues are generated.[65]

Hooke then referred the reader to another figure (Fig. 8) showing a colored corpuscle, which has a greater refraction than its solution. If CD is a lightwave propagated through the medium, it will be impeded by the corpuscle, refract, and would lag behind lightwaves that did not encounter the colored particles. Hooke concluded that as the lightwaves "

> do meet with more and more of these tinging particles in their way, by so much more will the pulse of light further lagg behinds the clearer pulse, or that which has few refractions, and thence the deeper will the colour be and the

[64] Hooke, *Micrographia*, 68.

[65] Alan Shapiro, *Fits, Passions, and Paroxyms* (Cambridge, 1993), 102-3.

fainter the light trajected through it.[66]

This was because "not onley many waves are reflected from the surfaces" of the corpuscles, but those waves that "did get through" the medium "are very much disordered."[67]

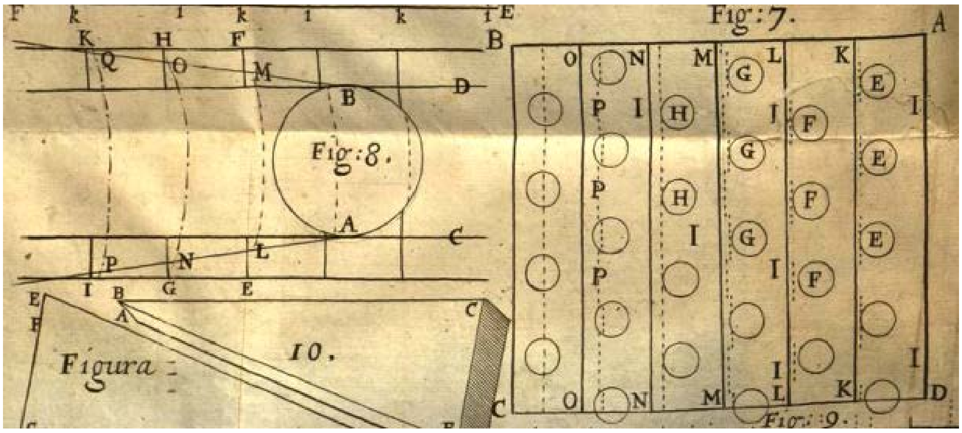

Figure One: Robert Hooke's diagrams of light pulses travelling through vessels with colored particles from the *Micrographia* (1665), between pages 60 and 61. Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

Comment [NF10]: - to AR - we are awaiting the journal editors' decision re: image/caption placement – hence lines yellow.

But how could Hooke prove his hypothesis about the colored particles and red and blue light ? He used Boyle's experiments with saline chymistry. Hooke claimed that "all the experiments about the changes and mixings of colours related in the Treatise of Colours, produced by the Incomparable Mr Boyle […] so easily and naturally flow from these principles."[68] Hooke first observed "saline menstruums were most

66 Hooke, *Micrographia*, 69.

67 Hooke, *Micrographia*, 69.

68 Hooke, *Micrographia*, 69.

operative upon [plant] colours that were Purple," indicative of the fact that anthocyanin plant pigments that give reds, blues and purples are significantly influenced by the pH of the medium in which they are dissolved. [69] Making reference to the "twentieth experiment" in Boyle's *Experiments and Considerations touching Colours*, Hooke noted that Boyle had demonstrated that the purple color of violets may be turned into a green by "alcalizate salts" and to red by a saline acid.[70] First, Hooke noted that the purple color consisted of the primary red and blue colors, and when the blue "is diluted, or altered, or destroy'd by acid Salts," the red becomes predominant. But, "when the Red is diluted by Alcalizate Salts and the Blue heightened, there is generated a Green; for of a Red diluted, is made a Yellow, and Yellow and Blue make a Green."[71]

We recall that Hooke postulated that one side of the light wave, when striking obliquely upon any optical surface produced red light, while the other produced blue. Thus, "those Saline reflecting bodies" that dilute the color of blue light, deepen the color of red light, and vice versa.[72] To answer objections that not all diluted reds would produce yellows (and here he was perhaps also addressing De Boodt's idea that yellow was a primary color), Hooke noted that "Saffron affords us a deep Scarlet tincture, which may be diluted into as pale a Yellow as any […] by making a weak solution of the Saffron by infusing a small parcel of it into a great quantity of liquor."[73] Hooke was clearly aware of debates about primary colors among artists.

[69] Hooke, *Micrographia*, 79. Joy Alkema and Spencer Seager, "The Chymical Pigments of Plants," *Journal of Chymical Education,* 59, 3 (March 1982), 182-6, on p. 184.

[70] Hooke, *Micrographia*, 69.

[71] Hooke, *Micrographia*, 69.

[72] Hooke, *Micrographia*, 69.

[73] Hooke, *Micrographia*, 70.

His knowledge of grinding and preparing pigments made him realize that not all color changes could be caused by mixing pigments, and that some fluctuations happened at the chymical level. To explain these chymical changes, he used Boyle's experiments with saline menstrua causing color change to support his own conclusions reached with his optical experiments. Hooke's theory of color in the *Micrographia* was thus a form of corpuscularian optics informed by artistic practices and his observations when mixing paint pigments.

After Boyle and Hooke published reports on their work reacting saline acids and bases with plants to observe color changes, members of the Royal Society continued to research the chymical nature of flower color and color changes using a variety of saline menstrua. In 1670, the botanist John Ray reported in the *Philosophical Transactions* that he had stained yellow chicory flowers red with formic acid produced by disturbing "an ant hill with a stick," and then casting the flowers upon the ants' nest.[74] Ray had been the first to distill formic acid, and was testing it as a chymical diagnostic tool. Upon hearing Ray's report, Henry Oldenburg, the secretary of the Royal Society, also wrote naturalist Martin Lister a query in a letter of the eighteenth of January 1670/1 asking whether he had observed the same behavior, and "how these flowers […] come to be so stained."[75] Lister subsequently replied that the pismires' acid made red flowers "of a fairer red," and "alcaly's quite alter and change the Colours of the same flowers […] from red to green."[76] He noted that he had

Comment [NF11]: Is it possible to be more specific? If not, then no change needed.

[74] John Ray "Extract of a Letter . . .Concerning Some Un-Common Observations and Experiments Made with an Acid Juyce to be Found in Ants," *Philosophical Transactions,* 5 (1670), 2064.

[75] Henry Oldenburg, *The Correspondence of Henry Oldenburg*, ed. A. Rupert and Marie Boas Hall, 14 vols. (Madison, 1970), 7:403.

[76] Martin Lister, "Some Observations, Touching Colours […] ," *Philosophical Transactions,* 6 (1671), 2132-33.

> tried concerning Cochineal which of itself is red, that upon the affusion of the Oyl of Vitriol, that is, an Acid salts, it strikes the most vivid crimson that can be imagined; and with … Alcalys, it will be again changed into an obscure violet twixt a violet and a purple.[77]

The Work of Nehemiah Grew and Robert Plot: Salt and Plant Color

An exploration of the connection between plant color, salts and saline acids characterized the botanical work of Nehemiah Grew, also conducted under the auspices of the Royal Society. As historian P. Anker has argued, "Inspired by the neo-Epicurean hypothesis that atoms have geometric shapes, Grew argued that organic clusters grew geometrically thanks to the interactions and connections of the atoms. Geometry was nature's language."[78] Grew's extensive macroscopic and microscopic research and the series of plates he drew in the *Anatomy of Plants* revealed to him that plants had a fundamental geometrical structure, or that "the Essential Constitutions of the said Parts are in all Plants the same."[79] In his studies, Grew concluded that the "*Leaves* of most *Plants*, have a Regular *Figure*, and this Regularity, both in Length and Circuit," were always definable in terms of the "*Arches* or *Segments* of Several *Circles*."[80]

At the microscopic level, leaves also had a mathematical pattern of fibres that

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77 Lister, "Touching Colours," 2133.

78 P. Anker, "The economy of nature in the botany of Nehemiah Grew (1641-1712)," *Archives of Natural History,* 31, 2 (2004), 191-207, on 196.

79Grew, *Anatomy of Plants*, 1.

80Grew, *Anatomy of Plants*, 150.

underlay their structure, leading Grew to assert "we must not only consider the visible *Mechanism* of the *Parts*, but also the *Principles* of which they are composed; wherewith, Nature seems to draw her first *Strokes*."[81] For him, the key to the plant's regular structure, "the chief Governing *Principle*" lay in the "*Saline* whether *Alkaline*, *Acid*, or of any other Kind: being in some sort as the *Mold* of a *Button*, to which the other *Principles*, as its *Attire*, do all conform. Or the *Salts* are, as it were, the *Bones*; the other *Principles*, as the *Flesh* which covers them."[82]

Grew first argued that plants were saline in nature from observing the phenomena of concretions in distilled waters and vinegars, which he stated had "always a tendence to *Vegetation*."[83] These substances consisted of mineral lees whose structure of branching crystals had a similarity to "*Vegetable Principles* […] the *Saline* […] the chief."[84] Grew also argued that fertilizers that nourished plants contained salt, suggesting by analogy that plants were also made of saline substances.[85] In order to better understand how salts combined to form the leaf structure, he then sought to classify the types of vegetative salts. As I have indicated previously, Grew argued 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*."[86] Marine salts produced right angles, and alkaline salts were square at one end, and pointed at the other; placed end

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[81]Grew, *Anatomy of Plants*, 157.

[82]Grew, *Anatomy of Plants*, 158.

[83] Grew, *Anatomy of Plants*, 158.

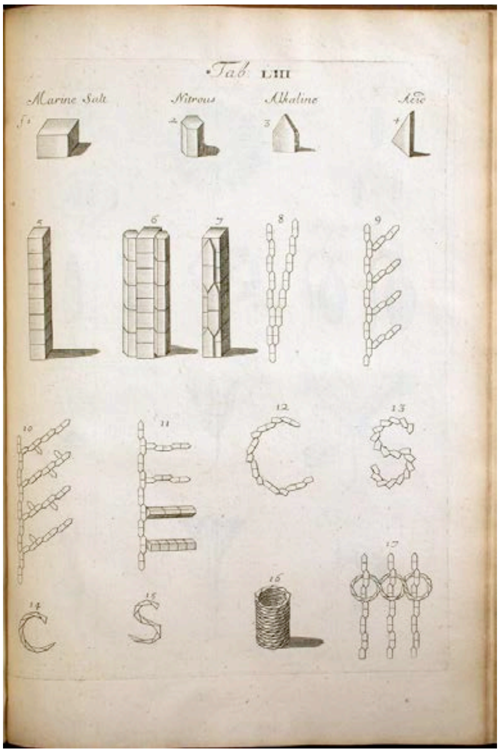
[84] Grew, *Anatomy of Plants*, 158.

[85]Grew, *Anatomy of Plants*, 158.

[86]Grew, *Anatomy of Plants,* 159. Roos, "Nehemiah Grew and Saline Chymistry," 54-55.

to end, alkaline salts would form oblique angles.[87] Grew demonstrates how the indented shape of a leaf or the cylinder stem is created by the angles of the salt crystals interacting (see figure two). Although the 'c' and sigmoid shapes formed by the salts that are portrayed in Grew's table were not actual letters, at least in terms of geometric structure, he clearly considered salt crystals as part of "nature's language." Indeed, Grew noted "thus doth *Nature* every where γεωμετρειν [measure]," a possible reference to Plato's statement that God created all things in number, weight, and measure; for Grew, the mathematics of salt crystals showed nature's underlying architecture. [88]

Comment [NF12]: Reference needed, thanks.



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[87] Grew, *Anatomy of Plants*, 159.

[88] Grew, *Anatomy of Plants*, 160. The Greek is the infinitive, "to measure," used with English "doth." It refers to what geometer and land surveyors do. My thanks to Professor Richard Sharpe for his assistance with the Greek grammar.

Figure Two: Interactions of salts to produce plant structures, Table LIII, in Nehemiah Grew's *Anatomy of Plants* (1682). Image courtesy History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.

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. The idea of a salt or aerial nitre in the air derived from the theories of Czech chymist Michael Sendivogius (1556-1636) who stated thunder and lightning were caused by an aerial nitre reacting with sulphurous parts of the atmosphere, resulting in the bangs and sulphurous smells we encounter after a lightning storm (ozone).[89] The aerial nitre was also thought to have formative power, Grew noting "*Dew* or *Water* on *Windows* or Plan and Smooth *Tables*, by virtue of a *Nitro-Aerial Salt*, is often frozen into the resemblance of little *Shrubs*," thus connecting the substance to the saline structure of plants.[90] Grew may have been thinking of the chymical procedure 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. Salt crystals would arise from the ashes, which resembled a stem, leaves and flowers, an apparition of the plant that had been submitted to combustion. The salt was thus thought to contain the essential virtue of the plant, which could be harnessed to use in medicines. Grew prepared salts of plants himself in this manner, donating them to the Royal Society repository, and mentioning them in the catalog of the repository's contents that he compiled.[91]

[89] A. Rupert Hall, "Isaac Newton and the Aerial Nitre," *Notes and Records of the Royal Society*, 52, 1 (January 1998), 51-61; Allen Debus, "The Paracelsian Aerial Niter," *Isis*, 55 (1964), 43-61.

[90] Grew, *Anatomy of Plants*, 158.

[91] Nehemiah Grew, *Musaeum Regalis Societatis* (London, 1681), 352-3.

Robert Boyle wrote in his *Suspicions about some Hidden Qualities of the Air* (1674) that atmospheric air was likewise impregnated with such salts, and that volatile salts in the air could cause color changes in a variety of substances. As Meli has demonstrated, Boyle was part of an experimental programme in the Royal Society to examine changes in the color of blood when exposed to air, and Boyle dedicated his *Natural History of Humane Blood* (1684) to John Locke, who in the mid 1660s "was interested in the colour change of blood and believed it was due to nitre in the air."[92] In his *Suspicions*, Boyle himself performed a number of experiments with vitriols, or metal sulphates, which suggested to him that something within the air affected chymical reactions. The air had a "pregnant influence" upon vitriols, one which he noticed was "considerably diversified by Circumstances" such as the time of day and relative humidity.[93] Thus, he subsequently did experiments with copper sulphate ($CuSO_4$) or "Colcothar Vitriol of Blew" that was variously calcined, or subjected to heat, while exposed to air.[94] Anhydrous copper sulphate in this state is a white salt and hygroscopic; in other words, the salt will immediately combine with water, and if it is exposed to the atmosphere, it will combine with water in the air to form the hydrated compound ($CuSO_4 \bullet 5H_20$), which is a bright blue.[95] This color shift caused

Comment [NF13]: The chemical names are fine to use, of course, but the black dot is unclear – is this intentional?

[92] Meli, "Colour of blood," 121.

[93] Robert Boyle, *Tracts containing I. suspicions about some hidden qualities of the air: with an appendix touching celestial magnets and some other particulars : II. animadversions upon Mr. Hobbes's Problemata de vacuo : III. a discourse of the cause of attraction by suction* (London, 1674), 56-7. I explored these changes as part of a different analysis of Boyle's beliefs about solar and lunar astrological emanations in *Luminaries in the Natural World: The Sun and Moon in England, 1400-1720* (Bern and Oxford, 2001), 196-7.

[94] "Colcothar of vitriol" was the salt of vitriol. Blue vitriol was the "sulphate of copper." *OED.*

[95] Lee R. Summerlin and James L. Ealy, Jr., "Demonstration of the dehydration of copper (II) sulfate pentahydrate," in *Chymical demonstrations: a sourcebook for teachers,* 2 vols. (Washington D.C., 1988), 2:69.

Boyle to postulate that there might exist "some *vital substance*, if I may call it, diffus'd through the Air, whether it be a *volatile Nitre*, or rather some *yet anonymous* substance."[96] Although Boyle admitted it might be a

> boldness to *affirm*, that any, or perhaps all of these together, will have any interest in the production of the Salt […] yet in things new and exorbitant, it may be sometimes rash and peremptory to *deny*, even such things as cannot, without rashness, be positively asserted.[97]

Boyle, in a discourse about shining diamonds appended to his *Colours*, speculated about the effects of atmospheric salts on changing the color of gemstones, particularly on softer stones such as turquoise. Turquoise in fact does change color from sky blue to green as it oxidises and is exposed to body oils. Boyle referred again to De Boodt's treatise on gemstones, stating

> And though I admir'd to see, that I know not how many Men otherwise Learn'd, should confidently ascribe to Jewels such Virtues as seem no way compatible to Inanimate Agents, if to any Corporeal ones at all, yet as to what is affirm'd concerning the Turquois's / changing Colour […] so Judicious a Lapidary as *Boetius de Boot* who upon his own particular and repeated Experience delivers so memorable / a Narrative of the Turquois's changing Colour, that I cannot but think it worth your Perusal.[98]

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[96] Boyle, *Tracts: Suspicions about hidden qualities,* 27.

[97] Boyle, *Tracts: Suspicions about hidden qualities*, 59.

[98] Boyle, "A Short Account of Some Observations Made by Mr Boyle About a Diamond that Shines in the Dark" (London, 1664), a tract appended to *Colours*, 406-8.

Boyle speculated,

> it seem'd not impossible, that certain warm and Saline steams issuing from the Body of a living man, may by their plenty or paucity, or by their peculiar Nature, or by the total absence of them, diversifie the Colour, and the splendor of so soft a Stone as the Turquois.[99]

In much the same vein, Grew apparently thought aerial salts or steams caused plant and flower color. He first wrote a lecture and created a set of experiments exhibited to the Royal Society on 13 April and 1 June 1676 concerning "luctation" or chymical reactions such as ebullitions, exhalations or effervescence, listing twenty-three experiments testing various parts of minerals, animals and plants (such as seeds or stems) with acid and alkalis, noting the reactions that occurred in an attempt to determine if their composition was acid or alkali.[100] He used the results he obtained as the basis for his next paper, *A Discourse of the Colours of Plants*, which was read before the Royal Society in 1677. Grew stated that the green color of leaves was a chymical precipitate that formed when the acidic salts and sulphurs that plants contained mixed with volatile alkali salts in the air.[101] He indicated that similar chymical reactions controlled the colors of flowers.

Grew isolated the chymical substances within plants that he believed caused the green color of leaves. Much in the vein of John Ray, Grew poured sulphuric and

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[99] Boyle, *Diamond,* 406.

[100] Grew, *Anatomy of Plants*, 238-254.

[101] Grew, *Anatomy of Plants*, 271.

nitric acid on "several parts of vegetables" to observe color changes. He found that they made less of a chymical 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.[102] 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. Putting spirit of hartshorn on tinctures of borage flower turned them "*verdegreese Green*," and when it was dropped on green leaves, the color did not change at all, leading him to postulate that there was some alkali "or like *Salt* in the *Aer*, which is *predominant* in the production of *Green* in the *Leavs* of *Plants*."[103]

Grew also argued that the colors of flowers were produced by differing combinations of volatile alkaline salts and substances within the plant. Such knowledge of the salt chymistry of plants could be used to control plant coloration.[104] His suggestion was to start with the "tender and Virgin seed," which because of its small size would be more affected by the tinctures of the soil, claiming all the "strange varieties in *Carnations*, *Tulips*" and other striped or variegated blooms were "made this way."[105] Changing the soil, or transplanting seeds from one bed to another would also lead the plant to be "superimpregnated with several Tinctures."[106] Lastly, mixing soil with differing salts that would "concur with the *Aer*, to strike or precipitate their *Sulphur* into so many several *Colours*," would "bring even Natures

[102]Grew, *Anatomy of Plants,* 271. Roos, "Nehemiah Grew and Saline Chymistry," 61.

[103]Grew, *Anatomy of Plants,* 276.

[104] Roos, "Nehemiah Grew and Saline Chymistry," 63.

[105]Grew, *Anatomy of Plants,* 278. The reason for the striping is the tulip bulb becomes infected with Mosaic Virus. It is possible Grew wished to create the striped tulips so prized during the tulip mania in the seventeenth-century Netherlands.

[106]Grew, *Anatomy of Plants,* 278.

Art of *Painting*, in a great part, into our own power."[107] 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 chymical pigments.

Comment [NF14]: Are these quotations or simply being emphasized? Style guide advises double quotation marks only for quotations – please let us know, we can make the changes.

Grew also speculated about the saline nature of animals and their bodies, particularly their feathers and fur, claiming for instance that the structure of feathers was also like that of nitre crystals. Because birds had no organ for the evacuation of urine, "the urinous parts of their blood were evacuated by the habit or skin, where they produce and nourish feathers."[108] Experiments demonstrating the ebullitions arising when reacting hare's fur with nitric acid convinced Grew that animal hair was composed of alkaline salt.[109] In a similar vein, chymist and natural historian Robert Plot in his chorographic *Natural History of Staffordshire* also claimed saline chymistry could control color in animals. He noted that cattle that grazed in soil permeated with a "urinous kind of Salt in the juice of the grass" would have hoofs with a "shineing brasen Armature."[110] Plot reported that the naturalist Martin Lister speculated that the teeth of cattle could become gilded if they fed on "some plants of the Erica kind; or rather the viola grandiflora Montana […] which he observes to be a great part of the food" for Westmoreland cattle in the spring.[111] This flower was *viola lutea splendens*, the yellow mountain pansy. Plot also claimed that the color changes

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107 Grew, *Anatomy of Plants,* 278.

108 Nehemiah Grew, "Some Observations Touching the Nature of Snow," *Philosophical Transactions,* 8 (1673), 5193–96, on 5196.

109 Grew, *Anatomy of Plants,* 247.

110 Robert Plot, *The Natural History of Staffordshire* (Oxford, 1686), 111.

111 Plot, *Natural History*, 111.

> must be ascribed to the Saltness of the Soile and Grass, that if any Horned Cattle of never so deep a black or other colour, by put to feed in a place called the Clots in Newbold Ground in the the parish of Tatenhill [three and a half miles west-southwest of Burton upon Trent] they will certainly change the colour of their coat to a whitish dun […] in a Summer's running.[112]

Horses would also end up with dappled coats due to the 'saltness of the soil'. Indeed, Tatenhill is home to brackish salt springs called the "brinepits."[113] Using principles of humoral medicine which postulated we become colder and drier in complexion as we age, Plot speculated that the concentrations of salt meant that little moisture "was afforded" by the animal hair, "which as it does in old age upon defect of moisture turn white."[114]

Conclusion

Whilst early modern English practitioners did consider Aristotelian principles when investigating the relationships between color and chymistry, ultimately the Paracelsian *tria prima* dominated their theoretical considerations. This was the case whether they adhered to Paracelsus' argument that an elemental salt was seen as a discrete element with an inherent power to create color directly, or like

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112 Plot, *Natural History*, 111.

113 Reginald Hardy, *A History of the Parish of Tatenhill in the County of Stafford* (London, 1907), 8-9.

114 Plot, *Natural History*, 112. The literature on humoral medicine is vast, but for specific consideration of the evolution of ideas about humoral medicine and aging in the early modern era, see Cynthia Skenazi, *Aging Gracefully in the Renaissance: Stories of Later Life from Petrarch to Montaigne* (Leiden, 2013); Mary Ann Lund also explores connections between aging, melancholy and the cold and dry humoral complexion in: *Melancholy, Medicine, and Religion in Early Modern England: Reading the Anatomy of Melancholy* (Cambridge, 2010).

Robert Boyle, they demurred, claiming a saline menstruum could only cause material and corpuscular interactions to alter color. Artisanal techniques such as pigment grinding and investigations into the chymical properties of textile dyes also influenced conceptions of color and matter theory amongst seventeenth-century English virtuosi, demonstrating the close relationships between seventeenth century art and science. These relationships are epitomised by Robert Hooke, who united saline corpuscularianism, optics, and color theory from working artists to argue persuasively that salt chemistry was at the basis of color in the natural world. Some of these principles were in turn used by Nehemiah Grew to suggest that understanding principles of saline chymistry could be another means for the chymist to be an even more powerful artist of nature. Not only was color chymistry an analytical tool for seventeenth-century natural historians, it was a creative one, using disciplinal practices and concepts of different ‘color worlds’.

SUMMARY: Before Newton’s seminal work on the spectrum, seventeenth-century English natural philosophers such as Robert Boyle, Robert Hooke, Nehemiah Grew and Robert Plot attributed the phenomenon of color in the natural world to salts and saline chymistry. They rejected Aristotelian ideas that color was related to the object’s hot and cold qualities, positing instead that saline principles governed color and color changes in flora, fauna and minerals. In our study, we also characterize to what extent chymistry was a basic analytical tool for seventeenth-century English natural historians.

KEY WORDS: Robert Boyle, Nehemiah Grew, Robert Hooke, Robert Plot, botany, chymistry, color, natural history, pigments, Royal Society of London, salts.