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A SPECULUM OF CHYMICAL PRACTICE: ISAAC NEWTON, MARTIN LISTER (1639–1712), AND THE MAKING OF TELESCOPIC MIRRORS

by

Anna Marie Roos*

Modern History Faculty, University of Oxford, Old Boys' High School, George Street, Oxford OX1 2RL, UK

In 1674 the natural philosopher and physician Martin Lister published a new method of making glass of antimony for telescopic mirrors, using Derbyshire cawk or barite as a flux. New manuscript evidence reveals that Sir Isaac Newton requested samples of the cawk and antimony from Lister through an intermediary named Nathaniel Johnston. An analysis of Lister's paper and Johnston's correspondence and its context reveals insights not only about Newton's work with telescopic specula but also about his alchemical investigations. Analysing these sources also contributes to our understanding of the nature of correspondence networks in the early 'scientific revolution' in England.

Keywords: Isaac Newton; Martin Lister; telescopes; chymistry; Republic of Letters

Introduction

On 22 January 1676, Nathaniel Johnston (bap. ?1629–1705) a physician, naturalist, antiquary and future Jacobite, wrote to a fellow doctor and natural philosopher Martin Lister (1638–1711), requesting some mineral samples.[1] Lister had published a paper in *Philosophical Transactions* in 1674 that described a new way of fluxing antimony with a material called Derbyshire cawk. Johnston asked whether Lister could send samples of his chymical reactants and products by post to Cambridge.[2] The materials were not for him but for 'Mr. Newton', who was interested in them for their chymical properties and to create the mirrors for his reflecting telescopes.

Johnston and Lister had been friends for many years, and were both members of the York Virtuosi, a salon established by the glass painter Henry Gyles (1640–1709) that met at the artist's house in Micklegate. Other members included the artists Francis Place and William Lodge, the Leeds antiquary Ralph Thoresby, the mathematician Thomas Kirke, the doctor Dr John Place (relative of Francis and subsequently physician to the Grand Duke of Tuscany) and the publisher and print seller Pierce Tempest.[3] Not only did the group of northern virtuosi meet about literary and artistic matters, but several members were

*anna.roos@history.ox.ac.uk

also keen natural philosophers, many contributing information to the Royal Society and the Oxford Philosophical Society. Throughout the 1670s, for instance, Lister had papers published in *Philosophical Transactions* concerning fossils, insect behaviour and chymical experiments.

Johnston and Lister, in particular, were also interested in mining practices and ores, exchanging correspondence about their results. As Lister was writing his ‘Method for the history of iron’, a geological survey of iron deposits in England, and researching the chymical properties of iron pyrites, he required a large variety of mineral samples and cultivated a large network of friends and acquaintances who would send him parcels of ore in the post.[4] Lister’s friend, the naturalist John Ray, even participated, writing to Lister in 1674, ‘I have according to your desire written both into Sussex and Cornwall for tin and iron-ore; and I have advice, that out to Sussex there is a bag of the latter already come up to London and delivered in to Mr. Lodge, according to your direction.’[5] Nathaniel Johnson also sent him ‘vitriolic marcasites’ or pyrites along with experimental observations that he did with them, testing them for iron content with gall water and examining the growth of vitriolic salts under the microscope.[6] Johnston’s letter thus asked Lister to return the favour and to provide ore samples to Isaac Newton. Johnson’s request was the expression of a norm in the Republic of Letters, in which fulfilling social obligations, bartering intellectual property, and returning favours and sending presents were a means of a mutual paying of respect that enhanced one’s reputation as a gentleman and a scholar.[7]

Lister’s epistle from Johnson is in itself part of an unexamined correspondence network in the Republic that was both within and without the bounds of the early Royal Society. Most studies of early modern English epistolary communication concerning natural philosophy have concentrated on the highly centralized and voluminous network of Henry Oldenburg (1619–77), with whom Lister had the ‘Honour of . . . correspondence for Ten or Twelve Years’.[8] The importance of Oldenburg, however, has overshadowed other attempts at communication which have been characterized as ‘provincial’, informal, of little significance, or restricted to small circles of personal contacts.[9]

Lister’s correspondence network, however, kept him at the intellectual centre of discourse. In 1768 Dr John Fothergill bought at an auction ‘several bundles of Dr. Lister’s papers . . . put up in band-boxes, confused like waste paper’ to save them from annihilation in the ‘pastrycooks oven’ or as wrapping for purchases at the grocers.[10] This lucky rescue meant that Lister’s surviving correspondence dating from 1665 to 1711 consists of approximately 1000 letters. His missives were addressed to and received from natural philosophers not only in England but also in mainland Europe, the New World, and China.[11] Although Lister worked from a physical periphery, he was a full participant in the Republic of Letters, which united scholars by intellectual rather than by geographical centres of gravity. His communication by letter was thus an important tool in the pursuit of his intellectual endeavours, endeavours that in this case I will show influenced the telescopic work of a more ‘central’ natural philosopher, Isaac Newton.

Lister’s private letter as well as his paper in *Philosophical Transactions* also served the purpose of establishing and securing his *own* reputation—in this particular case, in chymistry. Although Lister has generally been known by scholars for his medical writings or for his publications in natural history because he was the first arachnologist and conchologist, little attention has been focused on his chymical work.[12] Analysis that has been done has delineated his work with fool’s gold and its role in metallogenesis.[13] The preparation and composition of the 'glass of antimony' and antimonial compounds is, however, also of recent historiographic interest. Lawrence Principe's work has demonstrated that the making of the glass of antimony has been central to discussions of the role of impurities of reactants in the identification and clarification of early modern chymical processes. First, I shall begin this paper with a close examination of Lister's method to demonstrate the importance of considering these impurities when attempting to interpret early chemical procedures.[14] I shall also briefly consider to what extent the cloak of secrecy that surrounded alchemical procedures still informed the public presentation of chymical reactions in this period. Second, the extent to which antimony was significant to Newton's creation of alloys to make telescopic specula has also been relatively unexplored, and I shall elucidate how Lister's procedure informed Newton's creation of telescopic mirrors.[15] Lastly, recent work by William Newman has demonstrated the centrality of the properties of ores to Newton's theories about the transmutation of matter and metallogenesis.[16] I argue that Lister's discovery of cawk ore and its interaction with antimony may have informed Newton's ideas about the formation of minerals.

Lister's vitrification of antimony and 'cawk'

Martin Lister was born near Radclive, Buckinghamshire, and educated at St John's College, Cambridge (MA 1655), before studying medicine at Montpellier from 1663 to 1666. While abroad, he became 'an avid natural historian' and physician, eventually becoming a court physician to Queen Anne in 1702.[17] Elected a Fellow of the Royal Society in 1671, Lister devoted himself to a variety of biological studies, including botany, fossils and shellfish. He forged a friendship and lengthy correspondence with John Ray (1628–1705) and ultimately contributed more than 50 papers to *Philosophical Transactions*.[18] He was elected vice-president of the Royal Society from 1683 to 1687, often chairing meetings when the president, Samuel Pepys, was called away on business. While a Fellow and officer of the Society, Lister sponsored Ray's books on insects and birds, helping to identify species, and was on the committee to see Frances Willoughby's (1635–72) and Ray's *Historia Piscium* through to completion, supervising the completion of the engravings and printing.[19] Lister sponsored Edward Lhwyd's (1660–1709) research into fossils, designed the cabinets for the mineral collection at the Royal Society Repository, and proposed a new method of barometric observation that involved the creation of the first histogram.

He also published several papers on iatrochemistry, including a work on English mineral waters, *De Fontibus* (1682), that was very well received.[20] To ensure priority for his discovery before he published, however, he cautioned Oldenburg in 1674, 'I am willing to entertain you with my thoughts upon the analysis of mineral waters; but desire nothing of this nature from me may be made publick by the press for quiet sake.' In a 'ritualised restriction on chemical communication', carried out by correspondence, Lister had other chymical secrets that he did not want publicized before he could profit by them, either monetarily or as assets to his reputation.[21] Although chemical procedures were increasingly made available to larger audiences, in the second half of the seventeenth century remnants of the secrecy and rituals of the alchemical adepti still survived. Chymical literature often displayed a tension between secret and shared, and private and public knowledge. In 1675, Lister wrote to Oldenburg stating that he had created an impermeable black resin out of plant material, the result of which was examined by Robert Boyle and discussed at a Royal Society meeting.[22] Prince Rupert of Bavaria also became intrigued by the black dye, because he was interested in the mezzotint processes as well as 'painting upon Marble; wch he said he could bring yet to greater perfection if he could be furnisht wth a good black.'[23] Lister, however, never did reveal his procedure for making the black dye to Boyle or to the Prince, because he was contemplating commercial ventures with his discovery. So, by the 1670s, Lister was well known for his chymical work among the English virtuosi, although he still kept some of his discoveries to himself, incompletely revealing their details.

Lister's paper about antimony for *Philosophical Transactions* unsurprisingly also had incomplete chymical information. It contained a miscellany of observations that reflected his virtuosic interests—the efflorescence of particular mineral glebes, the 'flower and seeds' of mushrooms, a discourse on fossilized sharks' teeth, and a final section elucidating the 'speedy vitrifying of the whole Body of Antimony by Cawk'.[24] In his treatise, Lister described the process of making the 'vitrium' or glass of antimony, which was commonly used as an emetic, a medicament and process with which he would have been familiar. Basil Valentine's *The Triumphal Chariot of Antimony* (1604) popularized the use of antimony in the treatment of disease, the famous patent medicine Lockyer's Pill was antimonial in composition, and Lister's great-uncle Matthew Lister, a court physician who was the driving force behind his great-nephew's medical education, left recipes for glass of antimony in his manuscript notes.[25] In this case, however, Lister was interested in the glass's chymical properties rather than its medicinal ones, and he considered the discovery significant enough to make it public, at least partly.

Glass or vitrum of antimony was traditionally created by using what Lister referred to as 'crude antimony' or stibnite (Sb_2S_3, antimony trisulphide) which was ground and then slowly calcined at high heat. The remaining antinomy calx or oxide was then vitrified in a wind furnace, and it was poured into a wide flat dish of metal, generally copper or brass, where it quickly cooled, resulting in the 'glass'. A wide flat dish of brass or copper with high heat conductivity ensured rapid cooling, the retention of the unchanged sulphide hindering the crystallization of the pure oxide sufficiently to allow glass formation; Rawson has noted that antimony trioxide is considered difficult to obtain in the glassy phase other than through rapid quenching or cooling.[26] Principe has described the chymical process that Basil Valentine used in modern chemical terms, noting: 'when antimony trisulphide is roasted slowly in the air, the oxides of antimony are formed and sulphur dioxide is released'.[27] Antimony oxides, together with residual trisulphide, compose a white ash, which on heating to fusion should produce a yellow or golden transparent glass of antimony:

$$2Sb_2S_3 + 10O_2 \rightarrow 6SO_2 + Sb_2O_3 \cdot Sb_2O_5.$$

However, if the stibnite is too purified, no glass will form, and later chemists such as Caspar Neumann (1683–1737), a chymist from Berlin and follower of Georg Stahl, and J. W. Mellor (1869–1938), author of *A comprehensive treatise on theoretical and inorganic chemistry* (1922), recommended adding sulphur, antimony sulphide or antimony trisulphide to the ash to make vitrification occur.[28] Although these chemists thought that by adding sulphur they were making the alchemists' glass of antimony, Principe has found that they were mistaken; their product was a deep red or violet glass, rather than the golden one of Basil Valentine's.[29] The addition of silica to the ash does, however, cause the reaction that Valentine described to occur. Valentine was probably using unrefined stibnite that contained silica, and the alchemist's crucible would probably have had an 'easily-dissolvable silica based glaze', so an impurity that was not mentioned in Valentine's original account was necessary for the formation of the glass.[30] Whether a red vitrium or a golden glass of antimony was created, the poisonous antimony powder, noxious sulphurous fumes and long heating process made these reactions dangerous and tedious.

Lister's method using cawk stone seemed to solve some of these problems. He stated, 'the several vitrifications of Antinomy are either opaque or transparent. To the first kind I shall add one, which is in itself very curious, and that these advantages about the rest, that it is done with great ease and Speed.'[31] He fluxed antimony 'clear', and while that occurred, heated to red heat 'an ounce or two of Cawk-stone' that had been gathered in Derbyshire lead mines, and placed it in the crucible with the antimony, continuing the flux for a few minutes.[32] The product was then cast into a clean mortar, and the melted liquor was decanted from the cawk, resulting in a substance 'like polish'd steel' and as 'bright as the most refined quicksilver'.[33] Lister then noted that the cawk itself did not incorporate with the antimony, so it served purely as a flux. He concluded by stating that he had reacted a variety of substances with antimony, such as *lapis calaminaris* (calamine or zinc carbonate), stone sulphur (native sulphur), galactites (natrolite, a milky white semiprecious stone), marcasites, alum and 'divers sparrs' but none of these minerals had 'any such effect on Antimony'.[34] Lister then promised 'another time' to discuss the spirit of the cawk that resulted from distillation, but he never did manage to publish any more about the topic, perhaps wanting to keep all details about it to himself.

From his brief account and his chymical manuscripts, we can deduce from the literature what was happening chemically (I am currently engaged in reproducing Lister's experiment in the laboratory so that I shall subsequently be an actual witness rather than a virtual witness of the procedure). Lister's description of the cawk-stone, which he termed a 'very odd mineral', as ponderous, white, with a smooth shining grain, is of barite (barium sulphate), otherwise termed by the miners 'heavy spar'.[35] In his unpublished manuscript dedicated to minerals or 'fossils' in northern England, Lister recorded a series of experiments with the cawk, noting that it was 'very full of Sulphur', so much so that when he calcined it in his home laboratory in York it 'smelt soe strongly sulphureous, yt ye fume of ye Furnace infected all ye neighbourhood'.[36] He noted that a lixivium of the cawk also tinged silver yellow, indicating its sulphurous content.[37] In his *Medicinal Experiments*, Robert Boyle mentioned a 'Tegument' of the Veins of Lead, 'which the Diggers name Cawk, which is white and opacous', so the term was a commonly known one; later mineral guides clearly identify Derbyshire cawk as barite.[38]

When barium sulphate was added to the antimony and the mixture was heated in the furnace, the resultant melt would contain primarily antimony sulphide. Just as in Valentine's case of impure stibnite promoting vitrification, Lister's more complex melt would more easily form a stable glass, and lead oxide impurities in the barium sulphate that originated from lead mines would also be a definite help in this regard.[39] Heaton and Moore (1957) observed that the glass of antimony was more stable in the presence of lead oxide.[40] As in Principe's description of Valentine's crucibles, the crucibles that Lister used in his work would probably be either fire-clay or sillimanite, and during melting the pot would be likely to suffer attack. Alumina would find its way into the melt by dissolution of the pot material, and again this would help to stabilize the glass and make the production of the glass easier.[41]

Birch's *History of the Royal Society* noted that after Lister's paper was read, it was ordered to be entered into the Letter Book and published in *Philosophical Transactions*; on 9 January 1675 Oldenburg wrote to Lister:

> observing ye sample, you were pleas'd to transmit, to be of an extraordinary polish, wch some of ye company thought might be good use for perspectives, especially of such are of Mr Newtons invention, they would desire you, to oblige ym further wth sending some more of yt Cawke, by wch that substance is made, yt so they may give order to some of their body to prepare some quantity of it for further tryall.[42]

His experimental claims verified, Lister subsequently promised that he would soon furnish the Royal Society 'wth a sufficient quantetie of Cawke, I daily expecting a parcel from ye Mines'. He reported that

> [the] vitrum was here judged to serve well the businesse of perspective, & espeacially *Concave speculums* of wch we cast some. There is some difficulty in the exceeding tendernesse of ye mettal, but we have in part corrected yt; ye mould we use to cast ym on, is a Christal-glasse.[43]

In the next month, Lister informed Oldenburg that he sent a 'bagg of Cawke, according to your desires', and noted that contaminating his metal with any others would make it 'loose its lustre & grain'.[44] The cawke was indeed produced at the Society's meeting on 18 February.[45]

This exchange of letters and samples was an example of 'epistolatory calibration', a term coined by Adam Moseley in his study of the role of Tycho Brahe's correspondence in the development of early modern astronomy. Moseley describes how epistolary exchange led to a fine-tuning or calibration of astronomical instruments as well as increased accuracy in the plotting of planetary and stellar positions.[46] Rather than fine-tuning instruments or locating stars, however, Lister and his correspondents were calibrating procedures for casting specula.

We do not know with whom Lister was casting mirrors, but it could have been several of the members of the York Virtuosi proficient in minerology or chymistry, a clear nexus of expertise outside the Royal Society. Henry Gyles, a glass painter who did several windows for Cambridge and Oxford and for civic buildings in York, had discussed enamel-making with Lister. Francis Place, an artist and engraver who illustrated Lister's papers in *Philosophical Transactions*, had his own pottery works and familial connections to mining.[47] The most likely candidate, however, was Francis Jessop (1638–91) of Broomhall, Sheffield. Jessop was a keen chymist, in 1670 reporting some experiments to the Royal Society that he was making with Samuel and John Fish, two Sheffield physicians, in distilling formic acid from ants.[48] Jessop was also considered an expert mineralogist, contributing several papers to the Royal Society about 'uncommon Mineral substances' in mines, and about methane and mining explosions, and he corresponded with Lister regularly about these matters. In a 1675 letter to Lister, he wrote of the spontaneous growth of pebbles and spars in lead ore and the cawk, stating: 'this commonly fills the interstices of ye rocks betwixt wch the ore lyes, & by its vicinity to ye ore, may perhaps be impregnated with some of those [qualities] that you mention.'[49]

Jessop was also apparently casting specula himself, because in 1676 Lister mentioned in a letter to Oldenburg:

> I shall transcribe for you a letter I had very lately from M. Jessop, who has not writt to me this 12 months before, by reason of some domestic affliction. In the first place (says he) I give M. Oldenburg many thanks for the offer of a better receipt for the mixture of Metalls for speculums, but I shall have noe occasion to trespass upon his civilitie, for I find my workmen here able to doe soe little, that the receipt he favoured me wth already is much to good for them. However if he thinkes I can serve him any way in these parts I . . . will endeavour to give him the best satisfaction I can.[50]

Lister's method and Newton's telescopes

Jessop and Lister were also casting specula, most probably in response to the work of Newton; the reports of his telescope had caused a sensation within the Royal Society and without, as news spread to Cassini, Auzout and Denis in Paris, Hevelius in Danzig, and via *Philosophical Transactions* to the York virtuosi.[51] Since 1668, when he made a miniature reflecting telescope, Newton had been experimenting with making mirrors for his instruments, presenting the second telescope to the Royal Society for its inspection in December 1671. Newton commented several years later that the speculum was 'two inches broad' and about one-third of an inch thick, and he ground the mirrors to their spherically concave profile and polished them with the assistance of John Wickins, his 'chamber fellow' at Trinity College, Cambridge.[52]

In 1672 Newton had asked Henry Oldenburg, secretary of the Royal Society, for samples of the 'steely matter' composing the speculum of a 4-foot telescope that the London instrument maker Christopher Cock had in hand, having recently given his first paper on his own astronomical instrument, which used a 'concave reflecting glass', a mirror made with copper covered with speculum metal—a mixture of tin, copper and silver.[53] As the silver tended to bubble, leading to aberrations in the mirror, Newton performed a good number of experiments to perfect the speculum's reflective surface by substituting arsenic for the silver; although arsenic makes the 'polished surface a little less reflective than some other alloys, the resultant finish is more stable'.[54] In the process, he discovered the proportions for a good metal alloy that was used for the next two hundred years:

arsenic	1 oz
copper	6 oz
tin	2 oz[55]

Despite making a good alloy, metal mirrors were notorious for tarnishing in England's damp climate and were highly porous; this porosity was accentuated with re-polishing with fine sand and putty to renew their reflectivity. Newton had in 1671 indicated to Oldenburg the necessity of getting a metal without pores visible in the microscope, and rubbing the specula with gentle leather, 'but not with putty or anything that will wear out the metal'.[56] Because his speculum tended to tarnish and weaken the reflection by the mirror, 'the transmission efficiency of the mirror Newton used was only about 20 per cent.'[57] Better alloys would increase telescopic efficiency and magnification, so Lister's 'quick and speedy' means of attaining glass of antimony would have been of interest to

Newton. When Newton measured the refractive indices of materials, eventually compiling them into a table for his *Opticks*, he realized that besides diamonds, glass of antimony had the highest index of all, which also may have sparked his interest in the material.[58] Newton had also mentioned to Oldenburg in a letter of 18 January 1672 that, when making his mirrors, 'what the stellate Regulus of Mars (which I have sometimes used) or other such like substance will doe, deserves particular examination.'[59] The stellate Regulus of Mars is metallic antimony that has been reduced from stibnite with iron and nitre (saltpetre) or tartar and allowed to cool slowly under a thick slag or scoria to give a crystalline star-like pattern.[60] It was clear that he was intrigued about antimony's properties for specula in the early 1670s.

Because Lister's paper about the cawk appeared in the same 1674 edition of *Philosophical Transactions* as the Jesuit Francis Linus's refutation of Newton's theory of colour, it is more than likely that Newton saw it. Newton subsequently enquired for samples of the cawk and the 'prepared Antimony' through an intermediary at Cambridge. Johnston's letter to Lister indicates that his son Cudworth, a student at St John's College, would serve in that capacity.[61] Cudworth Johnston, being young, obedient, fairly innocent, and desirous of future patronage, would be an ideal carrier of this requested cawk for adding to antimony. Lister was not the only one who wished to preserve his chymical secrets. Newton was experimenting with antimony not only to make telescopic mirrors but in chrysopoetic processes that he wished to keep confidential because he was in 'fearful awe of the immense power of alchemy'.[62] Because Lister was a former fellow of St John's and still kept in contact about elections of college officers, any packages that he sent via Cudworth would also not arouse suspicion.

In the mid 1670s, Newton also compiled some manuscript notes about lead, and, being a copious note-taker, he extracted the following passage about cawk from John Webster's *Metallographia*, perhaps in reaction to Lister's work:

> The lead ores that are commonly gotten in England lie either dispersedly (w^ch^ some call *floats*, some *loos* or *shaken* ore[)]; & this is for y^e^ most part in black bituminous earth or in yellowish red clay (w^ch^ some call y^e^ brown hen & then say her blew chickens are not far of) or in Marle & among small stone: or in a continued course or line w^ch^ some call strings, some veins, w^ch^ common ly lead to a greater stock or trunk, & these are enclosed some times in one sort of coat or matrix & some in another. In Darby Shire these commonly ly neare y^e^ Lead, Cauk, bastar Cauk, black Chert, Wheat stone, Sheafe. In these parts most usually in spar or in Cauk or in flints slates & other kinds of stones of divers colours, but most what of a grey or ash colour. The spar is somew^t^ transparent y^e^ Cauk not so but more ponderous & both help y^e^ fluxing of y^e^ ore.[63]

Webster's passage thus confirmed Lister's use of the barite as a flux and identified the mineral.

Newton continued to experiment with combining the copper ore with arsenic and antimony, his manuscript laboratory notebook (1678–96) including a section entitled 'De metallo ad conficiendum speculum componendo & fundendo' ['On compounding and casting a metal for making a mirror']. Newton noted that

> copper can be purified before it is mixed with the tin, by melting and adding to every 12 ounces of molten copper, first, one ounce of arsenic and two or three ounces of crude antimony, then three or four ounces of salt of nitre at a time, until all the salt has burnt away.[64]

Robert Hooke had suggested, in a 1676 paper concerning the making of a helioscope to observe the Sun, that vitrum of antimony could serve as a component for a telescopic mirror 'capable of receiving a very curious and exact polish, and qualified sufficiently to keep and retain it, without receiving injury from the Air, or ordinary wiping', so perhaps that was another influence in Newton's himself considering various forms of antimony as components for his own specula.[65] After all, Hooke and Newton had a notorious rivalry over the efficacy of Newton's reflecting telescope, Hooke harshly criticizing its observational ability in favour of a refracting telescope of longer focal length.[66]

Newton's laboratory notebook on casting mirrors subsequently noted that

> A metal can be composed from Copper, thus purged with Arsenic, and and [*sic*] Tin as above: but the composition will be rendered more strongly reflecting and (so far as I conjecture) more resistant to corrosion if, instead of the Arsenic, first one part of Zinc or white Marchasite and one part of Regulus of Antimony made per se without Mars be added to twelve parts of liquefied Copper, then four parts of tin as above. The sign of the best composition is that the metal appear smooth like glass where it is broken.[67]

By November 1679 Newton was still casting specula; he wrote to Hooke, 'Mr. Cock has cast two pieces of Metal for me in order to a further attempt about ye reflecting tube wch I was ye last year inclined to by ye instigation of some of our Fellows.'[68] Though we do not know who 'some of our Fellows' were, Hooke had in fact created a committee in the Royal Society to alloy speculum metals with antimony, including lead and iron.[69] On 23 March 1680 Hooke recorded in the 'Hooke folio', which contained extracts from the Royal Society's Journal Books and meeting minutes during his secretaryship:

> we made a Regulus of equall parts of Antimony & Iron .... This part we melted w^th. aequall parts of tin the graine of w^ch. was exceeding fine & clo*s*e & smooth and whiter then Both metall. we poli*s*hed it and found that It held a very good poli*s*h, which gaue a strong reflection. It weight in ~~water~~ Air was 859 1/2 in water 7~~5~~8 1/4. whence Its Specifique grauity is as 7 43/485—we conceiue it may be very v*s*e full for making specular gla*ss*es for Mr. Newtons Exp^t.[70]

Cawk and Newton's theory of metallogenesis

Newton's interest in Lister's process of vitrification may have extended beyond telescopic mirrors to a consideration of the cawk itself. In his article on cawk, Lister also mentioned that he had relayed to Oldenburg another point that may have been intriguing to Newton, as it apparently was to Robert Boyle. Lister stated of the cawk that

> it is a very odd Mineral, and I always looked upon it to be much akin to the white milky Mineral Juyces, I formerly sent you a Specimen of & this experiment is demonstrative that I was not mistaken, for the milkie juice of the lead mines vitrifyes the whole body Antimonie in like manner.[71]

This white milky juice, which Lister had sent to Oldenburg the year before, was what he believed to be a sample of *gur* or *bur*, sometimes called the 'butter of minerals'; Lister had received the specimen of gur from his friend Francis Jessop.[72] *Gur* was a metalline juice or liquor thought to be the source of metals that would develop embryonically in the womb of the earth, and it was frequently mentioned by mining author Georgius Agricola and Johannes Glauber, as well as by chymist Johann Baptista van Helmont.[73]

Gur for many mineralogists and chymists seemed to be particularly connected to iron and lead mines, Lister's colleague John Webster in his *Metallographia* claiming to have possessed several pounds of this metalline juice from lead mines; the chymist John Sherley (1638–78) wrote in his *Philosophical Essay* (1672):

> about eighteen years past, having made a Visit to a Friend, who dwelt upon the Borders of *Derby-shire;* and who had at that time newly discover'd a Lead-Mine in his Ground: I remember, that being at the said Mine I saw upon the Work-man's breaking a stone of Lead-Ore, a bright shineing Liquor spurt forth; which in a little while did coagulate, and become solid.[74]

Oldenburg had told Lister that 'Mr. Boyle . . . desires very much . . . a litle of yt White liquor, resembling cream' and asked him to send a sample for him.[75] Boyle would later indicate in his *General heads for the natural history of a country* . . . (1692) that one of the questions travellers should ask to compile a natural history is 'Whether there be Mineral Juices that harden into Stones or Metals, upon the touch of the Air, called *Gur*; of this *Helmont* relates an Observation.'[76] Newton also seemed intrigued with *gur*. In another manuscript written in the first half of the 1670s entitled *Of Natures obvious laws & processes in vegetation*, Newton formulated a theory of metallic generation that mentions *gur*.[77] As Newman indicates, Newton's manuscript contained his 'belief that the metals must undergo a continual process of generation that offsets their corruption at the hands of subterranean corrosive liquors and vapours'.[78] Newton begins with the observation that metals are dissolved by acidic liquors, whereupon they become 'vitriols' (corresponding to modern sulphates) or salts, or they could make *gur* or 'stony juices' that created mineral substances like coral or petrified wood. Newman has noted that Newton's theory of metallogenesis was influenced by the *Arca arcani* of the chymist Johann Grasseus.[79] After discussing the process of metallic generation that inspired Newton's work, Grasseus included a passage about *gur* from the author Johann Mathesius, a sixteenth-century German writer on mineralogy. The passage stated:

> The Matter of Metals before it be Coagulated into a Metalline form, is like Butter made of the Cream of Milk, which may be . . . spread as Butter, which he [he meaneth Mathesius] calleth Gur, which I also [saith the Author] have found in the Mines, where Nature hath produced Lead.[80]

If Lister's cawk was indeed akin to *gur* found in lead mines, Newton may have speculated that the cawk contained within it a transformative element important to metallogenesis. Grasseus also placed particular emphasis on the 'imitation of nature's generative methods within the earth and on the necessity of using unrefined metallic ores in the alchemical process'.[81] Unlike his other contemporaries interested in alchemy who worked with refined metals, Newton, like Grasseus, showed an abiding interest in working with unrefined ores of metals.[82] Lister's cawk was apparently one of these ores.[83]

Conclusion

Though he cast no more specula, Lister himself continued to work on metallogenesis and *gur*. In the *Historia Conchyliorum* (1685–92), which gave rise to his title as the 'father of conchology', Lister even asserted that living molluscs were able to secrete lapidifying juices similar to *gur* or *bur*. From these juices, by means of 'a nonvital process, their shells crystallized', and Lister attempted to prepare gur extracts from fossils and the bodily juices of snails, painting them over the surface of shells to see whether there was an increase in weight.[84] He also tried to grow pearls from snail juices.[85] Bernard Palissy and Girolamo Cardano had also argued that shells consisted primarily of a salt extracted by the mollusc from the sea and were thus easily petrified, so Lister may have been attempting to recreate this process.[86]

In addition, after the publication of *Historia Conchyliorum*, Lister's work on cawk continued to have a life of its own. In his study of the glass of antimony, Caspar Neumann repeated Lister's experiments. He wrote that he 'several times repeated this experiment with success', noting that the cawk could not be 'acted upon by acids', a characteristic of barite, which is virtually insoluble in water and acid.[87] In the eighteenth century, John Edwards (1748–84), a Cambridge-educated vicar in Ludlow who made telescopes and became well-known for his work in improving the reflective properties of telescopic mirrors, likewise 'vitrified' antimony with cawk by following Lister's directions.[88] He noted 'the crude antimony 16 parts, and cawk stone 1 to 2 parts, formed a very brilliant metal, similar to the glass of antimony, but not proper for mirrors' as a result of its tender qualities.[89]

Although Lister's cawk proved 'not proper for mirrors', his correspondence network resulted in his performing experiments in York that inspired chymical work by more exalted peers in Oxford or in London. This state of affairs is not surprising. Goldgar has demonstrated that in the early modern period, a reputation for virtue was accumulated through one's status as a man of learning, and the farther afield you were known, the greater was your personal credit at home.[90] Although some travelled distances to establish their reputations in the 'commerce' of scholarship where exchange of information was paramount, others, like Lister, wrote many letters. Scientific creativity is also engendered by having large numbers of far-flung social contacts. In their studies of scientific networks and innovation, Bruno Latour, Hal Cook and David Lux have demonstrated that 'new information and ideas . . . tend to come from people with many weak social bonds'.[91] Cook and Lux have, in particular, demonstrated that Royal Society virtuosi of the late seventeenth century collected and verified new 'matters of fact' by establishing contacts that created a 'minimal level of personal relationship' yet provided important information.[92] This was the strategy that Lister used when he was at York with his far-flung correspondence to collect and interpret information about the natural world; it was also the strategy that Newton used when requesting some cawk to accomplish his rather more important investigations.

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Notes

1 MS Lister 35, Letter 19, f. 39r, Bodleian Library, University of Oxford. See Mark Goldie, 'Johnston, Nathaniel (*bap*. 1629?, *d*. 1705)', in *Oxford Dictionary of National Biography* (Oxford University Press, September 2004), online edn January 2008; http://www.oxforddnb.com/view/article/14946, accessed 12 March 2007.

2 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', *Phil. Trans. R. Soc.* **9**, 221–226 (1674), at pp. 225–226. The letter that served as the basis of the paper, dated 20 November 1674, is in the *Royal Society Letter Book* VII, pp. 112–117, transcribed in *The Correspondence of Henry Oldenburg*, ed. A. Rupert Hall and Marie Boas Hall, vol. 11, pp. 127–134 (Mansell, London, 1977). My use of the term chymical and chymistry throughout this paper is quite deliberate, as it is anachronistic 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 that would be considered 'chemical'. For further analysis of this historiographic problem, please see William R. Newman and Lawrence M. Principe, 'Alchemy vs. chemistry: the etymological origins of a historiographic mistake', *Early Sci. Med.* **3**, 32–65 (1998).

3 Trevor Brighton, 'Gyles, Henry (*bap*. 1646, *d*. 1709)', in *Oxford Dictionary of National Biography* (Oxford University Press, 2004); http://www.oxforddnb.com/view/article/11824, accessed 6 June 2008. See also J. T. Brighton, 'Henry Gyles, virtuoso and glass painter of York, 1645–1709', *York Historian* **4**, 1–62 (1984), and Richard Tyler, *Francis Place 1647–1728* (York Art Gallery, York, 1971) for more information about the York Virtuosi.

4 'A Method for the History of Iron', MS Lister 1, Bodleian Library, University of Oxford.

5 R. W. T. Gunther (ed.), *Further correspondence of John Ray* (Ray Society, London, 1928), p. 133.

6 For correspondence between Johnston and Lister involving exchange of ores and observations, see MS Lister 35, f 9r–18r, *passim*, Bodleian Library.

7 Anne Goldgar's *Impolite learning: conduct and community in the Republic of Letters* (Yale University Press, New Haven, CT, 1995) analyses these norms in erudite detail.

8 Andrew Moseley, *Bearing the heavens: Tycho Brahe and the astronomical community of the late sixteenth century* (Cambridge University Press, 2007), p. 34; *The correspondence of Henry Oldenburg* (ed. and trans. A. Rupert Hall and Marie Boas Hall), vol. 1, pp. xvii–xviii (University of Wisconsin Press, Madison, WI, 1965).

9 Moseley, *op. cit.* (note 8), p. 34. See also William Eamon, 'From the secrets of nature to public knowledge: the origins of the concept of openness in science', *Minerva* **23**, 321–347 (1985), and B. C. Vickery, *Scientific communication in history* (Scarecrow, London, 2000). Unwin in particular has referred to Lister as 'provincial'. See Robert W. Unwin, 'A provincial man of science at work: Martin Lister, FRS, and his illustrators 1670–1683', *Notes Rec. R. Soc.* **49**, 209–230 (1995).

10 J. Nichols, *Illustrations of the literary history of the eighteenth century* (London, 1822), vol. 4, p. 458, and Fothergill to Huddesford, 4 April 1759, MS Ashmole 1822, no. 225, Bodleian Library, as quoted in Arthur MacGregor, 'William Huddesford (1732–1772): his role in reanimating the Ashmolean Museum, his collections, researches, and support network', *Ann. Nat. Hist.* **34**, 47–68 (2007).

11 The author is currently engaged in creating a calendar and scholarly edition of the Lister Correspondence.

12 Unwin, *op. cit.* (note 9); J. D. Woodley, 'Anne Lister, illustrator of Martin Lister's *Historiae Conchyliorum* (1685–1692)', *Arch. Nat. Hist.* **21**, 225–229 (1994). 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 Rec. R. Soc.* 56, 147–166 (2002); 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 Rec. R. Soc.* **31**, 9–114 (1976–77).

13 For details about Lister's research of iron pyrites, see Anna Marie Roos, 'Lodestones and gallstones: the magnetic iatrochemistry of Martin Lister (1638–1711)', *Hist. Sci.* **46**, 343–364 (2008); 'Martin Lister (1638–1711) and fool's gold', *Ambix* **51**, 23–42 (2004); 'All that glitters: fool's gold in the early-modern era', *Endeavour* **32**, 147–151 (2008).

14 Lawrence Principe, '"Chemical translation" and the role of impurities in alchemy: examples from Basil Valentine's *Triumph-Wagen*', *Ambix* **34**, 21–30 (1987).

15 Henry C. King, *The history of the telescope* (Dover, New York, 2003) does not mention Newton's work with antimony and telescopic mirrors, nor does Richard Westfall in his magisterial *Never at rest: a biography of Isaac Newton* (Cambridge University Press, 1980). Nor is it mentioned in Lesley Murdin's *Under Newton's shadow: astronomical practices in the seventeenth century* (Adam Hilger, Bristol, 1985), A. Rupert Hall and A. D. C. Simpson's 'An account of the Royal Society's Newton telescope', *Notes Rec. R. Soc.* **50**, 1–11 (1996), or Phyllis Allen's 'Problems connected with the development of the telescope (1609–1687)', *Isis* **34**, 302–311 (1943).

16 William R. Newman, 'Newton's theory of metallic generation in the previously neglected text "Humores minerales continuo decidunt"', in *Chymists and chymistry: studies in the history of alchemy and early modern chymistry* (ed. Lawrence Principe), pp. 89–100 (Science History Publications, Sagamore Beach, MA, 2007).

17 Harold J. Cook, 'Natural history and seventeenth-century Dutch and English medicine', in *The task of healing* (ed. Hilary Marland and Margaret Pelling), pp. 253–270 (Erasmus Publishing, Rotterdam, 1996), at p. 257.

18 J. D. Woodley, 'Lister, Martin (*bap.* 1639, *d.* 1712)', in *Oxford Dictionary of National Biography*, Oxford University Press, 2004, online edn January 2008; http://dx.doi.org/10.1093/ref:odnb/16763, accessed 6 June 2008. For Lister's correspondence with Ray, please see John Ray, *The correspondence of John Ray* (ed. Edwin Ray Lankester) (Arno Press, New York, 1975; reprint of London, 1848), and Gunther (ed.), *op. cit.* (note 5).

19 For instance, Lister's *De scarabaeis Britannicus* was printed as part of Ray's publication of Willoughby's *Historia insectorum* (London, 1710).

20 Martin Lister, *De fontibus medicatis Angliae exercitatio nova* [*Exercises on the healing springs of England*] (Walter Kettilby, London, 1682). For the positive reviews of *De fontibus*, see *Weekly Memorials for the Ingenious*, no. 50, pp. 376–382 (Henry Faithorne and John Kersey, London, 15 January 1683/4).

21 Hall and Hall, *op. cit.* (note 8), vol. 9, p. 282, as quoted in J. V. Golinski, 'Chemistry in the scientific revolution: problems of language and communication', in *Reappraisals of the scientific revolution* (ed. David C. Lindberg and Robert S. Westman), pp. 367–396 (Cambridge University Press, New York, 1990), at p. 379.

22 See Thomas Birch, *History of the Royal Society* (A. Millar, London, 1756–57), vol. 3, p. 323 for a November 1676 entry about the resin.

23 Oldenburg to Lister, 3 June 1676, in Hall and Hall, *op. cit.* (note 2), vol. 12.

24 Lister, *op. cit.* (note 2), pp. 225–226.

25 George Wilson gives Lockyer's recipe for his *Pilula Radiis Solis Extracta* in his *Compleat Course of Chymistry* (W. Turner and R. Bassett, London, 1700), pp. 103–104; Dr Matthew Lister, 'Collectanea medica et chemica', British Library, Sloane MS 3426, ff. 29–72b.

26 Harold Rawson, *Inorganic glass-forming systems* (Academic, New York, 1967), pp. 203–204. The heat conductivity of copper is 403 and brass 106 (in watts per metre per kelvin). That of austenitic stainless steel, of which most laboratory ware is made, is 15. So, if the modern chemist attempted to recreate Valentine's process with a stainless steel mortar, the rapid

cooling necessary to make the glass might not be achieved. See G. W. C. Kaye and T. H. Laby, *Tables of physical and chemical constants*, http://www.kayelaby.npl.co.uk/general_physics/2_3/2_3_7.html, accessed 27 July 2009.

27 Principe, *op. cit.* (note 14), p. 22.

28 *Ibid.*, pp. 22–23. Neumann and Mellor were not the only chemists who published their methods. More than 30 methods of preparation were published throughout the eighteenth and nineteenth centuries, including a procedure in the British Pharmacopoeia until 1932, and a method described by Gay-Lussac. See W. E. Thorneycroft, *A textbook of inorganic chemistry*, vol. 6, part 5 (*Antimony and bismuth*) (ed. J. Newton Friend), p. 111 (Charles Griffin, London. 1936).

29 Principe, *op. cit.* (note 14), p. 24.

30 *Ibid.*, p. 24.

31 Lister, *op. cit.* (note 2), p. 225.

32 Lister, *op. cit.* (note 2), p. 225.

33 MS Lister 7, 'A Treatise of the Fossils of England, cheifly the Northern Parts', f. 14r, Bodleian Library.

34 Lister, *op. cit.* (note 2), p. 226.

35 Donald A. Brobst, 'Barium and strontium minerals', in *Surface mining* (ed. Bruce A. Kennedy), 2nd edn, p. 116 (Society for Mining, Metallurgy, and Exploration, Littleton, CO, 1990).

36 Lister, *op. cit.* (note 33).

37 *Ibid.*

38 Robert Boyle, *Medicinal experiments, or, A collection of choice and safe remedies* (Samuel Smith, London, 1692), p. 3. William Adam, *The Gem of the Peak*; or *Matlock Bath and Its Vicinity* (Longman & Co., London, 1843), pp. 422–423, mentions its use of cawk or barite as a pigment, and John Mawe's *The Mineralogy of Derbyshire* (William Phillips, London, 1802), pp. 86–88, gives a rather fuller account of cawk.

39 Martin Horsley, Pilkington Glass, personal communication, 12 June 2009; Dr David Martlew, personal communication, 25 June 2009.

40 H. M. Heaton and H. Moore, 'A study of glasses consisting mainly of the oxides of elements of high atomic weight. Part I', *J. Soc. Glass Technol.* **41**, 3–27 (1957).

41 My thanks go to Dr David Martlew for making this point.

42 Birch, *op. cit.* (note 22), vol. 3, pp. 174 and 190, and Hall and Hall, *op. cit.* (note 8), vol. 11, pp. 153–154. The original letter is MS Lister 34, ff. 143–144, Bodleian Library.

43 Hall and Hall, *op. cit.* (note 8), vol. 11, pp. 156–157.

44 Hall and Hall, *op. cit.* (note 8), vol. 11, letter 2606.

45 Birch, *op. cit.* (note 22), vol. 3, p. 190.

46 Moseley, *op. cit.* (note 8), p. 55.

47 Place made a form of marbled and salt-glazed agate stoneware in the 1680s in Dinsdale, of which four samples survive. See R. T. Tyler, *op. cit.* (note 3), pp. 42–43.

48 W. H. G. Armytage, 'Francis Jessop, 1638–1691: a seventeenth-century Sheffield scientist', *Notes Queries* (7 August), 343–346 (1952), at p. 344.

49 MS Lister 35, f. 35r, Bodleian Library.

50 Hall and Hall, *op. cit.* (note 8), vol. 11, p. 430.

51 Westfall, *op. cit.* (note 15), p. 240.

52 Hall and Simpson, *op. cit.* (note 15), at p. 5.

53 H. W. Turnbull (ed.) *The correspondence of Isaac Newton* (Cambridge University Press, 1959), vol. 1, p. 217; Isaac Newton, 'An Accompt of a New Catadioptrical Telescope Invented by Mr. Newton, Fellow of the R. Society, and Professor of the Mathematiques in the University of Cambridge', *Phil. Trans. R. Soc.* **7**, 4004–4010 (1672).

54 Hall and Simpson, *op. cit.* (note 15), p. 6.

55 Allen, *op. cit.* (note 15), at p. 308.

56 Turnbull, *op. cit.* (note 53), vol. 1, p. 80.

57 Hideto Nakajima, 'Robert Hooke as an astronomer', in *Robert Hooke: tercentennial studies* (ed. Michael Cooper and Michael Cyril William Hunter), pp. 49–64 (Ashgate, Aldershot, 2006), at p. 61.

58 My thanks go to Professor Michael Cable of the University of Sheffield for this material. See Isaac Newton, *Opticks* (London, 1704), book 2, p. 73, for the table of refractive indices. Because the papers for his early work on thick plates have been lost, Richard Westfall speculates that Newton's research on thick plates in which he would have considered refractive indices of different materials may have coincided with his unsuccessful attempts to construct a reflecting telescope with a glass mirror silvered on the back side. This work took place in the early 1680s, when Newton did much of his systematic alchemical work with antimony. The fact that this article has shown that Newton was experimenting in the 1670s with antimony and mirrors may suggest that he was interested in its refractive index earlier. See Richard Westfall, *op. cit.* (note 15), p. 392, and Alan E. Shapiro, *Fits, passions, and paroxysms: physics, method and chemistry and Newton's theories of colored bodies and fits of easy reflection* (Cambridge University Press, 1993), p. 154.

59 Newton, 'Letter 35, Newton to Oldenburg, 18 January 1671/2', in Turnbull, *op. cit.* (note 53), vol. 1, p. 82.

60 For more on the star Regulus, see William R. Newman, *Gehennical fire: the lives of George Starkey, an American alchemist in the scientific revolution* (Harvard University Press, Cambridge, MA, 1994), p. 129.

61 Francis Linus, 'A Letter of Franc. Linus, animadverting on Mr. Newtons Theory of Light and Colors', *Phil. Trans. R. Soc.* **9**, 217–219 (1674/5). Newton responded to Linus with 'An Answer to this Letter [of Francis Linus]', *Phil. Trans. R. Soc.* **9**, 219 (1674/5).

62 Lawrence Principe, 'The alchemies of Robert Boyle and Isaac Newton: alternative approaches and divergent deployments', in *Rethinking the scientific revolution* (ed. Margaret J. Osler), pp. 201–220 (Cambridge University Press, 2000), at p. 209.

63 'Notes on the mining, preparation and properties of "Saturn" [i.e. lead]', in *The chymistry of Isaac Newton* (ed. W. R. Newman); http://webapp1.dlib.indiana.edu/newton/. The passage Newton cites in his notes is from John Webster, *Metallographia: Or, A History of Metals* (A.C., London, 1671), ch. 22, p. 281. The original manuscript of Newton's is 'Reading Notes on Alchemy', Mellon MS 79, ff. 1–8, on f. 3r. Beinecke Rare Book and Manuscript Library, Yale University, New Haven, Connecticut; http://beinecke.library.yale.edu/dl_crosscollex/brbldl/oneITEM.asp?pid=2014831&iid=1061804&srchtype=ITEM, accessed 10 December 2009.

64 Newton, 'A Manuscript by Newton c. 1671/2, MS Portsmouth University Library Cambridge University, Add 3493', in Turnbull, *op. cit.* (note 53), vol. 1, p. 95.

65 Robert Hooke, *A Description of Helioscopes And some other Instruments Made by Robert Hooke, Fellow of the Royal Society* (John Martyn, London, 1676), p. 6.

66 See Hideto Nakajima, *op. cit.* (note 57).

67 'Portsmouth Collection Add. MS. 3973', in *The chymistry of Isaac Newton* (ed. W. R. Newman); http://webapp1.dlib.indiana.edu/newton/, accessed 2 March 2009.

68 Turnbull, *op. cit.* (note 53), vol. 2, p. 303.

69 Because various alloys of molten antimony expand as they solidify, they were commonly combined with molten lead to produce finely cast objects, such as lead printer's type.

70 Entry for 23 March 1679, Hooke Folio, CELL/RS/HF_423. Centre for Editing Lives and Letters. See http://webapps.qmul.ac.uk/cell/Hooke/Hooke.html, accessed 21 April 2009.

71 Lister, *op. cit.* (note 2), p. 226.

72 Hall and Hall, *op. cit.* (note 8), vol. 10, letter 2415. Lister sent the letter to Oldenburg on 7 January 1673/4, and he heard about the 'milky juice' from Jessop.

73 Norma Emerton, *The scientific reinterpretation of form* (Cornell University Press, Ithaca, 1984), p. 217; Anna Marie Roos, *The salt of the earth: natural philosophy, medicine, and chymistry in*

England, 1650–1750 (Brill, Leiden, 2007), pp. 41, 46 and 68. For collected references to *gur* by Helmont, see John Sherley, *A philosophical essay declaring the probable causes whence stones are produced in the greater world . . .* (William Cademan, London, 1672), pp. 53–55.

74 Sherley, *op. cit.* (note 73), p. 52.

75 MS Lister 34, f. 139r. Bodleian Library. The letter was sent on 17 January 1673/4.

76 Robert Boyle, *General heads for the natural history of a country great or small drawn out for the use of travellers and navigators* (John Taylor, London, 1692), p. 46.

77 'Of Natures obvious laws & processes in vegetation', in *The chymistry of Isaac Newton* (ed. W. R. Newman); http://webapp1.dlib.indiana.edu/newton/, accessed 17 April 2009. See also Newman, *op. cit.* (note 16), pp. 89–100.

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84 J. Carr, 'Martin Lister', in *Dictionary of scientific biography* (ed. Charles C. Gillispie), p. 179 (New York, 1970–1980); http://www.chlt.org/sandbox/lhl/dsb/page.415.php, accessed 3 December 2007.

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92 Lux and Cook, *op. cit.* (note 91), p. 182.