The Rise of Cryptographic Metaphors in Boyle and Their Use for the Mechanical Philosophy

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ABSTRACT: This paper tracks the development of Boyle's conception of the natural world in terms of the popular "book of nature" trope. Boyle initially spoke of the creatures and phenomena of nature in a spiritual and moral register, as emblems of divine purpose, but gradually shifted from this ideographic view to an alphabetical account, which at times became posed in explicitly cryptographic terms. I explain this transition toward cryptographic metaphors in terms of Boyle's social and intellectual milieu and their concordance with the reductive and conjectural character of the mechanical philosophical program.

Key words: Robert Boyle; Royal Society; Mechanical Philosophy; Hypothetical Method; Cryptography

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1 Introduction

In the opening of his critique of university curricula, *Academarium Examen*, John Webster attacked the notion that learning classical languages would aid those seeking the true message of scripture:

> he that is most expert, and exquisite in the *Greek* and *Oriental* tongues, to him notwithstanding the language of the holy Ghost, hid in the letter of the Scriptures, is but as *Hieroglyphicks*, and *Cryptography*, which he can never uncypher, unless God brings his own key, and teach him how to use it (1654, p. 8).

Nearly twenty years later, the Jesuit Lorenzo Magalotti wrote to Boyle of the Church's images meant to represent the divine: "What I mean by 'image,' as I said at the beginning, is a sign, a figure, a cipher, a hieroglyphic which is expressive of the Divinity, without any feature which resembles its true form appearing in them" (*Correspondence* 4, p. 309a).[1] Among Boyle and his contemporaries, this language was not only apt for framing matters of biblical exegesis, but also naturalistic inquiry. For Boyle in particular, this was tied to the long-running tradition of referring to the natural world as the "book of nature," a notion that underwent significant development alongside his experimental and chymical[2] endeavors. The idea of a nature as a great book has roots at least as far back as Plato and the bible, and can be found explicitly in classical sources such as St. Augustine, who wrote of "a great book: the very appearance of created things" (1974, p. 123). As Massimo Bianchi (1987) recounts, this notion was popularized and developed by Renaissance Neo-Platonists and Paracelsians in terms of a doctrine of natural signatures and their hidden, magical associations, and eventually gave way to a demystified conception of the world as sign-bearer.[3] One possible cause of this shift was the Reformation-era

[1] Throughout this essay, I will refer to the multi-volume collections of Boyle's writing compiled by Hunter and Davis (2000), and Hunter, Clericuzio, and Principe (2001) as *Works* and *Correspondence* respectively followed by volume number.
[2] I follow Hunter and Principe's use of the term "chymical" to avoid conflation with the modern significance of chemistry.
[3] See also Curtius (1953) on the book of nature concept in the high Middles Ages and Stone (1969) on the early modern European shift from an image culture to a word culture.

prioritization of a literal or historical reading of the Bible as opposed to allegorical interpretations.[4] The case of Boyle, who defended a literalist interpretation of the Bible in 1661,[5] shows that this attitude was familiar to seventeenth century England.

According to historians such as Berger (1967) and McGrath (1988), this literalist approach was carried over to the interpretation of the book of nature. Here I will show how Boyle's own thinking on the topic underwent a transition akin to the shift from signatures to signs. Boyle initially spoke of the creatures and phenomena of nature in a spiritual and moral register, as emblems of divine purpose, but gradually shifted from this ideographic view to an alphabetical account, which at times became posed in explicitly cryptographic terms. I explain this transition toward cryptographic metaphors in terms of Boyle's social and intellectual milieu and their concordance with the reductive and conjectural character of the mechanical philosophical program. The occurrence of this metaphor in the writing of Boyle and his contemporaries shows how a conception of natural philosophy as a form of codebreaking became a tool to characterize and justify the use of mechanical hypotheses.

While scholars have examined shifting conceptions of the book of nature in the sixteenth and seventeenth centuries,[6] and have devoted considerable attention to the linguistic thinking of natural philosophers in this era,[7] their attitudes toward cryptography have rarely been a focus. Major technical innovations and the uses of ciphers for political purposes have been well-documented,[8] authors have begun to study more subtle topics such as the material culture of early cryptography,[9] and work has been done on related interests of particular figures in early modern science,[10] but none of these efforts have demonstrated that there existed a fairly unified view tying cryptographic practice to conceptions of natural

[4] On the allegorical view of the Bible and its influence on the medieval understanding of nature, see Tillyard (1959), White (2010), Barney (1989). See also Harrison (1998) on literalism among Protestants.
[5] In *Some Considerations Touching the Style of the Holy Scriptures*. For more on this work in connection with Boyle's natural philosophy and theology, see Bono (2017).
[6] See Berkel and Vanderjagt (2006) for a recent edited volume on the topic.
[7] For works focused on seventeenth century England in particular, see Salmon (1988), Maat (2004), Fleming (2016).
[8] The major historical works on this topic are Kahn (1966) and Singh (2000). De Leeuw and Bergstra (2007) is a recent source of note.
[9] Ellison and Kim (2017).
[10] E.g., Principe (1992), Strasser (1994), Peeley (2007).

philosophical method among mechanical philosophers.[11] I will exhibit evidence that such a view in fact existed and, for the case of Robert Boyle, indicate the social and personal factors that motivated its adoption. Rose-Mary Sargent (1995) has stressed the importance of the book of nature for Boyle, but has not laid out how this concept progressed from his early work into its later form as I do here. [12] While I provide grounds for thinking that cryptography was a particularly useful metaphor for early developers of the hypothetical method, I do not intend to claim that it was a driving force behind their research. It would be a massive undertaking to show that the wide-ranging interests of an author as prolific and—as Hunter (2015) puts it—convoluted as Boyle were steered by a single source, much less a single metaphor. I do not intend to argue for such a claim here. Instead, I simply aim to show why this metaphor was both intuitive given the social-intellectual context and a useful tool for thinking about mechanical philosophy.[13] I hope, however, that drawing attention to the similarities in different authors' appeals might stimulate further work on the topic.

2 The book of nature in Boyle's early writing

Sargent has noted that Boyle's conception of nature "was not only a device for justifying his pursuit of science to theologians. It also played an important role in the development of his ontology" (1995, p. 101) such that "Boyle's choice of method was guided by his ontological view of nature as a divine text" (Ibid., p. 122). Boyle's idea of the natural world as an epistle from God reinforced the attitude that nature was *fait accompli* following a divine blueprint. He writes of the world as a fabric of interrelated phenomena with a preordained and coherent overall structure, despite the variety and complexity encountered in its

[11] Pesic (2000) highlights this possible theme in Bacon, but does not produce evidence that Bacon himself explicitly made the connection between natural philosophy and cryptography.
[12] In addition to Sargent, I must mention Principe's (1992) and Hunter's (2011) essays on Boyle's codes and secrecy as the historical work upon which I am most directly building.
[13] There is ongoing debate over the relationship between Boyle's mechanical philosophy and his experimental work, e.g., Chalmers (1993), Pyle (2002), Anstey (2002), Chalmers (2002). While it has important implications for matters in the history and philosophy of science, I refrain from seriously entering this debate here.

distinct pockets.[14] The importance of this notion is indicated by the regularity of Boyle's references to the book of nature throughout his scientific career. One of Boyle's earliest treatises on natural philosophy from the early 1650s is titled, "On the Study of the Booke of Nature," while the last aphorism appended to his final, posthumously published work begins, "The book of nature, is a fine and large piece of tapestry rolled up, which we are not able to see all at once" (*Works* 12, p. 531). Between these poles, a wide variety of similar locutions inhabit Boyle's writing. To cite just a few: in *Seraphic Love* from 1659, "by the help of Anatomicall Knives, and the light of Chymicall Furnaces, I study the Book of Nature" (*Works* 1, p. 86). His *Free Enquiry into the Notion of Nature*, chiefly written in the 1660s, speaks of "the Characters and Impressions of Wisdom, that are Conspicuous in the curious Fabrick and orderly Train of Things" (*Works* 10, p. 519). 1675's *Imperfection of the Chymist's doctrine* criticizes the sufficiency of Paracelsian principles "to give an account of the Book of Nature" (*Works* 8, p. 403). And the treatise on final causes of 1688 describes God as "an Excellent Writing-Master" who wrote messages for humanity by "stamping Characters, or leaving Impresses […] upon the *World*" (*Works* 11, p. 96, 145).

A closer look reveals shifts in both the context and content of Boyle's use of this metaphor. Scholars have noted that Boyle showed little interest in scientific affairs prior to the late 1640s, instead writing primarily on moral and spiritual matters.[15] In *Occasional Reflections*, much of which was written in 1647-8 before his full identification as a natural philosopher, Boyle writes,

> the World is the great Book, not so much of Nature, as of the God of Nature, which we should find ev'n crowded with instructive Lessons, if we had but the Skill, and would take the Pains, to extract and pick them out: The Creatures are the true Ægyptian Hieroglyphicks, that under the rude forms of Birds, and Beasts, &c. conceal the mysterious secrets of Knowledge, and of Piety (*Works* 5, p. 40).

Similar reference to hieroglyphics is also found in "Study of the Booke of Nature" and *The Usefulness of Natural Philosophy*, primarily written in the early 1650s:

> the Book of Nature is to an ordinary Gazer, and a Naturalist, like a rare Book of Hieroglyphicks to a Child, and a Philosopher: the one is sufficiently pleas'd with the Odnesse and Variety of the Curious Pictures that adorne it; whereas the other is not only

[14] The idea is thus consistent with Boyle's eventual descriptions of the world as a "cosmical mechanism" (as in *Works* Vol. 10, p. 467).
[15] See Hunter (2015, Ch. 1) for recent commentary on Boyle's early intellectual life.

> delighted with those outward objects that gratifie his sense, but receives a much higher satisfaction in admiring the knowledg of the Author, and in finding out and inriching himselfe with those abstruse and vailed Truths dexterously hinted in them (*Works* 3, pp. 201-202).

The same idea recurs in these texts: God, with nature as intermediary, presents the careful observer with signatures that provide moral instruction, useful insights, and an increased sense of devotion and esteem for the creator. Boyle's ideal thinker is one "capable both of Understanding, and Rellishing the excellent Moralities, couch'd in those ingenious Emblems" (*Works* 1, p. 118).

Boyle's invocation of hieroglyphs and emblems in these passages recalls the European fascination with Egyptian (and later, Chinese) characters initiated by works such as Horapollo's *Hieroglyphics* from the late fifteenth century. Throughout the following century, hieroglyphs were often regarded as material instantiations of Platonic ideas in the sense that they were thought to directly connect to mental representations, and according to some strains of thinking could even reveal the workings of God's mind (Iversen, 1961). European written languages, on the other hand, were one step removed, providing mere representations of the spoken words that stood for concepts.[16] Ashworth (1990) identifies this interest in hieroglyphics as one component of an "emblematic world view" underlying natural histories from the late fifteenth and early sixteenth centuries. Works such as Conrad Gesner's *History of Animals* (1551-8) and Joachim Camerarius's four-volume *Collection of Symbols and Emblems* (1593-1604) treated flora and fauna as living symbols, understood not only by observation, but also through fables, epigrammatic folklore, and other sources revealing their similitudes and sympathies with the whole of creation. Emblem books and texts on hieroglyphics remained popular well into the seventeenth century,[17] and likely influenced Boyle's view that learned insight into the overarching order of the natural world would ultimately reinforce faith and understanding of God: "the Study of Nature is the Noblest

[16] Maat (2004, Ch. 2) discusses the Aristotelian framework that dominated most discussions of language in the fifteenth and sixteenth century. This framework is seen very clearly in a letter from Wallis to Boyle: "as things now are, it be very true that Letters are, with us, the immediate Characters of Sounds, as those Sounds are of Conceptions" (*Correspondence* 2, p. 14).

[17] Robert Hooke, Boyle's assistant and collaborator, owned a number of titles in these traditions by Ripa, Maier, Faerno, Cats, Hugo, Ficino, and Valeriano among others.

Memoria Localis of a Christian, & that he may turne the whole World into a *Conclave Mnemonicum*: God having every where trac't such instructive Hieroglyphicks" (BP 8, fol. 137^{r}).[18] His appeals to a *conclave mnemonicum*[19] here and elsewhere[20] reference ancient memory techniques popularized in the sixteenth and seventeenth centuries (Rossi, 2006).[21] Where memory arts were originally intended to arrange one's thoughts in an orderly way, Boyle proposed the scrupulous naturalist regard the world itself as an ordered system through which thoughts can reflect the message of God. The *Occasional Reflections* exemplify this idea, showing how observations of apparently insignificant phenomena—a horse's stumble, a milk-maid singing to a cow, and the like—can serve as guides for moral education.[22] Boyle thereby poses as "a knowing Naturalist, that is able to discern their secret Correspondencies and Alliances, these things which seem to be altogether Irrelative each to other" (*Works* 3, p. 263).

Talk of hieroglyphics and hidden correspondences was common among Boyle's Hartlib circle colleagues, who studied Paracelsus and Helmont, and associated the theory linking hieroglyphics to mental representations with projects for a 'real character'. This concept was introduced in Bacon's influential *Advancement of Learning*, where he wrote that "whatsoever is capable of sufficient differences, and those perceptible by the sense, is in Nature competent to expresse Cogitations," and so "it is the use of Chyna and the Kingdomes of the High Levant, to write in Characters reall, which expresse neither Letters, nor words in grosse, but Things or Notions" (Bacon, 1605, p. 59 Pp3^{v}). Motivated by concerns for religious unification and academic reform, associates of the circle such as Samuel Hartlib, John Wallis, John Wilkins, Seth Ward, and John Beale debated the possibility of a universal language

[18] I will use 'BP' followed by volume number for references to the collection of notebooks and manuscripts known as the Boyle Papers and curated online by Michael Hunter (cited). This passage is dated to be from the 1650s. Jacob (1972) ties quotes like these to religious motivations feeding into Boyle's natural philosophy. For Boyle's mature natural theology and its influence on his epistemology, see Wojcik (2002).
[19] Literally "memory room," an idea linked to Cicero's artificial memory system in which ideas are ordered using rooms in an imagined building.
[20] Cf. *Occasional Reflections* in *Works* 5.
[21] For more on Boyle's note-taking and mnemonic practice, see Yeo (2010a), (2010b).
[22] Boyle, appropriating an analogy from Bacon, compares his relation to these experiences to the bee that gathers up and transforms its food. See also Preston (2015, Ch. 2) on the style of *Occasional Reflections*.

throughout the 1640s and 50s, regularly citing Bacon and the case of hieroglyphics as inspiration.[23] Boyle kept a sustained interest in these efforts from as early as March 1647, when he expressed hope for the project in a letter to Hartlib.[24] Ten years later he wrote of plans to meet with Ward and Wilkins to discuss the latter's progress in devising a real character, eventually published in the *Essay* of 1668.[25] Boyle's efforts to improve his shorthand for recording experiments in the 1650s might have encouraged his patronage of George Dalgarno's *Ars Signorum* (1661), a universal language work developed out of Dalgarno's own shorthand system.[26]

3 The alphabet of nature enciphered

In the 1650s Boyle still wrote approvingly of Helmont, Paracelsus, and other iatrochemical figures who drew on a doctrine of natural signatures.[27] By 1661, he was predominantly cautious and critical. From this point on Boyle discussed the book of nature in alphabetical rather than ideographic terms and began to explicitly tie the metaphor to natural philosophical inquiry. Thus the *Sceptical Chymist* writes,

> I look upon the common Operations and practices of Chymists, almost as I do on the Letters of the Alphabet, without whose knowledge 'tis very hard for a man to become a Philosopher; and yet that knowledge is very far from being sufficient to make him One (*Works* 2, p. 330).

[23] See Salmon (1979, Ch. 8) for a discussion of the influence of irenicism, Bacon, Comenius, the Cabbala, and novel writing practices on these projects. As Rossi (2006) notes, there was a long-standing discussion of gestures and symbolic language in the seventeenth century, in which references to hieroglyphics and sometimes Chinese characters were a constant, often adjoined to topic of an artificial language of "real characters" designed to reflect the structure of nature. These references are found among a number of Boyle's contemporaries and interlocutors during this period. See, for example, the introductory poem to Wilkins's 1640 *Mercury* ("your diviner *Hieroglyphicks* tell, How we may Landskips read, and Pictures spell"); Webster's *Academarium Examen* (1654); Cave Beck's *Universal Character* (1658); Wallis's 1662 letter to Boyle (*Correspondence* 2, p. 15: relating a universal language to that of "the *Chineses*, whose whole Language is said to be made up of such Characters as to represent Things and Notions, independent on the Sound of words").

[24] *Correspondence* 1, p. 53.

[25] *Correspondence* 1, p. 245.

[26] On Boyle's relationship with Dalgarno, see Salmon (1979, Ch. 9).

[27] See, e.g., *Usefulness* (*Works* 3, p. 334) mentioning these authors alongside Martin Ruland and Petrus Severinus. This work also contains praise for the Helmontian Sir Kenelm Digby. Notes from Oldenburg on an unpublished treatise on poison from the late 1650s include positive references to Oswald Croll and Andreas Libavius (*Works* 13, p. 241). Newman (1994b, Ch. 2) details the influence on Boyle of the Helmontian George Starkey, who he funded and corresponded with extensively in the early 1650s.

As Newman (1994a) has shown, Boyle's chymical and alchemical interests inclined him toward corpuscularianism in his early career. However, this did not turn into full-fledged advocacy until the early 1660s. This is arguably a result of Hooke's encouraging Boyle to read Descartes, whose *Principia* he claims to have spent "seriously and orderly reading" in *Sceptical Chymist*'s opening (*Works* 2, p. 13).[28] The reductive program of the mechanical philosophy soon began to show itself in the book of nature. In 1666's *Origine of Formes and Qualities*, Boyle appealed to the book of nature to argue that a small number of mechanical principles is sufficient to generate the immense variety of phenomena in the natural world. He invited his reader to consider that

> all that innumerable multitude of Words, that are contain'd in all the Languages of the World, are made of the various Combinations of some of the 24 Letters of the Alphabet; [and with this in mind] 'twill not be hard to conceive, that there may be an incomprehensible variety of Associations and Textures of the Minute parts of Bodies (*Works* 5, p. 332).

The proper interpretation of the book of nature required a new "alphabet" suited to the constitution of the natural world, each letter corresponding to principles or qualities which can combine in diverse ways to form a range of phenomena. This formulation is markedly similar to Francis Bacon's rationale for his own reductive program based on the identification of simple forms that compose observable things:

> to enquire *the forme of the Soundes or Voices which make Simple Letters* is easily comprehesible, and being knowen, induceth and manifesteth *the formes of all words*, which consist, & are compounded of them; in the same maner to enquire *the forme* of a Lyon, of an Oake, of Gold: Nay of Water, of Aire, is a vaine pursuite: But [it is easier] to enquire *the formes* of Sence, of voluntary Motion, of Vegetation, of Colours, of Gravitie and Levitie, of Densitie, of Tenuitie, of Heate, of Cold, & al other Natures and qualities, which like an *Alphabet* are not many & of which the essences (upheld by Matter) of all creatures doe cosist (1605, p. 27).

Like Boyle, Bacon spoke in linguistic terms of a limited set of basic principles from which all the complexity of the natural world could be constructed.[29] Indeed, Boyle may have derived the idea of a natural alphabet from Bacon, who used the phrase in 1620's *Instauratio Magna*. But this language was

[28] Davis (1994) has written on Hooke's role in Boyle's reading of Descartes from 1658-1662. Anstey deems this a "crucial juncture in Boyle's development as a natural philosopher" (2000, p. 11).
[29] Further discussion of Bacon's metaphors and method in relation to the Royal Society can be found in Lynch (2005).

also familiar to language debates that likely caught Boyle's attention. The January 1668 issue of *Philosophical Transactions*, for instance, placed a review of van Helmont's *Alphabetum Naturae* immediately after Boyle's experiments on luminous wood.[30]

In *Cosmical Qualities*, published in 1670, Boyle began to emphasize the combinatorial function of these principles:

> supposing these ten [mechanical] Principles were but so many Letters of the Alphabet that could be only put together in differing numbers, and in various orders; the Combinations and other Associations that might be made of them, may be far more numerous then you your selfe will expect, if you are not acquainted with the way of Calculating the number of differing Associations that may be made between ten things proposed. The best way I know of doing this is by *Algebra* or Symbolicall Arithmetick (*Works* 6, p. 275).

These remarks harmonize with Boyle's manuscripts, in which he considers the possibility of inscribing known phenomena within a symbolic framework where "by adding, subtracting &c. in a way suitable to the nature of this Physical Algebra, we may frame new Propositions, whence will oftentimes result new Truths & which will at least frequently suggest new Inquirys & Experiments" (BP 9, fol. 73^{r}).[31] These remarks show that by the 1670s Boyle was drawing on an increasingly abstract, symbolic set of metaphors in relation to the book of nature and applying them to questions of reductive methodology. The natural world was no longer an emblematic array of creatures and behaviors bearing singular lessons for the careful observer. Rather, it was a mass of complex phenomena that could be broken down into a finite set of constituent parts arranged in a kind of syntactic structure: "There may be, if I mistake not, an Art devis'd that may be called *Grammatica Naturae* because it teaches a Man to understand Natures Language" (BP 9, fol. 74^{r}).

[30] *Transactions*, Volume 2, Number 31.

[31] Anstey and Hunter (2008) are quick to point out the likely influence of Hooke here. This manuscript entry, like *Cosmical Qualities*, was probably written in the late 1660s, around the same time that Hooke had delivered lectures on algebra and was composing his unpublished "General Scheme." The latter work contains a proposal for a "philosophical algebra" intended to apply the symbolic power and efficiency of the mathematical technique to natural philosophical method. For Hooke's "Scheme," see Hooke (1705). For further commentary on Hooke's algebra see Hesse (1966), Pugliese (1982).

Comments in Boyle's notebooks and correspondences help reinforce the notion that this shift from hieroglyphics to alphabets constituted a transition in Boyle's conception of the book of nature. Two separate entries in his workdiaries from the 1670s mention this distinction and show that he intended to relate it to other ideas: "[Remember] in the 15th Ess: the difference betwixt the Hieroglyphick writeing of the Egyptians & of European Alphabets together with other like resemblances" (WD 28, entry 963).[32] In some corners, association with European alphabets denoted superior clarity, as seen in a letter found among Boyle's correspondences celebrating the Royal Society's replacing the "dark, antick, hieroglyphical habit" of past philosophy with "more free generous English Apparell" (*Correspondence* 4, p. 411). And Boyle clearly sided with this judgment[33] in his notebooks from the 1670s:

> whilst Philosophers are without the true & fertile Principles, they must find nature to be to Them, like the Language of Chineses, or the old Aegyptian Hieroglyphicks, where for almost every particular word (or Expression) we must make a particular Hypothesis or guess, with little or no assistance from any knowledg antecedently acquir'd, whereas by a skillful Peruser the Book of Nature, may be look'd upon as written in one of our European languages, where by the help of 24 Alphabetical Letters, fitly rang'd & apply'd, One may make out that great variety of Eastern Expressions, in reference to wch the Alphabet is as the key of a Cypher, wch may wth due variations be extended & apply'd to a vast multitude of words & expressions contain'd in that great volumn (BP 9, fol. 67^{r}).

This passage serves as a lovely encapsulation of the trajectory of Boyle's reflections on the book of nature. The hieroglyphic view of the natural world, long absent from his writing, has returned as a marker of confusion; it is the attitude of someone who lacks the experiential grounds required to confront diverse phenomena with a general and unifying framework. Such "true & fertile Principles," once acquired, function as the key that allows the natural philosopher to decipher the alphabet by which the words in the book of nature were composed. Boyle's regard for worldly events in *Occasional Reflections* complexified the mundane through analogy to aspects of moral life: charcoal in a fireplace becomes the recalcitrant

[32] The note is one of numerous allusions to a series of planned works on natural philosophy, ranging from general critiques of Peripatetics to such Boylean specifics as "two differing ways of melting metalls with Sulphur" (WD 28, entry 869). Note that I will be using "WD" to refer to the collection of workdiaries edited by Hunter and Wiggins (2007).

[33] It should go without saying that these attitudes are deeply Eurocentric and betray a limited understanding of Chinese and Egyptian language.

heat of lust demanding vigilance from Boyle; a dog fetching a glove becomes the reverent Boyle selflessly devoting himself to the glorification of God. In his later writing, this piecemeal approach is supplanted by the will for a concise framework that can be extended to cover the expanse of the world, reducing a multitude to the same set of principles. Boyle thus subsumed the alphabetical perspective on his natural philosophy within a cryptographic metaphor: the natural world was like a book of enciphered words obscuring the order of an underlying alphabet, which was to be revealed through the skillful perusal of nature.

This is not to say that Boyle abandoned the religious underpinnings of his natural philosophy. On the contrary, he took effort to render this view compatible with his theological commitments. Among these was the idea that God was ultimately responsible for humans' capacity—and incapacity—to understand nature. Dating back to his early encounters with the Hartlib circle, Boyle subscribed to a voluntarism that held that God's creation of the world was an entirely free act guided by an intelligence beyond full human comprehension.[34] As he repeatedly stressed, the degree of human insight into the mind of God was similarly a free choice by the creator. This applied to natural philosophy as well: thus human faculties could only decode the natural world to the extent that God had equipped them to.

> Wherefore God having as well made the World, as given Man the Faculties whereby he is enabled to contemplate it; Naturalists are as much obliged to God for their Knowledge, as we are for our Intelligence to those that write us Secrets in Cyphers, and teach us the skill of decyphering things so written (*Works* 8, p. 40).

This left open the possibility that a significant portion of creation is unknowable through natural philosophical means. In his writing of the 1670s and 80s, Boyle increasingly turned to the limits of human understanding, a topic that bridged his theological and natural philosophical interests. Boyle's notebooks from this period involve extensive discussions of the limitations of faculties employed in natural philososphy. The heading on one page, for example, mentions a paper "about the Uses & Limits of Experience" (BP 9, fol. 127^{r}). Another notebook contains a manuscript titled "The Weakness of the Human Understanding" (BP 16 fol. 72). Yet another includes an introduction to a planned collection of

[34] For Boyle's voluntarism and the limits of natural philosophy see Wojcik (2002, Ch. 7-8).

works on the use and limits of experience, authority, and "the Use and bounds of Reason" (BP 36, fol. 30[r]).

Boyle drew on the language of ciphers in attempting to reconcile these imposed limits on understanding with the belief that God had written the book of nature as a coherent whole. Noting that the ends designed for some features of the world are not evident to humankind, he compared the world to:

> an excellent Letter about several Subjects, and to different Purposes, whereof some Parts were written in plain Characters, others / in Cyphers, besides a third sort of Clauses, wherein both Kinds of Writing were variously mix'd, to be heedfully perus'd by a very intelligent Person, if he finds that those Passages, that he *can understand*, are excellently suited to the scopes that appear to be intended in them, it is Rational as well as Equitable in Him to conclude, *that* the Passages or Clauses of the third sort, if any of them seem to be insignificant, or even to make an Incongruous Sense, do it but because of the illegible Words; and that both these Passages, and Those written altogether in Cyphers, would be found no less worthy of the excellent Writer, than the plainest Parts of the Epistle, if the particular purposes, they were design'd for, were as clearly discernable by the Reader (*Works* 10, p. 569).

The fact that the intelligible parts of the natural world are so finely structured gives reason to think that inscrutable aspects of nature obey a common order.[35] As in his early writing, Boyle encouraged his readers to find God's intentions written into the world, here in terms that further emphasized its manifest obscurity. Rather than forfeit when understanding fails, the experimental philosopher is driven by the curiosity this provokes in light of the overarching coherence of the world: "in the Book of Nature, as in a well contriv'd Romance, the parts have such a connection and relation to one another, and the things we would discover are so darkly or incompleatly knowable by those that precede them, that the mind is never satisfied till it comes to the end of the Book" (*Works* 8, p. 58).

4 Boyle's social and intellectual context

[35] Boyle repeats this cryptographic argument in his *Christian Virtuoso* (*Works* 12, p. 502). See also a letter to Oldenburg for an application of the same idea to scripture (*Works* 14, p. 276). The letter is undated, but considering its common subject matter with 1675's *Reason and Revelation*, and that Oldenburg's death occurred in 1677, it is likely that the letter was written in the early to mid-1670s.

Boyle's earliest uses of this cryptography metaphors occur in these discussions of the theological context and limits of natural philosophy, many of them written in the beginning of the 1670s.[36] As the decade progressed he came to apply them more directly to matters of natural philosophical method, as seen in the notebook quote above, and several notable contemporaries followed suit. Before discussing the appeal of these applications for mechanical philosophers, I will consider factors in Boyle's social and intellectual context that plausibly contributed to its intuitive quality.

Descartes is the best candidate for a direct influence. The final sections of the *Principia Philosophiae* contain an extended comparison of his use of corpuscular hypotheses to a cryptographic key. Descartes asks his readers to imagine someone who has been given an unintelligible letter, which becomes legible in a familiar language under supposition of a particular key. Descartes argues that, although the key was arrived at by conjecture, it is scarcely believable that an entirely different message could have been hidden in the same text.[37] Thus "he will be in no doubt that the true meaning of the letter is contained in these words." (Descartes, AT 328).[38, 39] In 1674 Boyle published a version of this argument tied to the book of nature concept that very closely follows the presentation of Descartes.[40] This, coupled with his 1661 claim to have closely read the *Principia*, is good prima facie evidence that Descartes was Boyle's main inspiration for this passage. It is unclear, on the other hand, why he would wait until the 1670s to exploit this metaphor.

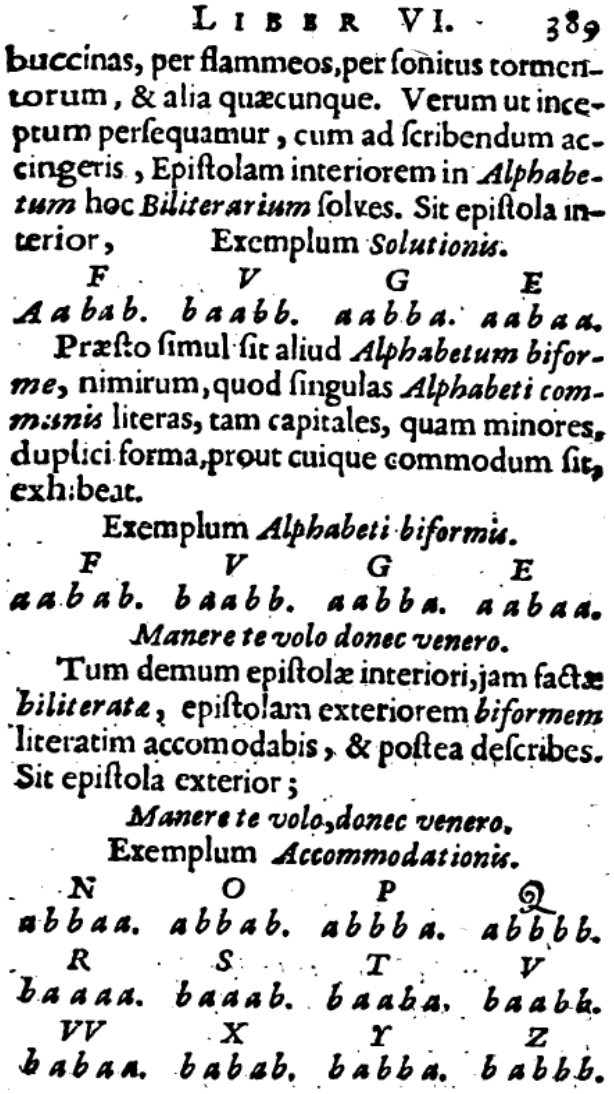
Perhaps Boyle was too preoccupied with his burgeoning experimental work, his rising reputation following the publication of his air-pump essay, the ensuing controversies, and the editing and publishing

[36] The occurrence in the *Free Enquiry* may have been the first time Boyle committed this idea to writing, given that much of this text was written in the mid-1660s.
[37] Given the complexity of certain ciphers, especially those with variable keys, this claim is less warranted than Descartes may have believed. He or Picot, his translator, became sensitive to this issue, specifying in the French edition of 1647 that one's confidence should be higher if the message contains many words.
[38] *Non dubitat quin illius epistolae verus sensus in istis verbis contineatur*. Translation from Cottingham, Stoothoff, and Murdoch (1985).
[39] The French edition clarifies that this lack of doubt is not absolute, but comparable to the case of someone who does not doubt that Rome is in Italy despite having never been there. This epistemic state is labeled "moral certainty" (*certa moraliter*).
[40] Laudan (1966) is the only other historian I have seen remark on this connection. This passage is discussed in greater detail in section 5.

prior writings to consider natural philosophy in these terms. Aside from these earlier treatises, talk of the book and alphabet of nature largely drops out of his work until the latter half of the 1660s. Perhaps it didn't occur to Boyle to integrate Descartes's comparison with the book of nature concept until he had started to develop the abstract, symbolic characterization of the late 1660s. Regardless of how precisely they came to mind, Boyle's use of cryptographic metaphors resulted from a confluence of factors beyond his reading of Descartes, the most salient of which I will mention here.

As with much of its history, cryptography was principally used for political purposes, but the topic attracted a number of prominent natural philosophers as well. Its first major boost in popularity in early modern England came with the political intrigues of the Elizabethan era (Barksdale-Shaw, 2017). In the late 1500s, Francis Bacon's brother Anthony worked for Sir Francis Walsingham, Elizabeth I's secretary, head of royal espionage, and major figure in foiling the Babington plot on the queen's life. Together, the Bacon brothers operated a scrivenery that produced works of cryptography among other writings (du Maurier, 2013). It is no surprise, then, that Francis included a section on cryptography in his discussion of language arts in the *Advancement of Learning*; this section was expanded in the 1620 Latin edition to include his biliteral cipher (Figure 1).[41]

[41] As with hieroglyphics, discussions of cryptography often occurred near talk of real characters in these works. Bacon's writing on cryptography immediately follows his coining this term, Wilkins's first published remarks on real characters occurs in *Mercury*, and Webster discusses the two together in the *Academarium*. According to Strasser (1994), these topics were closely related in the thinking of Samuel Hartlib as well.



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buccinas, per flammeos, per ſonitus tormentorum, & alia quæcunque. Verum ut inceptum perſequamur, cum ad ſcribendum accingeris, Epiſtolam interiorem in *Alphabetum* hoc *Biliterarium* ſolves. Sit epiſtola interior, Exemplum *Solutionis*.

F V G E
Aabab. baabb. aabba. aabaa.

Præſto ſimul ſit aliud *Alphabetum biforme*, nimirum, quod ſingulas *Alphabeti communis* literas, tam capitales, quam minores, duplici forma, prout cuique commodum ſit, exhibeat.

Exemplum *Alphabeti biformis*.

F V G E
aabab. baabb. aabba. aabaa.

Manere te volo donec venero.

Tum demum epiſtolæ interiori, jam factæ *biliteratæ*, epiſtolam exteriorem *biformem* literatim accomodabis, & poſtea deſcribes. Sit epiſtola exterior;

Manere te volo, donec venero.

Exemplum *Accommodationis*.

N O P Q
abbaa. abbab. abbba. abbbb.

R S T V
baaaa. baaab. baaba. baabb.

VV X Y Z
babaa. babab. babba. babbb.

Figure 1: A page from a 1652 reprint of the 1620 Latin edition of Bacon's *Advancement of Learning.*

Boyle's scientific pursuits began shortly after another increase in cryptographic activity, this time due to the political unrest of 1640s England. In fact, Boyle associates this era with encryption in a reference to "that private way of writeing which dureing the late civill warrs in England was employ'd & with great care" (*Works* 13, p. 309). One simple form of code-work which Boyle must have regularly encountered in his natural philosophical endeavors involved the use of Latin anagrams to encode statements of scientific discovery. This means of ensuring priority was by figures like Galileo, Huygens, Hooke, and Newton. In 1668, Huygens, alarmed to find Wallis and Wren working on theories of collision similar to his own, advocated for the general use of codes to Oldenburg (Oldenburg, 1968c, p. 362).

Boyle's early associates were also engaged in more detailed studies of cryptography. Oldenburg, for his part, counted Vigenère's *Traicté de Chiffre* among his "best books" (Malcolm, 2005). Strasser (1994) produces evidence that Hartlib perused early cryptographic works such as Selenus's *Cryptomenytices* and especially Trithemius's *Steganographia*. Wilkins published a cryptography manual in 1641, the first of a number of such works that would be published in the coming decades. Among these was a collection of letters deciphered by Wallis and published in 1653—an attempt to popularize and demystify cryptographic techniques—and Samuel Morland *New Method*. Wallis's knowledge was based on his employment as a cryptographer for Parliamentarians in the decade prior, though he would later put these skills to use for the royal court.[42] Wilkins's text is perhaps the most remarkable; alongside familiar substitution and translation ciphers, he presents forms of encoding alphabets through the use of non-linguistic objects such as the dots and lines on a page, or through pitches and lights (Figure 2). Through repeated the use of these examples, Wilkins was training readers to "always be observant and mindful that everything around them can be encoded" (Ellison, 2014, p. 18).

[42] Smith (1917) discusses the considerable effort Wallis put into deciphering encrypted texts during this time. See also Beeley (2007) for a more recent account.

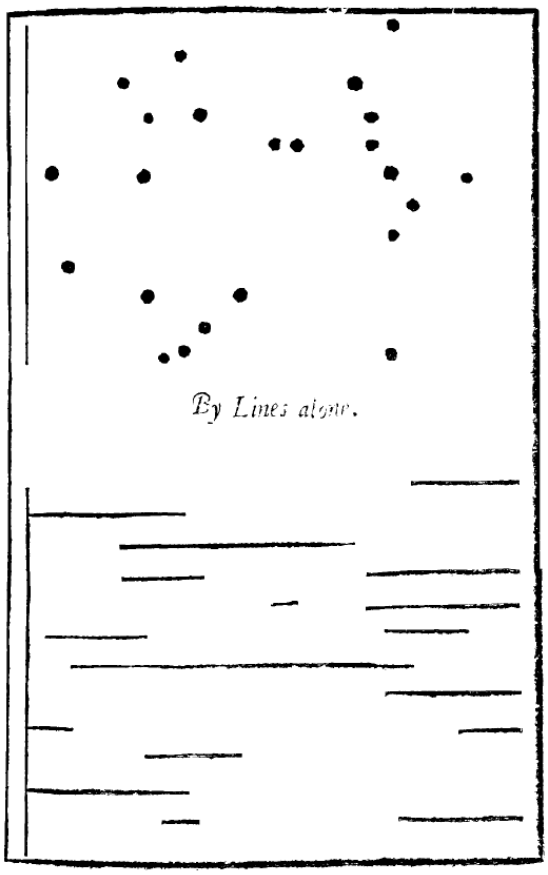

Figure 2: An example from Wilkins of enciphering by figures

Wilkins also discussed techniques of hiding writing through special inks or tools—a topic of particular interest to the later Royal Society. In 1658, Oldenburg wrote to Boyle about letters that could be "written by unseen white characters" that became visible on exposure to ink (*Correspondence* 1, p. 257). The same technique is then reported among fragments originally meant for the *Usefulness* (BP 10, fol. 64^{r}). Cases like this one encouraged Boyle to experiment with various substances and chemical reactions that could serve to hide sensitive information. Around the time of Oldenburg's letter, Boyle recorded trials in which he wrote messages on skin with pens dipped in urine that could be revealed when rubbed with paper ash (*Works* 6, p. 429).[43] The topic of secret writing techniques remained an interest of Boyle's for over a decade; notebook entries from the 1670s report further experiments on colorless ink (BP 38, fol. 47^{r}). By this time, however, Boyle had branched into other cryptographic methods.

[43] For further discussion of secret communication and early modern science, see Macrakis (2010).

Principe (1992) gives a thorough documentation of Boyle's work with codes and ciphers. Much of this revolved around Boyle's alchemical practice, where as many as ten different codes served to obscure his recipes.[44] The use of these code-names, or *Decknamen,* for guarding alchemical knowledge was a form of secrecy that Boyle engaged in freely. One example is found in keys kept in his notebooks, which allowed Boyle to translate invented Latinate code names into common chymical names and *vice versa* (BP vol. 28, fols. 332-333; see Figure 3). His workdiaries are full of related recipes:

> Take of Vagalus well burnt and then exposd a while to the Air, and of Banatu finely pouderd and well incorporated with it æquall parts Decoct them well together and haveing separated the Regulus beate it to fine powder, and with Tacula make […]" (WD 34, entry 2; note that Figure 3 lists 'Tacula' as the code-name for saltpeter).

[44] On Boyle's alchemy and the influence of alchemical writing on his chymical theory, see Debus (1967), Principe (1998), and Newman (1994a).

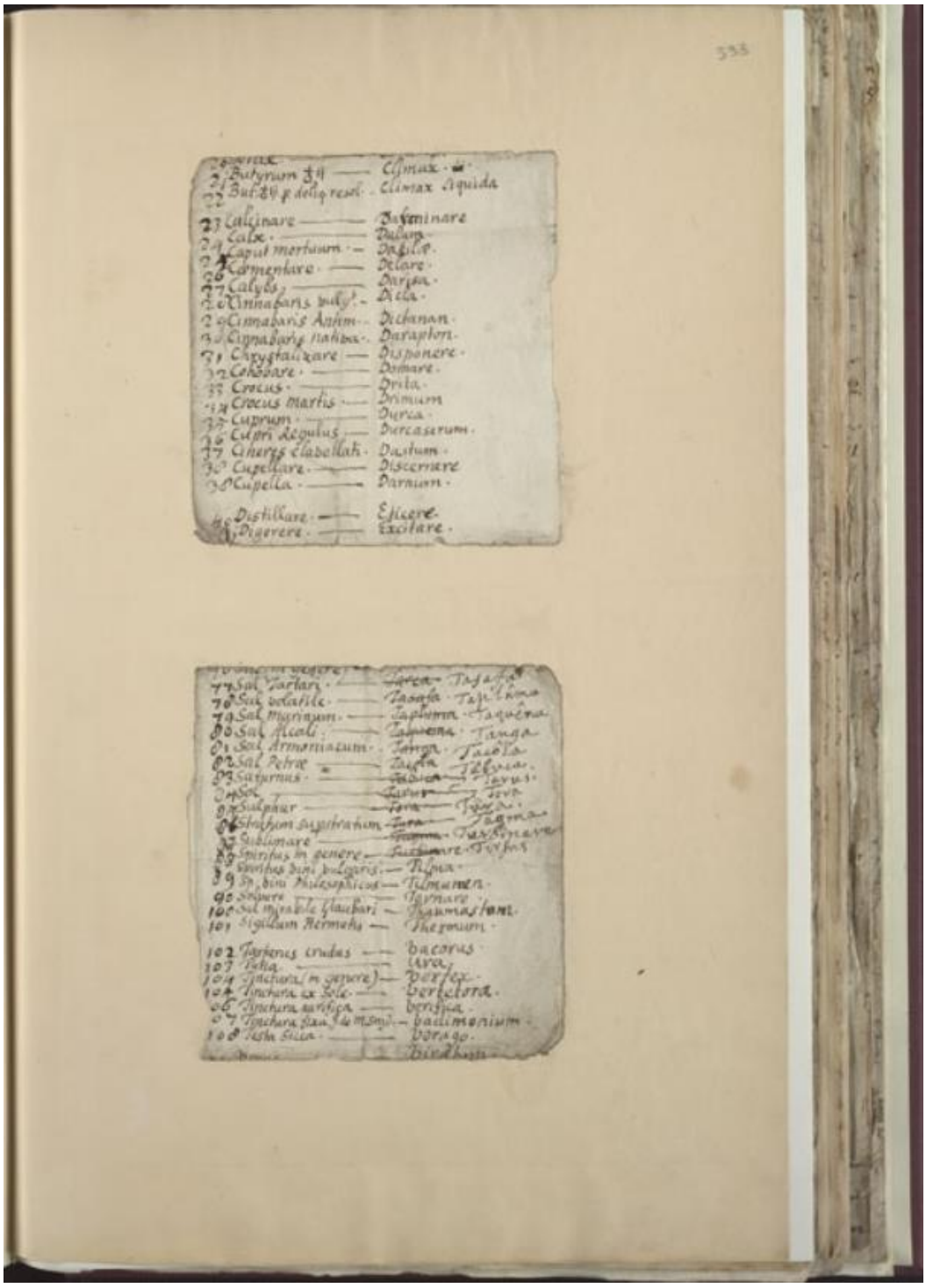

Figure 3: Fragments of a key for cryptonyms in Boyle's manuscripts, est. 1670s – 1680s

This was not merely a private practice; from 1669 to at least 1688 Boyle exchanged codes and enciphered messages with others. Some of these were lost,[45] others merely reference codes without employing them, as in a letter from de Longueuil from the early 1680s mentions an alchemical code-book: "I am sending you the processes and Paraginus's code in 6 sheets containing 24 pages each […] keep this matter secret" (*Correspondence* 5, pp. 336a-337a) or Clayton's reminder that Boyle had offered "to communicate some receits & Secrets which you said you would not trust to the hazards of a letter but under a hidden Character, the key of which you said you would send me in the first place" (*Correspondence* 6, p. 224-225).[46] Others employ numerical code-names to which Boyle already possesses a key: "I am saying a great deal since you are the only person to have the key to these numbers. Take common 47, made by 62 and alum instead of 82 or take the common 47, as it is, grind it to a powder […]" (Le Green to Boyle 1682, *Correspondence* 5, p. 345a). And still others contain keys meant to decode names from previous letters (St. Germain to Boyle 1680, *Correspondence* 5, p. 197a).

[45] See, e.g., *Correspondence* 4, p. 127, or *Correspondence* 6, p. 246.

[46] See also a 1678 letter from Pierre: "Send me the chemical code which you have told me about, and we shall enjoy ourselves together, as I shall send you some processes" (*Correspondence* 5, p. 57a). Pierre repeatedly wrote to Boyle in the first half of 1678 with enticements of access to alchemical secrets. The frequency of communication suggests that Boyle expressed considerable interest in Pierre's communication.

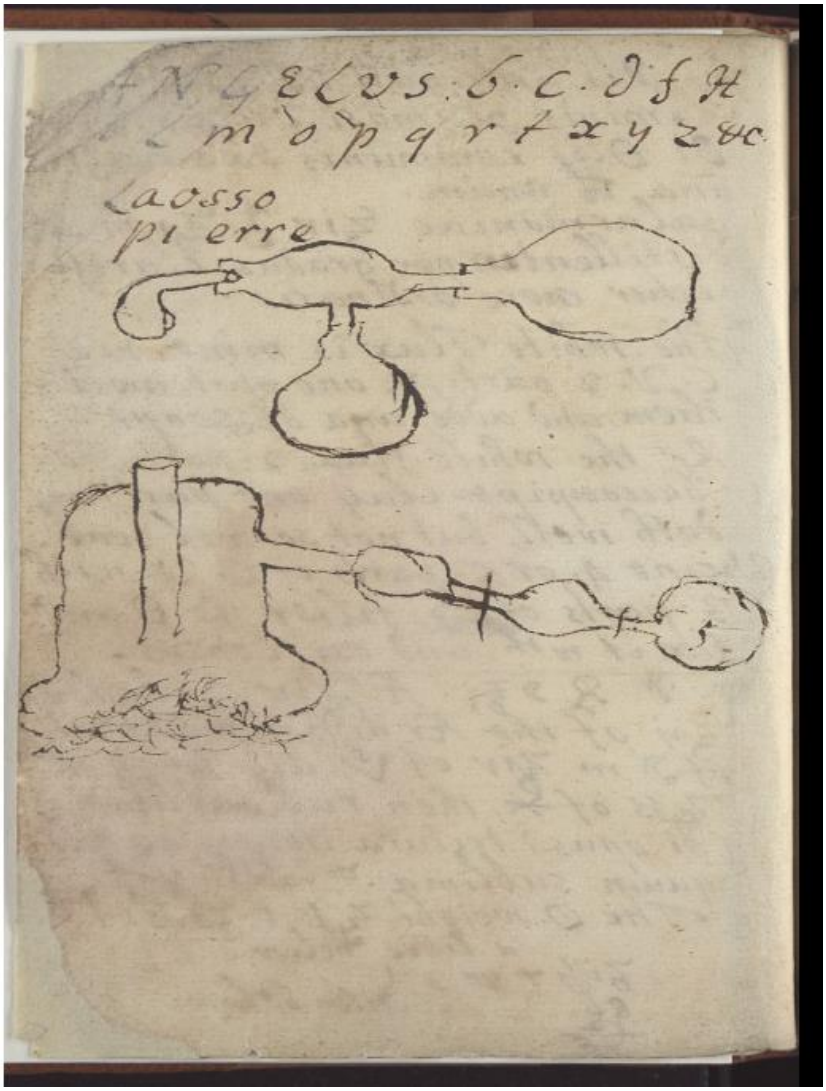

Figure 4: A cipher and chymical equipment from Boyle's workdiary (WD 33, entry 14).

Boyle copied down this cipher from St. Germain in one of his workdiaries, along with a cipher for the name "pierre," (see note 43) and some sketches of equipment for distilling and separating chemicals (Figure 4). Elsewhere in this workbook, one finds a ciphering key in the form of an "alphabet square" and an enigmatic string of numbers and letters that could have been related to a numerical cipher such as Le Green's (WD 33, entry 33, 40). The concurrence with alchemical correspondence and drawings show that Boyle's code-work was clearly stimulated by his alchemical activities, which had increased noticeably after a lull through most of the 1660s (Principe, 1994). In some ways, alchemical

discourse bore a resemblance to the depiction of natural philosopher as code-breaker.[47] In his cryptography manual, Wilkins remarked that the notation in "Chymical Treatises" drew on a shared code, since those "that are written in different languages, do all of them agree in the same form of writing their Minerals. Those that are attributed to any of the Planets, are decyphered by the character of the Planets to which they belong. The rest by other particular signs" (1641, p. 108).[48] Seventeenth century alchemists such as Becher believed in a close connection between symbol and substance, claiming each possessed a common character (Rossi, 2006, p. xxvi). This was part of a symbolic tradition in alchemy, whose most prominent advocate in early modern Europe was John Dee. In his *Monas Hieroóglyphica* (1564), Dee claimed "to have discovered a new and sacred writing or language that is an alphabet of nature" (Clulee 2005, p. 203). Dee's followers promoted the use of symbols from which a skilled reader could derive the chemicals used to produce a substance in the lab (Foreshaw 2005).[49] Hooke and Wilkins were so captivated by this tradition that they defended the writing of Johannes Trithemius and Dee against accusations of demonology, interpreting their writing on spirits as techniques for encoding valuable secrets about the natural world.[50] As Hooke wrote with respect to one of Dee's esoteric narratives, "I do conceive that the greatest part of the said Book, especially all that which relates to the Spirits and Apparitions, together with their Names, Speeches, Shews, Noises, Clothing, Actions, and the Prayers and Doxologies, &e. are all *Cryptography*" (1705, p. 206).

Alchemical discourse sometimes overlapped with cryptographic terminology. George Starkey, with whom Boyle worked closely in the 1650s, systematically referred to 'keys' in his letters as "any product or principle that had the ability to 'unlock' or reveal *further* secrets of nature" (Newman 1994b, p. 72). Principe (1994) notes that Boyle employed Basil Valentine's cryptic work of alchemical recipes

[47] Recent research on alchemy in seventeenth century England (Janacek, 2011; Parry 2012) shows how prevalently it was practiced, and that many regarded alchemy as one of the foremost fields of natural philosophy.
[48] A point is repeated in Webster's *Academarium*: "the Planetary Characters, the marks for minerals, and many other things in Chymistry, though they be alwaies the same and vary not, yet are understood by all nations in *Europe*, and when they are read, every one pronounces them in their own Countreys language and Dialect" (1654, p. 25).
[49] See also Foreshaw (2013) on the numerical-linguistic analyses of alchemical figures inspired by the Cabbala.
[50] For remarks on Trithemius, see Wilkins (1641, p. 122).

known as *The Twelve Keys* in his recipes for altering the properties of gold.[51] The processes in the *Keys* are presented through varying symbolic names for important ingredients such that only the dedicated reader steeped in alchemical *arcana* could follow each step. Successful alchemical practice thus involved skillful interpretation to properly decipher the recipes, as Boyle warns:

> I doubt not but Helmonts sayes true where he declares that the Alkahest is tædiosissimae Præparationis; & that other Arcana majora of the Chymical Philosophers, tho the processes were deliverd without Riddles, would be very difficult to prepare by persons not already very well versd both in the more common, & some of the more subtile operations of Chymistry. Thô I do not therefore blame your aspireing to the highest secrets (Boyle to Avery 1680, *Correspondence* 5, p. 193).

Alchemical recipes were themselves seen as providing a sort of material "key" capable of revealing secrets of nature in the form of new substances.

More generally, the language of secrecy suffused Boyle's communications and discussion of science. Natural philosophers in mid-1600s England inherited a manner of speaking that drew on the natural magic traditions of the prior century. Like the book of nature, talk of "nature's secrets" was first popularized among esoteric writings of the Middle Ages, but underwent several transformations during the Renaissance. By the mid-sixteenth century, an industry had arisen in England centered on the publication of "books of secrets." These were typically technical manuals comprised of recipes for practical traditions such as metallurgy, perfumery, dyeing, medicine, alchemy, and other arts. Yet their presentation often invoked the medieval notion of *arcana naturae*; readers were encouraged to think of themselves as gaining access to knowledge of the secret connections underlying the natural world, developing their skills as practitioners of a kind of natural magic that took advantage of hidden sympathies linking animal parts to diseases to climate variations, and so on. Eamon (1994) narrates the spread of this genre as it gave rise to the image of natural philosophy as *venatio,* or a hunt for secrets.[52] Among the so-called professors of secrets was Giambattista della Porta, whose Academia Secretorum

[51] The suggestive language of Valentine's title is also found in other alchemical work, such as one drawn on heavily by Newton known as the *Clavis*, or *Key* (Dobbs, 1975).
[52] Eamon uses his findings to advance the thesis that the spread of books of secrets made an important contribution to the rise of modern science in the 17th century. See also Kavey (2007).

Naturae, founded in 1560, is sometimes regarded as an early model of a scientific society (e.g., by Oldenburg).[53]

Talk of nature's secrets was rampant among Boyle's contemporaries. Harvey wrote of his "choice to consult Nature herself about Nature's secrets" (1981, p. 3).[54] Oldenburg described natural philosophers as having "unraveled […] secrets of nature" (1968c, p. 43).[55] For Hooke, the workings of nature were an elusive object of knowledge: "the Operations of Nature are more secret and abstruse and hid from our discerning, or discovering of them, than those more gross and obvious ones of Engines" (1705, p. 20). And this to the point where they actively sought to escape intellectual capture: "the footsteps of Nature are to be trac'd, not only in her ordinary course, but when she seems to be put to her shifts, to make many doublings and turnings, and to use some kind of art in indeavouring to avoid our discovery" (1667, Preface). The libraries of the Royal Society members who regularly interacted with Boyle provide substantial evidence that such statements were influenced directly by books of secrets.[56]

Boyle's library was unfortunately dispersed after his death,[57] but his correspondences reveal how utterly mundane it was to speak of nature's secrets. The concept is regularly used as a general term for discoveries resulting from experimental practice, as in Boyle's letter to Evelyn stating, "it cannot but be unwellcome News to a Person addicted to experimentall Learning, to be inform'd that soe great a Master in it & Patron of it as Mr Evelyn is hinder'd by the Unkindneses of Nature to prosecute his skillfull Enquiries into the secrets of it" (*Correspondence* 1, p. 215). It is also tied to specific properties, such as Newton's account of "a certain secret principle by which liquors are sociable to some things & unsociable to others" (*Correspondence* 5, p. 146). Often the historical association of secrets with technical

[53] In a letter to Boyle from the mid-1660s, Oldenburg describes Porta's Academia as "ye Soiety, yt had invented and practiced ye same way before any others, knowne to us" (1968a, p. 585).
[54] […] *de naturae arcanis, naturam ipsam consulere malueris* (Harvey 1651, p. 6).
[55] […] *penitus Naturae arcana reserarunt*.
[56] For example, Newton's library includes Agrippa, Agricola, della Porta, Ulstad, Paracelsus, and a wealth of alchemical texts ranging from pseudo-Lull to contemporaries such as Philalethes and Ashmole (Harrison, 1978). Oldenburg has multiple texts from della Porta alongside titles by Agricola, Vigenère, Cardano, Behme, and Trithemius (Malcolm, 2005). Hooke owned copies of Agrippa, Cortese, Ulstad, Liebault, pseudo-Fallopio, Agricola, Paracelsus, Trithemius, Fioravanti, Albertus Magnus, Libavius, Croll, Webster, among his own collection of alchemical, Lullian and Cabbalistic texts (Feisenberger, 1975).
[57] See, however, Avramov et al. (2010).

knowledge is apparent: Oldenburg writes of "a petition made to the king for a patent to practise a secret for the improving of any barren ground" (*Correspondence* 2, p. 87). And, unsurprisingly, more than half of the mentions of secrets in Boyle's letters occur in the context of alchemical discussions, where the term typically referred to recipes for specific substances. From his early correspondence with Starkey in the 1650s[58] to letters received in his final years,[59] Boyle was awash in talk of alchemy's secrets.

Boyle likewise refers to natural secrets throughout his published and unpublished works, both in terms of special trade techniques or recipes, and in reference to hidden features of nature. He writes of trade workers, "the Artificers are wont to be shy of communicating their secrets" (*Works* 9, p. 151), while in 1674's *Excellency of Theology* talks of "that great variety of Objects the Naturalist is not onely by His Curiosity, but by Their secret dependances upon one another, engag'd to consider" (*Works* 8, p. 57). Importantly, there are signs that Boyle directly engaged with authors who were affiliated with the intersecting natural magic and cryptographic traditions. References in his works show that he was particularly familiar with writing by Cardano and della Porta.[60] Boyle evidently took their claims seriously enough that he sought to verify them with his own experiments: "We could not upon the Burning of several small Loadstones one after another, discern any such blew sulphureous Flame as *Porta* in his Natural Magick relates himself to have seen" (*Works* 11, p. 379).

[58] "the secret of Tartar I shal seeke totally in Oyles mixed with it in forme of a Sapo" (Starkey to Boyle 1651, *Correspondence* 1, p. 93).

[59] "I desire not to be unsensible of the Almighty's blessing upon my endeavours so farr in the finding out of some medicine surpassing what is common, & hence to be encouraged in a further scrutiny into natures secrets, humbly begging your honour's help herein" (Avery to Boyle 1688, *Correspondence* 6, p. 256). Avery is here continuing a dialogue previously carried on between Boyle and his father, William, who sought the recipe for the Helmontian alkahest. Boyle refused to share his secrets, revealing a counter-tendency to his celebrated openness and early advocacy for the sharing of receits. See Hunter (2011) for more on this correspondence.

[60] Della Porta invented a novel substitution cipher in 1563. His later work, suggestively titled *Criptologia*, instructed readers on interpreting the divinely ordained sympathies written into the natural world through hidden similitudes between plants, animals, and other natural phenomena. Thus "the herb *scorpius*, which resembles the scorpion, is a good remedy against the scorpion's sting" (Eamon, 1994, p. 214). The discovery of such correspondences was a paradigm of naturalistic inquiry among those interested in code-writing and code-breaking: in 1563's *De Secretis* Cardano, inventor of a special method for encoding messages and author of a collection of writings on cryptography, characterized the entire scientific enterprise as a search for secrets. Scattered references to figures such as Albertus Magnus, Fludd, Ripley, and Mirandola are also found in Boyle's writing.

On the one hand, Boyle advocated for great openness among those who possessed useful knowledge, as seen in his "Invitation to a Free and Generous Communication Of Secrets and Receits in Physick" (1655).[61] Boyle would sometimes openly discuss secrets that were apparently revealed to him in confidence, as with his account of a technique for tempering steel shared by "an Ancient *Virtuoso*, who had purchas'd the Secret of a rare Arist, for a great Prince" (*Works* 6, p. 421). At other points, he sought to demystify and explain obscure techniques to his readers. On a way to produce fine writing with iron on copper, he wrote, "though this Artifice be kept for a choice Secret, and though I could not learn a considerable Particular or two, which belong to the Delicacy of it; yet (partly by putting Questions, and partly by some Tryals of my own) I attain'd to the substance of this Mystery, as they call it, which seems to be this […]" (*Works* 6, p. 500). Still, Boyle was often reticent about revealing too much, at times out of concern for the livelihood of trade workers,[62] at others by appealing to the danger certain knowledge could pose to humankind.[63, 64]

Though I've shown that Boyle distanced himself from the doctrine of signatures advanced by these figures, he nevertheless held an interest in magic for the remainder of his life.[65] He also retained the general stance that nature harbored "secrets" in the sense of a hidden structure of relations beneath its appearances. After the 1660s, however, these relations were revealed by mechanical and chymical principles rather than the moralistic and allusive insights of his early work.[66] Boyle, drawing on the book

[61] See Hunter (2011) for a detailed analysis of Boyle's complex attitude toward secrecy.
[62] "I never divulge *all* the Secrets and practices necessary to the exercise of any one Trade, contenting my self to deliver here and there upon occasion some few particular Experiments, that make for my present purpose" (*Works* 6, p. 399).
[63] "[…] for the true way of performing such an Effect, and divers others of the like nature, which I have sometimes for Curiosity prosperously experimented, I think it much fitter to be conceal'd than communicated, because if such Secrets should fall into the hands of persons incin'd to mis-apply them, they might very much disturb Humane Society" (*Works* 6, p. 430).
[64] For further work on the ambiguous attitude toward secrecy and publicness in seventeenth century science, see Shapin (1988), Weinberger (2005), DiMeo (2011), Janacek (2011, Ch. 3), Preston (2015, Ch. 3).
[65] For Boyle's complex attitude toward natural and demonic magic, see Hunter (2000, Ch. 5 and 10) and Webster (1982).
[66] Harrison (2006) argues that the book of nature metaphor was reoriented in the sixteenth century to stabilize the "realm of the visible" after the decline of the allegorical and imagistic thinking of the Renaissance. Yet there remained clear signs of interest in allegory in the writing of such luminaries as Bacon and Newton (McGuire & Rattansi, 1966; Barbour, 2005; Casini, 1984).

of nature metaphor, came to describe these revelations as a kind of code-breaking, in which mechanical hypotheses are the key that uncovers nature's alphabet. Boyle's renewed alchemical interests had increased his involvement with the cryptographic techniques that preoccupied his fellow Royal Society members. He was clearly familiar with their parallel efforts to develop a language attuned to the order of the natural world, encountered similar tendencies among the symbolic alchemists, and was immersed in the rhetoric of natural secrets in which hypotheses were devised "to illustrate the obscure transactions of nature" (*Works* 13, p. 273). Boyle had left behind the vestiges of emblematic thinking in his early work, but was still drawn to the notion of nature as a book written in a distinct language. This social and intellectual context thus made the idea of natural philosophy as cryptographer an intuitive way of framing his efforts.

5 Justifying the mechanical philosophy

In 1674, Boyle's first extensive application of a cryptographic metaphor to natural philosophical method appeared in print. This was one of only two published instances of the metaphor, yet it is nevertheless noteworthy for several reasons. First, the text in which it occurs, *About the Excellency and Grounds of the Mechanical Hypothesis*, was initially planned as an appendix to Boyle's work on "The Requisites of a Good Hypothesis."[67] Boyle had planned this essay since the mid-1660s, but never published it.[68] All that remains are brief fragments from his notebooks. Hence, the *Excellency* contains some of the only published material that is clearly related to Boyle's thinking on natural philosophical hypotheses in general. Boyle connects cryptography to these methodological considerations at several other points in his extant writing. The significance of these instances is in part due to the fact that they arose at a moment within Boyle's continued re-development of the book of nature concept, which indicates that cryptography provided him with a metaphorical tool for sharpening his thoughts on this topic.[69] This

[67] This is stated in the opening advertisement for this essay.
[68] *Works* 14 shows its appearance in a number of lists of unpublished works, with the earliest dating to 1665.
[69] This is not to say that it is the only metaphor that Boyle used in discussing the use of hypotheses. For instance, he repeatedly compared this activity to conjectures about the inner workings of a clock. Like the case of cryptography,

alone makes it a matter of interest, but it is equally worth considering due to the interest it generated among other mechanical philosophers, namely Huygens and Leibniz. These two began to make this comparison at roughly the same time, establishing the comparison with cryptography as a minor trope of this period. The vectors of influence are not perfectly clear, but it is evident that this metaphor held a particular allure for these authors. Here I will provide textual evidence showing how cryptography served to compactly illustration of several virtues of mechanical hypotheses, thereby aiding in the justification of these authors' theoretical framework.

Toward the end of his 1674 defense of mechanical hypotheses, Boyle writes the following:

> […] on this occasion let me observe, that 'tis not always necessary, though it be always desirable, that he that propounds an *Hypothesis* in Astronomy, Chymistry, Anatomy, or other part of Physicks, be able, *à priori*, to prove his *Hypothesis* to be true, or demonstratively to shew, that the other *Hypotheses* propos'd about the same subject must be false. For *as*, if I mistake not, *Plato* said, That the World was God's epistle written to Mankind […] *So*, in the Physical Explications of the Parts and System of the World, me thinks, there is somewhat like what happens, when men conjecturally frame several Keys to enable us to understand a Letter written in Cyphers. For, though one man by his sagacity have found out the right Key, it will be very difficult for him, *either* to prove otherwise than by trial, that this or that word is not such as 'tis ghess'd to be by others according to their Keys; *or* to evince, *à priori*, that theirs are to be rejected, and his to be preferr'd; yet, if due trial being made, the Key he proposes, shall be found so agreeable to the Characters of the Letter, as to enable one to understand them, and make a coherent sense of them, its suitableness to what it should decipher, is, without either confutations, or extraneous positive proofs, sufficient to make it be accepted as the right Key of that Cypher. And so, in Physical *Hypotheses*, there are some, that, without noise, or falling foul upon others, peaceably obtain discerning mens approbation onely by their fitness to solve the *Phænomena*, for which they were devis'd, without crossing any known Observation or Law of Nature. And therefore, if the Mechanical Philosophy go on to explicate things Corporeal at the rate it has of late years proceeded at, 'tis scarce to be doubted, but that in time unprejudic'd persons will think it sufficiently recommended by its consistency with it self, and its applicableness to so many Phenomena of Nature. (*Works* 8, pp. 115-116).

As before, mechanical principles are regarded as a kind of alphabet, the letters of which combine to form worldly phenomena. Now, however, the devising and testing of these principles is explicitly viewed in

these other metaphors were used to justify confidence in explanations provided by particular mechanical hypotheses. On the other hand, they do not defend the use of hypotheses with broad explanatory scope or suggest how hypotheses effective in one domain may be extended to others, both of which will be shown to occur alongside the cryptographic metaphor.

analogy with the construction of a cryptographic key, where phenomena are elements of an encrypted text whose hidden meaning must be deciphered through reduction to an appropriate combinatoric scheme.

One basic feature that cryptography shared with hypotheticalism was that it was regarded as the skilled trial-and-error use of probable conjecture in pursuit of a hidden truth. Wallis states as much in a letter to Boyle: "by a few Letters known, he may be able to Supply the rest of the Word; and by a few Words, the rest of the Sentence, or at least the sense of it, by a probable conjecture, (as when we Decipher Letters written in Cipher:)" (1662, *Correspondence* 2, p. 16). When confronted with an encrypted text, "hee that will do any Thing in it, must first furnish himself with Patience and Sagacity, and make the best Conjectures hee can, till hee shall happen upon something that hee may conclude for the Truth" (Davys, 1737, p. 14).[70] Such an account resonates with Boyle's description of the natural philosopher who "must vary his methods & alter his structures from time to time, as he is prompted by cross or lucky Incidents and further Discoveries" (BP 9, fol. 113^{r}). In line with Wallis and Boyle's language, Descartes says of his key, "hoc sola conjectura" and Huygens writes in 1673 of a cryptographer "having made some weak conjecture" (1897, p. 298).[71] The concordance between cryptographic and natural philosophical methods is perhaps stated most explicitly by Leibniz. In a 1673 manuscript, he compared the search for a rule for a mathematical series with the search for the key of a cipher, and related this to the doctrine of discovery or hypothesis (Beeley, 2007).[72] This comparison was enlarged in an early 1680s[73] manuscript on natural science:

> The conjectural method a priori proceeds by hypotheses, assuming certain causes, perhaps, without proof, and showing that the things which now happen would follow from these assumptions. A hypothesis of this kind is like the key to a cryptograph, and

[70] A similar emphasis on skill and ingenuity is found in Morland 1666.
[71] *"[…] ayant fait des suppositions sur quelques legeres conjectures"* My translation.
[72] For the sake space, I will draw from a single work of Leibniz. It must be noted that he compares cryptography to natural philosophical method, including the grand method of *mathesis universalis*, in a number of places in his letters, publications, and manuscripts, including several points in his *New Essays on Human Understanding*. See Rescher (2013) for further examples and an account of Leibniz's deep interests in cryptography, which include the invention of an enciphering machine.
[73] There is good reason to believe that Leibniz was familiar with Boyle's *Mechanical Hypothesis* by this time, as he wrote in 1675 to Oldenburg stating that he had read the volume in which it was included, "which influenced me wonderfully" (Oldenburg 1968d, p. 97).

> the simpler it is, and the greater the number of events that can be explained by it, the more probable it is (Leibniz 1956, p. 283).[74]

In addition to these methodological similarities, cryptographic metaphors provided a model for unificatory and explanatory virtues of mechanical hypotheses, and it did so in a way that helped lay emphasis on the pragmatic reasoning guiding such work. That is, it helped show how hypotheses could gain credence by being tried out and found successful among a range of phenomena. Boyle believed that mechanical hypotheses could provide explanations that were both broad in scope and internally consistent, and that this was a compelling reason to think they provided an apt description of the world. As with Descartes,[75] the comparison to cryptography found in *Mechanical Hypothesis* was a way for Boyle to justify confidence in his principles, and other mechanical philosophers latched onto the comparison for similar ends. Similarly, Christiaan Huygens made extensive use of this metaphor in defending his appeal to mechanical hypotheses. Responding to a 1673 letter from Pierre Perrault, who questioned his mechanistic explanation of phenomena encountered in air pump experiments, Huygens wrote,

> In physics all demonstrations are like the decryption of a letter where, having assumed some tentative conjectures, if one finds them borne out in practice, in the sense that following this assumption of letters [for a key] one finds one can comprehend the words in the message, one can be very certain that the conjectures are true, although there is no way of proving it and it is not impossible that more truthful ones are available (Huygens, 1897, p. 298).[76]

Such caveats are another constant in explications of this metaphor, mirroring Descartes's care to distinguish between absolute and moral certainty:[77]

> just as it is possible to write a letter intentionally so that it can be understood by means of several different keys, of which only one is the true one, so the same effect can have several causes. Hence no firm demonstration can be made from the success of

[74] Note that Leibniz is not describing an *a priori* form of knowledge, but a method of posting hypotheses that is not directly tied to experiment.
[75] See the above discussion on p. 14.
[76] […] *dans les choses de physique il n'y a pas d'autres demonstration* [sic] *que dans le dechiffrement d'une lettre. Ou ayant fait des suppositions sur quelques legeres conjectures, si l'on trouve qu'elles se verifient en suite, de sorte que suivant ces suppositions de lettres on trouve des paroles bien suivies dans la lettre, on tient d'une certitude tres grande que les suppositions sont varies, quoy qu'il n'y ait pas autrement de demonstration, et qu'il ne soit pas impossible qu'on n'en puisse y avoir d'autres plus véritables*. My translation.
[77] For more on the epistemic category of "moral certainty" in the seventeenth century, see Sargent (1989).

> hypotheses. Yet I shall not deny that the number of phenomena which are happily explained by a given hypothesis may be so great that it must be taken as morally certain (Leibniz 1956, p. 283).

Confidence in these hypotheses was thus tied to their unificatory power.[78] The condition that hypotheses suffice to explicate phenomena is found in Boyle's manuscript "On a Good and an Excellent Hypothesis," but the desideratum that they do so for a wide range of phenomena is not clearly stated here or in his "Requisites." Yet in *Mechanical Hypotheses* and elsewhere Boyle wields the broad explanatory scope of his principles as a reason to prefer them over those of Paracelsian chymists.[79] One such case again draws on cryptography:

> I know not, whether I may not add on this occasion, that, methinks, a Chymist, who by the help of his *Tria Prima*, takes upon him to interpret that Book of Nature of which the Qualities of bodies make a great part, acts at but a little better rate than he, that seeing a great book written in a Cypher, whereof he were acquainted but with three Letters, should undertake to decypher the whole piece. For though 'tis like, he would in many words find one of the Letters of his short key, and in divers words two of them, and perhaps in some all three; yet, besides that in most of the words wherein the known Letter or Letters may be met with, they may be so blended with other unknown Letters as to keep him from decyphering a good part of those very words, 'tis more than probable, that a great part of the book would consist of words wherein none of his three Letters were to be found (*Works* 8, p. 397).

Not only did they illustrate the explanatory and unificatory virtues of good hypotheses, they also helped show the use of such hypotheses for future inquiry. For example, a well-devised hypothesis should be capable of application to new domains, drawing previously unexplained phenomena under its purview:

> Any grand Physiological Truth discover'd by Competent Experience (or by any other way of Demonstration) in the Alphabet of nature, may be compar'd for its usefulnes to the Discovery of an Alphabetical Letter in an Epistle written in Cyphers. For one Letter being clearly known, dos not only help a sagacious Peruser to read the word it belongs to, but may much assist him to gain the knowledg of many other words, wherein that Letter *is* to be found, and so may prove a Key wherewth the Decypherer may attain to ye Understanding even of many other words, wherein ye Letter *is* not to be found at all, and

[78] See footnote 36 above.

[79] Remarks to this end are found in his theoretically oriented natural philosophical works from this time period, such as the introduction to *The Mechanical Origine of Qualities*: "the use of an *Hypothesis* being to render an intelligible account of the Causes of the Effects or Phænomena propos'd, without crossing the Laws of Nature or other Phænomena, the more numerous and the more various the Particulars are, whereof some are *explicable* by the assign'd Hypothesis, and some are *agreeable* to it, or at least are not dissonant from it, the more valuable is the Hypothesis, and the more likely to be true (*Works* 8, p. 325). For more on "Requisites," see *Works* 13, BP vol. 38, fols. 37-39, and Ducheyne (2013). For more on Boyle's method, see Anstey and Hunter (2008).

> may perhaps prove more than a partial Key, wherewth to understand the whole writing (BP vol. 9, fols. 62-63).[80]

Hypotheses successfully applied to one set of phenomena may thus provide keys to obscurities encountered elsewhere, or at least suggestions for further experimentation. Boyle writes of the capacity of thorough experimentation to uncover "Touchstones" for the discovery of further relations between a known object and those things it may interact with (BP 9, fol. 111^{r}). Leibniz describes such a procedure as the hypothetical method a posteriori, which draws on commonly known features to extend experience in one domain to another: "So it is also easier to solve cryptographs when we have found a number of letters in the concealed meaning which are written according to the same key" (1956, p. 284). Huygens describes how a hypothesis initially proposed for one phenomenon (in his case, that air has weight) can be used to devise further tests: "this is the same as the deciphering of a letter," he writes, "we can go on to imagine consequences of this hypothesis and experiments to test in order to see if these conform to the conclusions like here one says that if the weight of the air sustains water at the height of 31 feet, this same weight of air will not be able to sustain 27½ inches of mercury" (1897, p. 299).[81]

Of course, the prospects for the extension of mechanical hypotheses to new domains depends on the assumption that mechanical principles correspond to a common order in the world. Boyle and his contemporaries surely realized that the proof was in the pudding, so to speak, but this did not prevent some highly optimistic claims. At times it appears that Boyle regarded his basic principles—reduction of phenomena to matter, motion, size, shape, and the like—as so simple and intelligible as to render them consistent with any successful physical theory:

> the fear, that so much of a *New* Physical Hypothesis, as is *true*, will overthrow or make useless the Mechanical Principles, is as if one should fear, that there will be a Language propos'd, that is discordant from, or not reducible to, the Letters of the Alphabet (*Works* 8, p. 117).

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[80] This passage from Boyle's manuscripts is estimated to have been written in the 1670s – 1680s.

[81] *Et pour faire voir q'uil e nest de mesme icy qu'au dechiffrement d'une lettre […] on s'est allè imaginer en suite d'autres consequences de cette hypothese et des experiences pour voir si ells se trouveroient conformes aux conclusions qu'on avoit formées, comme icy l'on a dit si c'est la pesanteur de l'air qui soustient l'eau a la hauteur de 31 pieds, cette mesme pesanteur de l'air ne pourra donc soustenir que 27½ pouces de mercure.* My translation.

Boyle's notebooks from the 1670s contain memoranda that harken to this view. In one, he jotted a reminder "that no words cannot [sic] be fram'd beyond the reach of the Letters of the Alphabet" (BP vol. 9, fol. 67[r]). In another, he states this in physical terms: "[Remember] to shew how all the differing bodys mention'd are but differing Dresses of their common matter, or rather the same matter in variety of dresses" (WD 28, entry 803). In practice, thorough-going successes of the fully reductive program of Boyle's philosophy were hard to come by.[82] Still, the textual evidence shows that the cryptographic metaphor was viewed as a useful tool for clarifying and justifying the merits of the hypothetical method employed by mechanical philosophers.[83]

6 Conclusion

For a brief period in the mid-1670s, three prominent mechanical philosophers and members of the Royal Society suddenly converged on a comparison of their methods to cryptography. My goal has been to highlight this metaphor as a minor trope in seventeenth century science, to trace its emergence in Boyle's writing as part of the development of his conception of natural philosophy, and to show why he and his contemporaries were drawn to it on the basis of social and broadly scientific factors. Boyle's scientific work developed in a social context in which alchemical and cryptographic techniques were a matter of great interest, often presented in terms that echoed the sixteenth century books of secrets in which they gained prominence. As his alchemical endeavors intensified, Boyle came to frame the task of reading the book of nature as a matter of deciphering nature's secrets, a metaphor that provided mechanical philosophers with a compact representation with which to characterize their method and argue for its virtues. The rise of the cryptographic metaphor, carried into the following century by Leibniz before quickly dying out, offers a window into the state of reflections on natural philosophy at this time. During

[82] Chalmers (1993) and Clericuzio (2000) have argued this point compellingly.

[83] There may be grounds to locate a stronger influence of the search for nature's alphabet on the "higher-level" reductive strategy Boyle employed in his chymical analyses. Starting with his work in the mid-1660s, one might be able to trace the development of his notion of "the Specifical Difference that *constitutes* the Body, and *discriminates* it from all other sorts of Bodies […] which is consequently but a certain *Character*" (*Works* 5, p. 334).

a period where natural philosophers sought a general scheme for their rapidly diversifying experimental and theoretical practice, authors eagerly drew from a cross-section of arts popularized in the prior century—artificial languages, symbolic algebra, and cryptography—to help them frame their pursuits. The lasting influence of these efforts is unclear, but one can speculate that the perceived affinity between scientific hypotheses, algebraic methods, and cryptography, considered against the backdrop of Neo-Platonic, alchemical, and hermetic influences may be thought to reveal an intellectual context in which the application of mathematical symbolism to phenomena became a perfectly intelligible strategy for investigating nature.

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