Galileo, Hobbes, and the Book of Nature[1]

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This paper investigates the influence of Galileo's natural philosophy on the philosophical and methodological doctrines of Thomas Hobbes. In particular, I argue that what Hobbes took away from his encounter with Galileo was the fundamental idea that the world is a mechanical system in which everything can be understood in terms of mathematically-specifiable laws of motion. After tracing the history of Hobbes's encounters with Galilean science (through the "Welbeck group" connected with William Cavendish, earl of Newcastle and the "Mersenne circle" in Paris), I argue that Hobbes's 1655 treatise De Corpore *is deeply indebted to Galileo. More specifically, I show that Hobbes's mechanistic theory of mind owes a significant debt to Galileo while his treatment of the geometry of parabolic figures in chapter 16 of* De Corpore *was taken almost straight out of the account of accelerated motion* Two New Sciences.

The influence of Galileo Galilei on seventeenth century natural philosophy can scarcely be overstated. Nearly any figure of the period who had something to say about the study of nature found it necessary to come to terms with Galileo's views on astronomy, mechanics, mathematics, and methodology, to name four of the more salient topics. Thomas Hobbes is

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1. My references to Hobbes's *De Corpore* use the abbreviation "*DCo*" followed by part, chapter, and section numbers separated by periods; citations to the *Opera Latina* (Hobbes [1839–45] 1966a) or *English Works* (Hobbes [1839–45] 1966b) follow, using the abbreviations *EW* and *OL.* For Hobbes's works other than *DCo,* citations are to volume and page of *EW* or *OL.* References to Hobbes's correspondence (Hobbes 1994) use the abbreviation *CTH.* References to Galileo's *Opere* (Galilei 1890–1909) are abbreviated *Opere,* followed by volume and page number.

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no exception to this general principle, and it is a commonplace among Hobbes scholars that Galileo is an important source for Hobbes's methodology and natural philosophy.[2] I think, however, that Galileo's influence on Hobbes has been misunderstood and to a significant degree underestimated. On my view Hobbes's mechanistic conception of the world is heavily indebted to Galileo, and this debt is particularly significant in Hobbes's thesis that motion is the one great universal causal principle. In other words, what Hobbes took away from his encounter with Galilean natural philosophy is the fundamental idea that the world is a mechanical system, that all events in this system (including human thought and action) can be understood in terms of mathematically-specifiable laws of motion, and that all objects (including objects of thought and mathematics) arise from the motions of material bodies.

In making this claim for Galileo's influence on Hobbes, I do not mean suggest that Hobbes simply adopted Galilean ideas uncritically. On the contrary, I hold that Hobbes wanted to extend and amplify central theses in Galileo's natural philosophy. Neither do I wish to deny the influence of other figures in the development of Hobbes's thought. Nevertheless, I think that Hobbes's intellectual debts to Galileo stand out, and that the extent of this indebtedness can be made clear by an investigation of Hobbes's writings, most particularly his 1655 treatise *De Corpore.* My investigation of these matters is divided into two parts. The first traces the process by which Hobbes became acquainted with Galileo's ideas in the 1630s and later in the course of preparing *De Corpore,* especially in his interactions with Marin Mersenne and other acquaintances in Paris. The second part considers specific instances of Galileo's influence on Hobbes, focusing again on *De Corpore* and the philosophy Hobbes propounds in it.

1. The Hobbes-Galileo Connection

Hobbes's detailed knowledge of Galileo's work dates from the early 1630s. Although he had doubtless been made aware of Galileo's reputation somewhat earlier, Hobbes's intense interest in matters of natural philosophy and mathematics date from the period 1630–1634, and this is when he began a serious study of Galileo's writings. According to the famous story told by John Aubrey (and to some degree corroborated by autobiographical remarks of Hobbes), the life of the philosopher from Malmesbury was

2. The most sustained examination of Galileo's influence on Hobbes can be found in Brandt (1928). Rogers (1988, p. 196) notes that "The nature and depth of Hobbes's debts to Galileo is a subject on its own," but most accounts of Hobbes's relationship to Galilean science are brief and relatively superficial. The account offered by Watkins (1965) has been influential, but I hope to show that it is mistaken on some fundamental points.

changed during a Continental tour in the service of Sir Gervase Clifton in 1630. During a stay in Geneva Hobbes apparently came across a copy of Euclid's *Elements* "in a gentleman's library," which happened to be open to the Pythagorean Theorem. As Aubrey tells the story, Hobbes at first found the theorem incredible, but after tracing the result back through intermediate results to arrive at first principles, he was convinced of the theorem's truth and of the power of the geometric method. This chance encounter with Euclid ensured that "from that moment on, [Hobbes] was in love with geometry" (Aubrey 1898, 1:332). In his Latin autobiography Hobbes himself stressed that geometry impressed him "not so much because of the theorems, as because of the method of reasoning" (*OL* 1:xiv). Hobbes's 1660 dialogue *Examinatio et Emendatio Mathematicæ Hodiernæ* contains an interesting passage in which one of the interlocutors, speaking for Hobbes, recalled the incident. In the course of their discussion of various mathematical issues, we read:

> These things are indeed quite subtle, but nevertheless true. And they recall to my mind the occasion when I long ago had my *ἄρξειν τοῦ γεομετρεῖν*. In a certain library I saw by chance Euclid's *Elements,* which happened to be open to the 47th proposition of the first book. When I read these words: "In right-angled triangles, the square on the side subtending the right angle is equal to the squares on the sides containing the right angle," I immediately said that even if this were true, it could not be known by man, ignorant as I then was of mathematical matters. But upon inspecting the demonstration I was at once sent back to Proposition 46 and from there to others, until I arrived at first principles (Hobbes 1660, pp. 154–5).

We are certainly entitled to some skepticism about the details here, but there is no reason to doubt that Hobbes turned his attention to mathematics and natural philosophy in the early 1630s.

Hobbes's discovery of geometry in 1630 was followed by his close association with the savants of the so-called "Welbeck Academy" when he returned to England in 1631. This group was centered at Welbeck Abbey, one of the family seats of William Cavendish, earl (and later duke) of Newcastle. Newcastle was known to Hobbes as a result of his long-term association with the household of another branch of the Cavendish family, the earls of Devonshire. The Welbeck group included Newcastle's brother, Sir Charles Cavendish, a mathematician who kept up a steady correspondence with learned men on the Continent; Robert Payne, Newcastle's chaplain and a man of broad scientific interests who translated Galileo's *Della Scienza Mecanica* into English in 1636;[3] and Walter Warner, who was deeply involved both optical research and in editing the *Artis Analyticæ Praxis* of the mathematician Thomas Harriot.[4]

We know that the Welbeck group discussed Galileo's astronomy and mechanics in some detail, although we lack specific evidence of their opinions on these subjects. One illustration of the of the group's interest in Galileo can be found in a letter from Hobbes to Newcastle in early 1634. The letter reports that

> My first businesse in London, was to seeke for Galileos dialogues; I thought it a very good bargaine, when at taking my leaue of your Lordship I vndertooke to buy it for you, but if yo^r^ Lo^p^ should bind me to performance it would be hard enough, for it is not possible to get it for mony; There were but few brought ouer at first, and they that buy such bookes, are not such men as to part w^th^ them againe. I heare say it is called in, in Italy, as a booke that will do more hurt to their Religion then all the bookes haue done of Luther and Caluin, such opposition they thinke is betweene their Religion and naturall reason. I doubt not but the translation of it will here be publiquely embraced, and therefore wish extreamely that Dr. Webbe would hasten it (Hobbes to Newcastle, 26 January [5 February] 1634; *CTH* 1:19).

The dialogue in question here is of course the 1632 *Dialogue Concerning the Two Chief World Systems,* and the letter establishes that both Newcastle and Hobbes had a powerful interest in that particular work; the translation by Dr. Joseph Webb (assistant to Newcastle) was never published.[5] The theologico-political overtones of Hobbes's letter are certainly interesting, but they are not the focus of my interest, since I regard his concern with Galileo as more closely tied to matters of method and metaphysics.

Hobbes embarked upon another tour of the Continent in 1634, this time as tutor and companion to William Cavendish, the third earl of Devonshire. The pair spent nearly a year in Paris, and during this period Hobbes was introduced to Mersenne. Through Mersenne, Hobbes was brought into contact with a wide network of Parisian mathematicians and natural philosophers, and it was at this time that he was inspired to con-

3. On Payne see Feingold (1985) and Malcolm (2002, chapter 4). The treatise *Della Scienza Mecanica* (*Opere* 2:147–191) was composed around 1600 and circulated in manuscript for decades. Its first Italian publication was not until 1649, but Mersenne published French paraphrase of it in 1634 (Mersenne [1634] 1966).

4. On Warner see Prins (1994), which can be supplemented by the discussion of Hobbes and Warner in Prins (1993); on Harriot see the collection Shirley (1971).

5. On Webb, see Malcolm (2002, p. 89, n. 41). The translation survives as British Library MS. Harl. 6320.

struct a system of natural philosophy in which the only substance is body and all change arises from the motion and impact of material bodies. In his Latin autobiography Hobbes recalled that he began to investigate "the principles of natural science," during this sojourn in Paris, concluding that such principles "were contained in the nature and variety of motions" (*OL* 1:xiv). The problem that led him to propound this thoroughgoing mechanistic program was the explanation of sense perception, which he discussed with learned men in Paris only to find that nobody could provide an adequate explanation of how sensation arises. As Hobbes recounted the genesis of his mechanistic materialism in his Latin *vita:*

> at a meeting of learned men, when mention was made of the cause of sensation, somebody asked 'what is sense?' and he heard no reply; he wondered how it could happen that people who, by virtue of their alleged wisdom so scornfully despised other men, should yet not know what their own senses were. From that time on he thought often about the cause of sensation; and by good fortune it occurred to him that if all corporeal things and their parts were at rest, or were always moved with a similar motion, the distinction among all things would be removed, and so, consequently, would all sensation. And therefore *the cause of all things was to be sought in the differences between their motions* (*OL* 1:xviii–xix).

It is interesting to note the similarity of this reasoning and Galileo's defense of the reality of the Earth's motion in the "Second Day" of the *Dialogue.* Hobbes's principle that "if all corporeal things and their parts were at rest, or were always moved with a similar motion, the distinction among all things would be removed," echoes the Galilean principle that "whatever motion comes to be attributed to the Earth, it is necessary that to us, as inhabitants of the earth and consequently participants in the same motion, such motion must remain imperceptible and as if nonexistent, so long as we regard only terrestrial things" (*Opere* 7:139–40). Although I don't care to place much emphasis on this point, it is useful to think of Galileo's treatment of motion as part of the background to Hobbes's fundamental principle that the distinctions among things is based in their various motions.

By the late summer of 1635, Hobbes's mechanistic theory of the mind was largely in place. Writing to Newcastle and discussing the theories of Warner, he remarked "For y^{e} soule I know he has nothinge to giue yo^{r} Lo^{p} any satisfaction. I would he could giue good reasons for y^{e} facultyes & passions of y^{e} soule, such as may be expressed in playne English. If he can, he is the first (that I euer heard of) could speake sense in that subject. If he can not I hope to be y[e] first" (Hobbes to Newcastle, 15/25 August, 1635; *CTH* 1:29).

Hobbes and the earl of Devonshire journeyed to Italy late in 1635, remaining in Italy until the spring of 1636 when they made their way back to Paris. During this tour of Italy Hobbes met Galileo, although the dates and details of the meeting are not altogether clear. In a letter to Fulgenzio Micanzio from 1 December, 1635, Galileo reports that "I have had many visits by persons from beyond the alps in the last few days, among them an English Lord who tells me that my unfortunate *Dialogue* is to be translated into that language, something that can only be considered to my advantage."[6] The "English Lord" is almost certainly Devonshire, and the projected English translation of the *Dialogue* is presumably the work of Dr. Joseph Webb mentioned in Hobbes's February, 1634 letter to Newcastle.[7] It is therefore likely that Hobbes met Galileo in December of 1635, although Hobbes was not otherwise known to be in Florence until April of 1636. Aubrey reports that while in Florence Hobbes "contracted a friendship with the famous Galileo Galileo, whom he extremely venerated and magnified; and not only as he was a prodigious witt, but for his sweetness of nature and manners" (Aubrey 1898, 1:366). Legend even has it that a conversation with Galileo in 1635 or 36 inspired Hobbes to pursue the goal of presenting moral and political philosophy in a rigorously geometrical method, although the evidence here is hardly compelling.[8]

When Hobbes returned again to England in 1636 he renewed his contacts with the Welbeck academy, and even considered relocating permanently to Welbeck Abbey in order to pursue his scientific and mathematical researches in the company of the savants gathered at Newcastle's estate.[9] It should be recalled that Hobbes's friend and Welbeck habitué

6. "Ho hauto li giorni passati molte visite di oltramontani, tra' quali un Signor principlae Inglese, il quale mi dice, il mio sfortunato Dialogo essere stato transportato in quella linqua; cosa che non può se non progiudicarmi" (*Opere,* 16:355).

7. Antonio Favaro (1921) first drew this conclusion, and Karl Schumann (1998, 47) identified Webb as the likely translator.

8. The evidence, such as it is, comes from the eighteenth century historian of mathematics Abraham Kästner, who reported "John Albert de Soria, former teacher at the university in Pisa, assures us it is known through oral tradition that when they walked togeteher at the grand-ducal summer palace *Poggio Imperiale,* Galileo gave Hobbes the first idea of bringing moral philosophy to mathematical certainty by treating it according to the geometrical method" (Kästner 1796–1800, 4:195). Schumann (1998, p. 47) dismisses the tale as "certainly false," basing this judgment on a variety of evidence, including the fact that Soria himself expressed skepticism about the story (see 1975, pp. 88–9).

9. In a letter to William Cavendish, Earl of Newcastle dated 16 [/26] October, 1636, Hobbes declared "I must not deny my selfe the content to study in y[e] way I haue begun, & that I cannot conceaue I shall do any where so well as at Welbecke, and therefore I meane if

Robert Payne translated Galileo's *Della Scienza Mecanica* in November of 1636, a task probably undertaken on the basis of a manuscript copy brought from Paris by Hobbes. Mersenne had published a French paraphrase of this work in 1634 as *Les mechaniques de Galiée,* and there can be no doubt that Hobbes was deeply engaged with Galileo's work in the late 1630s. He had by this time conceived the plan of writing a general treatise on logic and metaphysics—a plan that would ultimately produce *De Corpore.* In January of 1637 Sir Kenelm Digby remarked on Hobbes's "perfect freedome of minde and time to study," and expressed interest in a treatise "Logicke" that Hobbes had been working on and from which Digby expected a great deal.[10] This "Logicke" would eventually be *De Corpore,* and as we will see, Galileo's influence is very prominent in it.

In the course of events, the "perfect freedome" that Digby admired was disturbed by political developments. The growing conflict between Charles I and Parliament turned Hobbes's attention to matters of politics and resulted in the 1640 *Elements of Law,* in which Hobbes outlined his theory of absolute sovereignty founded on a purely mechanistic conception of humans and their motivations. Concern for his personal safety in the face of serious Parliamentary opposition to the King and his partisans (as well, one suspects, as his desire to resume the life of philosophical study and research with his Parisian friends) induced Hobbes to flee England for France in late 1640. He was to remain there for a decade, and during this period of exile he wrote his political masterpiece *Leviathan* and nearly brought *De Corpore* to completion.

Although his 1635–6 sojourn to Italy and meeting with Galileo was surely significant in the development of the system of *De Corpore,* Hobbes's exposure to and engagement with Galileo's ideas was far more profound during the 1640s in Paris. Mersenne is the central figure in this part of Hobbes's concern with Galilean principles.[11] The Minim friar had a long-

yo^r^ Lo^p^ forbid me not, to come thither as soone as I can, and stay as long as I can without inconuenience to yo^r^ Lo^p^" (*CTH* 1:37).

10. "I am exceeding glad to heare you haue so perfect freedome both of minde and time to study, and do expect proportionable effects of them: which produced, (j know) must make all men admire and discourage the boldest form ayming to imitate. In your Logike, before you can manage men's conceptions, you must shew a way how to apprehend them rightly: and herein j would gladly know whether you work vpon the generall notions and apprehensions that all men (the vulgar as well as the learned) frame of all things that occurre unto them; or whither you make your ground to be definitions collected out of a deep insight in to the things themselues" (Digby to Hobbes, 17[/27] January 1637; *CTH* 1:42–3).

11. On Mersenne's relationship with Hobbes, see Beaulieu (1990). Hobbes aptly described Mersenne as the axis about which all of the stars of the world of science revolved (*OL* 1:149).

standing interest in mechanics: aside from his French version of the Galilean *Della Scienza Mecanica* in 1634, he frequently discussed mechanics with the learned men who gathered at regular meetings in his chambers and he corresponded extensively with Descartes and others on fundamental questions in the science of motion.[12] These researches led to the publication of his *Tractatus mechanicus theoricus et practicus* as part of his 1644 collection *Cogitata physico-mathematica.* Hobbes participated in the meetings of the "Mersenne circle," which functioned like a Parisian version of the Welbeck group and was every bit as interested in the physics of Galileo. Mersenne's approach was to involve his network of correspondents and associates in an issue by posing problems to them and requesting their solutions. One project that Mersenne apparently proposed to Hobbes was to read and critique the 1642 *De mundo dialogi tres* of Thomas White. This work is a series of three dialogues intended as an answer to Galileo's *Dialogue Concerning the Two Chief World Systems,* and Hobbes's reply to it is a lengthy rebuttal that takes up all manner of questions in metaphysics, mathematics, physics, and general methodology. Indeed, the treatise is not so much a critique of White as an exposition of Hobbes's own theories, set out in a format that defends the fundamental claims of Galilean science. Not surprisingly, Hobbes shows a great familiarity with Galileo's writings in this work, and he expresses his veneration for the Italian savant by referring to him as "the greatest scientist, not only of our own, but of all time" (Hobbes 1973, p. 178).

Hobbes's writing of *De Corpore* was a long and tortured process that dragged on through the 1640s. Sir Charles Cavendish remarked in December of 1644 that "Mr. Hobbes puts me in hope of his Philosophie, which he writes he is nowe putting in order, but I feare that it will take a longe time" (Cavendish to Pell 17/27 December, 1644; British Library MS. Add. 4278, f.190^r^). That expectation was abundantly fulfilled. Nearly four years later, Cavendish's judgment proved premature by some six years when he made his optimistic assessment that "M^r^: Hobbes hath nowe leasure to studie and I hope we shall have his within a twelve month" (Cavendish to Pell 23 July/2 August, 1648; British Library MS. Add. 4278, f.273^r^). In the actual course of events, the publication of *De Corpore* had to wait until April of 1655, well after Hobbes had returned from France to England. When it finally appeared, *De Corpore* showed the influence of Galileo quite clearly, not least in the Dedicatory Epistle to the

12. See Dear (1988, chapter 6) and Palmerino (1999) on the occasionally complex relationship between Mersenne, Galileo, and the subject of mechanics. In particular, Mersenne had reservations about the adequacy of Galileo's laws of motion and his defense of Copernicanism. This topic is also explored by Galluzzi (2001) in the context of Mersenne's reaction to Pierre Gassendi's support of Galilean science.

earl of Devonshire, where Hobbes lavishly praised Galileo as "the first to open to us the first gate of universal physics, which is the nature of motion" (*DCo* epistle; *OL* 1: sig. h4^{v}). The extent to which *De Corpore* is indebted to Galileo's ideas, and specifically his ideas on motion, is a subject to which I would now like to turn.

2. *De Corpore* and the Book of Nature.

Some scholars have seen the focal point of Galileo's influence on Hobbes in his endorsement of the methods of analysis and synthesis or (as it is sometimes known) the method of resolution and composition. Thus, C. B. Macpherson declared that "What was needed was a two-part method, which would show how to reach . . . simple starting propositions, as well as what to do when one had them. Hobbes found it in the method used by Galileo—the 'resolutive-compositive' method" (Macpherson 1968, pp. 25–6). John Watkins makes a similar claim for Galileo's influence, seeing in Hobbes's account of analysis and synthesis an adaptation of a methodological doctrine of the "School of Padua," and more specifically Jacopo Zabarella.[13] On this reading, the main point of contact between Hobbes and Galileo is to be found in chapter 6 of *De Corpore,* "On Method," where Hobbes discusses the distinction between analysis and synthesis.[14]

There is certainly no reason to doubt that Hobbes was influenced by talk of analytic and synthetic methods, but this is because nearly every discussion of methodology in the seventeenth century contains a set piece on the distinction between analysis and synthesis. There is consequently nothing unique about Galileo and the Paduan school on this score. Indeed, the sources all trace back to a relatively small number of Greek

13. As Watkins summarizes the Paduan method, "To understand something scientifically we have to resolve or analyse it into these ultimate causes, and then, their nature ascertained, recompose it by tracing deductively their production of it. There is 'a double procedure in natural science'—a resolutive method followed by a compositive method" (Watkins 1965, p. 52). Gargani (1971, Chapter 2) follows much the same line, depicting Hobbes's methodology as indebted to the analytic-synthetic method as set out by Galileo and the Paduan commentators on Aristotle. Peters (1956, p. 82) sees the "paradigm" of Hobbes's methodology as "the resolution and composition of the Paduan school," which Hobbes inherited from Galileo.

14. Hobbes's account of analysis and synthesis in *DCo* 1.6 differs somewhat from the tradition by being expressed in terms of analysis leading from effects to causes, while synthesis goes from causes to effects. Summarizing his account at *DCo* 3.20.6, Hobbes says "analysis is ratiocination from the supposed construction or production of a thing to the efficient cause or many coefficient causes of what is produced or constructed. And synthesis is ratiocination from the first causes of a construction, continued through middle causes to the thing itself that is produced" (*DCo* 3.20.6; *OL* 1:254).

texts, most notably the seventh book of the *Mathematical Collection* of Pappus of Alexandria.[15] We therefore have reason to doubt whether Galileo (or the Paduan school) offered Hobbes anything like a unique model of analytic-synthetic reasoning, and it is unlikely that much weight should be assigned to Galileo's account of analysis and synthesis.[16]

It must be noted that Hobbes made no secret of the fact that he regarded Galileo's study of motion as vastly more significant than talk of analysis and synthesis. As we have already seen, Hobbes credited Galileo with being "the first to open to us the first gate of universal physics, which is the nature of motion" (*DCo* epistle; *OL* 1: sig. h4^{v}). The "universal physics" Hobbes had in mind is concerned with the general nature and affections of body *simpliciter.* But, in light of Hobbes's materialistic equation of substance and body, such a universal physics must play the role traditionally assigned to metaphysics. This becomes evident in chapters 7–11 of *De Corpore* where Hobbes develops his list of the key notions in first philosophy. The list includes the paired concepts of space/time, body/accident, cause/effect, power/act, and identity/difference. Such a list could well be found in a Scholastic or Cartesian catalog of the principles of metaphysics, but Hobbes systematically interprets them in purely physical terms. The concept of cause, for example, is reduced to that of efficient or material cause, the "principle of individuation" is rendered as a principle of bodily continuity, and the traditional substance/accident dichotomy is reinterpreted as body/accident, which is the same as declaring substance and body to be convertible terms.

Motion figures very prominently in this scheme, because Hobbes held

15. A Pappus puts the matter: "analysis is the path from what one is seeking, as if it were established, by way of consequences, to something that is established by synthesis. That is to say, in analysis we assume what is sought as if it has been achieved, and look for the thing from which it follows, and again what comes before that, until by regressing in this way we come upon some principle. . . . In synthesis, by reversal, we assume what was obtained last in the analysis to have been achieved already, and, setting now in natural order, as precedents, what before were following, and fitting them to each other, we attain the end of the construction of what was sought" (Pappus [1875] 1965: 2:635; Heath [1921] 1981 2:400).

16. In this I follow Malcolm, who concludes that "This sort of conceptual 'compounding,' and its converse, conceptual resolution, provided the primary model for Hobbes's theory of resolutive-compositive method—a method which, I believe, owed almost nothing to Galileo and very little to the Paduan tradition of commentary on Aristotle" (Malcolm 2002, p. 153). Hanson (1990) sees a somewhat closer connection between Galileo and Hobbes on method, but denies any significant debt to the Paduan tradition of commentary on Aristotle, instead seeing the common methodological source in the tradition of geometric analysis as derived from Pappus. Prins (1990) sees Hobbes as pursuing an approach to scientific investigation that owes little or nothing to the Paduan school.

that the only cause of anything is motion (and impact). Further, he took it as a metaphysically necessary truth that "mutation can be nothing else but motion of the parts of that body which is changed. . . . And to this it is consequent, that rest cannot be the cause of anything, nor can anything *act* by rest; since neither motion nor mutation can be caused by it" (*DCo* 2.9.7; *OL* 1:121–12). Moreover, there "can be no cause of motion in a body, except in a body contiguous and moved" (*DCo* 2.9.7; *OL* 1:110). Thus, anyone in possession of the true science of motion will have the true account of the one great causal principle that lies at the base of all metaphysics.

One fairly obvious application of the doctrine that motion is the ultimate explanatory principle can be found in Hobbes's account of sensation. As noted earlier, Hobbes was led to his thoroughgoing mechanistic metaphysics by the attempt to explain sense perception. In so doing, Hobbes came to adopt a theory very similar to that propounded by Galileo in *The Assayer,* namely that sensory qualities are caused by and reducible to motion. In the famous case of the quality of heat, Galileo argued that motion is the cause of heat, proposing this as an alternative to the Aristotelian notion that heat is a real accident or a genuine quality inhering in external objects. This generalizes to Galileo's conclusion that: "I do not believe that external bodies need anything more than size, shape, number, and slow or quick motion, to excite in us tastes, smells, and sounds. I think that if ears, tongues, and noses were taken away, shapes, numbers, and motions would certainly remain, but there would no longer be smells, tastes, or sounds. Without a living animal, I do not believe that these would be anything other than just names (*Opere* 6:350)." Galileo was hardly alone in proposing that the Aristotelian conception of qualities be abandoned in favor of a corpuscularian model, but he does stand out as one of its most prominent advocates and we should see Hobbes's account of sensation as strongly influenced by Galileo.[17]

A more important source for Hobbes's admiration of Galileo can be found when we turn to the issue of what the world looks like when divested of its "secondary" sensory qualities such as heat, color, or taste. As the passage quoted from *The Assayer* states it, what remains would only be "shapes, numbers, and motions." This is a corollary to Galileo's famous metaphor of the book of nature:

17. Brandt (1928, pp. 150–1) regards Hobbes's mechanistic theory of sensation as little influenced by Galileo, on the grounds that none of Hobbes's theory of sensation "is strictly speaking Galilean," so that Hobbes "occupies himself with problems which Galileo practically left alone." I think Brandt overstates the case here somewhat, but agree that Galileo's influence on Hobbes involves much more than the theory of sensation.

> Philosophy is written in this vast book, which lies continuously open before our eyes (I mean the universe). But it cannot be understood unless you have first learned to understand the language and recognize the characters in which it is written. It is written in the language of mathematics, and the characters are triangles, circles, and other geometrical figures. Without such means, it is impossible for us humans to understand a word of it, and to be without them is to wander around in vain through a dark labyrinth (*Opere* 6:232).

The consequence is clear: the world as it is in itself, shorn of the subjective qualities we attribute to it (and which are only so many diverse motions in our sensory apparatus), is to be understood in geometric terms. Thus, an understanding of geometry becomes essential to an understanding of the way the world works, and the principal application of geometry is in the science of motion. The metaphor of the "book of nature" in the *Assayer* was both provocative and highly influential, offering as it did the prospect of an entirely new science that could account for nature's workings in the language and methods of geometry.[18]

Hobbes was fascinated by such a prospect, and I hold that what he saw as truly significant in Galileo is the idea that genuine *scientia* depends upon an understanding of motion. Because his ontology recognizes only bodies as real, Hobbes concluded that the traditional geometrical definitions of Euclid must be scrapped and replaced by ones defining the objects of mathematical investigation as bodies; points, for example, are bodies whose magnitudes are sufficiently small that they can be neglected, lines are produced by the motion of points, surfaces by the motion of lines, etc.[19] This program requires that points have (negligible) extension and lines (negligible) breadth, and such a materialistic reading of the science of mathematics was a radical departure from the traditional view of the subject in which mathematical objects are understood as abstract entities not found in nature. Hobbes, however, saw it as the way to found all of mathematics on the principles of matter and motion.

Galileo's role in this project is illustrated in Hobbes's 1660 dialogue *Examinatio et Emendatio Mathematicæ Hodiernæ.* The dialogue features two

18. Redondi has remarked that in respect of the great Book of Nature, "*The Assayer*'s originality consisted in the proposal of deciphering that book's signs, which when brought together formed its text. . . . The goal is to decipher the book of nature, to discover its secret code, to decode the illusory appearance in order to know the mysterious laws that govern it. Here, then, is another great intellectual suggestion—evocative, extremely captivating, and immediate to its readers" (Redondi 1987, p. 53).

19. Hobbes's program for geometry is examined at some length in Jesseph (1999, chapter 3).

interlocutors, ingeniously named *A* and *B,* who discuss various mathematical matters. Commenting on the problematic definition of the compounded of ratios,[20] these two engage in the following exchange:

> *B.* I see that it is so. But it seems to me that Hobbes demonstrated it somewhat better in Chapter 13, article 13 of his book *De Corpore,* deducing the definition from the doctrine of motion.
> *A.* But the doctrine of motion is known to very few, notwithstanding the fact that the whole of nature, not merely that which is studied in physics, but also in mathematics, proceeds by motion. Galileo was the first who wrote anything on motion that was worth reading (*OL* 4:84).

The claim that Galileo was the first to have written anything useful about motion recalls Hobbes's earlier assessment that Galileo had been the first to "open the gate" to the science of nature by his account of motion. But, in Hobbes's estimation, even Galileo himself did not grasp the full import of his achievement, since he failed to see that the doctrine of motion could be used as a foundation for geometry and as a powerful means to obtain new geometric results.

Hobbes boasted that he was "the first to have made the grounds of Geometry firm and coherent" (*EW* 7:242), basing this outsized opinion of his accomplishments on his having brought the concept of motion into the definition of geometric objects. In particular, when he first prepared *De Corpore* for publication Hobbes was convinced that he had come up with the means to solve any geometric problem, including such notoriously intractable problems as the quadrature of the circle and the arbitrary section of an angle. More specifically, Hobbes thought that he had uncovered a special kind of analysis by the concourse of motions, which he referred to as his means of demonstration "by the Method of motion."[21]

Hobbes held that attending to the motions by which geometric objects are produced would open the path to the simple solution of problems for

20. The problem of compounded ratios and Hobbes's account of are explored in Jesseph (1999, pp. 153–159). The fundamental problem derives from Book V of Euclid's *Elements* and is concerned with explaining how the ratio A:B can be compounded with the ratio C:D to produce a new ratio, and to do so in a way that is faithful to the traditional thesis that ratios are not numbers *per se* but relations holding between numbers. Hobbes's solution involves defining ratios (and their composition) in terms of the motion of bodies. It is interesting to note that Galileo addressed the problem. In fact, one of his very last written works was an incomplete draft of a discussion of compounded ratios that was to appear in a projected "fifth day" of the *Two New Sciences* (*Opere* 8:349–62).

21. See, for instance, the fifth of his *Six Lessons to the Savilian Professors of Mathematics* (*EW* 7:307), where Hobbes contrasts his method of motion with John Wallis's *Arithmetica Infinitorum.*

which the ancients had been forced to introduce special "mechanical" curves such as the quadratrix.[22] In praise of what he imagined to be the power of his new analysis by motions, Hobbes listed the great results he thought he had obtained with it, contrasting them with the meager consequences delivered by a more traditional "analysis by the power of lines":

> From those things which have been said concerning the dimension of the circle so many others can be deduced that it seems to me that geometry, which for the longest time has remained stalled in this place as if before the pillars of Hercules, is now driven forth into the ocean, and will navigate the globe of other most beautiful theorems. And indeed I do not doubt that from the known ratio of right lines to the arc of a circle, to the parabola, and to the spiral, knowledge of the ratio of the same right line even to a hyperbolic line, an elliptical line, and even the discovery of any number of continually proportional means between two extremes will at last be threshed out, all which are problems for which the analysis by powers of lines can provide no solution.[23]

Hobbes was not a modest man, least of all when it came to the estimation of his contributions to geometry. In fact, even when he had been shown the inadequacy of a proposed circle quadrature, his confidence in the superiority of his method and the efficacy of his principles led him to propose an "analysis by motion" of the shortcomings in his putative solution, with the intent of showing how, by a proper analysis of the relevant motions, a true solution could be effected. However, he abandoned even this plan in the final version of *De Corpore,* being instead content to include a brief account of the virtues of his new method of motion.[24]

The centerpiece of Hobbes's new analysis by the method of motion is chapter 16 of *De Corpore,* which bears the title "On Accelerated and Uniform Motion, and on Motion by Concourse." More significant for present purposes is the fact that this chapter was lifted almost straight out of Galileo's *Two New Sciences.* Two of the fundamental results from that Galilean work are the law of fall (i.e., the tenet that bodies in free fall are uniformly accelerated so that the distance fallen is proportional to the square of the elapsed time) and the associated principle that the path of projectile mo-

22. On the classical problems and various means introduced to solve them, see Knorr (1986).

23. This passage was left out of *De Corpore* as eventually published, although it was part of Hobbes's first impression of chapter twenty. It is printed in Hobbes (1999, Appendix X, p. 384).

24. For the details, see Schumann's reconstruction of the failed quadrature and the method of motion in Hobbes (1999, Appendix X, p. 383).

tion is parabolic. They appear in Hobbes's *De Corpore,* but are put to very different uses than those foreseen by Galileo. Hobbes takes uniform motion to be the result of a constant *impetus,* so that a body moved uniformly traverses equal distances in equal times. Representing the motion of a body by a figure, one side of which designates the time and the other the impetus generated in the corresponding instant, we have a rectangle (such as *ABDC* in figure 1) in the case of uniform motion. Uniform motion begins with a given impetus *AB,* which remains unaltered as the body moves through time *AC.* On the other hand, motion uniformly accelerated from rest is represented by the triangle *ACD,* where the impetus increases continually with the time. Finally, the calculation of distances covered by such motions proceeds in essentially the same manner as that used by Galileo—a body uniformly accelerated from rest covers distances that stand in the duplicate ratio of the elapsed times, so that the distance dispatched is as the square of the time.

The investigation of "motion by concourse" in the remainder of the sixteenth chapter of *De Corpore* is appropriated more or less straight out of the "Fourth Day" of the *Two New Sciences.* In exact analogy with Galileo's treatment of projectile motion, Hobbes treats motion of a body acted upon by two forces as a complex "concourse" of the two simpler motions. In the simplest case, where the combined motions are both uniform, the resulting motion is a straight line, namely the diagonal of the parallelogram. This can then be extended to more complex cases. Hobbes concludes that

> [i]f a moving body [*mobile*] is carried by two movements together, meeting at any given angle, of which the first motion is uniform and the second is uniformly accelerated from rest (that is, so that the impetuses are in the ratio of the times; that is, so that the ratio of the lengths is the duplicate ratio of the times) until the greatest impetus acquired by acceleration is equal to the impetus of uniform motion, the line in which the moving body is carried will be a semiparabola, whose base is the impetus last acquired (*DCo* 3.16.9; *OL* 1:196).

So, in Figure 1, the path *AGD* is traced by a body whose motion is uniform in the direction *AC,* and accelerated uniformly in the direction *AB;* at point *G,* its motion can be analyzed as a "concourse" of two perpendicular motions, one uniform and the other uniformly accelerated.

There is an obvious similarity between Hobbes's and Galileo's treatments here, amounting more or less to plagiarism.[25] Although his debt to

25. Hobbes's nemesis John Wallis was happy to point this out in his *Due Correction for*

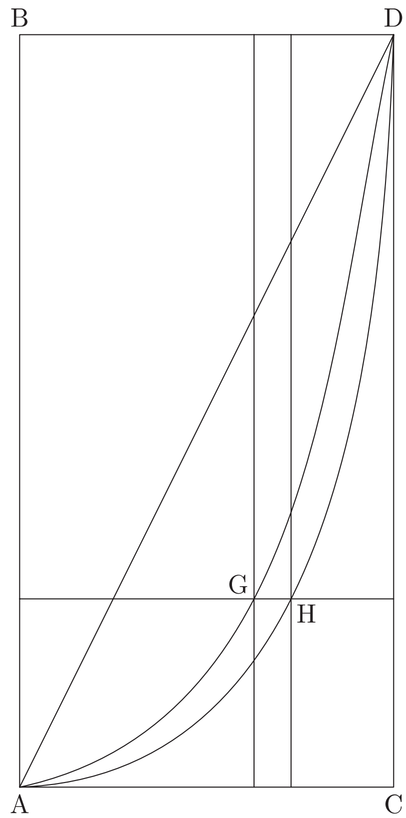

Figure 1: Adapted from Hobbes, *De Corpore,* Chapter 16, art. 9

Galileo on this point is obvious, Hobbes used the remainder of the sixteenth chapter of *De Corpore* to develop his account of motion by concourse as a generalization of the account of motion in the *Two New Sciences.* Galileo confined himself to such phenomena as arise from naturally accelerated and projectile motion. Hobbes, however, pursued a much more general and abstract inquiry in *De Corpore,* considering motions that correspond to nothing in nature. For instance, he investigated the case of projectile motion and the simple semiparabola and extended it to the case of motion accelerated as the triplicate ratio of the time; and then he introduces a gen-

Mr. Hobbes, observing that in *DCo* 3.16.9 "we have nothing but a proporsion [sic] of *Galilæo's* transcribed" and then faulting Hobbes's accompanying demonstration with the remark "So much of this Article as you tooke out of *Galileo* was good, before you spoil it" (Wallis 1656, pp. 103, 105–6).

eral rule for describing and investigating the quadrature of "parabolasters" of higher degree that correspond to accelerations of any degree whatever. So, for instance, in the diagram the curve *AHD* arises from the motion of a point uniformly in the direction *AC* and accelerated in triplicate ratio of the times along *AB.*

This extension of Hobbes's investigations beyond the case of natural motion led Frithiof Brandt to see a certain incongruity between chapter 16 of *De Corpore* and Hobbes's general program for a mechanistic science of nature. Brandt regarded it as strange that Hobbes should have bothered to consider motions that do not arise in nature. He put the matter thus:

> That this is far removed from Galileo, seems to us fairly obvious. The latter did not occupy himself at all with the possibilities posited by Hobbes, of course because they have no relation to experience. Result: *Hobbes both directly and indirectly shows a conspicuous lack of interest in mathematics as applied to the motions occurring in experience. He shows this directly by making no mention of the fact that the formula* $s=at^2$ *is the law for the free fall and that the parabola of projection is compounded of the uniform motion and the accelerated motion on the assumption* $s=at^2$*. And he shows it directly by placing the aforementioned possible formulae of motion on an equal footing. This is mathematically warrantable but seems strange in a philosopher who is driving at a mathematico-mechanical conception of Nature* (Brandt 1928, p. 310)

I think Brandt got it all backwards here, and in doing so misunderstood the Hobbesian philosophy of mathematics and the relationship between Hobbes and Galileo.

Hobbes did not see some kind of conceptual gulf between mathematical and physical objects, or between what we would call pure and applied mathematics. Mathematical objects are produced by the motion of bodies, and when we understand how such things are brought about we can deduce all of their properties by attending to the causes that generate them. Every mathematical problem is ultimately statable as a problem about what can be effected by motion, and this is why Hobbes thought his method of motion was the key to the solution of every mathematical problem. Brandt judged it "strange" to find Hobbes using the concept of motion used to define and solve general mathematical problems with no immediate application to physics, because he took Hobbes to be engaged in elaborating a "mathematico-mechanical conception of Nature." But there is absolutely nothing strange in this. Hobbes took the concepts of body and motion as fundamental to mathematics, physics, and even first philosophy; it is therefore to be expected that he should formulate abstract geometric problems involving complex curves in terms of the motions of bodies.

In contrast, Galileo did not identify the objects of mathematics with physical objects. In his understanding, the points, lines, surfaces, and figures of classical geometry are idealized "Platonic" objects not to be found in nature.[26] The book of nature may be written in this "supernatural" or idealized language of Platonic forms, but nature itself is distinct from the mathematics that describe it. We can therefore see why Hobbes wanted to take some of Galileo's insights and extend them to cover more general cases. Defining the simple parabola in terms of a certain concourse of uniform and accelerated motions allows the cubical parabola and higher "parabolasters" to be defined by the concourse of motions that fall under slightly different rules. The end result is that Hobbes saw in Galileo's analysis of natural motion a tool that could be generalized to cover all possible kinds of motion, and thus deliver a method that could solve any geometrical problem. The book of nature may be written in the language of mathematics, but the alphabet in which this language is written is nature itself, namely material bodies in motion.

3. Conclusion

The story told thus far leads to a fairly straightforward conclusion. In Galileo's writings on the science of motion, Hobbes found what he took to be the key to unlocking a complete account of nature. Hobbes held that all phenomena, from qualities like temperature or color, to mathematical objects like proportions or parabolas, to the very nature of human thought itself must be understood as arising from the motions of material bodies. Galileo's investigations into the motion of the Earth, as well as the new science of mechanics, offered a starting point and a model of correct procedure—he was, after all "the first who wrote anything on motion that was worth reading"—but he had not pursued the task quite far enough. Had he done so, Galileo would have written a book that included all of logic, metaphysics, mathematics, mechanics, and physics; this would have been the one true Book of Nature, and it would have to have been entitled *De Corpore.* It fell to Hobbes to write this book and fill in the lacunae in Galileo's program. Or so Hobbes would have us believe.

26. This is not the place to decide the much-discussed question of Galileo's Platonism. To whatever extent Galileo may have been committed to a fully Platonistic ontology and methodology, there is no doubt that he thought the objects of mathematical investigation are not identical with material objects. This is made clear, for instance, in the opening exchanges of the first dialogue of the *Two New Sciences,* where the "imperfections of matter" are distinguished from "pure" geometry (*Opere* 8:51). For an overview of the question of Galileo's Platonism, see Datel (1979).

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