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Natural Philosophy, Geometry, and Deduction in the Hobbes-Boyle Debate

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> [...] ingenuity is one thing and method [*ars*] is another. Here method is needed. The causes of those things done by motion are to be investigated through a knowledge of motion, the knowledge of which, the noblest part of geometry, is hitherto untouched.
>
> Hobbes, *Dialogus Physicus*, 347[1]

Abstract

This paper examines Hobbes's criticisms of Robert Boyle's air-pump experiments in light of Hobbes's account in *De Corpore* and *De Homine* of the relationship of natural philosophy to geometry. I argue that Hobbes's criticisms rely upon his understanding of what counts as "true physics." Instead of seeing Hobbes as defending natural philosophy as "a causal enterprise ... [that] as such, secured total and irrevocable assent,"[2] I argue that, in his disagreement with Boyle, Hobbes relied upon his understanding of natural philosophy as a mixed mathematical science. In a mixed mathematical science one can mix facts from experience (the 'that') with causal principles borrowed from geometry (the 'why'). Hobbes's harsh criticisms of Boyle's

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[1] I cite Simon Schaffer's translation of the 1661 edition of *Dialogus Physicus* from Steven Shapin and Simon Schaffer, *The Leviathan and the Air-Pump* (Princeton, NJ: Princeton University Press, 1985) as Hobbes, *Dialogus Physicus*. I cite Thomas Hobbes, *The English works of Thomas Hobbes*, 11 volumes, ed. by Sir William Molesworth, (London: John Bohn, 1839–1845) and Thomas Hobbes, *Thomae Hobbes malmesburiensis opera philosophica*, 5 volumes, ed. by Gulielmi Molesworth, (London: John Bohn, 1839–1845) as EW and OL, respectively, by reference to volume and page number.

[2] Steven Shapin and Simon Schaffer, *The Leviathan and the Air-Pump* (Princeton, NJ: Princeton University Press, 1985), 19.

philosophy, especially in the *Dialogus Physicus, sive De natura aeris* (1661; hereafter *Dialogus Physicus*), should thus be understood as Hobbes advancing his view of the proper relationship of natural philosophy to geometry in terms of mixing principles from geometry with facts from experience. Understood in this light, Hobbes need not be taken to reject or diminish the importance of experiment/experience; nor should Hobbes's criticisms in *Dialogus Physicus* be understood as rejecting experimenting as ignoble and not befitting a philosopher. Instead, Hobbes's viewpoint is that experiment/experience must be understood within its proper place – it establishes the 'that' for a mixed mathematical science explanation.

1. Introduction

Thomas Hobbes's debate with Robert Boyle places the status of knowledge to be gained by experience/experiment into focus. This paper examines Hobbes's view of the proper method for discovering possible causes by looking to Hobbes's criticisms of the conclusions that Boyle derives from the air-pump experiments. I argue that Hobbes's treatment of the nature of air in the *Dialogus Physicus* reflects his understanding of natural philosophy as "true physics," which he claims in *De Homine* 10.5 is "usually numbered among the mixed mathematics."[3] In Hobbesian "true physics" one mixes the 'that' established from experience with the reason 'why' borrowed from geometry.[4] Given this account of natural-philosophical explanation as "mixed," all that the

[3] Thomas Hobbes, *Man and Citizen: De Homine and De Cive*, Bernard Gert, ed. and trans. [Indianpolis, IN: Hackett, 1994/1658], 42; OL II.93.

[4] Two recent works have argued that mixed mathematics, and not a deductive link from geometry to natural philosophy, is Hobbes's model for understanding natural philosophy. See Marcus P. Adams, "Hobbes on Natural Philosophy as 'True Physics' and Mixed Mathematics," *Studies in History and Philosophy of Science* 56 (2016): 43-51 and Zvi Biener, "Hobbes on the Order of Sciences: A Partial Defense of the Mathematization Thesis," *The Southern Journal of Philosophy* 54.3 (2016): 312-332.

air-pump experiments could establish is the 'that'; the reason 'why' that explains the behavior of air must be borrowed from geometry, which borrowing Hobbes does when he cites the principle of 'simple circular motion' in the *Dialogus Physicus*. It might seem strange to understand a principle of 'simple circular motion' as *mathematical*, and thus fit to be borrowed for use in a mixed-mathematics explanation, but Hobbes himself identifies principles of motion as "easy and *mathematical*" in the very context of the *Dialogus Physicus*,[5] and he includes demonstrations about simple circular motion in the section on geometry of *De Corpore* 21 (Part III). I contrast this account of Hobbesian mixed-mathematical natural philosophy with Shapin and Schaffer's view that Boyle sought to defend against the Hobbesian "beast of deductivism."[6]

The paper proceeds in three stages. First, I discuss Hobbes's use of the principle of 'simple circular motion' in the *Dialogus Physicus*.[7] Second, I examine Hobbes's discussions of

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[5] Hobbes, *Dialogus Physicus*, 273 (emphasis added).

[6] Shapin and Schaffer, *The Leviathan and the Air-Pump*, 176.

[7] I do not address the fraught issue of the provenance of Hobbes's views of simple circular motion in this paper. John Henry ("Hobbes, Galileo, and the Physics of Simple Circular Motions," *Hobbes Studies*. 29.1 [2016]: 9-38) argues that Galileo's view of circular inertia inspired Hobbes (see also Frithioff Brandt, *Thomas Hobbes' Mechanical Conception of Nature* [Copenhagen: Levin & Munksgaard, 1927], 330ff; Samuel I. Mintz, "Galileo, Hobbes, and the Circle of Perfection." *Isis* 43.2 (1952): 98-100; Pagnini's introduction to the Italian translation of *De Motu* (i.e., *Anti-White*) links Hobbes's first philosophy in that earlier work to Galileo [see introduction in Thomas Hobbes, *Moto, Luogo, e Tempe*, Gianni Paganini, ed. and trans. (Torino: UTET, 2010); also see the review by Luc Foisneau, "Hobbes's First Philosophy and Galilean Science," *British Journal for the History of Philosophy* 19.4 (2011): 795-809, here 798ff and Gianni Paganini, "Hobbes's Galilean Project: Its Philosophical and Theological Implications," *Oxford Studies in Early Modern Philosophy* VII (2015): 1-46.]). However, there are significant differences between Hobbes and Galileo as seen, for example, in Hobbes's placement of the definitions of 'body' and 'motion' within first philosophy (*De corpore* Part II) and his discussion of the consequences of 'magnitudes' and 'motions' within geometry (*De corpore* Part III). Daniel Garber ("Natural Philosophy in Seventeenth-Century Context," in A.P. Martinich and Kinch Hoekstra, eds., *The Oxford Handbook of Hobbes* [Oxford: Oxford University Press, 2016], 106-133) articulates this difference as Hobbes providing an account of body and motion *as such* and not, as Galileo, an account of heavy bodies in motion. Providing an answer to this question of provenance is beyond the bounds of the present paper, but a brief point can be made. If we see Galileo's

natural philosophy in *De Corpore* and *De Homine* and argue that Hobbes views the explanation of the nature of air *Dialogous Physicus* as part of mixed-mathematical natural philosophy. Finally, I consider the sort of "deductivist" we find Hobbes to be in light of his usage of geometry in natural philosophy, arguing that borrowing geometrical principles on the mixed mathematical science model does not commit Hobbes to the strong claim that there are deductive connections between the science of geometry and natural philosophy.[8]

2. Simple Circular Motion in *Dialogus Physicus*

2.1 Setting up Discussion of the Experiments

Hobbes's *Dialogus Physicus* (1661, 1668) was published at a key point in Hobbes's career. He had finished *Leviathan* (1651) and was thus able to return to his pursuits in natural philosophy, leading to the publication of *De Corpore* (1655). Hobbes had also by this point published *De Homine* (1658), which occupies a strange place in the Hobbesian corpus insofar as it is the middle volume of Hobbes's *Elementa* trilogy but published last. Given this place within

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natural philosophy as mixed mathematics (as do Zvi Biener, "Galileo's First New Science: The Science of Matter," *Perspectives on Science* 12.3 [2004]: 262-287 and James Lennox, "Aristotle, Galileo, and the 'Mixed Sciences'," in *Reinterpreting Galileo*, William A. Wallace, ed. [Washington, DC: Catholic University Press, 1986], 29-51), then understanding Hobbes's natural philosophy in Part IV of *De corpore* and in *Dialogus Physicus* as mixed mathematics (as do Adams, "Hobbes on Natural Philosophy as 'True Physics' and Mixed Mathematics" and Biener, "Hobbes on the Order of Sciences: A Partial Defense of the Mathematization Thesis") will provide an additional link to Galileo. The reason for the difference that emerges between Hobbes and Galileo, the difference being Hobbes's placement of the concepts 'body' and 'motion' within first philosophy and their consequences in geometry, is due to Hobbes's insistence that to provide scientific knowledge geometry must include 'motion' even in its most basic definitions (discussed below).

[8] In addition to Shapin and Schaffer, *The Leviathan and the Air-Pump*, Richard Peters, *Hobbes* (Baltimore: Penguin, 1967), J.W.N Watkins, *Hobbes's System of Ideas* (London: Hutchison University Library, 1973), and Jean Hampton, *Hobbes and the Social Contract Tradition* (Cambridge: CUP, 1986) articulate versions of Hobbes as a "deductivist" according to which natural philosophy follows deductively from geometry.

Hobbes's writing career, within the discussion of the *Dialogus Physicus* we find citations to *De Corpore*. In this section, I will discuss these explicit citations to *De Corpore*. My goal is to show that Hobbes is not merely repeating himself and emphasizing that he had already proposed a solution to a problem elsewhere in his voluminous writings, as he does in other contexts such as *Examinatio et Emendatio Mathematicae Hodiernae* (1660).[9] Instead, I shall argue that these citations of principles from *De Corpore* in *Dialogus Physicus* are examples of Hobbes borrowing geometrical principles – the 'why' – within a mixed mathematical explanation.

The *Dialogus Physicus* begins with a dedication of the work to Samuel Sorbière. In his typically unabashed manner, Hobbes proclaims that those who are making experiments at Gresham College "…may meet and confer in study and make as many experiments as they like, yet unless they use my principles they will advance nothing."[10] But in addition to Hobbes's irascibility and hubris, behind the claim that they will "advance nothing" was his view that natural philosophy must be done according to the proper method: "…ingenuity is one thing and method [*ars*] is another." Proper method, Hobbes argues, requires that one "investigate the causes of those things done by motion through a knowledge of motion, the knowledge of which, the noblest part of geometry, is hitherto untouched." Hobbes see himself as having given just this sort of knowledge of motion considered as part of geometry, but since the experimenters of Gresham College have, in Hobbes's mind, neglected his work he feels that his work has been for naught: "…as yet it seems I live in vain."[11]

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[9] OL IV.84. For discussion of this example from *Examinatio et Emendatio Mathematicae Hodiernae*, see Douglas Jesseph, "Galileo, Hobbes, and the Book of Nature," *Perspectives on Science* 12.2 (2004): 191-211, here 202-203.

[10] Hobbes, *Dialogus Physicus*, 347.

[11] Ibid.

The dialogue occurs between two participants – A and B – and participant B is supposed to represent a member of the meetings at Gresham College. After discussing the construction of the air-pump, interlocutor B questions A regarding what he thinks follows from the experiments, asking "Would not the space left by the sucker be a vacuum?"[12] Speaker A replies that the answer to this question requires that we first know the nature of air.

Speaker A, as Hobbes's mouthpiece, supposes that air is a liquid that is capable of infinite divisibility: "if a part of the air, whose quantity is less than any water-drop you have seen, is fluid, how is it to be proved to you by anyone that a part half the size of its parts… might not be of the same nature?"[13] The claim holds, A asserts, even for parts of air "one hundred thousand thousandeth." B concedes A's claim that the nature of air must be supposed before a judgment can be made regarding what remains in the space left by the sucker; he articulates that he and the others engaging in the experiments distinguish fluids from nonfluids by the "size of the parts of which any body consists."[14] With this view, ashes and dust count as liquid and, furthermore, B holds that liquids may be composed of nonfluids. Thus, upon division it might be discovered that a fluid such as air may be composed from nonfluid parts.

When B asserts that the experimenters do not "stomach …infinite divisibility," A grants that infinite *division* itself cannot be "conceived" but that infinitely *divisibility* can be.[15] To support this claim regarding the conceivability of infinite divisibility, A appeals to God's ability

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[12] Hobbes, *Dialogus Physicus*, 353.

[13] Hobbes, *Dialogus Physicus*, 353-354; OL IV.244.

[14] Hobbes, *Dialogus Physicus*, 354; OL IV.244.

[15] From the late 1630s onward Hobbes constrains philosophy to that which is conceivable, understanding conceivable as imaginable (Marcus P. Adams, "The Wax and the Mechanical Mind: Reexamining Hobbes's Objections to Descartes's *Meditations*," *British Journal for the History of Philosophy* 22.3 [2014]: 403-424., here 415ff).

and asserts that it is no more difficult for God to "create a fluid body less than any given atom whose parts might actually flow" than it is for God to create the ocean.[16] So God could create water such that all of its parts, no matter how small, are also water. This reference to "almighty God" as grounding that which shows whether a claim about something's nature is conceivable is odd given Hobbes's view on our limited knowledge of God as first cause, but I will leave this to the side.[17]

If we grant this point with Hobbes's spokesperson A, as B does, then we should agree as well that "it is not necessary for the place that is left by the pulling back of the sucker to be empty."[18] Given the conceivability of "infinitely subtle" parts of air, we cannot be certain that air does not enter between small gaps between the sucker and the cylinder, thus calling into question the claim that "the space left by the sucker" must be taken to be a vacuum.[19]

B's rebuttal to Hobbes's spokesperson A regarding this possibility of infinitely subtle bits of air entering by means of small gaps appeals directly to experience: "But when the tap was turned, we observed that a sound was made as if air were breaking into the cylinder."[20] The sound, B claims, counterweighs against A's proposal, but A has a reply at the ready: the sound heard was caused by the collision of the air in the cylinder with the air outside of it. In the remainder of this section, I will examine two suppositions that arise in the resulting disagreement: the supposition held by B that air possesses an elastic force that accounts for its

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[16] Hobbes, *Dialogus Physicus*, 354; OL IV.245.

[17] For example, in his Fifth Objection to the *Meditations*, he argues that Christians are forbidden from making graven images because "otherwise we might think that we were conceiving of him who is incapable of being conceived" (AT VII.180; CSM II.127).

[18] Hobbes, *Dialogus Physicus*, 354; OL IV.245.

[19] Hobbes, *Dialogus Physicus*, 353.

[20] Hobbes, *Dialogus Physicus*, 355; OL IV.246.

behavior in appearing to resist compression and the supposition held by A, which relies upon Hobbes borrowing principles from *De Corpore*, that the air moves according to simple circular motion.

2.2 *Two Suppositions Concerning Air*

Interlocutor B explains the sound made when the tap is turned by supposing that there is an "elastic force" in the air; air is such that its parts are "endowed with this nature."[21] To understand this, B asks A to imagine that the air nearest to the surface of the Earth is "like a heap of corpuscles" that are similar to wool in how they behave. The spring in air from its elastic force causes it to bounce back after compression, similar to the way that wool bounces back after being pressed between one's hands. We can understand both behaviors by supposing the parts of both to be "endowed with a power or principle of dilation."[22] After A and B agree that "all things supposed" in hypotheses must be conceivable, A questions B's hypothesis about the supposed principle of dilation, asking how experimental philosophers akin to B could have gained knowledge of such a cause from merely observing phenomena like crossbows and wool.

B admits that the cause of elastic force being supposed is not "very certain." Nevertheless, it is certain that the bodies in question – wool and crossbows – cannot self-move. Furthermore, B asserts that the motion cannot be straight motion, for if it were "the whole body (so to speak) would be carried away by the motion of the crossbow itself…[t]herefore it is necessary that the endeavour be circular, such that every point in a body restoring itself may perform a circle."[23] Hobbes, speaking as A, disagrees with B at this stage and claims that this

[21] Hobbes, *Dialogus Physicus*, 355; OL IV.247.

[22] Hobbes, *Dialogus Physicus*, 356; OL IV.247.

[23] Hobbes, *Dialogus Physicus*, 357; OL IV.248-249.

assertion about circularity is "not necessary." Instead, A claims that it must be a motion that returns the body to its starting point. Granting A's point that the motion must be one of restitution – this is the motion that will eventually explain the sound when the tap of the air-pump was turned – B posits that perhaps the source of this restitutional motion must be located in particulars smaller than air, which smaller parts have "their own natural motion of which there is no beginning."[24]

Speaker A proposes that the possible cause of this restitutional motion by the parts of crossbows and wool fibers relates to a type of motion that Hobbes develops as part of his geometry in Part III of *De Corpore* in 21.1 and 21.10 (more on simple circular motion as part of geometry below).[25] Hobbes, as A, further claims that the only way to hold that there is an "elastic force" in air is to hold this supposition; without supposing the Hobbesian possible cause, it is impossible. Given the earlier remarks regarding "conceivability" as a constraint for suppositions, Hobbes means that without the supposition of circular motion by smaller parts of bodies the supposition related to the "elastic force" of air is impossible because it is inconceivable. The project in the next section of the dialogue is to argue, on the one hand, that this "natural motion of which there is no beginning," which A will argue is simple circular motion, is conceivable

[24] Hobbes, *Dialogus Physicus*, 358; OL IV.249.

[25] A textual note is in order. There appears to be an error in the printing and translation of *Dialogus Physicus* regarding this reference to *De corpore* 21. Both Molesworth (OL IV.251) and Schaffer's translation (Hobbes, *Dialogus Physicus*, 360) reproduce these references as being to *De corpore* 2.1 and 2.10 from the original printing (cf. Thomas Hobbes, *Dialogus Physicus, sive De Natura Aeris* [London: A. Crook, 1661], 9), but this cannot be the passage to which Hobbes, as interlocutor A, intended to refer since Hobbes does not discuss motion at all in *De corpore* 2.1 and 2.10. Instead, in those articles of chapter 2 he discusses names. It is possible that that the 1661 edition of *Dialogus Physicus* introduced this error in printing since there is an odd space between the '2' and the decimal point that is not present in the other references to *De corpore* that are within that edition of the text. The references in this section of *Dialogus Physicus* (Hobbes, *Dialogus Physicus*, 360; OL IV.251) clearly refer to *De corpore* 21.1 and 21.10.

while, on the other hand, arguing that elastic force is not conceivable and thus should be discarded.

A's introduction of simple circle motion into the dialogue relates to two distinct parts of the Hobbes's project in *De Corpore*: first, understanding motion as part of geometry proper (Part III of *De Corpore*); and second, using geometrical principles within natural philosophy as suppositions for how bodies *may* behave (Part IV of *De Corpore*). Distinguishing the different roles that discussions of 'motion' play in *De Corpore* makes A's brief comments about simple circular motion in the *Dialogus Physicus* clearer.

The first part of the *De Corpore* project to which A refers are the geometrical consequences of simple circular motion that Hobbes demonstrates in *De Corpore* 21, of which speaker A explicitly cites articles 1 and 10 (cf. fn. 25). First speaker A cites a principle about how any body behaves when moving according simple circular motion: when a body moves in simple circular motion, all its points describe the circle the body makes (from *De Corpore* 21.1). Next, A refers to Hobbes's claim that simple circular motion is generated from simple circular motion (from *De Corpore* 21.10). These two citations are from Part III (the geometrical section) of *De Corpore*, but within the same paragraph interlocutor A discusses how these geometrical principles are *used* within another section of *De Corpore*, Part IV on natural philosophy, where they become suppositions about how actual bodies (conceivably) may behave.

Speaker A gestures to Hobbes's usage of these geometrical principles related to simple circular motion by mentioning how Hobbes's connects them in Part IV to the Copernican hypothesis.[26] A notes that Hobbes posits two simple circular motions to explain the diurnal and

[26] Schaffer (Hobbes, *Dialogus Physicus*, 360 fn. 22) notes Hobbes's supposition that simple circular motion is responsible for the motions of the earth in *De corpore* 26.5-7 (Part IV), but this misses that A's introduction of the principles related to simple circular motion draws upon the Hobbes's section on geometry, Part III.

annual motions of the earth. The earth's annual motion, A states, Hobbes explains by supposing that the sun has in its nature a simple circular motion and that it moves the earth around it with this motion. Given the supposition that the sun moves in this way, Hobbes can claim that it moves the earth circularly around it because, as discussed above, simple circular motion is generated from simple circular motion (from *De Corpore* 21.10); the claim about the motions of the earth due to the sun's supposed motion relies upon this inference made in the geometry of Part III. Similarly, Hobbes supposes that the earth itself has its own simple circular motion, which A says is "due to its own nature or creation,"[27] and this allows him to explain the earth's diurnal motion. Speaker A will use this second supposition relating to the earth's natural circular motion to explain the nature of air.

A next asks B what would result if the Earth were "annihilated by divine omnipotence or if half this Earth were removed to some other distant place beyond the fixed stars."[28] B agrees with A that any part of Earth – in B's words even "one of its atoms" – would retain the simple circular motion that is "congenital" to the Earth. In other words, since simple circular motion is congenital to the Earth considered as a whole, any of its parts, even its atoms, would retain this same circular motion. Thus, if we take the air as having "particles of earth and water… interspersed" throughout it, we can then use these hypotheses to explain the sound made when the tap of the air-pump is turned. B grants that the "hypotheses are by no means absurd," but B requests that A further show how they help in saving two phenomena related to the air-pump, which B still takes to be better explained by positing an elastic force in the air.

[27] Hobbes, *Dialogus Physicus*, 360; OL IV.252.

[28] Hobbes, *Dialogus Physicus*, 361; OL IV.253.

The first *explanandum* relates to B's observation that he has "seen the handle fall back from the hands of whoever happens to pull back from the sucker" after the suction has been engaged repeatedly.[29] A's treatment of the phenomenon straightforwardly follows from understanding air as a combination of particles of earth and water. He claims that the continual motion of the sucker caused pure air to be drawn into the cylinder while not allowing earthy particles to be drawn in. Drawing pure air into the cylinder caused a "greater ratio of earthy particles that were near the sucker outside the cylinder to the pure air in which they exercised their motion than before" the sucker had been engaged.[30] Since the ratio is greater following this suction, the particles closest the sucker press upon it, which A claims "is the phenomenon itself."

Since both A's and B's hypotheses both save the phenomenon of the handle of the sucker being pulled away from the hand of the user, A explains why his—Hobbes's—is to be preferred. To make this choice, A introduces two constraints on hypothesis choice: first, that the hypothesis be "conceivable";[31] and second, that it if one assumes a hypothesis the effect follows necessarily. The first criterion, A claims, is the deciding factor between his hypothesis and B's: "[y]our hypothesis lacks the first of these; unless perhaps we concede what is not to be conceded, *that something can be moved by itself*."[32] As Hobbes understands 'inconceivable' this implies that B's hypothesis that air moves by an elastic force is unimaginable. In other words, we are unable to imagine in a way that is mechanically intelligible how a body could move itself. In contrast, in

[29] Hobbes, *Dialogus Physicus*, 362; OL IV.254.

[30] Ibid.

[31] Adams ("The Wax and the Mechanical Mind: Reexamining Hobbes's Objections to Descartes's *Meditations*," 415) discusses conceivability as a constraint that Hobbes places upon philosophizing in *Anti-White*.

[32] Hobbes, *Dialogus Physicus*, 362-363 (emphasis added); OL IV.254-255.

Hobbes's understanding of 'conceivable', we can easily imagine that with less space to "exercise their natural motion" the earthy particles will naturally press against the sucker.

The second *explanandum* B highlights is that after the sucker is repeatedly operated it is difficult for anyone to remove the cover of the upper orifice; it is "as if a weight of many pounds hung from it."[33] To explain this, A appeals to a "very strong circular endeavour of the air, made by the violent entry of the air in between the convex surface of the sucker and the concave surface of the cylinder."[34] The repeated action of the sucker stirs up the air into a more violent circular motion than usual, and this more violent motion of the air in the cylinder makes it more difficult to remove the cover. If the "air were at rest," removing the cover would not be so difficult. B concedes that this is a plausible explanation and both interlocutors agree that the swiftness of the air inside the cylinder could also explain why bubbles appear inside the cylinder when the sucker is engaged, apart from any addition of heat.[35] Similarly, A argues that the behavior of wind-guns can be explained by the violent circular motion of air impacted by the force of a sucker;[36] the violently moving air pushes out of the chamber forcefully when released and shoots the ball.

The interlocutors discuss several other phenomena in the remaining discussion, but I shall only mention one additional phenomenon that is most relevant to the discussion of circular motion in the next section. After B admits that A has provided a plausible explanation of the behavior of both the wind-gun and the air-pump, B questions A on how his understanding of the nature of air in terms of circular motion can explain what the experimenters have witnessed

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[33] Hobbes, *Dialogus Physicus*, 365; OL IV.257.

[34] Ibid.

[35] Hobbes, *Dialogus Physicus*, 365; OL IV.258.

[36] Hobbes, *Dialogus Physicus*, 368; OL IV.260.

concerning the weight of bladders. B reports that the experimenters have hung an inflated bladder from the cover of the air-pump and placed a scale inside the device. After engaging the sucker, they observe that the bladder appears to weigh more, and they attribute this to the air inside the bladder weighing more when weighed in an "empty space."[37]

Notably, Hobbes as speaker A does not question the experimenters' report. He notes: "They can be certain that the scale in which the bladder is, is more depressed than the other, their eyes bearing witness."[38] However, A argues that they cannot know that the gravity of air is the cause of what they observe. A argues that it is plausible that a "greater quantity of atoms from the bellows or sooty corpuscles from the breath being blown in" could be responsible for the greater weight. To explain the observations related to the greater weight of the bladder following the action of the sucker, A draws upon Hobbes's account of 'fermentation' from *De Corpore*. Hobbes thinks of fermentation as a type of 'seething' circular motion whereby heterogeneous particles are separated from one another and homogeneous particles are joined together (more on fermentation below). Hobbes develops this geometrical principle of fermentation in *De Corpore* 21.5 (Part III of *De Corpore*), which A cites here in *Dialogus Physicus*, and then he posits that the sun moves the air around it in simple circular motion and causes fermentation. With this geometrical principle and the added supposition that the sun moves in this way, Hobbes explains various phenomena in *De Corpore* Part IV, such as his explanation in *De Corpore* 27.3 for why human bodies sweat and swell when warm.[39]

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[37] Hobbes, *Dialogus Physicus*, 368; OL IV.261.

[38] Hobbes, *Dialogus Physicus*, 369; OL IV.261.

[39] Hobbes's explanation is that by a process of fermentation, from the posited simple circular of the sun, the fluid parts of human bodies are removed from the non-fluid parts (the separation of heterogeneous particles) and they are joined with fluidic parts of the air (the joining of homogeneous particles). For discussion of this explanation in *De corpore* 27.3, see Adams, "Hobbes on Natural Philosophy as 'True Physics' and Mixed Mathematics," 48-50.

In similar fashion, speaker A explains the greater weight of the bladder by suggesting that we understand the increase in weight as due to fermentation moving homogeneous particles together. Attributing the greater weight to the "cause of gravity" is insufficient, A contends, because it "could not bring together the homogenous substance when separated by force and tear apart heterogeneous bodies brought together by force."[40] Interlocutor A's point is that simply positing that air has weight because of its "natural gravity" will not account for why the bellows full of air weighs *more when the sucker is engaged*. In other words, gravity could not explain why there were more particles of air in the bladder after the action of the sucker, but Hobbes's fermentation could if we supposed that the sucker action caused a fermenting motion of the air. This fermenting motion of the air would then join homogeneous particles of air, one with another, causing the bladder to be filled with a greater number of particles of air than there were prior to the action of the sucker. This is not the place to offer criticisms of the explanation, but Hobbes is right, of course, that simply appealing to a "natural gravity" would not explain the increase in weight; however, his proposal is not without problems of its own. For example, given A's supposition that the sucker causes the air to move by fermentation, how would interlocutor A explain why the homogeneous particles of air go *into* the bladder rather than *out of* the bladder to be joined with like particles outside of the bladder?

This section has focused upon two features of the *Dialogus Physicus*. First, it has examined the detailed description of the experiments and apparatuses of the air-pump experiments. Importantly, interlocutor A does not deny the veracity of the experimenters' reports but instead questions the explanation they provide. Second, this section has drawn attention to interlocutor A's explicit citations of geometrical principles from Part III of *De Corpore* within

[40] Hobbes, *Dialogus Physicus*, 369; OL IV.262.

the *Dialogus Physicus,* which is just like Hobbes's borrowing of geometrical principles within the natural philosophy of Part IV of *De Corpore*. A two-part approach to natural philosophy is thus evident in both *De Corpore* and *Dialogus Physicus*: first one establishes on the basis of experience/experiment *that* a phenomenon occurs, and then one explains *why* by borrowing a principle from geometry. In the next section, I will argue that Hobbes's conception of natural philosophy as mixed mathematics, what he calls "true physics," makes sense of how Hobbes (and interlocutor A as Hobbes's mouthpiece) approached explaining the phenomena surrounding the air-pump experiments as well as his criticisms of the conclusions made from them. In the final section, I will reassess Hobbes's putative 'deductivism' in light of the debate concerning the air-pump experiments.

3. Mixing Experience with the 'Easy' and 'Mathematical' Doctrine of Motion

After discussing these various phenomena witnessed by the experimenters, interlocutor A pinpoints what he takes to be the hopelessness of the attempts by Boyle and others at advancing physics: "…how did you dare take such a burden upon yourselves, and to arouse in very learned men…the expectation of advancing physics, when you have not yet established the doctrine of universal and abstract motion (which was easy and *mathematical* [*quod facile et mathematicum erat*])?"[41] The view that principles of motion, such as those related to the 'simple circular motion' that has been discussed already, are *mathematical* is a feature of Hobbes's philosophy throughout *De Corpore*. In this section, I will show that Hobbes has this two-part conception to natural philosophical explanation, as part of mixed mathematics, where one first

[41] Hobbes, *Dialogus Physicus,* 379 (emphasis added); OL IV.273.

establishes the 'that' from experience and then one borrows the 'why' from the science of geometry.

It is not immediately obvious what Hobbes might mean in the *Dialogus Physicus* when he says that "the doctrine of universal and abstract motion" is both "easy and mathematical."[42] By looking to his description of the knowledge one has of constructed geometrical figures, I will suggest that, as a part of mathematics, Hobbes views the doctrine of motion as 'easy' because we are able to gain *actual* causal knowledge when we make geometrical constructions related to motion, something which is unavailable in natural philosophy where we have only knowledge of *possible* causes.[43]

Hobbes's example of a circle in *De Corpore* 1.5 illustrates this point about the special status of "easy" knowledge gained from construction in mathematics. Hobbes argues that examining a circle by "sense" cannot give one knowledge of that figure's properties – one cannot know whether a figure observed by sense is actually a circle.[44] One could know that it is circular insofar as it *appears* to be a circle, but one could not know whether, in fact, it has all the properties of a circle because one did not construct that circle. However, according to Hobbes the person who has *constructed* this circle is in an epistemically privileged situation, for this individual sees the causes as she constructs the figure. Hobbes says that determining all of the properties "from the known generation of the displayed figure, is *most easy* [*ex cognita figurae propositae generatione, facillime*]."[45] Since Hobbes assumes that knowing the causes of a thing

[42] Hobbes, *Dialogus Physicus*, 379; OL IV.273.

[43] See also Noel Malcolm, "Hobbes and Roberval," in Noel Malcolm, ed., *Aspects of Hobbes* (Oxford: OUP, 2002).

[44] OL I.5.

[45] Ibid. (emphasis added).

entails knowing all of its properties,[46] once one has constructed a figure the task of knowing that figure's properties is "most easy."[47]

Hobbes sets apart knowledge gained through geometrical construction in his discussion of scientific knowledge in *De Corpore* 6.1 by appealing to the distinction between a demonstration of the 'that' and a demonstration of the 'why':

> We are said to know [*scire*] some effect when we know what its causes are, in what subject they are, in what subject they introduce the effect and how they do it. Therefore, this is the knowledge [*scientia*] τοῦ διότι or of causes. All other knowledge [*cognitio*], which is called τοῦ ὅτι, is either sense or imagination remaining in sense or memory.[48]

In this discussion from *De Corpore* 6.1, Hobbes connects scientific knowledge with causal knowledge, distinguishing it from knowledge (*cognitio*) of the 'that'.[49] Causal knowledge is available only to *makers* – we make figures in geometry so this accords a special epistemic status to geometrical principles gained from construction. However, in natural philosophy we act not as

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[46] David Gauthier, "Hobbes on Demonstration and Construction," *Journal of the History of Philosophy* 35.4 (1997): 509-521, here 512.

[47] In *Six Lessons,* Hobbes holds that construction is relevant to whether someone would think a circle was *possible*: "But if a man had never seen the generation of a circle by the motion of a compass or other equivalent means, it would have been hard to persuade him that there was any such figure possible […]" (EW VII.205). See also *De Homine* 10.5 (OL II.93-94; Hobbes, *Man and Citizen: De Homine and De Cive*, 41-42).

[48] Thomas Hobbes, *Computatio Sive Logica*, Part I of *De corpore*, A.P. Martinich, trans. (New York: Abaris Books, 1981), 289; OL I.59.

[49] Hobbes argues in *Examinatio et Emendatio* that the term 'demonstration' should be reserved only for the 'why' (OL 4.38; for discussion, see Douglas Jesseph, *Squaring the Circle: The War between Hobbes and Wallis* [Chicago: University of Chicago Press, 1999], 204-205).

makers; we cannot know actual causes because "of natural bodies we know not the construction but seek it from the effects" so we can know "only of what [the causes] may be."[50]

This limitation upon knowledge in natural philosophy helps make sense of what Hobbes intends when he says in *De Homine* 10.5 that "true physics" depends on geometry:

> […] since one cannot proceed in reasoning about natural things that are brought about by motion from the effects to the causes without a knowledge of those things that follow from that kind of *motion*; and since one cannot proceed to the consequences of motions without a knowledge of *quantity*, which is geometry; nothing can be demonstrated by physics without something also being demonstrated *a priori*. Therefore physics (I mean true physics) [*vera physica*], that depends on geometry, is usually numbered among the mixed mathematics [*mathematicas mixtas*]. […] Therefore those mathematics are pure which (like geometry and arithmetic) revolve around quantities in the abstract [*in abstracto*] so that work [in them] requires no knowledge of the subject; those mathematics are mixed, in truth, which in their reasoning some quality of the subject is also considered, as is the case with astronomy, music, physics, and the parts of physics that can vary on account of the variety of species and the parts of the universe.[51]

Thus, when one considers the "quality of the subject", such as in physics, one is engaged in mixed mathematics. The natural philosopher will consider "quantity and number, not

[50] EW VII.184.

[51] Hobbes, *Man and Citizen: De Homine and De Cive*, 42 (modified translation); OL II.93.

[merely] abstractly [*non abstracte*], but with regard to the motion of the stars, or the motion of heavy [bodies], or with regard to the action of shining [bodies], and of those which produce sound [...]."[52]

Hobbes's use of 'easy' in *Dialogus Physicus* should be understood in this light. The causal principles related to simple circular motion that Hobbes (through interlocutor A) saw as necessary to explain the behavior of air are 'easy' since they are derived from constructions related to motion. But even if 'easy' why would Hobbes hold that the "doctrine of motion," and in particular simple circular motion, is part of *mathematics*?

Hobbes's criticisms of Euclidean definitions provide a partial answer to this question. Hobbes argues that Euclid "maketh not" in his definitions and thus Euclidean principles "ought not to be numbered among the principles of geometry."[53] Instead, for Hobbes definitions of simple geometrical figures must instruct how to make those figures—they must incorporate *motion* within the definitions themselves. Hobbes's definition for 'line' can serve as an example: "a line is made from the motion of a point."[54] Hobbes assumes that one learns the nature of the line by moving a point, and the motion of that point creates a line. Beyond the line, we make more complex geometrical figures by using a line. For example, Hobbes argues that a surface is made by the motion of a line, and a solid is made by the motion of a surface. These generative definitions in geometry give efficient causes and describe the mechanical way in which a body is moved to make a new body.[55]

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[52] MS fonds Latin 6566A (Bibliothèque nationale, Paris, f. 6; the critical edition is Thomas Hobbes, *Critique Du De Mundo De Thomas White*, Jean Jacquot and Harold W. Jones, eds. [Paris: Vrin, 1973 [1642-43]]).

[53] EW VII.184; see also EW VII.202.

[54] Hobbes, *Computatio Sive Logica*, 297; OL I.63.

[55] See Jesseph (*Squaring the Circle*, 203-204) on Hobbes's appeal to efficient causes.

However, notice that these geometrical definitions, such as the definition of 'line', employ the concept of motion only as *locomotion*. Beyond his claim that all geometrical definitions must include motion, Hobbes views motion itself as part of geometry.[56] Hobbes holds this view because he treats both motion and magnitude as the "most common accidents of all bodies,"[57] which are part of geometry because they are both treatable in terms of proportions. Indeed, this is why *De Corpore* Part III is called "Proportions of Motions and Magnitudes." Thus, beyond locomotion, to which Hobbes appeals in his reconfiguration of Euclidean definitions, we find in Part III that he first defines different types of motion in terms of the kinds of bodies that move (*De Corpore* 15.4); and second, that he develops the principles of various kinds of motion by means of constructed geometrical diagrams. In what remains of this subsection, I shall examine these two aspects of Part III and, with regard to the second aspect, focus upon the development of simple circular motion in *De Corpore* 21 by means of construction.

De Corpore Part III begins with a review of the principles established in the preceding section and introduces additional principles, including those related to endeavor and impetus. It may seem strange to include discussion of 'endeavor' within geometry, but Hobbes justifies doing so by describing how one may compare one endeavor with another, just like one may compare points of inequality for lines that intersect concentric circles:

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[56] Adams ("Hobbes on Natural Philosophy as 'True Physics' and Mixed Mathematics," 44-46) argues that this aspect of Hobbesian geometry shares affinity with Isaac Barrow's consideration of motion in the *Mathematical Lectures* (1683).

[57] EW I.203; OL I.75.

> …if a straight line cut many circumferences of concentric circles, the inequality of the points of intersection will be in the same proportion which the perimeters have to one another. And in the same manner, if two motions begin and end both together, their endeavours will be equal or unequal, according to the proportion of their velocities; as we see a bullet of lead descend with greater endeavour than a ball of wool.[58]

Hobbes's desire in treating motions as part of geometry, and thus subject to comparison by proportions, reflects his desire to develop a geometry that serves the interests of physics.[59] Since motion is the only intelligible cause of change for Hobbes (*De Corpore* 9.9),[60] incorporating motion within geometry serves the goal of placing the principle of change within mathematics, which places knowledge of the consequences of it (the consequences of motion) within the realm of certain knowledge (*scientia*).

Hobbes develops the notion of 'simple motion' by assuming that we can "consider" bodies in various ways. Elsewhere, Hobbes consistently uses the term 'consider' to denote the status of mathematical objects as relying upon our interests and goals.[61] For example, we can "consider" the earth as a point when we are interested in its annual revolution.[62] Had we other interests we would not have taken such a cognitive stance toward to the earth and instead could have seen it as composed of many points. We likewise should understand 'line' as "a body

[58] EW I.206-207.

[59] EW I.204; OL I.176.

[60] EW I.126; OL I.111-112.

[61] Adams ("Hobbes on Natural Philosophy as 'True Physics' and Mixed Mathematics," 46) connects Hobbes's use of 'consider' with Aristotle's view of mathematical objects.

[62] OL I.98-99.

whose length is *considered* without its breadth."[63] Here we see a crucial difference between the Euclidean and Hobbesian view of mathematical objects; against Euclid's definition of line, Hobbes argues that "there is no such thing as a broad length."[64] For Hobbes there are only bodies with breadth, and we form the conception of 'line' when we do not consider a body's breadth.

Similarly, in his account of *simple* and *compound* motion Hobbes holds that we may "consider" bodies as either having parts or not, depending upon our interests. He claims that "…when a mobile is considered [*consideratur*] as having parts, there arises another distinction of motion into *simple* and *compound*. *Simple*, when all the several parts describe equal lines; *compounded*, when unequal."[65] This distinction between simple and compound thus applies when we consider a body in a certain way. To recall the earlier example, when we are interested in the annual motion of the earth we consider it as a point and do not consider it as having parts. However, when we are interested in how the various parts that make up a body such as the earth move, we will find that those motions are either simple or compound.

De Corpore 21.1 begins with Hobbes reiterating this definition of simple motion and adding to it with consideration of simple *circular* motion: "…in simple circular motion it is necessary that every straight line take in the moved body be always carried parallel to itself…"[66] By "simple circular motion" Hobbes means something like the motion of a sieve, a sort of gyrating motion around a center point.[67] Hobbes compares this simple circular motion in *De*

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[63] EW VII.202 (emphasis added).

[64] Ibid.

[65] EW I.215; OL I.181.

[66] EW I.318; OL I.259.

[67] Henry ("Hobbes, Galileo, and the Physics of Simple Circular Motions") connects Hobbes's view of simple circular motion to Galileo (more on this below). In the demonstration to be discussed below from *De corpore* 21. 2,

Corpore 21.2 to what would happen "…if a man had a ruler, in which many pens' points of equal length were fastened, he might with this one motion write many lines at once."[68] Hobbes demonstrates this claim that "every straight line take in the moved body be always carried parallel to itself" with a geometrical construction with figure 1 in the 1655 printed text.

In the articles that follow this definition of simple circular motion (*De Corpore* 21, articles 2-6), Hobbes uses another constructed diagram (see figure below). Using this diagram, he first demonstrates that in circular motion (not *simple* circular motion) the axis of an epicycle, such as the axis E-C of epicycle C-D-E in the figure below, will always be carried parallel to itself when moved around a center point such as A and when revolving around its own center point such as B.

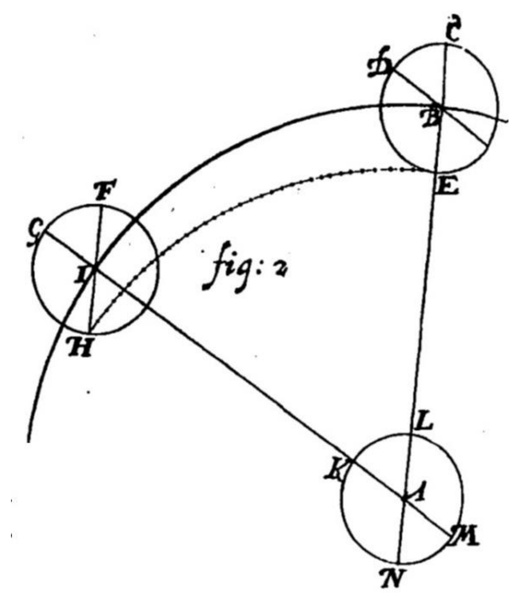

Figure 2 from 1655 edition of *De Corpore* 21.

Hobbes does not appeal to the motion of C-D-E as a gyrational simple circular motion, but only as a contrary revolution.

[68] EW I.320; OL I.261.

Hobbes demonstrates this claim using the figure by asking the reader to suppose that equal angles are made in equal time. On that assumption, as the angle B-A-I is made when C-D-E moves leftward in the diagram in revolution around K-L-M-N, it will require the same amount of time to make any angle equal to it, such as angle F-I-G. Were there no contrary revolutionary motion of C-D-E, which causes point E to move toward C through D, the radius B-C would end at G-I as B-I is traversed. However, the contrary revolutionary motion causes C-B to end at I-F. Here is Hobbes's description: "Wherefore, in what time B C comes to I G by the motion from B to I upon the centre A, in the same time G will come to F by the contrary motion of the epicycle, that is, it will be turned backwards to F, and I G will lie in I F."[69]

Hobbes draws a corollary from this demonstration. He suggests that his account of simple circular motion will allow him to save the phenomena without needing the two annual motions of the earth proposed by Copernicus. In other words, he thinks that he needs only "one circular simple motion" to account for the earth's axis remaining parallel to itself without needing a third motion beyond the annual movement around the sun and diurnal rotation.

Hobbes's immediate application of the principles of simple circular motion to phenomena such as the earth's motion might make it strange to claim that the demonstration proceeding that application is *geometrical*. Were Hobbes being more circumspect, he would not have made this a corollary and instead consistently talked only of circles, i.e., bodies *considered* as circles, and made claims only that apply to "any solid body [*quodlibet corpore solido*],"[70] as he does with Figure 1 in *De Corpore* 21.1. I suggest that we take this slide into application, or more precisely

[69] EW I.320.

[70] EW I.318; OL I.259.

“mixing,” to be in the service of making the geometrical section more accessible to readers. Indeed, this way of understanding the example makes sense of the fact that immediately following the brief discussion of how simple circular motion simplifies the Copernican system, Hobbes connects it to “the same [motion] which is used by all men when they turn anything round with their arms, as they do in grinding and sifting.”[71]

After this example and its corollary, Hobbes seeks to “set down some properties” of simple circular motion.[72] Hobbes uses the diagram from above (figure 2 from the 1655 edition) to demonstrate the first three properties, all of which relate to the properties of bodies moving according to simple circular motion in fluid media. The first property, which he demonstrates in *De Corpore* 21.3, is as follows: “…there are no parts so small of the fluid ambient, how soever far it be continued, but do change their situation in such manner, as that they leave their places continually to other small parts that come into the same.”[73]

He first asks the reader to consider a body, such as K-L-M-N, being moved with simple circular motion in a fluid medium. Given his understanding of simple circular motion as a sieve-like motion whereby all points of a body move around a center point, it follows that all points of a body so moved create lines parallel to each other. As K-L-M-N moves in this way, Hobbes argues that “the centre A and every other point [in K-L-M-N], and consequently the moved body itself, will be carried sometimes toward the side where is K, and sometimes toward the other side where is M.”[74] On the assumption that there is a plenum, Hobbes argues that when K-L-M-N is

[71] EW I.320.

[72] EW I.321.

[73] Ibid.

[74] Ibid.

so moved all parts of the fluid medium will move as well, no matter how small, so that their place can be taken by K-L-M-N.

The second property that Hobbes demonstrates about simple circular motion in *De Corpore* 21.4 is that when all the parts of a fluid medium are moved with simple circular motion by a body moving so in the medium, we should think of the motions in terms of concentric circles radiating out from the center. The parts farther from the center will make their circles in longer times than those closer, and we can understand the relationships among these times as being in "…the same proportion with their distances from the movent."[75]

It is the third property – fermentation – that relates most directly to the discussion of the nature of air in *Dialogus Physicus*. Hobbes asks the reader to consider a body with the "same simple motion" already considered with body K-L-M-N. Hobbes reminds the reader that bodies are not different from one another insofar as they are bodies but only insofar as they differ in their respective motions, from "some internal motion, or motions of their smallest parts."[76] This view that both likeness and difference of one body to another is explained exclusively in terms of a difference or similarity in internal motions is a view that follows straightforwardly from a principle in *De Corpore* 9.9, which Hobbes here mentions as being shown already. As a body is moved with simple circular motion in a fluid medium, Hobbes claims that this continual motion puts together homogeneous bodies, understood as those bodies with similar internal motions.

Likewise, simple circular motion drives apart heterogeneous bodies, those with dissimilar internal motions. Hobbes says that this property of simple circular motion – that it results in the joining of homogeneous bodies and driving apart of heterogeneous ones – is the cause of what

[75] EW I.322; OL I.263.

[76] EW I.323; OL 264.

we commonly call “fermentation.” He traces the etymology of the term to *fervere* and relates it to the meaning of “seething.” Hobbes takes it that the cause of this seething in fermentation is due to “all parts of the water chang[ing] their places” so that as a result “…the parts of any thing, that is thrown into it, will go several ways according to their several natures.”[77]

What makes these demonstrations related to the simple circular motion that is part of geometry? It would be uninformative to say that they are geometrical simply because they are contained within Part III of *De Corpore*. Furthermore, they are not geometrical merely because they concern demonstrations about bodies considered abstractly, i.e., bodies considered apart from their unique qualities like “shining” (see *Anti-White* quotation above). In addition to being about bodies considered abstractly, these are geometrical because *we make the figures* – we manipulate the figures in the construction, such as circle C-D-E, and as we move them from center B to center I we gain causal knowledge. Furthermore, each step of the demonstrations relies only upon considering the two features (mentioned already) that Hobbes describes as characterizing geometry because they are the most common accidents of all bodies, *motion* and *magnitude*. In other words, they are abstractly-considered bodies at the right level – the subject of geometry at the level of magnitude and motion – and not merely an abstraction. Indeed, for Hobbes considering bodies abstractly as having magnitude without motion would not lead one to geometrical principles. Furthermore, attempting to make a claim about motion *without* extension would cause one to make absurd claims, in Hobbes’s terms.[78] Thus, I suggest that Hobbes

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[77] EW I.324.

[78] On this point Hobbes is not clear since he thinks, on the one hand, of motion as a “simplest conception” (OL I.62-63) to be defined by itself, but, on the other hand, he would require that when we use ‘motion’ in a demonstration we do so only with a particular body under consideration. We define the simplest conception ‘motion’ as “the leaving of one place, and the acquiring of another continually” (OL I.72). Although the definition of ‘motion’ qua simplest conception will not include a particular body moving (a cause), nevertheless he says “at the hearing of that

understands these principles relating to simple circular motion as geometrical because they are about abstractly considered bodies, those with magnitude and in motion, and because we arrive at them by engaging in the making of diagrams.

Given that they fall within the purview of Hobbesian geometry, we possess causal knowledge of the principles related to simple circular motion. In the *Dialogus Physicus*, interlocutor A argues that attributing the greater weight of the bladder to the "cause of gravity" is insufficient because it "could not bring together the homogenous substance when separated by force and tear apart heterogeneous bodies brought together by force."[79] If we instead posit that the sucker causes fermentation, we can then borrow the geometrical principle from Part III of *De Corpore*. Borrowing this causal principle will allow us to explain why the weight increases – it is due to the motion of fermentation joining together homogeneous particles.

Such a borrowing lends a higher degree of plausibility, Hobbes would contend, to A's explanation. Although Hobbes grants that in natural philosophy we have only possible causes, this need not imply that all possible causes should be treated alike. Instead, since fermentation motion is a consequence of continual simple circular motion, we can know that if a body (like the sucker) causes the simple circular motion of a medium through continuous motion (repeated movements of the sucker) then fermentation will result. We cannot know with certainty that fermentation is in fact responsible (since we are not the makers of natural things); nevertheless, we can know that *if* continuous simple circular motion were occurring then fermentation would necessarily occur and also that *if* fermentation were involved then the joining of homogeneous

speech, there will come into the mind of the hearer an idea of motion clear enough" (EW I.81; OL I. 71–72; see discussion in Marcus P. Adams, "Hobbes, Definitions, and Simplest Conceptions." *Hobbes Studies*. 27: 35-60, here 44).

[79] Hobbes, *Dialogus Physicus*, 369; OL IV.262.

particles would necessarily occur. We may call this suppositional certainty.[80] This is Hobbes's *method* that he emphasizes cannot be replaced with mere *ingenuity* on the part of Boyle and colleagues: natural philosophy must begin with consideration of bodies as magnitude in motion, demonstrate necessary consequences of those bodies in motion (like fermentation), and finally borrow those consequences as causal principles within explanations of natural phenomena.

4. Deduction, Deductivism, and the *Dialogus Physicus*

Shapin and Schaffer have understood Hobbes as defending that status of natural philosophy as "a causal enterprise ... [that] as such, secured total and irrevocable assent."[81] Indeed, Boyle may have seen himself as defending "the proper procedures of experimental philosophy against the beast of deductivism."[82] The goal of the present essay is to assess Hobbes's criticisms in *Dialogus Physicus*, regardless of Boyle's viewpoint of them, in light of Hobbes's broader works and view of method in natural philosophy.

In Shapin and Schaffer's[83] discussion of these criticisms, the following claim of Hobbes's figures centrally: "[...] ingenuity is one thing and method [*ars*] is another. Here method is needed."[84] Shapin and Schaffer explicate this criticism as Hobbes making clear that he saw the experimentalists like Boyle as denigrating the role of the philosopher. The philosopher inhabited a noble role, not something on par with the role of an "apothecary" or a "gardener."[85] Shapin and

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[80] Adams, "Hobbes on Natural Philosophy as 'True Physics' and Mixed Mathematics," 47.

[81] Shapin and Schaffer, *The Leviathan and the Air-Pump*, 19.

[82] Ibid., 176.

[83] Ibid., 125ff.

[84] Hobbes, *Dialogus Physicus*, 347.

[85] Hobbes, *The Leviathan and the Air-Pump*, 130.

Schaffer rely upon a possible etymological pun by Hobbes in his usage of 'ingenuity', perhaps meant to intimate both the sense of cleverness and related to a mill, as seen in the Old French *engin* derived from it.[86]

However, Shapin and Schaffer's neglect the crucial sentence that immediately follows this juxtaposition of *ingenuity* and *method*, a sentence that seems to be intended as a brief description of what counts as 'method': "The causes of those things done by motion are to be investigated through a knowledge of motion, the knowledge of which, the noblest part of geometry, is hitherto untouched."[87] We need not import notions of one version of the role of the philosopher as noble compared with another to understand Hobbes's criticism of Boyle and colleagues having mere ingenuity. Instead, Hobbes's claim should be understood in light of his view of the priority of geometry—geometry is the science that provides causal principles, which are the 'why' borrowed within a mixed mathematical natural philosophy.

The issue of 'method' at stake in the *Dialogus Physicus* relates not to whether experiments should *ever* legitimately count within natural philosophical explanation. In this respect, the present account agrees with the view offered by Shapin and Schaffer.[88] Instead, Hobbes can be understood as emphasizing the necessity of knowing the 'why' in advance of any experiment. It is for this reason that in *De Homine* 10.5 (quoted above) Hobbes claims that "nothing can be demonstrated by physics without something also being demonstrated *a priori*."[89]

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[86] Hobbes, *The Leviathan and the Air-Pump*, 129-130.

[87] Hobbes, *Dialogus Physicus*, 347.

[88] Cf. Shapin and Schaffer, *The Leviathan and the Air-Pump*, 129

[89] Hobbes, *Man and Citizen*, 42; OL II.93. My focus in the present paper is upon the relationship between the natural philosophy of *Dialogus Physicus* and Part IV of *De corpore* and geometry; however, Hobbes also uses principles from first philosophy in natural philosophy. Douglas Jesseph ("Hobbesian Mechanics," *Oxford Studies in Early Modern Philosophy* III [2006]: 119-152, here 138-139) sees two parts to natural philosophy: first, a priori principles

The ‘why’ in geometry must be known in advance of any experiment, and then principles are borrowed from geometry in an explanation.

Hobbes’s focus upon causal principles borrowed from geometry does not make the ‘that’ that one gains from experience or an experiment unimportant for doing natural philosophy. Instead, Hobbes claims that knowledge ‘that’ is “[...] very useful (no, indeed necessary) for philosophy [...].”[90] Similarly, in *De Homine* 11.10 Hobbes asserts that “[...] histories are particularly useful, for they supply the experiences/experiments [*experimenta*] on which the sciences of the causes rest.”[91]

Given Hobbes’s commitments within the broader corpus surveyed in this paper, I suggest that we understand his central complaint in the *Dialogus Physicus* as relating neither to the role of experiment or experience in natural philosophy nor to the ignoble nature of experimenting qua philosopher. Rather the primary issue at stake for Hobbes is that proper method in natural philosophy must be followed at all times—the proper method begins with *a priori* work in geometry, deduces consequences in geometry related motion and magnitude, and then borrows those causal principles to provide the reason why in a natural-philosophical explanation.

Deduction will still play a role in a natural-philosophical explanation, but we should not, *pace* Shapin and Schaffer, view Hobbes or his system as the “beast of deductivism” against

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of first philosophy (what Jesseph calls the “persistence principle” in *De corpore* 8.19 and the principle of “action by contact” in *De corpore* 9.17); and second, the use of these principles within natural philosophy by hypothesis (e.g., OL I.339; OL I.354; OL I.417). In addition to these two principles, Hobbes also borrows other principles from first philosophy, such as a principle related to the division of bodies and places used in *De corpore* 25.6 (OL I.321) and another related to the necessity of an effect following from a necessary cause used in *De corpore* 25.13 when explaining deliberation (OL I.333). A complete account of Hobbes’s claim that “something also being demonstrated *a priori*” will include both first philosophy and geometry.

[90] Hobbes, *Computatio Sive Logica*, 189; OL I.9.

[91] OL II.100.

which Boyle mounts a defense. Hobbes does, of course, view the principles of geometry as following deductively from first principles of body and motion, what Hobbes calls the "simplest conceptions."[92] However, a virtue of understanding natural philosophy, and thus the explanation of the nature of air in the *Dialogus Physicus*, as a mixed mathematical science is that it removes the need to see deductive connections *between* the sciences of geometry and natural philosophy. The mixed mathematical science view of Hobbes's natural philosophy is thus able to articulate both the unity of geometry and natural philosophy as well as show that they are independent sciences. The natural philosopher will explain by means of syllogistic deductions, but when borrowing geometrical principles the natural philosopher will treat the physical body as if it were a mathematical body. As a result, the explanation in natural philosophy will attain suppositional certainty, not "total and irrevocable assent."

Conclusion

In this paper, I have argued that we should understand the *Dialogus Physicus* as continuous with Hobbes's natural-philosophical project in Part IV of *De Corpore*. With Part IV in view, Hobbes need not be taken to reject or diminish the importance of experiment or experience; nor should his criticisms of Boyle and colleagues in *Dialogus Physicus* be understood as rejecting experimenting as ignoble and not befitting a philosopher. Instead, Hobbes's primary contention is that experiment/experience must be understood within its proper place – it establishes the 'that' for a mixed mathematical science explanation – but the 'why' must come from geometry.

[92] OL I.62-63.