Hobbesian Mechanics[1]

The concept of motion lies at the very center of Hobbes's philosophical system. In his scheme of things motion is the only cause, and because all of philosophy involves reasoning about causes, he is committed to the thesis that motion is the ultimate explanatory concept. Indeed, Frithiof Brandt noted that '[w]henever we sift the subject to the bottom we come across motion in Hobbes,' and he concluded that instead of being characterized as a materialist 'Hobbes should more properly be called a motionalist, if we may be permitted to coin such a word.'[2]

Notwithstanding the absolute centrality of motion in Hobbes's philosophy, there is nevertheless some difficulty involved in understanding how an evidently physical concept like motion can properly play a central role in first philosophy.[3] Hobbes himself insisted on a firm distinction between the absolute demonstrative certainty of first philosophy and the ineradicably conjectural and hypothetical nature of physics. Yet the part of his treatise *De Corpore* that bears the title 'First Philosophy' contains what appear to be substantive physical principles, including laws of motion and collision. One might therefore wonder whether the Hobbesian system is grounded in a fundamental confusion of physics with first philosophy, in which empirical concepts like space and motion intrude into the realm of abstract first principles governing all of philosophy.

My purpose here is to explain how Hobbes could claim that the basic principles of motion can be *a priori*, necessary, and fundamental to first philosophy while regarding physics or natural philosophy as uncertain, fallible, and based upon hypotheses. To do this, I will begin with an account of the structure of Hobbes's program for philosophy as

it set out in *De Corpore*, after which I will contrast Hobbes's view of the proper development of the science of mechanics with the *Mechanica* of his nemesis, John Wallis. Several significant points will emerge from this investigation. First, that Hobbes regarded the laws of motion as *a priori* principles belonging to first philosophy rather than physics proper. Second, that much of his disaffection for Wallis's *Mechanica* is grounded in his own conviction that a true science of mechanics must take the form of a deductive system which proceeds from first principles that specify the causes of things. Finally, it should become clear that Hobbes's grand dream of establishing an *a priori* science of mechanics and philosophy came to grief, at least in part, because his treatment of motion does not provide an adequate basis for understanding concepts like force, acceleration, or collision.

1. Physics and First Philosophy in Hobbes's *De Corpore*

Hobbes reserved the terms 'philosophy' or 'science' for demonstrative knowledge, which he characterized as 'knowledge of Consequences, and dependence of one fact upon another' (*Leviathan*, ch.5 ; *EW* III.35). The advancement of such knowledge requires systematic organization, and in *De Corpore* Hobbes announced his intention to 'lay open the few and first Elements of Philosophy in generall, as so many Seeds, from which pure and true Philosophy may hereafter spring up by little and little' (*DCo* I.i.1; *EW* I.2). He envisioned a grand tripartite system of treatises *De Corpore*, *De Homine*, and *De Cive*, that he intended to contain all the philosophy worth knowing. This order reflects Hobbes's ideal arrangement of the subject: beginning with a treatise on the

nature of body, he intended to proceed next to a study of the nature of man (*i.e*. an animated, rational body), and thence to the doctrine of the commonwealth, an artificial body formed by the covenants that bind men together. As a matter of historical accident, *De Corpore* was not published until 1655, some 13 years after *De Cive*. Although these treatises made their public appearance out of their intended order, Hobbes was nevertheless committed to the principle that all philosophy ultimately takes its principles from the nature of body.

The starting point for philosophy thus conceived is a small collection of definitions. Indeed, Hobbes characterized first philosophy as nothing more than setting out definitions, and he insisted that 'the making of Definitions, in whatsoever Science they are to be used, is that which we call *Philosophia prima.*'[4] Hobbesian method demands that syllogisms are then to be constructed from these definitions, thereby establishing conclusions as firmly as the definitions themselves; these conclusions can then serve to construct further syllogisms, with the result that ever more remote consequences of the initial definitions are established with absolute certainty.[5] Hobbes also defined philosophy as an inherently causal investigation or, in his words, '*the Knowledge acquired by Reasoning, from the Manner of the Generation of any thing, to the Properties; or from the Properties, to some possible Way of generation of the same*' (*Leviathan*, ch. 46; *EW* III.664). Despite appearances, there is no real tension between these two characterizations of philosophy, because the investigation of causes and the construction of syllogisms are two essentially similar activities. Hobbes held that all reasoning is a kind of calculation involving the addition and subtraction of mental contents, or as he famously put it, 'REASON . . . is nothing but *Reckoning* (that is, Adding

and Substracting) of the Consequences of generall names agreed upon' (*Leviathan*, ch. 5; *EW* III.9). A Hobbesian syllogism is consequently 'nothing but a Collection of the summe, of two Propositions, joyned together by a common Term, which is called the *Middle Terme*. And as Proposition is the addition of two Names, so Syllogisme is the adding together of three' (*DCo* I.iv.6; *EW* I.48). This sort of mental arithmetic also applies to the formation of concepts and the investigation of causes. To form the complex concept *man*, the more general concepts *body*, *animated*, and *rational* are summed together and applied to the same thing (*DCo* I.i.3; *EW* I.4). Likewise, the investigation of causes involves a search for the conditions which, taken together, suffice for a given effect.[6] The point here is that, when combined, causal factors necessitate their effects, just as the premises of a syllogism, when drawn together in a 'sum', necessitate their conclusions. Furthermore, Hobbes demanded that the definitions forming the basis for the syllogisms of the true *philosophia prima* be such as to express the causal generation of the things defined: 'where there is place for Demonstration, if the first Principles, that is to say, the Definitions contain not the Generation of the Subject; there can be nothing demonstrated as it ought to be.' (*Six Lessons*, epistle; *EW* VII.184). The result is that all of philosophy is an investigation in to causes.

The four-part structure of *De Corpore* mirrors this picture of the method and structure of philosophy. Its first part (encompassing chapters i - vi) is entitled 'Computation or Logique' and sets out Hobbes's theory of reasoning as calculation, together with his treatment of names, syllogisms, and general methodology. The second part (chapters vii - xiv) bears the title 'The First Grounds of Philosophy' and contains the fundamental definitions and categories of being, all of which are ultimately concerned

with body and motion. As Hobbes explained, 'words understood are but the seed, and no part of the harvest of Philosophy,' and his fundamental definitions in *De Corpore* are set out in accord with 'the Method I have used, defining Place, Magnitude, and other most generall Appellations in that part [of *De Corpore*] which I intitle *Philosophia Prima*,' (*Six Lessons*, p. 15; *EW* VII. 226). The third part of *De Corpore* (chapters xv - xxiv) is devoted to 'Proportions of Motions and Magnitudes.' It develops a highly kinematic treatment of geometry, whose foundations were laid in the account of 'First Philosophy' in part two. The fourth and final part of *De Corpore* (chapters xxv - xxx) is called 'Physiques, or the *Phænomena* of Nature.' In it Hobbes explicates natural phenomena by advancing causal hypotheses which suffice to explain them, even if the hypotheses themselves must remain conjectural. The essential difference in method between part four and the rest of *De Corpore* is this dependence upon causal hypotheses: the other branches of philosophy rest upon transparently true first principles and known causes, while the detailed treatment of nature can only be undertaken hypothetically. In Hobbes's formulation of the matter at the beginning of the fourth part of *De Corpore*:

> There are therefore two Methods of Philosophy, One from the Generation of the things to their possible Effects, and the other from their Effects or Appearances to some possible Generation of the same. In the former of these, the Truth of the first Principles of our ratiocination (namely Definitions) is made and constituted by our selves, whilest we consent and agree about he Appellations of things. And this part I have finished in the foregoing Chapters. . . . I now enter upon the other part, which is the finding out by the

> Appearances of Effects of Nature which we know by Sense, some wayes and means by which they may be (I do not say, they are) generated. The Principles therefore, upon which the following discourse depends, are not such as we our selves make and pronounce in general terms, as Definitions; but such, as being placed in the things themselves by the Author of Nature, are by us observed in them, and we make use of them in single and particular, not universal propositions. Nor do they impose upon us any necessity of constituting Theoremes, their use being onely (though not without such general Propositions as have been already demonstrated) to shew us the possibility of some production of generation. (*DCo* IV.xxv.1; *EW* I.387-8)[7]

This point will be of significance later, but the distinction between these two sorts of method is worth pointing out here.

The procedure by which causes are uncovered in Hobbesian first philosophy is 'resolution' or 'analysis' that begins with an object or event and proceeds to its causal antecedents. When applied at the most general level in the search for universal causal principles, this analytic procedure terminates with the concept of motion, because motion is the ultimate cause of everything. As Hobbes explains: 'the Causes of Universall things (of those at least that have any Cause) are manifest of themselves; or (as they say commonly) known to Nature; so that they need no Method at all; for they have all but one Universall Cause, which is Motion' (*DCo* I.vi.5; *EW* I.69). Elsewhere, he remarked that

one salient cause of erroneous reasoning is 'not knowing what motion and its properties are; that is, not knowing the immediate natural cause of everything'[8]

Because motion is the ultimate causal principle in Hobbes's system, the whole of his philosophy becomes a study of the consequences of motion. The development of this philosophy proceeds synthetically (or 'compositively') from causes to effects, beginning with the most basic definitions which do not so much identify causes as set out 'the explication of our Simple Conceptions' (*DCo* I.vi.6; *EW* I.70). These simplest definitions are of such concepts as place and motion, to which Hobbes then adds definitions of 'their Generations or Descriptions; as (for example,) that *a Line is made by the Motion of a Point, Superficies by the Motion of Line*, and *one Motion by another Motion, &c.*' (*DCo* I.vi.6; *EW* I.70-1). The things thus generated or described are geometrical objects, and Hobbes thereby makes geometry one of the fundamental branches of philosophy. Pursuing the synthetic development further Hobbes comes to

> the consideration of what Effects one Body moved worketh upon another; and because there may be Motion in all the severall parts of a Body, yet so as that the whole Body remain still in the same place, we must enquire, first, what Motion causeth such and such Motion in the whole, that is, when one Body invades another body which is either at Rest, or in Motion, what way, and with what swiftnesse the invaded Body shall move; and again, what Motion this second Body will generate in a third, and so forwards. From which Contemplation shall be drawn that part of Philosophy which treats of Motion. (*DCo* I.vi.6; *EW* I.71-2)

Instead of characterizing this part of first philosophy as that which 'treats of Motion,' it might more aptly be called mechanics.[9] Hobbes's doctrines imply that all philosophy 'treats of Motion' at some level, but what is distinctive about this part of philosophy is that it yields the basic laws of motion and impact.

From the account sketched so far it is evident that Hobbes saw a tight link between first philosophy and natural philosophy. Geometry mediates between these two, as Hobbes explains:

> because all Appearance of things to sense is determined, and made to be of such and such Quality and Quantity by Compounded Motions, every one of which has a certaine degree of Velocity, and a certaine and determined way; therefore in the first place we are to search out the wayes of Motion simply, (in which Geometry consists;) next the wayes of such generated Motions as are manifest; and lastly the wayes of internal and invisible Motions, (which is the Enquiry of Naturall Philosophers.) And therefore they that study Naturall Philosophy, study in vaine, except they begin at Geometry; and such Writers or Disputers thereof, as are ignorant of Geometry, do but make their Readers and Hearers lose their time. (*DCo* I.vi.6; *EW* I.73).

This close connection between geometry and natural philosophy also implies that there is no fundamental distinction between first philosophy and natural philosophy. Indeed, it would be fair to say that Hobbes's first philosophy is founded on concepts traditionally assigned to natural philosophy.

Hobbes proposed that the best way to begin his inquiry into first philosophy is, in his words, 'from *Privation*; that is, from feigning the World to be annihilated. But if such annihilation of all things be supposed, it may perhaps be asked, what would remain for any Man (whom onely I except from this Universal annihilation of things) to consider as the Subject of Philosophy, or at all to reason upon; or what to give Names unto for Ratiocinations sake' (*DCo* II.vii.1; *EW* I.91). Hobbes concluded from this thought experiment of an annihilated world that such a person could still think, and indeed remember previous experiences. The imagined solitary thinker would thereby have such concepts as space, body, motion, and cause, as well as having a language in which to describe these concepts. However, one concept he would lack is that of an immaterial self or soul. On Hobbes's principles, no such thing could have been perceived when the world of external bodies was in existence, and the supposed annihilation of the world does nothing to bring such a concept into introspective focus.

Although the thought experiment of the 'annihilated world' bears some resemblance to the *cogito* of Descartes, it proceeds from an entirely different set of assumptions and is directed toward a very different goal. The Cartesian *cogito* places the existence of the entire material world in doubt in order to establish the fundamentally immaterial nature of the mind; Descartes then proceeds to take the mind's knowledge of itself as the means to investigate other principles of first philosophy. In contrast, Hobbes simply assumes that the solitary thinker exempted from otherwise universal annihilation is a material being and that his thoughts are motions taking place in his (material) sensory apparatus.[10] The announced goal of Hobbes's thought experiment is to show that 'though all things be still remaining in the world, yet we compute nothing but our own

Phantasmes' (*DCo* II.vii.1; *EW* I.92). The hypothesis of an annihilated world is therefore intended to show that all reasoning (which Hobbes identifies with computation) takes as its object certain 'phantasms' or sensory experiences. The result is that in Hobbes's account of the mind there can be no non-sensory, purely intellectual faculty of the sort Descartes held to be the locus of genuine knowledge. In the Cartesian scheme, such knowledge must be attained by withdrawing the mind from the senses and turning the intellect to the contemplation of such abstract concepts as God, the soul, or the geometric notion of extension. In stark contrast, Hobbes famously declared that 'the Originall of [all ideas] is that we call SENSE; (For there is no conception in a mans mind, which hath not at first, totally, or by parts, been begotten upon the organs of Sense). The rest are derived from that originall' (*Leviathan*, ch 1; *EW* III.2). This restriction of all concepts to those derived from sensation, together with Hobbes's doctrine that sensory experience is nothing more than motion in the human sensory apparatus, therefore requires that the foundations of first philosophy be sought in concepts that are accessible to the senses and presuppose nothing further than the elementary notions of body, motion, and impact.

Chapters vii-xi of the second part of *De Corpore* contain Hobbes's definitions of the key concepts in first philosophy, which concepts he takes to be available to anyone who engages in the thought experiment of the 'annihilated world.' 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 any Scholastic or Cartesian catalog of the principles of first philosophy, but Hobbes systematically interpreted them in purely physical terms.[11] 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.

One might very well expect that a philosopher who identifies substance with body should offer something like a reason for accepting this quite radical identification, but Hobbes nowhere mounts anything like a sustained argument for his materialism. Rather than construct a case for materialism, a project which would require appeal to premises an opponent might well reject, Hobbes structured his first philosophy in a way that systematically excludes the possibility of an immaterial substance. As we saw, the 'annihilation experiment' and the fundamental concepts that Hobbes derives from it presuppose an epistemology in which all legitimate concepts are constructed from antecedent sense experience. This epistemology in turn rules out such insensible, immaterial notions as a Cartesian soul; a materialistic treatment of sense perception then closes the circle by identifying sensation with motions in the brain and sensory organs. The result, as Hobbes intended it, is that all concepts in the one true philosophy are rendered explicable in terms of the motion and impact of material bodies. To some degree, Hobbes's procedures can be seen as appealing to a sort of principle of parsimony: by undertaking to show that matter and motion account for all of the relevant phenomena, he can motivate his materialism by making immaterial substances superfluous. At a somewhat deeper level, however, the Hobbesian project makes the concept of body so basic that it cannot be 'thought away', and reflection is supposed to show that the concept of body is essential to an account of anything at all that exists or might exist.

We can see this sort of procedure at work in Hobbes's objections to Descartes' second meditation. In response to the Cartesian *cogito*, Hobbes first identifies thought with the having of 'phantasms' when he reasons that 'from the fact that I think, or have phantasms, whether I am awake or dreaming, it follows that I am thinking' (*AT* VII.172). He then argues that thoughts or phantasms require a subject in which they inhere, and this subject may well be something corporeal.[12] Hobbes then infers that matter must, in fact, be understood as the underlying subject in which thought inheres. In his words:

> It seems to follow from this that a thinking thing is something corporeal. For it seems that the subject of any act can be understood only in terms of something corporeal or in terms of matter, as the author himself shows later in his example of the wax: the wax, despite the changes in its color, hardness, shape, and other acts, is still understood to be the same thing, that is the same matter that is the subject of all these changes. (*AT* VII.173)

Hobbes's point is that the only model we have for a persisting subject that underlies qualitative change is that of bodies enduring even as their sensible properties alter. He takes this to be exemplified by the example of the notorious piece of wax in the second meditation, as well as something presumed in the Aristotelian ontology of matter and form. He then concludes that matter must be the underlying subject that endures through change, regardless of the qualities that change, be they shapes, colors, motion, or thoughts. As he puts it: 'knowledge of the proposition "I exist" depends on knowledge of the proposition "I think"; and knowledge of this depends on the fact that we cannot separate thought from the matter that thinks; so it seems that it would be better to infer

that the thinking thing is material rather than immaterial' (*AT* VII.173-4). Furthermore, Hobbes holds that the only way in which material bodies can be changed or initiate change is through motion and impact, and this has the consequence that the laws of motion must occupy an especially privileged place in his philosophy.

2. Hobbes and the Laws of Motion

We have seen that Hobbes's philosophical system is founded on concepts that would traditionally be assigned to natural philosophy rather than first philosophy. This interpretation can be further illustrated by considering Hobbes's statement and justification of the laws of motion. As I have argued, Hobbes regarded the fundamental principles of motion as part of first philosophy, and this means that what appear to be substantive physical principles (such as laws of motion) appear in those sections of *De Corpore* concerned with first philosophy. There is no anomaly here, however, because Hobbes conceived of motion as the most basic explanatory concept in all of philosophy, so his account of first philosophy must be framed in terms of motion and its principles. I want now to focus on two principles of motion and their justifications, because by examining them we can get a better picture of the relationship between Hobbesian natural philosophy and first philosophy. The first of these is a version of the law of inertia set out in chapter viii of *De Corpore*, while the second is the mechanistic principle of action by contact set out in chapter ix.

Although it makes sense to speak of Hobbes as setting out laws of motion, these should not be thought of in close analogy with the 'Axioms, or Laws of Motion' in

Newton's *Principia*.[13] In the Newtonian presentation, the axiomatic status of the laws of motion means that they are incapable of proof and must be accepted without further justification, presumably because they are either evident to reason, or at least because they are useful for making systematic predictions. Hobbes, however, took his laws of motion to be capable of proof, and he even offered proofs of them. In fact, he was convinced that his own first philosophy would enable the proof of such traditionally indemonstrable principles as the eighth axiom from Book I of Euclid's *Elements*, which asserts that the whole is greater than the part.[14] Hobbes's proofs of such geometrical axioms or laws of motion proceed by analyzing the concepts contained in them, until the analysis reaches fundamental definitions whose truth depends only upon the meanings of the terms employed. Such geometric and mechanical principles therefore have the status of purely semantic or conceptual truths, the apprehension of which requires nothing more complex than the grasp of definitions, which themselves are essentially made true by stipulation.

Before investigating Hobbes's account of the laws of motion, it is worth pointing out that his epistemology requires something beyond the simple verbal exercise of propounding definitions. Although his account of first philosophy puts a great deal of stress on the importance of proper definitions, Hobbes also holds that the inferential connection between concepts can be grasped with a level of intuitive certainty that places them beyond doubt. Moreover, he makes no scruple of calling some principles 'evident to reason' or 'known by the natural light', thereby employing standard locutions to be found in an epistemology locating criteria for knowledge in an intellectual act of comprehension that is self-ratifying or otherwise unchallengable.[15] The point here is that

Hobbes entertains no serious skeptical doubts about the reliability of our basic grasp of definitions or the drawing of simple consequences from them; nor does his philosophy reduce to a crude empiricism that denies any role to intellectual faculties.[16]

Hobbes's statement and proof of his version of the inertial principle are contained in section 19 of chapter viii of *De Corpore*. To avoid possible confusions that might result between this principle and more familiar (i.e. Newtonian) laws of motion, I will call it the 'persistence principle' rather than the law of inertia, for reasons that should become clear.[17] The chapter containing the persistence principle is part of Hobbes's exposition of first philosophy and bears the title 'Of Body and Accident.' Hobbes is concerned in this chapter with the distinction between body (or substance) and its accidents; the most important accident of body is motion, which he defines as '*a continual relinquishing of one Place, and acquiring of another*' (*DCo* II.viii.10; *EW* I.109). The persistence principle governs the manner in which this accident of body is generated or destroyed, and therefore has two parts. The first part concerns the generation of motion and asserts '*Whatsoever is at Rest, will always be at Rest, unleß there be some other body besides it, which, by endeavouring to get into its Place by motion, suffers it no longer to remain at Rest*' (*DCo* II.viii.19; *EW* I.115). The second part of the principle concerns the destruction of the accident of motion. It reads: '*Whatsoever is Moved, will always be Moved, except there be some other body besides it, which causeth it to Rest*' (*DCo* II.viii.19; EW I.115).[18]

More significant than the statement of the persistence principle is Hobbes's justification for it. He appeals to something like a principle of sufficient reason to show

that a resting (or moving) body cannot bring itself out of its state of rest (or motion). As he puts it:

> For suppose that some Finite Body exist, and be at Rest, and that all Space besides be Empty; if now this Body begin to be Moved, it will certainly be Moved some way; Seeing therefore there was nothing in that Body which did not dispose it to Rest, the reason why it is Moved this way is in something out of it; and in like manner, if it had been Moved any other way, the reason of Motion that way had also been in something out of it; but seeing it was supposed that Nothing is out of it, the reason of its Motion one way would be the same with the reason of its Motion every other way; wherefore it would be Moved alike all wayes at once, which is impossible. (*DCo* II.viii.19; *EW* I.115)

The proof of the second half of the persistence principle follows essentially the same line of argument: if a body is in motion and we suppose nothing else to exist, then there is no reason for it to come to rest at one time rather than another, so it would have to come to rest at every point, which is absurd. One might note in passing the methodological similarity between this argument and Hobbes's 'annihilation experiment' which introduces his first philosophy. Both proceed from the assumption of a world lacking anything other than a solitary object whose properties are investigated; then from the examination of a single case he derives principles of unlimited scope.

There is obviously a great deal in this argument that might meet objection from one who does not share Hobbes's assumptions. In particular, an Aristotelian might

conceive of motion as dictated by an internal principle or form, through which a body's potentiality to be at different places is actualized. In such a case, the fact that nothing 'outside' of a moving body could determine it to motion or rest does not imply that there is literally nothing to determine it.[19] Further, it seems just plain crazy to think that such a principle is some sort of conceptual truth following from the very definition of motion. We surely *seem* to have the capacity to imagine worlds in which material bodies spontaneously initiate motion in themselves or grind to a halt with no outside interference. Indeed, Aristotelian physics assumes that (sublunar) bodies can remain in motion only as long as an external force is applied, since their natural state is one of rest. But if Hobbes is right, such things are as unimaginable as round squares or married bachelors.

In point of fact, Hobbes granted that, although we may 'feign in our Mind' that an accident such as motion could be initiated without an external cause, or that 'we may imagine something to arise where before was Nothing, and Nothing to be where there where before was something,' nevertheless 'we cannot comprehend in our Minde how this may possibly be done in Nature' (*DCo* II.viii.20; *EW* I.116). I take Hobbes to be claiming that philosophically untutored common sense is simply mistaken about what is metaphysically possible. We might reason that, because we think we can form an image of a body spontaneously setting itself in motion or coming to rest, such things are at least possible. I suggest, however, that Hobbes would hold that what we imagine in such a case is radically incomplete and in fact not capable of being made coherent. To succeed in fully imagining a body being set in motion one must imagine some cause that necessitates the motion, which in Hobbes's scheme of things means imagining some

body or bodies that collide with it. If we think we can imagine the motion initiating without imagining such an external cause, we are simply mistaken about what we can conceive. This, I take it, is what lies behind Hobbes's declaration that 'Philosophers, who tie themselves to natural reason,' recognize that it is inconceivable that a body should initiate its own motion or spontaneously bring itself to a halt (*DCo* II.viii.20; *EW* I.116).[20]

The second Hobbesian law of motion which I wish to consider is what I call the principle of action by contact. It is intimately connected with the persistence principle, but fills in Hobbes's mechanistic picture of the world by stating that a body can only be set in motion through contact with a contiguous body. Hobbes's statement of the principle and his argument for it appear in section seven of chapter ix of *De Corpore*, which bears the title 'Of Cause'. Hobbes writes:

> There can be no Cause of Motion, except in a Body Contiguous, and Moved. For let there be any two Bodies which are not contiguous, and betwixt which the intermediate Space is empty, or if filled, filled with another body which is at Rest; and let one of the propounded Bodies be supposed to be at Rest, I say it shall always be at Rest. For if it shall be Moved, the Cause of that Motion (by the 8th. Chapter 19th. Article) [i.e., the persistence principle] will be some external body; and therefore if between it and that external Body there be nothing but empty Space, then whatsoever the disposition be of that external Body, or of the Patient it selfe, yet if it be supposed to be now at Rest, we may

> conceive it will continue so til it be touched by some other Body; but seeing Cause (by the Definition) is the Aggregate. Of all such Accidents, which being supposed to be present it cannot be conceived but that the Effect will follow, those Accidents which are either in external Bodies, or in the Patient itself, cannot be the Cause of future Motion; and in like manner, seeing we may conceive, that whatsoever is at Rest, will still be at Rest, though it be touched by some other body, except that other Body be moved, therefore in a contiguous Body which is at rest, there can be no Cause of Motion. Wherefore there is no Cause of Motion in any Body, except it be Contiguous and Moved. (*DCo* II. ix.7; *EW* I.124-5)

The argument here is compressed and needlessly baffling, but the general line of reasoning is clear enough. By the persistence principle, a body at rest cannot initiate its own motion. Furthermore, Hobbes has available his definition of cause as the aggregate of all accidents in the agent and patient such that, having supposed them, the effect must be understood to follow (*DCo* II.ix.3; *EW* I.121). These together imply that any cause of motion in a resting body must lie outside of it and be of such nature that the cause necessitates motion in it. But a body at rest and surrounded by empty space can be understood to remain motionless, so empty space lacks the requisite causal power to initiate motion in a body at rest. If, however, the motionless body is in contact with another motionless body, the collection of motionless bodies can likewise be understood to remain motionless, since an adjacent body at rest has no motion to contribute to the

original motionless body. Thus, a body at rest and surrounded either by a vacuum or other motionless bodies can never initiate motion; which is equivalent to saying that the only cause of motion in a body is a contiguous moving body.

Again, there is much in this reasoning that might draw criticism, and I will not attempt to defend it. At a minimum, Hobbes's procedure begs the central question because he rules out things like action at a distance or a self-moving body as incoherent or conceptually impossible. The upshot is that if Hobbes is right, a violation of the principle of action by contact is not just empirically false but downright unthinkable. Of course, many have proposed physical or metaphysical theories that deny the principle of action by contact -- Cartesian mind-body dualism, or an Aristotelian theories of change and motion come to mind as instances where the principle is denied. Hobbes is evidently committed to the claim that such doctrines are not even worth discussing, since they amount to nothing more than empty words that can convey no real content.

Another interesting feature of Hobbes's treatment of the action by contact principle is that his discussion of it contains a criticism of Descartes' laws of impact. After stating his argument for the action by contact principle, Hobbes continues:

> The same reason may serve to prove, that whatsoever is Moved, will always be Moved on in the same way and with the same Velocity, except it be hindered by some other Contiguous and Moved Body, and consequently that no Bodies either when they are at Rest, or when there is an interposition of *Vacuum*, can generate or extinguish or lessen Motion in other Bodies. There is one that has written, that things Moved are more resisted by things

> at Rest, then by things contrarily Moved, for this reason, that he conceived Motion not to be so contrary to Motion as Rest. That which deceived him was, that the words *Rest* and *Motion* are but contradictory Names; whereas Motion indeed is not resisted by Rest, but by contrary Motion. (*DCo* II.ix.7; *EW* I.125)

The reference here is to Descartes's fourth rule of impact set out in section 49 of part II of his *Principles of Philosophy*. This rule, one of the great embarrassments of Cartesian physics, asserts that a quiescent body cannot be set in motion by impact with a smaller body, irrespective of the relative sizes or velocities of the two bodies. The ultimate source of this error is, as Hobbes noted, the Cartesian principle that 'rest is contrary to motion, and nothing can be led by its own nature to its own destruction'(*Principles* II.37; *AT* VIII.63).[21] Evidently, Hobbes took Descartes to be a philosopher so confused about the nature of motion that he elevated an incoherent principle to the status of a divinely-sanctioned law of impact.

In addition to these two laws of motion, Hobbes introduced the concepts of *conatus* (or 'endeavour' in English)[22] and *impetus* into the foundations of his mechanics. Among other things, these play the basic role of accounting for the transmission of motion from one body to another in collision, as well as figuring in the account of phenomena such as equilibrium. As Hobbes defines it, *conatus* is essentially a point motion, or motion through an indefinitely small space: 'I define ENDEAVOUR *to be Motion made in leß Space and Time then can be given*; that is, *leß then can be determined or aßigned by Exposition or Number*; that is, *Motion made through the length of a Point, and in an Instant or Point of Time*' (*DCo* III.xv.2; *EW* I.206). Impetus is defined as '*the*

Swiftneß or Velocity of the body moved, but considered in the several points of that time in which it is moved; In which sense Impetus is nothing else but the quantity or velocity of Endeavour' (*DCo* III.xv.2; *EW* I.207). Impetus therefore amounts to a measure of the *conatus* exercised by a moving body over the course of time, and it provides a means of comparing the relative forces exerted by moving bodies.[23] The concepts of *conatus* and impetus give Hobbes the means to study simple mechanical concepts such as static equilibrium or laws of impact for inelastic bodies.

Having briefly considered the foundations of Hobbes's mechanics, I would like to return for a moment to the issue of the demarcation between first philosophy and natural philosophy in Hobbes's system. From the account assembled thus far it is evident that Hobbes took mechanics or the doctrine of motion to be an *a priori* science whose truths are both necessary and demonstrable. This much explains why the persistence principle and the action by contact principle are granted the status of conceptual truths whose negations are supposed to be incoherent and literally unimaginable. But there is more to natural philosophy than mechanics, and Hobbes used the term 'physics' for that part of natural philosophy which could not be deductively established from transparently true definitions. This distinction is brought out in the famous declaration in the Epistle to Hobbes's *Six Lessons*:

> Of Arts, some are demonstrable, others indemonstrable; and demonstrable are those the construction of the Subject whereof is in the power of the Artist himself; who in his demonstration does no more but deduce the Consequences of his own operation. The reason whereof is this, that the Science of every Subject is derived

> from a præcognition of the Causes, Generation, and Construction of the same; and consequently where the Causes are known, there is place for Demonstration; but not where the Causes are to seek for. Geometry therefore is demonstrable; for the Lines and Figures from which we reason are drawn and described by our selves; and Civill Philosophy is demonstrable because, we make the Commonwealth our selves. But because of Naturall Bodies we know not the Construction, but seek it from the Effects, there lyes no demonstration of what the Causes be we seek for, but onely of what they may be. (*Six Lessons*, epistle; *EW* VII.193-4)

The result is that natural philosophy must have two parts. One is the doctrine of motion or mechanics, which is at best conceptually distinct from geometry or first philosophy: it is grounded in definitions which express true causes while its conclusions are both necessary and *a priori*. The remainder of natural philosophy (for which Hobbes more or less consistently reserves the term 'physics') will be grounded in hypotheses which express the possible causes of natural phenomena. This undertaking is ineradicably conjectural and it therefore cannot attain the epistemic status of mechanics. As Hobbes expressed the distinction between these two parts of natural philosophy:

> Since one cannot proceed in reasoning from the effects to the causes of natural things produced by motion without a knowledge of those things that follow from every kind of motion; and since one also cannot proceed to the consequences of motions without a knowledge of quantity (which is geometry); nothing can be

> explained by physics without something being demonstrated *a priori*. [24]

Similar remarks can be found at the beginning of part IV of *De Corpore*, when Hobbes announces that his investigation into 'Physiques, or the Phænomena of Nature' must proceed without the 'synthetic' method of demonstration from known causes and undertake an 'analytic' approach in which causes are hypothesized, and the results compared to experience.

Nevertheless, the fundamental properties of motion are known *a priori*, and it is also *a priori* certain that the phenomena of nature are produced by the motion and impact of bodies. Explanations in terms of non-mechanical causes such as substantial forms or other accoutrements of Scholastic natural philosophy can thus be ruled out from the beginning. The result is that the science of motion belongs to first philosophy, and indeed the concept of motion is the fundamental concept in all of philosophy. In contrast, the explanation of specific natural phenomena belongs to physics or natural philosophy, and the detailed development of physics requires the application of the principles taken from first philosophy. This application, however, proceeds hypothetically and therefore lacks the absolute certainty characteristic of geometry and mechanics. The principles of Hobbesian mechanics will, however, encompass a good deal. The geometric or mechanical sections of Hobbes's *De Corpore* include the study of uniformly accelerated motion, collision, centers of gravity, and an analysis of the statics of the beam balance. This much follows from definitions that specify the causes of the phenomena studied, and is certain and necessary. On the other hand, the explanation of such things as 'sense or animal motion,' the freezing of water, or the attractive power of the magnet remain

hypothetical and uncertain. Further, the source of the uncertainty in physics is the fact that the principles on which it depends are 'placed in the things themselves by the Author of Nature' (*DCo* IV.xxv.1; *EW* I.388), and thus cannot be known with certainty by humans, who lack 'makers knowledge' of the material world.

3. Hobbes vs. Wallis on the Science of Mechanics

My account of Hobbes and his science of mechanics can be put in a somewhat different light when we attend to his criticisms of John Wallis's treatise *Mechanica*, a work published in three parts between 1669 and 1671.[25] As part of his long and bitter controversy with Wallis, Hobbes appended a critique of the first part of the *Mechanica* to his 1671 treatise *Rosetum Geometricum*.[26] This polemical piece, which bears the title *Primae partis Doctrinae Wallisianae de motu Censura Brevis*, was Hobbes's attempt to show the superiority of his treatment of mechanics over that of his great antagonist. As such, it has the obvious limitations of a piece produced in the course of a controversy, in that it frequently aims to score cheap rhetorical points without actually offering much in the way of substantive or thoughtful criticism. Nevertheless, there are some interesting and significant theoretical points that emerge in the course of Hobbes's *Censura*, and I will be concerned with them here.

Mechanics as understood in Aristotelian and Scholastic science incorporated the principle that constant application of force is required to keep a body in motion, and it distinguished between natural and violent motions – the former being those dictated by an internal principle of motion or rest and directed toward a body's natural place, while

the latter depart from the ordinary course of nature and arise from an externally applied force. The study of simple machines in this science was undertaken as a means of *intervening* in nature to produce motions that would otherwise be hindered. Mechanics, thus understood, is a way of producing literally unnatural results to serve human purposes. In the course of the seventeenth century, this notion lost its centrality and the term 'mechanics' became synonymous with the theory of motion itself, and indeed all motions eventually came to be seen as equally natural.[27] By the time Wallis published his treatise on mechanics, the very title of the work reflected this change: he called it *Mechanica, sive tractatus geometricus de motu*. In its first definition he declared 'I call *mechanics* the geometry of motion', explaining that he opposed the traditional relegation of mechanics to the 'illiberal' arts as well as the characterization of non-constructive geometric solutions as merely 'mechanical' (*Mechanica* I.i, def. 1; *OM* I.575). Instead, Wallis declared, 'We take *mechanics* in neither of these two senses, but understand it as the part of geometry which considers motion and investigates by means of reasons and demonstrations the force by which any motion is propagated,' (*Mechanica* I.i, def. 1; *OM* I.575). The result of this methodological orientation is that the *Mechanica* takes the form of a treatise in the Euclidean style, with definitions, propositions, and scholia.[28]

Part one of Wallis's *Mechanica* is a very general and foundational treatment dealing with the basic laws of motion, the descent of heavy bodies, and the theory of statics developed through a study of the beam balance.[29] Notwithstanding his antipathy to Wallis and seemingly everything associated with him, Hobbes held that the general method employed in the *Mechanica* was not merely correct, but in fact the only way to develop a true science of motion. And indeed, by casting his treatise in Euclidean form

and beginning with definitions, Wallis followed the Hobbesian model for a proper science. Of course, Hobbes found Wallis's actual implementation of this model deficient in many crucial respects. As he remarked, Wallis 'uses the right method, proceeding from definitions, but these are flawed and some of them cannot be used to demonstrate anything, which is the worst flaw' (*Censura*, p.1; *LW* V.51). Many of Hobbes's criticisms are sufficiently petty and beside the point that they do not merit extended consideration.[30] Nevertheless, Hobbes also raised some substantive objections, and a consideration of them can be of use in understanding his conception of mechanics and its place in his philosophy.

One complaint that Hobbes raised time and again was that his own *De Corpore* had delivered a superior treatment of the subject. He thus argued that, in the odd cases where Wallis's *Mechanica* actually gets something right, the relevant truth had already been revealed in parts II and III of *De Corpore*, and Wallis had either failed to acknowledge the prior (and superior) presentation of it or he might in fact have plagiarized from it. So, for instance, when Wallis defined 'resistance or force of resisting' to be 'a contrary power of motion, or that which resists motion,' (*Mechanica* I.i, def. 7; *OM* I.576), Hobbes remarked

> This is flawed. The powers of an act, that is of motion cannot be contrary, nor can the word 'resist' appear in the definition of 'resistance' in order not to define a thing by itself.
>
> Resistance is where there are two contiguous mobile bodies and the *conatus* of one is contrary to the *conatus* of the other, either in

> whole or in part. This is what [Wallis] intended, for he read this definition in my book *De Corpore* at Chapter 15, article 2. But not wanting to seem to use something of mine, which he had earlier dared to contradict, when he took the pains to change it and make his own definition, he corrupted mine. (*Censura*, p. 3 ; *LW* V.53-54)

This sort of criticism reflects more of Hobbes's disdain for Wallis than any essential difference in their respective approaches to mechanics, but it does highlight the principle (which we saw applied against Descartes) that motion only resists motion. Here, instead of arguing that rest is not contrary to motion, Hobbes uses the principle to claim that a body cannot have two contrary motions and therefore one body can only be resisted by *another* body whose motion is contrary. This is a point to which Hobbes frequently returns, charging that Wallis falsely attributes motion to things at rest and generally fails to give a proper explication of resistance and momentum.[31]

Hobbes's most fundamental differences with Wallis's *Mechanica* can be summarized in two distinct objections. First, that Wallis self-consciously avoided offering a causal explanation of the central phenomena to be studied, and second that he based his mechanics on a mathematical theory that departs in significant ways from the geometric paradigm that Hobbes took to be fundamental to all science.

Wallis made clear his reluctance to consider the causes of mechanical phenomena in the twelfth definition of the first chapter of the *Mechanica*, where he defined gravity as 'a motive force [directed] downward, or toward the center of the Earth.' In explicating this definition he remarked that 'We shall not investigate what the principle of gravitation

might be, considered physically, nor whether it should be called a quality or affection of body, or go by some other name.' After a brief list of various proposals that had been put forth as to the nature of gravity, Wallis remarked 'It is enough that by the name *gravity* we understand that force of moving downward which we perceive by sense, both in the heavy body itself and in the less efficacious obstacles which impede it,' (*Mechanica* I.i, def. 12; *OM* I.576). This sort of approach obviously fails to satisfy Hobbes's criteria for a genuine science of motion, since it refuses to take up the question of what causes gravitation. Hobbes poured scorn on the definition with the remark that 'knowledge [*scientia*] of the causes of gravity or the motion of heavy bodies does not seem to our Savilian professor to contribute anything to the doctrine of weight. It is enough for him that heavy bodies admit of +, –, = : that is greater, less, and equal, so that if the cause of gravity were other than what it is, all the phenomena concerning weight would still appear the same as they now do' (*Censura*, p. 5; *LW* V.55).

Hobbes voiced a similar complaint against the fifteenth definition of part 1, where Wallis defined 'the direction of force or of the moving body' to be 'the right line along which the motive force tends,' (*Mechanica* I.i, def. 15; *OM* I.578). Hobbes objected that 'in applying this to the descent of a heavy body, [Wallis] assumes that heavy bodies are born downward of their own accord [*sua sponte*], that is that they are moved by themselves without an efficient cause, which is both a Scholastic way of speaking, and false' (*Censura*, p. 6; *LW* V.58).

The point of these objections and their connection to Hobbes's first philosophy and methodology should be clear enough: he demands more from a science of mechanics than an accurate description or quantitative treatment of motion, and in fact he requires

that the true causes of mechanical phenomena be set out in the definitions and first principles upon which such a science is founded. By failing to account for motion through its causes, Wallis is led to embrace a theory which is both incomplete (because it fails to specify the causes that bring things about) and absurd (because it erroneously attributes self-motion to bodies). In the specific case of gravitation, Hobbes himself did not think he had sure and certain knowledge of its cause – he treated it hypothetically in the thirtieth (and final) chapter of *De Corpore* as part of physics proper, attributing the descent of heavy bodies to a complex communication of circular motion arising from the diurnal rotation of the earth.[32] But Wallis's refusal even to take up the question of the cause of gravitation was, according to Hobbes, a serious shortcoming in his *Mechanica*.

Hobbes's objections to the mathematics employed in Wallis's *Mechanica* derive from his conception of geometry as the fundamental mathematical science and his denigration of algebraic and analytic methods. In Hobbes's view, the application of algebra to geometry yields no new results, and instead introduces as 'scab of symbols' which clutter the otherwise clear and convincing 'synthetic' demonstrations set out in the style of the ancients.[33] Wallis was an enthusiastic proponent of algebraic techniques, and much of his *Mechanica* is given over to the algebraic statement and solution of physical problems. Hobbes took such an approach as symptomatic of Wallis's atrophied or underdeveloped intellectual powers and declared it 'manifest' that Wallis 'understood absolutely nothing about the nature of motion beyond what is commonly known, but when he transcribed what he had read into symbols, he not only did not demonstrate these things, but through his ignorance of the rule of subtraction in the arithmetic of species, he corrupted them' (*Censura*, p. 25; *LW* V.82).[34] This sort of criticism is connected with

Hobbes's demand for a science of motion that deals with causes. Hobbes took synthetic geometric demonstrations to be proper demonstrations by way of causes, particularly when the foundations of geometry had been re-written in his style, where geometry is a generalized science of body whose first principles express the motions by which geometric objects are generated. Algebraic treatments of motion, such as that offered by Wallis, fail to be truly scientific, first by disregarding the genuine causes of motion and second by employing a mathematics that manipulates symbols without attending to true causes. Hobbes raised another line of objection to the mathematics of Wallis's *Mechanica*, namely that it illegitimately relied upon infinitary considerations by employing the method of indivisibles.[35] Fascinating as this line of inquiry is, I will avoid addressing it specifically, since I think it ultimately reduces to the same basic contention, namely that Wallis's 'analysis by indivisibles' does not proceed from causes.

4. Conclusions

The results of this foray into Hobbes's science of mechanics can be summarized fairly readily. In Hobbes's estimation, 'this saying of Aristotle is true, 'to know is to know through causes' (*Principia et Problemata*, 1; *LW* V.156). Consequently, both first philosophy and natural philosophy are concerned with the investigation of causes. As it happens, motion is the ultimate cause of everything, and to the extent that philosophy is a demonstrative body of knowledge, it must include motion and the laws of motion among its first principles. Small wonder, then, that the persistence principle and the principle of action by contact make their appearance in that part of *De Corpore* entitled 'philosophia

prima'. The Hobbesian science of mechanics is *a priori*, strictly necessary, and turns out to be only conceptually distinct from pure geometry. It is therefore no accident that Hobbes included such mechanical material as center of gravity determinations and a study of the beam balance in the third (or geometric) part of *De Corpore*. The rest of natural philosophy, which consists in the detailed construction of mechanical explanations of natural phenomena, fails to have this level of certainty. It is not demonstrative, but rather hypothetical, although the hypotheses upon which it is based must be mechanical in the sense that they concern only local motion and impact. Hobbes's account of the shortcomings of Wallis's treatment of mechanics highlight his concern with developing a science that proceeds demonstratively from definitions expressing the true causes of things. Wallis was right to think that mechanics is the 'geometry of motion', but (at least according to Hobbes) he used the wrong sort of geometry and forgot to concern himself with the causes of motion. Had Wallis done so, his *Mechanica* would have turned out to be a recapitulation of parts two and three of *De Corpore*. Or so Hobbes would have us believe.

We can close this study by considering the fate of Hobbes's program for a science of mechanics. In stark contrast to the case of his political philosophy, Hobbes's writings on mechanics had essentially no influence on the subsequent development of the subject. This includes instances of the sort of 'hidden influence' detailed by G. A. J. Rogers, in which Hobbes's ideas were either assimilated without explicit acknowledgement or provided a theoretical position against which later thinkers reacted.[36] The failure of Hobbes's program for mechanics is evident in the fact that in his *History of Mechanics* René Dugas made no mention whatever of Hobbes,[37] while Wallis (who seldom passed

up the opportunity to rebuke Hobbes) never once bothered to address the criticisms of his *Mechanica* set out in Hobbes's *Censura*, even as he replied *ad nauseam* to the mathematical criticisms in Hobbes's writings from the same period. In light of Hobbes's status as a respected and active participant in scientific discussions in Paris in the 1640s (where his theories of motion, optics, and other scientific contributions were taken seriously[38]), it may seem odd that his approach to mechanics went essentially nowhere.

The spectacular failure of Hobbes's ambitions in this regard is partially explained by the fact that his scientific reputation has been demolished as a result of his many failed attempts to square the circle and solve other famous geometrical problems. The third part of *De Corpore*, which contains Hobbes's geometry and the foundations of his mechanics, also features several botched attempts to square the circle. These (along with other aspects of Hobbesian mathematics) were the object of Wallis's withering criticism in *Elenchus Geometriæ Hobbianæ*,[39] and in the ensuing exchange of polemics Hobbes saw his once-considerable reputation as a mathematical *savant* thoroughly devastated. The damage done to Hobbes's intellectual standing by these mathematical misadventures is illustrated by Christian Huygens' 1662 remark that Hobbes had 'so diminished his credit with everyone, that almost as soon as they see a new problem propounded by Hobbes, they declare that a new ψευδογράθημα has appeared'.[40]

A fuller explanation for why Hobbes's program for mechanics sparked so little interest can be discerned by considering both the strengths and weaknesses of his approach. Hobbes's assimilation of mechanics to first philosophy has the virtue of taking the principles of mechanics as truths whose absolute necessity guarantees that they will hold regardless of the arrangement or contents of the actual world. There is no need, in

Hobbes's view, to fear that the basic laws of motion and collision might face empirical disconfirmation, since they have the kind of necessity traditionally associated with the principles of pure geometry. Hobbesian mechanics is therefore a *scientia* in the strictest classical sense: a deductively-organized body of knowledge whose first principles identify causes.

Such virtues are, however, offset by serious drawbacks in Hobbes's approach. In the first place, the organization of Hobbes's mechanics (especially in its canonical formulation in *De Corpore*) seems haphazard, with elements developed out of their order of logical dependence and a general structure that is more a random walk through topics in physics than a reasoned exposition of the subject matter.[41] A second and related flaw is that Hobbes offers little in the way of rigorous demonstrations from first principles, notwithstanding his many claims to have pursued precisely that method in his mechanics. As we saw in the case of the 'proofs' for the persistence principle and the principle of action by contact, Hobbes's level of argumentation falls well short of the strict deductions he advertised in his grand programmatic statements. The remainder of his geometry and mechanics rarely achieves a significantly higher level of rigor. Indeed, Hobbes's treatment of motion and its principles in *De Corpore* contrasts unfavorably with that in Wallis's *Mechanica*, where a structure of definitions, axioms, and theorems is matched by a generally high level of rigor in the argumentation (although Wallis's treatment is far from flawless). A third defect in Hobbes's mechanics is the fact that it contains little or nothing new or groundbreaking. Hobbes spent more than a decade putting *De Corpore* in order, and the mechanical material included many topics Hobbes discussed with Parisian *savants* in the 1640s during his self-imposed exile in France. But what had seemed

cutting edge when Mersenne was preparing his *Cogitata* in the early 1640s was rather more stale than novel by the time *De Corpore* was published in 1655.[42] Hobbes's treatment of such topics as static equilibrium or centers of gravity added nothing to the science of mechanics, and Wallis gleefully declared that whatever *De Corpore* might have gotten right in matters of mechanics had been published earlier elsewhere, particularly by Mersenne, and he charged Hobbes with plagiarizing from his French associates.[43]

All of the shortcomings mentioned thus far certainly contributed to the failure of Hobbes's mechanics to exercise a significant influence on the subsequent development of the subject. However, they are all to one degree or another 'cosmetic' problems that could, at least in principle, be remedied by alterations in Hobbes's presentation. A far more serious, and I believe ultimately fatal, problem confronts Hobbesian mechanics, and this is the inability of the concept of motion to do the explanatory work Hobbes requires of it. In his definition, motion is '*the continual relinquishing of one Place, and acquiring of another*' (*DCo* II.viii.10; *EW* I.109).[44] Thus understood, motion involves no more than the transition from place to place, and there is nothing in the definition to account for the fact that a moving body's collision with a resting body of equal magnitude will set the second body in motion. Indeed, Hobbes's scheme does not even permit the introduction of the concept of force, if by the term *force* we understand something like the power to initiate motion. Hobbes does indeed offer definitions of the terms '*conatus*', 'impetus', 'force', and 'resistance', but they all reduce back to the concept of motion: *conatus* is motion through an indefinitely small space, impetus is the quantity or velocity of *conatus*

over time, force is the product of impetus and magnitude of a body, and resistance is a *conatus* of one body directed against that of another (*DCo* II.xv.2; *EW* I.206 – 212).

The point can be brought home by considering Hobbes's objection to Wallis's definition of *gravity* as 'A motive force [directed] downward, or toward the center of the Earth' (*Mechanica* I.i, def. 12; *OM* I.576). Hobbes objects:

> *Gravity* is a quality or accident of a body moved downward; but *motive force* is a quality or accident of a body moving downward. Yet nobody except a schoolboy [*præter Scholarem*] will doubt that the thing moving and the thing moved are different subjects. Both of them, *gravity* as well as *motive force*, are a certain *conatus*, that is the beginning of a motion; but the one is in a body moving, and the other in the body that has moved; and *conatus* is the same thing to motion that a point is to a line (*Censura*, p. 5; *LW* V.55-56).

Thus, the motive force by which a body descends is nothing more than a *conatus* or point motion in the direction of its descent. One could paraphrase this by saying that the force responsible for a body's motion is nothing other than the body's motion itself, so that the explanation of why a body is set in motion is the fact that it moves. The inadequacy of this approach is made all the clearer when we recall Hobbes's dismissal of Scholastic accounts of gravitation in *Leviathan*, where he declared:

> the Schools will tell you out of Aristotle, that the bodies that sink downwards, are *Heavy*; and that this Heavinesse is it that causes them to descend: But if you ask what they mean by *Heavinese*,

> they will define it to bee an endeavour to goe to the center of the Earth: so that the cause why things sink downward, is an Endeavour to be below; which is as much as to say, that bodies descend, or ascend, because they doe (*Leviathan*, ch. 46; *EW* III.678)

It would thus be reasonable to infer that there is something fundamentally mistaken about Hobbes's whole project for a science of mechanics. As Alan Gabbey has put the matter, 'we discover that forces in general have evaporated completely from [Hobbes's] system, leaving only a collection of names defined in terms of each other and, ultimately, in terms of motion and body, the sole explanatory principles admissible in natural (and indeed civil) philosophy;' this leads him to conclude that 'the extremism of just such a mechanistic programme explains in large measure why the Hobbesian approach proved unfruitful for the development of the mechanical sciences' ('Force and Inertia', 233 – 4).

I think Gabbey's analysis is essentially correct, and it highlights a fundamental problem for Hobbes's philosophical system, at least as it is set out in *De Corpore*. Hobbes defines philosophy as an investigation into causes, and he holds that motion is the one universal cause of everything. But he defines motion purely in terms of change of place, without reference to any power or agency through which a body changes its location or by which it might bring about any effect at all. A contrast with the Cartesian system is instructive here. Descartes grounded his laws of motion in the immutability of God's nature; this guarantees that when the deity exercises the power by which He sustains the world, the sum total of motion will remain constant. As a result, bodies in motion or collision will acquire or lose the requisite motion necessary to conserve the

total quantity throughout the world as a whole. In such a system, causal power can be attributed to moving bodies, even if the ultimate ground of such power lies with God's activity. In Hobbes system, however, there is no mention of God (or any other agent) in the formulation and justification of the basic laws of motion. The result is that the foundations of Hobbes's grand mechanical philosophy remain essentially mysterious, for if we ask why a body in motion remains in motion, or why motion should be transmitted from one body to another in collision, we discover nothing that even approaches an answer. Hobbes thought that he could show the persistence principle and the principle of action by contact to be necessary truths on which an entire science of motion could be based. As we have seen, his attempted proofs of these principles encounter serious difficulty, and I think the underlying problem has now been identified: Hobbes's own concept of motion, from which all else is supposed to flow, is bereft of any notion of causal power or agency and consequently incapable of delivering the desired results.

Notes

[1] Earlier versions of this paper were presented at the University of Chicago and the University of Minnesota. My thanks to the audiences for helpful comments and discussion.

[2] Frithiof Brandt, *Thomas Hobbes' Mechanical Conception of Nature* [*Mechanical Conception*] (Copenhagen and London, 1928), p. 379.

[3] In discussing Hobbes I generally use the term 'first philosophy' for what usually goes by the name 'metaphysics'. This is the expression Hobbes preferred, since he regarded metaphysics as an unintelligible exercise in Aristotelian obscurantism. In Hobbes's words: 'There is a certain *Philosophia prima* on which all other Philosophy ought to depend; and consisteth principally, in right limiting of the significations of such Appellations, or Names, as are of all others the most Universall. . . . The Explication (that is, the settling of the meaning) of which, and the like Terms, is commonly in the Schools called *Metaphysiques*; as being a part of the Philosophy of Aristotle, which hath that for title. . . . And indeed that which is there written, is for the most part so far from the possibility of being understood, and so repugnant to naturall Reason, that whosoever thinketh there is anything to bee understood by it, must needs think it supernaturall' (*Leviathan*, ch. 46; *EW* III.672). On first philosophy or metaphysics in Hobbes see Pierre Magnard 'Philosophie première ou métaphysique', in Yves-Charles Zarka and Jean Bernhard (eds.), *Thomas Hobbes: Philosophie première, théorie de la science et politique* (Paris: PUF, 1990), 29-37.

[4] Hobbes, *Six Lessons to the Professors of the Mathematiques, one of Geometry, the other of Astronomy* [*Six Lessons*] (London: 1656), p. 13; *EW* VII.222.

[5] Thus, Hobbes was convinced that his exposition of the elements of philosophy in the first three parts of *De Corpore* included 'nothing (saving the Definitions themselves) which hath not good coherence with the Definitions I have given; that is to say, which is not sufficiently demonstrated to all those that agree with me in the use of Words and Appellations, for whose sake onely I have written the same' (*DCo* IV.xxv.1; *EW* I.388).

[6] In Hobbes's definition: '*A Cause is the Summe or Aggregate of all such Accidents both in the Agents and the Patient, as concurre to the producing of the Effect propounded; all which existing together, it cannot be understood but that the Effect existeth with them; or that it cannot possibly exist if any one of them be absent*' (*DCo* I.vi.10; *EW* I.77).

[7] Hobbes makes essentially the same point at the close of *De Corpore*, when he announces that 'In the first, second, and third Parts [of *De Corpore*], where the Principles of Rationcination consist in our own Understanding, that is to say, in the legitimate use of such Words as we our selves constitute, all the Theoremes (if I be not deceived) are rightly demonstrated. The fourth Part depends upon *Hypotheses*; which unless we know them to be true, it is impossible for us to demonstrate that those Causes which I have there explicated, are the true Causes of the things whose productions I have derived from them' (*DCo* IV.xxx.15; *EW* I.531). On Hobbes and the necessity of hypotheses in physics, see Frank Horstmann, 'Hobbes on Hypotheses in Natural Philosophy', *The Monist* 84 (2001), 487-501.

[8] Hobbes, *Principia et Problemata aliquot Geometrica, Ante Desperata, Nunc breviter Explicata et Demonstrata* [*Principia et Problemata*] (London: 1674), p. 38; *LW* V.206.

[9] The term 'mechanics' (or its Latin equivalent, *mechanica*) underwent a substantial change in meaning during Hobbes's lifetime, as I will discuss in section 3. Hobbes himself rarely used the term, except in his polemical *Censura Brevis* directed against Wallis's treatise *Mechanica*. Nevertheless, it makes sense to see this part of Hobbes's *De Corpore* as his system of mechanics because it contains many principles traditionally associated with the science of mechanics: laws of motion and collision (*DCo* III.viii, III.xv, III.xxii), an analysis of angles of incidence and reflection (*DCo* III.xix, III.xxiv), the determination of centers of gravity (*DCo* III.xxiii), the study of static equilibrium (*DCo* III.xxiii) and an account of accelerated motion (*DCo* III.xvi).

[10] Hobbes's account of sensation as 'nothing else but motion in some of the internal parts of the Sentient' (*DCo* IV.xxv.2; *EW* I.390) appears explicitly only in the fourth part of *De Corpore* as the most likely hypothesis for the phenomenon of sense, but it is clearly assumed in the opening chapters of that work and it could not be contradicted by any supposition at the outset of the treatise. Hobbes's assumption that the solitary thinker is a material being is likewise implicit, but his commitment to a thoroughgoing materialism is evident even in his definition of the subject of philosophy as 'every Body, of whose Generation or Properties we can have any knowledge' (*DCo* I.i.8; *EW* I.10). The result is that the only things about which we can philosophize are bodies, and the hypothesis of the annihilated world cannot suppose the existence of immaterial minds or souls. On the

methodological role of Hobbes's argument from the 'annihilated world' see Michel Malherbe, 'Hobbes et la fondation de la philosophie première', in Michel Malherbe and Martin Bertman (eds.) *Thomas Hobbes: de la métaphysique à la politique* (Paris: 1989), 17 – 32.

[11] This point has also been made by Yves-Charles Zarka, 'First philosophy and the foundation of knowledge', in Tom Sorell (ed.), *The Cambridge Companion to Hobbes*, (Cambridge and New York: Cambridge University Press, 1996), 62-85, at 65-7.

[12] 'all philosophers distinguish a subject from its faculties and acts, that is, from its properties and essences; for an entity is one thing, and its essence is another. Hence it may be that the thinking thing is the subject of mind, reason, or intellect, and this subject may be something corporeal. The contrary is assumed, not proved' (*AT* VII.172).

[13]On Newton's conception of laws of motion and force, see I. Bernard Cohen, 'A Guide to Newton's *Principia*', in Sir Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I. Bernard Cohen and Anne Whitman, assisted by Julia Budenz (Berkeley, Los Angeles, and London: University of California Press, 1999), 1-370, at ch. 5; Alan Gabbey, 'Force and Inertia in the Seventeenth Century: Descartes and Newton' ['Force and Inertia'], in Stephen Gaukroger (ed.), *Descartes: Philosophy, Mathematics and Physics* (Sussex: 1980), 230 – 320; and Richard S. Westfall, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century* (London and New York: 1971).

[14] As he puts it: 'From what has been said, those Axiomes may be demonstrated which are assumed by *Euclide* in the beginning of his first Element about the Equality and Inequality of Magnitudes; of which (omitting the rest) I will here demonstrate onely this one, *the Whole is greater then any Part thereof*; to the end that the Reader may know that those Axioms are not indemonstrabele, & therefore not Principles of Demonstration; and from hence learn to be wary how he admits any thing for a Principle, which is not at least as evident as these are. *Greater* is defined to be that, whose Part is Equal to the Whole of another. Now if we suppose any Whole to be A, and a Part of it to be B; seeing the Whole B is Equal to itself, and the same B is a Part of A; therefore a Part of A will be Equal to the Whole B. Wherefore by the Definition above, A is Greater then B, which was to be proved' (*DCo* II.viii.25; *EW* I.119).

[15] This tendency is particularly evident in Hobbes's writings on mathematical methodology. For instance, he speaks of axioms as 'known by the natural light and not found out by teachers of arithmetic, but grasped by boys with the understanding of the words themselves', Hobbes *Examinatio et Emendatio Mathematicæ Hodiernæ* (London: 1660), p. 61; *LW* IV.95. Faulty or absurd principles are characterized as 'most horribly flawed and contrary to the immediate light of nature', Hobbes, *Lux Mathematica* (London, 1672), p. 38; *LW* V.148.

[16] Brandt (*Mechanical Conception*, p. 227) makes this point in the context of distinguishing between what he terms 'rationalist' and 'sensualist' elements in Hobbes's philosophy, concluding that '*Hobbes was a rationalist in so far as he clearly saw that*

there is a kind of knowledge, purely deductive, which arrives at new knowledge syllogisticaly by mans of concepts and propositions . . . . Hobbes therefore acknowledges a province of knowledge which is distinct from mere empirical knowledge by its absolute, formal certainty, and this province of knowledge is science. But, on the other hand, he must be called a sensualist in so far as he is of opinion that ultimately it is perception that furnishes us with the material for knowledge, also the material for scientific knowledge.'

[17] It is worth mentioning that the term 'inertia' meant something quite different at the time than it came to mean after Newton. In Hobbes's day, inertia was conceived of as the tendency of a body to come to rest, which is rather far from the import of Hobbes's persistence principle. My terminology is close to that used by Daniel Garber, *Descartes' Metaphysical Physics* [*Descartes' Physics*] (Chicago: University of Chicago Press, 1992), who terms Descartes' version of the law the 'principle of persistence'.

[18] The 1656 English version differs from the 1655 Latin original here, which asserts only that 'Whatever is at rest is understood always to be at rest, unless there is some other body outside of it, by whose action it is supposed that it can no longer remain at rest. . . . Similarly, whatever is moved is understood always to move, unless there is something outside of it because of which it comes to rest' (*DCo* II.viii.19; *LW* I.102 - 3). The alteration in the English version helps clarify the first part of the persistence principle by adding that a body at rest can be brought into motion only by being pushed by another body, rather than the vague and indeterminate language of the Latin original, which states only that some external body must be supposed to bring a resting body out of its state of

rest. This modification foreshadows the principle of action by contact, which I will consider shortly. More interesting is the fact that Hobbes's language in the 1656 English version goes beyond what his definition of motion permits. Motion as defined by Hobbes is simply change of location, but he finds himself needing to speak of a moving body exercising power by 'endeavouring' to occupy the place of a second body so that it 'suffers it no longer to remain at Rest.' Whether Hobbes's system can accommodate this sort of language is a matter I will take up in the concluding section.

[19] Seth Ward, in his long and detailed polemic against the Hobbesian philosophy, raised precisely this point: 'What an assertion! Let us see the argument. "If a body is at rest", (he says) "the cause of motion" (or, if it moves, the cause of its resting) "is outside of it, but it was supposed that there was nothing outside of it." That is, because no body is supposed, then nothing is supposed, which fits so well with his principles. But we can say that there is nothing supposed outside of the body (for indeed we have learned from Hobbes himself to say this), and yet God could either set it in motion and determine its direction, or destroy it absolutely; nor would anyone judge our words to be empty' Ward, *In Thomæ Hobii Philospohiam Exercitatio Epistolica* (Oxford: 1656), p. 81.

[20] For a fuller account of Hobbes's treatment of explanation and understanding, see Ioli Patellis, 'Hobbes on Explanation and Understanding', *Journal of the History of Ideas* 62 (2001), 445-462.

[21] On Descartes and the laws of impact see Gabbey 'Force and Inertia', 245-272; Garber *Descartes Physics,* Chapter 8; and Stephen Gaukroger , *Descartes' System of Natural*

Philosophy (Cambridge: Cambridge University Press, 2002), 125-30. Descartes' principle that motion is fundamentally opposed to rest is contradicted by Hobbes at *DCo* III.xv.3: 'it is therefore manifest, that Rest does nothing at all, nor is it of any efficacy; and that nothing but Motion gives Motion to such things as be at Rest, and takes it from things moved' (*EW* I.213).

[22] The term *conatus* derives fro the Latin verb *conor*, meaning to strive or attempt. Hobbes's English equivalent is the term 'endeavour,' but (except when directly quoting Hobbes's English) I will retain the Latin term, since it has gained wide currency in the secondary literature. For studies of this doctrine see Jeffrey Barnouw, 'Le vocabulaire du *conatus*', in Yves-Charles Zarka (ed.), *Hobbes et son vocabulaire: études de lexicographie philosophique* (Paris: Vrin, 1992), 103 - 124; Martin Bertman, 'Conatus in Hobbes's *De Corpore*', *Hobbes Studies* 14 (2001), 25-39; Brandt, *Mechanical Conception*, chap. 9; and Kurd Lasswitz, *Die Geschichte der Atomistik von Mittlealter bis Newton*, 2 vols. (Hamburg: 1890) 2.214-24. Howard R Bernstein, 'Conatus, Hobbes, and the Young Leibniz', *Studies in History and Philosophy of Science* 11(1980), 167-81 studies Hobbes's conception of *conatus* in connection with Leibniz's early doctrines of motion.

[23] So, for instance, having defined resistance in terms of the *conatus* of one body contrary to the *conatus* of one that comes in contact with it, Hobbes defines 'FORCE *to be the* Impetus *or Quickneß of Motion multiplyed either into it self, or into the Magnitude of the*

Movent, by means whereof the said Movent works more or leß upon the other body that resists it' (*DCo* III.xv.2; *EW* I.212).

[24] Hobbes, *Elementorum Philosophiae Sectio Secunda De Homine* (London: 1656), chapter 10, section 5, p. 60; *LW* II.93.

[25] The work in question is Wallis, *Mechanica, sive, De motu, tractatus geometricus* [*Mechanica*], 3 parts (London: 1699 - 71). I use the version in Wallis, *Johannis Wallis S.T.D. . . Opera Mathematica* [*OM*], 3 vols (Oxford:1693 - 99). References are to part, chapter, and definition or proposition number, with a volume and page citation to *OM*.

[26] On the nasty, brutish, and long mathematical controversy between Hobbes and Wallis see Douglas Jesseph, *Squaring the Circle: The War Between Hobbes and Wallis*. [*Squaring the Circle*] (Chicago: University of Chicago Press, 1999). Hobbes's *Primæ Partis DoctrinæWallisianæ De Motu Censura Brevis* [*Censura*] (London: 1671) is his critique of Wallis's *Mechanica* and was published as a separately paginated appendix to Hobbes, *Rosetum Geometricum* (London: 1671).

[27] On the development of the understanding of mechanics in the seventeenth century see Alan Gabbey, 'The case of mechanics: One revolution or many?', in David C. Lindberg and Robert S. Westman (eds.), *Reappraisals of the Scientific Revolution* (Cambridge: Cambridge University Press, 1990), 493-528; and Alan Gabbey, 'Mechanics', in J.L. Heilbron (ed.), *The Oxford Companion to the History of Modern Science* (Oxford: Oxford University Press, 2003), 502-505. See Daniel Garber, 'Descartes, Mechanics,

and the Mechanical Philosophy', *Midwest Studies in Philosophy* 26 (2002), 185-204, for an account of the issues in the context of Cartesian mechanics.

[28] One point worth mentioning here is that Wallis has no specifically mechanical axioms; instead he uses definitions and then develops the material by applying geometry to the definitions.

[29] The three chapters of part one bear the titles 'De Motu Generalia,' 'De Gravium Descensu, et Motuum Declivitate,' and 'De Libra.'

[30] For instance, when to Wallis's definition of the term *momentum* as 'that which conduces to the production of motion,' Hobbes retorted 'and so, a hand, a lever, a bow, and any instrument which we use to move something is a momentum' (*Mechanica* I.i, def. 3; *OM* I.576; *Censura*, p. 2; *LW* V.52).

[31] To take instance among several, Hobbes objects to proposition 10 of the first chapter in part I of Wallis's *Mechanica*, which analyzes the case where the joint effect of a momentum (i.e., that which conduces to the generation of motion) and an impediment (that which impedes or opposes motion) is determined. The proposition reads 'Where momentum and impediment are conjoined, if the momentum is more powerful [*præpollet*], they are to be taken together as a momentum; but if the impediment is more powerful, they are to be taken together as an impediment; and in both cases in the amount of the excess of the more powerful over the less; but if they are of equal strength, they are to be taken together as neither momentum or impediment. And if many momenta or impediments are conjoined: the total momentum or impediment is to be taken as the sum

of all of them' (*Mechanica* I.i, prop. 10; *OM* I.585). Hobbes retorts that 'He takes the demonstration from the fact that momentum and impediment are contraries: the one bringing motion about, the other destroying it [*causa ut sit, causa ut non sit*]. But this is false. Two motions coming together from different termini of the same right line are contraries: for motion and rest are not opposed contrarily, but rather privatively [*Motus & Quies non opponuntur contrariè, sed privativè*]' (*Censura*,p. 18; *LW* V.72).

[32] Hobbes's account of gravitation in *DCo* IV.xxx is complex enough to deserve separate treatment and cannot be investigated in detail here. It proceeds from the assumption that the world is a plenum. Thus, if a body (a stone, say) is thrown upwards the spaces successively vacated by the stone will be successively filled by displaced air. Hobbes then supposes 'Seeing aire is by the diurnal revolution of the Earth more easily thrust away, then the Stone, the aire which is in the Orbe that contains the Stone will be forced further upwards then the Stone. But this, without the admission of *Vacuum*, cannot be, unless so much aire descend ... from the place next above; which being done, the Stone will be thrust downwards. By this means therefore the Stone now receives the beginning of its Descent, that is to say, of its Gravity. Furthermore, whatsoever is once moved, will be moved continually (as hath been shewn in the 19th Article of the 8th Chapter [i.e. the persistence principle]) in the same way, and with the same celerity, except it be retarded or accelerated by some external Movent. Now the aire (which is the onely Body that is interposed between the Earth A and the stone above it E) will have the same action in every point of the straight line EA, which it hath in E. But it depressed the stone in E;

and therefore also it will depress it equally in every point of the straight line EA. Wherefore the stone will descend from E to A with accelerated motion. The possible cause therefore of the Descent of Heavy Bodies under the Æquator, is the Diurnal motion of the Earth.' (*DCo* IV.xxx.4; *EW* I.512-3). The difficulties facing this account are obviously huge, not the least being its implication that gravitational acceleration will vary with longitude, due to the differential rotational velocity of the parts of the Earth.

[33] Hobbes dismissed Wallis's *De Sectionibus Conicis Tractatus* (Oxford, 1655)as 'so covered over with the scab of Symboles, that I had not the patience to examine whether it be well or ill demonstrated' (*Six Lessons*, p. 49; *EW* VII.316). On Hobbes's rejection of analytic geometry, see Jesseph, *Squaring the Circle*, chapter 5.

[34] The 'arithmetic of species' is Hobbes's term for algebra, with the idea that algebra is concerned with arithmetical operations on variables which represent kinds or species of magnitude. His complaint that Wallis is ignorant of the proper rule for subtracting species reprises his objection to proposition 8 of the first chapter of part I of *Mechanica*:. Wallis proposed that 'The aggregate of contrary magnitudes [*contrarium*], insofar as they are contraries, is equal to the excess of the greater; but the aggregate of magnitudes of the same sign [*congruentium*] is their sum' (*Mechanica* I.i, prop. 8; *OM* I.584). Hobbes objects that the difference, for instance, between the magnitudes A and –A is equal to 2A, while their aggregate is 0. The basis of Hobbes's objection is the ambiguity of the Latin term *aggregatum contrarium*, which could be taken to mean the arithmetical sum, but could also refer to the sum of their absolute values. That is, Wallis interprets the

aggregate of A and –3A as –2A, where Hobbes points out that they differ by a total of 4A, and the aggregate could be taken as |A| +|-3A| (*Censura*, p. 16; *LW* V. 70).

[35] In essence, Hobbes argues that Wallis's use of infinitesimal magnitudes is unrigorous because it falsely assumes that a continuous magnitude can be composed of an infinity of infinitesimal parts. His criticisms are contained in the 'Postscript' to the *Censura* (*Censura*, pp. 26-29; *LW* V. 84-88).

[36] See G. A. J. Rogers, 'Hobbes's Hidden Influence', in G. A. J. Rogers and Alan Ryan (eds.), *Perspectives on Thomas Hobbes* (Oxford: Oxford University Press, 1988), 189 – 205.

[37] See René, Dugas, *A History of Mechanics*, trans. J. R. Maddox (Neuchâtel, Switzerland, 1955; reprint New York, 1988).

[38] For an account of Hobbes's scientific reputation on the European continent see Noel Malcolm, 'Hobbes and the European Republic of Letters' ['Republic of Letters'], in Malcolm, *Aspects of Hobbes* (Oxford: Oxford University Press, 2002), 457 – 545. Some measure of the standing accorded Hobbes's scientific works by French *savants* can be taken from the fact that Marin Mersenne included extracts from Hobbes's writings in the preface to his *Ballistica* , which appeared as part of his *Cogitata Physico-mathematica* [*Cogitata*] (Paris: 1644).

[39] Wallis, *Elenchus Geometriæ Hobbianæ* [*Elenchus*] (Oxford, 1656).

[40] Christian Huygens to Sir Robert Moray for Hobbes, 10/20 December, 1622, in Noel Malcolm (ed.), *The Correspondence of Thomas Hobbes*, 2 vols. (Oxford: Oxford University Press, 1994) 2.537.

[41] To take a few salient examples, the treatment of accelerated motion in *De Corpore* (taken almost straight out of Galileo's *Two New Sciences*) appears in the third, or geometric, part at chapter xvi, while the account of gravitation is postponed to the fourth part, in chapter xxx. The equality of angles of incidence and reflection is assumed in chapter xix and used to derive results concerning bodies in collision, but is not proved until chapter xxiv. The persistence principle and the principle of action by contact are stated and justified in chapters viii and ix, then reprised in the account of *conatus* and collision in chapter xv, where they appear with other principles. The scattershot nature of Hobbes's physics is apparent in the title of chapter xxviii: 'Of Cold, Wind, Hard, Ice, Restitution of Bodies bent, Diaphanous, Lightning and Thunder, and of the Heads of Rivers.'

[42] As Malcolm puts the matter: 'The world-view [*De Corpore*] presented, which might have seemed adventurous and challenging had it appeared in the 1640s, was much less novel in the mid-1650s' ('Republic of Letters', p. 498).

[43] In his *Elenchus* (pp. 132 - 34) Wallis assembled a catalog of results from *De Corpore* which he claimed could be found in the writings of Mersenne, and particularly in the *Tractatus Mechanicus, Theoricus et Practitucs* which appeared as part of the *Cogitata*.

[44] Essentially the same definition appears in *Leviathan*: 'Motion is change of Place.' (*Leviathan*, ch. 46; *EW* III.676).