Oxford Handbooks Online

Newton on Body

Katherine Brading

The Oxford Handbook of Newton
Edited by Eric Schliesser and Chris Smeenk

Subject: Philosophy, Philosophy of Science, History of Western Philosophy (Post-Classical)
Online Publication Date: Jun 2018 DOI: 10.1093/oxfordhb/9780199930418.013.10

Abstract and Keywords

This article argues for Newton's concept of body as a powerful tool of analysis in examining his natural philosophy, including his matter theory, metaphysics, epistemology, and methodology. Newton certainly had views on matter theory, but the methodology he developed transformed the relationship between matter theory and the theory of bodies, enabling him to arrive at results concerning bodies while remaining largely silent about matter theory. Topics covered include the mathematical and physical treatment of bodies; condensation and rarefaction; cohesion; the law-constitutive approach to bodies; and the qualities of bodies. The article shows that the bodies of our experience are Newton's primary explanatory target, connecting his views on such quintessential Newtonian topics as atomism, inertia, force, gravity, space, and motion.

Keywords: Newton, natural philosophy, concept of body, matter theory, atomism, law-constitutive, condensation and rarefaction, cohesion, qualities of bodies

Introduction

Newton's earliest philosophical writings, recorded in the so-called Trinity Notebook, include a section entitled "Questiones quaedam Philosophicae" (published as *Certain Philosophical Questions* by McGuire and Tamny, 1983). This section opens with the topic "Of the first matter" and the question "Whether it be mathematical points, or mathematical points and parts, or a simple entity before division indistinct, or individuals, i.e., atoms."[1] Newton rejects the first option on the grounds that "what wants dimensions cannot constitute a *body* in their conjunction." He goes on: "An infinite number of mathematical points sink into one, being added together, and that being still a mathematical point, is indivisible. But a *body* is divisible."

In posing this question, Newton follows Charleton.[2] From his selection of this question as his starting point, and from the manner in which he responds, we get an early indication of themes that will be important in his later thinking. First, and most importantly, bodies are the target of explanation. More specifically, it is bodies (count noun), not generic "body" (mass noun), that is the target. As a consequence, a matter theory that cannot account for bodies is not acceptable, and what is known about bodies independently of matter theory acts as a constraint on matter theory. Second, bodies have dimensions, that is, they are extended, and bodies are divisible. In the passage quoted in the previous paragraph, these characteristics of bodies (as being extended and divisible) are asserted without argument. As we shall see, this pre-theoretical status of extension and divisibility comes under pressure in the *Principia*.

Discussions of Newton's matter theory have focused primarily on his atomism, his ether theories, and his appeal to forces of attraction and repulsion associated with "ultimate" particles (Hall and Hall, 1960). Since such "ultimate" particles are those out of which bodies are made, a theory of matter (or of "body," mass noun) may seem to be a prerequisite for a theory of bodies. By taking "bodies" as my primary tool of analysis, I reverse this priority, and in so doing reflect an important epistemological and methodological shift wrought by Newton himself, wherein our theory of bodies in motion may be pursued in the absence of a detailed matter theory, and indeed may act as a constraint on matter theory.

Newton's criticisms of Descartes's account of body in the manuscript "De Gravitatione" (Newton, 2004), written prior to the *Principia*, offer an early example of this reversal. In this text, Newton criticizes Descartes's definitions of body and motion as being inadequate for the purposes of explaining observable phenomena in terms of matter in local motion, moving according to laws, which is the project that Descartes set up in Part II of his *Principles of Philosophy*. The laws of nature, which govern the motion and collision of bodies, play a central role in this explanatory project. The subject of Descartes's laws of nature is bodies and, therefore, in order for the project to be viable, matter must be such that there can be bodies that are (at the very least) capable of motion. Newton argues that Cartesian matter theory, which identifies matter with extension, fails to meet this condition and must therefore be rejected on pain of conceptual incoherence (see Newton, 2004, 19–21). Famously, Descartes's conclusion concerning the nature of matter is secured via his criterion of clear and distinct ideas, and is unrevisable in the light of anything discovered in the course of carrying out his explanatory project. Newton, by contrast, explicity states in "De Gravitatione" that he has no such clear and distinct idea of the nature of body. Rejecting Descartes's rationalist epistemology, he asserts that our epistemic access to bodies is through our senses, and that our knowledge of bodies is fallible. According to Newton, bodies must be not merely extended but also mobile, impenetrable, and sensible, and must move around according to certain laws; matter, whatever its nature may be, must be capable of supplying such bodies.

In what follows, I argue for "bodies" as the target of explanation as an ongoing theme in Newton's epistemology, and for the reversal in priority of bodies over matter theory as an important element of Newton's methodology. Though he had views on matter theory, the methodology he developed enabled him to develop results concerning bodies while remaining largely silent on matter theory.

Through attention to "bodies" we can explore Newton's physics, metaphysics, epistemology, and methodology. His concepts of mass, inertia, force, gravity, and space are intimately tied to body, and bodies are the subject of his laws of motion. His early writings show his engagement with contemporary issues of matter theory in relation to bodies, including not just atomism but also condensation and rarefaction, the cohesion of bodies, the relations between parts and wholes, the qualities of bodies, and the physical processes by which these qualities can be varied. This last topic takes us into his alchemical work via his matter theory. By the time of the *Principia*, Newton offered a sophisticated methodology for the investigation of bodies, one that is intimately bound up with his approach to the metaphysical and epistemic status of bodies and their properties, and one that includes his highly important distinction between a mathematical and a physical treatment of bodies. Finally, in the Queries to the *Opticks* we find, among other things, connections between body (the subject of the *Principia*) and light (the subject of Newton's second great published work in natural philosophy, the *Opticks*). To study Newton on bodies, then, is to reach broadly and deeply into Newton's philosophy. Despite this, discussion of Newton on bodies most often takes place within the context of investigating some other Newtonian concept, such as mass, inertia, gravity, absolute space, and so forth, rather than as the primary concept of interest. As a result, a unified treatment of Newton on bodies is hard to find. Newton's views evolved over the course of his life, and in what follows I begin at the beginning, focusing primarily on his earlier writings. Though incomplete in its coverage, this paper is a contribution toward giving "body" greater visibility as an appropriate topic of Newton scholarship in its own right.

Bodies Treated Mathematically

A crucial aspect of Newton's methodology is his distinction between mathematical and physical treatments of bodies.[3] The first two books of the *Principia* offer a mathematical treatment of bodies, and the draft definitions of body for the third edition make explicit the distinction between mathematical and physical treatments. It would be a mistake to think that because certain qualities of bodies are given a mathematical treatment they are therefore not physical. Rather, the mathematical treatment of physical qualities affords a number of philosophical advantages, including enabling Newton to bypass certain aspects of matter theory in developing his theory of bodies, as we shall see.

From very early on, Newton treats the motions of bodies mathematically, using geometry,[4] and in "De Gravitatione" both the mathematical and the physical treatments of bodies are present. Indeed, "De Gravitatione" begins with the following remark (Newton, 2004, 12):

> It is fitting to treat the science of weight and of the equilibrium of fluids and solids in fluids by a twofold method. To the extent that it appertains to the mathematical sciences, it is reasonable that I largely abstract it from physical considerations.

Then, when introducing his discussion of body, Newton offers the following explanation and qualification (Newton, 2004, 13):

> Moreover, since body is here proposed for investigation not in so far as it is a physical substance endowed with sensible qualities, but only in so far as it is extended, mobile, and impenetrable, I have not defined it in a philosophical manner, but abstracting the sensible qualities … I have postulated only the properties required for local motion. So that instead of physical bodies you may understand abstract figures in the same way that they are considered by geometers when they assign motion to them, as is done in Euclid's *Elements* …

Thus, according to "De Gravitatione," the properties of body that are necessary and sufficient in order to get the project of treating bodies in local motion off the ground are the "mathematical" properties of extension, mobility, and impenetrability.

The next step in building a corpuscularian philosophy is (following Descartes's *Principles of Philosophy*) to provide rules for the motions of bodies such that the problem of collisions can be solved. For this, Newton added a property of hardness to bodies. In the so-called *Waste Book*, on a folio dated "Jan. 20th 1664" (see Herivel, 1965, 133), Newton opens his discussion as follows:

> Suppose that the bodys a,b, have noe *vis elastica* to reflect from one another but at theire occursion conjoine and keepe together as if they were one body. Then first if Theire bulke and motion be equall then at theire meeting they shall rest.

His starting point here is a perfectly hard body. Shortly thereafter, he considers bodies that rebound on collision by means of "some springing motion in themselves or in the matter crouded betwixt them" (Herivel, 1965, 138). These are elastic collisions, and in the next folio Newton considers the case of *perfectly* elastic collisions (see 142), in which the bodies in question are compressed and then rebound so that no motion is lost. Hardness is of course a physical quality of bodies, and it is introduced here in order that a mathematical treatment of bodies can proceed toward its goal of solving the problem of collisions. The qualities of extension, impenetrability, and mobility were introduced in order to ensure conceptual coherence for Descartes's project with respect to the definitions of motion and body. Hardness is introduced to ensure that the treatment of collisions, necessary for the next step of the project, can proceed. We return to the status of hardness as a quality of bodies later, in the section "Universal Qualities of Bodies". My point here is that hardness is introduced as that *physical* quality necessary for the *mathematical* treatment of collisions to proceed; no further account of hardness as a physical quality, in terms of matter theory, is given or required.[5]

The mathematical treatment of bodies enables Newton to bypass certain details of matter theory in other ways, too. Newton stresses in "De Gravitatione" that in order to proceed with our mathematical treatment of bodies we must make simplifications and idealizations, such as working with bodies of uniform density and that are either "perfectly fluid" or "perfectly hard."[6] He writes (Newton, 2004, 38–39):

> In these definitions, however, I refer only to absolutely hard or fluid bodies, for one cannot reason mathematically concerning bodies that are partially so, on account of the innumerable figures, motions, and connections of the least particles.

In order to treat fluid bodies mathematically, such bodies must be treated as if made not of hard particles but rather of "no small portion or particle which is not likewise fluid" (Newton, 2004, 38), and though the parts are not in motion among themselves they are really divided from one another so that they are easily capable of relative motion. Similarly, we must treat a hard body such that (39):

> the parts of hard bodies do not merely touch each other and remain at relative rest, but that they also so strongly and firmly cohere, and are so bound together—as it were by glue—that no one of them can be moved without all the rest being drawn along with it; or rather that a hard body is not made up of conglomerate parts, but is a single undivided and uniform body which preserves its shape most resolutely, whereas a fluid body is uniformly divided at all points….

And thus I have accommodated these definitions not to physical things but to mathematical reasoning, after the manner of the geometers …

Thus, bodies are to be treated mathematically as uniform and without parts. This is an important move, because it enables Newton to bypass certain details of matter theory in investigating bodies: we do not need an account of the constituents of a body, nor of the means by which the constituents cohere, in order to proceed with our investigation. This feature of Newton's methodology is present not only in the early writings that we have been considering here, but also in both the *Principia* and the *Opticks*. The move has another important advantage. In light of Newton's epistemology, according to which we must begin from the bodies to which we have access through our senses, the move enables Newton to bring to bear his mathematical treatment on (at least some of) the *very same bodies* to which we have empirical access: the medium-sized objects of our experience. We return to this issue in the following section.

From Bodies to Matter Theory

The problem of varying density (i.e., of condensation and rarefaction) is a key test issue for any matter theory, and Newton discusses it in his earliest writings (McGuire and Tamny, 1983, 359). Under the heading "Of Rarity and Density. Rarefaction and Condensation," Newton begins with an observation concerning cork (that it can be greatly compressed and yet continue to float), and sets up the following task: "Given two bodies to find which is more dense." He describes an experimental setup in which he proposes using a spring to compare the motions of bodies and thereby the "quantity of body," on the assumption that the same "swiftness" of the bodies means the same quantity of body. Thus, the means of investigation that he suggests is empirical: he proposes a connection between "quantity of body" and motion as a means of measuring "quantity of body."[7]

The problem of varying density, discussed in matter theory under the problem of condensation and rarefaction, provides an example of the way in which Newton's methodology allows him first to pursue an account of bodies and then to use this in investigating matter theory. Newton initially treats bodies as having uniform density, bypassing questions concerning how different densities are to be accounted for in terms of matter theory. This allows Newton to investigate the very same set of bodies using both theory and experience, in experiments such as that with the cork: the physical cork is treated mathematically (see the section "Bodies Treated Mathematically") and is the subject of empirical enquiry (in Newton's experiments). This dual treatment allows Newton to use the motion of a body to measure the quantity of matter present in that body, thereby providing quantitative empirical access to density. This in turn may yield a route into the empirical investigation of condensation and rarefaction, and thereby into questions concerning matter theory.

Prior to Newton, the problem of condensation and rarefaction was of primary importance to exploring the nature of bodies, because the particular solution depended on the details of the associated matter theory (such as atomism), which in turn has implications for the account of body. Solving the problem of how varying density is possible is therefore prior to the account of bodies. After Newton, the problem of condensation and rarefaction can be avoided in the initial pursuit of a theory of bodies, and indeed a theory of the motions of bodies can be used as a tool for *investigating* the variation of density in bodies and thereby how condensation and rarefaction are possible.

Epistemology of Bodies

In “De Gravitatione,” Newton offers a tentative account of bodies in terms of their qualities. His goal is to offer an account such that the resulting bodies would be (at the very least) “similar in every way to bodies,” and especially in the way in which they “display all their actions and exhibit their phenomena” (Newton, 2004, 27). That is to say, we are being offered an account intended to recover the bodies of our experience. According to Newton, our epistemic access to bodies is through our senses, and if we are to have an account of the nature of bodies, then bodies must therefore be sensible.

While our senses are our epistemic route to the nature of bodies, appearances are not a straightforward source of knowledge according to Newton, and so our methodology must be chosen accordingly. Newton says (McGuire and Tamny 1983, 377):

> The nature of things is more securely and naturally deduced from their operations one upon another than upon our senses. And when by the former experiments we have found the nature of bodies, by the latter we may more clearly find the nature of our senses.

We are to begin by investigating the actions of bodies on one another. He is explicit that the reason for adopting the proposed methodology is epistemological:

> But so long as we are ignorant of the nature of both soul and body we cannot clearly distinguish how far an act of sensation proceeds from the soul and how far from the body.

Learning about the nature of bodies therefore requires us to separate the appearances of bodies from the qualities of bodies, and so Newton needs a primary/secondary quality distinction. However, Newton rejects an epistemic version of the primary/secondary quality distinction as a guide to ontology, because we do not know (and cannot tell by introspection) the relationship between the qualities of bodies and the appearances. Uncovering what role the mind and body each play in the resulting appearances is simply too hard to make this an appropriate place to start.[8]

Newton’s approach is in contrast to many of his contemporaries for whom the distinction between manifest and occult is the first step toward a primary/secondary quality distinction. First, the Aristotelian manifest qualities are rejected in favor of a new set that is nevertheless common to all bodies of our experience: shape, size, and motion. These become the primary qualities of the mechanical philosophy, this result being justified by appeal to either experience or reason. With the primary qualities thereby established and put on sound epistemic footing, one strategy for dealing with occult qualities associated with macro-sized objects was to reduce them to “unproblematic” primary qualities of the micro-constituents. For example, one might attempt to explain magnetism via the particular shapes, sizes, and motions of the micro-particles constituting and surrounding magnetic bodies. For Newton, in contrast, it is an open empirical question whether any such reduction can be achieved. For example, although we cannot directly sense the magnetic quality of a body—our access is indirect via the motions of such bodies—this epistemic point implies nothing about the ontological status of magnetism and whether or not it is reducible to other qualities. Only careful investigation of the actions of bodies on one another can reveal which qualities are primary qualities.

As noted at the beginning of this section, the bodies of experience are the target of explanation. In common with many of the “new philosophers” of the period, Newton favored a corpuscularian approach to matter theory, and faced the problems of how to identify the qualities of corpuscles and how to recover the bodies of our experience from collections of such corpuscles. Newton’s experimental and mathematical approach to natural philosophy is a means of ascertaining the primary qualities of bodies, mobilizing in a single methodology both our sensible experience of bodies and our reasoning about bodies.

Cohesion

Corpuscularians, be they atomists or plenists, begin from tiny corpuscles as the primary elements of their ontology, and attempt to build from there to an account of the larger bodies of our sensible experience. The problem of cohesion of bodies is therefore central to any matter theory that aspires to explanations of the properties and behaviors of the bodies of our experience. In “De Gravitatione,” Newton says that in order to treat bodies mathematically, he will treat them as perfectly hard and “bound together—as it were by glue” (Newton, 2004, 39); this move enables him to treat bodies directly, prior to providing a matter theory, and thereby temporarily bypassing the problem of cohesion. Nevertheless, the problem of cohesion is present in Newton’s earliest and latest writings. For our purposes, two points stand out: first, just how difficult the problem of the cohesion of bodies proves to be; and second, how much Newton is able to achieve *without* first solving this problem. A careful examination of the relationship between the difficulties with cohesion, and the successes and limitations of Newton’s method for treating bodies without first solving this problem, remains to be carried out. Here, I focus on Newton’s early struggles with the problem.

In the Trinity Notebook, Newton considered two possibilities for cohesion. First, he argued (against Descartes) that the mere relative rest of the parts is not sufficient for the formation of a composite body, writing (McGuire and Tamny, 1983, 349):

> Whether the conjunction of bodies be from rest? No, for then sand by rest might be united sooner than by a furnace, etc.

The argument is empirical: Newton’s experience in compounding bodies provided for him sufficient demonstration that being at relative rest is insufficient for parts to form a whole.[9]

Second, Newton considered an account of cohesion that appeals to pressure from surrounding bodies. The proposal is that when the parts are well-fitted to one another so that there are no gaps, and when the surrounding bodies press on these parts to keep them together, then we have a composite whole. McGuire and Tamny (1983, 193 and also chapter 6, section 3) discuss this account of the cohesion of bodies, describing it as based on an analogy with air pressure. Such an account is developed in some detail by Newton in his letter to Boyle of February 28, 1678/9 (Newton, 2004, 1–11), where he appeals to an ether in order to achieve cohesion (1–2):

> I suppose this aether pervades all gross bodies, but yet so as to land rarer in their pores than in free spaces, and so much the rarer, as their pores are less. And this I suppose (with others) to be the cause … why the parts of bodies cohere.

The idea is that the pressure difference between the rarer ether within the pores of the body and the denser ether outside it is responsible for the cohesion of the body. Such a theory requires an account of varying density. For atomists, condensation and rarefaction is readily accounted for by varying the proportion of atoms to empty space, and we should understand the account offered by Newton as appealing to his atomism. The problem for plenists is much trickier, and Newton's discussion of non-elastic fluids in "De Gravitatione" can be read as showing that an account of cohesion depending on fluid pressure—that is, one that is plenist—is inconsistent with a vortex theory of planetary motion.[10] Toward the end of the manuscript (Hall and Hall, 1962, 152–155), Newton introduces the axioms and propositions by which he proposes to treat non-elastic fluids.

> Proposition 1. All the parts of a non-gravitating fluid, compressed with the same intension in all directions, press each other equally (or with equal intension).

> Proposition 2. And compression does not cause a relative motion of the parts.

Newton demonstrates these propositions by appeal to a spherical fluid region "contained and uniformly compressed" by a spherical boundary, and shows that the parts of such a sphere remain in equilibrium. It follows from this, as Newton argues, that the external pressure on the boundary surface is equal to the intension (i.e., the force with which the parts press on one another). So far, so good, for a model of the cohesion of a spherical body based on pressure and consistent with Cartesian principles.

However, such a model of the cohesion of a spherical body based on pressure is inconsistent with a theory of motion for that body also based on pressure. Internal equilibrium is necessary for cohesion of the whole, and external non-equilibrium is necessary for the motion of that whole, but as Newton has shown, and as he makes explicit in Corollary 1, there can be no such situation. Corollary 1 states (155):

> Corollary 1. The internal parts of a fluid press each other with the same intension as that by which the fluid is pressed on its external surface.

Corollaries 2 and 3 develop the point, elaborating on the connections between pressure, equilibrium, and motion:

> Corollary 2. If the intension of the pressure is not everywhere the same, the fluid does not remain in equilibrium. For since it stays in equilibrium because the pressure is everywhere uniform, if the pressure is anywhere increased, it will predominate there and cause the fluid to recede from that region.
>
> Corollary 3. If no motion is caused in a fluid by pressure, the intension of the pressure is everywhere the same. For if it is not the same, motion will be caused by the predominant pressure.

Thus, a theory of motion for spherical bodies based on non-equilibrium conditions is inconsistent with a pressure account of the cohesion of such bodies. Newton had already dispatched the Cartesian vortex theory of planetary motion earlier in the manuscript, and he does not make an explicit connection to Descartes here, but it seems to me that one can read these passages as continuing the same style of argumentative engagement with Descartes exhibited earlier in the manuscript, where Newton charges Descartes's theory of bodies in motion with one internal contradiction after another. Indeed, prior to introducing his propositions on non-elastic fluids, Newton is at pains to draw a distinction between bodies and fluids: the parts of a fluid though perhaps at rest with respect to one another are readily put into relative motion, whereas the parts of a body move all together as one. The ensuing discussion of non-elastic fluids can in part be read as substantiating why this distinction must be made.

Thus, both of the Cartesian-friendly options for the cohesion of bodies discussed in the Trinity Notebook (mutual rest and fluid pressure) are rejected by Newton by the time of "De Gravitatione." Nevertheless, his atomist mechanical ether theory of cohesion, described in his letter to Boyle to Boyle, cannot survive his overall rejection of a mechanical ether during the development of his theory of gravitation, and by the end of his life Newton's account of cohesion appeals to forces, as is evident in drafts for the General Scholium, as well as in the *Opticks* and "De natura acidorum" (Newton, 1958, 255–258). In Proposition 3 from a draft of the General Scholium, Newton states (manuscript C in Hall and Hall, 1962, 351):

> Proposition 3. That attraction of particles at very small distances is exceedingly strong (by Experiment 5) and suffices for the cohesion of bodies.

In Newton's *Opticks* we find evidence of the empirical problems that Newton wrestled with in an account of cohesion depending on forces. Bechler (1974) draws our attention to a 1706 formulation of Query 23,[11] where Newton writes:

> Now the smallest particles of matter may cohere by the strongest attractions, and compose bigger particles of weaker virtue; and many of these may cohere and

> compose bigger particles whose virtue is weaker still, and so on for divers successions.

Bechler calls this a “screening mechanism,” introduced as Newton struggled with optical dispersion.

We have leapt from Newton’s early mechanically-inclined matter theory to that of the queries in the *Opticks*, simply to highlight that the problem of cohesion of bodies is present in Newton’s latest work on physical bodies as well as in his earliest. My focus has been the earlier work, where I have argued that he considered several different possible accounts and found them wanting.

When Newton began his work, the problem of cohesion was pressing for all would-be corpuscularian philosophers. Without a solution to this problem there cannot be bodies, and without bodies such philosophers cannot begin to compete with Aristotelian accounts of the world as we experience it. As noted earlier, Newton’s target of explanation is the bodies of our experience. By the end of Newton’s work, he had wrought a methodological transformation the upshot of which is demonstrated by the *Principia*: corpuscularian philosophers no longer need solve the problem of cohesion in order to make progress in the natural philosophy of bodies. In its mature form, the methodology is a “law-constitutive” approach to bodies.

The Law-Constitutive Approach to Bodies

The centerpieces of Newton’s *Principia* are his laws of motion and his law of universal gravitation. These laws apply to bodies, and so any investigation of Newton on bodies must ask about the bodies that are the subject matter of his laws. Although Newton offers a definition of body in Definition 1 of the *Principia*, this definition is not sufficient to constitute the bodies that are the subject of the laws. The reason for this is that the definition allows any collection of volumes (for example), no matter how disjointed and spread out, to count as “a body.” Rather, Definition 1 takes a body as given, and relates its quantity of matter to its volume and density.

Taking “body” as given is sufficient for mechanics, but for natural philosophy we expect an account of the bodies themselves. I have argued in Brading (2012) that for Newton, the laws themselves play a role in constituting the bodies that are their subject-matter, and that in developing this position Newton was responding to a difficulty that he (and others) saw in Descartes’s account of bodies and their laws. In “De Gravitatione,” the requirement that bodies move in accordance with the laws is included in the definition Newton gives of bodies, and this requirement is preserved in the draft definitions of body that Newton prepared for the third edition of the *Principia* (see McGuire, 1995, 116–117). As Newton writes in the draft definitions, he is offering a definition of body in order to characterize those bodies that are the subject of his mathematical and physical treatment (that is, of his experimental philosophy), and in order to count as such bodies they must be subject to the laws of bodies. "About other sorts of bodies," he writes (116), "let authors in other sciences dispute."

A similar view of Newton's approach to bodies in the *Principia* is found in Biener and Smeenk (2012, 115), who argue that bodies are there defined "only derivatively—as entities subject to forces and for which the laws of motion hold." They conclude (ibid.):

> The nature of body in the *Principia* thus depends upon whatever constraints are implied by satisfaction of the laws. Furthermore, empirical support for this view of bodies derives from the empirical support for the laws of motion and the physical theory based on them.

We can distinguish a strong and a weak version of the law-constitutive approach. On the strong version, the laws are necessary and sufficient for constituting the bodies that are their subject matter, and on the weak version the laws remain necessary but are not themselves sufficient. I think it is clear that Newton adopts the weak version: moving in accordance with the laws is only one of the several conditions listed in his definitions of body.

An interesting question is the extent to which the remaining conditions could be derived from the law-constitutive requirement. It seems to me that the qualities of mobility (including being movable by us), inertia, and gravity, are good candidates for following from the laws. In such a case, the meaning of the associated term is given by implicit definition via the statement of the laws, and what it is for a body to possess the quality of inertia (for example) *just is* (no more and no less) for it to move in accordance with the three laws of motion. On the other hand, extension, impenetrability, and being tangible, are (in different ways) independent of the laws and must be asserted in addition to the laws. I return to the relationship between the qualities of bodies and the law-constitutive approach in the subsection "Impenetrability, Mobility, and Hardness" .

Universal Qualities of Bodies

In the *Principia*, Newton defines body as "quantity of matter," for which he offers the following definition (Newton, 2004, 59): "Quantity of matter is a measure of matter that arises from its density and volume jointly." The terms "body," "quantity of matter," and "mass" are to be used interchangeably, Newton says. Proportional to the quantity of matter is (a) the weight of a body, and (b) the inherent force of matter, that is, the inertia of a body. By specifying the role of volume in relation to quantity of matter, Newton preserves extension as a characteristic of bodies (recall the discussion in the Introduction to this chapter), and by introducing inertia as proportional to quantity of matter (i.e., as a measure of matter), Newton introduces a dynamical conception of body (of which more later).

In the Rules of Reasoning (introduced in the second edition of the *Principia*), Newton asserts that six of the seven following qualities are universal qualities of bodies, with divisibility being the problematic case: (1) extension; (2) hardness; (3) impenetrability; (4) mobility; (5) inertia; (6) divisibility; and (7) gravity.[12] In draft revisions for the third edition of the *Principia*,[13] Newton gives definitions of body that move from the mathematical treatment (associated with the opening definition of Book I of the *Principia*) to a physical treatment, by adding three things—(8) being tangible; (9) being movable by us; and (10) reflecting and emitting light (by which bodies are visible to us)—and by asserting that (11) bodies of the kind Newton is considering move in accordance with the laws of bodies. These are all present in the account offered in “De Gravitatione,” and have their roots in the methodology dating back to the Trinity Notebook (see the section on “Epistemology of Bodies”).

Inertia and gravity are highly developed topics in Newton scholarship in their own right. I end with comments on some of the other qualities of Newtonian bodies.

Extension and Divisibility

I mentioned in the Introduction that extension and divisibility, asserted pre-theoretically as properties of bodies in Newton’s Trinity Notebook, become somewhat problematic in the *Principia*. Extension as a quality of bodies is discussed explicitly by Newton through “De Gravitatione” and on through the *Principia*, as we have seen. Biener and Smeenk (2012) argue that it nevertheless comes under pressure by the second edition of the *Principia*. First, they argue that the *Principia* contains two different conceptions of body, or quantity of matter, one geometrical (involving extension) and the other dynamical (involving inertia). It is quantity of matter as inertia that appears in the Laws of Motion and is subject to measurement and investigation by means of these laws through the resistance of a body to acceleration. The two conceptions can come apart, and Biener and Smeenk argue that by the second edition of the *Principia* the dynamical conception is taking precedence (Biener and Smeenk, 2012, 115):

> In the *Principia*, the two methods of quantifying matter co-exist, but the geometrical conception is relegated to the wings while the dynamical conception takes center stage.

When Cotes was preparing his preface to the second edition of the *Principia*, he pointed out that these two ways of quantifying matter need not agree. Biener and Smeenk (2012, 133) report that “Cotes, to his credit, was quite clear that Newtonian mechanics does not support a geometrical conception. He even pointed out the precarious status of extension to Clarke.” In response to Cotes, Newton turned his crucial claim into a conditional in the second edition of the *Principia* (Book III, proposition 6, corollary 4):

> If all the solid particles of all bodies have the same density and cannot be rarefied without pores, there must be a vacuum. I say particles have the same density when their respective forces of inertia [or masses] are as their sizes.

We can put Cotes's point this way: if we rely on the laws to do our matter theory (if we adopt a law-constitutive approach), then there is no reason to assume that all solid particles (i.e., particles lacking any interstitial void spaces) have the same inertia.

That Newton took a long time to understand Cotes's challenge is an indication of how deep-seated the connection between extension and quantity of matter was in Newton's thinking, and there are interesting reasons why this was so. At the beginning of this paper, I quoted from the opening remarks of the Trinity Notebook, in which Newton discusses "the first matter" and argues for atomism. In these remarks, Newton claims that all matter is of "the same temper the first was," so that "there will be no change in nature unless you will allow it either to arise from vacuities interspersed or from the several proportions that quantity has to its substance—matter acquiring a harder nature by less quantity and a softer by more."[14] Two options for body are thereby put on the table, one in which body consists of parts of matter interspersed by spaces between those parts, and a second in which matter is continuous but its quantity in a given volume can change (thereby explaining condensation and rarefaction). Newton endorses the first, and says that the second "will in its due course be proved impossible." Notice that this "impossibility" has implications for the atomist as well as for the plenist: the second possibility corresponds to the idea that different parts of matter (be they atoms or parts of a continuum), though of the same size and being entirely uniform (i.e., lacking any vacuities), may have associated with them different quantities of matter. Nothing in the ensuing pages of the Notebook rules this out (despite Newton's promise), and so far as I know Newton never did so, yet this is the very possibility (as it applies to the atomist) that returns to haunt Newton in Cotes's questions.

The second option cannot be adopted without cost to Newton's overall position. On the atomist account, bodies of the same size can have different quantities of matter associated with them depending on the proportion of atoms to vacuum present in the overall volume of the body. No such explanation is available at the level of the atoms themselves. Therefore, if atoms of equal size have different quantities of matter, then this must be either postulated as brute and inexplicable or, perhaps, explained by appeal to Aristotelian hylomorphism (the same sized regions of prime matter are impressed with different forms, and therefore have different densities). Either way, if we adopt this approach, then the *intelligibility* of density is challenged, and this accusation will require a response.[15]

Moreover, if quantity of matter is independent of volume, then inertia may not require volume at all, and we may do Newtonian mechanics using point particles. Extension thereby teeters toward the "precarious" status mentioned by Biener and Smeenk. But Newton argued (Trinity Notebook) that points cannot be added together to give dimension. Without dimension a body cannot be impenetrable, and it is impenetrability, in

"De Gravitatione," that renders a body sensible. Sensible bodies are the target of our explanation, and so without extension the whole project comes crashing down, epistemology and methodology and all. If we follow this line of thought, then there are good reasons for postulating extension as a quality of bodies. As we saw earlier, Newton adopted the weak version of the law-constitutive approach to bodies, according to which the laws are necessary but not sufficient for the complete characterization of bodies. He used the laws to add to the account of bodies that he had begun developing way back in his Trinity Notebook, but he did not replace it. In that account, it is taken as an a priori premise that bodies are extended (see the Introduction to this chapter). Though matter became ever more attenuated in Newton's system, with forces playing a greater and greater role in the composition and qualities of bodies, the possibility that extension and impenetrability of bodies might arise from the forces between point particles became a live option only after Newton.[16]

Divisibility faces problems of its own in the context of the *Principia*. Divisibility (unlike extension) never features in Newton's explicit definitions of bodies, but is ever-present, and actual and potential divisibility is discussed in Rule 3 of his Rules of Reasoning (Newton, 2004, 88). There, Newton begins with bodies that have contiguous but actually divided parts, noting that these are separable by us into these actual parts. He then says that these actual parts have potential parts (i.e., parts that "can be distinguished into smaller parts by our reason"), and states that it is uncertain whether this division can be actualized by the forces of nature. In other words, it is uncertain whether any undivided body—that is to say, a body that does not already consist of actual parts, but merely of potential parts—can in fact be divided by means of the forces of nature. Finally, he claims that if even one instance of this is witnessed, we should conclude "not only that divided parts are separable but also that undivided parts can be divided indefinitely." In short, whether a potentially divisible body lacking any actual parts is in fact divisible by the forces of nature is an empirical question, and moreover the general thesis of the indefinite divisibility of matter can be settled by a single empirical incidence of such a division.[17]

Impenetrability, Mobility, and Hardness

In "De Gravitatione," Newton invites us to consider what qualities a body must have such that we would count it as a body were we to encounter it. The first quality that he suggests is impenetrability: a region of space is impressed with impenetrability such that it is "impervious to bodies," and it is in virtue of this impenetrability that bodies are sensible (they are tangible, they stop or reflect light and are therefore visible, and so on). Impenetrability as a quality of bodies is therefore intimately tied to their being extended and to their being sensible: impenetrability is what distinguishes bodies from space and at the same time renders them epistemically accessible through our senses (see the section on "Epistemology of Bodies", earlier).

As noted earlier, the qualities of bodies listed by Newton are tightly inter-related. For example, as Bennett and Remnant (1978) make clear, without mobility, impenetrability fails to characterize matter, since it is only through the attempt of one body to occupy a region of space occupied by another that the impenetrability of bodies manifests itself.[18] Moreover, impenetrability is intimately linked to bodies being extended and to their being sensible, and there are connections to inertia and quantity of matter (the problems with these connections have been noted earlier). Crucial to Newton's conception of bodies as physical bodies is their epistemic status as sensible and movable by us (see the section "Epistemology of Bodies", earlier), and crucial to their being sensible and movable by us is their impenetrability (which implies extension and is necessary but not sufficient for being sensible) and their resistance (which together with impenetrability becomes their inertia). It is their inertia that comes to be the starting point for Newton's mathematical natural philosophy in the *Principia* by which he develops his account of bodies.

Impenetrability itself is all or nothing (space is utterly penetrable; body utterly impenetrable), but an impenetrable body may be more or less elastic. Impenetrability is a prerequisite for hardness, and impenetrability has associated with it degrees of hardness. The most obvious place where the hardness of bodies is relevant is in collisions, and it is present in Newton's early treatments of this topic (see his treatments in the so-called "Waste Book," in Herivel, 1965, 133, for example). In the *Principia*, Newton lists hardness as a quality to be attributed to all bodies universally. To make sense of this, hardness must be interpreted as a matter of degree, since not all bodies are perfectly hard. Thus, a degree of hardness (between perfect hardness and perfect elasticity) is to be attributed to all bodies universally. The warrant for this claim is that the hardness of the whole arises from the hardness of the parts, but we need to be careful in how we handle this. A strong version would infer the degree of hardness of the parts from the degree of hardness of the whole (e.g., a composite body that is perfectly elastic arises from parts that are themselves perfectly elastic). A weak version would deny this, allowing the degree of hardness of the whole to differ from the degree of hardness of the parts (e.g., perfectly hard parts might be so composed as to result in an elastic composite body). According to McGuire (1995, 122), that matter has no internal principles of change requires not only the inertia of matter but also its inelasticity, so that it contains no sources of activity in itself (in contrast with Leibniz's elastic matter). If this is right, then the elastic power of bodies arises from their composite nature, and the ways in which they are compounded, rather than directly from the elasticity of the parts.

It is important to notice that the issue of how the qualities of corpuscles "add" to give the qualities of bodies is a general issue applying to all the universal qualities. Inertia is straightforwardly additive, for example, and it is essential to Newton's argument for universal gravitation that the gravity of the whole arises from the gravity of the parts also by simple addition. However, such composition rules are subject to empirical investigation; Newton's Trinity Notebook records his proposals for testing whether the weight of a body can be altered by a variety of physical and chemical processes,[19] and

Bechler (1974) suggests that late in his life Newton considered revising his composition rule for gravity in the light of his struggles with optical dispersion.

According to Newton, hardness is a universal quality of bodies and as such requires no further account in terms of other qualities of bodies. However, attributing this status to hardness is neither uncontroversial nor without problems of its own. For example, William Neile (who took part in the Royal Society discussions of the problem of collisions) repeatedly expressed his concern that the problem of collisions is not adequately solved until we have given an account of "hardness" and "elasticity," *prior to and independently of* our specification of the laws, in terms of the Cartesian resources of extension and motion. John Wallis disagreed, arguing that the rules of collision themselves constitute a complete physical account (see his letter to Oldenburg, December 5, 1668). Newton followed the lead of his English predecessors, including Wallis and Wren, in pursuing such an approach to the qualities of bodies (see "Bodies Treated Mathematically", earlier). Newton's three Laws of Motion allow him to treat the problem of collisions in generality, and it is therefore via these laws that we are able to begin a quantitative treatment of hardness, with coefficients of restitution (for example) appearing in our equations as a means of characterizing hardness. However, this is far from giving an implicit definition of hardness: as a coefficient, the measure of hardness of a body is put in by hand and is not systematically correlated to other qualities of the body such as its inertia. In this respect, hardness and inertia receive an importantly different treatment in Newton's account of bodies: while a law-constitutive treatment may be developed for inertia, hardness has an intermediate status and is not integrated into the laws in an analogous way.

Conclusions

I have suggested that bodies are both the target of explanation and a central conceptual tool by which Newton developed his philosophy. I have indicated some of the ways in which attention to bodies allows us to explore the intimate connections between Newton's epistemology and methodology, his matter theory and his physics, including both continuities and changes over his lifetime. I have done little more than scratch the surface. As I hope is clear, "bodies" are a fertile and under-utilized research tool for exploring Newton's philosophy, and there is a great deal more work to be done.

References

Bechler, Z. 1974. "Newton's Law of Forces which Are Inversely as the Mass: A Suggested Interpretation of His Later Efforts to Normalise a Mechanistic Model of Optical Dispersion." *Centaurus* 18: 184–222.

Belkind, O., 2012. *Physical Systems*. Springer.

Bennett, J. and P. Remnant. 1978. "How Matter Might at First Be Made." *Canadian Journal of Philosophy*, supplementary volume 4: 1–11.

Biener, Z. and C. Smeenk. 2012. "Cotes's queries: Newton's empiricism and conceptions of matter." In Janiak and Schliesser, eds., 2012.

Brading, K., 2011. "On Composite Systems: Descartes, Newton, and the Law-Constitutive Approach." In Jalobeanu and Anstey, eds., 2011.

———. 2012. "Newton's Law-Constitutive Approach to Bodies: A Response to Descartes." In Janiak and Schliesser, eds., 2012.

———. 2016. "Émilie Du Châtelet and the Problem of Bodies." In *Early Modern Women on Metaphysics*, E. Thomas, ed., 150–168. Cambridge University Press.

Buchwald, J.E., and M. Feingold. 2013. *Newton and the Origin of Civilization*. Princeton University Press.

Hall, A.R., and M.B. Hall. 1960. "Newton's Theory of Matter," *Isis* 51: 131–144.

———. 1962. *Unpublished Scientific Papers of Isaac Newton*. Cambridge University Press.

Herivel, J. 1965. *The Background to Newton's Principia*. Clarendon Press.

Jalobeanu, D., 2011. "The Cartesians of the Royal Society: The Debate over Collisions and the Nature of Body (1668–1670)." In Jalobeau and Anstey, eds., 2011.

Jalobeanu, D., and P. Anstey, ed. 2011. *Vanishing Matter and the Laws of Motion: Descartes and Beyond*. Routledge.

Janiak, A., 2008. *Newton as Philosopher*. Cambridge University Press.

Janiak, A., and E. Schliesser., ed. 2012. *Interpreting Newton*. Cambridge University Press.

McGuire, J.E. 1995. *Tradition and Innovation*. Kluwer Academic Publishers.

McGuire, J.E. and M. Tamny. 1983. *Certain Philosophical Questions: Newton's Trinity Notebook*. Cambridge University Press.

Newton, I. 1958. *Isaac Newton's Letters and Papers on Natural Philosophy*. ed. I.B. Cohen. Havard University Press.

———. 2004. *Philosophical Writings*. ed. A. Janiak. Cambridge University Press. Second edition, 2014.

Schliesser, E. 2011. "Gravity as a Relational Quality of Matter in Newton's *Treatise*." In Jalobeanu and Anstey, eds., 2011.

Thackray, A. 1968. "'Matter in a nut-shell': Newton's Opticks and Eighteenth-Century Chemistry." *AMBIX* 15: 29–53.

Notes:

([1]) McGuire and Tamny, 1983, 335. Emphasis on the word "body" in the following quotations are mine.

([2]) See McGuire and Tamny, 26ff, for a discussion of Newton's response to Charleton.

([3]) Newton's distinction between mathematical and physical has been most discussed in the context of his treatment of forces. See, for example, Janiak 2008, 60ff., and references therein.

([4]) See, for example, the early manuscript "To resolve problems by motion," in Hall and Hall, 1962, 15ff. The distinction between a mathematical and a physical treatment of bodies is not new in Newton (think of Galileo, for example), but has some distinctive features in his hands.

([5]) This is an important feature of the methodology, in which Newton follows Wren and Wallis in opposition to William Neile (see Brading, 2011, 139, and Jalobeanu, 2011).

([6]) In between the opening remarks, and the later quotations given here later, Newton enters into his physical discussion of body as tangible and sensible and movable by us. See the sections on "Epistemology of Bodies" and "Universal Qualities of Bodies" .

([7]) The term "quantity of body" is used explicitly here for the first time, and it is the search for an appropriate concept for "quantity of body" that leads to mass as the cornerstone concept of the *Principia*, with the distinctions between inertial mass, weight, volume, and density being crucial to the achievements therein. The opening definition of the *Principia* introduces "quantity of matter" or mass or body, and the work unfolds from there.

([8]) For discussion of Newton's interest in a sense perception, and the variety of approaches available in the sources that he read, see Buchwald and Feingold (2013, chapter 1), especially page 12 and preceding pages.

([9]) The empirical character of Newton's considerations of cohesion is further emphasized by his interest in the practical problems of how bodies of different kinds can be put together, and with what effects for the properties of the resulting bodies (see McGuire and Tamny, 1983). This interest is seen also in his alchemical work, and stayed with him to the end of his life (see, for example, "De natura acidorum," in Newton, 1958, 255–258).

([10]) The dating of the manuscript "De Gravitatione" is controversial, but with widespread agreement we can confidently date it to after the Trinity Notebook and before the

Principia, which is all that matters at this point. The relevant sections of "De Gravitatione" are not reprinted in Newton (2004), but can be found in the second edition (2014), and in Hall and Hall (1962).

([11]) According to Bechler, a revised and corrected version was offered in 1717.

([12]) Janiak (2008) contests the interpretation that for Newton gravity is a universal quality of bodies. See also Schliesser (2011) for a response. Note that Newton does explicitly deny that gravity is *essential* to matter.

([13]) McGuire, 1995, 114ff.

([14]) The explicit phrase "quantity of matter" does not occur until later in the Notebook, but it is clear that matter and its quantity are being discussed here.

([15]) It was not until Dalton, so far as I know, that the possibility of *irreducible* elements of different densities became a live option.

([16]) The idea of a point particle having an effective extension in virtue of a force associated with that particle arises late in the eighteenth century, in response to the problem of bodies that was inherited by eighteenth-century natural philosophers in the wake of the *Principia*. For the state of this problem prior to Boscovich and Kant, see Brading (2016). See Thackray (1968) for the "nut-shell" theory of matter and its developments through the eighteenth and nineteenth centuries. I see these developments as evidence of the power of Newton's methodology: even the most entrenched assumptions can be brought to the surface and revised in the light of what we learn through the process of pursuing his project according to his methodology.

([17]) Rather than concluding that we have successfully divided a merely potentially divisible body, we might instead try reconceptualizing our original simple body as a composite body by introducing a new force to hold new parts together. But then we have actual rather than potential parts, and the original question concerning a body that is merely potentially divisible remains unresolved. Newton's test requires both that we successfully divide the body and that the body cannot be reconceived as having been a composite held together by forces.

([18]) Bennett and Remnant (1978) challenge the viability of impenetrability as the first quality of bodies, but that is because they are considering a different question from the one that concerns Newton in "De Gravitatione." See Brading (2012), page 25.

([19]) McGuire and Tamny, 1983, 431. For a discussion of the general issue, see Belkind (2012).

Katherine Brading

Department of Philosophy, University of Notre Dame