Émilie Du Châtelet and the problem of bodies

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Introduction

The first edition of Du Châtelet's *Institutions de Physique* (hereafter translated as *Foundations of Physics*) was published in 1740,[1] and was written in France in the late 1730s, in the wake of Newton's *Principia*, at a time when Cartesian natural philosophy remained popular in France (the first edition of Newton's *Principia* was published in 1687, Descartes's *Principles of Philosophy* was published in 1644, and Rohault's textbook of 1671, and multiple editions thereafter, remained the standard Cartesian textbook[2, 3]). Both Descartes's and Newton's systems of natural philosophy center around their laws, and in both cases the subject-matter of the laws is "bodies". The question therefore arises: What are these "bodies" that are the subject-matter of the laws? I call this the "problem of bodies".

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[1] For a partial English translation of the 1740 edition of Du Châtelet's *Institutions de Physique*, see Zinsser 2009.

[2] See Shank (2008) for an alternative to the "received narrative" on the reception of Newton in France.

[3] According to Zinsser (2009, p. 251), Du Châtelet had access to the second (1713) and third (1726) editions of Newton's *Principia*, the Jacquier and Le Seur edition with its commentary, and the 1731 publication of Newton's *De Systemate mundi*.

I begin by outlining the problem of bodies and the solutions available, as things stood at the time Du Châtelet was writing. As we will see, each of the available solutions faced difficulties. This background enables us to situate Du Châtelet's work on the problem of bodies within the context of an existing philosophical narrative. I outline her solution to the problem of bodies, and then discuss a difficulty arising from gravitational theory. Finally, I offer some remarks about the significance of this lack of solution for our understanding of eighteenth century natural philosophy, and for the how we might situate Du Châtelet's work on the problem of bodies with respect to later developments in the 18th century.[4]

The problem of bodies

Cartesian philosophy is the backdrop against which Du Châtelet introduces her discussions in her *Foundations of Physics*. In this section, I begin from the problem of bodies as it arises in Descartes's philosophy, and argue that it was a difficult and enormously important problem that remained unsolved in the early decades of the eighteenth century. In the next section I then turn my attention to Du Châtelet's solution.

[4] For discussions of Du Châtelet's *Foundations of Physics* more broadly, see Detlefsen (2013), Hagengruber (2012), Hayes (1999), Hayes and Zinsser (2006), Hutton (2004), Iltis (1977), Janik (1982), Zinsser (2009), and references therein.

The context for addressing the problem of bodies in Descartes's system is Part II of his *Principles of Philosophy*,[5] where Descartes sets out his account of bodies and offers his laws of nature. In this part of the *Principles*, Descartes suggests that all the rich variety of the world around us, as we experience it through our senses, is to be explained in terms of the following resources: matter, whose sole essential attribute is extension; motion, by which Descartes means local motion, i.e. motion from place to place; and the laws of nature, which say how the parts of matter (i.e. bodies) move. Parts III and IV of the *Principles* proceed to use the resources set out in Part II in order to carry out the explanatory project, first for celestial phenomena in Part III, and then for terrestrial phenomena in Part IV, concluding (IV. 199): "*That no phenomena of nature have been omitted in this treatise"* , where by "phenomena" Descartes means "what is perceived by the senses". It is this portion of Descartes's philosophy, begun in Part II, that is labelled "Descartes's metaphysical physics" by Garber (1992), and that I will refer to here as "Descartes's project".[6]

If Descartes's project, of explaining all the phenomena in terms of bodies and their shapes, sizes and motions, is to succeed, then there must be bodies. According to Descartes, bodies are simply "parts of matter", where matter is just "extension". However, extension by itself seems to lack any properties or qualities by which it can admit of determinate parts: on the one hand, we might ask what divides extension (mass noun) into parts of extension (count noun); and on the other hand,

[5] Quotations are from Descartes (1991).

[6] This is a convenient shorthand; Decscartes had many other philosophical projects underway, of course.

since matter is indefinitely divisible according to Descartes (*Principles* II.20), we might ask how there can be any extended part of matter that doesn't simply disintegrate into indefinitely many parts. This is the problem of bodies, as it arises in Descartes's system: how are the bodies that are to serve as the subject-matter of the laws of nature to be constituted from matter? Given the resources available in Descartes's project as he sets it up in Part II of the *Principles*, there are three options for constituting bodies from extension: (1) use motion and rest; (2) use the laws; (3) modify the account of matter.

Option 1 for constituting bodies from extension: use motion and rest

The first option, of using motion and rest, is the one adopted by Descartes. He wrote (*Principles*, II.25): "By one body, or one part of matter, I here understand everything which is simultaneously transported." This statement follows immediately after his definition of motion as "the transference of one part of matter or of one body, from the vicinity of those bodies immediately contiguous to it and considered as at rest, into the vicinity of some others", thereby introducing what is, at best, a very tight circle. I have discussed this problem elsewhere (see Brading, 2012), and here I will focus on other, equally pressing problems with using motion and rest to constitute bodies from extension.

Descartes suggests (*Principles* II.54 and 55) that mutual rest among parts of matter is sufficient for a body. However, Newton worried that this seems insufficient for providing bodies with the coherence and stability necessary for them to play the

roles required of them as the subject-matter of the laws. In his early notebook, he wrote (McGuire and Tamny, 1983, p. 349):

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

Newton's experience in compounding bodies provided for him sufficient demonstration that being at relative rest is insufficient for parts to form a whole. More generally, if Cartesian bodies cannot survive collisions, disintegrating on impact, then they cannot serve as the subjects of the laws of nature. Indeed, it might seem that bodies constituted by mutually resting parts are rather ephemeral, slipping in and out of existence with the relative motion and rest of the ever tinier parts into which their collisions indefinitely divide them.

Garber (2009) discusses the problem of the indefinite divisibilty of Cartesian matter in the context of Leibniz's developing philosophy. He quotes several passages from 1676 in which Leibniz worried that if matter is indefinitely divisible then there can be no bodies, and labels this the "division-to-dust" problem. If matter's sole essential property is extension, and if that which is extended is indefinitely divisible, then – absent any further principle – there is nothing to prevent divisible bodies from dividing over and over into finer and finer dust. Leibniz wrote: [7]

[7] Garber (2009, p. 62), quoting from Leibniz, *De summa rerum*.

> Matter is divisible, therefore it is destructible, for whatever is divided is destroyed. Whatever is dividied into minima is annihilated; that is impossible.

With the problem thus stated, "division-to-dust" as a label seems not quite radical enough: division-to-nothingness seems to better capture the impossibility of what indefinite divisibility entails according Leibniz. This stronger conclusion asserts not merely that there cannot be bodies in Descartes's system, but that his conception of matter leads to self-contradiction (because something cannot be nothing) and is therefore conceptually incoherent. Be that as it may, both Leibniz and Newton worried, in their different ways, that Descartes's preferred option for solving the problem of bodies could not succeed, with Leibniz maintaining that a part of extension cannot, merely by means of motion and rest, achieve the unity necessary for a body, and Newton maintaining that mere rest among the parts is insufficient for the cohesion of a body.

As it turns out, the overall tendency of any approach of this kind is towards a fluids account of matter,[8] in which bodies, if any there are, are derivative ontology rather than primitive, and are therefore not the subject of the basic laws of matter. Indeed, at the time Du Châtelet was writing, there was no version of this option available that didn't face serious problems. At best, appeal to mutual motion and rest would need to be supplemented with something else in order to arrive at bodies as the subject-matter of the laws.

[8] See, for example, Crockett (1999).

Option 2 for constituting bodies out of extention: use the laws

The second option for constituting bodies out of extension is to make use of the laws in a constitutive role with respect to their subject-matter. I believe that this was among the approaches adopted by Newton (see Brading, 2012), and I believe that in the end this approach is the best, if not the only, viable philosophical option. However, at the time that Du Châtelet was writing, even had this option been explicitly on the table (and I know of no evidence that it was), it would not have looked promising. As Marius Stan's recent work has made vivid,[9] by the 1730s it was becoming clear to the French mathematicians that the resources of the *Principia* (especially Newton's second law of motion) were insufficient to handle extended bodies. The force law copes well with point masses, but lacks the resources to deal with the rotation of extended bodies, or with the stresses and strains within them. Du Châtelet was in correspondence with the leading French mathematicians of the period, and knew of their work. Thus, even had she considered a law-constitutive approach (and I have no evidence that she did), she would have known that Newton's laws, despite being the most promising laws of mechanics available, nevertheless looked unpromising for a law-constitutive approach to bodies.

Option 3 for constituting bodies from extension: modify the account of matter

[9] See, for example, Stan (2016), which makes the connection to Kuhnian paradigms, and Stan (forthcoming, section 1).

The third option is to modify the account of matter as Cartesian extension, and there were various possibilities available at the time. By far the most popular was atomism, but this approach carries huge epistemic risk, for the following reason. Consider the following three propositions:

(i) That which is extended is divisible.

(ii) Atoms are extended.

(iii) Atoms are indivisible.

These are mutually inconsistent, so at least one must be rejected. Atomists endorse (ii) and (iii), and reject (i). But on what grounds? There was widespread agreement that extension is conceptually divisible.[10] Therefore, if no reason can be given for denying (i), admitting atoms into our physics carries the risk that we are admitting something unintelligible, and perhaps even self-contradictory, into physics at the outset. In the context of the time (the recent overthrow of the Aristotelian cosmological system, which turned out to have "obvious" yet false propositions at its core; the epistemic crisis of which Cartesian doubt is a part; and so forth), this epistemic risk seemed to many too great a risk to take if other alternatives were available. This is one way to read Du Châtelet's position: atomism carries the risk of incoherence,[11] and an alternative is to be preferred (of which more below).

[10] For detailed discussion of the problems associated with the infinite divisibility in early modern philosophy, see Holden (2004).

[11] See *Foundations*, 7.119-121, where Du Châtelet applies the principle of sufficient reason, as a principle of our knowledge, to the possibility of atoms. See also Detlefsen (2013).

A second possibility for modifying matter might be the addition of further essential properties. Indeed, many believed that the addition of impenetrability was necessary. However, unless there is a finite-sized least part of extension necessary for the instantiation of this property and sufficient to prevent further division, the division-to-dust problem is not solved by this move. So far as I know, no-one at the time suggested that impenetrability – or any other property – satisfied this condition.

A third possibility might be the addition of "forces". At the time, there was no settled concept of force, and "force" was being invoked in philosophy in a variety of ways to solve a variety of different problems. If the proposal is to use forces to glue bodies together (thereby attempting to solve the unity and cohesion issues worried about by Leibniz and Newton, for example), this is of course hopeless: unless there are small, finite-sized, parts of extension available to be glued together in the first place, then adding glue into the picture won't help. Another proposal might be to add force to point particles to yield "effective" extension, but this option did not appear until later in the 18th century (with Boscovich and Kant), and was not available at the time Du Châtelet was writing.

Finally, we might include under this general umbrella any proposal to add something non-material to our ontology in order to arrive at extended bodies possessing the required unity and cohesion. The most important example here is Leibniz, and Garber (2009) argues that the "division to dust" problem was one of two key motivations for Leibniz's reintroduction of sustantial forms into his account of bodies. He writes (Garber, 2009, p. 62), "The worries about unity and

individuality that ultimately lead Leibniz to the revival of substantial forms in physics seem first to arise in some reflections on views like those of Descartes, for whom matter is indefinitely divisible." As early as 1676, Leibniz stated: "There seem to be elements, i.e. indestructible bodies, because there is a mind in them."[12] This move invokes a resource that lies outside the investigative reach of Descartes's project: the qualities, properties and nature of mind cannot be investigated through the study of matter in motion. Thus, to make this move is to conclude that the project cannot be modified in such a way as to make it viable on its own terms. From the point of view of Descartes's project, then, it is problematic because it is to concede defeat.

The significance of the problem

As of the early eighteenth century, all of the available options for solving the problem of bodies faced serious problems. Natural philosophers faced the challenge of showing that extended material bodies are possible *at all*. This is how things stood at the time Du Châtelet was writing, in the 1730s.

The significance of the problem is twofold. First, one might think – and Du Châtelet did – that a complete physics would be one which could say what its subject-matter is, so that if it is about bodies it would be able to say what bodies are. At issue here is what counts as a complete physics: is a complete physics one which

[12] Quoted in Garber (2009, p. 64).

can provide an account of its subject-matter, and if so, what are the requirements on such an account?

Second, there is a much wider significance. At this point in the history of philosophy, physics and philosophy had not yet gone their separate ways (they were on the cusp of doing so). What we're looking for, in trying to solve the problem of bodies in early eighteenth century philosophy, is an account of bodies in general (not just the bodies of physics). Among the bodies that there are in the world are human bodies. If we don't have an account of bodies, then we don't have an account of our embodiment in the world, or of our action in the world; and if we don't have these, then we can't have either a moral philosophy or a political philosophy. Du Châtelet was acutely aware that the problem of bodies was a much bigger problem than "merely" being a problem for "physics". Her work on bodies in physics is intimately related to her discussions of human liberty, and her contributions to the debate over thinking matter (see Hagengruber, 2012, pp. 47-51) in which she argues against Locke. With respect to the former issue, Du Châtelet wrote to Maupertuis, in the midst of her work on the *Foundations*, worrying about the relationship between conservation laws within physics and freedom of human action. In discussing Leibniz's *forces vives*, she wrote (Letter to Maupertuis, 30th April 1739, translated in Zinsser, 2009, p. 109):

> "But the only thing that puzzles me at present is liberty, for in the end I believe myself free and I do not know if this quantity of force, which is always the same in the universe, does not destroy liberty. Initiating motion, is that

not to produce in nature a force that did not exist? Now, if we have not the power to begin motion, we are not free. I beg you enlighten me on this point."

Du Châtelet attempted a solution to this problem in her manuscript on liberty, and there is evidence this manuscript was originally intended as a chapter in the *Foundations*,[13] further supporting the view that Du Châtelet saw these issues of bodies and of human liberty as deeply inter-related.[14]

With this context in mind, we now turn our attention to Du Châtelet's solution.

Du Châtelet's solution to the problem of bodies

Du Châtelet accepted the Leibnizian position that in order to have extended bodies we must begin from non-extended simples, on the basis of her worries about material atomism mentioned above (see *Foundations*, 7.119-122). She argued from non-extended simples to extended bodies as follows (this is a reconstruction; for the argument in her own words see *Foundations* 7.133):

Argument from non-extended simples to extended bodies

(P1): Bodies are composite beings, composed of a multiplicity of non-extended simple beings.

[13] See Janik (1982).

[14] For a discussion of this relationshup see M. Jones, "Liberty, Sociability, and *Vis Viva*: Emilie Du Châtelet on Social and Natural Order", ms.

(P2): All simple beings are interconnected (see Chapter 7.130: "All is linked in the world; each being has a relationship to all the beings that coexist with it").
From (P1) and (P2), (C1): Bodies are composed of a multiplicity of interconnected simple beings.
(P3): We necessarily represent a multiplicity as spatially extended (see Chapter 5).
Conclusion (from (C1) and (P3)): We necessarily represent (i.e. represent to ourselves) composite beings (i.e. bodies) as spatially extended.

The upshot of this argument is that the possibility of bodies *as extended* is established. This is merely the first step in solving the problem of bodies, but it is a vitally important one.

For Du Châtelet, bodies are not merely extended, but also non-overlapping and capable of action and reaction by contact.[15] In order to arrive at an account of such bodies, much more is needed than the above argument, and Du Châtelet appeals to notions of force in order to complete her account of bodies,[16] as well as to mutual

[15] Arriving at bodies that are capable of action and reaction is crucial for Du Châtelet, not just for her physics, but for her wider concerns with the possibility of human action in the world, and of human liberty. Also crucial for this is an account in which genuine change is possible. For her approach to the latter, see Aaron Wells, "Émilie Du Châtelet on the fundamentality of change", ms.

[16] In addition to showing how extended material bodies are possible, Du Châtelet was also concerned with the problem of *action*: if the properties of matter (such as extension) are merely passive, then how can bodies act on one another? For Du

motion and rest (see option 1 in section 2, above).[17] However, for our purposes, I wish to focus our attention on the above aspect of her account of bodies, for it is by

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Châtelet, as for other philosophers of the time, "force" was invoked as a means of solving both the problem of bodies and of their action (see *Foundations*, Chapter 7). However, there was no single, stable, notion of force available at the time, and an appropriate concept of force had to be worked out. Indeed, it was far from clear that a concept of force adequate for solving the problem of bodies and their action would be consistent with that demanded by Newton in his *Principia*. Different philosophers differed over which of these problems they attempted to address, and the extent to which they saw these problems as inter-related. Du Châtelet sought to address all three in a single, unified account of bodies, and that at least part of her motivation was to ensure the possibility of human bodily action, as a necessary condition for the possibility of *free* human action. Her treatment of force in relation to the problem of bodies requires a detailed investigation of her over-arching and complex theory of force as a pre-requisite. Such an investigation is beyond the scope of this paper, but would draw on her work on *vis viva*, for which see Hankins (1965), Iltis (1970), Papineau (1977), along with Reichenberger (2012) and references therein. See also A. Reichenberger, "Émilie du Châtelet's interpretation of the laws of motion in the light of 18th century mechanics", ms.

[17] What role mutual motion and rest play in Du Châtelet's account of bodies remains to be given detailed consideration. My thanks Jeremy Steeger for pointing out that it does play some role, and for drawing attention to some of the resulting problems for her account.

means of this argument that Du Châtelet solves the "division-to-dust" problem, thereby showing that extended bodies are indeed possible.

The reason why the resulting bodies do not face the "division-to-dust" problem is due to a distinction that Du Châtelet makes between geometrical bodies and physical bodies. This distinction is not explicit in the argument as stated, but is of vital importance. For Du Châtelet, geometrical bodies have only potential parts and are divisible to infinity, whereas physical bodies have determinate, finite, actual parts and are not divisible to infinity. This latter is because – as the above argument makes clear – each extended body arises from a determinate number of simple beings standing in determinate relations to one another. Thus, the smallest physical body arises from a determinate number of simples standing in determinate relations to one another, and it cannot be further divided, *qua* physical body.[18]

Before moving on, some brief comments on (P1) and (P2) are in order. Premise 2 (P2) is part of an extended argument leading to a strong version of determinism. The argument for (P2) begins from Leibniz's Principle of Sufficient Reason, from which Du Châtelet argues for the law of continuity (*Foundations* 1.13).[19] Du Châtelet

[18] This solution, relying on a distinction between geometrical and physical extension, is of wider interest in the context of the lively discussions of the time, concerning the relationship between the mathematical and the physical. This issue of the applicability of mathematics to the natural world remains a topic of discussion today.

[19] Du Châtelet attributes both PSR and the law of continuity to Leibniz. Unlike Leibniz, Du Châtelet argues for the law of continuity as a consequence of PSR.

then offers a causal interpretation of the law of continuity, and from this argues (*Foundations* 7.129-130) for (P2). From here, Du Châtelet arrives at a strong version of Laplacian determinism (*Foundations* 7.131), several decades before Laplace, and there is a clear historical line that can be traced through Du Châtelet and on to Laplace. [20]

Premise 3 (P3) is an interesting and highly unusual claim about the extension of bodies,[21] which deserves attention in its own right. Du Châtelet distinguishes between bodies, which belong to the phenomenal, spatiotemporal world of our experience, and the non-spatiotemporal, but causally related, simples which underlie the world of our experience. Whether this results in a version of idealism about bodies requires further discussion.

I shall not pursue further investigation of the argument here. Rather, my point is that this is the argument by which Du Châtelet establishes the possibility of extended bodies. It is immediately and obviously striking how far we have strayed from "physics" into "metaphysics", as we understand these enterprises today. But, as I emphasized in section 2, above, it's not as though there were other unproblematic

[20] For the principles of sufficient reason and continuity in relation to Laplacian determinism see van Strien (2014). For Du Châtelet on continuity see John Hanson, "Du Châtelet on space and continuity", ms., and van Strien "Continuity in nature and in mathematics: Du Châtelet and Boscovich" ms.

[21] For a discussion of Du Châtelet on extension, space and time, see Monica Solomon, "Émilie Du Châtelet and Christian Wolff on extension, space and time: a comparative analysis", ms.

options out there. We could choose to become quietist, and say "Who knows whether physical science has a coherent subject-matter? Let's just get on and see what we can do". But if we're not prepared to do that, then we have to make one of the above options work, and for Du Châtelet the one that I have just outlined was the best available option.

Du Châtelet's solution is a version of the Leibnizian solution, but one which does not concede defeat (see 2.3, above) insofar as the forces by which bodies are held together and constitute genuine unities are themselves subject to investigation through the study of matter in motion. The extent to which Du Châtelet is able to retain this element of Newton's conception of force (its empiricial accessibility via matter in motion), whilst solving the problem of bodies along Leibnizian lines, and simultaneously arriving at an account of bodies in which bodies are causal agents, remains a matter for further investigation.[22] Her project is nothing if not bold.

4. A difficulty for Du Châtelet's solution arising from gravitational theory

In the preceding section I outlined Du Châtelet's solution to the problem of bodies, focusing on the argument by which she establishes the possibility of extended bodies. As noted, for Du Châtelet bodies are not merely extended, but also non-overlapping and capable of action and reaction. Her account favors action and reaction by contact among bodies, and this in turn favors a vortex theory of gravitation. In this section, I present the considerations of gravitation which, by Du

[22] See Steeger, "title?" ms., and note 16(?) above.

Châtelet's own admission, put her solution to the problem of bodies under severe pressure, and I argue that her response is an example of her sophisticated scientific methodology.

Some context is helpful in order to understand the significance of what Du Châtelet is doing. At the time she was writing, vortex theories of gravitation were a live competitor to Newtonian gravitation. Newton had argued in the *Principia* for his universal theory of gravitation, in which gravity acts particle-to-particle, concluding (*Principia*, Book 3, Proposition 7, Corollary 1):[23]

> "Therefore the gravity toward the whole planet arises from and is compounded of the gravity toward the individual parts."

Huygens (and other proponents of vortex theory) rejected this last step in the argument, maintaining that the phenomena of gravitation arise by local action of particles in contact with other particles.

As already noted, Du Châtelet's account of bodies favors action by contact and therefore vortex theory. However, for Du Châtelet this is not sufficient to decide the issue between Newtonian and vortex theories of gravitation. Having introduced the two approaches, Du Châtelet turns to the empirical evidence, and considers two arguments.

The first argument concerns the planetary trajectories. In Book 2 of the *Principia*, Newton had argued that if the matter making up the vortex is of the same

[23] References to Newton's *Principia* are to Cohen and Whitman (1999).

kind as the matter making up the planets, and is therefore subject to Newton's laws of motion, then "the hypothesis of vortices can in no way be reconciled with astronomical phenomena."[24] Huygens responded by rejecting the idealizations and assumptions about fluids that Newton used in making the argument go through. He offered instead a vortex theory recovering the trajectories of the planets.[25] Supposing this successful, the upshot is that empirical evidence does not distinguish between Newtonian universal gravitation and vortex theory for planetary trajectories.[26]

Du Châtelet then moves on to a second argument, concerning the shape of the Earth. She notes that the two approaches, Newtonian universal gravitation and Huygens' vortex theory, give rise to *different* predictions in this case. She writes (*Foundations*, 15.379):

> M. Huygens believed the gravity to be the same everywhere [because it pertains to the body considered as a whole], and Newton assumed it to be different in different places on earth and dependent on the mutual attraction of the parts of matter: the only difference between them is the shape they

[24] *Principia*, Book 2, Section 9, Scholium to Proposition 53.

[25] Huygens (1690).

[26] As pointed out by Eric Schliesser in discussion, Du Châtelet's treatment of the empirical equivalence of the theories with respect to trajectories does not take into account comets, which will prove to be problematic for vortex theories.

> attribute to the earth – since from M. Newton's theory arises a greater flattening than from that of M. Huygens.

So she is very clear about the difference between the two approaches being due to the disagreement over universal gravitation (i.e. whether it is particle to particle or not), and on where the observational consequences differ. She is also up-to-date with the efforts to measure the shape of the Earth, and reports that she is awaiting further results that will help determine the question between Huygens and Newton. She reports the initial results from the measurements taken on the expedition to Lapland led by Maupertuis, as follows (*Foundations*, 15.384):

> The one that comes from the measurements at the Pole is approximately as the one that M. Newton had determined with his theory. Thus, it is true to say that M. Newton made great discoveries owing to the measurements and observations of the French and that he will most likely receive confirmation.

In short, by the 1730s, the empirical evidence on the shape of the Earth favored Newtonian universal gravitation.

This situation puts enormous pressure on the concept of body as extended and impenetrable. The empirical evidence favors an account of gravitation in which the effects of gravity arise not from each body considered as a bulk whole but from every particle of every body interacting with every other particle: the interior particles of a body seemingly interact with one another and with the interior

particles of distant bodies, dependent on the distances of the particles from one another and not at all on whether they are located within the body or on its surface. How could a fluids account reproduce this? Certainly, it would require the fluid to flow through pores in the body, without penetration of the particles making up the body, reaching every tiny particle and affecting its behavior in such a way as to recover the predictions of universal particle-to-particle interaction. The threat is that no pores could ever be sufficiently fine-grained, and no fluid flow could be achieved through such pores, such as to mimic the effects of universal gravitation. Here is d'Alembert, some decades later in the *Encyclopedia*, expressing the problem:[27]

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[27] The *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers*, edited by Diderot and d'Alembert, was published between 1751 and 1772. It can be found online at the ARTFL Encyclopédie Project, https://encyclopedie.uchicago.edu/. The above passage is translated from the entry *Gravité*, which reads as follows: "Or s'il y a quelque matiere qui pousse continuellement les corps, il faut que cette matiere soit fluide & assez subtile pour pénétrer la substance de tous les corps: mais comment un corps qui est assez subtil pour pénétrer la substance des corps les plus durs, & assez raréfié pour ne pas s'opposer sensiblement au mouvement des corps, peut - il pousser des corps considérables les uns vers les autres avec tant de force? Comment cette force augmente-t-elle suivant la proportion de la masse du corps vers lequel l'autre corps est poussé? D'où vient que tous les corps, en supposant la même distance & le même corps vers lequel ils tendent, se meuvent avec la même vîtesse? Enfin un fluide qui

> Now, if there is matter that continually pushes the bodies, it must be that this matter is fluid and subtle enough to penetrate the substance of all the bodies: but how can a body that is subtle enough to penetrate the substance of the hardest bodies and rarified enough to not be perceptibly opposed to the movement of bodies, push considerable bodies toward each other with so much force? How does this force increase following the proportion of the mass of the body that the other body is pushed towards? Where does it come from that all bodies, in supposing the same distance and the same body towards which they tend, move with the same speed? Finally, as regards a fluid that only acts on the surface, whether that be of the bodies themselves or their interior particles, how can it communicate to the bodies a quantity of movement that follows exactly the proportion of the quantity of matter enclosed in the bodies?

What Du Châtelet made clear in her *Foundations* is that the empirical crux of this issue arises from considerations of the shape of the Earth.

If we return now to Du Châtelet's text, we see that she ends her discussion of Newtonian gravitation as follows (*Foundations*, 16.399):

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n'agit que sur la surface, soit des corps mêmes, soit de leurs particules intérieures, peut-il communiquer aux corps une quantité de mouvement, qui suive exactement la proportion de la quantité de matiere renfermée dans les corps?"

> "[It remains] to be examined if some subtle matter is not the cause of this phenomenon… perhaps a time will come when we will explain in detail the directions, movements, and combinations of fluids that operate the phenomena that the Newtonians explain by attraction, and that is an investigation with which the physicians must occupy themselves.

Why does she say this? Why doesn't she simply accept the empirical evidence against vortex theory and adopt Newtonian universal gravitation?

One reason is surely the apparent conflict with her solution to the problem of bodies. Her account demands bodies that are extended and impenetrable, yet universal gravitation works with point particles interacting via a force that is particle-to-particle, independent of that particle's location within or on the surface of a body. Perhaps one should say "so much the worse for the account of bodies", but with our understanding of the deep and far-reaching significance of the problem of bodies, and our appreciation that no other promising solution was available, it is far from obvious that this would be the appropriate response. I believe that Du Châtelet had good grounds for being cautious.

We can situate Du Châtelet's caution in the systematic context of her methodology of science, which offers a second reason for the position she took concerning the gravitational evidence. At the time Du Châtelet was writing, there were widespread and deep divisions over methodology. Du Châtelet was familiar with the Cartesian method of hypothesis; she had read the Leibniz-Clarke correspondence and so would have seen the deep differences over methodology

exhibited in the disagreements between Leibniz and Clarke, and would have been aware of Leibniz's use of his principle of sufficient reason as an inviolable constraint on all physical theorizing. Also on the table were Newton's sparse remarks about methodology in the *Principia*, including his Rules of Reasoning and "hypotheses non fingo", along with his approach to method in the *Opticks*, which might seem somewhat different from that in the *Principia*, at least superficially. References in the extant manuscript of the *Foundations* indicate that the first chapter of the 1738 version of the text (which does not survive, and which was heavily revised prior to the published version) discussed Newton's Rules of Reasoning.[28] Looming large in

[28] See Janik (1982, p. 99). In the manuscript, crossed out, we find the following remark (my thanks to Lauren Montes for this): "According to the third law, given by Mr. Newton for guiding his research into nature (section 10), a law that is accepted by all philosophers. According to this third law, I say, the qualities that we find belonging at all times to all bodies that we know, can be added as universal and inherent to all the bodies since we can not know their properties but through the experiment, and it is only by this law that we are sure that extension and impenetrability universally belong to them." While Du Châtelet uses the French word "loy" as opposed to "règle", she is referring to Newton's third rule of reasoning (that is, his *Regulae Philosophandi*, translated by Cohen and Whitman, 1999, as "Rules for the study of natural philosophy"). In addition to telling us that Du Châtelet initially drew on Newton's rules of reasoning in her methodological considerations, this also tells us that she was working with at least the second edition of Newton's *Principia*, since Rule 3, being discussed here, was new in the second edition.

the background are also Bacon and Boyle in England, and Huygens in France (Huygens had offered a hypothetico-deductive approach). At stake were such fundamental questions as "What principles should be used to constrain theorizing?"; "What interplay should there be between these principles and empirical evidence?"; "What should the role(s) of hypotheses be?"; "What criteria should be used for assessing hypotheses?".

Du Châtelet proposed a methodology which involved an interplay between "principles of knowledge", especially PSR, and detailed empirical considerations, of which I can give only a brief indication here. She wrote (*Foundations*, 1.4 & 1.8):

> [T]he source of the majority of false reasoning is forgetting sufficient reason, and you will soon see that this principle is the only thread that could guide us in these labyrinths of error the human mind has built for itself in order to have the pleasure of going astray.
>
> So we should accept nothing that violates this fundamental axiom; it keeps a tight rein on the imagination, which often falls into error as soon as it is not restrained by the rules of strict reasoning.

With this in place from Chapter 1, in Chapter 4 of the *Foundations* she turns her attention to hypotheses,[29] offering criteria for their utilization and assessment. She

[29] The chapter was reproduced in almost its entirety in the *Encyclopédie* of Diderot and d'Alembert. For discussion of Du Châtelet in relation to the *Encyclopédie* see Carboncini (1987), Maglo (2008), and Seul, A., "Recognizing Du Châtelet : *Les*

emphasizes that a hypothesis must conform to the principles of knowledge, on the one hand, and on the other that the detailed empirical consequences of a hypothesis must be worked out and tested. She writes:

> Without doubt there are rules to follow and pitfalls to be avoided in hypotheses. *The first is*, that it not be in contradiction with the principle of sufficient reason, nor with any principles that are the foundations of our knowledge. *The second rule* is to have certain knowledge of the facts that are within our reach, and to know all the circumstances attendant upon the phenomena we want to explain. This care must precede any hypothesis invented to explain it; for he who would hazard a hypothesis without this precaution would run the risk of seeing his explanation overthrown by new facts that he had neglected to find out about. (4.61)

Institutions de physique in Diderot's *Encyclopédie"* ms. For discussion of Du Châtelet on hypotheses see Hagengruber (2012, pp. 16-25), and the current research of Anne-Lise Rey. As Bryce Gessell discussed in his comments on my paper at the *New Narratives* conference, Duke 2016, the Cartesian context is extremely important for understanding Du Châtelet's discussion of hypotheses. For a discussion of Du Châtelet and Descartes on hypotheses, see Detlefsen, "Du Châtelet and Descartes on the Roles of Hypothesis and Metaphysics in Natural Philosophy", forthcoming.

Moreover, we must draw out all the observational consequences of any hypothesis and check them by observation (4.58). This is the methodology at work in her considerations of gravitation: the hypotheses of Newton and Huygens were assessed with respect to whether they are consistent with an account of bodies that satisfies the principles of our knowledge, on the one hand, and with respect to detailed empirical consequences, on the other. Moreover, while I did not discuss this above, Du Châtelet also argued that Newtonian action-at-a-distance fails to satisfy the principle of sufficient reason, and is therefore problematic.[30] As we saw, in concluding her discussion of gravitation (*Foundations*, 16.399), she urges the "Physiciens" to seek a fluids account of Newtonian attraction. However, importantly, her methodology does not allow us to entertain, let alone accept, the suggestion that there is such a fluid *as a scientific hypothesis* in the absence of detailed empirical implications of that hypothesis. The proposal of such an "ether", unaccompanied by detailed empirical implications, would be a mere "fiction unworthy of a philosopher".[31]

Where does this leave us as regards the problem of bodies in relation to gravitation? Du Châtelet leaves unresolved the tension between (i) the solution to

[30] See Jamee Elder, "Émilie du Châtelet on Newtonian Attraction", ms.

[31] More needs to be done to examine in detail the relationship between Du Châtelet's statements on hypotheses and the chapters in which she engages with contemporary physics. In addition to her discussion of gravitation, Du Châtelet's engagement with the *vis viva* controversy also exhibits features of her methodology; both deserve closer scrutiny in relation to her explicit methodological commitments.

the problem of bodies and the preferred account of gravitation, both of which are based on principles of knowledge, and (ii) the account of gravitation that is to be preferred on the basis of the detailed empirical evidence that her methodology requires us to take seriously. She claims (Chapter 4, see above) that no account is to be accepted that is in conflict with the principles of knowledge, and this leads her to suggest that the "Physiciens" should seek a fluids account of gravitation. Such a suggestion cannot, for her, have the status of a scientific hypothesis, however: scientific hypotheses must have testable empirical consequences. Rather, her achievement is to make precise where the conflict lies, and vivid what the challenge of addressing this conflict demands.

The search for a unified theory of matter, from which to construct an account of physical and mechanical bodies, of living bodies, and of free, moral, embodied agents, was abandoned by some and pursued by others throughout the 18th century, through Kant and beyond. Du Châtelet's *Foundations of Physics* occupies an important place in this story.[32]

5. Conclusions

I have argued that Du Châtelet's *Foundations of Physics* occupies an important place in the unfolding drama of the problem of bodies in the 18th century. If that is so, then why is her text so invisible to us today? Surely, there are sociological and political

[32] This story is, as yet, untold, and is the subject of a joint monograph project with Marius Stan.

reasons for this, but I am not going to discuss those here. Instead, I want to highlight one of the philosophical reasons for the invisibility: treating Newtonian physics as a Kuhnian paradigm makes Du Châtelet's *Foundations of Physics* invisible.

If we think of the early 18th century French Newtonians as already working within a Newtonian paradigm, then we will think that certain questions have already been answered, and we will view their work from the perspective of normal science (articulating the theory, solving problems within the theory, "matching of facts with theory" to quote Kuhn). What that does is to make invisible some of the key problems left unsolved in the wake of the *Principia*, including the problem of bodies as well as the disputes over methodology. To see this more clearly, consider the following quote from Kuhn's *Structure of Scientific Revolutions* (1962, pp. 4-5):

> Effective research scarcely begins before a scientific community thinks it has acquired firm answers to questions like the following: What are the fundamental entities of which the universe is composed? How do these interact with each other and with the senses? What questions may legitimately be asked about such entities and what techniques employed in seeking solutions?"

None of these questions had answers at the time that Du Châtelet was writing, 50 years after the *Principia*. The early 18th century was dealing with deep and important problems about what a body is, how there can be action in the world, and

about how best we can mobilize empirical means to address our philosophical questions, be they physical or metaphysical.

The point I want to stress is this: we know that there are advantages and disadvantages of thinking in terms of paradigms, and that one of the disadvantages is all the things that become invisible. We need to be very aware that if we apply the notion of a "Newtonian paradigm" to the early 18th century, then we are using it as a weapon of power that makes certain kinds of work very visible, and other kinds of work irrelevant and invisible.[33] Specifically, if we treat Newtonian physics as a Kuhnian paradigm established soon after the publication of Newton's *Principia*, this makes Du Châtelet's work on the problem of bodies, and on scientific methodology, invisible.

I concluded the above discussion by noting Du Châtelet's failure to solve the problem of bodies, arguing that this failure arises due to the demands of her methodology, and that the failure is located in a tension between the requirements of her principles of knowledge and the requirements of attention to empirical details. This failure is not surprising. The difficulties in solving the problem of bodies, indeed the failure to find a general solution, is one of the key issues that drives the split between philosophy and physics that emerges in the 18th century. Yet this philosophical struggle itself becomes invisible when 18th century mechanics is viewed through the lens of a Kuhnian paradigm.

I believe that Du Châtelet's *Foundations of Physics* is an interesting and important text in the history of philosophy of science. I have provided evidence for this by

[33] See, for example, Stan, forthcoming, on classical mechanics.

looking at some aspects of her treatment of the problem of bodies. I began the paper by arguing that the problem of bodies was a significant problem at the time Du Châtelet was writing. I then outlined one importan thatt element of her solution to the problem of bodies, and discussed a problem that her solutiuon faces. I showed that the manner in which she addressed this problem is an illustration of the method that she explicitly develops and advocates. Finally, I suggested that treating Newtonian physics as a Kuhnian paradigm established soon after the publication of Newton's *Principia* obscures the status of the problem of bodies in the 18th century, and that this is one philosophical reason why her work is largely invisible to us today. Recovering this broader story will require the recovery of Du Châtelet's *Foundations* as an important text in the history of philosophy. I am delighted to be contributing to the recent upswing of interest in Du Châtelet among philosohers. Long may it continue.

Acknowledgements

This paper is part of the work on Du Châtelet's *Foundations of Physics* being undertaken by a research group at the University of Notre Dame, whose members include Jamee Elder, John Hanson, Lauren Montes, Anne Seul, Phillip Sloan, Monica Solomon, Jeremy Steeger, and Aaron Wells. I am grateful to them all for their work, for our many discussions, and for their contributions to this paper. My thanks to those who offered comments and criticisms on aspects of this work that were presented at the universities of Knoxville (February 2015) and Princeton (March

2015), Notre Dame (April 2015) the British Society for the Philosophy of Science (June 2015), UC Davis (March 2016), Groningen (March 2016) and at the Duke New Narratives conference (April 2016).

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