Du Châtelet and the philosophy of physics

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Abstract

In her *Foundations of Physics*, Du Châtelet contributed to the central foundational issues in philosophy of physics at the time, ranging from Newtonian gravitation to the question of proper method for physics. I present Du Châtelet's *Foundations* as a unified attempt to address these issues. Du Châtelet used rational constraints such as the principle of sufficient reason as well as empirical evidence to guide theorizing in physics. She developed an account of the nature of body, and of how bodies act on one another, that enabled her to intervene in the dispute over Newtonian gravitation and in the ongoing discussions concerning contact action. She advocated mechanism as an explanatory ideal for physics, endorsed a plenum over atoms and the void, and sought a middle path between absolutism and relativism in the debates over space, time and motion. This paper offers an introduction to Du Châtelet's *Foundations* for those interested in these familiar themes from the philosophy of physics.

1. Introduction

For philosophers of physics, the *Leibniz-Clarke Correspondence* (Leibniz and Clarke, 1956) provides a rich entry-point into seventeenth and eighteenth century discussions of space, time, motion, force, gravitation, atomism, and method, the subsequent evolution of which persists into debates in philosophy of physics today. Emilie Du Châtelet's *Foundations of Physics* was published twenty-three years after the *Correspondence*; it offers a comprehensive and accessible update on all of these issues, and moves the debates forward. Like the *Leibniz-Clarke Correspondence*, it should be required reading for philosophers of physics.

At the heart of these discussions is the theory of bodies in motion. Famously, Newton believed that developing such a theory required the introduction of absolute space and time, whereas Leibniz rejected this move. Moreover, in developing his account of planetary motions, Newton introduced his theory of universal gravitation, which seemed to imply that the planets – and indeed all particles of matter in the universe – act on one another at a distance by means of a gravitational force. Leibniz rejected action-at-a-distance, favoring contact as the only intelligible means by which one body may act on another.

Running throughout these debates is the issue of method: disagreements over the appropriate role of the Principle of Sufficient Reason (PSR) and the Principle of the Identity of Indiscernibles (PII), and over the use of observations and the place of hypotheses. And so, as Du Châtelet saw well, the issues concerning the motions of bodies must be addressed in tandem with those of method. The primary philosophical problem that motivates her book is bodily action (how, if at all, does one body act on another?), and the framework for addressing this issue is provided by her account of method.[1] These two themes structure and unify the text, or so I maintain.

Chapters 1-4 of the *Foundations* concern the principles of our knowledge; the role of God in theorizing; essence, attributes, and modes; and hypotheses. In my view, these chapters are primarily methodological in intent, and contain the conceptual resources she believes she needs for addressing the problem of bodily action.

Chapters 5 and 6 are on space and time respectively. These are followed by four chapters (7-10) on the nature and constitution of bodies, and then the remaining chapters concern the motions and actions of these bodies, including the laws of motion (chapters 11 and 12), gravitation (chapters 13-19), and action by contact (chapters 20-21) including "vis viva" (chapter 21).

As we will see, Du Châtelet used both PSR and empirical evidence as guides to theorizing in physics. She developed an account of the nature of body and of how bodies act on one another that enabled her to intervene in the dispute over Newtonian gravitation as well as in the ongoing discussions concerning contact action. She advocated mechanism as an explanatory ideal for physics, endorsed a plenum over atoms and the void, and sought a middle path between absolutism and relativism in the debates over space, time and motion. In this paper, I offer an introduction to Du Châtelet's *Foundations* for those interested in these familiar philosophy of physics themes, and thereby argue for the importance of Du Châtelet's *Foundations* for philosophers of physics.

Du Châtelet's contributions to philosophy of physics go beyond the *Foundations*: she also wrote on the nature of heat and fire and on optics, and wrote a commentary on Newton's *Principia* (accompanying her translation). These texts lie outside the scope of the present paper; further work is needed to integrate them into a comprehensive picture of Du Châtelet's philosophy of physics.[2]

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[1] See Brading 2019a.

[2] The primary sources and reference materials on these texts can be found by visiting ProjectVox (https://projectvox.library.duke.edu/).

2. Method

I begin with a brief review of the main elements of Du Châtelet's discussion of method.[3]

Du Châtelet worried about the lack of a secure epistemic basis for physics, arising from inadequacies in the methods of physics. She had examined the methods of the Cartesians and of the Newtonians and had found them wanting: neither offered a secure path forward for addressing her principal concern, of how bodies act on one another. On the one hand, Cartesians were too free in their use of hypotheses, leading to books filled with "fables and reveries" (Du Châtelet, 2009, 4:55). On the other, Newtonians claimed to reject hypotheses altogether, but this goes too far the other way since the progress of physics depends on building on earlier hypotheses. How, then, to admit hypotheses as part of scientific practice, without allowing the profligate errors of the Cartesians?

In Leibniz's principle of contradiction (PC) and principle of sufficient reason (PSR), Du Châtelet found the additional resources she was looking for. She uses PC to distinguish between the impossible (that which implies a contradiction) and the possible (that which does not). When we are theorizing, and we claim that something is possible, we are required to "show that the idea is free of contradiction" (Du Châtelet, 2009, 1:6). This will be important later when we consider her discussion of atomism. Notice that Du Châtelet adopts PC as a constraint on our reasoning: it is introduced as her preferred tool (one that she contrasts explicitly with the Cartesian criterion of clear and distinct ideas, for example) by which we are to develop and assess our theoretical claims. Yes, PC has metaphysical import, but Du Châtelet's reasons for adopting it are its utility for us in our attempts to arrive at truths concerning what is possible and impossible. In adopting PC as a principle of our knowledge, she adopts it as a method of reasoning concerning possibility.

Similarly, in Du Châtelet's hands PSR is not, first and foremost, a metaphysical principle. Rather, it is the means by which we determine the actual from within all that is possible. In particular, the sufficient reason for the present state of something must be found in the preceding state of that thing and of everything with which it is causally connected. This will be important later when we consider Du Châtelet's discussion of the interaction of bodies, including by gravitation.

It is not simply that PC and PSR are useful and powerful tools for theorizing. Du Châtelet makes the stronger claim that they are presuppositions that must be adopted for knowledge to be possible, and this justifies their status as

[3] For more details see Brading, 2019a, chapter 2, and references therein.

methodological requirements. She writes that without PC something could exist and not exist at the same time, and that "everything could be, or not be, according to the fantasy of each person" (2009, 1.4). So, as a consequence of supposing that it is possible for us to know things, we must adopt PC as a constraint on our theorizing. PSR is similarly entailed. Du Châtelet offers a series of examples (see 1740, chapter 1), the most interesting for philosophers of physics is perhaps the following. Newtonians explicitly rely on inductive practices in their empirical enquiries, but Du Châtelet claims that without the presumption of PSR there can be no measurements, and so empirical science would not be possible. This is because measurements involve comparisons of equality and inequality, identity and difference. She writes (2009, 1.8):

> Thus, for example, if I have a ball made out of stone, and a ball of lead, and I am able to put the one in the place of the other in a basin of a pair of scales without the balance changing, I say that the weight of these balls is identical, that it is the same, and thay they are identical in terms of weight. If something could happen wihtout a sufficient reason, I would be unable to state that the weight of the balls is identical, at the very instant when I find that it is identical, since a change could happen in one and nother other for no reason at all; and consequently, their weights would no longer be identical…

The choice of weight is apt. Newton's *Principia* is all about gravity, and the empirical evidence on which it depends involves not only weighing terrestrial objects but also "weighing" the Moon. Where some appealed to the benevolence of God in maintaining a well-ordered universe as justification for their use of induction (see, for example, 's Gravesande 1720, Preface), Du Châtelet committed herself to PSR as a presupposition with powerful methodological implications. If PSR must be presupposed in order for knowledge to be possible, then it should be respected as a constraint on theorizing. We can ask about its metaphysical justification -- the world must co-operate, and how can we know that this is the case? – but that was not Du Châtelet's primary concern. If we suppose that knowledge is possible, then we have no choice but to adopt PC and PSR as principles of our knowledge, and Du Châtelet demands that having done so we recognize them explicitly as constraints on our theorizing and place them at the heart of our methods for achieving knowledge. This is how I see the place of PC and PSR in her philosophy of physics.

In the *Leibniz-Clarke Correspondence*, Leibniz argued against Newton's absolute space, time, and motion, and against atomism, using PSR and PII. Du Châtelet's

account of method gives weight to these arguments, but does not make them decisive. This is because a good hypothesis must satisfy further requirements. In addition to respecting the principles of our knowledge (PC and PSR) it must also meet specific empirical considerations. These latter Du Châtelet spelt out in perhaps her most famous chapter, the chapter on hypotheses (subsequently reproduced in the highly influential *Encyclopedia* of Diderot and d'Alembert). There, Du Châtelet argued for the importance of hypotheses for theorizing and theory-development, and argued that a good hypothesis is one that not only fits all known observations, but agrees with observations in all its consequences. Moreover, we should seek novel predictions, be careful about which elements of a hypothesis are confirmed (or rendered probable) or falsified by observations, and we must not make *ad hoc* modifications to our hypotheses. The chapter is strikingly familiar to philosophers of science today, and can be read in full in Bour and Zinsser 2009.

With this brief review of the main elements of Du Châtelet's method in hand (for more on which see Brading 2019a, Detlefsen 2014, Hagengruber 2012, Janik 1982, Rey, forthcoming), we now turn to her discussion of bodies in motion, and their actions upon one another, where this method is at work.

3. Bodies, forces, and the laws of motion

Newton's laws of motion are about bodies: "*every body* continues in its state of rest or of uniform motion…" and so on. But what is a body? In the early 18th century, physics was the subdiscipline of philosophy charged with providing a general account of bodies: their nature, properties, and behaviors; the causes and effects of those behaviors; and so forth. There was widespread agreement that bodies are extended, mobile, and impenetrable, and that they act on one another by contact. Nevertheless, as we will see, there are conceptual difficulties with each of these that were the subject of dispute. Morever, there were disagreements over what other properties, if any, belong to the nature of body, and what other ways, if any, bodies act on one another. Du Châtelet sought an account of the nature of bodies that would resolve these problems. In my view, this is the central movitating problem of the *Foundations*.

Her approach to the problem of bodies begins from the Cartesian position that extension is the essence of body. Du Châtelet argues that this conception of body leads to occasionalism, which she rejects seeking instead an account in which bodies have causal efficacy.[4] Moreoever, any account that admits only extension to the essence of body violates PII, Du Châtelet says, since such matter would be entirely

[4] See Du Châtelet, 2018, chapter 8; and Brading, 2019a, p. 67.

homogeneous and all its parts similar to one another. These two issues are addressed with a single solution: Du Châtelet adds "force" to the essence of matter in order to ensure that the parts of matter are distinct from one another and capable of acting. How does this work? The argument seems to go like this. Suppose that matter were purely extension. Suppose that the parts of a portion of this matter, however small, were all at rest. Then they would be entirely similar. But this violates PSR (via PII). Therefore, the parts of matter must be in different states. Let a "force" internal to the parts of matter be the source of this real difference between them, and let it also be that which provides a body with the power to act. Then both of our problems are solved. In other words, Du Châtelet identifies the force of a body introduced to satisfy PSR with the force by which a body is able to act, so that the "internal force" is also a "force tending towards motion" and a "motive force" (see Du Châtelet, 2018, 8.139-141). This does not complete Du Châtelet's account of body. In order for one body to act on a second, the latter must resist the action of the first, for otherwise PSR would be violated: there would be no sufficient reason for the first body to act (2018, 8.142). According to Du Châtelet, the essence of body consists of extension, active (or motive) force, and passive (or resisting) force. The justification for this claim is our requirement that PSR be satisfied, and our experience that bodies (including our own) do indeed act. Du Châtelet claims that these three principles are mutually independent and jointly necessary and sufficient for an account of the nature of body.

With her account of the nature of bodies in place, Du Châtelet then turns to their motions. Her laws of motion are similar to Newton's, but differ from them in important and interesting ways. At the time, Newton's laws were not universally accepted and were given different formulations by different people, so Du Châtelet was not alone in offering her own version.[5] Moreover, the epistemic status of such laws was controversial. What justification of them was required? Are they inductive generalizations? Do they follow deductively from the nature of bodies? Are they to be derived at least in part (as Descartes suggested) from the nature of God? Newton had stated them as "Axioms, or Laws of Motion", and in his discussion he offered some empirical considerations while also suggesting that his laws already had the status of generally accepted principles. Du Châtelet rested her version of the laws on her account of bodies, and argued for them using PSR. She stated them as follows (2009, 11.229):

> *First Law.* A body perseveres in the state it is in, be it rest or motion, unless some cause removes its motion or its rest.

[5] See Reichenberger 2018 for a detailed discussion of Du Châtelet's laws of motion.

Second Law. The change that happens in the motion of a body is always proportional to the motor force that acts on it; and no change can happen to the speed and the direction of the moving body except by an exterior force; for without that, this change would happen without sufficient reason.

Third Law. The reaction is always equal to the action; for a body could not act on another body if this other body did not resist it. Thus the action and the reaction are always equal and opposite.

Du Châtelet appeals to her account of the forces of bodies (active and passive) and to PSR in order to provide a justification for each of the laws. Whether this justification is successful is another question, and one we will not pursue here.

4. Bodily action: gravitation and collision

With her account of bodies and laws in hand, Du Châtelet is in a position to address the driving question of the *Foundations*: how is it that bodies act on one another? The *Leibniz-Clarke Correspondence* (1956) opens with questions of God's presence and action in the world, and quickly turns to the issue of how one body acts on another, both in collisions and also, more famously, in accordance with Newton's theory of gravitation. Leibniz wrote (1956, 94):

> But then what does he mean, when he will have the sun to attract the globe of the earth through an empty space? Is it God himself that performs it? But this would be a miracle, if ever there was any. …
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> … That means of communication (says he) is invisible, intangible, not mechanical. He might as well have added, inexplicable, unintelligible, precarious, groundless, and unexampled.
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> … If the means, which causes an attraction properly so called, be constant, and at the same time inexplicable by the powers of creatures, and yet be true; it must be a perpetual miracle: and if it is not miraculous, it is false. 'Tis a chimerical thing, a scholastic occult quality.

Du Châtelet addresses the question of whether bodies act on one another via gravitational attraction in chapters 15 and 16 of the *Foundations*. In chapter 15, she reviews both Newton's theory of universal gravitation and Huygens' version of a vortex theory of gravitation with respect to the empirical evidence. In Newtonian universal gravitation, every particle acts on every other particle in the universe by a mutual attraction proportional to the masses of the particles and inversely

proportional to the square of the distance between them, and this attraction is responsible for the motions of the planets as they orbit the Sun in otherwise empty space. Leibniz, among others, opposed Newtonian attraction on the grounds that action-at-a-distance is unintelligible. They favored instead various versions of Descartes' vortex theory of gravitation, in which the Sun and planets are immersed in a medium of finely divided and fast-moving matter, swirling in a vortex around the Sun and carrying the planets around in their orbits. In chapter 15, Du Châtelet examines the empirical evidence and argues that recent measurements of the shape of the Earth favor Newton's theory over Huygens's.

Du Châtelet does not, however, end her discussion there. Her method requires that theories answer not only to empirical evidence but also to the "principles of our knowledge". In chapter 16, she argues against Newtonian universal gravitation via appeal to PSR. Moreover, as Janiak (2018 and forthcoming) has shown, chapter 3 of the *Foundations* (on essences, attributes and modes) has a crucial role to play for, if the question is whether or not gravity is an essential property of bodies, then we must be clear about what such a claim does (or does not) amount to. This is something on which Newton was notoriously terse, even by his own standards, and what he does say leaves the situation unclear. Du Châtelet's arguments from PSR seem to me to be unconvincing,[6] but the upshot is that Du Châtelet sides with Leibniz in rejecting action-at-a-distance as an ultimate explanation. She does not think that, in the end, bodies act on one another via attraction (for more on this, see "mechanism", below).

Nevertheless, she does not think this is reason to reject Newtonian universal gravitation from physical theorizing. Rather, we can admit gravity as a physical quality and make use of gravitational attraction in doing physics, while continuing to search for a mechanical explanation of gravity. She writes (2018, 16.399):

> perhaps a time will come when we will explain in detail the directions, motions, and combinations of fluids that bring about the Phenomena that the Newtonians explain by attraction, and this is a quest to which all Physicists must apply themselves.

Meanwhile, physics will have to make use of explanations that appeal to attraction. Du Châtelet discusses action-at-a distance quite generally (including gravitational attraction as well as additional proposed cases of attraction and repulsion) in chapters 15 and 16.

[6] For more details, see Brading, 2019a pp. 93-5, and Janiak (2018 and forthcoming).

The other candidate for bodily action as of the early 18th century was action by contact, and in particular collisions. In contrast to Newtonian gravitational attraction, Leibniz held contact action to be intelligible. Yet debates continued over how to theorize contact action, with the controversy over *vis viva* being the most famous strand of these debates, one that is also found in the *Leibniz-Clarke Correspondence*. If gravitational attraction is unintelligible and therefore to be rejected, while collisions are to be admitted as the only intelligible means by which one body acts on another, then the onus falls on those rejecting attraction to demonstrate the intelligibility of contact action.

What would this involve? The parallel with Newton's theory of gravitation is instructive. Newton provided a mathematical rule for the behavior of bodies acting on one another via gravitation. The rules of collision can be thought of as analogous. Leibniz demanded that the rule for gravitation be rendered intelligible in terms of an underlying theory of matter, one which showed how it is that one body acts on another such that the upshot is motion in accordance with the law of gravitation. The analogous demand is to provide an account of the collision process, in terms of an underlying theory of matter, that renders intelligible how it is that one body acts on another such that the upshot is motions in accordance with the rules of collision. At the time of the *Leibniz-Clarke Correspondence*, and later when Du Châtelet came to write her *Foundations*, there existed no generally accepted account.[7]

Du Châtelet's investigation of contact action takes place in the final chapters of the *Foundations*, chapters 20 and 21, following completion of her discussion of gravitation (chapters 13-19). Earlier in the *Foundations*, we have already learned about the active and passive force of bodies (see above), and about the division of active force into "dead force" – when a body strives to move but fails – and "living force" – when a body strives to move and succeeds.[8] She writes (2009, 11.268):

> When a moving body encounters an obstacle, it strives to displace this obstacle; if this effort is destroyed by an invincible resistance, the force of this body is a *force morte* [dead force], that is to say, it does not produce any effect, but it only tends to produce one.
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> If the resistance is not invincible, the force then is *force vive* [live force], for it produces a real effect, and this effect is called *the effect of the force of this body*.

[7] See Brading and Stan (forthcoming), from which this paragraph is drawn.
[8] Dead force, like living force, also comes in two kinds, active and passive. See 20.529-30.

Chapters 20 and 21 develop the account in detail. The early decades of the 18th century saw rapid developments in rational mechanics, with an accompanying search for new principles that would be adequate for the new problems that mathematicians and physicists were trying to solve. This included conservation of *vis viva* (living force) as well as attempts to re-purpose and extend principles of statics, and in particular the notion of equilibrium, for situations involving motion.[9] Both are important for philosophers of physics interested in the development of Lagrangian mechanics. Chapter 20 concerns itself with "dead force" which is the means by which Du Châtelet explains equilibrium situations in which bodies press on one another but no motion results. In such cases, the active force by which one body acts on another is dead force, but once the obstructing body yields and motion ensues, the active force manifests as living force. Living force is the subject of Chapter 21. With these resources, Du Châtelet is able to offer an explanation of how bodies act on one another by contact.[10]

In both chapters, Du Châtelet is concerned with the empirical measures of force, be it dead or living, and this is what leads to her involvement in the debates over *vis viva*, another topic of the *Leibniz-Clarke Correspondence*. Du Châtelet's intervention in the *vis viva* debate has been widely discussed,[11] and I will not review it further here. The upshot of chapters 20 and 21 is that Du Châtelet believed she had shown contact action to be both intelligible (via her version of the Leibnizian theory of active, passive, living and dead forces) and consistent with the empirical demands of her method.[12]

This completes her response to the question of how it is that bodies act on one another. She has provided an account of the nature of bodies -- in terms of extension, active force, and passive force -- that has enabled her to show that contact action is intelligible and empirically successful, whereas Newtonian attraction, though empirically successful, fails to satisfy the requirement of intelligibility.

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[9] This is due especially to Jakob Bernoulli, and then D'Alembert built on this notion of equilibrium in his *Traité de Dynamique* of 1743 in which he formulated what later developed into "D'Alembert's Principle". See Brading and Stan (ms.) for details.
[10] See Brading, 2019a, pp. 82-7 for how this account applies to collisions. As was standard at the time, Du Châtelet divides bodies into hard, soft and elastic (see 11.267).
[11] For Du Chatelet and *vis viva* see Brading 2019a, pp. 95-97; Hagengruber 2012, pp. 35-8; Hutton 2004, especially pp. 527-9; Iltis 1977, pp. 38-45; Reichenberger 2012, pp. 157-71; Terrall 1995 pp. 296-8; Kawashima 1990; and references therein.
[12] Or so she believed. For a critical appraisal, see Brading 2019a, pp. 86.

5. Mechanism and atomism

Du Châtelet prefaces her laws of motion with the following statement (11.229):

> The active and passive force of bodies is modified by their impact, according to certain laws that can be reduced to three principles.

This does not rule out the applicability of her laws to other forms of interaction among bodies, but in practice Du Châtelet seems committed to contact action as the only means by which bodies act on one another (see the discussion of gravity, above). There are several places in her text where one might hope to extract an argument for this conclusion, but none that seems successful (see Brading, 2019a, pp. 87-9). In my view, her commitment to mechanism is primarily methodological rather than metaphysical, in two respects. First, it represents an ideal of intelligibility for explanations, and second it encourages persistence in theorizing about the nature and motions of bodies.

As an ideal, mechanical explanations may be beyond our capacities in many cases. Du Châtelet maintains that we must not rush to give such explanations where these are out of reach of empirical investigation. Much of what we observe arises from parts of matter so finely divided and fast-moving as to be beyond the reach of our senses, and so we must begin by limiting ourselves "to observing carefully the qualities that fall under our senses and the phenomena that result" (2014, 9.176), for "these physical qualities, which make up the effect of mechanical causes, must necessarily precede them in the explanation of phenomena" (2014, 9.184). We should use these physical qualities, including magnetism, electricity, fire, cohesion, elasticity, and gravitation, to provide interim explanations as we work towards the underlying mechanical explanations, which may nevertheless be forever out of our reach. Nevertheless, we should continue to seek such an explanation because "it is the only one with which one can make sense of the phenomena in an intelligible fashion" (2014, 9.182). Insofar as that which is intelligible is that which satisfies the principles of our knowledge, Du Châtelet's position seems to be that only mechanical explanations sastisfy PSR. Mechanical explanations are an explanatory ideal, a goal that should be approached in accordance with her two-pronged method (see above).

This explanatory ideal encourages persistence because, while Du Châtelet endorses appeal to physical qualities, she also urges that explanations in terms of such qualities should not be thought of as the end point of theorizing: "we must try, as far as possible, to explain the Phenomena mechanically, that is to say, by matter

and motion" (2018, 8.162). And so, even when a mechanical explanation is far from our reach, we must persist in working towards it and not stop at explanations in terms of higher level physical qualities such as magnetism, elasticity, cohesion and gravity.

The higher level physical qualities are associated with regularities in observable phenomena, and these seem to offer empirical evidence in favor of atomism (see chapter 9 of the *Foundations*). On the one hand, constructively, the same seeds consistently produce the same animals and plants, they take the same time to grow, and they have the same properties over time. Were matter infinitely varied, this stability would be difficult to explain. Appeal to atomism, with its stability in the shapes and sizes of the ultimate building blocks of plants and animals (as well as their sources of nutrition and so forth), makes the stability and differentiation of species over time explicable. Du Châtelet states (2014, 9.172):

> The order that reigns in the universe, and the conservation of that order, thus appear to prove that there are solid particles in matter.

On the other hand, destructively, "[t]he dissolution of bodies has fixed limits": we can melt gold, pulverize it, do all that we can to divide it into constituents, but we never succeed in dividing it into a different kind of substance. Du Châtelet did experiments herself, and she was familiar with the limits of our ability to transform bodies of one kind (such as lead) into bodies of another (such as gold). This is difficult to explain if matter is indefinitely divisible, but readily explicable if there are species of atoms of fixed shape and size that cannot be further divided. Du Châtelet concludes:

> It is thus strongly likely that there are particles of matter of a certain determinate littleness which nature does not divide further.

This is what the empirical evidence suggests. However, the principles of our knowledge tell a different story. In the *Leibniz-Clarke Correspondence* Leibniz rejects atomism on the grounds that atoms violate PII. And, as we saw above, in light of PII Du Châtelet includes "force" in addition to extension in the essence of matter, in order to ensure that the parts of matter are distinct from one another. She repeats this conclusion in chapter 9, writing (2014, 9.172):

> indivisible atoms, or parts, of matter are inadmissible, if one considers them as simple, irresolvable and primitive matters, because one cannot give a sufficient reason for their existence.

Here, she refers back to chapter 7 (2009, 7.120-21) where she argued against atomism. There, the question was how extended bodies are possible at all. The postulation of atoms, understood to be small parts of extended matter, fails to address this issue because it fails to explain how extension is possible in the first place. Du Châtelet explains that such beings cannot be necessary since their divisibility implies no contradiction. Moreover, given her understanding of PC (see above), we can conversely argue that the postulation of extended yet indivisible atoms risks introducing a contradiction into physics:[13] unless we can show that there is no such contradiction, we have failed to show that atoms are possible, and have thereby failed to meet the methodological demands placed on us by adopting PC as a principle of our knowledge.

How are we to reconcile the empirical evidence with the demands of PC, PSR and PII? Du Châtelet's answer is that though divisible, there are parts of matter that nevertheless remain undivided, and that "all the bodies that compose the universe result from the composition and the mixture of these solid particles, so that one can regard them as elements" (2014, 9.172). The ultimate constituents satisfy PII, but they come together to form particles that persist undivided and are sufficiently similar that they serve as elements. Addressing their persistence as undivided parts of matter, she writes:

> If one asks for the sufficient reason of this actual irresolvablity of the little bodies of matter, it would be easy to find in the mutual movements of its parts, for mutual movements are the cause of cohesion, according to Leibniz. (2014, 9.173)

It is not at all clear that this is an adequate response, but to investigate it further would take us into her account of cohesion (see 2014, 9.179) and too far from our present concerns. In short, Du Châtelet believes the empirical evidence to show that matter divides and is divisible way beyond the limits of our senses; that there is nevertheless a limit to this division, with stable configurations or particles of matter beyond which matter does not in fact further divide naturally; and that these particles of matter arise from constituents satisfying PII.

[13] For more on this see Brading 2019a, p. 55-8.

6. Space, time and motion

As philosophers of physics know well, any physics of the motions of bodies requires a theory of space, time, and motion, and the *Leibniz-Clarke Correspondence* is the canonical source for the debate over absolute versus relative space, time and motion. Here, Du Châtelet's *Foundations* is interesting in two respects: for her summary and analysis of the state of the debate at the time, and for the ways in which she attempts to move the debate forward, taking lessons from both sides. As we will see, while she endorses a relationist metaphysics of space, time, and motion, she seeks to recover the epistemic benefits of the absolutist position.

Du Châtelet opens her chapter on space by setting up two opposing views. According to the first (2017, 5.72), space is

> nothing over and above things, it is a mental abstraction, an ideal Being, it is nothing other than the order of things as they coexist, and there is nothing to Space except bodies

This is her characterization of Leibniz's relationist position, familiar from the *Leibniz-Clarke Correspondence*.

According to the second (2017, 5.72), space is

> an absolute Being, real, and distinct from the bodies it contains… an intangile, penetrable extension, lacking solidity, the universal vessel that receives the Bodes that are placed in it…

This is the absolutist position, most familiar from Newton. Du Châtelet explicitly offers a *container* interpretation of absolute space: it is a vessel in which bodies are placed. Du Châtelet seems to associate contemporary absolutism primarily with Gassendi, Locke, Newton, Keill and Clarke.

According to Du Châtelet, the arguments in favor of the relationist position are metaphysical, whereas the reasons for adopting the absolutist view are negative arguments against the relationist position, and these arguments are empirical (they are arguments from the phenomena).

Du Châtelet offers two arguments in support of relationism, both of which rely on PSR. The first is an argument against the possibility of there being atoms in a void. Were there such an atom, it would have to be of a determinate shape and size. Yet the void contains no reason for the atom to have any particular shape and size. And so there cannot be atoms in the void, since this would violate PSR. Then, since

there cannot be void space, there cannot be absolute space. The second is Leibniz's argument from his correspondence with Clarke, which we paraphrase as follows. Were there absolute space, then the finite material universe would have to be placed somewhere determinate in that space. Yet space being perfectly homogeneous, there can be no reason for placing the universe in one location rather than another. And so there cannot be absolute space, since this would lead to a violation of PSR.

Du Châtelet reports Clarke's response: the reason is simply the will of God. This is one of the many places in the *Leibniz-Clarke Correspondence* where we find Leibniz and Clarke talking past one another, and Du Châtelet correctly diagnoses the issue, siding with Leibniz (2018, 5.74):

> one can easily see that this admissions undermines his view, and lays bare the weakness of his case; for God would not be able to act wihtout reasons within his own Understanding, and his will must always be determined by reason. Thus being obliged to resort to an arbitrary will of God, which is not based on sufficient reason, is to be reduced to the absurd.

Du Châtelet agrees with Leibniz: PSR requires that we reject absolute space.

What, then, of the empirical arguments against relationism, and thereby in favor of absolutism? The arguments that Du Châtelet addresses concern the plenum. This is because the first of Du Châtelet's arguments against absolutism yielded the conclusion that there cannot be void space. This, in turn, means that the relationist must endorse the plenum, and Du Châtelet sees the arguments against relationism arising from the associated commitment to a plenum. She claims that there are three principal objections, and she dispatches all of them in one short paragraph (see 2018, 5.76). Yet as we read the absolute versus relative debate today, we take Newton's bucket experiment to be crucial, and to be independent of whether or not one is a plenist. Du Châtelet doesn't even mention it. The significance of the bucket and of rotational motion seems at first sight to have escaped Du Châtelet entirely. We return to this issue below.

We have seen that Du Châtelet sides with Leibniz when it comes to the metaphysical status of space. However, she is also keenly aware of the utility of the *idea* of absolute space for the purposes of physics. The next several paragraphs of the chapter (77-87) concern our idea of space: how we come to have this idea, and what its properties are (see Lin, ms.). In her view, we form the idea of space by abstraction from considering one thing external to another. This ideal space has the familiar Newtonian properties of being homogeneous, uniform, continuous, penetrable, immutable, eternal, infinite, and so forth (see 5.84). Then, in the final

paragraphs of the chapter, she tells us what the distinction between "absolute" and "relative" place amounts to, given her relationist account of space. We return to this below, as well.

Turning next to the case of time, Du Châtelet gives even more short shrift to the metaphysical arguments over absolutism versus relativism. She says that the cases of space and time are parallel, and that Leibniz's argument using PSR is once again effective. For if time were an absolute being then the time at which the world was created would lack sufficient reason. Her chapter on time opens with the following summary of the relationist position, which she endorses (6.94):

> The notions of time and space are very similar. In space, one simply considers the order of the coexistents insofar as they coexist; and in time, the order of successive things, insofar as they succeed each other, discounting any other internal quality than simple succession.

However, as in the case of space, she nevertheless recognizes the importance of the idea of absolute time, and she moves swiftly to consider the origin of this idea. Here, we arrive at two asymmetries, one in the origin of our ideas of space and time, and the other in the measurement of space and time. The second is of particular interest for philosophers of physics, and we approach it via the first.

For Locke, there is an asymmetry in our ideas of space and time. We arrive at our idea of space from our experience of the impenetrability of other bodies, and by distinguishing this from the extension of these bodies (see Locke, *Essay* 4th edition, 1700, Book II chapter IV). These bodies are external to us, and so our idea of space involves the idea of an extension *external* to us, stretching away from us in all directions. We arrive at our idea of time, on the other hand, from the succession of our ideas. Locke is at pains to show that this succession is *internal* to us, not deriving from our experience of the motions of bodies; it does not depend on anything external to us.

Du Châtelet's account of the origin of our idea of space also involves externality, but is different from Locke's: it does not involve the impenetrability of bodies, but it does involve imagining other objects external to ourselves (see 2009, 5:77, and for detailed analysis see Lin, ms.). Moreover, for Du Châtelet, there are important similiarities between our ideas of space and time. In particular, each provides a structural unity to the multiplicity of beings as we experience them. For example, in the case of space she writes (2018, 5:77):

> Since we represent to ourselves in extension several things that exist external to one another and are *one* through their union, all extension has parts that exist external to one another and are *one*; and once we represent to ourselves parts both diverse and unified we have the idea of an extended Being.

Time is a little more complicated (see Du Châtelet 2009, 6:97), for in this case too we structure non-coexisting as well as coexisting things, and our idea of time arises "insofar as one gathers together these diverse existences, and considers them as making *one*". Nevertheless, this similarity hides an asymmetry, for whereas the idea of space depends necessarily on the representation of externality, the same is not true for time. At the end of her account, Du Châtelet seems to agree with Locke when she says: "we would have a notion of time even if nothing other than our soul existed". Like Locke, she denies that we get our idea of time from our experience of the motion of bodies external to us; so long as there is a succession of our ideas, then we can get our idea of time. It seems, then, that Du Châtelet has a version of the internal/external asymmetry between time and space that we have already seen in Locke.

There is more work to be done on the origin of idea of time in Du Châtelet, and on its relationship to our idea of space. Her account is highly interesting and original, deserving detailed treatment in its own right. I make these inadequate remarks here because they pave the way for a second asymmetry, one that is of particular interest to philosophers of physics.[14]

Suppose we think of spatiality as external in origin, whereas temporality is internal, as the first asymmetry suggests. Du Châtelet argues that, in experiencing the succession of our ideas, each of us has our own "time", one that cannot be directly compared with anyone else's.[15] Yet our communal activities, whether in ordinary life or in doing physics, require a shared measure of time, and this means that "we have been obliged to take the measurements of time outside of ourselves". Specifically, we have chosen to use the motions of the Sun as they appear to us from

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[14] There are further fascinating analogies and disanalogies between space and time in Du Châtelet's overall picture. For example, both space and time – considered physically and not mathematically -- have finite least parts (see 6.105 for time), but the reasons why differ subtley.
In the former case, bodies are that which is physically extended, and bodies

[15] Except, perhaps, for the shortest interval of experienced time, during which a single idea stays in our mind; Du Châtelet allows that this might be universal (6.115).

our shared vantage point on Earth. This brings us to the second asymmetry between space and time (6.113):[16]

> There is not, and cannot be, a very accurate measurement of time; for one cannot apply a part of time to itself to measure it, as one measures extension by *pieds* and *toises*, which are themselves portions of extension. Each has his own measurement of time in the quickness or slowness with which his ideas succeed each other…

The measurement of time seems to pose special challenges not present in the measurement of space.

To clarify the asymmetry here, begin from the claim that the measures of extension are themselves portions of extension. This is ambiguous between two claims, both of which are interesting. The first is that, since extension is itself external to us, the external units by which we measure it are identical to actual portions of that which we seek to measure. The second is that the tools by which we measure extension – such as rulers and yardsticks – are themselves extended and so when we apply a yardstick to measure extension there is no gap between the length of a true yardstick and a yard of extension. Now consider the disanalogous claims for time. First, since time is internal to us, the external units by which we measure it (such as the motions of the Sun that yield the length of a day from one sunrise to the next) cannot be identical to the internal intervals in our heads (the motions of the Sun are external, and so by definition are not taking place inside anyone's head). And second, since the tools by which we measure time use periodic motions to indicate elapsed duration, there can be a gap between the presumed regularity of these motions and equal intervals of time itself (whether internal or external, whether relative or absolute). That is to say, any physical clock may be imperfect: it may tick irregularly with respect to time itself.

The second of these claims, that the relationship between measuring tools (rods and clocks) and that which is measured (extension and duration) differs between space and time, reflects an asymmetry present in Newton's *Principia*,[17] and one that persisted until the early 20th century. So in Locke's *Essay* and Newton's *Principia* there is a very interesting conflux of issues concerning the epistemology of space and time, and of their measures, and Du Châtelet is the first to begin to tease these issues apart and give them explicit treatment.

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[16] One *pied* was a little longer than one foot is in imperial measurements today, and one *toise* was six *pieds*, see Bour and Zinsser, p. 45, footnote 29.
[17] See Brading 2019b.

We have seen that when it comes to the debate over the ontology of space and time, Du Châtelet sides unequivocally with the relationists and against the absolutists. However, as we have also seen, she takes seriously the apparent need for absolute space and time in physics. She is particularly concerned with the epistemology of space and time, and with constructing ideas of space and time that suffice for the purposes and practices of physics while maintaining a relationist metaphysics. This is a bold and innovative proposal.

Du Châtelet's position is an important development in the debates over space and time, one that was widely read both in the *Foundations* itself and via the *Encyclopedia* of Diderot and d'Alembert where the entries on space and time were extracted from the *Foundations*. Philosophers of physics today are prone to move from Newton and Leibniz directly to Kant, perhaps with a mention of Berkeley and Euler in between, but this misrepresents the philosophical dialectic, not least because Kant read Du Châtelet. So what does all this mean for how we read the arguments over space and time as they unfolded in the 18th century, including the mapping of the options that were made available, both explicitly and implicitly, in philosophers of the period? We don't know: there is work here for philosophers of physics to do.

With all that said, Du Châtelet's treatment of space and time will remain unsatisfactory unless it can do justice to role of absolute motion in physics, since this was the reason why Newton introduced absolute space and time in the first place. Elsewhere, Qiu Lin and I have argued (forthcoming) that Du Châtelet shifts the debate about motion away from the ontological underpinnings of absolute motion to the epistemic and pragmatic challenges of pursuing Newton's goal of determining the system of the world (i.e. resolving whether the Earth or Sun sits at the center of our planetary system). In that context, Du Châtelet believes that the fixed stars provide adequate references bodies. In astronomical theorizing, the preferred material frame had long been the fixed stars, and she believed that they would continue to suffice even though they may be in fact not be truly immobile (2018, 5.91):

> We perceive that a Being has changed location when its distance from other Beings, which are immobile (at least for us), is changed. Thus, we made the catalogs of fixed stars in order to know whether a Star changes location, because we regard the others as fixed, and indeed they effectively are relative to us.

Note the phrases “at least for us” and “effectively”. What these emphasize is that, as observers on Earth, our epistemic situation is such that the fixed stars appear to be at rest relative to each other and to move uniformly, and so we can ascribe rest to them for the practical purpose of providing us with a standard of rest, even though we do not know whether they are truly at rest. “Effective” absolute motions are then motions relative to this standard of rest.

With the benefit of hindsight, we know that using the fixed stars in this way is well-suited for the task of determining the changing locations of celestial bodies in our planetary system. Thus, while our lack of epistemic access to the true state of the fixed stars may sound discouraging at first, it turns out that this limitation does little harm to our theorizing. Similarly, for the bucket experiment, we are permitted to choose reference bodies that work for the purposes of theorizing, always recognizing that we may need to revise those choices as we run into their limitations.

As Lin and I point out, this does not help with the explanatory task of providing an ontology that distinguishes uniform from non-uniform motion, a distinction that Newton’s first law of motion requires. Instead, it re-directs our attention to the epistemic resources needed to make use of the first law, and the other laws too, in solving particular problems -- be they large (such as the system of the world) or small (such as the bucket). For this, Du Châtelet’s “effective” absolute motion seems to suffice. I take her position to be an interesting response to unsolved issues in the *Leibniz-Clarke Correspondence*, one that seeks to shift the debate in a new direction via careful attention to the epistemology of physics, its practices and its methods.

Conclusion

I have offered an introduction to Du Châtelet’s *Foundations of Physics* viewed through the lens of philosophy of physics. This book is extraordinarily useful for philosophers of physics because of the remarkable combination of five factors, or so I claim. In the *Foundations* Du Châtelet: identified the most pressing foundational problems in physics of the time; articulated them with clarity and perspecuity; drew on resources from all leading philosophical approaches to physics of the time; was current with the most recent results in physics; and moved the debates forward in interesting and novel ways. In the Preface, she wrote that physics is “an immense building”, and that rather than adding to its construction with a stone here or there she would “survey the plan of the building”. I enjoy this conception of the philosopher of physics, and I recommend her book to all those who share it.

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