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# 38

# DU CHÂTELET AND THE PHILOSOPHY OF PHYSICS

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## 38.1 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 23 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, or so I shall argue.

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 bodies act on one another.

Running throughout these debates is the issue of appropriate method for physics, including disagreements over the role of the Principle of Sufficient Reason (PSR) and the Principle of the Identity of Indiscernibles (PII), the use of observations, and the place of hypotheses in scientific theorizing.

And so, as Du Châtelet recognized, disputes concerning the motions of bodies must be addressed in tandem with those of method. The primary philosophical topic that motivates her book is bodily action, and the framework for addressing this is her account of method (see Brading 2019a). I maintain that these two themes structure and unify the *Foundations*.

This reading allows me to argue for the main conclusion of this chapter: Du Châtelet offers a systematic treatment of the most pressing concerns in the foundations of physics of her day, one that includes innovative positions on several important topics.

To that end, I begin by highlighting key features of Du Châtelet's position on method (Section 38.2). I then turn to her general account of the nature of body (Section 38.3). I show how these together enabled her to intervene in (a) the dispute over Newtonian gravitation, and (b) ongoing discussions concerning collisions (Section 38.4), staking out her own position. Systematically related to these interventions are: her advocacy of mechanism as an explanatory ideal for physics (Section 38.5); her endorsement of a plenum over atoms and the void (also Section 38.5); and her

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attempt to construct a middle path between absolutism and relativism in the debates over space, time and motion (Section 38.6). Each of these topics deserves a more extended discussion than I can give here. However, presenting them together enables me to draw attention to some of the most interesting and innovative elements of her philosophy of physics, and to demonstrate my conclusion (Section 38.7).

Du Châtelet's *Foundations* was widely read and influential in the mid-eighteenth century (Janiak forthcoming). Moreover, her contributions to philosophy of physics do not end there. She also wrote on the nature of heat and fire and on optics, and her exposition of Newton's *Principia* was published alongside her translation in 1756. These texts lie outside the scope of the present chapter; further work is needed to integrate them into a comprehensive picture of Du Châtelet's philosophy of physics.[1]

## 38.2 Method

I begin with a brief review of the main elements of Du Châtelet's discussion of method (see Brading 2019a, Chapter 2, and references therein).

Du Châtelet worried about the lack of a secure epistemic basis for physics, arising from inadequacies in the various methods used for pursuing physics at the time. She had examined the methods of the Cartesians and of the Newtonians and had found them wanting. On the one hand, Cartesians were too free in their use of hypotheses, leading to books filled with "fables and reveries" (Du Châtelet 2009: Chapter 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?[2]

In Leibniz's principle of contradiction (PC) and 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: Chapter 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. Though PC has metaphysical import, 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.[3] As a principle of our knowledge, PC is a means of reasoning concerning possibility.

Similarly, in Du Châtelet's hands, PSR is not, first and foremost, a metaphysical principle. Rather, it is how we distinguish the actual 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 bodily interaction, including 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 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: Chapter 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 in support of her position (see 2009: 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: Chapter 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 that they are identical in terms of weight. If something could happen without 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 not the other for no reason at all; and consequently, their weights would no longer be identical…

The choice of weight here 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 physicists justified their use of induction by appealing to the benevolence of God in maintaining a well-ordered universe (see, e.g., 's Gravesande 1720, Preface), Du Châtelet committed herself to PSR as a presupposition for all knowledge.

This position has powerful methodological implications. If PSR must be presupposed for knowledge, then it should be respected as a constraint on theorizing. In supposing that knowledge is possible, we have no choice but to adopt PC and PSR as principles of our knowledge; having done so we must place them at the heart of our method for achieving knowledge in physics. We can ask about the metaphysical justification for PSR – the world must cooperate, and how can we know that this is the case? – but this was not Du Châtelet's primary concern. It's in the proper method for doing physics that I see the most important place of PC and PSR in Du Châtelet's 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 her most famous chapter, on hypotheses (subsequently reproduced in the highly influential *Encyclopedia* of Diderot and d'Alembert). There, she insisted on the importance of hypotheses for theorizing and theory-development, arguing 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.[4]

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

## 38.3 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 eighteenth century, physics was the subdiscipline of philosophy charged with providing an account of bodies generically: their nature, properties, and behaviors; the causes and effects of those behaviors; and so forth. This "general physics" includes both metaphysics and physics, as we would draw that boundary today.

There was widespread agreement that bodies are extended, mobile, and impenetrable, and that they act on one another by contact. Nevertheless, conceptual difficulties with each of these commitments led to disputes. Moreover, there were disagreements over what other properties belong to the nature of body and what other ways bodies act on one another, if any. Du Châtelet sought an account of the nature of bodies that would resolve these problems. In my view, this is the central motivating problem of the *Foundations* (see Brading 2018, 2019a).

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 (see Du Châtelet 2018: Chapter 8; Brading 2019a: 67). Moreover, any account that asserts extension as the sole essence of body violates PII, Du Châtelet says, since such matter would be entirely 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. 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 toward motion" and a "motive force" (see Du Châtelet 2018: Chapter 8. §139–41). 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, Chapter 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.

Next, Du Châtelet turns to motion. Her laws 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. 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: Chapter 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.
>
> *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 (see Reichenberger 2018 for a discussion). Whether this justification is successful is another question, and one we will not pursue here. For our purposes, we have what is important: the main ingredients in her physics of bodies.

## 38.4 Bodily Action: Gravitation and Collision

With 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. …
>
> … That means of communication (says he) is invisible, intangible, not mechanical. He might as well have added, inexplicable, unintelligible, precarious, groundless, and unexampled.
>
> … 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' vortex theory. In Newtonian 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 opposed Newtonian attraction on the grounds that action-at-a-distance is unintelligible. He, and others, favored instead an ether theory (such Descartes' vortex theory), 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. Huygens followed this latter path in searching for a quantitative theory of gravitation. 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'.

Du Châtelet does not end her discussion there. First, her method requires that theories answer not only to empirical evidence but also to the "principles of our knowledge." In Chapter 16, Du Châtelet argues against Newtonian universal gravitation via appeal to PSR, siding with Leibniz.[5] Second, and surprisingly, Du Châtelet retains a role for Newtonian universal gravitation in physical theorizing. 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 (see Section 38.5).[6]

The other candidate for bodily action as of the early eighteenth century was contact action. In contrast to Newtonian gravitational attraction, Leibniz held collisions to be intelligible. Yet debates continued over how to theorize contact action, most famously in the *vis viva* controversy. 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 superior intelligibility of contact action.

What would this involve? The parallel with Newtonian 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 motion 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 of either.[7]

Du Châtelet's investigation of contact action takes place in the final two chapters of the *Foundations*, drawing on resources developed earlier: the active and passive force of bodies (see above), and 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: Chapter 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.
>
> 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*.

Chapters 20 and 21 develop the account in detail. When active force manifests as "dead force" we have equilibrium (Chapter 20). Then, once one body yields and motion ensues, active force manifests as living force (Chapter 21).[9] In both chapters, Du Châtelet is concerned with the empirical measures of force, be it dead or living, and therefore in relating her account of the force of bodies to quantitative empirical measures. It is an open question of the extent to which she succeeded.[10] Nevertheless, the task Du Châtelet set herself is clear. She aimed to meet the dual demand of her method by demonstrating the *intelligibility* of contact action (via her version of the Leibnizian theory of forces) with a theory that is also *empirically* successful, not just qualitatively but quantitatively.[11]

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

## 38.5 Mechanism and Atomism

Du Châtelet prefaces her laws of motion with the following statement (2009: Chapter 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.

Though other forms of interaction are not ruled out by this, in practice Du Châtelet seems committed to contact action as the only means by which bodies act on one another (Section 38.4). There are several places in her text where one might hope to extract an argument for this conclusion, but none seems successful (see Brading 2019a: 87–89). 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.

Du Châtelet notes that mechanical explanations may be beyond our capacities in many cases, but maintains that we must not rush to give such explanations where this is so. 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. So, we must begin by limiting ourselves "to observing carefully the qualities that fall under our senses and the phenomena that result" (2014: Chapter 9, §176), for "these physical qualities, which make up the effect of mechanical causes, must necessarily precede them in the explanation of phenomena" (2014: Chapter 9, §184). We should use these physical qualities, including magnetism, electricity, fire, cohesion, elasticity, and gravitation, to provide interim explanations as we work toward the underlying mechanical explanations, which may be forever out of our reach.[12] 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: Chapter 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 satisfy PSR. Mechanical explanations are an explanatory ideal, a goal that should be approached in accordance with her two-pronged method (Section 38.2).

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: Chapter 8, §162). And so, even when a mechanical explanation is far from our reach, we must persist in working toward it and not stop at explanations in terms of higher-level physical qualities.

Such qualities are associated with regularities in observable phenomena, and Du Châtelet notes the empirical support for atomism that this might seem to offer (see *Foundations*, Chapter 9). On the one hand, constructively, the same seeds consistently produce the same animals and plants, having the same properties over time. Were matter infinitely varied, these regularities 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, makes the stability and differentiation of species over time explicable. Du Châtelet states (2014: Chapter 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" (2014: Chapter 9, §172). Du Châtelet did experiments and was familiar with the limits of our ability to transform bodies of one kind (such as lead) into bodies of another (such as gold), by heating, pulverizing, etc. This limitation is difficult to explain if matter is indefinitely divisible, but readily explicable if there are species of atoms of fixed shape and size that we cannot further divide. 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.
>
> *(2014: Chapter 9, §172)*

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: Chapter 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: Chapter 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 urges 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 (see Brading 2019a: 55–58): 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 remain undivided; "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: Chapter 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:

> If one asks for the sufficient reason of this actual irresolvability 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: Chapter 9, §173)*

To investigate this further would take us into her account of cohesion (see 2014: Chapter 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 far 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.

## 38.6 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 associated absolute-relative debate. 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 attempted to move the debate forward, taking lessons from both sides. As we will see, while she endorsed a relationist metaphysics of space, time, and motion, she sought to recover the epistemic benefits of absolutism.

Du Châtelet's space chapter begins by setting up two opposing views. According to the first (2018: Chapter 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 (2018: Chapter 5, §72), space is

> an absolute Being, real, and distinct from the bodies it contains… an intangible, penetrable extension, lacking solidity, the universal vessel that receives the Bodies 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 associated 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.

Du Châtelet offers two arguments in support of relationism, both of which rely on PSR. The first is against the possibility of 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, by PSR.

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 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: Chapter 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. 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.

Though Du Châtelet sides with Leibniz when it comes to the metaphysical status of space, she is keenly aware of the utility of the *idea* of absolute space for the purposes of physics. The next several paragraphs of the chapter (2018: Chapter 5, §77–87) concern our idea of space: how we come to have this idea, and what its properties are (see Lin unpublished manuscript). 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 2018: Chapter 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, also.

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 (2009: Chapter 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.

Du Châtelet's account of the origin of our idea of space also involves externality, but is different from Locke's. In a fascinating passage, Du Châtelet appeals to our *imagining* objects as external to ourselves (see 2018: Chapter 5, §77), and for detailed analysis see Lin (unpublished manuscript). Moreover, for Du Châtelet, there are important similarities 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: Chapter 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: Chapter 6, §97), for in this case, 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 our 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.[13]

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.[14] 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" (2009: Chapter 6, §112). For example, we use the diurnal motion of the Sun as a clock. This brings us to the second asymmetry between space and time (2009: Chapter 6, §113):[15]

> 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 this asymmetry, 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 motion of the Sun that yields the length of a day) 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* (see Brading 2019b), and one that persisted until the early twentieth 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.

We have seen that when it comes to the debate over the ontology of space and time, Du Châtelet sides unequivocally with the relationists. 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 analyze the arguments over space and time as they unfolded in the eighteenth 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 the 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 believed that the fixed stars provide adequate reference bodies. In astronomical theorizing, the preferred material frame had long been the fixed stars, and she believed that they would continue to suffice (2018: Chapter 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 motion 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.

## 38.7 Conclusion

Du Châtelet offered a view of physics as a communal, ongoing, and open-ended enquiry in which adherence to proper method is our constant guide and engine of progress. I have argued that, in the *Foundations*, she investigated the most important problems in the foundations of physics of the day, and that her proposed solutions are part and parcel of the systematic philosophy of physics she presents therein.

In my view, Du Châtelet's *Foundations of Physics* is extraordinarily useful for philosophers of physics, because of a remarkable combination of five factors. Du Châtelet: identified the most pressing foundational problems in physics of the time; articulated them with clarity and perspicuity; drew on resources from all leading philosophical approaches to physics; was current with the most recent results in physics; and moved the debates forward in interesting and novel ways. I have attempted to indicate some of the ways in which this is so, while also demonstrating the unity of the overall project.

In the Preface, Du Châtelet 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" (2009). I enjoy this conception of the philosopher of physics, and I recommend her book to all those who share it.

## Notes

1 For primary sources and reference materials visit ProjectVox (https://projectvox.library.duke.edu/).

2 The proper role for hypotheses in science had become a central topic of discussion in the wake of Newton's *Principia*, one in which "Newtonians" sought to distinguish themselves from their "Cartesian" opponents. Du Châtelet's strategy is to set up the two poles of "Cartesians" and "Newtonians" and then position herself as mediating between them. See also her discussion of absolute versus relative space, time and motion.

3 The questions motivating Du Châtelet straddle metaphysics and physics. So too does her understanding of PC (and of PSR). See (Detlefsen 2014) for discussion of Du Châtelet's understanding of PC in comparison to that of Leibniz and of Wolff.

4 The full translation is in Du Châtelet (2009).
5 Her arguments seem rather weak (Brading 2019a: 93–95). However, as Janiak (2018) and (2021) has shown, Chapter 3 of the *Foundations* (on essences, attributes, and modes) has a crucial role to play, for if the issue is whether gravity is an essential property of bodies, then we must be clear about what such a claim amounts to. This is something on which Newton was notoriously terse, even by his own standards, and what he does say leaves the situation unclear. See also (Chen unpublished manuscript).
6 In Chapters 15 and 16, Du Châtelet discusses action-at-a distance in general.
7 See (Brading and Stan 2021), from which this paragraph is drawn.
8 Dead force, like living force, comes in two kinds, active and passive. See (2018: Chapter 20, §529–30).
9 Her intervention in the *vis viva* debate has been widely discussed. See (Iltis 1977: 38–45; Kawashima 1990; Terrall 2004: 296–98; Hutton 2004, especially 527–29; Hagengruber 2012: 35–38; Reichenberger 2012: 157–71; Brading 2019a: 95–97) and references therein.
10 See (Brading 2019: 82–87) for how this account applies to collisions.
11 Or so she believed. For a critical appraisal, see (Brading 2019a: 86).
12 Qiu Lin (2022) has emphasized the importance of physical explanations for Du Châtelet's philosophy of science, pointing out that Du Châtelet develops this idea in the 1742 second edition of the *Foundations*.
13 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 2009: Chapter 6, §105 for time), but the reasons why differ subtly.
14 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 (2009: Chapter 6, §115).
15 One *pied* was a little longer than one foot is in imperial measurements today, and one *toise* was six *pieds*.

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