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A Problem in Du Châtelet's Metaphysical Foundations of Physics

Abstract: On providing the metaphysical ground for the physics of her time, Du Châtelet argues for the notion of an active force. This is different from impressed force in Newton's second law. The former force is a property of a body, whereas the latter is an external cause. I shall study this discrepancy and argue that the interactive concept of force in Newton's third law is consistent with Du Châtelet's standards of intelligible physics. Consequently, the interaction embedded in the law of universal gravitation complies with Du Châtelet's principles of human knowledge.

Keywords: Du Châtelet; foundations of physics; Newton; principle of sufficient reason; active force; universal gravitation

Introduction

This paper examines Du Châtelet's attempt to provide a metaphysical foundation for the physics of her time. Her contribution is significant because it was unique in the French context.[1] In her *Foundations of Physics* (henceforth *Foundations*), Du Châtelet makes it clear that her work should

[1] Beyond the French context Euler to some degree and later Kant were also preoccupied with the same issue.

back up the central result of Newton's *Principia: Mathematical Principles of Natural Philosophy* (henceforth *Principia*), namely the law of universal gravitation. In her view, expressed in the Preface of the *Foundations*, Newton had discovered a universal force of nature, which is spread throughout the universe. However, the natural philosophical context in which she worked lacked a metaphysical basis for Newton's *Principia*. To remedy this neglect, Du Châtelet needs to reconcile the universal force of gravity with her two principles of human knowledge, the principles of contradiction (PC) and sufficient reason (PSR). This reconciliation leads to some difficulties, as Newton's law of universal gravitation is in tension with the demands of PSR.

Du Châtelet favors active forces over Newton's impressed forces. This is not to say that the two have simplistic conceptions of force. Du Châtelet distinguishes active and passive forces. Active force makes bodies move and passive force resists motion. She further divides active forces into living and dead forces. Dead force denotes a situation in which a body strives to move but cannot due to an obstacle, and the living force refers to situations of successful motion (Brading 2019: 83). For his part, Newton lists several types of forces. Impressed forces incorporate contact forces like pressure and percussion, and long-range centripetal forces like gravity. Other dynamic notions include, for example, the quantity of motion as momentum, inherent force of matter as inertia, and air resistance (*Principia*, Definitions and Axioms, or the Laws of Motion). However, Du Châtelet's active force and Newton's impressed force are in one respect entirely different: the former is a force that resides *in* bodies, whereas the latter is an external causal action *on* bodies. Du Châtelet defends Newton's universal gravitation metaphysically, but the impressed centripetal force of gravity is ontologically separate from her preferred dynamic concept.

To alleviate the contention between Du Châtelet's metaphysical foundationalism and the results of Newton's physics, the rest of this article proceeds as follows. The next section introduces

Du Châtelet's strategy for providing metaphysical foundations for physics. It is followed by a brief subsection that shows the dissonance between Du Châtelet's principles and Newton's physics. The subsequent section provides an explanation to reconcile the tension. I argue that Du Châtelet's principles countenance interaction, a crucial feature in the law of universal gravitation. The force of gravity is not an active force for Du Châtelet, because it does not reside in bodies. A focus on interaction will not explain away all the quirky features of gravity. Nonetheless, this article provides a novel argument for the compatibility of Du Châtelet's principles of knowledge and Newton's law of universal gravitation.

1. The objectives of *Foundations of Physics*

Du Châtelet devised *Foundations* as a textbook for her son. In the Preface, she indicates that there were no cutting-edge physics textbooks written among her contemporaries. Jacques Rohault's *Treatise of Physics* from the year 1671 contains some valuable insight, but in course of eighty years the book had become fairly obsolete. This motivates the need for a new introduction to the physics of her time.

To understand Du Châtelet's ambition, it is useful to compare her objective to that of Descartes. In broad strokes, Descartes sought to refute the Aristotelian-scholastic natural philosophy and provide new principles of philosophy (for a detailed analysis, see Slowik 2017: Section 2 onwards). Like Descartes, Du Châtelet starts with indubitable principles of knowledge. For her they are principles of contradiction (PC) and sufficient reason (PSR). Her argument for PC resembles Aristotle's axiomatic approach, and her version of PSR is Leibnizian and Wolffian in spirit.

For Du Châtelet, PC is needed to differentiate necessary and contingent truths. PC picks out all the contingent truths about the world. It decides on what is possible and what not.[2] For its part, PSR does not render any being or existence claim possible or impossible. We need PSR to explain why the contingent truths that actually obtain in the world obtain as they do. More specifically, Du Châtelet's version of PSR is comprised of the following interconnected principles: there is an ultimate reason for any being for why it exists and does not exist; there is no effect without a cause; there is an explanation for all true propositions; there are no brute facts (Detlefsen 2014: Section 2).

Among philosophers to whom PSR is central—like Spinoza, Leibniz, Wolff, Du Châtelet and some contemporary philosophers—there is no universal agreement on how to formulate the principle (see Melamed and Lin 2010). In the words of Karen Detlefsen (2014: Section 2), a prominent feature in PSR is "that everything is explainable and thus intelligible." To apply such a definition to Du Châtelet's foundations for classical dynamics, it must be that central physical concepts, like force, are intelligible. What, in Du Châtelet's view, is the intelligible notion of force that physics should subscribe to?

Newton's original formulation of his second law is this: "A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed" (*Principia*, Axioms or the Laws of Motion). In her careful perusal, Andrea

[2] This article primarily tries to understand Du Châtelet on universal gravitation, which is not a contradictory phenomenon in any way. Hence I will not advance an elaborate discussion on PC but I shall concentrate on PSR.

Reichenberger (2012: 163) notes that Du Châtelet abjures the term 'impressed' when she rewrites Newton's second law in the *Foundations*:

> In the second law, Du Châtelet omits the word *impressed*. She does not maintain that the alteration of motion is ever proportional to the motive force impressed. She only speaks about motive force (frz. *force motrice*). Further, Du Châtelet adds the note that otherwise the change of motion of a body would happen without sufficient reason «car sans cela ce changement se seroit sans raison suffi sante».

Eschewing the term 'impressed' implies that force is not an external action on a body. This is also apparent in her formulation of Newton's first law. To quote again from Reichenberger (*Ibid.*), by switching the words 'force' and 'cause,' she

> does not write that every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed. She says that every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by cause «à moins que quelque cause ne le tire de son mouvement, ou de son repos».

Why Du Châtelet does not refer to impressed forces? Marius Stan (2017: 259) finds some evidence for the following hypothesis. Leibnizians, who in this case should include Du Châtelet, did not need impressed forces, because they wanted to found mechanics in a separate, non-Newtonian concept of force. This is the Leibnizian active force, measured as mv^2, not as mdv/dt like in Newton's second law. To make sense of this point, more needs to be said about the history of the *vis viva* controversy. Du Châtelet helped to revive the controversy by debating the issue with Dortous de Mairan in 1741 in their correspondence.

Leibniz came up with *vis viva* in 1686 when noting an error in Cartesian physics (Iltis 1971: 21). In the view of Leibniz, the force of a body should not be measured by the product of speed and size, but instead it should be measured by the product of the square of the speed and size. For Descartes, size meant volume, not mass. It is common that the debate over *vis viva* is presented as a debate between Leibniz and Newton. However, Newton, in the first edition of his *Principia* in 1687, jettisons the Cartesian approach and replaces it with the concept of mass (the factor in a body that resists acceleration). So, the fundamental disagreement between the Leibnizian and the Newtonian positions is not a debate about the measures of mv^2 or mv. Instead, as I will argue below, the fundamental issue is about whether i) force is a property of a body, or ii) an external action which does not reside in a body.

According to Katherine Brading (2018; 2019: 54), Du Châtelet's focus is bodies, which she takes to be the subject matter of physics.[3] Important issues about bodies involve their nature, behavior, and relevant causal relations. In the *Foundations*, Du Châtelet "sought an account of bodies as true causal agents in the world," writes Brading (*Ibid*.). Du Châtelet is against the view that bodies are mere inactive matter, as Cartesian metaphysics and Newtonian physics maintain. In the *Foundations* (8.138), Du Châtelet repudiates such a position. She writes that a view like that removes "all force and all activity from creatures," making it impossible to "see how there can arise from it [inert extension] a force and an internal principle of action." Du Châtelet thinks bodies are not solely passive substances but "endowed with an activity" (*Ibid*.; Brading 2019: 67). She backs this up with an argument subsumed under PSR. If extension is the only essence of body, the identity of indiscernibles would be violated. If every body was substantially just extension, all matter would be homogenous. The internal difference of separate bodies would be utterly

[3] For the scope of physics in Du Châtelet, see Janiak (2018: Section 3).

inexplicable. This inexplicability is in stark contrast with PSR, which stipulates that everything is explainable and perfectly intelligible (Brading 2019: 69). Postulating active forces that reside in bodies explain the different kinds of behaviors (importantly, motions resulting from forces) of each body.

Brading (*Ibid*.) notes that "Du Châtelet moves immediately to assert that by the addition of 'force' to the essence of matter, we ensure PSR is satisfied." This is not to say that Du Châtelet rejects external causes to bodies. To the contrary, contact among bodies modifies the quantities of active and passive forces in bodies (*Ibid*. 80–1). She writes that "the active force and the passive force of Bodies is modified in their collision, according to certain laws that can be reduced to three principles" (IP 11.229). By the three principles she means Newton's laws of motion. Contact should still not be equated with forces, because forces are something active. Du Châtelet is very clear that active force is in the body: "The only real motion is that which operates by a force residing in the body that moves" (IP 11.225).

Du Châtelet makes an explicit argument for active force in the *Foundations*. The argument consists of a theoretical and an experimental part. In section 575 of *Foundations*, entitled "Very obvious reasoning which proves forces vives," she provides a measure for the active force. Du Châtelet compares the speeds and forces of three travelers. The first traveler covers a distance in one hour. The second traveler covers double that distance in double that time. Naturally, if a traveler wants to cover a longer distance in lesser time, more force needs to be applied. So, if a third traveler covers two distances in one hour, she will be using twice the force as the second traveler. "Now," Du Châtelet (IP 21.575) has it,

> since the third traveler uses two times more force than the second, and the second uses two times more than the first, it is obvious that the traveler who walks at double the speed

during the same time, uses four times more; and consequently the forces that these travelers expended will be as the square of their speeds.

The theoretical argument yields the proportionality of active force of the body to the square of the speed of the body, $F_{active} \propto v^2$. In the next paragraph, du Châtelet refers to the experiment made by Willem Jacob s' Gravesande and Giovanni Poleni. She also contributed to the same experiment. Du Châtelet showed that dropping heavy lead balls into a bed of clay is in accordance with the active force being proportional to the square of the speed of the falling body. Balls with twice the velocity penetrate four times as deep, whereas balls with trice the velocity penetrate nine times as deep (Chodos, Tretkoff, Ouellette, Ramlagan 2008).[4]

PSR is tightly connected to Du Châtelet's preferred concept of force. Without PSR, we could not ascribe any properties, including forces, to things. We could not say that some object remains the same over time. In section "Absurdities that result from the negation of this principle [of sufficient reason]," she writes:

> If we tried to deny this great principle, we would fall into strange contradictions. For as soon as one accepts that something may happen without sufficient reason, one cannot be sure of anything, for example, that a thing is the same as it was a moment before, since this

[4] To corroborate her point, Du Châtelet "uses," Judith P. Zinsser (2009:) notes,

> gravity as an example and cites Galileo's formula measuring the force of gravity as the square of the speed of fall. Thus, she concludes that *force vive* is measured by the square of the speed of motion of the body multiplied by its mass, mv^2 (expressed as $1/2\,mv^2$ today).

> thing could change at any moment into another of a different kind; thus truths, for us, would only exist for an instant (IP 7.129).

For Du Châtelet, the interchangeability of active and passive forces (in our language, the conservation of energy) is something permanent in bodies. By raising a body to a height h, the value for the body's passive force is maximum. When it hits the bottom of the system, $h = 0$, the active force gains its maximum value. Here it is important to remember the dual distinction among active/passive and living/dead forces. Active force and living force are equal, as they are the measure of the body in motion. Passive and dead forces are not exactly the same thing. Passive force is the measure of resistance (of lifting a body from the floor, for example) whereas by dead force Du Châtelet means a situation in which a body tries to move, but cannot because of some obstacle (a falling object will eventually stop at the floor, not go through it). The role of PSR is to guarantee that we can ascribe a permanent quantity to a body. The quantity of the force, mv^2, remains invariant over time. Without its conservation—if forces would somehow disappear—physics would not have an intelligible, rational basis.

In explaining the relevance of PSR, Du Châtelet's example in the *Foundations* concerns the identity of the properties of two different objects (IP 1.17). Applying this to the conservation of forces, we may consider the following case. Two bodies, A and B, collide. Say their masses and initial speeds are equal, v_A and $-v_B$, and the collision is perfectly elastic. What we observe (or would observe in the ideal case) after the impact is that the two bodies return to the place where they originally came from, with the exact same speeds but opposite velocities, $-v_A$ and v_B. There is something that must explain why the bodies retain the salient quantities. In the view of Du Châtelet, there are no jumps in nature: "a being does not pass from one state to another without passing through all the different states that one can conceive of between them" (IP 1.13). This is

embedded in PSR, because there is a sufficient reason for a body's state at any time. The position of a body is determined by the preceding state of the body.[5] "Therefore," Du Châtelet (IP 1.17) claims,

> this antecedent state contained something which gave birth to the current state that followed it, so that these two states are so completely interconnected it is impossible to put another state between the two. For if there was a state possible between the current state and that which immediately preceded it, the nature of the being would have left the first state without yet being determined by the second to abandon the first. Thus, there would be no sufficient reason why it should pass to this state rather than to any other possible state.

Disagreeing with the above conclusion would be like admitting that a traveler could move from one city to another immediately, without taking the path that connects the two places. In that case, PSR would be violated. Such reasoning applies to the force conservation case. Du Châtelet (*Ibid*.) thinks it is well established that

> two equal bodies colliding with equal speeds must rebound with the same speed, and this is very true, for there being no reason why one of the two should continue in its path rather than the other, and these bodies being unable to penetrate each other or stay in repose, because the force of their equal speeds would be lost, which cannot happen, they must necessarily both rebound with the same speed with which they collided.

It is notable that Du Châtelet's explanation of this law of motion is ultimately based on PSR. The forces in bodies—the modifications of active and passive forces—remain constant. Collisions of

[5] Including all other bodies in the universe, as is evident from the law of universal gravitation.

bodies interchange active and passive forces, but there is no need to add an external force to bodies that causes their changes of motions.

In this section, I went through Du Châtelet's strategy for providing a metaphysical foundation for physics by leaning on PSR and active force. Before analyzing the most controversial piece of Newtonian physics, to wit, the law of universal gravitation, I shall briefly note the incongruity that follows from Du Châtelet's foundationalism and Newton's formulations.

1.1. Tension between Du Châtelet and Newton

Newton's fourth Definition of the *Principia* reads: "impressed force is the action exerted on a body to change its state either of resting or of moving uniformly straight forward." He adds that the causally efficacious factor, the impressed force, is not in the body. It is the action to move the body: "This force consists solely in the action and does not remain in a body after the action has ceased. For a body perseveres in any new state solely by the force of inertia." The list of impressed forces include three: percussion, pressure, and the centripetal force. On commenting centripetal forces, Newton notes that "one force of this kind is gravity" (*Principia*, Definition 5). None of the impressed forces reside in bodies, like Du Châtelet's Leibnizian forces. She recognizes her difference with Newton. At the end of the section on the concept of force in the *Foundations*, she feels obliged to tell, against the authority of Newton, that he "did not acknowledge forces vives, for the name of M. Newton is in itself nearly an objection" (IP 21.586). In her view, Newton's force of inertia as the inherent force in matter leads to an unexplained dissipation of forces. Du Châtelet's Newton must conclude that

> motion is constantly diminishing in the universe; and lastly that our system will some day need to be formed anew by its Author, and this conclusion was a necessary consequence

of the inertia of matter, and the opinion held by M. Newton that the quantity of force was equal to the quantity of motion (*Ibid*.).

The quote above suggests that Newton (or Newtonians) cannot explain the conservation of forces. In Du Châtelet's view, he should rely on the constant involvement of the Deity. God should constantly add momentum to bodies to keep them moving. Instead of impressed forces, Du Châtelet argues that conserved quantities are explained with active forces. This branch of force is the intelligible force for physics. It is in accordance with both PSR and experimental evidence.

Despite significant disagreements on the foundations of dynamics, I submit there is a way to make Du Châtelet's metaphysical principles (if not completely, at least partly) consistent with Newton's physics. To that end, the next section will highlight the interactive character of force in Newton's third law. Interactivity is consistent with PSR, and hence with Du Châtelet's foundations of physics.

2. The interactivity in universal gravitation

Newton's third law and the law of universal gravitation are tightly connected. In his *Principia*, he formulates the third law as follows: "To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction" (Axioms, or the Laws of Motion). Newton is clear that forces are interactive; there cannot be a force without its counterpart. [6] According to Max Jammer's (1957: 127) analogy, force

[6] This suggest that if there is only one particle in the universe, no forces could exist. This issue is closely related to the debate whether Newton had the notion of force field. Stein (1970) and Harper (2016) argue that Newton had the concept of gravity field. Schliesser (2011) disagrees. In

and its opposite force are like a business transaction.[7] There cannot be a purchase without a sale. As the magnitude of a force equals its opposite force, so does the magnitude of a purchase equal that of the sale. Forces are action and reaction simultaneously.

Why are force and its opposite force scalarly equal? In the Scholium to the Axioms, or the Laws of Motion, Newton answers with a theoretical and an experimental argument. He asks us to imagine two bodies, A and B, and some obstacle that keeps them from coming together. If A is more attracted in the direction of B than B toward A, the obstacle would be more strongly pressed by A than B. The system of the bodies would not remain in equilibrium. The stronger pressure would push the obstacle with a constant net force. Without other material present in a completely empty space, there would be a never-ending acceleration from the direction of A to B. This is contrary to the first law of motion. Newton backs this up with a reported experiment. He used two vessels, one containing a lodestone and the other a piece of iron. When the vessels are put on still

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analyzing the relationship between gravity and bodies, Janiak (2018: 57-58) considers something like a middle position: "Newton's theory tells us that bodies gravitate toward one another, or are heavy toward one another, in proportion to their masses and in inverse proportion to the square of the distance between them. This does not seem to entail that a lonely corpuscle would gravitate or would be heavy: there would be nothing to gravitate, or to be heavy, toward! Of course, one might reply that gravity is nonetheless some kind of dispositional property of a lonely corpuscle, on the grounds that it has the power to attract other bodies, even if none such exist."

[7] Newton's own examples in the *Principia* are finger pressing a stone / the stone pressing the finger and a horse drawing a stone / the stone drawing the horse (Corollary of Law 3, Axioms, or the Laws of Motion).

water, neither of the bodies will push the other forward. Rather, they will attract each other and reach an equilibrium. Then they remain at rest to infinity.[8]

In his argument for the law of universal gravitation, Newton does not present the law according to one formula. The algebraic variant of the law can be expressed as $\vec{F} \alpha\, m_1 m_2 / r^2$, although this is not in the *Principia*. The law states that there is a universal force that is directly proportional to the masses of bodies and inversely proportional to the square of their distance (Proposition 7, Book 3; see Harper 2016 for a thorough analysis). In the final step of his long argument at the end of the *Principia*, Newton makes the sweeping claim that the force of gravity "is proportional to the quantity of matter in each [body]" (Proposition 7, Book 3). He connects and universalizes the third law and the gravity law:

> Further, since all the parts of any planet A are heavy [or gravitate] toward any planet B, and since the gravity of each part is to the gravity of the whole as the matter of that part to the matter of the whole, and since to every action (*by the third law of motion*) there is an equal reaction, it follows that planet B will gravitate in turn toward all the parts of planet A, and its gravity toward any one part will be to its gravity toward the whole of the planet as the matter of that part to the matter of the whole (*Ibid*., emphasis added by the author).

As the law of universal gravitation and the third law are essentially connected, the force of gravity is fundamentally about interaction. The Sun pulls the Earth as much as the Earth pulls the Sun. What does Du Châtelet think about gravitational forces, and their interactivity? In the first section of this paper, I demonstrated that, in her view, active forces (consisting of living and dead forces)

[8] Newton also uses pendulum experiments to corroborate the third law and the conservation of momentum in the Scholium to Axioms, or the Laws of Motion.

are in bodies. They are not impressed upon them, like Newton has it. This is major difference between the two. Regarding gravity, their views seem not to differ.

In Rule 3 to his *Principia*, Newton is explicit that gravity is not inherent in matter.[9] Gravity is a centripetal, impressed force. Impressed forces are external actions, which cease after the action of exerting the force is completed. What is inherent is the force of inertia. Du Châtelet criticizes the Newtonians for ascribing the force of gravity to matter itself. Her view resembles Newton's, not Newtonians. Already in the Preface to the *Foundations*, she claims: "M. Newton discovered this universal force spread throughout nature, which makes the planets circle around the Sun, and that operates as gravity on Earth." In chapter 16, paragraph's 396 title is telling: "Attraction cannot be an inherent property." Du Châtelet points out that "now, since attraction cannot be essential to matter, and since it does not flow from its essence, it follows that God could not give this property to matter" (IP 16.396) Two paragraphs later, she argues that gravity must be an external cause:

> Since all that is, must have a sufficient reason for why it is as it is rather than otherwise, the direction and the speed impressed by attraction must therefore find their sufficient reason in an external cause, in some matter that collides with the body that we regard as pulled, and that determines by its action the direction and the speed of this body, to which by itself these determinations are indifferent. Thus, we must seek by means of the laws of Mechanics some matter capable of producing by its motion the effects that we attribute to attraction (IP 16.398).

[9] For a discussion on whether gravity is i) in bodies merely in the sense of the weight of the bodies, or whether it is ii) an action, iii) a property, or iv) a quality, and on the confusion over interconnected terms like v) inherent, vi) innate, and vii) essential, see Janiak (2018: Section 2).

In the interpretation of Detlefsen (2014: Section 6), PSR rules out the predication of attraction of matter. Newtonian attraction does not explain the nature of bodies. Detlefsen notes that if attraction was an active force in bodies, then bodies would move to infinity without the counteractive passive force. Because gravity is external to bodies, Du Châtelet goes on to speculate on the mechanism that transmits gravitational forces. This is also the case with Newton in the Queries of the *Opticks*, in which he formulates a provisional hypothesis about ether.[10] Sarah Hutton (2004: 521) argues that Du Châtelet "takes a relatively agnostic position as to the explanatory value of Newton's theories, especially on the subject of attraction." She distances herself from many of the Newtonians. Postulating attraction to bodies potentially explains the cohesion of bodies, along with properties like hardness, softness, fluidity, and viscosity. Du Châtelet recognizes that Newton's Queries in the *Opticks* are the source for wild speculations about the explanatory power of attraction, especially among his followers.

Neither Du Châtelet nor Newton explain what gravity is. They agree that gravity is a cause external to bodies. What this cause is exactly, how and why does it exist, is left unspecified. Newton was not able to provide any reason for the strange operations of gravity, notably instant non-mediated distant action. He admits this in the General Scholium, right before introducing his most famous line:

[10] The purpose of the Queries is to devise tentative hypotheses for the future study of nature. In Query 21 he speculates with the idea of a mechanical ether. Newton is however clear that he lacks knowledge of this putative mechanism: "for I do not know what this *Æther* is." (*Opticks*, Query 21).

> I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical have no place in experimental philosophy.

This is not keeping in with the broadly Leibnizian PSR and the demand of intelligibility of natural philosophy.[11] Given Du Châtelet's principles of human knowledge, gravity must ultimately have an explanation. Newton's work did not disclose the cause of gravity. However, it is worth stressing how different this is from saying that gravity has no cause whatsoever. The current stage of gravity research had not yet explained gravity; this is not to say that gravity will never be explained. Du Châtelet's PSR maintains that there is, in principle, an explanation for everything. The lack of explanation does not make the law of universal gravitation incompatible with PSR. To expound on this point, it is useful to contrast Newton's and Du Châtelet's positions on the status of hypotheses.

One of Newton's reasons for composing the General Scholium and adding it to the second and third editions of the *Principia* was to polemically refute the speculative philosophies of Descartes and Leibniz by leaning on experimental philosophy (Anstey 2005: 234).[12] Du Châtelet

[11] For intelligibility of natural philosophy and the law of universal gravitation in Newton and Leibniz, see Slavov (*Forthcoming*).

[12] Shapiro (2004) argues that before adding the General Scholium in the second and third editions of the *Principia*, Newton emphasized the mathematical nature of his work. The experimental method and reasoning are introduced precisely in the context in which he argues against his speculative predecessors and interlocutors.

has a more permissive view on hypothesis than Newton.[13] Du Châtelet seems to think that experiments do not constrain hypothesizing. The first principles themselves do the constraining work. However, the principles are extremely wide in their scope. One cannot simply resort to the principles to explain all specific scientific details. The explanation of gravitational phenomena is not deducible from the principles of knowledge or experimental results, at least not in any simple way. Hypotheses are needed to fill the gap between principles and explanation of phenomena. As Du Châtelet has it:

> Hypotheses are… sometimes very necessary… in all cases when we cannot discover the true reason for a phenomenon and the attendant circumstances, neither *a priori*, by means of truths [identified as principles in IP 53] that we already know, nor *a posteriori*, with the help of experiments" (IP 60, quoted from Detlefsen 2014: Section 5).

Du Châtelet makes room for hypotheses in natural philosophy and allows that they are necessary for the advancement of gravity research. According to her analysis, hypotheses are abundant in the history of astronomy. In Detlefsen's rendition, "she even goes so far as to claim 'without hypotheses… there would be no astronomy now'" (IP 57). To provide evidence for the centrality of hypotheses, she refers to the application of hypotheses in the theories of Copernicus (IP 57 and 67), Kepler (IP 58) and Huygens (IP 57 and 67). Denying the criticality of hypotheses hinders scientific progress. By allowing a limited role to hypothesizing on the cause of gravity, Du Châtelet's position conforms to Newton's theory of gravitation. Accordingly, there is no contradiction between two of her commitments, 1) preference of active forces, and 2) the denial

[13] And no doubt a more permissive view than the anti-hypothetical Newtonianism of Voltaire. For an overview of Voltaire's position, see Shank (2015: Section 2.4).

that gravity is inherent in matter. Hypotheses concerning a mechanism that is extrinsic to bodies is required for advancing theories about gravity.

Newton's reasoning on the interactive character of force is consistent with Du Châtelet's principles of human knowledge. Consider her formulation of Newton's third law in the *Foundations*: "The reaction is always equal to the action; for a Body could not act upon another Body, unless that other Body resisted it: thus action and reaction are always equal and opposite" (IP 11.229; Reichenberger 2018: 9). Unlike the two first laws of motion, the third law does not need to be reformulated. Interaction is intelligible—Newton provided a cogent theoretical and experimental argument for it—and such interactivity is apparent in the law of universal gravitation.

Conclusion

Du Châtelet leans on PC, and more importantly, on PSR to establish a metaphysical foundation for physics. She rewrote Newton's first two laws to accommodate her preferred notion of force, the active force. Nevertheless, she did not alter Newton's third law. The third law adds an additional characteristic to the concept of force, not mentioned by the first and second laws: interaction. Du Châtelet's views on the law of universal gravitation are consistent with Newton's interactive concept of force.

I do not claim that I would have perfectly assimilated Du Châtelet's principles with Newton's theory of gravity. The two do not claim to have knowledge of the cause of gravity. Both speculate on the possibility of a mechanism which transmits forces across space. However, it should be noted that there still are many unresolved issues concerning gravity. Significant progress in gravity research has been made, of course. Still after more than 250 years, with major developments in mathematics, physical theories, and experimental techniques, gravity remains a

somewhat of a mystery. The Du Châtelet–Newton connection is worth studying, as it is an interesting example in the history of philosophy and physics on how to advance our thinking about the abiding problem of gravity.[14]

[14] This paper was written after an incredibly inspiring workshop at UCLA on early modern women philosophers. I thank the speakers Jacqueline Broad and Karen Detlefsen for exciting presentations, and John Carriero for organizing the event. I appreciate the critical comments by the three evaluators of this journal. My research has been funded by The Finnish Cultural Foundation and Alfred Kordelin Foundation, coordinated by the Foundations' Post Doc Pool. I am thankful for the grants that made this research possible.

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