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Du Châtelet, induction, and Newton's rules for reasoning

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Abstract

I examine Du Châtelet's methodology for physics and metaphysics through the lens of her engagement with Newton's Rules for Reasoning in Natural Philosophy. I first show that her early manuscript writings discuss and endorse these Rules. Then, I argue that her famous published account of hypotheses continues to invoke close analogues of Rules 3 and 4, despite various developments in her position. Once relevant experimental evidence and some basic constraints are met, it is legitimate to inductively generalize from observations; general hypotheses can thereafter be assumed as true until contrary experiments show otherwise. I conclude by arguing that this account of induction plays an essential role in her metaphysics, both in an argument for simple substances—which has an inductive premise—and in her attempt to distinguish acceptable and unacceptable metaphysical commitments.

1 | INTRODUCTION

Émilie Du Châtelet's *Institutions de physique* is crucially concerned with how observations are successfully transformed into hypotheses and theories. Her account of hypotheses was widely influential in the eighteenth century. Yet despite a wealth of recent scholarship on the *Institutions*, commentators have not focused on what licenses the move from particular experimental observations to general conclusions—such as Newton's law of universal

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gravitation, which Du Châtelet treats as a hypothesis—or on the conditions under which hypotheses either remain acceptable, or must be discarded as false.

Starting with Du Châtelet's early manuscript drafts, I show how her thought on these issues developed through engagement with Newton's Rules for reasoning in natural philosophy, and in particular Rules 3 and 4. In her early manuscripts, as I detail, she not only endorses Rules 3 and 4 but draws stronger conclusions from them than did Newton himself (section 3). Next, I argue that close analogues of the third and fourth Rules remain central to Du Châtelet's conception of what constrains acceptable theories. Her treatment of hypotheses invokes, as independent constraints, two rules that are comparable to Newton's (section 4). Along the way, we'll see how her reflection on the Rules interacts with her thoughts on the metaphysical status of gravity; the level of certainty appropriate for induction; the consequence relation between hypotheses and their explananda; the relationship between empirical evidence and non-empirical criteria for theory choice; and other topics.

The Newtonian Rules also illuminate her methodology for metaphysics (section 5). One of her most prized metaphysical arguments, namely that there must exist simple substances or elements, has an inductive premise. Since her account of induction is supported by analogues of the Newtonian Rules, so too is her argument for simple substances. Furthermore, the bright line she seeks to draw between legitimate and illegitimate metaphysical hypotheses is clarified once we distinguish between metaphysical claims that are subject to empirical confirmation and fall under the scope of the Newtonian Rules, and those that do not.

2 | NEWTON'S *REGULAE* AND DU CHÂTELET'S *INSTITUTIONS*

Before turning to Du Châtelet's texts, I'll present some historical and scholarly context, beginning with Newton's four Rules themselves. These appear late in the *Principia*: at the start of Book III. This book treats the system of the world, or the natural causes studied in celestial mechanics. Rules 3 and 4, which are the most important for Du Châtelet, go as follows:

> Rule 3. Those qualities of bodies that cannot be intended and remitted and that belong to all bodies on which experiments can be made should be taken as qualities of bodies universally. [...]
>
> Rule 4. In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly [*quamproxime*] true notwithstanding any contrary hypotheses, until yet other phenomena make such propositions either more exact or liable to exceptions. This rule should be followed so that arguments based on induction may not be nullified by hypotheses. (Newton, 1726/1999, p. 795)

Without wading too far into interpretive debates, let me make a few basic remarks about these claims and their historical context.[1]

Rule 3 asserts that at least in some cases, we can consider the "qualities" we observe in particular experiments as belonging to bodies universally. This licenses inductive generalizations, which play an important role in the *Principia* (even though Newton's methods are more sophisticated than simple enumerative induction).[2] The laws of motion are "made general by induction," for example, and this generalization seems to depend in part on Rule 3 (Newton, 2004, p. 118). But although Newton suggests Rule 3 is the "foundation of all natural philosophy," he does not use it to defend inductive inference against the general skepticism later articulated by Hume (Newton, 1726/1999, p. 786; Smith, 2001, p. 333). Newton begins key inferences with generalized phenomena, and does not explicitly use Rule 3 to justify this.[3] He may instead be targeting an old objection revived by Huygens, Fatio, and Leibniz, namely that we'd need to directly experiment on celestial beings such as stars or comets in order to show that they have the same qualities as terrestrial matter.[4]

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Rule 4, in turn, seems to say that we can presume some results of induction as true—or at least approximately true. We should not take these results to be defeated by merely possible counter-examples or hypotheses: they can be "pronounced generally" unless exceptions from "phenomena" or "experiment" are found (Newton, 1730/1979, p. 404). To illustrate, consider Newton's response to an apparent counterexample. His editor Roger Cotes objected that a satellite's orbit around a central body might be due not to the central body, but to some other cause, which he called an *invisible hand*. The invisible hand, and not the central body, could then be subject to an equal and opposite reaction to the force maintaining the satellite in its orbit. Newton replies that the invisible hand is a merely possible hypothesis, not implied by the phenomena.[5] Therefore, given Rule 4, it does not defeat his inductively supported claims (Newton, 2004, pp. 118–119).

Newton's texts do not clearly settle whether the results of induction are supposed to yield certainty or just high probability. The point was debated in the eighteenth century, and it is still controversial. For example, Voltaire thought Newton's arguments against Cartesian vortices demonstrated conclusively that "the plenum is a chimera," so void space exists (Voltaire, 1738, p. 166).[6] Du Châtelet, by contrast, eventually concluded that Newton's arguments only rule out some vortex theories, rather than the basic proposal that subtle matter is present throughout space. As we'll see, however, her views on the epistemic payoff of induction are complex, and evolve as she revised her *Institutions de physique* toward publication.

But first, some background on the *Institutions* and its composition. The book is presented as an exposition of Newton's "system" for readers who only know elementary geometry (1742, p. 7). In fact, it rejects several of Newton's doctrines, such as rigid atoms and absolute space and time (Stan, 2023). The published version of the work, moreover, does not begin with Newton's rules for reasoning in natural philosophy. Instead, pride of place goes to two principles that reflect the influence of Leibniz and Wolff: the principle of contradiction and the principle of sufficient reason. So the work is committed to rationalism in at least two senses. It is rationalist in accepting robust non-empirical knowledge. And it is rationalist in taking a priori principles to underlie cognitive claims in mathematics, physics, and everyday life. To be clear, Newton himself need not have rejected rationalism so understood. His extensive writings on theology invoke non-empirical knowledge, and his Rules may well be a priori: Rule 4, notably does not admit of non-circular inductive justification (Biener, 2018; Di Fate, 2011, pp. 34–35). That said, Newton and his followers did not take the principle of sufficient reason to impose substantive constraints on mathematics and physics. Furthermore, given Newton's criticisms of speculative metaphysics, he might regard the principle of sufficient reason as merely speculative.

Moreover, it has been known since the 1960s that Rules 3 and 4 are first principles in the early manuscripts of Du Châtelet's book. These manuscripts, which were completed in 1738, are only partly extant.[7] The manuscript account of the Rules as first principles does not survive—it must be reconstructed through Du Châtelet's references to it—but we do have a discussion applying Rules 3 and 4 to the case of gravity. William Barber, having pointed this out, concludes that between the manuscript drafts and the published version Du Châtelet recognized a need for "metaphysical foundation[s]," and shifted away from her earlier "Newtonianism," by way of a "Leibnizian illumination" or "conversion" (Barber, 1967/2006, p. 22; Barber, 1955, p. 182; see also Gardiner Janik, 1982).

Recent scholarship has moved on from Barber's account. Many would challenge Barber's assumption that Newton's Rules bear no relation to metaphysical and theological foundations (McMullin, 1978, pp. 13–21; Biener, 2018). Also, Du Châtelet is no longer seen as a mere follower first of Newton, then of Leibniz. On the one hand, her physics is not straightforwardly Newtonian (Stan, 2023). On the other, Ursula Winter has shown that before starting to write the *Institutions*, Du Châtelet knew and sharply criticized work by Leibniz and Wolff (Winter, 2012; see further Du Châtelet, 2018, pp. I, 337; 393). She selectively integrated some of their ideas into the *Institutions* in service of her own aims, which included addressing metaphysical and epistemological challenges raised by bodily action (Brading, 2019, p. 2).

Despite these developments in the literature, since Barber's publications almost 60 years ago there has been almost no direct discussion of how Du Châtelet's early manuscripts deal with Newton's Rules. The fact that the Rules are no longer framed as first principles in the published book might at first suggest that, as Katherine Brading has put

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it, Du Châtelet "had examined the method of the Newtonians, and…found it wanting" (2018, p. 28; see also Janiak, 2021, pp. 269; 295). Brading concludes that Du Châtelet adopts a "double-pronged" methodology, where one prong is a "hypothetico-deductive approach" to hypotheses, and the other is a pair of first principles, namely the principle of contradiction and the principle of sufficient reason (p. 27; see also Detlefsen, 2021). Newton and his followers typically did not appeal to these two principles in their natural philosophy. So in adding them, Du Châtelet implies that Newtonian foundations require supplementation.

Although I don't dispute this overall picture, there is room for further investigation of the empirical side of her methodology, and how much it represents a turn away from the Newtonian tradition. Most pressingly: what licenses the move from particular observations to general hypotheses? In the next section, I analyze manuscript evidence that illuminates how early on, Du Châtelet turned to Newton's Rules to deal with this problem. Then, in section 4, I argue that her account of empirical hypotheses, even in the published *Institutions*, remains substantially indebted to the method of the Newtonians.

3 | THE EARLY MANUSCRIPTS

This section argues that Du Châtelet's manuscript explicitly endorses Rule 3 and implicitly subscribes to Rule 4, and that her position at this stage is in several ways stronger than Newton's own.

Some caveats before turning to the textual details: first, I don't assume that her later, published stance can be inferred from the manuscript passages I discuss. Instead, I take these manuscript passages to show the strength of Du Châtelet's early endorsement of Rules 3 and 4, and to allow us to more clearly trace her development. Second, it's important to note that this discussion is part of an 11-page stretch dealing with Newton's argument for universal gravitation that, after several revision stages, was finally canceled out in its entirety. But these passages are not mere notes or unfinished drafts. They appear in two polished fair-copy versions, destined for an aborted 1738 printing of the *Institutions*. In 1739 or early 1740, Du Châtelet revised the chapter, which originally endorsed Newtonian attraction as a genuine cause and defended it against objections, to focus more narrowly on Newton's empirical discoveries. She then apparently added a new chapter that is close to the published version and denies that attraction is a genuine cause.[8]

We can begin with an important parallel between the epistemology of Newton's *Principia* and Du Châtelet's manuscript. In his explication of Rule 3, Newton states that we only have epistemic access to the properties of matter though experiment and induction.

> The qualities of bodies can be known only through experiments; and therefore qualities that square with experiments universally are to be regarded as universal qualities…. The extension of bodies is known to us only through our senses, and yet there are bodies beyond the range of these senses; but because extension is found in all sensible bodies, it is ascribed to all bodies universally….Indeed, the argument from phenomena will be even stronger for universal gravity than for the impenetrability of bodies, for which, of course, we have not a single experiment, and not even an observation, in the case of the heavenly bodies. (Newton, 1726/1999, pp. 795–796)

Now compare a passage from Du Châtelet's manuscript:

> We can know their [*sc*., bodies'] properties only by experiment and it is only by this route that we are assured that extension and impenetrability belong to them universally….It is indispensable to conclude that all bodies in the universe have this attractive force, and this argument for a universal gravitation in all matter drawn from phenomena, is stronger than the one by which one concludes that all bodies

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> are impenetrable, for we have no phenomenon that demonstrates to us the impenetrability of celestial bodies, but everything demonstrates their gravity to us.[9]

Du Châtelet begins, like Newton, with the point that bodies' properties are known only through experience or experiment.[10] The French *experience* can have either meaning, which is appropriate given Newton's broad conception of experimental philosophy (Shapiro, 2004; Spencer, 2004, pp. 771–772). Additionally, she endorses Newton's *tu quoque* argument for universal gravitation, quoted above. This argument first stresses that Newton's mechanist opponents allow that we "justly infer" the universality of impenetrability from experience, next contends that the experimental evidence for universal gravitation is more general than the evidence for universal impenetrability, and concludes that Newton's opponents ought to also accept his inference to universal gravitation.

Given that we can only know the properties of bodies by experience, and experience is particular, how can our inferences or demonstrations cover all bodies whatsoever? To answer this question, just before the previous quoted passage, Du Châtelet cites Rule 3:

> By to the 3rd law given by M. Newton for conducting oneself in the study of nature (§10), a law that is accepted by all philosophers, by this 3rd law, I say, the qualities that we find to belong at all times to the bodies which we know, can be taken as universal and inherent to all bodies.[11]

So she presents Rule 3 as underlying a crucial inductive step in Newton's argument for universal gravitation.

Du Châtelet does not explicitly cite Rule 4 here, but appears to endorse it nonetheless. Newton, she states, has given a "certain proof" of his conclusion about universal gravitation, namely that "each of the parts" that compose matter gravitates (1737-1740, f. 267^{r}). This certainty comes from the fact that "all the phenomena concur" in supporting Newton's conclusions (267^{r}). Moreover, even particular phenomena, on their own, can provide strong support for the Newtonian theory. The tides, for example, are "inexplicable" unless gravitation applies to all parts of matter (f. 267^{v}). These passages imply that some conclusions reached by induction can be assumed as certain if and only if all the phenomena known to us support them, bringing her close to Rule 4.

Now consider five major differences between Du Châtelet's presentation of the rules and what we find in Newton.[12] First, Du Châtelet does not discuss Rules 1 and 2 here. Those rules state, respectively, that "no more causes of natural things should be admitted than are both true and sufficient to explain the phenomena," and that "therefore, the causes assigned to natural effects of the same kind must be, so far as possible, the same" (Newton, 1726/1999, pp. 794–795). So in the important case of Newton's argument for universal gravitation, Du Châtelet does not seem to invoke the first two rules. This suggests that she took Rules 3 and 4 to be of particular importance, and perhaps also as more or less independent from Rules 1 and 2.

Second, as seen in the quotation above, Rule 3 is repeatedly presented as a *law*. It would be more natural to translate Newton's *Regulae* as "*règles*," and that is what we find in her translation of Newton's *Principia*, suggesting a distinction between rules constraining method and laws of nature proper (Du Châtelet, 2015, pp. II:246–249). Her choice to use "law" in the manuscript might indicate that she assigned Rule 3 a more universal or objective status than did Newton. On a more cautious reading, she might be aligning herself with especially strong interpretations of the rule among later followers of Newton.

Third, Du Châtelet stresses that Rule 3, at least, is "accepted by all philosophers."[13] Such a claim is not made explicitly by Newton. At this stage in her career, then, Du Châtelet appears to take a stronger line on Rule 3 than Newton himself. A related point is that she presents the rule as basic, rather than as founded on some further principle. While there's some dispute about the precise evidential status of the Rules in Newton, they seem to be backed up by his theological commitments. This is made explicit by later thinkers who use the Rules. Certain editions of 's Gravesande's *Physices Elementa*, for example, state that (some of) Newton's Rules follow from a more basic, theological axiom.[14]

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Fourth, Du Châtelet stipulates a strict logical relation between general theoretical claims and the phenomena they are supposed to explain. Tidal phenomena, for example, are "a necessary consequence of the attraction of the Moon and the Sun on the earth and of the earth's diurnal movement," where this attraction affects "each of the particles that compose" the earth. "By consequence," she concludes, "gravitation belongs to all of these parts."[15] She is stating, at least, that universal gravitation is a necessary condition for particular tidal phenomena. So, universal gravitation is a logical "consequence" of the tidal phenomena. Now, Newton famously uses the language of deduction from phenomena. But most contemporary interpreters deny that he has logical deduction in mind.[16] Du Châtelet's emphasis on necessary consequence, which recurs in the published version of her *Institutions*, therefore suggests she had an especially strong reading of the Newtonian Rules.

Fifth, the Rules allow her to conclude that attraction and other properties are not only "universal," but "inherent" to all bodies (1737-1740, f. 267^{r}). Attraction is framed as a new, irreducible force:

> Here then is a new motive force, which Newton discovered in mechanics, which operates in nature: bodies…in addition to all the other properties that the creator has given them, also have the property of tending toward one another.[17]

Depending on how we understand "inherence," she may think Rule 3 allows us to draw conclusions about the essence of bodies—or at least about *propria*, the necessary consequences of bodies' essence. These are departures from Newton. He asserts that gravity is universal, but denies that Rule 3 establishes that gravity is essential or inherent to bodies: "only" the "immutable" force of inertia is an inherent force (Newton, 1726/1999, p. 796). His texts leave room for debate on the ultimate cause of gravity, since he often characterizes it in terms of an action exerted *on* all bodies, rather than *by* all bodies.[18] As is well known, some of Newton's most influential interpreters—such as Roger Cotes and Samuel Clarke—went further, stating that gravity is a primary or essential quality of all matter. On the hotly disputed question of the inherent properties of matter, then, the early Du Châtelet is closer to Cotes or Clarke, drawing bolder conclusions than Newton himself.

Before turning to how the *Regulae* fare in the published *Institutions*, there is a further textual complication to consider. The pages discussing the Rules include multiple stages of revision. The earliest fair copy is replaced by a second fair copy, with relatively minor changes. Next, the second fair copy is significantly revised in Du Châtelet's hand. These autograph corrections introduce important notes of caution about reasoning with the Rules as well as the status of the theory of gravitation.

In Du Châtelet's autograph revisions, arguments for universal gravitation and universal impenetrability are for the most part no longer called demonstrations, but only "proofs" (*preuves*) (1737-1740, f. 266^{v}). Despite the strong evidence for universal gravitation, we lack a "demonstration properly speaking" (f. 266^{v}). So she seems to retract her earlier claims that the tides, for example, afford a strict demonstration of universal gravitation. Although Newton's arguments leave no room for "doubt," the question "may not" be the "kind of thing subject to rigorous demonstrations" (ff. 266^{v}–267^{r}).[19] For she adds that facts nobody doubts, such as the motion of the earth, lack such rigorous demonstrations (f. 267^{r}). Even if the case for universal gravitation falls short of strict demonstration, then, this need not show a fault in Newton's arguments. Though his arguments can serve as proofs that preclude doubt, the topic may be one where objectively rigorous demonstration is impossible for us.

Furthermore, Du Châtelet adds telling caveats about the cause of attractive force. Given Newton's arguments, she writes, it "seems indispensable to conclude that all bodies in the universe have this attractive force, whatever might be the cause."[20] The qualifications "seems" and "whatever might be the cause" are later additions to this sentence in her own hand. In an anonymous review published around the same time, by contrast, she takes Newton's arguments to "prove" that universal attraction cannot be due to mechanical contact forces, since it acts on all parts of bodies, not just their surfaces (1738, pp. 540; 539). The revised manuscript does not endorse this claim. Though granting that "many philosophers" consider attraction an inherent property of matter, she hesitates to agree (f. 267^{r}). For there is no ruling out that "all the effects that Mr. Newton attributes to attraction" might be "brought about by

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an impulse [*impulsion*] that is unknown to us," for example by the contact action of subtle matter.[21] We know from a definition in her review that "*impulsion*" means a contact-mediated mechanical cause (1738, p. 540). Even though the revised manuscript does not endorse a mechanistic cause of attraction, then, the fact that she does not rule it out signals an important shift. All the same, she does not question the logic of Newton's inductive argument via the Rules. "All the phenomena prove" the law of universal gravitation, and these proofs are "certain" and "direct," like our evidence for the motion of the earth, rather than merely analogical (1737-1740, ff. 266^{v}; 267^{r}). As I see it, this commitment to the success of Newton's inductive argument remains in the published *Institutions*, to which I now turn.

4 | THE FATE OF NEWTON'S RULES IN THE PUBLISHED *INSTITUTIONS*

The manuscripts considered so far were completed before September 1738, when a first printing of the *Institutions* began. Printing was then suspended, notably in order to add new chapters with a more metaphysical bent, partly inspired by Leibniz and Wolff.[22] In the version that was finally published in 1740, the first chapter lays out new first principles of sufficient reason and contradiction. The second and third chapters, respectively, discuss rational theology and an ontology of substances, accidents, and modes. As I touched on in the second section, Du Châtelet was aware of Leibniz and Wolff throughout the composition of the *Institutions*, but only saw a need to discuss them in her final revisions of 1739 and early 1740. One reason for this shift, explored by Brading (2019), seems to be a new anxiety about our empirical knowledge claims. Whereas her early manuscripts are closer to the laissez-faire empiricism of Maupertuis, the later writings show a concern with skepticism about the external world and induction, as well as the fact that previous generations' best theories have turned out false. Her response is complex. It contains elements of foundationalism, given her new emphasis on rationalist first principles. For example, she adds a clause to her second law of motion suggesting that it is not just physically but *metaphysically* inviolable, thanks to the principle of sufficient reason (1742, p. 233; compare 1737-1740, f. 208^{r}). Yet there are also idealist or reductionist strains in her response to the skeptic, as when she affirms that natural science treats phenomena rather than true substances (p. 176).

Here, I cannot hope to cover the epistemological project of the *Institutions* in its full complexity. Instead, I focus on how the published text deals with worries about induction. I will argue for important continuities between the early manuscripts and the fourth chapter of the published *Institutions*, which is devoted to hypotheses. Du Châtelet defines hypotheses as putative explanations for particular phenomena that are entailed neither by the phenomena themselves, nor by a priori truths (1742, pp. 80; 85–86). This raises the question of what guides and constrains hypothesis choice. To answer this question, the chapter lays out several rules for hypotheses. I will argue that two of these rules parallel Newton's Rules 3 and 4. Despite considerable discussion of hypotheses in Du Châtelet, these links with Newton have not been fully appreciated.[23]

First consider a parallel to Rule 3. One of Du Châtelet's precepts is that successful hypotheses must take all available phenomena and experimental circumstances into account, even as hypotheses go beyond purely experimental results.

> We have seen that we can make a good hypothesis only when we are well assured of the facts that we seek to explain, and know the greatest number of circumstances that accompany these facts… finally, [we have seen] that a hypothesis is only true and merits being adopted when it explains all of these circumstances (1742, p. 93; see also pp. 86; 88).

Recall Newton's Rule 3: to take a given property as belonging to all bodies universally, we must establish that the property belongs to all the bodies on which we can experiment. Now, Du Châtelet's discussion is supposed to apply to hypotheses of varying degrees of generality, as shown by her examples. Huygens's hypothesis of the rings of

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Saturn is relatively local: it does not identify a putative property of all bodies. But even here, a single experience or experiment does not establish a hypothesis (p. 88). Other examples of facts that require explanation by hypothesis include electricity and gravitational attraction (pp. 86; 83). In these more general cases, the injunction to be well assured of all the facts and circumstances that are "within our grasp," and the conclusion that the hypothesis is worthy of adoption, will converge with Newton's third rule (p. 86).[24] She takes electricity to be exhibited by all matter, such that experiments with electricity "invincibly prove" conclusions about the structure of all bodies universally (1740, p. 206). As for attraction, she grants that Newton determined "the proportion of forces that direct the motions of celestial bodies," and takes this proportion to hold for gravitational attraction in general (pp. 83; 317). That is, she grants that from a limited number of experiments—which nonetheless assure us of the facts and circumstances within our reach—we may conclude that Newton's law of gravitation holds of bodies in general.[25] As such, a key application of her guideline for hypotheses is to a Newtonian claim about all bodies in general, and in this case, her guideline coincides with one reading of Newton's Rule 3. For to adopt the hypothesis that Newton's law of gravitation holds of all bodies in general is just to take a property, broadly construed, as belonging to all bodies universally. But as we'll see, Du Châtelet denies that from the truth of this law of proportion, it must follow that matter has an inherent property that is the cause of attraction.

We also find a parallel to Rule 4. Du Châtelet introduces a principle governing the conditions under which an accepted hypothesis can be overturned (as opposed to the initial inductive step from phenomena to general hypothesis). Hypotheses, once they meet certain criteria, may be assumed as true until some "contrary experiment" or experience shows that they are wholly false (1742, pp. 88; 91). That is, acceptable hypotheses cannot be overruled solely by raising speculative alternatives: experimental evidence is required. This precept has much in common with Newton's fourth Rule, whereby propositions based on induction can be asserted as true even if they aren't demonstrated with absolute certainty.[26] She celebrates Newton's "success" at using hypotheses: it is his disciples who are overly suspicious of them (p. 93; compare pp. 8; 89). For her, this includes Newton's theory of gravitation, so long as questions about the ultimate cause of attraction are bracketed. She classifies this theory as a hypothesis, not in the pejorative sense reserved for merely speculative hypotheses, but as what Alan Shapiro calls an experimental hypothesis (2004, p. 188). She also sees the Copernican system and Huygens's account of the rings of Saturn as hypotheses in this sense. So there is not a sharp epistemological distinction between the best experimental hypotheses and verified theories: both can be affirmed as true, even if they are less than absolutely certain.

To be sure, her published views are importantly different from those in the manuscript. But these changes often bring her closer to Newton himself, or else do not alter her basic picture of inferences in accord with Rules 3 and 4. I'll consider six of these developments, though a full discussion of the issues they raise is beyond the scope of this paper.

First, although she begins the published work by considering fundamental principles, these are no longer the Rules but the principles of contradiction and sufficient reason (Du Châtelet, 1742, pp. 14–15). To understand what might motivate this development, consider that she presents her new first principles as *self-evident foundations* of "all our knowledge" (*toutes nos connaissances*) (p. 16). The Rules were presented in the manuscripts merely as common ground for all philosophers: she does not say they are self-evident, foundational, or universal. There is a further reason why she might not want to regard rules for hypotheses as self-evident. Compared to the surviving portions of the manuscript, the published *Institutions* puts a sharper focus on *unacceptable* hypotheses advanced by philosophers. In the wake of Descartes, for example, philosophical texts have been filled with hypotheses that are no more than "fables" and "delusions" (p. 79). Metaphysical hypotheses without an inductive or experimental basis are "the poison of philosophy" (p. 10; see also p. 79). This problem is easier to explain if not all philosophers agree on the rules for hypotheses. As she puts it, the rules for hypotheses are an achievement in the scientific "art of discovery" (p. 93). If anything, this brings her closer to the Newtonian idea that the Rules prune away ill-founded metaphysics.[27]

Second, the published work, unlike the manuscript, does not use the term "law" for rules of method. She now regiments her vocabulary so that "laws" usually refer to laws of motion or dynamical laws governing attractive and repulsive forces; "principles" to her new principles of contradiction and sufficient reason; and "rules" to

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methodological precepts, including those governing hypotheses. She may be especially attentive to these distinctions because the published work devotes considerable attention to the status and justification of first principles of knowledge—perhaps pointing up how those principles differ from laws of motion or methodological rules. These distinctions bring her closer to Newton, since he distinguishes between the *Regulae*, which are rules for reasoning, and laws proper.

Third, Du Châtelet newly stresses how conclusions from induction, despite their high probability, remain open to revision. Hypotheses are "probable reasons" or grounds for phenomena (1742, p. 78). To take a hypothesis as true "for us" is just to regard it as highly probable, and this is the most we can expect (p. 91). We must never, with "an air of demonstration," present the truth of a hypothesis as strictly certain (p. 87). Still, inductive results can "morally be taken as certain" for practical purposes, in the sense that they will have "almost the same effect" on us as absolute certainties (p. 91).[28] Here, she commits to a probabilist position that was earlier raised as a possibility in her revisions of the manuscript, when she suggested that attractive force might not be the sort of thing that could be rigorously demonstrated. The published work, perhaps in line with her worries about inductive knowledge, decisively denies that we can "demonstrate the causes" of most phenomena, and concludes that we instead must employ hypotheses (p. 80). This is an attempt to clearly delineate demonstrative from merely probable knowledge. However, a complication is that some of Du Châtelet's published remarks on hypotheses apparently conflict with her probabilism. Much as in the manuscripts, she suggests that phenomena are "necessary consequences" of a successful hypothesis, and adds that that no "new assumptions" are needed in order to derive the phenomena (this is not just a slip of the pen, since it remains in the heavily revised second edition of the *Institutions*) (1742, p. 92). But if a successful hypothesis gives (logical) necessary conditions for phenomena, then the hypothesis can be logically deduced from those phenomena. For example, if universal gravitation is a necessary condition for the behavior of the tides, then the truth of universal gravitation can be deduced from observations of the tides. This appeal to necessary consequence relations seems to exclude the probabilistic relationship she sees between a hypothesis and a phenomenon it is supposed to explain (pp. 80; 88). For if all hypotheses have a degree of probability less than 1, and many concurring experimental phenomena must build up for a hypothesis to become highly probable, than tidal phenomena shouldn't independently entail universal gravitation. I don't seek to resolve this tension here, but only to call attention to how it is partly prefigured in her early manuscripts. For as we saw, she first endorses the logical deduction of universal gravitation from phenomena, but then removes talk of deduction in subsequent revisions. The reappearance of necessary consequence relations suggests continued hesitation on this point, and also that she did not take a straight path from Newtonian to non-Newtonian methodology.

A fourth issue was already foreshadowed in later rounds of manuscript revision. Du Châtelet still accepts Newton's case for the law of universal gravitation, but denies that we can draw conclusions about the inherent properties of bodies. Newton's argument does not enable us to infer that attraction is either an essential property of matter, or a necessary consequence of an essential property of matter (1742, p. 73). Whereas the manuscript found her aligned with Cotes and Clarke, she now argues against them, as Andrew Janiak discusses (2021, pp. 283–288). The reasons for this change are too complex to summarize here, but a leading factor is a new argument that Newtonian action at a distance conflicts with the principle of sufficient reason, and can therefore only be a phenomenon, not a genuine cause that inheres in bodies.[29] A related development is that she now explicitly distinguishes ordinary ponderable matter from subtle matter, which weighs nothing but can bear other properties. In her view, since action at a distance must be rejected, subtle matter will likely turn out to be the cause of gravity.[30] In consequence, general properties founded by induction need not inhere in ponderable matter, since subtle matter can also bear and exercise causal powers. She continues to think that when we perform induction and come to conclusions about general properties, the latter must be seen as grounded in some nonrelational qualities or causal powers of matter. These general properties cannot be relations independent of material relata, as action-at-a-distance relations were sometimes taken to be. But what follows in the first instance from experiment or induction seems to be not a direct conclusion about ponderable matter, but a disjunction: some general properties are either inherent to ponderable bodies *or* inherent

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to subtle matter. This change, while complicating the conclusions of inductive inferences about matter, does not affect her reliance on something like Rules 3 and 4.

Fifth, there is a new emphasis on how a theological and metaphysical framework undergirds the success of induction. Du Châtelet sketches a foundationalist account of the correctness of her rules for hypotheses, though she accepts that we can come to true beliefs about the rules on a posteriori grounds, without knowing their foundations. In particular, she holds that knowledge of God, and specifically knowledge that God maximizes overall perfection in the world, is a "necessary…foundation" for good physics (1742, p. 40; see also pp. 50–51; 56). Citing Leibniz, she proclaims that "this world is…the best of the possible worlds, that in which the greatest variety prevails along with the greatest order, and in which the most effects are produced by the simplest laws" (p. 51; see also pp. 23–27). God's choice to create the best possible world entails simplicity and uniformity, and therefore greater explicability. Unlike Leibniz, however, she does not use final-causal reasoning to attain specific conclusions in natural philosophy. She instead seems concerned by broader threats to empirical knowledge, which can be mitigated by the theological assumption that the world has an "order" and "simple laws." For example, she suggests that Galileo's free fall law not only enjoys strong experimental support but is also admirably "simple and true to the genius of nature": this is an extra-empirical reason to regard the law as general (p. 272). This theological development, if anything, brings her closer to Newton. Newton's first Rule of Reasoning—which counsels only admitting causes that are "true and sufficient to explain their phenomena," and supports Rules 3 and 4—is grounded on the fact that "nature is simple."[31] The simplicity of nature is not a brute fact for Newton, but has theological backing (Biener, 2018). Both philosophers leave room to distinguish between the rules that govern induction, and the metaphysical and theological basis for these rules.

Sixth, as flagged earlier, Du Châtelet now takes two fundamental principles—non-contradiction and sufficient reason—to constrain legitimate hypotheses (1742, p. 86).[32] This means that hypotheses must meet tests of logical and metaphysical possibility (p. 92). Some spurious hypotheses can thereby be eliminated a priori, assuaging the skeptical worry that we have no way to distinguish genuine hypotheses from mere fables or delusions (Brading, 2019, pp. 36–37). Despite this change, however, her rules for hypotheses are irreducible to the fundamental principles. As Gianni Paganini (2022, p. 39) observes, the rules for hypothesis concern the degree to which experimental data provide evidence for hypotheses. By contrast, the principle of sufficient reason gives independent criteria for assessing the explanatory power of empirical claims. For example, the Cartesian vortex theory has explanatory virtues—it is exemplary in its simplicity and intelligibility—but is falsified by observation (1740, p. 289). Conversely, Du Châtelet concedes that the conservation of *vis viva* faces serious empirical challenges, but insists that it should be upheld on the basis of the principle of sufficient reason (1742, 435ff.; Brading, 2019, pp. 91–97). I do not intend to settle here if Du Châtelet has a principled way to resolve conflicts between empirical evidence and the a priori principle of sufficient reason. The key points to observe are that the published *Institutions* does not take the principle of sufficient reason to independently warrant generalizations by induction,[33] and instead continues to endorse rules that parallel Newton's Rules 3 and 4. These rules are logically independent from the principles of contradiction and sufficient reason, and cannot be derived from them.

That is not all. In the next section, I will contend that key metaphysical claims of the published *Institutions* rely on her rules for induction.

5 | INDUCTION AND METAPHYSICS

On a common 18th-century reading, advanced for example by Voltaire (1738), Newton uses the Rules to undercut metaphysics and the a priori claims of rationalism. By contrast, Du Châtelet begins with what she describes as an exposition of metaphysics, as opposed to physics or geometry (1742, p. 13). In this section I'll argue that induction, and consequently analogues to Newton's third and fourth rules, play at least two roles in her metaphysics. First, her

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crucial argument for simple substances is premised on an account of matter attained through induction. Second, her rules for induction can illuminate a distinction she draws between legitimate and illegitimate metaphysics.

To begin, consider her case for simple substances. The argument has a regressive structure. Rather than deducing simple substances solely from first principles, she holds that *if* bodies in general have certain properties, such as extension and active and passive force, *then* these properties must be grounded in underlying simple substances (1742, pp. 138; 144; 162). I cannot detail here how she supports this whole conditional claim.[34] Instead, I focus on its antecedent, namely the attribution of three properties—extension, active force, and passive force—to "all bodies" (p. 137). Only given this assumption can her regressive argument to simple substances get going.

The source of evidence for this factual assumption is clear. Repeatedly, Du Châtelet affirms that "experience proves" (*l'expérience prouve*) all bodies to have these properties, and if that were not explicit enough, she adds that "we observe" these properties (1742, pp. 162; 145; 143). This is an echo of her early manuscripts, which follow Newton in holding that we can only know the properties of actual bodies by experience.

Individual experiences or experiments do not, however, establish consequences for all bodies. Nor can she appeal to an a priori grasp of the essence of matter here. A priori contemplation only informs us that matter of a certain kind is possible (in virtue of not violating the principle of contradiction), not that matter actually exists, or that all matter has the same essential properties. Her account of our knowledge of essences itself involves an implicit inductive step. We begin with observed "constant determinations" in *one* particular, then generalize to properties that hold for all members of a kind (1742, pp. 62–65). To bridge the gap between particular observations and truths holding for a kind, she can be seen as relying on the induction principle, paralleling Newton's Rule 3, that she expounded in her chapter on hypotheses. We've seen that she thinks Newton's law of universal gravitation, though hypothetical and not a complete description of underlying causes, can be considered as holding universally unless it is disconfirmed by future observations. Our assumptions about the general properties of matter, which are an essential premise in her argument for the properties of simples, can similarly be taken to hold universally unless they are disconfirmed. At least in her argument for simples, then, Du Châtelet can be read as doing *inductive* metaphysics.[35] This may explain her decision to expound her conception of hypotheses before turning to a metaphysical argument for simple substances, a choice that might otherwise seem at variance with her claim that the "first chapters" of her work deal with "metaphysics" (p. 13).

Second, recall that despite her ambitious metaphysics of simples, Du Châtelet is critical of some metaphysical hypotheses, which she calls the poison of philosophy (1742, p. 10). The vision of metaphysics in the Preface to her *Institutions* is deflationary. Properly, she holds, metaphysics includes only what is obvious to anyone who can correctly use their cognitive faculties (p. 14). For example, we "naturally" tend to follow the principle of sufficient reason, so the truth of this principle is obvious, and it is part of legitimate metaphysics (p. 23). Most so-called metaphysics is not obvious, and concerns what beings like us "can never know" (p. 14). So most metaphysics will not bring us closer attaining knowledge. In this vein, she states that the opening chapters of her work will provide a *closer look* at the legitimate claims of metaphysics, where the contrast is with revisionary, speculative metaphysical *foundations* (p. 13). In telling contrast with Descartes, who put metaphysics at the root of all the sciences, her official foundations of physics are "geometry and…observations" (p. 12).

Her critique of metaphysics can, I think, be better understood in light of principles of induction along the lines of Newton's Rules. I take her main target to be spurious metaphysical hypotheses that, while speculative, purport to make predictions that are in principle testable *within* physics. Such putative hypotheses, such as Scholastic vegetative souls, are poorly supported by the evidence, if at all, and do not meet the criteria for induction articulated in Newton's Rules 3 and 4 or in Du Châtelet's chapter on hypotheses. Her own first principles of contradiction and sufficient reason, by contrast, fall outside what she calls physics—so criteria for admissible inductive hypotheses do not apply to them.

One might object that unobserved simple substances are unobserved, and a flagrantly non-obvious metaphysical posit. Why then does Du Châtelet endorse them, rather than skeptically concluding that we will never know whether they exist?[36] The role of induction from observations in her argument for simples may help answer this concern.

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Individual observations are unproblematic, and she also assumes that induction has been shown to be legitimate under certain conditions. Once general properties of matter are established, she plausibly takes her argument for simples to only require the principle of sufficient reason, which she regards as natural and obvious. The existence of simples follows from premises all of which are either inductively supported or obvious metaphysical principles. Conclusions about simples, moreover, are not supposed to directly entail testable predictions in physics (1742, p. 159). Instead, the existence of simples is a distinctively "metaphysical truth" that affords a deeper understanding of the properties of matter (pp. 158; 140). As such, Du Châtelet can make a case that, even if there are many speculative hypotheses that threaten to poison philosophy, her commitment to simple substances is not among them.

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ENDNOTES

[1] Critical literature on Rules 3 and 4 and their reception includes Koyré (1965, pp. 261–272), McMullin (1978, pp. 13–27), Le Ru (2001), Smith (2001), Spencer (2004), Di Fate (2011), Biener and Smeenk (2012), Ducheyne (2012, pp. 109–120), Walsh (2017), Biener (2018), and Janiak (2021).

[2] See Cohen (1980), Worrall (2000), Smith (2001, 2016), Harper (2011), and Ducheyne (2012). One upshot of this literature is that the methods used in the *Principia* go beyond what is encapsulated in the Rules. For reasons of space, I focus on the Rules and their reception. Even limiting attention to them, important subtleties in Newton's discussion were often lost on followers who considered the Rules as methodological foundations. Henry Pemberton, for example, presents Rule 3 and adequate supporting experiments as a sufficient basis for enumerative induction, "whereon all philosophy is founded" (Pemberton, 1728, p. 26).

[3] "The word "phenomena" for Newton does not refer to individual observations, but to inductively generalized summaries of observations, such as Kepler's area rule (Smith, 2016, 224n.33; Spencer, 2004; also see Worrall, 2000, p. 65).

[4] Leibniz writes in 1715: "I am strongly in favor of experimental Philosophy, but Mr. Newton strays far from it, when he claims that…each part of Matter attracts each other part…which experiments do not prove in the least, as Mr. Huygens has already very well judged" (1720a, pp. 7–8, cf. 1720b, pp. 55–56; Du Châtelet owned this volume). See also Biener's (2018, pp. 11–13) account of Rule 3 as a response to Huygens's (1690, pp. 152–180) criticisms.

[5] See Koyré (1965, pp. 273–82), Harper (2011, pp. 346–55), and Biener and Smeenk (2012).

[6] See Biener and Smeenk (2012, pp. 108–109). Newton's explicit claim is just that *if* subtle matter exists, its resistance is either zero or negligible (1726/1999, p. 790). Yet he was often understood as doing more: in 1752, Kant still cites Newton as having "*demonstrated* that space…is filled with a substance of infinitely small resistance" (Kant, 2012, p. 1:186; my emphasis).

[7] It is harder to determine exactly when Du Châtelet began the manuscripts. A draft of what was then supposed to be the fifth chapter circulated in October 1737, suggesting that writing was underway by then (Gardiner Janik, 1982, pp. 88–89).

[8] In a significant footnote to the second fair copy, Du Châtelet states that she treats the words "*attraction*" and "*gravitation*" as synonyms (Du Châtelet, 1737-1740, f. 267^{v}). By contrast, the published work distinguishes between *gravitation* or *pesanteur* as phenomena, and Newtonian *attraction* as a putative causal explanation of these phenomena—an explanation that Du Châtelet ultimately rejects. The title of the chapter is revised accordingly. The earliest title is "Of Newtonian attraction, as it brings about [*opere*] gravity and the fall of bodies toward the earth," which is first revised to "Of Mr. Newton's discoveries concerning the cause of gravity," and finally the reference to a cause is deleted (f. 254^{r}; cf. 1742, p. 301). The next chapter in the manuscript—entitled "*de l'attraction newtoniene*"—is an autograph draft rather than a revision of fair copies, and appears to have been written at a later stage (f. 275^{r}; on the chronology see Barber, 1967/2006, p. 20). In the end, two chapters in the published work (XV and XVI) correspond to a single chapter in the early fair copy.

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[9] "Nous ne pouvons connoitre leurs proprietés que par lexperience et c'est par cette voie seulement que nous sommes assurés que l'etendue et l'impenetrabilité leur appartiennent universellement…jl est jndispensable de conclure que tous les corps de l'univers ont cette force attractive, et cet argument d'une gravitation [marginal note: *preuves*] universelle dans toute la matiere tiré des phenomenes, est plus fort que celui par lequel on conclut que tous les corps sont jmpenetrables, car nous n'avons aucun phenomene qui nous Demontre l'impenetrabilité des corps celestes, mais tous nous demontrent leur gravité" (1737-1740, ff. 267r–267^{v}).

[10] For a similar point, see the Preface to 's Gravesande (1720), translated in (1747, pp. I, iv).

[11] "Selon la 3°. loy donnée par m^{r}. neuton pour se conduire dans la recherche de la nature (§10) loy qui est Recüe de tous les philosophes, selon cette 3e. loy, disje, les qualités que nous trouvans apartenir en tout tems atous les corps que nous connaissons peuvent etre reputés universelles et jnherentes atous les corps" (1737-1740, f. 267^{r}). The reference to Newton's Rules has been noted by Barber (1967/2006, p. 21) and Brading (2018, 164n.35), but not discussed in further detail.

[12] Other differences include Du Châtelet's dropping Newton's criterion of intension and remission, which is still found in other eighteenth-century discussions of Newton (e.g., Pemberton, 1728, p. 24), but faces well-known difficulties (McMullin, 1978, pp. 9–13).

[13] "Recüe de tous les philosophes" (1737-1740, f. 267^{r}; see also 266^{r}).

[14] This axiom is described as "the Foundation of all Reasonings in Natural Philosophy" and reads: "That the Creator of the Universe governs all Things, by Laws determin'd by his Wisdom, or spontaneously flowing from the Nature of the Things" ('s Gravesande, 1747, pp. I, 2; this English translation is based on the 1747 sixth edition). 'S Gravesande then lays out the first three of Newton's Rules as "founded upon" this axiom, but does not mention Rule 4 (on the significance of this omission, see Ducheyne, 2014, pp. 99–100). Interestingly, the 1720 first edition of the *Elementa* does not include the general axiom, but gives the first three Rules without comment on their foundation (1720, pp. I, 2).

[15] To quote the original at greater length: "ce phenomene dis je est une suitte necessaire de l'attraction de la Lune et du Soleil sur la terre et du mouvement diurne de la terre, or sî le soleil et la lune agissent sur les meres et les attirent, c'est une preuve certaine que l'attraction qu'ils exercent sur laterre, agit non seulement sur le Planete entier de la terre, mais aussy sur chacune des parties qui le composent, et que par consequent la gravitation apartient a toutes ces parties" (1737-1740, f. 267^{v}).

[16] See among others Harper (2011), Shapiro (2004), Smith (2016), and Worrall (2000).

[17] "Voila donc une nouveau Ressort que mr neuton a decouvert dans la mechanique qui opere dans la nature, les corps… outre toutes les autres proprietés que le createur leur a données ont encore celle de tendre lun vers lautre." (f. 267^{v}).

[18] For more on these complex issues see Koyré (1965, p. 281), McMullin (1978, pp. 57–74), Biener (2018, pp. 10–11), and Janiak (2021).

[19] "Peut etre nest elle point du genre des choses soumises aux demonstrations rigoureuses" (1737-1740, ff. 266^{v}–267^{r}). Her paradigm of demonstration is geometrical proof, which renders its conclusions maximally certain (Du Châtelet, 1742, p. 147). She also seems sympathetic to a tradition—which she probably knew through the Port-Royal *Logic*—on which a proper demonstration does not merely produce certainty, but also provides understanding of *why* the conclusion obtains (Arnauld & Nicole, 1996, pp. 255–256; cf. Du Châtelet, 1742, p. 28). As such, lacking a proper demonstration may also mean failing to understand why universal gravitation obtains.

[20] "Il paroit indispensable de conclure que tous les corps de l'univers ont cette force attractive quelqu'en puisse etre la cause" (1737-1740, f. 266^{v}). The earlier fair copy has "*est*" instead of "*paroit*" and does not include the clause after "*attractive*."

[21] In full: "Quel est le philosophe qui osea nier qu'il ne soit possible que tous les effets que m^{r} neuton attribue a l'attraction soient operés par une impulsion qui n[ou]s est inconnuë" (f. 267^{r}).

[22] See the publisher's "*Advertissement*" included after the title page of Du Châtelet (1740), which refers to her adding a new exposition of "*la Métaphysique de M. de Leibnits*" after the publication of the work was postponed.

[23] Recent relevant work includes Brading (2019), Detlefsen (2021), Janiak (2021), Paganini (2022), Reichenberger (2020), and Suisky (2019).

[24] These criteria for good hypotheses also have much in common with 's Gravesande's first and fourth rules for hypotheses, given in his *Introductio* (1737, pp. 228–229). He thinks we must take as much relevant knowledge into account as possible, and check whether the relevant circumstances "follow" (*sequantur*) the assumed hypothesis. There is solid evidence that Du Châtelet did not have 's Gravesande's *Introductio* available when she drafted the *Institutions*, but only his *Physices elementa mathematica* (2018, pp. I, 367). So these similarities probably stem from common influences, like Huygens and Newton. There are also several points of difference. 's Gravesande does not state that hypotheses *explain* the

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phenomena or give *reasons* why they obtain. Nor would he agree that hypotheses can be directly treated as "truths" or moral certainties (1742, p. 91). In his view, all hypotheses are "fictions": though they can lead to a "fully established" truth, this involves discarding the hypotheses itself (p. 227; 1747, pp. I, xii; Ducheyne, 2014). Du Châtelet, by contrast, does not draw a sharp line between empirical truths and hypotheses—both are just probable—and insists that successful hypotheses are not mere "fictions" or "fables" (Du Châtelet, 1742, pp. 79; 93).

[25] Newton's double pendulum experiment, for example, is a "demonstration" of the proportionality between quantity of matter and weight for "all bodies" (1742, p. 287). Likewise, Galileo's experiments license a general law of proportion, between speed of time of bodies falling from rest, for "all bodies, no matter their nature"; she underscores this by quoting Galileo's original reference to "*tutte le materie*" (p. 270). The truth of the Copernican system could also be "demonstrated" (p. 82; see further Suisky, 2019, p. 138).

[26] On a widespread and plausible reading of Newton, by the 1710s he takes results of induction to be less than totally certain (Biener, 2018; Harper, 2011, pp. 372–396; Smith, 2001; Spencer, 2004; Worrall, 2000). Walsh (2017) dissents, but even on her reading, induction gives only "moderate" certainty.

[27] Compare Newton (1726/1999, p. 943), as well as unpublished remarks on Leibniz's metaphysics, such as Cambridge University Library MS Add. 3968 f. 587^{r}–87^{v} (quoted in Koyré & Cohen, 1962, p. 75) and MS Add. 3970, f. 621^{v} (quoted in Shapiro, 2004, p. 198).

[28] The key issue seems to be that the degree of certainty is high enough to justify action. Huygens made a similar point in his well-known discussion of hypotheses, which likely influenced Du Châtelet (Huygens, 1690, Preface). Many of Newton's followers would be willing to agree. Pemberton, for example, holds that arguments in physics yield conviction, but lack the "absolutely conclusive" status of mathematical proofs (1728, p. 23).

[29] See Du Châtelet (1742, pp. 343–345). Wolff (1737, pp. 239–240) is a likely influence here. At the same time, Du Châtelet continues to praise the empirical advantages of Newton's theory, which "marvelously explains" many "phenomena" (p. 331). She even remains committed to a "force" that actively brings about gravitation and follows an inverse square law (pp. 315–316). For more on this ambivalent position, see Brading (2019, pp. 91–95), Detlefsen (2021), and Janiak (2021).

[30] Gravity has an "external cause" which "must be a matter [*une matière*] that collides with the body we regard as attracted, and which determines by its immediate action the direction and the speed of this body" (1742, p. 347; compare 's Gravesande, 1720, §1194). She elsewhere clarifies that this matter must "weigh nothing" and "move itself very rapidly," even if we cannot yet characterize such subtle matter in detail (p. 301).

[31] Newton (1726/1999, p. 794). On what Newton means by "explain," compare Spencer (2004) with Ducheyne (2012, pp. 47–49). While I don't assume Du Châtelet and Newton have the same conception of natural simplicity, they both reason (1) from premises about God to assumptions about natural simplicity, and then (2) from natural simplicity to conclusions about empirical explanation. As I discussed in footnote 14, 's Gravesande is particularly explicit about this sort of move, claiming that Newton's Rules are grounded in an axiom of divine wisdom.

[32] See Du Châtelet (1742, pp. 23–29; 218–19; 224; 346–47). For more on her use of the principle of sufficient reason, see Brading (2019, pp. 25–53, 79–101), Detlefsen (2021), Janiak (2021), and Wells (2021).

[33] This is actually not a major departure from Wolff and Leibniz, who introduce additional principles of induction, beyond the principle of sufficient reason. Wolff thinks we need a principle of uniform natural kinds to ensure not just that every effect has a cause, but that we can make inductive generalizations. His principle bears comparison with Newton's Rules 1 and 2 (Wolff, 1720, 221ff.; 1725, pp. 77–107). The young Leibniz also identifies a number of rational rules for hypotheses, independent of the principle of sufficient reason, which help back induction (Leibniz, 1875-1890, vol. I, pp. 193–99; vol. IV, pp. 159–62).

[34] In brief: given the principle of sufficient reason, the extension of observed bodies cannot be explained merely by appeal to parts of bodies that are themselves extended. Explaining the property of extension in terms of extended parts leaves no distance between *explanans* and *explanandum*. That makes bodily extension a brute fact, lacking sufficient reason. So in general, a property *F* of matter cannot be non-vacuously explained—such that we understand "how and why" *F* "is possible"—by pointing out that parts or components of matter have *F* (1742, p. 140). Since simples aren't extended, however, they can non-vacuously explain extension. A problem is that she holds that bodily forces are explained by the forces of simples (pp. 143–45; 179–80). Despite hints that simple substances exert special "metaphysical" forces (p. 154), this attempt to explain force in bodies seems subject to her own worry about vacuity. For more details, see Stan (2018) and Brading (2019, pp. 54–78).

[35] A possible influence here is the inductive strand in Christian Wolff's metaphysics (Engelhard, 2021; Leduc, 2021).

[36] Brading (2019, p. 86) raises this problem.

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