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Newton's Law of Universal Gravitation and Hume's Conception of Causality

Abstract

This article investigates the relationship between Hume's causal philosophy and Newton's philosophy of nature. I claim that Newton's experimentalist methodology in gravity research is an important background for understanding Hume's conception of causality: Hume sees the relation of cause and effect as not being founded on *a priori* reasoning, similar to the way that Newton criticized non-empirical hypotheses about the properties of gravity. However, according to Hume's criteria of causal inference, the law of universal gravitation is not a complete causal law, since it does not include a reference either to contiguity or to temporal priority. It is still argued that because of the empirical success of Newton's theory – the law is a statement of an exceptionless repetition – Hume gives his support to it in interpreting gravity force instrumentally as if it bore a causal relation to motion.

Zusammenfassung

Dieser Artikel untersucht die Beziehung zwischen Humes kausaler Philosophie und Newtons Naturphilosophie. Ich behaupte, dass Newtons experimentalistische Methodik der Gravitationsforschung eine wichtige Grundlage darstellt, um Humes Auffassung der Kausalität zu verstehen: Hume sieht die Beziehung von Ursache und Wirkung nicht in einem a priori Grund – ähnlich wie Newton, der nicht-empirische Hypothesen über die Eigenschaften der Schwerkraft kritisiert. Aufgrund Humes Kriterien der kausalen Inferenz jedoch kann Newtons Gravitationsgesetz nicht als vollständig kausales Gesetz bezeichnet werden, da es sich weder auf Kontiguität noch auf zeitliche Priorität beziehen lässt. Es wird dennoch argumentiert, dass Hume die Newton'sche Theorie aufgrund ihres empirischen Erfolges – das Gesetz ist ein Ausdruck ausnahmsloser Wiederholung – unterstützt, indem er die Schwerkraft als Instrument interpretiert, als ginge sie eine kausale Beziehung mit Bewegung ein.

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Introduction

Studies concerning the relationship between David Hume's philosophy and Isaac Newton's natural philosophy have come out a variety of different ways. The more traditional line of interpretation sees Hume as a robust proponent of Newton's scientific methodology (e.g. Nicholas Capaldi (1975), James E. Force (1987), Harold W. Noonan (1999), Graciela De Pierris (2001, 2006, 2012), Peter Millican (2007), and Stephen Buckle (2011)). From this perspective, as Graciela De Pierris (2001, 351) puts it, Hume "consistently takes Newtonian science as a model for the proper employment of causal inferences in inquiries into matters of fact." The core of the traditional outlook can roundly be summarized by James Noxon's (1976, 104–15) words: "Hume's theories of causality and induction are philosophical formulations of the epistemological principles presupposed by Newtonian method." Against this reading, some dissident views have been proposed (e.g. Peter Jones (1982), Yoram Hazony (2009), Eric Schliesser (2009), Michael Barfoot (2010), and Hazony and Schliesser (forthcoming)). Roughly speaking, these portray Hume rather as a man of letters, as a humanist lacking the mathematical competence to be deeply interested in the philosophy of nature. In particular, this vantage point emphasizes the priority of Hume's psychological science of man: In the Introduction to *A Treatise of Human Nature*,[1] Hume insists that all branches of learning, including mathematics and natural philosophy, "lie under the cognizance of men, and are judged of by their powers and faculties" (T Intro 4; SBN xv). Eric Schliesser (2009, 167–68) has recently gone so far as to claim that Hume "attacks" the authority of Newton's natural philosophy, since Newton's physics would depose the epistemic supreme "Science of Human Nature" as Hume's "first philosophy," as his "true metaphysics."

In this paper, I defend a more traditional line of interpretation. In my view, Hume is a proponent of Newton's experimentalist methodology. Examining the methodological position Newton took regarding the topic of universal gravitation can increase our understanding of Hume's conception of causality and hence shed light on the epistemological conclusions he draws. After giving a detailed reading of the connection between Newton and Hume, I will take into account the work done by Schliesser (2002, 2007), which I regard as being astute

in limiting and contextualizing the influence of Newton's theory to Hume's causality.

The paper is structured in the following way. Section 1 discusses Newton's methodology and the philosophical ramifications of gravity law. I will focus to his experimentalism and the problem of causation in gravitation, since these themes are central to Hume's epistemology. In section 2, the investigatory focus is on Hume's conception of causality and its relation to Newton's theory of gravity. After presenting Hume's general advocacy of Newtonian experimentalism, section 2.1 illustrates how Hume sees the relation of cause and effect as not being founded on reason, similar to the way that Newton criticized non-empirical hypotheses about the properties of gravity. However, gravity force as a cause of motion is not sensible in the way Hume's Copy principle insists. But as gravity law is still a statement of an exceptionless repetition, it will be argued that Hume supports interpreting gravity instrumentally, as if this force were a cause of motion. Nevertheless, there are some caveats that I will take into account: Hume could not hold the law of gravity to be a complete causal law, since the law does not fulfill the criteria he imposes on causal explanation, namely, contiguity and temporal priority. The closing section 3 shows the upshot of Hume's Newtonian epistemology. Hume wanted, just like Newton, to eschew metaphysical theorizing about the unobservable causes or essences of observable phenomena. Since there is nothing in *a priori* reason – in the faculty of human understanding itself – that would inform us about the relations between causes and effects, repeated experience affords us the only possible assistance we can have for our causal inferences shaping our beliefs concerning nature or human action. Since the law of gravity is a statement of an exceptionless repetition, Hume gives a high epistemic status to the law, but he could not see it as a complete causal law, because the law does not ascribe either contiguity or temporal priority to the way gravity works.

I do not wish to state that Newton's and Hume's philosophies, in all their complexity, would be exactly alike. Not all of Hume's methodological commitments can be traced back to Newton. For instance, mathematics was drastically important to Newton's methodology while Hume more or less excluded it, generalizing from Newton's method so as to cover his science of human nature, for which mathematics is useless.[2] And though induction was important to both Newton and Hume,

its status differs in the two.[3] But my investigatory focus in this paper is on the specific relationship concerning Newton's theory of gravity and Hume's conception of causality. As I wish to show, this enables us to see how Hume's epistemology is essentially Newtonian in spirit.

1. Universal gravitation, Newton's experimentalism and the problem of causal efficaciousness

In the General Scholium of the *Principia* (which appeared both in the second and the third edition of the *Principia*)[4] Newton acknowledges that gravity force operates according to the law of universal gravitation, $F \alpha Mm/r^2$,[5] being a branch of the third law of motion. The universal law proposes that every object in the universe attracts every other object with a force that is directly proportional to the product of the masses of the two bodies, and inversely proportional to the square of the distance between the two bodies. In justifying the law, Newton appeals to the third rule for the study of natural philosophy. Induction based on "universally established [...] experiments and astronomical observation" enables us to conclude that

> ... all bodies on or near the earth gravitate [lit. are heavy] toward the earth, and do so in proportion to the quantity of matter in each body, and that the moon gravitates [is heavy] toward the earth in proportion to the quantity of its matter, and that our sea in turn gravitates [is heavy] toward the moon, and that all planets gravitate [are heavy] toward one another, and that there is a similar gravity [heaviness] of comets toward the sun, it will have to be concluded by this third rule that all bodies gravitate toward one another. (Principia, Book 3, Rule 3)

Newton defines the concept of a force in causal terms. As he asserts in his unpublished pre-*Principia* writing *De Gravitatione*: "Force is the causal principle of motion and rest" (Newton, Janiak, 2004, 36). In the Scholium of the Definitions of the *Principia*, Newton (1999, 412) claims that "the causes which distinguish true motions from relative motions are the forces impressed upon bodies to generate motion," and that "true motion is neither generated nor changed except by forces impressed upon the moving body itself." From his second law of motion (see, *Principia*, Law 2, 416) it follows that impressed forces are the causes of "true motions," that is, accelerations (see DiSalle, 2004, 42). Centripetal force

is an impressed force, and "one force of this kind is gravity" (Newton 1999, 405). Without this force, planetary orbits and projectiles would "go off in straight lines with uniform motion" (*Ibid.*).

As Hylarie Kochiras (2011, 169) remarks, Newton is "confident that the gravitational force is causally efficacious," keeping "the celestial bodies in their orbits." On Andrew Janiak's (2007, 142) interpretation, Newton genuinely thinks that "a wide range of previously disparate phenomena," such as the free fall of bodies and parabolic trajectories near the surface of the Earth, the tides, the planetary and satellite orbits, and the orbits of distant comets from the Earth, "have the *same* cause." In this sense, he seems to indicate that gravity is a real force causing motion universally, effecting a wide range of (both terrestrial and celestial) phenomena on the scale of our solar system. As Janiak (2007, 81) argues, to measure the accelerations produced by gravity, the quantities of mass and distance, which are "perfectly uncontroversial," are required.

On the other hand, at the end of the General Scholium, Newton allows that he could not tell what "the reason for these properties of gravity" was. In particular, he asserts that these "motions do not have their origin in mechanical causes …" (*Principia*, General Scholium). In the paradigm of mechanical philosophy, such a lack of a causal background was not easy to accept. Its proponents such as René Descartes, Christiaan Huygens and Galileo Galilei, would have expected Newton's theory to produce a contact mechanism (Smith, 2004, 150), to offer an explanation that, more or less, as Katherine Dunlop (2012, 86) puts it, "takes as its model the working of machines." But the new theory did not encompass any physical contact; it did not account for any push or pull between the surfaces of bodies. A corollary of Newton's equation is that any two given bodies with mass, no matter how enormously great their distance from one another, have a mutual force as an interaction between them. This action is instantaneous. In addition, the force postulated by the theory is invisible, and it has to penetrate into the centers of hard, supposedly impenetrable bodies.[6] Leibniz, among other Early Modern philosophers, was dissatisfied with this kind of postulate. He could not find an intelligible mechanical explanation for such a force. He did not accept the fact that a body could be moved naturally if there was no other body that would touch and push it. The mechanical background assumption of the Early Modern period, as Ori Belkind (2012, 142) sums up the matter, "was that

all physical forces are reducible to mechanical forces of push-and-shove." To Leibniz (1717, §35, §118), "any other kind of operation on bodies is either miraculous or imaginary."[7]

Newton was puzzled that his law did not include a medium through which bodies separated by long-range would interact gravitationally. As he writes in his often quoted correspondence with Richard Bentley in 1693:

> It is inconceivable that inanimate brute matter should, without the mediation of something else which is not material, operate upon and affect other matter without mutual contact [...] That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through vacuum, without the mediation of anything else, by and trough which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers (Newton, Janiak, 2004, 102–103).

To explain why Newton is so reluctant to accept action at a distance, it is noteworthy to expound on his conception of space. In the General Scholium, Newton makes the point that space is an empty Boylean vacuum (see also *Opticks*, Query 28). As he writes in *De Gravitatione*: "... in space there is no force of any kind that might impede, assist, or in any way change the motions of bodies" (Newton, Janiak, 2004, 26). There is nothing between two distant particles that could cause their motion. According to Newton's conception of space, it is just a place which physical objects fill (*Ibid*., 13). As space is distinct from bodies, space and matter do not interact in any way that would cause the gravitational motion of bodies. Particles do not alter the space around them, so there is no altered space which functions as an agent to other particles' motions. Matter and space are distinctly separable.

In my opinion, this is a true dilemma that Newton faces. There clearly is tension in treating gravity as a real causally efficacious force, *and* finding action at a distance to be utterly unintelligible. Forces are the causes of change in state of motion (see Newton, Janiak, 2004, 36), but non-mediated action at a distance is "so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it" (*Ibid.* 102–03).

In the quote above, Newton insists that "gravity must be caused by an agent," but what that agent is, as Ernan McMullin (2001, 297) puts it, "is left unspecified." Newton did not identify any physical medium, nor any physical cause or reason, nor any kind of agent that would cause the gravitational motions of objects. As Janiak (2006) argues, when writing the General Scholium, "there was no independent empirical evidence to support the relevant causal explanations of gravity, so they remained merely hypothetical."

But though Newton was puzzled by this dilemma – how to make the causal efficaciousness of gravity force and the unintelligibility of action at a distance compatible – his famous methodological answer to the critique posed by his interlocutors, in the very end of the General Scholium, was: "I do not feign hypotheses." According to my interpretation, what he means by this is that there is no burden of proof to innovate a supposedly intelligible explanation for certain phenomena, such as gravitational attraction. Newton continues in the General Scholium, asserting that:

> 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. In this experimental philosophy, propositions are deduced from the phenomena and are made general by induction.

As in the *Principia*, according to the methodology that Newton sets down in letters to Henry Oldenburg and Roger Cotes, "experimental philosophy proceeds only upon phenomena and deduces general propositions from them only by induction. And such is the proof of mutual attraction." Hypotheses should only be used to the extent that they have testable implications: "For hypotheses ought to be applied only in the explanation of the properties of things, and not made use of in determining them; except in so far as they may furnish experiments" (Newton, 1974a, 1974b, 5–7).[8] In essence, Newton confines the domain of physics to explanatory statements that are deducible from the phenomena. Propositions that do not satisfy this criterion are mere hypotheses that are not acceptable in experimental science (Rutherford, 2007, 12).

Though Newton (1974b, 5–6) is highly critical towards "conjectures about the truth of things from the mere possibility of hypotheses," he is not saying that hypotheses should be altogether eluded.[9] In my opin-

ion, Newton argues that we are in no position to *stipulate* that nature *is* intelligible. If the law of gravity implies seemingly unintelligible properties, this is not in itself a valid counter-argument against it. Newton thinks that we should not give conditions to nature in what she ought to be so that she would be intelligible for us. He insists that principles in natural philosophy "are deduced from phenomena and made general by induction, which is the highest evidence that a proposition can have in this philosophy" (Newton, 1974a, 6).

So, "the main business of natural philosophy," as Newton's famously points out in Query 28 of the *Opticks*, "is to argue from phenomena without feigning hypotheses." Nevertheless, in the Queries of the *Opticks*, Newton is willing to discuss hypotheses (in his definition, propositions that are not deduced from the phenomena) that prompt future study of nature. An essential purpose of the Queries, as he tells himself, is to propose provisional questions "in order to a further search to be made by others." In Query 21, Newton puzzles over the idea of there being an ether, a subtle fluid (something like, but less dense than air) which generates forces through the interaction of this medium's minute particles. Though Newton sympathizes with this provisional physical hypothesis (see, Jaakkola, 1996, 62), he explicitly denies of having knowledge about ether: "for I do not know what this aether is." Though this hypothesis would give an intelligible basis for the law, there were no observations made nor experiments carried out which would have confirmed its existence (see, Janiak (2006) chapter 5 "*Hypotheses non fingo*.") For Newton, the physical cause of gravitational motions is *yet* unknown, but the future study of nature may discover an explanation which, as Kochiras (2011, 173–174) remarks, "is amenable to empirical investigation." But given the current situation in which Newton did lack empirical evidence, he admits in the end of the Queries that he does not want "to propose the principles of motion" from unobservable qualities "as they supposed to lie hid in bodies," but to "leave their causes to be found out."

Though Newton's theory does not contain a contact mechanism that would produce gravitational motions – it did not, in his words, "unfold the mechanism of the world" (*Opticks*, Query 28) – the mathematically characterized proportions of the law can be *quam proxime* compared to phenomena (*Principia*, Scholium, Book 1, Section 11, and Smith, 2004, 150). According to Newtonian experimental philosophy, it is not

required to reveal the supposedly intelligible essence of nature, such as the *reason* of gravity.[10] Its objective is rather to describe mathematically gravity's operations and to justify the resultant theory with experiments and observations.

Next, I proceed to analyze Hume's conception of causality, keeping Newton's experimentalism in gravity research as a frame of reference. As I wish to show, Hume's conception of causality and his epistemological conclusions are essentially Newtonian in spirit.

2. Hume and causality

According to Peter Millican (2009, 651), "Humean science aims to systematize the causal laws that govern observed phenomena." The idea that empirical science is not looking and it does not have to look for the supposedly intelligible essence of nature, or human mind, is a crucial aspect of Hume's Newtonian epistemology. The epistemological consequence Hume draws is, as I will detail in what follows, that the acquisition of knowledge is to be organized along the lines of a fallible inductive empirical science, not according to reasoning *a priori*. I begin my analysis from the Introduction of the *Treatise*, where the premise of Newtonian experimentalism is loud and clear.

As Stephen Buckle puts it, in the Introduction of the *Treatise* Hume "takes up the prominent Newtonian theme that the philosopher must eschew 'hypotheses.'" Hume thinks that philosophical reasoning is to stay within the bounds of experience, that is, within the results of "careful and exact experiments, and the observation of those particular effects" (T Intro 8; SBN xvii). Buckle continues: "The improvement of philosophy depends on being experimental in this sense, and does so because the hidden properties of things can never be known."[11] For Hume, "the utmost extent" of human reason is when we acknowledge "our ignorance, and perceive that we can give no reason for our most general and most refined principles, beside our experience of their reality" (T Intro 9; SBN xviii). Like Newton, Hume also wants to be careful "in avoiding that error, into which so many have fallen, of imposing their conjectures and hypotheses on the world for the most certain principles" (T Intro 9; SBN xix). When it comes to questions of natural or human phenomena, even when dealing in the best theories – "ulti-

mate principles" in his language – we cannot "go beyond experience, or establish any principles which are not founded on that authority" (T Intro 10; SBN xviii).

For Hume, "experience" enables us to "infer the existence of one object from that of another" (T 1.3.6.2; SBN 87). Heiner F. Klemme (2006, 378) expounds on Hume's term "experience": "We observe and recall that an object of class A always appears in contiguity with and in temporal sequence with an object of class B." Experience is our memory of objects related in a linear fashion contiguously and temporally. This renders *causality* essential to experience. Both in the *Treatise* and the first *Enquiry*, Hume holds all matter-of-fact beliefs to fall under the relation of cause and effect.[12] Importantly, he figures that this relation is *not* founded on *a priori* reasoning. As I will illustrate in the next section, this critical enterprise bears a striking similarity to Newton's critique of "hypotheses" as well as to his overall experimentalism.

2.1 The relation of cause and effect not founded on reasoning

In the first *Enquiry*, Hume repeatedly states that the relation between cause and effect is founded on experience, not on reasoning:

> I shall venture to affirm, as a general proposition, which admits of no exception, that the knowledge of this relation is not, in any instance, attained by reasonings *à priori*; but arises entirely from experience … (EHU 4.6; SBN 27)

> I say then, that, even after we have experience of the operations of cause and effect, our conclusions from that experience are *not* founded on reasoning, or any process of the understanding. (EHU 4.15; SBN 32)

> It is only experience, which teaches us the nature and bounds of cause and effect, and enables us to infer the existence of one object from that of another. (EHU 12.29; SBN 164)

In Hume's rigidly empiricist paradigm, the way of acquiring knowledge[13] is by repeated experience. Consider this reformulated example Hume presents in the first *Enquiry* (4.9; SBN 29). I hold a pen in my hand. When I let it go, I anticipate that it will fall straight on the ground. But if we look at the phenomenon from the point of view of *a priori* reason alone, what reasons do we have for this hypothesis? Why would it be more *reasonable* to assert that after my letting go of the pen, it should

fall straight down than rather than, say, rise up, stay at rest, or initiate motion horizontally? What reason do we have for picking a certain effect from an indefinite number of logical possibilities?[14]

In my view, the epistemologically relevant point Hume makes here is that he denies the independent authority of *a priori* reasoning in knowledge acquisition. *A priori* inferences that are supposed to extend to real existence, Hume thinks, are arbitrary:

> The existence, therefore, of any being can only be proved by arguments from its cause or its effect; and these arguments are founded entirely on experience. If we reason á priori, any thing may appear able to produce any thing. (EHU 12.29; SBN 164)[15]

Outside the scope of experience, there is no guarantee that causes and effects would be related in any intelligible way. As the quote (EHU 12.29; SBN 164) above continues: "The falling of a pebble may, for ought we know, extinguish the sun; or the wish of a man controul the planets in their orbits." The Humean standpoint is that from an *a priori* position, there is no reason for a certain phenomenon to be succeeded by another. To reiterate an earlier quote (T Intro 10; SBN xviii) with emphasis: "we can give *no reason* for our most general and most refined principles, beside our experience of their reality." And here we have our first clue towards understand Hume's Newtonian epistemology.

For Hume, the law of gravity is the "most general and refined" principle in accounting for the motion of bodies.[16] In section 6, "Of Probability," in the first *Enquiry*, he classifies the law of gravity as a "proof." As such, it belongs to a set of causes and effects which are supported by past uniform experience. As a high-order matter of fact, gravitation belongs to

> causes, which are entirely uniform and constant in producing a particular effect; and no instance has ever yet been found of any failure or irregularity in their operation. […] The production of motion by […] gravity is an universal law, which has hitherto admitted of no exception. (EHU 6.4; SBN 57)

However, because Hume stresses that all hypothetical relations between causes and effects are arbitrary within the domain of *a priori* reasoning, the only way for us to know gravity's effects, such as the free fall of objects near the surface of the Earth, is to have such beliefs justified *a posteriori*. A problem then arises, in that gravitational force as a cause of motion is not directly detectable. According to Hume's Copy Prin-

ciple, all cognitive and meaningful ideas have to be originally derived from corresponding individual sensuous impressions.[17] Hume's point is that if knowledge is dependent upon ideas having a sensuous origin, associated with one another, then we plainly lack knowledge about the fundamental forces effecting motion in nature:

> The scenes of the universe are continually shifting, and one object follows another in an uninterrupted succession; but the power or force, which actuates the whole machine, is entirely concealed from us, and never discovers itself in any of the sensible qualities of body. (EHU 7.8; SBN 63–64)

But how can Hume be ready to admit a high epistemic status to the law of gravity? Gravity is a concept that should represent the cause of this force's effects, yet this cause cannot be sensed.

Hume refers to the concepts of power and force as the most "obscure and uncertain ideas to occur in metaphysics." In chapter 7 of the first *Enquiry* his intention is "to fix, if possible, the precise meaning of these terms" (EHU 7.3; SBN 61–62). How does, then, Hume fix "the precise meaning of these terms"? I suggest that the solution to the problem is this: Hume interprets forces, or powers, instrumentally. As Hume remarks in footnote 16 to the first *Enquiry*: "when we talk of gravity, we mean certain effects, without comprehending that active power."[18] He sees this physical concept instrumentally *as if* it provides a cause which refers to an effect: "... the idea of power is relative as much as that of cause; and both have a reference to an effect." (EHU 7.29; n. 17). As Millican (2002, 145) notes, "the ascription of powers to objects has considerable instrumental value," though Hume suggests that the concept force is "the *unknown* circumstance of an object." Forces are not perceivable, but they function as meaningful instruments in providing a phenomenal account for the laws of motion. The effect can be predicted by measuring the cause: "the effect is the measure of power" (*Ibid.*).[19]

Hume claims that the term force is a mathematical instrument which enables us to measure its effect, the change in state of motion: "The degree and quantity" of an effect "is fixed and determined" by a force or power (*Ibid.*). What is known about gravity force is what the mathematical proportions of the law say about it. Beside this we do not "comprehend" what that force is. This is largely consistent with Newton's view. He did not have sufficient evidence to characterize gravity physically: his theory did not refer to any observable mechanism which

relates gravity force to acceleration. Rather, as I. Bernard Cohen (1980, 28) argues, in Newton's approach to gravity force "a mathematically descriptive law of motion was shown by mathematics to be equivalent to a set of causal conditions of forces and motions." As Newton writes in the original Book II of the *Principia* (see, Westfall, 1993, 188), where he emphasizes the mathematical interpretation of gravity force:

> But our purpose is only to trace out the quantity and properties of this force from the phenomena, and to apply what we discover in some simple cases as principles, by which, in a mathematical way, we may estimate the effects thereof in more involved cases [...] We said, *in a mathematical way*, to avoid all questions about the nature or quality of this force, which we would not be understood to determine by any hypothesis.

I think Martin Bell (1997, 85) has it right, as he writes that Hume

> did not conclude that all talk of powers and forces in nature should be eliminated from science. Rather, he argued that Newton's caution about the real nature of these entities was justified precisely by the absence of any 'just' ideas of them, and that cautious empiricist scientist should follow Newton in recognizing that these terms are strictly definable only in terms of observable effects.

The so-called New Humeans (e.g. John P. Wright (1983), Janet Broughton (1987), Galen Strawson (1989, 2000), and Peter Kail (2007, 2011)) would certainly disagree with the notion that Hume interpreted powers and forces instrumentally. A central claim of the New Humeans is that causal powers which ground experiential regularities exist in nature, though these powers or forces are, due to Hume's Copy Principle, epistemically inaccessible to us. As Peter Kail (2011, 448) writes, "regular succession," which in this example can be interpreted to stand for Newton's law of gravity, "is all that is *available* to us, and the powers or forces underlying these regularities are secret or hidden."

In my instrumentalist interpretation, I do not claim that Hume would be denying the existence of forces. My contention is rather that Hume is agnostic about unobservable causes: he does not affirm nor deny the existence of such entities whose operations go beyond observed constant conjunctions. In Hume's view, we are justified to accept gravity law, as he remarks in EHU 6.4 (SBN 57), in as much it is supported by past uniform experience,[20] though an entity to which the law appeals is imperceptible.

Granted, as the New Humeans point out (see, Winkler, 2000, 54), Hume speaks about forces necessitating the effects of the material world in the first *Enquiry*. As he writes: "It is universally allowed, that matter, in all its operations, is actuated by a necessary force" (EHU 8.4; SBN 82). The previous claim seems to support the New Hume interpretation. But right in the next paragraph, Hume clarifies his position:

> ... the memory and senses remain the only canals, by which the knowledge of any real existence could possibly have access to the mind. Our idea, therefore, of necessity and causation arises entirely from the uniformity, observable in the operations of nature ... (EHU 8.5; SBN 82)

Here Hume suggests that after repeated experience of uniform operations of objects, the mind abstracts an idea of necessary connection. But the idea of necessary connection does not have its origin in any sensuous impression. Rather, this is brought to the mind by the principle of custom and habit (EHU 5.5; SBN 43). By a customary inference, we expect objects to behave in the future as they have behaved in the past. Accordingly, Hume supports the law of gravity not because he would support the thesis that non-observable causal powers necessitate observable effects, but because it operates in a regular, unexceptional manner. Experience, our memory of objects been related contiguously and temporally linearly in the past, sets limits to our knowledge of causal relations manifested in nature.

Having analyzed Hume's conception of causality in the preceding manner, I find it plausible to assert a connection between it and Newton's experimental methodology in gravity research. Both Newton and Hume would contend that metaphysical hypotheses about the unobservable causes of phenomena are neither legitimate nor required. As in Newton's (see 1974b, 5–6) methodology, in which this kind of hypothesizing is both unnecessary and an inappropriate way to proceed in experimental philosophy, so also in Hume's epistemology it plainly transcends the proper limits of *a priori* reasoning in an arbitrary manner.[21]

Consequently, Newton's method has a hold on Hume's epistemological conclusions. Since projecting conjectures and hypotheses onto the world is epistemologically ungrounded, the authority of knowledge acquisition should be, Hume thinks, granted to experience. If there were some way to have information about matters of fact or real existence, about the motion of bodies or the operations of human cognition,

for instance, the only way left would be committing to "reflections of common life, methodized and corrected" (EHU 12.25; SBN 162). Day-to-day experience[22] and – as a continuation of it and a corrective to it – inductive empirical science[23] can offer us inferences from causes to effects.

Hume does advocate beliefs founded on constant observance from causes to effects. They give us a ground to generalize our beliefs, and evaluate their reliability.[24] But Hume does not see that we could find "a satisfactory reason, why we believe, after a thousand experiments, that a stone will fall …" (EHU 12.25; SBN 162). Hume cannot produce any type of intuitively intelligible medium from causes to effects.[25] Analogously, this is the case with Newton, too. Neither could he present any type of intuitively intelligible medium in which gravitational attraction physically occurs. As Newton cannot give a *reason* for "the properties of gravity," Hume cannot give a *reason* for our "experience of the operations of cause and effect."

So, for Hume, as Alexander Rosenberg (1993, 73) explains, "the whole notion that causation rests on or reflects the intelligibility or rationality of sequences among events is a mistake […] the aim of science cannot be to reveal the intelligible character of the universe, but simply to catalogue the regularities that causal sequences reflect." Millican (2007, xxx) pushes the issue further: "Intelligibility is not to be had, *but nor is it required*, and the proper ideal of science is rather to discover and simplify the laws that describe phenomena." As Hume writes:

> Hence we may discover the reason, why no philosopher, who is rational and modest, has ever pretended to assign the ultimate cause of any natural operation, or to show distinctly the action of that power, which produces any single effect in the universe. It is confessed, that the utmost effort of human reason is, to reduce the principles, productive of natural phenomena, to a greater simplicity, and to resolve the many particular effects into a few general causes, by means of reasonings from analogy, experience, and observations. (EHU 4.12; SBN 30)

For Hume as a Newtonian philosopher, it is consistent to say that Newton's laws do not "pretend to assign the ultimate cause of any natural operation."[26] Newton would agree with this, as he readily allows not being yet able to assign a cause to gravity in the end of General Scholium.

The way Hume understands scientific theorizing, it cannot, as Millican (2002, 126) expounds, "provide pure rational insight into why

things behave as they do." A particularly good example of this can be found in the *Dialogues*. In chapter 4, Philo argues that a search for a supersensible, intelligible principle of natural operations which would answer why things ultimately behave as they do, would lead to an infinite, never-ending quest. Even if some intelligible principle were posited, a question about *its* intelligible principle would remain open. For instance, if the origin and complexity of motion of celestial bodies in our solar system[27] is explained by positing an intelligent designer, what ultimately explains *it*? What is its origin? Why would postulation of any purely intelligible principle mark the end for a search for a cause to observable phenomena? As Philo argues: "But if we stop and go no farther [in positing an intelligible principle such as intelligent designer], why go so far?" (DNR 4.4). The Humean answer is that this kind of postulate, which clearly is neither observable nor empirically testable (yet supposedly remains intelligible), does not in fact offer a legitimate causal explanation – it just prompts further explanatory problems of its original cause. This is what Hume means by his famous slogan in the first *Enquiry* (EHU 4.12; SBN 31): "The most perfect philosophy of the natural kind only staves off our ignorance a little longer." Hume remains skeptic about ultimate rational explanations of natural phenomena, and insists that experience sets limits to acquisition of knowledge.

Again, an analogy between Hume and Newton can be seen, as Newton expresses his objection against "the mere possibility of hypotheses" in his letter to Oldenburg: "one or another set of hypotheses may always be devised which will appear to supply new difficulties" (Newton 1974a, 6). To avoid this kind of problem, one that inevitably follows from the *ex hypothesi* methodology (supported notably by Descartes and Leibniz),[28] both Newton and Hume maintain that causal explanation should be restricted to what can be inferred from the phenomena.[29] As Philo argues: "experience alone can point out [...] the true cause of any phenomenon" (DNR 2.13). If we remain confined only to the domain of *a priori* reasoning, all hypotheses are just guesswork. There is no guarantee that an effect would have a cause that is intelligible for human cognizers. If we stipulate that an intelligent designer, analogous to human reason, is responsible for the ultimate causes of the operations in nature, "we are," as Demea says, "guilty of the grossest and most narrow partiallity, and make ourselves the model of the whole universe" (DNR 3.12). Once more, Hume's thought here can be traced back to

Newton, who, according to my interpretation, argues that we are in no position to *stipulate* that nature *is* intelligible.[30]

In natural philosophy, some observations may arise that are contrary to our intuitive reasoning. Such is the instantaneous long-range mutual action of gravity. But Hume proposes that as long as we report the relations of causes to effects, and resolve these "many particular effects into a few general causes," we are not making "obscure and uncertain speculations" (T 1.1.4.6; SBN 13) or empirically unsupported hypotheses "which," as Philo concludes his line in the *Dialogues* (4.11), "so far exceed the narrow bounds of human understanding." Calling gravity an occult force, which cannot be explained in an intelligible manner, would not be a valid counter-argument against Hume's Newtonian epistemology. The reason for this is that Hume shares the premise of Newton's experimentalism, as he comments on Newton in his *History* (LXXI) as being "cautious in admitting no principles but such as were founded on experiment; but resolute to adopt every such principle, however new or unusual." Hume does not require that causal inferences be intuitive comprehensible either in issues of common life or in natural philosophy. They are mere matters of fact, not rational constructions. Gravity does not need such an explanation either.

However, assimilating Hume's causal philosophy to Newton's law of gravity brings out some caveats that have to be taken into account. Newton did not explicate the philosophical background assumptions that follow from holding the law of gravity law to be a complete causal law. For his part, Hume does explicate some relevant assumptions. As Schliesser (2002, 12–13) notes, the rules by which one is to judge causes and effects according to the *Treatise*, section XV are not, however, consistent with the law of universal gravitation. Hume offers two essential requirements that are both incompatible with interpreting the law of gravity as a complete causal law.

First, Hume sees contiguity as being essential to causation (T 1.3.2.6; SBN 75). He seems to be rather uncomfortable with non-physical action at distance, since he speculates that

> 'tho' distant objects may sometimes seem productive of each other, they are commonly found upon examination to be link'd by a chain of causes, which are contiguous among themselves, and to the distant objects … (T 1.3.2.6; SBN 75)

Evidently, as Schliesser points out, this could not be "made consistent with the universal nature of attraction" since Newton's law stipulates that "the most distant particles of the universe attract each other." Interestingly, after nearly a decade since the *Treatise's* publication in 1739–1740, the contiguity criterion disappears in the first *Enquiry*, published in 1748 (Schliesser, 2002, 12–13).

Second, Hume asserts that causes are prior in time. They come "before the effect" (T 1.3.2.7; SBN 75–76). But as Newton's gravity law is "a branch of the third law of motion" (Newton 1974a, 6), it must be that a force between objects is mutual, and that it appears instantaneously between any two given bodies with mass. Acceleration is simultaneous with an exercise of a force. The observable acceleration of an object does not emerge from a temporally preceding cause but from the mutual force between masses.

I find there to be a substantive detail in Hume's conception of causality that is not compatible with Newton's third law. For Hume, "every effect is a distinct event from its cause" (EHU 4.11; SBN 30). Again, this cannot readily be reconciled with the concept of force as Newton's third law describes it.[31] A force is not a distinct event which has an existence of its own. It is an *interaction* between two members of an action/reaction pair. "Force," as Max Jammer (1957, 127) comments on Newton's concept, "manifests itself invariably in a dual aspect." As Schliesser (2011, 93) points out, gravity is an "accidental quality of matter that arises through what Newton calls "the shared action" of two bodies."[32] It is hard to see how "force" is distinct from "opposite-force" in the sense that Hume understands the idea of cause to be distinctly separable from the idea of effect.[33]

To accept the fact that gravity produces motion causally in a way that Newton described it by his law, one has to challenge the intuitive assumption that motion is caused by a sequence of temporally linear physical contacts. But for Hume, as Todd Ryan's (2003) study confirms, giving up the criteria of contiguity and temporal priority would lead to a *reductio ad absurdum*, since these are exactly the features that ground causal judgments in Hume's theory. As he writes in the *Treatise* (1.3.2.7; SBN 76): "for if one cause were co-temporary with its effect, and this effect with *its* effect, and so on, 'tis plain there wou'd be no such thing as succession, and all objects must be co-existent." Since Hume's rules for causal inference stipulate cause and effect to be "entirely divided by

time and place" (T 1.3.14.18; SBN 164), he would not accept the law of gravity to be a complete causal law. Gravitational force and motion are not "*contiguous* in time and place" (T 1.3.14.1; SBN 155). Gravitational force as a cause does not precede motion as an effect.

Hume's criteria therefore expose pivotal problems concerning gravity's causal nature. For him, gravitational force as an instrumentally interpreted cause is not "an object precedent and contiguous to another, and so united with it" (T 1.3.14.31; SBN 170), which is the definition what it is to be a cause. Newton thought of gravity as a causally efficacious force. This is not entirely compatible with Hume's views.

However, it can be noted that one of Hume's rule for causal judgement is compatible with the law of gravity. It is the requirement of exceptionless repetition. As Hume writes: "The same cause always produces the same effect" (T 1.3.15.6; SBN 173). This criterion is similar to Newton's rule 2 in Rules for the study of natural philosophy in the *Principia*: "Therefore, the causes assigned to natural effects of the same kind must be, so far as possible, the same" (*Principia*, Book 3, Rule 3).

This analogy between Newton's and Hume's views clarifies, why Hume calls the law of gravity as a universal law, but still cannot take it to be a complete causal law. Though the causal relation between gravity force and acceleration is not known – it is not present to our senses – the law of gravity operates in a regular, unexceptional manner. The causal nature of the unperceived entity to which the law appeals is unknown, but essential to Hume's Newtonian epistemology is that the law-like succession of gravity and motion is known *a posteriori*, by repeated experience. It is not known *a priori*, since there is nothing in the faculty of human understanding, in the domain of pure reason, which would inform us about the motion of objects. Though Newton's and Hume's views about gravity's causal efficaciousness are not exactly alike, Newton's *methodology* is nevertheless compatible with Hume's theory of causality and indeed clearly at its intellectual background.

3. Conclusion

I have shown that Hume is a Newtonian philosopher: the experimentalist stance Newton assumed with respect to gravity inspired Hume's epistemological conclusions. The law of gravity, $F \alpha Mm/r^2$, entails

seemingly unintelligible properties, but intelligibility is not a necessary requirement for human knowledge. For Hume, factual information is gained by repeated experience, not by putting forward supposedly intelligible *a priori* explanations. Both Newton and Hume suggest that human cognizers are not in a position to posit that nature is in fact intelligible. Nevertheless, although Newton's law of gravity does not reveal the ultimate nature of the force effecting motion on the scale of our solar system, it does give a phenomenal account of the motion of objects. Since the law is a statement of exceptionless repetition, Hume classifies it as "proof," as a high-order matter of fact.

However, Hume cannot maintain that the law of gravity would be a complete causal law, since it does not include a reference either to contiguity or to temporal priority. Though Newton saw gravity as a causally efficacious force, Hume could not take this literally: instantaneous action at a distance does not fulfill the requirements he imposes on causal explanation. Gravitational force as a cause is not contiguous, nor does it antedate motion as its effect. Still, given the success of Newton's theory, Hume supports it in interpreting gravity force instrumentally as if it bore a causal relation to motion.

Notes

1 References to Hume's *A Treatise of Human Nature* and *An Enquiry concerning Human Understanding* are in accordance with the Hume Society's exhortation. I employ the abbreviations T and EHU as well as the Selby-Bigge/Nidditch (SBN) numbering. Hume's *Dialogues concerning Natural Religion* is abbreviated as DNR, and his *The History of England from the Invasion of Julius Caesar to the Revolution in 1688* as *History*.

2 Whereas Newton named his major work *Mathematical Principles of Natural Philosophy*, Hume largely excludes any "mathematical principles." See Buckle (2004, 79–80), Schliesser (2007), and De Pierris (2012, 259). However, Hume's treatment of "mixed mathematics" complicates the issue, since Hume stresses the importance of applied mathematics in assisting natural philosophy. See Millican (2002, 126) and Claudia Schmidt (2003, 64–65).

3 See footnote 23 of this paper.

4 When referring to Isaac Newton's work *The Principia. Mathematical Principles of Natural Philosophy* I shall use the abbreviation *Principia*; for the *Opticks or, a treatise of the reflexions, refractions, inflexions and colours of light : also two treatises of the species and magnitude of curvilinear figures* I will use the abbreviation *Opticks*.

5 This notation can be found in George E. Smith's article "The Methodology of the Principia" (2004, 150). Newton did not himself express the law of universal gravitation in a single quantitative formula.

6 Gravitational force does not act "in proportion to the quantity of the *surfaces* of the particles on which it acts (as mechanical causes are wont to do) but in proportion to the quantity of *solid* matter …" (*Principia*, General Scholium), that is, in proportion to the whole matter that is in bodies (see, *Principia*, Book 3, Proposition 7, Theorem 7). Gravitational force acts between the centers of mass of bodies, not between the common boundaries of the contiguous parts of them (*Principia*, Definition 8, and Newton, Janiak, 2004, 22).

7 Though Leibniz did not accept the unintelligible long-range action of gravity he nevertheless sympathized with the inverse-square law, $1/r^2$. See Domenico Bertoli Meli (1993, 138) and Alfred Rupert Hall (2002, 210).

8 See also Smith (2004, 142). Newton's letter to Oldenburg was written in 1672, 15 years before the first edition of the *Principia* appeared in print, and his letter to Cotes was written the same year as the publication of the second edition of the *Principia*, that is to say, 1713. In spite of the vast amount of time that had lapsed between the two letters, one can still see the same methodological spirit in both. What is different is Newton's ability to use gravity as an example for arguing for his methodology, since the *Principia*, including the General Scholium attached to the second edition, was then published.

9 As Kochiras (2011, 173–74) informatively argues:
"His method prohibits mere hypotheses, including metaphysical principles, from acting as constraints upon physical theory. He does allow *physical* hypotheses a legitimate, though limited, role in natural philosophy. Physical hypotheses are those that, while currently lacking sufficient empirical support, are yet amenable to empirical investigation. Their proper role, accordingly, is to "furnish experiments". Metaphysical principles or hypotheses, however, cannot have even the limited role of furnishing experiments since, however great their appeal for making the world intelligible, they do not seem amenable to empirical investigation."
Cf. Janiak (2006) chapter 5 "*Hypotheses non fingo*."

10 I am not arguing that Newton was uninterested in finding the reason for gravity, nor that there would not be any reason for gravity's actions (on this point see Eugene Sapadin (2009, 80)). My point, rather, is that although Newton may have wished to discover the reason for gravity, the mere fact that he could not produce any reason for the universal attraction postulated by his theory did not confer legitimacy on the hypotheses portraying the theory as irrational.

11 See the *Treatise* (Intro 8; SBN xvii), and Buckle (2004, 27–28). As Buckle notes, Hume's Introduction (8; SBN xvii) closely resembles the methodological parts of Newton's *Opticks* (1979, 542–43).

12 Concerning the *Treatise* see (1.3.9.12; SBN 113), (1.4.2.14; SBN 193), (App. 2), and concerning the first *Enquiry*, see (4.4; SBN 26), (4.14; SBN 32), (7.29; SBN 76), (12.22; SBN 159).

13 By "knowledge acquisition" I do not mean "knowledge" in the way that the term is used it both in the *Treatise* and the first *Enquiry*, where Hume indicates that it is certain (T 3.1.2; SBN 70) or demonstrative (EHU 12.27; SBN 163). Here as well as in this paper more in general I take the term "knowledge acquisition" to mean the generation of new information through inductive inferences concerning factual issues. Hume also uses the term "human knowledge" in this sense at the conclusion of the first *Enquiry* (12.29; SBN 164).
14 Cf. David Owen (1999, 101).
15 Cf. *Treatise* (1.4.5.30; SBN 247).
16 In no uncertain terms, Hume sees Newton to have "determined the laws and forces by which the revolutions of the planets are governed and directed" (EHU 1.15; SBN 14). See also Bell (1997, 70).
17 For Hume's own formulation of the Copy Principle see the *Treatise* (1.1.4–1.1.5; SBN 1–10) and sections 2 and 3 of the first *Enquiry*.
18 To a modern reader the term "power" may sound like a confusion between force *F* and power *P*, where power is defined as an amount of work done over a period of time. Colin Maclaurin, who was a professor in Edinburgh in the second quarter of the 18th century, clearly uses the expression "the power of gravity" in his *An account of Sir Isaac Newton's philosophical discoveries: in four books* (1750, 255), published two years after Hume's first *Enquiry*. What this indicates is that present-day terminology in physics is different from the terminology of the Early Modern period, not that Hume would have misunderstood the central concept of Newtonian dynamics.
19 See Ernan McMullin (1978, 82).
20 Notice that this does not exclude the fallibility of the law; "the production of motion [...] by gravity is an universal law, which has *hitherto* admitted of no exception" (*Ibid*., my emphasis), but it might be shown to be fallible in the future. See, De Pierris (2006, 298–99).
21 See the first *Enquiry* (12.27; SBN 163): "It seems to me, that the only objects of the abstract sciences or of demonstration are quantity and number, and that all attempts to extend this more perfects species of knowledge beyond these bounds are mere sophistry and illusion." However, the case of mixed mathematics may complicate the issue. In the first *Enquiry* (4.13; SBN 31) Hume clearly thinks that natural laws, such as the conservation of momentum, require employing "abstract reasoning," and "determining [...] precise degree of distance and quantity." But though Hume understands mathematical demonstrative reasoning to assist natural philosophy and the applications of the laws of nature, he still contends that "... the discovery of the law itself is owing merely to experience, and all the abstract reasonings in the world could never lead us one step towards the knowledge of it." (EHU 4.13; SBN 31) See Millican (2002, 126) and Schmidt (2002, 64–65).
22 For Newton's preference for day-to-day experience over hypothesizing see Ducheyne's (2012, 23), which is a study of Newton's (CUL Add. Ms. 9597.2.11 (ca. 1716–1718)).

23 In the end, Hume's stance on induction may be slightly more skeptical than Newton's. Hume would not allow that principles or universal laws could be "deduced from the phenomena" in the sense that Newton understands his theories to be derived "from experiments concluding positively and directly" (Newton, 1974b, 7). As Millican (2002, 118) affirms, to Hume inductive inference is simply "extrapolation from what has been experienced to something which has not been experienced." Newton's position on induction would be closer to the Aristotelian account: as Antony Flew (1984, 171) defines it: "a method of reasoning by which a general law or principle is inferred from observed particular instances" (Millican, 2002, 119). On the other hand, Newton uses Humean induction in arguing for the universal impenetrability of matter in rule 3 for the study of natural philosophy of the *Principia*.

24 This is an essential point for Hume in discrediting the reliability of miracles. As Richard H. Popkin (1998, xix) affirms, to Hume, "as violations of the laws of nature, the reported miracles would be contrary to all of our experience, since the laws of nature are generalizations of our constant regular experiences." For instance, "the raising of a house or ship into the air is a visible miracle" (EHU 10.12; SBN 114–15, fn. 23) that would refute our belief that unsupported objects fall down toward the earth. Since such evidentially strong examples as motion produced by gravity have not "ever yet been found of any failure or irregularity in their operation" (EHU 64; SBN 57), believing a miracle which reports houses or ships as having been lifted up into the air is something so far-fetched that if we did believe it, we would have faith in something like gravitational force not operating in certain individual cases.

25 See the first *Enquiry* (4.16; SBN 34): "But if you insist, that the inference is made by a chain of reasoning, I desire you to produce that reasoning. The connexion between these propositions is not intuitive. There is required a medium, which may enable the mind to draw such an inference, if indeed it be drawn by reasoning and argument. What that medium is, I must confess, passes my comprehension; and it is incumbent on those to produce it, who assert, that it really exists, and is the origin of all our conclusions concerning matter of fact." According to Owen (1999, 84), for Hume "intuition requires no steps of reasoning: no intermediate ideas need be found." Yet with respect to causation Owen (1999, 84) writes: "the mere examination of two ideas present in our mind is not enough to tell whether or not they stand in the causal relation." This confirms that for Hume, there is no instantaneous intuition regarding causes and effects – our information concerning their relation is acquired *a posteriori,* observing their spatio-temporal relations.

26 Hume makes the exact same point in his *History*, chapter LXXI.

27 Or for that matter the origin of life on Earth: Philo in the *Dialogues* (7.5) presents a naturalistic hypothesis about the origin of life, and he rejects the possibility of explaining the origin of nature in a manner that would be empirically unsupported (DNR 7.11).

28 See chapter 5, "*Hypotheses non Fingo*" in Janiak (2006).

29 See Newton's CUL Add. Ms 3965.9 (early 1710s) in Ducheyne (2012, 22). The original Cohen–Whitman translation can be found in Newton (1999, 53–54).

30 Surely, Newton and Hume have largely different opinions when it comes to theological matters. The General Scholium lends its support to the Abrahamic God, whereas the *Dialogues* can be characterized as a mitigated critique of religion and the theistic notion of God. My contention is merely that Newton's scientific methodology and Hume's conception of causality operate analogously on this issue.

31 Newton's third law is not a causal law in the sense that it would explain how force generates change in a state of motion. This is surely described by his second law. But since Newton holds gravity law to be "a branch of the third law of motion" (Newton 1974a, 6) I think it is relevant to discuss it in this context. If the law of gravity is given a realist interpretation in a sense that gravity causes motion, the problem of causal explanation emerges, since Hume understands causal explanation to require contiguity and temporal priority, neither of which is included by the law.

32 Newton may not always have held the idea that gravity is generated only between a pair of bodies. For instance, in his unpublished treatise *De Gravitatione*, written before the first edition of the *Principia* (1687), Newton defines gravity as "the force in a body impelling it to descend" (Definition 10). This implies that before the publication of the *Principia* Newton took gravity to be something *in a* body, not an interaction between two bodies.

33 See the *Treatise* (1.3.14.18; SBN 164).

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