FORCE, MATTER, AND METAPHYSICS IN NEWTON'S NATURAL PHILOSOPHY

Hylarie Kochiras

A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Philosophy.

Chapel Hill
2008

Approved by:

Alan Nelson

Andrew Janiak

William G. Lycan

John T. Roberts

Friedel Weinert

ABSTRACT

HYLARIE KOCHIRAS: Force, Matter, and Metaphysics in Newton's Natural Philosophy
(Under the direction of Alan Nelson)

Metaphysical principles may be intuitively appealing by making the world intelligible, yet they are very difficult to justify. The role that such principles should play in the development of a physical theory becomes a pressing question for Newton, for he seeks a causal explanation of gravity that will eliminate the spectre of matter acting at distance, with sun and planets attracting one another across empty space. Does Newton reach an answer to his question about gravity's causal story, and if not, what stands in the way? Despite his empiricism, he is strongly drawn to the metaphysical principles that matter is passive and that causation is local, so at one level, his problem about gravity seems to be that of discovering some immaterial medium that might possess active powers. Yet I identify in Newton's reasoning a more fundamental problem about gravity, Newton's Substance Counting Problem. His ontology includes immaterial substances as well as material ones, and while his penchant for certain metaphysical principles keeps the search for an immaterial medium alive, his empiricism prevents him from postulating such a medium. He also allows, on empirical grounds, the possibility that substances of different kinds can co-occupy regions of space. Yet if two things can be in the same place at the same time, I argue, Newton has no empirical means of determining how many substances are present on the basis of perceived properties, or of associating those properties with one substance rather than another. Nor will he make those determinations by asserting the metaphysical principles he suspects to be true. Thus he has no means of associating active powers with an immaterial medium rather than with matter, and Newton's problem of discovering gravity's complete causal story is one that cannot be solved.

ACKNOWLEDGEMENTS

I am grateful to a number of people for their assistance with this dissertation. For highly beneficial comments and discussion, I thank my advisor, Alan Nelson, and my committee members, Andrew Janiak, Bill Lycan, John Roberts, and Friedel Weinert. John Henry, from his very different perspective on Newton, generously provided me with a number of comments, as did Lon Becker, Marc Lange, and Jesse Prinz. For their encouragement, I am indebted to my family, especially Thalia Jeffres, Dorothy Kochiras, and Elaine Tamvakis, and to a number of friends, especially Alfred Eisner and Michael Ferejohn.

TABLE OF CONTENTS

ABBREVIATIONS

Background	*The Background to Newton's Principia; A Study of Newton's Dynamical Researches in the Years 1664-84*, John Herival.
CSM	*The Philosophical Writings of Descartes*, trans. John Cottingham, Robert Stoothoff, and Dugald Murdoch.
De Gravitatione	*De Gravitatione et Aequipondio Fluidorum*. Unless otherwise noted, this refers to the translation by Christian Johnson with the assistance of Andrew Janiak and a partial translation by Howard Stein, in *Philosophical Writings*, ed. Andrew Janiak.
"Eighth Boyle Lecture"	The Eighth Boyle Lecture: "A Confutation of Atheism from the Origin and Frame of the World", Part II (preached December 5, 1692 and published 1693), Richard Bentley, in I. Bernard Cohen (ed.), *Isaac Newton's Papers & Letters on Natural Philosophy*.
Essay	*An Essay Concerning Human Understanding*, John Locke, collated and annotated by Alexander Campbell Fraser.
Force	*Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century*, Richard S. Westfall.
"Force, Active Principles"	"Force, Active Principles, and Newton's Invisible Realm", J.E. McGuire.
Forces and Fields	*Forces and Fields, The Concept of Action at a Distance in the History of Physics*, Mary Hesse.
"God and Newton's Gravity"	"'Pray do not ascribe that notion to me': God and Newton's Gravity", John Henry.
"Guide"	"A Guide to Newton's *Principia*", I. Bernard Cohen, in Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I. Bernard Cohen and Anne Whitman.
Leibniz-Clarke	*The Leibniz-Clarke Correspondence*, ed. H.G. Alexander.
Locke to Stillingfleet	*Mr. Locke’s Reply to the Right Reverend the Lord Bishop of Worcester’s Answer to His Second Letter*, John Locke.
Never at Rest	*Never at Rest: a Biography of Isaac Newton*, Richard S. Westfall.
Observations touching the principles of natural motions	*Observations touching the principles of natural motions; and especially touching rarefaction and condensation: Together with a reply to certain remarks touching the gravitation of fluids"* Mathew Hale, (London, 1677), 3-5, quoted in John Henry, "Occult Qualities and the Experimental Philosophy".

"Occult Qualities and the Experimental Philosophy"	"Occult Qualities and the Experimental Philosophy: Active Principles in Pre-Newtonian Matter Theory", John Henry.
Opticks	*Opticks, Or A Treatise of the Reflections, Refractions, Inflections & Colors of Light*, Isaac Newton (Dover edition).
Papers & Letters	*Isaac Newton's Papers & Letters on Natural Philosophy*, 2nd edition, ed. I. Bernard Cohen.
Philosophical Writings	*Newton: Philosophical Writings*, ed. Andrew Janiak.
Principia	*The Principia: Mathematical Principles of Natural Philosophy*, Isaac Newton, trans. I.Bernard Cohen and Anne Whitman.
"Seventh Boyle Lecture"	The Seventh Boyle Lecture: "A Confutation of Atheism from the Origin and Frame of the World", Part II (preached November 7, 1692 and published 1693), Richard Bentley, in I. Bernard Cohen (ed.), *Isaac Newton's Papers & Letters on Natural Philosophy*.
The Copernican Revolution	*The Copernican Revolution: Planetary Astronomy in the Development of Western Thought*, Thomas S. Kuhn.
The Key to Newton's Dynamics	*The Key to Newton's Dynamics: The Kepler Problem and the Principia*, Bruce Brackenridge.

TEXTS AND TRANSLATIONS

I have retained archaic spellings, punctuation, and abbreviations of texts written in English, as the archaic style indicates immediately to the reader that the language is original. Unless otherwise noted, the translation of Newton's *Principia* is that by I. Bernard Cohen and Anne Whitman; and unless otherwise noted, the translation of *De Gravitatione* is that by Christian Johnson with the assistance of Andrew Janiak and a partial translation by Howard Stein (in *Philosophical Writings*, edited by Andrew Janiak).

CHAPTER I

INTRODUCTION

The gravitational force is a persistent problem for Newton. He famously solves the mathematical problem set by Kepler, that of finding a mathematical expression for the force governing the planetary orbits. Once that is accomplished, however, he struggles to solve Kepler's other problem—that of finding a causal explanation of gravitational effects. Does Newton reach an answer to his question about gravity's cause, and if not, what stands in the way? I examine Newton's efforts to find a causal explanation of gravity, and the role that metaphysical principles play in his efforts, for despite his empiricism, he is strongly drawn to certain metaphysical principles, including the principle that matter cannot cause effects from a distance, without any intervening medium.

I begin in chapter II with a history of the problem about the planetary orbits, examining the conceptual changes that transformed it into a problem about force. I trace this transformation from Aristotle, who shared Newton's belief that the universe contains some generative source of new motion, to Hooke, whose presentation of the problem turned Newton's attention away from the Cartesian blind alley of outward endeavors. Between these two figures, Kepler's work is a watershed, for he transforms the problem about the orbits by taking them to be caused by a central force; and he sets himself the dual goals of expressing the force mathematically, and explaining it physically and causally. Newton conceives the problem about the force governing the orbits as Kepler did, and having achieved the first goal, struggles to accomplish the second.

In chapter III, I examine the two components of Newton's explanation of the planetary orbits, the *vis inertiae*, or force of inertia as it is translated, and the gravitational force. For each of these, there are grounds for thinking that Newton considered it a genuine force, and grounds for thinking that he did not. The status of the *vis inertiae* depends upon how Newton defined 'force' generally, and so I ask whether he retains the one general definition that he does give, or whether he abandons that definition, to identify all forces with impressed forces. I do not reach a definitive conclusion about whether he considered the *vis inertiae* to be a genuine force; I instead explore the problems with both the affirmative and negative answers to the question. Further exploring Newton's concept of the *vis inertiae*, I examine its relation to Law 1, opposing those commentators who argue that Newton takes the persistence of state to be uncaused and thus denies universal causation. I also examine the *vis inertiae*'s relation to Law 3, arguing that the conceptual basis of one of its functions and of the related Law 3 may be found in Descartes' principle of reciprocal action. I then examine Newton's relational concept of the gravitational force. Questions about the status of this force arise from a possibility implied by the *Principia*—that gravitating matter might be acting distantly, with sun and planets attracting one another across vast reaches of space. I distinguish two senses in which we may ask whether Newton considers the gravitational force to be genuine or real, a question I take it up in subsequent chapters.

I examine Newton's ontology of substance in chapter IV, as well as his hypotheses about gravity's cause. Since Newton is drawn to certain metaphysical principles—by which I mean principles not derived empirically—most notably the principle that matter cannot act where it is not, some commentators have interpreted him as attributing gravitational effects to God. I provide a new argument against that position, showing that while he does consider that explanation, Newton repeatedly treats the gravitational force as independent of God, and thus as real in the sense that its causal story belongs to the created world. Examining the texts in which Newton speaks of action at a distance, I argue that despite initial appearances, these texts do not attribute active powers of attraction or repulsion directly to the particles of matter, such that no intermediate substance is required for bodies to affect one another. Here I do not distinguish between essential and inessential powers of acting distantly. The possibility of the latter power remains for me to address in the final chapter. In chapter IV I also examine the electric spirit and its associated force, and I oppose the argument that Newton takes some electrical effects to occur by matter acting distantly. Finally, I explore some of the difficulties in the aethereal hypothesis of gravitational effects that appears in Query 21.

Newton speculatively denies that the quantity of motion in the world remains constant, or that it would so absent some generative source of new motion, and he classifies nearly all motions, including gravitational effects, as new motions. In chapter V, I examine the reasons Newton presents in Query 31 for thinking that the universe contains a generative source of new motion—some "active principles". Focusing upon his internal reasoning rather than the concepts that he lacks, such as energy and the conservation of angular momentum, I examine the collision cases and two-globe case of Query 31. I show that in both cases, there are means by which Newton could have denied that motion is lost—and so denied the need to invoke active principles. Yet he passes those opportunities by, for he strongly associates active principles with distance forces—that is, forces acting between spatially separated bodies. Although Newton associates active principles with distance forces, they are conceptually distinct, and he is uncertain what active principles might be. Since he at one point identifies them with laws of nature, I examine the possible conceptions of laws that he might have in mind.

In the sixth and final chapter, I consider how Newton's empiricism intersects with certain metaphysical principles that guide his search for gravity's cause, and I show how this intersection generates a problem about gravity. I examine three explanations of Newton's overall view of gravity, matter, and action at a distance, beginning with a view mentioned earlier—that Newton took active powers of attraction to be inessential powers of matter, and so he allowed action at a distance. I oppose this view, arguing that it would require a distinction between properties that are merely universally realized and those that are essential in the strong sense that matter could not exist without them—a distinction that Newton's empiricism cannot accommodate. According to the closely related second and third explanations that I consider, Newton accepts a general principle of local causation, or he accepts the principle that matter is passive. Newton does not assert these principles, since they lack empirical warrant, but neither does he free himself of them. They guide his search for a medium that might convey gravitational effects locally, by contact, and the principle of local causation determines the nature of the only available models for an inanimate immaterial medium, namely, God and minds.

At one level, then, Newton's problem about gravity seems to be that of discovering some immaterial medium, such as an aether, that might possess active powers to produce gravitational attraction. However, I identify a more fundamental problem about gravity, Newton's Substance Counting Problem. His ontology includes immaterial substances as well as material ones, and while his penchant for certain metaphysical principles keeps the search for an immaterial medium alive, his empiricism prevents him from postulating such a medium. He also allows, on empirical grounds, the possibility that substances of different kinds can co-occupy regions of space. Yet if two things can be in the same place at the same time, I argue, Newton has no empirical means of determining how many substances are present on the basis of perceived properties, or of associating those properties with one substance rather than another. Nor will he make those determinations by asserting the metaphysical principles he suspects to be true. Thus he has no means of associating active powers with an immaterial medium rather than with matter, and Newton's problem of discovering gravity's complete causal story, I argue, is one that cannot be solved.

By way of preliminaries, I note that intend the term 'distance forces' to be neutral with respect to causal questions. It refers to forces that operate between spatially separated material bodies, and which therefore appear to involve action at a distance, but the term itself implies no answer to the question of what gravity's full causal story might be. Also, my discussion considers Newton's speculations as well as those propositions that he asserts. In his mature work, he came to draw that distinction sharply, confining hypotheses—whose proper role is only to furnish experiments—to unpublished manuscripts or to the queries of the *Opticks*. Finally, my analysis focuses upon Newton's internal reasoning, which is to say the arguments and concepts that he employs. So while I do mention certain concepts that Newton lacks, such as energy, and the role that that absence plays in his reasoning, the problem about gravity that I investigate is a problem as Newton conceives it, on the basis of his own concepts.

CHAPTER II

HISTORY OF THE PROBLEM ABOUT THE PLANETARY MOTIONS

How is the problem about the planetary motions transformed into the problems that Newton takes up?

In attempting to explain the planetary motions, Newton sets himself two problems. First, he attempts to find the mathematical expression of the force that governs the elliptical planetary orbits, and in this he brilliantly succeeds. Second, he attempts to find a physical, causal explanation of the gravitational force whose mathematical expression he has discovered, by discovering the substance that communicates the effects and its means of operation. In large measure, Newton inherits these related problems from Johannes Kepler, and Kepler is therefore a turning point in the history I trace in this chapter. I examine some of the conceptual changes that transformed the problem about the planetary motions, and I note the developments that variously pushed either the causal problem or the mathematical one into the foreground. Due to the scope of this historical path, I cover only the most central figures, beginning with Aristotle. Newton's own natural philosophy, that is, his attempt to explain natural phenomena, will differ dramatically from Aristotle's, however, as we shall see, he shares Aristotle's belief that the universe contains some generative source of new motion.

ARISTOTLE’S TELEOLOGICAL NATURAL PHILOSOPHY

Aristotle's natural philosophy—his account of natural phenomena—is strongly teleological. Natural kinds have internal principles or essences that determine their natural changes in accordance with some characteristic *telos* or end. This is so of inanimate as well as of animate substances, and so understanding why a dropped stone falls to earth requires understanding the end it seeks, just as understanding the growth of a tree, the activity of an animal, and the motions of the celestial spheres requires understanding their respective ends. Indeed, understanding why the cosmos is arranged as it is requires an understanding of the characteristic ends of the substances comprising it. In reviewing Aristotle's explanations of change, of motion, and of the cosmos, then, I begin with his account of matter, substance, and form.

Matter, Substance, and Form

In answer to the question of what basic constituents comprise the world we see, Aristotle rejects both atomism and monism. He rejects the views of 5th century atomists such as Democritus (c. 460 – 360 B.C.), who argued that the universe's basic constituents are tiny, impenetrable, indivisible, material atoms moving in void space. Instead, Aristotle denies atomism and rejects the very possibility of a vacuum or void as incoherent (a position that will avoid any troublesome implications that matter can act distantly). And instead of following monists such as Thales, Anaximenes, or Heraclitus, who tried to reduce all existents to water, air, or fire, respectively, Aristotle follows Empedocles in accepting four basic material elements: earth, water, air, and fire. However, these elements exist only in the region below the moon, and the celestial spheres in the superlunary region are made of a fifth element, the quintessence or aether, which is not material.

These elements are not to be identified with substances, for a substance is that which can exist independently.[1] Neither matter nor form can exist independently, and forms, Aristotle argues against Plato, are immanent; according to Aristotle's doctrine of *hylomorphism*, forms are contained within material substances, as the essence or organizing principle. In virtue of this

[1] See Aristotle, *Metaphysics*, 12.5: "Some things can exist apart and some cannot, and it is the former that are substances."

form or essence, a substance is a kind of thing, as opposed to a mere lump of stuff, having properties that are characteristic of it as that kind of thing. The forms of most substances are complex, in that they cannot be identified with a single property or with a static set of properties. This is most evident in living organisms, which develop in characteristic ways over time, actualizing in maturity the potencies possessed in youth. In living substances the form is the soul. Aristotle distinguishes three types of soul, nutritive, sensitive, and rational, but common to these is the shared, fundamental notion of a soul as a principle of self-motion. Thus the self-moving celestial spheres are living and indeed intelligent substances.

Aristotle eventually distinguishes three kinds of substance, two of which are sensible. The first kind of sensible substance is material, and as already noted, there are four material elements comprising the sublunary realm, earth, water, air, and fire. Although these elements differ in their qualities—cold, dry, hot, and moist—they can be converted into one another because they are all material. They can also be combined, and to characterize them quite generally, they are mutable; the nature of matter, and thus of the four sublunary elements, is to have the potency for change. The second sort of sensible substance is immutable. This is the fifth element, the immaterial aether, which comprises the celestial spheres of the superlunary realm, of which the heavenly bodies are the visible part. The third kind of substance is immaterial, insensible, and immutable. This is the deity, or Unmoved Mover. Engaging in pure contemplation of thought itself, the Unmoved Mover is pure actuality, having no potency for change.

Change and the Four Causes or Explanatory Principles

Rejecting the Parmenidean position, Aristotle claims on empirical grounds that change is real.[2] And rejecting the atomists' explanation of changes as the results of chance collisions,

[2] Whereas Parmenides argued that the appearance of change is illusory, Aristotle (*Physics*, I.2) argues that changes in material things are real, for such changes are evident to us by observation: "To investigate whether Being is one and

which break up existing aggregates of matter and form new ones, Aristotle presents a strongly teleological account of change.

All change involves the actualization of some potency existing in a thing capable of being altered, and is brought about by something capable of producing change.[3] In the case of self-motion, the thing itself brings about the alteration (except insofar as all change must ultimately have its source in the unchanging and purely actual Unmoved Mover). For example, the changing of an acorn into a tree is brought about by the acorn's own form, or internal organizing principle, which actualizes its potency for being a tree. As this potency is actualized, the matter persists, but a tree form takes the place of an acorn form. Since one form takes the place of another in this example, this is also a case of substantial change, as opposed to qualitative change. The qualities essential for being an acorn are replaced by those essential for being a tree, and thus one substance ceases to exist as another takes its place. In qualitative change, by contrast, only inessential qualities change, and so the self-same substance persists through the change. Notably, there is something that persists through substantial change as well as through qualitative change, namely the matter or substrate. This notion of a substrate, or prime matter, will prove a vexing problem over the centuries, and as we will see in a later chapter, Newton's concept of body eliminates the notion of prime matter.

To understand any change or substance is to understand it in terms of four explanatory principles, or four causes, as they are more often known. The material cause is the matter comprising the entity, while the formal cause is, as already noted, the organizing principle that gives the entity its essential form. Aristotle's remaining kinds of causes may be said to characterize the scientific revolution to the extent that those seeking causal explanations tended to seek efficient rather than final causes. The efficient cause is the agent or force that brings about

---

motionless is not a contribution to the science of Nature....We physicists...must take for granted that the things that exist in nature are, either all or some of them, in motion which is indeed made plain by induction."

[3] See Aristotle, *Physics*, VIII.1: "There must be something capable of being burned before there can be a process of being burned, and something capable of burning before there can be a process of burning."

the change, and the final cause is the *telos* or end—the purpose for which the change occurs. Crucially, Aristotle does not take the end-seeking behavior in nature to involve any intelligence or deliberation.[4]

Although the four causes are conceptually distinct, a single agent often plays the role of several causes. This is the case with case with living organisms, whose formal explanation or essence is also their final explanation or *telos.* Thus the essence and *telos* of a human being is to live a life of virtue and rational activity; the essence and *telos* of the celestial spheres is to emulate the Unmoved Mover, insofar as they can, by moving eternally in perfectly circular motion; and the essence and *telos* of the Unmoved Mover is the activity of pure contemplation.

A *telos* may be internal or external. The *telos* of the Unmoved Mover is wholly internal, depending upon nothing outside that entity; as such, it is not a process that reaches completion and is therefore eternal. The perfectly circular motion of the celestial spheres is also an eternal activity rather than a process reaching completion, though in this case the entities' *telos* is not fully internal, depending as it does upon the Unmoved Mover. By contrast, the *telos* of a rock is the center of the universe, and once it reaches the closest point to the center that it can, which is typically the surface of the Earth, the process is completed and its rectilinear motion ends. More generally, any object made up primarily of one or another of the four sublunary elements also has a *telos* external to itself; this *telos* is a spatial location, for the elements have natural places in Aristotle's cosmos.

[4] In *Physics*, II. 8, Aristotle writes, "Those things are natural which, by a continuous movement originated from an internal principle, arrive at some completion: the same completion is not reached from every principle; nor any chance completion, but always the tendency in each is towards the same end, if there is no impediment....It is absurd to suppose that purpose is not present because we do not observe the agent deliberating. Art does not deliberate. If the ship-building were in the wood, it would produce the same results by nature. If, therefore, purpose is present in art, it is present also in nature. The best illustration is a doctor doctoring himself: nature is like that. It is plain then that nature is a cause, a cause that operates for a purpose."

Aristotle's Cosmos

Aristotle's cosmos is geocentric, finite and spherical, comprising three distinct realms. The inner, sublunary realm is distinct from the outer superlunary realm that contains the celestial spheres. The moon itself is connected to the innermost celestial sphere, and so moves with the circular motion characteristic to those spheres. Each realm has its distinctive kinds of elements and its distinctive kind of natural motion.

In the inner, sublunary or terrestrial realm, the four material elements are found, as noted earlier. Each element has its natural place, and occupying the regions closest to the earth's center were those elements with *gravitas*. Thus *gravitas* or heaviness is a monadic property, as opposed to a relation, as Newton would later claim. *Gravitas* is possessed by both earth and water, but as the heaviest element, earth's natural place is at the center of the universe. Therefore the cosmos is geocentric, with the center of the body Earth coinciding with the center of the universe. Water's natural place is at the next level, followed by air and then fire, for air and especially fire tend to rise, having the property of *levitas* or lightness.

The kind of motion natural to the elements of this realm is rectilinear motion, which is finite motion. Since Aristotle denies the possibility of any actual infinitude, including an infinite line, a straight line must have a starting point and an end point,[5] which means that the rectilinear motions of the sublunary realm must be completed. For earth and water, the rectilinear motion natural to them is downward, whereas for air and fire it is upward. Thus a stone dropped from the hand will return to the earth in a downward path; since it is made primarily of earth, it seeks the center of the universe. (This stone is moving according to its nature, unlike a stone hurled

[5] See Aristotle, *Physics*, VIII.9: "The straight line traversed in rectilinear motion cannot be infinite: for there is no such thing as an infinite straight line....Now rotary motion can be eternal: but no other motion, whether locomotion or motion of any other kind, can be so, since in all of them rest must occur and with the occurrence of rest the motion has perished. Moreover...rotatory motion is single and continuous, and rectilinear motion is not....In rectilinear motion we have a definite starting-point, finishing-point, and middle-point, which all have their place in it in such a way hat there is a point from which that which is in motion can be said to start and a point at which it can be said to finish its course (for when anything is at the limits of its course, whether at the starting point or at the finishing point, it must be in a state of rest). On the other hand in circular motion there are no such definite points: for why should any one point on the line be a limit rather than any other?"

sideways, to which non-natural motion has been imparted and which must be explained in part by different principles.) Similarly, the rain falls downward, seeking water's natural place at the region outside the Earth. An air bubble trapped in water, by contrast, moves upward, but still its motion is rectilinear process. In all of these cases, the rectilinear motion is a process that seeks completion, and terminates once the natural place is reached. The air bubble stops once it breaks free of the water's surface, and the stone stops once it lands on the Earth's surface, which is an impediment to its actual *telos*, the universe's center.[6] Consequently, if a hollow passage allowed the stone to reach the Earth's center, the stone would stop immediately upon reaching its *telos*, rather than oscillating about the point; and if the body Earth suddenly ceased to exist, the stone would still seek the same point.

Since the motions natural to elements in the sublunary realm seek completion, will motion in this realm eventually cease, as each element eventually reaches its natural place? One reason that terrestrial things continue to move is that they interfere with each other's efforts to reach their natural places, as when an air bubble is trapped in water, or twigs are moved by a bird. Yet the air bubble eventually breaks free of the water. If sublunary motions seek completion, and the elements seek their natural places, why has the sublunary realm not become a static set of nested, concentric spheres of motionless elements? Aristotle reasons that since motion in the sublunary continues, it must ultimately derive from some external source. Terrestrial processes, including the changing seasons, derive their motion from the circulating motions of the superlunary realm's celestial spheres.

In the outermost, superlunary realm, then, are the celestial spheres, and as noted previously, the element distinctive to this realm is quintessence or aether. Unlike the mutable elements of the sublunary realm, quintessence is incorruptible, that is, unchanging. (The moon

[6] Aristotle, *Physics*, II. 8: "Those things are natural which, by a continuous movement originated from an internal principle, arrive at some completion: the same completion is not reached from every principle; nor any chance completion, but always the tendency in each is towards the same end, if there is no impediment....In natural products the sequence is invariable, if there is no impediment."

too is made of quintessence and therefore smooth and incorruptible. Galileo's telescopic observations of a cratered lunar surface would undermine the longstanding belief that celestial and terrestrial bodies were composed of fundamentally different elements.[7])

To explain the planetary motions, Aristotle adopts from his predecessors, Eudoxus and Calippus, the mathematical device of homocentric spheres, but modifies it by taking the spheres to be real entities.[8] Since the planets are wanderers, their motions could not be explained simply by claiming each planet was embedded in a single sphere; Aristotle therefore has a more complex account, in which several spheres are associated with certain planets,[9] and a planet is the visible part of some sphere. Since much of each sphere is not visible, we see through them to the outer planets, and finally to the stars. The motion distinctive to the superlunary realm is, again, the perfectly circular motion by which the intelligent celestial spheres attempt to emulate the Unmoved Mover, insofar as they can. Unlike rectilinear motion, rotatory motion can be eternal,[10] and in the immutable, superlunary realm, the celestial spheres engage in a motion that does not seek completion.[11] The claim that the superlunary realm is characterized by eternal and perfectly circular motion has implications for the location of comets and meteors. Since any body that appears only briefly or that moves in a non-circular motion cannot belong to the eternal, superlunary realm, Aristotle says that comets and meteors are below the moon.[12]

Although the celestial spheres are, as living, intelligent entities, self-movers, they also in some manner derive their motion from something outside themselves. As the motions in the

[7] See Galileo's descriptions in *Siderius Nuncius*, 36, and 40-49, with his drawings to be found on 16 and 44-46.

[8] See Munitz, *Theories of the Universe, from Babylonian Myth to Modern Science*, 62-63.

[9] For a discussion of the concentric sphere system, treated generally for Aristotle and for his predecessors, Eudoxus and Callipus, see Cohen, *The Birth of a New Physics*, 26.

[10] See Aristotle, *Physics* VIII.9: "Rotatory motion can be eternal: but not other motion...since in all of them rest must occur and with the occurrence of rest the motion has perished."

[11] As Michael Ferejohn noted to me, this may ultimately turn upon the distinction between *kinesis* and *energeia.* I thank him for a discussion of this issue.

[12] See Munitz, *Theories of the Universe, from Babylonian Myth to Modern Science*, 64.

sublunary realm would cease if not for the circulating celestial spheres, the spheres themselves would not move if not for the Unmoved Mover. For as mentioned earlier, the *telos* of the celestial spheres is to emulate the perfect, Unmoved Mover insofar as they can, and the most perfect activity they can undertake is perfectly circular motion. For Aristotle, then, a deity is part of natural philosophy in that he invokes it to explain the ultimate source of motion. In very different ways, Newton too will take a deity to belong to natural philosophy, and seek a generative source of motion.

Physics

In the *Physics*, Aristotle attempts to explain, among other things, change and especially motion. All motion requires a mover.

> Everything that is in motion must be moved by something. For if it has not the source of its motion in itself it is evident that it is moved by something other than itself, for there must be something else that moves it.[13]

Motion is classified as either natural or non-natural ('violent', as it is sometimes termed), according to the motion's source. In natural motion, a thing moves itself, in accordance with an internal principle, that is, its nature, form, or essence. The animate celestial spheres move themselves in perfectly circular motion, and an inanimate stone dropped from the hand naturally moves toward the center of the universe, according to its internal principle. In these cases, the explanation of the motion depends primarily upon the formal and final causes.

Non-natural motion, by contrast, is explained primarily by efficient causes, for the motion produced is not in accordance with the object's nature. When I push a heavy stone across the ground, it remains by its nature on the ground, as opposed to traveling upward as is the nature of fire; however, its sideways motion is non-natural, forced by the continual contact of my hand.

[13] Aristotle, *Physics*, VII.1.

Similarly, when I hurl a stone through the air to my left, the downward component of its arc depends upon its own nature, and explains why it eventually lands on the ground, but the horizontal component is non-natural motion imparted by me. If every motion requires a mover, why does the stone arc through the air, as opposed to dropping straight down the moment it leaves my hand? Since its natural tendency is to move downward in a straight path toward the Earth's center, and since Aristotle both denies the void and holds that every motion requires a mover, he must supply an efficient cause of the horizontal component of the stone's arcing motion. That cause, he concludes, must be the air; once the stone leaves my hand, the air before it is pushed around and behind the stone, where it continues to push the stone from the back.

Aristotle's medieval followers would replace this unlikely explanation of projectile motion, however much of Aristotelian physics would remain compelling for centuries, largely because it agrees with common experience. We do not feel the Earth's rotation, and Aristotle holds that the Earth is stationary. It looks to us as though the sun and stars are revolving around the Earth, and Aristotle says that they are. It seems that every motion requires a mover, just as Aristotle asserts in his *Physics*, for we never observe objects moving inertially, in the absence of any force. It seems that no force is needed for a rock tossed up by force to fall back to Earth, and Aristotle agrees, saying that the falling rock is not responding to a force but only seeking its natural place. Eventually, the geocentric model would be replaced by a heliocentric one; circular motions would give way to elliptical orbits; efficient causes would largely supplant final ones; the law of inertia would do away with the belief that all motion requires a mover; the beliefs in distinct kinds of matter and distinct sublunary and superlunary realms would be erased; and Newton would unify the phenomena of earthly projectiles and planetary orbits under a single explanation. Some first steps away from Aristotle would be taken by the medievals, who yet preserved much of his system.

THE MEDIEVALS AND COPERNICUS

The medieval view of the natural world was fundamentally Aristotelian, in that it was fundamentally teleological. Scholastic thinkers retained Aristotle's belief that natural kinds have essential natures, and that each natural change undergone by an entity, including so-called natural motions, is explicable in terms of the *telos* or end peculiar to that kind of entity. The belief that things in the celestial realm were composed of a fundamentally different element than those of the terrestrial realm retained its grip, as did the belief that the celestial spheres were characterized by perfectly circular motion. This latter belief would, ironically, prove instrumental to Copernicus' model, which split with its geocentric forerunners and led Kepler to realize that the planetary orbits were not circular but elliptical.

Medieval Accounts of Motion

In the Aristotelian scheme, it will be recalled, there was no categorical difference between a natural motion through space and any other kind of natural change, since a natural motion through space was explicable in terms of an internal principle. However, the Aristotelian scheme did distinguish between natural and non-natural motions, since the former's explanation lay in an internal principle and the latter's in some external body that forced the motion. Medieval explanations of motion retained this distinction, and much of Aristotle's account of natural and non-natural motions.

Yet Aristotle's explanation of projectile motion was unconvincing. Without the law of inertia introduced much later by Descartes, the medievals continued to believe, with Aristotle, that every motion requires a cause. Therefore, replacing Aristotle's account of projectile motion meant fashioning a replacement cause for the horizontal component of the motion. Whereas Aristotle held that the cause was something external that must remain in contact with the projectile, specifically, the air that pushed the object from behind, John Buridan (1300-1358) and his followers introduced the concept of *impetus*.[14] In throwing the stone, they argued, I transfer an *impetus*, a capacity for motion to it; but since *impetus* gradually wears away, the stone eventually falls to earth, following its natural tendency to seek the earth's center. While the concept of *impetus* was distinctively medieval, it was easily incorporated into the fundamentally Aristotelian explanatory system. It retained the common-sense assumption, held universally until the 17th century, that any motion not produced by an object's own power or principle requires some continual force or action, whether by an external agent that remains in continual contact or by an external agent that is transferred to the body.

Since the medievals retained not only the belief that all motion requires a mover but also the belief that the celestial and terrestrial realms are fundamentally different, the *impetus* theory for projectile motion has no counterpart in their explanation of planetary motions.

The Medieval Geocentric Cosmos

Ideas about the cosmos were strongly influenced by Aristotle during the medieval period, however the period was also characterized by a separation between causal explanations and geometric models of the cosmos, with the latter taking precedence over the former. Aristotle's causal story about the planetary motions now bore the stamp of some Islamic thinkers; the nested spheres carrying the planets, formerly made of quintessence, had become solid, crystalline spheres.[15] This causal account lacked serious competitors, but still did not invite conviction. The geometric models needed to account for observations tended to undermine belief that the crystalline spheres could be real.

The model that served as the basis, being modified rather than replaced by medieval thinkers, was that of Ptolemy (Claudius Ptolemaeus, c. 90-168 A.D.). The model was both

[14] Buridan's notion of *impetus* had precursors in the 6th century thought of John Philoponus, and according to Philoponus, in Hipparchus, a Hellenistic astronomer whose theory Philoponus cites. On this point see Kuhn, *The Copernican Revolution*, 119.

[15] Butterfield, *The Origins of Modern Science,* 20. See also Cohen, *The Birth of a New Physics*, 27.

geocentric and geostatic, to borrow Cohen's term, with sun and planets circling an immobile earth. To account for observations such as the apparently retrograde motion of some planets, Ptolemy employed a complex set of epicycles and other devices inherited in part from his predecessors. These devices included the equant, which characterized a body as moving circularly about a point but at a non-uniform rate.[16] The equant would become a target of criticism by Nicholas Copernicus (1473-1543), and its elimination a significant advantage that he would claim for his own, non-geocentric model. For Copernicus remained committed to Aristotle's attribution of perfectly circular, uniform motion for the celestial bodies, a commitment compromised by Ptolemy's equant.[17] Ptolemy had his own Aristotelian commitments, however. While he might have developed a simpler model by following the heliocentric example of Aristarchus (c. 310-230 B.C.), he rejected Aristarchus' model on the grounds that a moving Earth conflicted with Aristotle's doctrine of the element earth's *gravitas* and natural place.[18]

Ptolemy made no realist claims for the geometric devices of his model,[19] and the medieval astronomers who produced variants of his model similarly tended to leave such questions aside. Their task was only to develop geometric models that "saved the phenomena"—that were consistent with observations—not to represent physical reality or explain how the celestial bodies moved. The position that astronomy's goals were so circumscribed perhaps drew some strength from the crystalline sphere hypothesis. It was an unlikely causal explanation, since real crystalline spheres could not easily be reconciled with the deferents and epicycles needed to account for the astronomical data.[20] Yet the existence of a possible or even

---

[16] On the equant and Copernicus' objections to it, see Kuhn, *The Copernican Revolution,* 70-72. See also Butterfield, *The Origins of Modern Science*, 25.

[17] See Butterfield, *The Origins of Modern Science*, 25.

[18] See Butterfield, *ibid.*, 33.

[19] Cohen, *The Birth of a New Physics*, 29.

[20] The epicycles needed to account for apparently retrograde motion immediately give rise to vexing questions such as the following. Would a circular epicycle drawn itself represent a solid sphere, one smaller than the main sphere it intersects, and if so, how might a planet move from the greater sphere to the smaller one?

unsatisfactory explanation can keep a question at bay. As we shall see later, it was after the existence of real crystalline spheres had been definitively disproved that one theorist at least (Johannes Kepler) became preoccupied with the causal question. In trying to answer that causal question, Kepler would defend a model for which he was indebted to Copernicus.

Copernicus

The model that Copernicus set out in *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*[21]) had revolutionary potential, but was not in itself revolutionary. Indeed, a prime advantage that Copernicus claimed for his theory, one mentioned earlier, is that it did away with Ptolemy's equants, thereby preserving the uniform circular motion that Aristotle had associated with the immutable, celestial realm. And though Copernicus' model was nearly as complex as Ptolemy's—and no more accurate—he had good grounds for considering it more geometrically elegant. Among other things, it implied the retrograde motion observed for some planets to be only apparent; it explained why such observations were not made for Mercury and Venus, except when those planets lay at inferior conjunction; and it explained why those same planets are never observed at 180^{o} away from the sun, as is the case for Mars, Jupiter, and Saturn.[22] All of these results were implied by Copernicus' placement of the bodies, for his model was not geocentric.

But while the model was not geocentric, neither was it heliocentric, as were some of the so-called Copernican models it would later inspire. (I shall follow the tradition of using the term 'Copernican' to refer to such models, which derive from Copernicus but differ from it in critical features.) The heliocentric model that Galileo would defend placed the sun at the center of circular planetary paths. Kepler's model might be called 'heliofocal', for it located the sun at the

[21] Ernan McMullin notes that the title of Copernicus' work should be translated using the term "spheres" rather that "bodies", since "'orbis' for him meant a [crystalline] sphere, not a planet or merely a 'body,' as the more usual translation of the title would suggest." See McMullin, "The Origins of the Field Concept in Physics", 17.

[22] On these and related points, see Cohen, *The Birth of a New Physics*, 38.

focus of elliptical orbits. Copernicus' own model, however, was not heliocentric but only heliostatic, to borrow Cohen's term. The sun was immobile, but it did not coincide with the center of the universe or the planetary paths. Instead, Copernicus took the center to be the mean of the planetary paths, paths given by inaccurate data that were not to be improved upon until Tycho Brahe's meticulous observations. This point lay slightly outside the sun, and did not correspond to any real body—a feature that would be critical to Kepler's response. (Also critical to Kepler's response would be the absence of causal claims, for Copernicus made no claims about the sun acting upon the other celestial bodies.[23])

Copernicus' non-geocentric model had revolutionary potential, then, because it would inspire heliocentric and heliofocal models, but also because it had causal implications. Copernicus himself made no causal claims, avoiding the question of whether the crystalline spheres were real.[24] Since disproof of that hypothesis would wait until the next generation, and since astronomers were agreed upon the goal of saving the phenomena, there was no call to augment his geometric model with causal claims. Yet the model had causal implications. If it represented the actual positions of the celestial bodies (and the question of whether Copernicus himself thought so remains controversial[25]), then the Aristotelian physics could not be correct.

According to the Aristotelian view, the celestial bodies were light whereas earth was very heavy, possessing the monadic property of *gravitas*. To suppose that the Copernican model represented actual relations among the celestial bodies was to suppose that the Earth was simply a planet, along with Mercury, Venus, and Mars. This suggested in turn that the Earth and the

---

[23] See Hesse, *Forces and Fields,* 127.

[24] See McMullin, "The Origins of the Field Concept in Physics", 17: "Despite his [Copernicus'] frequent references to 'spheres,' he prudently stayed away from the long-disputed issue of their nature. It was not clear how, if the spheres were taken to be solid to perform their carrier function, they could be compatible with the minor epicycles that the Copernican system still required."

[25] When Copernicus' work was finally published in 1543, it contained a cautionary preface stating that the model's relations among the heavenly bodies that need not be taken as physically real, however as Johannes Kepler later discovered, the preface's author was not Copernicus but a Lutheran clergyman Andreas Osiander. As McMullin notes (*Newton on Matter and Activity*, 280), Galileo argued that Copernicus did believe his model to represent the celestial bodies' actual relations.

planets had the same composition, undermining the claim that the element earth possessed *gravitas*, while the planets were made of the aethereal quintessence. And without the claim that different elements had different natures and, concomitantly, both different characteristic kinds of motions (rectilinear for earth and circular for quintessence) and different natural places, one was left without any explanation of how the celestial bodies move. If the heavy Earth moved, then the motion of planets could not be a function of their aethereal composition. Similarly, without the claim that the nature of the element earth is to seek the center of the universe, one was left without an explanation of why stones released from heights fall to Earth. The motion of celestial bodies and of terrestrial gravitational effects became mysterious. Such concerns prompted political philosopher Jean Bodin to reject the notion of a moving earth.

> No one in his senses, or imbued with the slightest knowledge of physics, will ever think that the earth, heavy and unwieldy from its own weight and mass, staggers up and down around its own center and that of the sun; for at the slightest jar of the earth, we would see cities and fortresses, towns and mountains thrown down....For if the earth were to be moved, neither an arrow shot straight up, nor a stone dropped from the top of a tower would fall perpendicularly, but either straight ahead or behind....Lastly, all things on finding places suitable to their natures, remain there, as Aristotle writes. Since therefore the earth has been allotted a place fitting its nature, it cannot be whirled around by other motion than its own.[26]

These objections, which because of the inaccessible nature of Copernicus' book were raised significantly after its first appearance, would persist through Galileo's famous defense of a heliocentric cosmos. The question of why, on the hypothesis of a moving earth, objects projected straight up into the air fall back to the launching spot, rather than ahead or behind it, would not be answered until the old belief that all motion requires a mover had been abandoned.[27] The

[26] Jean Bodin, *Universae Naturae Theatrum,* 1597, trans. by Dorothy Stimson, quoted in Kuhn, *The Copernican Revolution*, 190.

[27] Galileo gives an experimental argument against the Aristotelians in his *Dialogue Concerning the Two Chief World Systems*. When asked whether an object dropped from the mast of a ship will land at different points on the deck, depending upon whether the ship is resting or moving, Simplicio, the Aristotelian, replies that it will; it will land at the foot of the mast for the resting ship, but behind the mast for a moving ship. The character of Salviati then presents Galileo's experimental results that in fact the object will land at the mast's foot regardless of whether the ship is resting or moving. Kepler's response, part of his incorrect theory of attractive force, is that the earth's magnetic virtue would

questions of how the earth could move, and why stones released from heights fall to Earth, if not because seeking their natural places, would of course be taken up by Newton. Yet Newton's theory would not provide a causal explanation to satisfy either himself or his critics. Aristotle's theory, meanwhile, supplied causal explanations that to Copernicus' critics were preferable to his more elegant geometrical model, and to those of his defenders, Galileo and Kepler.

GALILEO AND KEPLER

Galileo Galilei (1564-1642) and Johannes Kepler (1571-1630), contemporaries and correspondents, applied mathematical methods to motion. Kepler's most enduring contributions were his empirical laws for the elliptical orbits, while Galileo's were his quantitative treatment of terrestrial motion and his steps toward a concept of inertia. The contributions of the two thinkers would converge with Newton's unification of terrestrial projectiles and planetary orbits under a single explanation.

Galileo

Galileo helped set the course of modern science largely by abandoning the Aristotelian worldview. In *The Assayer* of 1623, Galileo rejects the Aristotelian doctrine of substantial forms by distinguishing subjective or sense-dependent properties, such as color and warmth, from objective properties such as shape and speed.[28] He also abandons the Aristotelian preoccupation with final causes, a critical move for his quantitative treatment of motion.

---

hold and drag the projectile, is given in *Mysterium Cosmographicum,* vol. 16, 196 (quoted in Max Jammer, *Concepts of Force*, 84-85): "How is it possible that a sphere, thrown vertically upward—while the earth rotates meanwhile—does return to the same place? The answer is that not only the earth, but together with the earth, the magnetic invisible chains rotate by which the stone is attached to the underlying and neighboring parts of the earth and by which it is retained to the earth by the shortest, that is, the vertical line." The problem would be solved by Huygens.

[28] Galileo classifies shape (length in particular) and motion (speed) as objective, observer-independent qualities; his view would of course be overturned centuries later with Einstein's relativistic physics. Galileo explains in these excerpts from *The Assayer*: "Tastes, odors, colors, etc., so far as their objective existence is concerned, are nothing but mere names for something which resides exclusively in the sensitive body (*corpo sensitivo*), so that if the perceiving creatures were removed, all of these qualities would be annihilated and abolished from existence. But just because we have given special names to these qualities, different from the names we have given to the primary and real properties, we are tempted into believing that the former really and truly exist as well as the latter....If ears, tongues, and noses be taken away, the number, shape, and motion of bodies would remain, but not their tastes, sounds, and odors....I confess myself to be very much inclined to believe that heat, too, is of this sort." (*The Assayer*, 56-57, 59, 60.)

Galileo's Aristotelian predecessors and contemporaries explained motion as a kind of change, and explained all changes in terms of a substance's *telos*, which is to say a future-directed end. In many cases, an object's *telos* was a spatial location, because each of the elements had some natural place. Understanding the motion of a released stone therefore meant discovering the element of which the stone was primarily composed (earth), and the spatial location natural to that element (the center of the universe, and thus of the body Earth). On the Aristotelian view, then, only one spatial point in an object's trajectory was salient to an understanding of its motion, namely, the terminal point. Since the rest of the trajectory was not relevant to the motion, this account of motion was not conducive to the quantitative treatment of trajectories critical to the scientific revolution.

When it is said, then, that Galileo asked how bodies move instead of asking why they move, we should not understand this to mean that Galileo took no interest in causation at all. For he did sometimes seek the efficient causes of motions, that is, the prior events and conditions producing the motions.[29] We should instead understand this slogan to mean that Galileo eschewed the search for final causes. In so doing, he turned his attention not only to the terminal point in a body's trajectory, but to the entire trajectory. Thus he advanced from the known fact that falling bodies accelerate to a discovery of their rate of acceleration, and from the known fact that projectiles have curved paths to the discovery that the curve is parabolic.[30]

Galileo did not fully break free of Aristotelian assumptions, and this is evident in his concept of inertia. His concept was an advance, for unlike Kepler, who took inertia to be a tendency toward rest, Galileo's concept broke with the old idea that all motion requires a mover, by allowing some continuous states of motion to qualify as natural. However, it was not

[29] According to E.A. Burtt, Galileo distinguished secondary (immediate) causes, which were specific motions, from primary (ultimate) causes, which were forces such as gravity. Galileo managed to avoid the temptation to speculate about gravity's nature, instead conceding that it was unknown to him. See Burtt, *The Metaphysical Foundations of Modern Physical Science: A Historical and Critical Essay,* 91-92.

[30] Galileo's early, unfinished book, *De motu*, would use the concept of *impetus* to try to explain motion, but as his work in mechanics progressed, he abandoned the notion, moving closer to the concept of inertial motion. He did not fully articulate it because he continued to identify natural motion with circular motion.

rectilinear motion that he took to be natural or unimpeded, but circular motion. An object moving without restraint, Galileo held, would follow the curve of the earth.[31] Hence Galileo did not construe circular motion as motion produced by a force. His attachment to ancient ideas about circular motion is also evident in the model of the cosmos he defended. In his heliocentric model, one that was much simpler than Copernicus' and which he took to represent the real relations among the celestial bodies, the planetary paths were circular.[32] Thus Galileo followed the ancient belief in circular path, taking no account of Kepler's results, which showed the planetary paths to be elliptical.

Kepler and the Astronomical Tradition of Geometric Models

Kepler's model of the cosmos, though inspired by Copernicus' model,[33] differed on several critical points. First, Kepler rejected all elements of a model that he regarded as "purely geometric assumptions", including some epicycles that Copernicus had retained. Instead, Kepler

---

[31] See Westfall, "Galileo was thinking in similar terms [i.e., in terms of natural, circular motion] when he confronted the problem of motion on a spinning earth, and the concept of inertia that he formulated reflects [this]....What is a horizontal plane? It is of course a plane which is everywhere 'equally distant from the center.' Inertial motion was conceived as uniform circular motion, the natural motion of a body in its natural place in a well-ordered universe." (*The Construction of Modern Science,* 19.)

[32] On this point, see Westfall: "Even in formulating a new conception of motion, he [Galileo] was bound by elements of the old cosmology. His universe was not an impersonal universe of mechanical laws and matter in motion. It was a cosmos, rather, organized by infinite intelligence. As such, it was ordered, inevitably, according to the perfect figure, the circle. Following the old tradition, Galileo held that...circular motion alone is compatible with an ordered cosmos. Only in a circle can a body move forever in its natural place, maintaining always the same distance from the same point, and only in circular motions can the bodies of the cosmos retain forever their primordial relations. Rectilinear motion implies disorder; a body removed from its natural place returns to it along a straight line. Once there, it remains in its place by resuming a natural circular motion. Thus the astronomy of the *Dialogue* was such as no professional astronomer could have accepted. Published over twenty years after Kepler's *Astronomia Nova*, the *Dialogue*, which intended to support the heliocentric system, ignored Kepler's conclusions....It discussed the Copernican system as though each planet moved in a simple circular orbit." (*Ibid.,* 18.)

[33] Galileo similarly defended a model based upon that of Copernicus, but dispensing with many elements. As Peter Machamer notes, "The Copernican theory that Galileo was constructing was a physical realization of parts of Copernicus' theory, which, by the way, dispensed with all the mathematical trappings (eccentrics, epicycles, Tusi couples and the like)." ("Galileo", 6-7.) There were also important differences between Kepler and Galileo. In particular, Galileo followed Copernicus in accepting circular paths for the planets.

sought a physical explanation of the planetary motions, and the only paths to appear in his model would be those correlated with the motions of real bodies.[34]

Second, Kepler abandoned the longstanding belief that planetary paths were circular. Although Kepler shared his predecessors' tendency to associate circular motion with divine providence[35], and though they shared his goal of devising models that accounted for the empirical data, Kepler had far more data at his disposal, inherited from Brahe. Once his laborious efforts to understand Mars' motions were complete, Kepler achieved the result that would be the basis for his so-called First Law of elliptical orbits.[36] He concluded that the planet's path was elliptical, and that the sun was positioned at one focus of the ellipse.

The sun's position was a third, key departure from the Copernican system. In Copernicus' model, the sun was merely near the center of the planetary paths, as noted previously. Its position therefore did not suggest any causal relation to the planetary paths. Kepler, however, became preoccupied with causal questions, partly because Tycho Brahe's observations of the 1577 comet had translated earlier misgivings about the crystalline spheres into a sure demonstration that they did not exist. The comet's trajectory passed through the area allegedly occupied by the crystalline spheres carrying Mercury and Venus. Since those spheres would have been shattered by the comet had they been real, Brahe concluded that they could not exist as solid bodies.[37] For Kepler, this result shifted the question of how the planets moved into the foreground. If no spheres existed to carry the planets around, what caused them to move?

---

[34] Kepler's notes on a 1616 letter from Maestlin: "I call my hypotheses physical for two reasons...My aim is to assume only those things of which I do not doubt they are real and consequently physical, where one must refer to the nature of the heavens, not the elements. When I dismiss the perfect excentric and the epicyle, I do so because they are purely geometric assumptions, for which a corresponding body does not exist. The second reason for my calling my hypotheses physical is this...I prove that the irregularity of the motion [of planets] corresponds to the nature of the planetary sphere, i.e., is physical." The quote appears in Holton, "Johannes Kepler's Universe: Its Physics and Metaphysics", 346.

[35] See Brackenridge: "Despite his description of planetary motion as elliptical, the circle remained the primary element for Kepler in his understanding of the archetypal cause central to God's plan of the universe, and that understanding was strengthened by his complementary concern for physical cause." (*The Key to Newton's Dynamics*, 12.)

[36] Kepler discovered his so-called Second Law—that equal areas are swept out in equal times—before the other two. See Holton, "Johannes Kepler's Universe: Its Physics and Metaphysics", 344.

[37] See Stephenson, *Kepler's Physical Astronomy*, 26. See also Donahue, "Kepler", 251.

The empirical "laws" that Kepler produced brought him a partial answer to that causal question. The fact of elliptical rather than circular paths eliminated the ancient explanation of the planets' motion, according to which circular motion was natural to them. The sun's position at a focus instead suggested that the planetary paths were caused by the sun. This causal relation was further suggested by Kepler's Third Law, which related a planet's speed to its distance from the sun.

> Because it is apparent that in so far as any planet is more distant from the sun than the rest, it moves the more slowly—so that the ratio of the periodic times is the ratio of the $3/2^{th}$ powers of the distances of the sun. Therefore we reason from this that the sun is the source of movement...The closer any one planet approaches the sun during any time, it is borne with an increase of velocity in exactly the ratio of the square.[38]

This was a critical break not only with his predecessors, but also with his contemporaries, including his teacher Michael Maestlin, who urged him to "leave physical causes out of account, and explain astronomical matters only according to astronomical method with the aid of astronomical, not physical, causes and hypotheses."[39] Yet Kepler resisted such circumscribed goals, sharing the view that perhaps motivated Plato in his *Timaeus*—though the universe operates according to mathematical harmonies, mathematics can only describe motion, not produce it. Thus he emphasized that a geometric point cannot determine motion: "A mathematical point, whether or not it is the centre of the world, can neither effect the motion of heavy bodies nor act as an object toward which they tend".[40] In his model and his causal conception, he therefore replaced Copernicus' mathematical point with a body, the sun.

> The seat to be assigned to this same source of movement is not in any mathematical point, very near to the most noble body [the sun], but rather in that most noble body, for

[38] Kepler, *Epitome of Copernican Astronomy*, IV.3: 55.

[39] Michael Maestlin, Letter of October 1, 1616, quoted in Holton, "Johannes Kepler's Universe: Its Physics and Metaphysics", 345.

[40] Kepler, Author's Introduction, *New Astronomy*, 54.

> three reasons: first, in order for us to avoid the absurdity that the source of movement...should be very near to the heart of the world, but nevertheless should not be at the very heart of the world, namely the sun; secondly, because the motor force cannot reside in a mathematical point but requires a body, namely the heart of the world, the sun; thirdly, because the motor force absolutely demands for itself the centre of the world, where the sun itself is: just as stillness belongs to the surface of the world, so movement belongs to the inside....Copernicus...places that common node of the planets very near to the sun, but not in the sun itself.[41]

In asserting that the sun causes the planetary motions, Kepler was, as Goldstein and Hon have argued, forging the new concept of a planetary orbit: the path of a body through space, as governed by a force.[42] The planetary paths were not natural circular motions produced by teleological internal principles, as the Aristotelians had argued, nor should they be treated as mere geometrical forms; they were the elliptical trajectories of bodies moving under the influence of the sun's "motor force" (*anima motrix*).

So, setting himself against the astronomical tradition of his time, Kepler includes the sun's force upon the planets as one of the "physical forces", or as he sometimes writes, "bodily forces"[43] that he is trying to explain, as the causal power of one body to act upon another.

Kepler's "physical forces", Presented through "calculation and geometry"

Having identified the sun as the source of the motor force, Kepler hoped to discover the nature of the physical force that produced elliptical orbits, and to be able to represent it mathematically. He expressed these related goals in1605, while composing his *Astronomia Nova*.

---

[41] Kepler, *Epitome of Copernican Astronomy* IV.3: 70-71.

[42] Goldstein and Hon argue that the concept of an orbit originates with Kepler, and that he considered an orbit to be "the trajectory of a planet that results from physical causes expressed as laws." ("Kepler's Move from *Orbs* to *Orbits*: Documenting a Revolutionary Scientific Concept", 105.) In *Epitome of Copernican Astronomy*, Kepler gives this definition: "What is understood by the name 'orbit'? Properly speaking, it is that line [i.e., curve] which the planet describes around the sun by means of the centre of its body. For example, in the diagram, if ECGD is a part of the plane of the ecliptic, HCFD will be the orbit." (*Epitome of Copernican Astronomy*, 999m quoted in Goldstein and Hon, *op.cit.*, 94.)

[43] Kepler states in his 1607 letter to D. Fabricius that he uses "bodily forces". This excerpt appears in Holton, "Johannes Kepler's Universe: Its Physics and Metaphysics", 345.

> I am much occupied with the investigation of the physical causes. My aim in this is to show that the celestial machine is to be likened not to a divine organism but rather to a clockwork...insofar as nearly all the manifold movements are carried out by means of a single, quite simple magnetic force...This physical conception is to be presented through calculation and geometry.[44]

As a number of commentators have observed, the full title of this work—*Astronomia Nova: Physica Coelestis*—expressed Kepler's goal of uniting astronomy and physics. He sought to extend the search for physical causes to the heavens, and then bring astronomy's mathematical methods to bear upon them. It was the formulation of this goal, rather than success in achieving it, that would be an enduring contribution. For Kepler's pursuit of this goal, together with his empirical laws, paved the way for a belief that would be fully accepted only later, with Descartes' law of inertial motion: the belief in a central, attractive force. Kepler's efforts to characterize the sun's force mathematically failed, and though he had sufficient confidence in his theory of the orbits to continue developing it in qualitative terms, it turned out to be fundamentally incorrect. Newton would pursue similar goals, but after succeeding in the mathematical quest, write that gravity's "physical cause" eluded him.[45]

According to Kepler's physical theory, which drew upon William Gilbert's magnetic theory, the planetary orbits are produced by a combination of the sun's active faculty upon the planets' passive but resistive tendency.

> Besides the motor force of the sun there is also a natural inertia of the planets themselves with respect to movement: hence by reason of their matter they are inclined to remain in their own place. So the motor power of the sun [*potentia vectoria*] and the powerlessless or material inertia of the planet are at war with one another. Each has its share of victory: the motor power moves the planet from its seat; the material inertia removes its own, i.e., the planetary, body somewhat from those bonds by which it was laid hold of by the sun, so that it is laid hold of first by one part and then by another part of this circle of

[44] Letter to Herwart von Hohenburg, February 10, 1605, quoted in Holton, "Johannes Kepler's Universe: Its Physics and Metaphysics", 342.

[45] Galileo, like Newton, considered gravity's ultimate nature a mystery.

> virtue...that is, by the part which comes next after the part from which the planet has just loosed itself.[46]

The sun has an active power or "motor soul", by which it moves the planets. This active power should not be identified with intelligence, however. Kepler emphasizes in the *Epitome* that the sun's motor soul is not intelligence but rather something like "material necessity".[47] Here Kepler rejects Aristotle's notion that the celestial bodies are living and intelligent. Of course, the notion of material necessity could be compatible with an Aristotelian picture if one construed it teleologically, in terms of a form or essence that guides end-seeking motions. And Kepler does not free himself of ideas about form. When the analogy to magnetism fails, he tries to explain the causal interaction of the sun and planets by drawing upon Neo-Platonic ideas. Yet the passive faculty is associated with matter, he writes opaquely, the active "smells more of form".[48] Still, he has abandoned the ancient preoccupation with final causes, and is instead trying to explain the action of the sun in terms of efficient causes.

Unlike the sun, the planets lack a motor soul, and consequently would not move if they were not in the vicinity of the sun's active faculty. The planets are made of matter, matter is inert, and according to Kepler, inertia is a tendency toward rest.[49] However, to be inert is not to lack

---

[46] Kepler, *Epitome of Copernican Astronomy*, IV.3, 59.

[47] See Kepler: "There is no need of these intelligences, as will be proved....On the contrary, the elliptic figure of the route of the planet and the laws of the movements whereby such a figure is caused smell of the nature of the balance or of material necessity, rather than of the conception and determination of the mind." (*Epitome of Copernican Astronomy*, IV.2, 52-53.) In the next section, Kepler continues: "There is absolutely no need of mind for the functions of movement....The laying hold of the planetary bodies, which the rotation of the sun makes to revolve, is a bodily virtue, not animal, not mental." (*Ibid.*, IV.3, 57.) So again, the sun and planets are not intelligent, contra Aristotle. Of course, the notion of material necessity could be compatible with an Aristotelian picture if one construed it teleologically, in terms of an internal principle or essence that guides end-seeking motions and other changes. Kepler's concept of material necessity, however, seems to be one of efficient rather than final causation.

[48] Kepler, *Epitome of Copernican Astronomy,* IV.3, 58. See also IV.3, 60-61, where Kepler rhetorically raises the question of whether the sun's material power, once extended into the ether, constitutes a power without a subject. He replies that he has not postulated a power without a subject: "At the very source the subject of the natural faculty is the body of the sun, or the threads stretching out from the centre to its circumference; thus even in this very emanation, I think a rational distinction should be made between the immaterial form [*speciem*] of the solar body, which flows as far as the planets and beyond, and its force or energy which actually lays hold of the planet and moves it—so that the form is the subject of the force, though it is not a body but an immaterial form of a body."

[49] See Kepler, *Epitome of Copernican Astronomy,* IV.2, 54 and 55: "A celestial globe is not heavy in the way in which a stone on the earth is said to be heavy...nevertheless by reason of its matter it has a natural...powerlessness of crossing

resistive powers. Kepler recognizes that a body lacking resistive power could be accelerated to infinite velocity, contrary to observations.

> If the celestial bodies were not endowed with inertia, something similar to weight, no force would be needed for their movement from their place; the smallest motive force would suffice to impart to them an infinite velocity.[50]

Since the inert or powerless nature of matter still includes a resistive tendency, the planets resist the sun's attractive force. This resistance is the "share of victory" that Kepler mentions, and the explanation of why the planets remain in their orbits rather than being drawn into the sun.

Yet recognition of matter's resistive tendencies does not begin with Kepler. His concept of inertia is the tendency toward rest, the old concept that supports the belief that all motion requires a mover. His theory therefore includes a force to provide the tangential component of the planets' motion, as well as a force to explain the radial component. The tangential component is supplied by a "bodily virtue", emitted in straight lines by the sun as it revolves on its axis. Kepler suggests that these lines of virtue lay hold of the planets and move them, in a manner similar to that by which a loadstone turns an iron pointer, without bodily contact. The radial component is supplied by the sun's "energetic faculty of attracting or repulsing and retaining the planet".[51]

Kepler would therefore be remembered for his three "laws"—empirical generalizations which Newton would later derive from the laws of motion and gravity's inverse square relation to distance—for his physical theory was fundamentally incorrect. He thought the attractive force was restricted to certain kinds of bodies rather than being universal, and that it held in virtue of some affinity between like forms. He had not distinguished mass from weight and thus could not

---

from place to place, and it has a natural inertia or rest whereby it rests in every place where it is placed alone....Any globe, placed in any place on the world beyond the motor virtues, naturally rests in that place, because matter, as such, has no faculty of transporting its body from place to place."

[50] Kepler, *De causis planetarum*, quoted in Jammer, *Concepts of Mass*, 55.

[51] Kepler, *Epitome of Copernican Astronomy,* IV.3, 58.

construe the attractive force as proportional to mass. He retained the old concept of inertia as a tendency toward rest, he construed force as the cause of motion rather than acceleration, and he attributed the tangential component of the planets' motions to the sun's activity. He believed the attractive force to hold between like substances rather than among matter universally.[52] And because he thought that the sun's virtue was emitted only in the plane of the planetary orbits, he rejected his initial suggestion of an inverse square relation, concluding instead that the sun's force on the planets diminishes as1/r.

But though Kepler's physical theory cannot be construed as a preliminary version of Newton's, there are still some interesting similarities. Kepler and Newton are both committed to the old physics of finding physical causes even as they develop the new physics of mathematical deducibility, devoting a great deal of effort to understanding the force that explained the planetary orbits in terms of some substance. And the search for causes aside, Newton in some manner unifies physics and astronomy, a project Kepler had begun. Both retain the Scholastic notion that matter has a resistive power, though Kepler pairs this with the ancient concept of inertia, and Newton with the Cartesian concept. (Thus Kepler holds matter to be powerless to move itself, and in need of some external power for continued motion. Newton, on the other hand, attributes the continuance of any state of motion or rest to the *vis inertiae*, which gives rise to his three laws of motion. Newton's variant of Kepler's claim that matter is powerless is, as we shall see, the principle that matter cannot initiate motion.) Also, Kepler and Newton both try to explain natural phenomena in terms of both active and passive faculties. Descartes, by contrast, eliminates active powers from his physics, holding matter to be passive and explaining all changes in motion as the transfers of motion by contact among the passive material bodies.

[52] But see Jammer, *Concepts of Force*, 84, who quotes Kepler as saying the following: "The familiar behavior of falling bodies and the majestic sweep of the moon in its orbit were all part of the same great scheme."

DESCARTES

In his *Principles of Philosophy*, Descartes develops what comes to be known as his mechanical philosophy, a physics that strictly distinguishes matter from minds and that he hopes will replace the Scholastic philosophy's teleological explanations. Material bodies do not have the variety of diverse natures ascribed to them by the Scholastics. Instead, all matter has the same nature, and its nature is to be extended: "The nature of body consists not in weight, hardness, colour, or the like, but simply in extension."[53] Thus space and body are identical: "There is no real difference between space and corporeal substance....The difference between space and corporeal substances lies in our way of conceiving them."[54] This implies a plenum, clearly enough, and Descartes states the implication directly; since there is no distinction between the extension of space and the extension of body, all space is filled and to suppose a void area of space would be a contradiction.[55] Descartes rejects atomism as well as the void, on the grounds that the doctrine of atomism holds the particles to be indivisible, yet such a claim would diminish the power of God, who surely could divide any substance he created.[56]

In this material plenum, there is no real distinction between action and passion. Whereas Kepler treated the distinction between action and passion as real, attributing active powers to the

[53] Descartes, *Principles of Philosophy*, Part II.4 in CSM, 224.

[54] *Ibid.*, II.11-12 in CSM, 227-228.

[55] *Ibid.*, II.16-17 in CSM, 229: "16. *It is a contradiction to suppose there is such thing as a vacuum, i.e. that in which there is nothing whatsoever.* The impossibility of a vacuum, in the philosophical sense of that in which there is no substance whatsoever, is clear from the fact that there is no difference between the extension of a space, or internal place, and the extension of a body. For a body's being extended in length, breadth and depth in itself warrants the conclusion that it is a substance, since it is a complete contradiction that a particular extension should belong to nothing; and the same conclusion must be drawn with respect to a space that is supposed to be a vacuum, namely that since there is extension in it, there must necessarily be substance in it as well. 17. *The ordinary use of the term 'empty' does not imply the total absence of bodies*. In its ordinary sense the term 'empty' [void] usually refers not to a place or space in which there is nothing at all, but simply to a place in which there is none of the things we think ought to be there."

[56] *Ibid.*, II.20, CSM, 231. In II.34, Descartes goes on to say, "The number of particles into which matter is divided is in fact indefinite, although it is beyond our power to grasp them all." This is not an assertion of atomism since he is not suggesting that there are indivisible particles. Instead, he explains that minute particles shifting position are actually undergoing subdivisions. Unlike Descartes, Newton embraces atomism, and does not consider it to imply any diminution of God's powers. In the *Opticks'* Query 31 (an essay whose original version was composed around the time of the *Principia* but which Newton revised over the years), he writes that the particles of matter cannot be divided by any "ordinary power".

sun but very different, passive qualities to the planets it moves, Descartes holds that the distinction between action and passion is not real. Only substances can be really distinct from one another.[57] The distinction between action and passion, both in the case of collisions between material bodies, and for interactions among substances generally,[58] is only a distinction in reason. We will realize that two attributes are only rationally distinct if we find that when we attempt to separate the one attribute from the other, we can no longer perceive it clearly and distinctly.[59] Such is the case with the attributes of mover and moved for any body in a plenum. Since there is no space separating any body from other bodies, the body cannot be moved without moving some other bodies; it expels the body contiguous to it on one side, and is expelled by the body contiguous on the other side.[60] If we assume a plenum, the body's being a mover cannot be conceived without its also being moved, and so there is only a rational distinction between mover and moved, that is, between action and passion. This will be important for Newton.

If all matter has the same nature, what explains the differences among bodies that we observe? The motions of the component parts, Descartes answers: "All the variety in matter, all

---

[57] Only substances can be really distinct, that is, able to exist apart from one another. See Descartes, *Principles of Philosophy*, II.60, CSM, 213.

[58] In *The Passions of the Soul*, I.1, CSM, 328, Descartes writes, "What is a passion with regard to one subject is a always an action in some other regard....Although an agent and patient are often quite different, an action and passion must always be the same thing which has these two names on account of the two different subjects to which it may be related."

[59] "*What is meant by a 'conceptual distinction'.* Finally, a *conceptual distinction* is a distinction between the substance and some attribute of that substance without which the substance is unintelligible; alternatively, it is a distinction between two such attributes of a single substance. Such a distinction is recognized by our inability to form a clear and distinct idea of the substance if we exclude from it the attribute in question, or, alternatively, by our inability to perceive clearly the idea of one of the two attributes if we separate it from the other." (Descartes, *Principles of Philosophy*, I.62, CSM, 214.) On the Scholastic provenance of the notion of a rational distinction, see Garber, *Descartes' Metaphysical Physics*, 69. See also Nolan, "Reductionism and Nominalism in Descartes' Theory of Attributes", 137, which discusses Francisco Suarez as an important source of Descartes' ideas about the rational distinction.

[60] "*How in every case of motion there is a complete circle of bodies moving together.* I noted above that every place is full of bodies, and that the same portion of matter takes up the same amount of space, <so that it is impossible for it to fill a greater or lesser space, or for any other body to occupy its place while it remains there>. It follows from this that each body can move only in a <complete> circle <of matter, or ring of bodies which all move together at the same time>: a body entering a given place expels another, and the expelled body moves on and expels another, and so on, until the body at the end of the sequence enters the place left by the first body at the precise moment when the first body is leaving it." (Descartes, *Principles of Philosophy*, II.33, CSM, 237.)

the diversity of its forms, depends on motion."[61] These claims—that all matter has the same nature and that variety arises from the shape, size, and motions of the component parts—are central to the philosophy of nature that becomes known as the mechanical philosophy. (This will do as a rough characterization, but there is disagreement about what constitutes the mechanical philosophy—whether it must include the claim that motion can be communicated only by contact action, for instance—and who its proponents were. The canonical figures are, at least, Descartes and Boyle.[62] Some commentators include the early 17th century atomist, Gassendi, though he did not explain observable properties of bodies in terms of motion,[63] explaining heat and cold in terms of calorific and frigorific particles. Commentators also disagree about whether to include Newton; he took all matter to have the same nature, but instead of explaining all phenomena in terms of matter and motion, he introduced forces that did not operate by contact action between the surfaces of bodies.[64])

In Descartes' system, motion must be communicated by contact. This is first because in a plenum no other mechanism is needed, and second because he considers matter to be inert in the sense that bodies lack Aristotelian, end-seeking natures. Teleological notions are properly

---

[61] *Ibid.,* II.23, CSM, 232.

[62] For a discussion of Descartes' mechanical philosophy, see Garber, *Descartes' Metaphysical Physics*. In Boas, "The Establishment of the Mechanical Philosophy", see Section V for a discussion of Descartes and Sections VI-VIII for a discussion of Boyle's mechanical philosophy. Before Descartes and Boyle, Bacon and Galileo had both taken the motion of particles to figure in the explanation of observable properties in bodies. Newton, though he introduced forces that do not operate by surface action, remained a mechanical philosopher to the extent that he too explained observable properties by matter and motion. See Boas on this point:

> The early seventeenth century atomists explained the sharp taste of acids by assuming that the acid particles had sharp points that pricked the tongue….According to Newton, however, acids had a sharp taste because, under the influence of the force of attraction, the acid particles rushed to the tongue with such violent haste as to bruise it, thus causing the pricking sensation. No longer is the shape of the atoms their most salient features; it is their motions. (Boas, *op.cit.,* 521.)

Newton is not, however, what Westfall terms an "orthodox mechanical philosopher", since he allows that some some causes are not mechanical; in the 1713 General Scholium, he writes that gravity's cause "acts not 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*, 943.)

[63] See Boas: "Though Gassendi, like the ancients, assumed that the atoms were in motion, he never attempted to explain any of the properties of bodies in terms of *variation* of this motion." ("The Establishment of the Mechanical Philosophy", 434.)

[64] For a discussion of mechanist views and Newton's stance toward them, see Janiak, *Newton as Philosopher*, 118-129. Janiak identifies four distinct mechanist views, and argues that Newton rejects each of them.

attributed only to minds, and so contra the Scholastics, a body cannot have any internal tendency to seek one spatial location over another. When vapors rise, it is not because they seek a higher place, nor are rocks pushed from a cliff seeking the center of the Earth. Because the concept of force that Descartes inherits from his predecessors is animistic, he attempts to eliminate that from his system as well. (He is not entirely successful, for his vortex theory of gravitation relies crucially upon pressure.) Like Kepler and the Scholastics, Descartes does attribute to matter the power to resist, but there is an important difference, one that Newton would incorporate. Descartes grounds the resistive power of matter in his first law of nature, the tendency of bodies to maintain their states.[65]

Having eliminated all teleological and animistic notions from his concept of matter, Descartes overthrows the old concept of inertia as a tendency toward rest, realizing that passive matter could have no preference for rest over motion. From this he derives his first law:

> The first law of nature: each and every thing, in so far as it can, always continues in the same state; and thus what is once in motion always continues to move.[66]

With this law of nature, Descartes can do away with the medieval concept of *impetus* and other forces supplying the continuation of motion.

> Our everyday experience of projectiles completely confirms this first rule of ours. For there is no other reason why a projectile should persist in motion for some time after it leaves the hand that throws it, except that what is once in motion continues to move until it is slowed down by bodies that are in the way. And it is clear that projectiles are normally slowed down, little by little, by the air or other fluid bodies in which they are moving, and that this is why their motion cannot persist for long.[67]

[65] "43. *The nature of the power which all bodies have to act on, or resist, other bodies.* In this connection we must be careful to note what it is that constitutes the power of any given body to act on, or resist the action of, another body. This power consists simply in the fact that everything tends, so far as it can, to persist in the same state, as laid down in our first law. Thus what is joined to another thing has some power of resisting separation from it....what is at rest has some power of remaining at rest and consequently of resisting anything that may alter that state of rest; and what is in motion has some power of persisting in its motion." (Descartes, *Principles of Philosophy*, II.43, CSM, 243.)

[66] *Ibid.,* II.37, 240.

[67] *Ibid.,* II.38, 241.

This realization was historically momentous. While his own analyses of collisions and his vortex theory of gravity were fundamentally flawed, Descartes' law of inertia set the course for his successors, replacing the old problem of explaining the persistence of motion with the new problem of explaining changes in motion.

With his second law of nature, Descartes corrected Galileo's erroneous understanding of inertial motion as a tendency to follow the curve of the earth, stating that it is in fact rectilinear.

> The second law of nature: all motion is in itself rectilinear; and hence any body moving in a circle always tends to move away from the centre of the circle which it describes.[68]

The second conjunct of this law, however, became an obstacle for the development of mechanics. Instead of suggesting a tendency to move off along the tangent, Descartes suggests that bodies in circular motion have a tendency to move outward from the center.[69] Huygens would later coin the term 'centrifugal force' for this endeavor, and Newton would initially follow his predecessors. In his early attempts to explain gravitational effects, he expected the sun's inward force to be balanced by the planets' outward endeavor, which he had not yet understood as an inertial effect.

Another flaw was Descartes' third law of nature. Based upon the belief that the force of motion supplied by one body in a collision need not equal the resistance of the other, the law erroneously indicated that a lighter body's momentum is unchanged when it collides with a heavier one.[70]

---

68 *Ibid.,* II.39, 242.

69 *Ibid.,* II.39, 241: "The second law of nature: all motion is in itself rectilinear; and hence any body moving in a circle always tends to move away from the centre of the circle which it describes."

70 On this point, see Herivel: "In the case of a collision between a moving and a stationary body Descartes supposed that the 'resistance' of the latter could exceed the force of motion of the former. In this case, if the two bodies were soft the moving body would be brought to rest, its motion being absorbed in some unspecified manner; whereas if the bodies were hard it would be reflected without loss of motion. On the other hand, if the force of the motion of the moving body exceeded the resistance of the stationary one the two would move on together the total quantity of motion being conserved, the *quantity of motion* in a body being proportional the magnitude of the body and its velocity. As for the conservation, this was necessary to ensure that the *total* quantity of motion in the universe was unaffected by such

> The third law: if a body collides with another body that is stronger than itself, it loses none of its motion; but if it collides with a weaker body, it loses a quantity of motion equal to that which it imparts to the other body.[71]

This flawed description of collisions was significant because impact was the only causal mechanism in Descartes' natural philosophy.[72] He had not achieved his goal of explaining material phenomena by mathematical concepts alone,[73] for he not only had to ascribe impenetrability to bodies, but also employ a force, pressure. He rejected action at a distance entirely, however. To suggest that spatially separated bodies could act upon one another was to retreat into Scholasticism's occult properties and animism. Material bodies can affect one another by transferring motion to one another; this requires contact, but no intelligence. If the bodies are not in contact with one another, to suggest that one could act upon the other is, Descartes held, to suppose it to have the intelligence to be aware of the other body's existence.[74] Descartes argued that all of the variety and diversity of matter depends upon motion,[75] and all changes in motion occur through impacts.

Ultimately, these actions communicated by contact depended upon God, and from God's nature Descartes derives a principle of the preservation of motion (as I shall call it, in order to distinguish it from Newton's conservation principle, which I discuss later.) It follows from God's

---

encounters between bodies in accordance with the general law of conservation derived from the immutability of God's working in the universe." (*Background*, 50.)

[71] Descartes, *Principles of Philosophy*, II.39, CSM, 241.

[72] Descartes holds that God continually recreates the world, writing in the *Principles of Philosophy*, II.36, CSM, 240: "He now preserves all this matter in the same way, and by the same process by which he originally created it." On the basis of such passages, one might argue that strictly speaking, Descartes' natural philosophy contains no causal mechanism, for he accepts occasionalism. The attribution of occasionalism is explored, and opposed, by Daniel Garber; see especially *Descartes' Metaphysical Physics*, 301-302.

[73] Descartes, *Principles of Philosophy*, II.64, CSM, 247: "The only principles which I accept, or require, in physics are those of geometry and pure mathematics; these principles explain all natural phenomena, and enable us to provide quite certain demonstrations regarding them."

[74] See Jammer, *Concepts of Force,* 104. For a discussion of Descartes' criticism of Roberval's explanation of the solar system, which employed attractions acting at a distance, see Westfall, *Force*, 86-87.

[75] Descartes, *Principles of Philosophy*, II.23, CSM, 232.

immutable nature that the quantity of motion in the world is constant. Speaking in terms of secondary causation, this quantity is held constant as the quantity of motion in some individual bodies changes, because those bodies transfer their motions to other bodies in collisions.[76] Alan Gabbey notes that Descartes was probably reacting to an implication of Isaac Beeckman's work on collisions, namely, that if motion could be lost in collisions, the world could run down.[77] As we shall see, Newton will side with Beeckman in the observation that motion is lost in collisions, and in consequence will speculatively invoke active principles or powers, active powers which Kepler had included but which Descartes eliminated.

Descartes explains the planetary motions with the vortex theory he develops in Part III of his *Principles of Philosophy*. Having distinguished two senses of motion earlier in Part II, Descartes now uses these distinctions to avoid attributing motion to the earth. Motion in the ordinary sense is "the action by which a body travels from one place to another",[78] and in this sense, the earth moves relative to the other planetary bodies over the course of a year. In the strict, or "philosophical" sense, however, motion is the transfer of a body away from bodies that formerly were contiguous with it. In this sense, the earth is at rest because it remains contiguous with the fluid aether in which it travels.[79] The heavens are filled with celestial matter, the aether;

---

[76] *Ibid.*, II.36 and II.42, CSM 240 and 243: "36. *God is the primary cause of motion; and he always preserves the same quantity of motion in the universe.*...The nature of motion....is in fact twofold: first, there is the universal and primary cause—the general cause of all the motions in the world; and second there is the particular cause which produces in an individual piece of matter some motion which is previously lacked. Now as far as the general cause is concerned, it seems clear to me that this is no other than God himself. In the beginning <in his omnipotence> he created matter, along with its motion and rest; and now, merely by his regular concurrence, he preserves the same amount of motion and rest in the material universe as he put there at the beginning.....42. *The proof of the second part of this [third law of nature: if a body collides with a weaker body, it loses a quantity of motion equal to that which it imparts to the other body]*...Since God preserves the world by the selfsame action and in accordance with the selfsame laws as when he created it, the motion which he preserves is not something permanently fixed in given pieces of matter, but something which is mutually transferred when collisions occur."

[77] See Barbour's discussion of Gabbey in *Absolute or Relative Motion*, 459: "Gabbey has pointed out that this fruitful idea of Descartes was probably in large part introduced in reaction to a problem in Beeckman's work, in which motion could be lost in collisions, so that the world would eventually run down."

[78] Descartes, *Principles of Philosophy*, II.24, CSM, 233.

[79] Descartes, *op.cit.* II.25, CSM, 233, contains the definition of motion in the strict sense; and in III.19 (CSM, 251) Descartes indicates that he has avoided attributing motion to the earth: "My denial of the earth's motion is more careful than the Copernican view and more correct than Tycho's view." Worried by the Church's reaction to Galileo, Descartes

and with the sun's rotation producing a vortex, the planets are carried around the sun. To explain the motions of satellites, including the earth's moon, Descartes posits local vortices produced by the planets to carry their satellites.

Vortex theories remained influential after Descartes' death, despite their shortcomings, with variants being developed by Leibniz and Huygens. Such theories could not account for Kepler's empirical laws, and they were difficult to reconcile with the motion of comets. Another failing, once Newton introduced the concept of mass, was that they failed to explain why gravitational effects are proportional to mass rather than surface area. Yet vortex theories had one strongly appealing feature. They avoided action at a distance, which despite Kepler's efforts to explain as some sort of "material necessity" seemed animistic and occult.

Newton will be strongly influenced by Descartes in his early efforts, but will then react strongly against much of the Cartesian system. Newton's unpublished manuscript, *De Gravitatione*,[80] marks a clear break with Descartes. There, Newton rejects the identification of body with extension, asserting instead that space exists independently of matter, and that matter is particulate.[81] This particulate matter is not mere extension, but is endowed with the properties of mobility and impenetrability. Newton also attacks Descartes' doctrine of relative motion, in part by noting that it implies the possibility that motion can be generated without force. Yet in his early efforts to explain the planetary orbits, Newton is still working within the Cartesian tradition,

---

hoped that his doctrine of relative motion would make the rest of his theory acceptable to the Church. On this point, see Burtt, *The Metaphysical Foundations of Modern Physical Science: A Historical and Critical Essay,* 105-106.

[80] The manuscript is undated. The Halls argue that it belongs to a very early period, c. 1664-1668 (see *Unpublished Scientific Papers of Isaac Newton,* 89). B.J. T. Dobbs argues for a much later date, shortly before *Principia*. Stein's remarks in "Newton's Metaphysics" weigh against Dobbs, and in favor of an earlier dating. According to Stein, the Halls' translation of *De Gravitatione* contains a number of errors, including an incorrect suggestion that in the opening sentence, Newton indicates that he will discuss a "science of gravity". Relying upon this, Dobbs concludes that the manuscript represents, as Stein puts it, "an abortive draft of an introduction to Newton's *Principia*." In fact, Stein writes, "Newton's phrase has nothing to do with a 'science of gravity'; he is speaking of the *weight* of fluids and of solids in fluids, which is the exact subject of the classic treatise, 'On Floating Bodies' of Archimedes." (Stein, "Newton's Metaphysics", 298-299, n. 27; see also 302-303, n.39.)

[81] Newton's acceptance of atomism is first seen in his undergraduate *Questiones*. See McMullin, *Newton on Matter and Activity*, 75.

by seeking the planets' outward endeavor. It is Hooke who turns Newton away from that Cartesian expectation.

HOOKE

Robert Hooke (1635-1703) made a critical contribution to Newton's theory of gravity by posing a question that set Newton on the right path. Prior to that event, Newton had been working in the Cartesian tradition. Descartes' second law of nature moved from the claim that motion in itself is rectilinear, rather than circular, to the claim that a body moving in a circle will tend to recede from that circle's center; and in vortex theories, the inward pressure produced by the material plenum must be balanced by some outward endeavor for a body to remain in an orbit. Newton, having ignored the Aristotelian philosophy still taught in the universities, initially worked in the tradition of Descartes' mechanical philosophy, and like Huygens, took the fictitious centrifugal force to be real. His early efforts to understand the planetary orbits therefore involved an attempt to characterize this centrifugal force—the planets' outward endeavor.

Hooke around this time was also considering the problem of the orbits, along with other problems of natural philosophy that he discussed with Edmund Halley and Sir Christopher Wren. On the basis of Kepler's results—in particular the Third Law's result that a planet's speed varies as a function of distance—Hooke expected the sun to exert a force upon the planets, a force diminishing as the inverse square of distance. This had been Kepler's initial idea too, however Kepler discarded that in favor of the proportion 1/r, thinking that the sun's *anima motrix* was emitted, like chains taking hold of the planets, only in the plane of the planetary orbits. Hooke by contrast expected the sun's force to diminish with distance as $1/r^2$, just as light's intensity diminishes.

In 1679, Hooke wrote to Newton, setting the problem of deriving a planet's path, given the assumption of a force proportional to $1/r^2$. This letter critically reoriented Newton's thought, and upon receipt of it, he dropped the Cartesian notion of an outward endeavor from a center.

The rectilinear motion that would figure in Newton's solution to the problem of the orbits did not emanate from the center but instead lay along the tangent; for Hooke presented the problem as that of combining one motion toward the focus of an ellipse with another motion along the tangent to the curve.[82] Using a method of limits, Newton solved the problem without fanfare, having first recast it.[83] Whereas Hooke assumed the proportion of the force and then sought the planet's path, Newton assumed Kepler's elliptical orbit and then proved that such an orbit requires an inverse-square force from a focus.[84] When Halley visited Newton in 1684—his offer of a prize having failed to elicit a solution to the problem of the orbits from Hooke—Newton reported that he had solved the problem. Having mislaid the papers containing his solution, he solved the problem again in the unpublished manuscript known as *De Motu*. This he later sent to Halley, and upon Halley's urging to publish, used it as the basis for his 1687 *Mathematical Principles of Natural Philosophy* (*Philosophiae Naturalis Principia Mathematica*).

Concluding Remarks

In solving the so-called Kepler Problem,[85] Newton drew upon Hooke's formulation of the problem, as well as upon his predecessors' work, including Kepler's empirical laws and the

---

[82] See McMullin, *Newton on Matter and Activity*, 48.

[83] In terminology used contrariwise to that used today, inverse problems were problems of finding a body's path about a center of force, and direct problems those of finding the force given the path. Thus Hooke presented Newton with the inverse problem, and he tackled and solved the direct one. See Brackenridge: "The direct problem that challenged mathematicians in the seventeenth century was determining the nature of the gravitational force acting on planets....Kepler determined that the path of Mars is an ellipse, with the sun located at a focal point. He published the result in 1609. The direct problem, however, remained unsolved until after 1679, when Newton determined the functional dependence on distance of the force required to sustain such an elliptical path of Mars about the sun as a center of force located at a focal point of the ellipse." (*The Key to Newton's Dynamics,* 15-16.)

[84] See Westfall, *Never at Rest*, 387.

[85] Bruce Brackenridge refers to this mathematical problem as the 'Kepler problem'. As emphasized previously, Kepler and Newton both sought a physical, causal explanation of gravity in addition to a solution to the problem of characterizing the gravitational force mathematically. As Brackenridge notes, Newton's pursuit of the physical characterization was confined mainly to his unpublished writings. See Brackenridge, *The Key to Newton's Dynamics,* 13: "For Newton, the problem....was the dynamic challenge of seeking the mathematical description of the force that produces the Keplerian planetary ellipses. In his published work, he set aside his concern with physical cause and emphasized the mathematical form of the force. Newton offered this limited type of mathematical answer amid the seventeenth-century concern for the physical causes of gravity, and his approach was not immediately or universally found to be fulfilling. The technique that Newton employed, a unique combination of limits and approximations, was

concept of inertia partially developed by Galileo and fully articulated by Descartes. Newton would give the credit for the law of inertia to Galileo alone, as he rejected much of Descartes' system—and Aristotle's. Yet as we shall see, as Newton sought to augment his solution to Kepler's mathematical problem with a causal explanation of gravity, he remained drawn to Aristotle's belief in a generative source of motion, and to Descartes' claim that matter cannot act at a distance.

rapidly replaced on the continent by alternate techniques that employed the calculus more directly. Nevertheless, the *Principia* would set the stage for the mathematical, mechanical model of the world that would follow."

REFERENCES

Aristotle, *Physics*, trans. R. P. Hardie and R. K. Gaye, in W. D. Ross (ed.), *The Works of Aristotle*, Oxford: Clarendon Press, 1908-52. Reprinted at: The University of Adelaide Electronic Texts Library.

Aristotle, *Metaphysics*, trans. W.D. Ross, in *The Works of Aristotle* W. D. Ross (ed.), *The Works of Aristotle*, Oxford: Clarendon Press, 1908-52. Reprinted at: The Internet Classics Archive, http://classics.mit.edu/Aristotle/metaphysics.

Barbour, Ian, *Issues in Science and Religion*, Englewood Cliffs: Prentice-Hall Inc., 1966.

Barbour, Julian, *Absolute or Relative Motion? Vol. I, The Discovery of Dynamics*, Cambridge: Cambridge University Press, 1989.

Blackwell, Richard J., "Galileo Galilei", in Gary B. Ferngren (ed.), *Science & Religion, A Historical Introduction*, Baltimore: The Johns Hopkins University Press, 2002, 105-116.

Brackenridge, Bruce: *The Key to Newton's Dynamics: The Kepler Problem and the Principia*, Berkeley: University of California, 1995.

Burtt, E.A., *The Metaphysical Foundations of Modern Physical Science: A Historical and Critical Essay*, London: Routledge and Kegan Paul Limited, 1932/1972.

Butterfield, Herbert, *The Origins of Modern Science*, New York: The Macmillan Company, 1961.

Cohen, Bernard, *The Birth of a New Physics*, New York: W.W. Norton & Company, 1985.

Copleston, Frederick: *A History of Philosophy,* Book I, Vol. 1, Garden City: Image Books, 1985.

Cushing, James T., *Philosophical Concepts in Physics*, Cambridge: Cambridge University Press, 1998.

Descartes, Rene, *Principles of Philosophy*, in *The Philosophical Writings of Descartes*, trans. John Cottingham, Robert Stoothoff, and Dugald Murdoch; Vol. I, Cambridge: Cambridge University Press, 1985/1999.

Donahue, W.H., "Kepler", in Norriss S. Hetherington (ed.), *Cosmology: Historical, Literary, Philosophical, Religious, and Scientific Perspectives*, New York: Garland Publishing, Inc., 1993.

Edel, Abraham, *Aristotle and his Philosophy*, Chapel Hill: University of North Carolina Press, 1982.

Galilei, Galileo, *Siderius Nuncius*, trans. Albert Van Helden, Chicago: University of Chicago Press, 1610/1989.

Galilei, Galileo, *Letter to Madame Christina, Grand Duchess of Tuscany*, circulated in 1616 and published in 1636, in *Discoveries and Opinions of Galileo*, trans. Stillman Drake, New York: Doubleday, 1957, 173 – 216.

Galilei, Galileo, *The Assayer* (1623), trans. A. C. Danto, reprinted in Michael R. Mathews (ed.), *The Scientific Background to Modern Philosophy, Selected Readings,* Indianapolis: Hackett Publishing Co., 1623/1989.

Galilei, Galileo, *Dialogue Concerning the Two Chief World Systems—Ptolemaic & Copernican*, trans. Stillman Drake, Berkeley: University of California Press, 1953.

Garber, Daniel, *Descartes' Metaphysical Physics*, Chicago: The University of Chicago Press, 1992.

Gingerich, Owen: "The Copernican Revolution", in Gary B. Ferngren (ed.), *Science & Religion, A Historical Introduction*, Baltimore: The Johns Hopkins University Press, 2002, 95-104.

Goldstein, Bernard R. and Hon, Giora: "Kepler's Move from *Orbs* to *Orbits*: Documenting a Revolutionary Scientific Concept", *Perspectives on Science*, vol. 13, no. 1 (2005), 74-111.

Herivel, John, *The Background to Newton's Principia; A Study of Newton's Dynamical Researches in the Years 1664-84*, Oxford: Clarendon Press, 1965.

Hesse, Mary, *Forces and Fields, The Concept of Action at a Distance in the History of Physics*, New York: Philosophical Library Inc., 1961.

Holton, Gerald, "Johannes Kepler's Universe: Its Physics and Metaphysics", *American Journal of Physics* 24 (1956), 340-351.

Jammer, Max, *Concepts of Force*, Cambridge: Harvard University Press, 1957.

Jammer, Max, *Concepts of Mass*, Cambridge: Harvard University Press, 1961.

Janiak, Andrew, *Newton as Philosopher*, Cambridge: Cambridge University Press, 2008.

Kepler, Johannes, *Epitome of Copernican Astronomy* IV, 3, trans. Charles Glenn Wallis, Amherst: Prometheus Books, 1618-21/1995.

Kepler, Johannes: *New Astronomy* (New Astronomy Based upon Causes or Celestial Physics treated by means of commentaries on the motions of the star Mars, from the Observations of Tycho Brahe; MDCIX), trans. William H. Donahue, Cambridge: Cambridge University Press, 1992).

Kuhn, Thomas S., *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought,* New York: MJF Books, 1957/1985.

Machamer, Peter: "Galileo", *The Stanford Encyclopedia of Philosophy*, 2005, Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/entries/galileo/>

McMullin, Ernan, *Newton on Matter and Activity,* Notre Dame: University of Notre Dame Press, 1978.

McMullin, Ernan, "Galileo on science and Scripture" in *The Cambridge Companion to Galileo* Cambridge: Cambridge University Press, 1998.

McMullin, Ernan, "The Origins of the Field Concept in Physics, *Physics in Perspective*, 4 (2002), 13-39.

Munitz, Milton K., *Theories of the Universe, from Babylonian Myth to Modern Science*, New York: Free Press, 1957.

Newton, Isaac: *Unpublished Scientific Writings of Isaac Newton*, ed. A.R. Hall and Marie Boas Hall, Cambridge: Cambridge University Press, 1962.

Nolan, Lawrence, "Reductionism and Nominalism in Descartes' Theory of Attributes", *Topoi* 16 (1997), 129-140.

Stephenson, Bruce, *Kepler's Physical Astronomy, Studies in the History of Mathematics and Physical Sciences*, New York: Springer-Verlag, 1987.

Westfall, Richard S., *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century*, London: Macdonald and Co.; New York: American Elsevier Publishing Company, 1971.

Westfall, Richard S., *Never at Rest: a Biography of Isaac Newton*, New York: Cambridge University Press, 1980.

Westfall, Richard S., *The Construction of Modern Science: Mechanisms and Mechanics*, Cambridge: Cambridge University Press, 1977/1991.

Wisan, Winifred L., "Galileo and God's Creation", *ISIS,* 77 (1986), 473-486.

Zilsel, Edgar, "The Genesis of the Concept of Physical Law", *The Philosophical Review*, vol. 51, no. 3 (May, 1942), 245-279.

CHAPTER III

FORCE, THE *VIS INERTIAE*, AND GRAVITY

What is a force for Newton, might the vis inertiae *be a genuine force, and how do questions about gravity's status as a force arise?*

Introduction

Newton solves the problem of the planetary orbits in terms of inertia and gravity. Inertia supplies the tangential component of the planets' motions,[86] and gravity supplies their radial component, pulling them away from the rectilinear paths they would have followed without gravity's impressed force. For Newton's successors, there was no kind of force other than impressed force, and so gravity was a force while inertia was not. For Newton himself, however, matters are less clear, and this is so for both inertia and gravity. Surprising as it seems today, there are some reasons for thinking that Newton considered the *vis inertiae*, or "force of inertia" as it is translated, to be a genuine force. (And because it is surprising, I shall from this point onward use the *Principia*'s term, '*vis inertiae*', rather than the English term 'inertia'; for while Newton does in some texts use the Latin '*inertia'*, the term as adopted in English has

[86] The initial tangential motion was supplied by God, at the creation. Although Newton vacillates about the cause of gravity, he seems consistently to hold that since the laws of motion could not have produced the initial tangential motions, they must have been supplied by God. He expresses this position in a 1692/93 letter to Bentley, and later in the 1713 General Scholium. In Newton's third letter to Bentley, February 11, 1692/3 (*Philosophical Writings,* 101), he writes, "The diurnal rotations of the planets could not be derived from gravity, but required a divine arm to impress them. And though gravity might give the planets a motion of descent toward the sun, either directly or with some little obliquity, yet the transverse motions by which they revolve in their several orbits required the divine arm to impress them according to the tangents of their orbits. In the General Scholium of 1713 (*Principia*, 940), he writes, "Planets and comets must revolve continually in orbits given in kind and in position, according to the laws set forth above**.** They will indeed persevere in their orbits by the laws of gravity, but they certainly could not originally have acquired the regular position of the orbits by those laws." (For an explanation of the slash date in the correspondence with Richard Bentley, see note 371 in chapter VI.)

contemporary associations that may prejudice the question.) Equally surprising, perhaps, we cannot hastily assume that Newton considered gravity to be a genuine force.

In this chapter, I examine the concepts of the *vis inertiae* and gravity, and I show how, in different ways, questions about their statuses arise. The question about the *vis inertiae*'s status arises from questions about Newton's concept of force, in particular the question of whether he identifies impressed forces with forces generally. That particular question arises because of a quite broad definition appearing in an early manuscript, *De Gravitatione*, together with the absence of any general definition in subsequent texts. So the question of whether the *vis inertiae* is a genuine force is, at bottom, a question about whether the mature Newton's concept of force extends beyond impressed forces, to include other sorts of causes. The next section therefore begins by asking what general concept of force Newton held. While I cannot here do justice to that question, I argue that he later retains some and perhaps all components of the early definition. One component remains unclear, however.

I then examine the *vis inertiae*, including its relation to Law 1. While some commentators have argued that Newton considers the persistence of inertial states to be uncaused, and hence denies universal causation, I oppose this, showing that Newton consistently attributes causal efficacy to the *vis inertiae*. I also examine the *vis inertiae*'s relation to Law 3, arguing that Descartes' principle of reciprocal action is the conceptual basis of the *vis inertiae*'s exercised function and of Law 3. Turning to the question about status, is Newton's talk of the "*vis inertiae"* or "force of inertia" simply a manner of speaking, or does he consider the *vis inertiae* to be a genuine force? There are two features in virtue of which the *vis inertiae* might qualify as a genuine force, one as the force is unexercised, the other as exercised. Neither feature yields a conclusive answer to the question. Knowing whether the *vis inertiae* is a genuine force in virtue of its unexercised functions requires knowing whether Newton retained all components of *De Gravitatione*'s general definition of 'force', yet one component of that distinction remains unclear, as we shall see. And claiming that the *vis inertiae* is a genuine force in virtue of its exercised function requires overlooking some serious conceptual problems in that exercised function. One way to avoid those problems, and to deny that the *vis inertiae* is a genuine force, is to identify it with mass. But however congenial that solution is, I argue, it does not fit well with some textual evidence.

I then examine Newton's concept of gravity. I show how the question about its status arises, reserving answers about that question for later chapters. The question about gravity's status is quite different from that of the *vis inertiae*. For even if the mature Newton does restrict his concept of force generally to impressed forces, gravity as an impressed force would clearly meet the definition. With gravity, questions about its status are questions about whether the force that Newton identifies via his law of universal gravitation has causal efficacy. Such questions are due to a disturbing possibility raised by the *Principia*—that gravitating matter might act across empty space without a medium. This disturbing possibility raises the question of whether the gravitational force is real, and here there are two senses to consider.

First, to say that a force is real or genuine is to say that it is not due to primary causation but rather to secondary causation. That is, the effects are not produced directly by God, but rather by some means in the created world. Whereas the *vis inertiae* is a secondary cause, and (regardless of whether it is a force) unproblematically, gravity is associated with the possibility of action at a distance, and primary causation offers a clear means of denying that possibility.

According to the second sense, to say that a force is real or genuine is to say that it genuinely has causal efficacy. It is not a mere fiction, instrument, or calculating device, nor a provisional placeholder, useful until the actual cause of gravitational effects is identified. Within Newton's lifetime, his gravitational force was interpreted in such instrumentalist terms, notably by Berkeley. Limiting real existents to perceptible objects and relations, Berkeley considers Newton's forces to be unreal, and attributes that view to Newton: "Force, gravity, attraction…are useful for computations about motion and bodies in motion, but not for understanding the simple nature of motion itself….As for attraction, it was certainly introduced by Newton not as a true, physical quality, but only as a mathematical hypothesis."[87] This second sense became the focus of debate for Newton's critics.

In subsequent chapters, I shall argue that Newton takes gravity to be real in both of these two senses.[88] I shall focus mainly upon the first sense, arguing that he did not attribute gravitational effects directly to God. I shall also defend the claim that he considered his gravitational force to be real in the second sense, presenting textual evidence showing that he did not consider the force to be a calculating device but instead took it to be causally efficacious.[89]

FORCE

The kernel of Newton's solution to the mathematical problem about the orbits is contained in the unpublished manuscript *De Motu*, and it is only afterward, once he begins at Halley's urging to write the *Principia,* that he adds the concepts we find in that treatise's Definitions.[90] However, some of the *Principia*'s concepts have antecedents in the earlier, unpublished manuscript, *De Gravitatione.*[91] Interestingly, that manuscript contains a general definition of force, whereas the *Principia* does not. This omission in the *Principia* raises the question of whether Newton retains the definition set out in *De Gravitatione*. It is possible that by the time of the *Principia*, Newton has abandoned parts of the manuscript's general definition. Yet it is also possible that Newton retains the definition in full, and that its absence in the

[87] Berkeley, *De Motu*, published 1721 (quoted in Downing, "Berkeley's Natural Philosophy and Philosophy of Science", in *The Cambridge Companion to Berkeley*, 247-248). Berkeley is writing some eight years prior to Newton's death. Earlier, in his correspondence with Leibniz, Samuel Clarke takes a similar stance, by treating Newton's gravitational force as referring only to gravitational effects. See Clarke's fifth letter in *Leibniz-Clarke*, 115. See also Andrew Janiak's discussion of Clarke's interpretation in *Newton as Philosopher*, 65-74.

[88] It is possible to hold that a force is real in the first sense but not the second. One might hold, for instance, that gravitational effects have *some* secondary cause, and thus that there is a real gravitational force yet to be identified, but that the force as Newton has identified it is not real.

[89] I shall not address the question of how exactly Newton could consider the force causally efficacious, while also acknowledging that its causal story is incomplete. The question of how Newton could hold this position is tackled by Andrew Janiak in chapter 3 of *Newton as Philosopher*, and in "Newton and the Reality of Force".

[90] See McMullin, *Newton on Matter and Activity*, 49.

[91] The manuscript is undated, and its date is a matter of controversy, as note 80 in chapter II explains in more detail.

Principia is due only to that treatise's restricted aims; for as its full title indicates, the *Principia* is concerned with the mathematical principles of natural philosophy—of natural phenomena—whereas *De Gravitatione* is quite philosophical.

Force in De Gravitatione

De Gravitatione sets out the following general definition of force:

> Definition 5. Force is the causal principle of motion and rest. And it is either an external one that generates, destroys, or otherwise changes impressed motion in some body, or it is an internal principle by which existing motion or rest is conserved in a body, and by which any being endeavors to continue in its state and opposes resistance.[92]

The first notable point in the definition is that force is a causal principle—forces have causal efficacy. Like Kepler, but unlike some of his successors, Newton does not appear to take causation to be an epistemologically troubling concept. This is not for lack of an empiricist's values. Those values are evident in the concept of body he develops in *De Gravitatione*.[93] Instead of associating accessible properties with an inaccessible and indeed unintelligible notion of "prime matter", as the Aristotelians did, he eliminates prime matter or substratum by associating properties with regions of space. Matter might have some "essential and metaphysical nature", but it is not accessible to us. As for causal connections, however, they are not analogous either to

[92] *De Gravitatione* in *Philosophical Writings*, 36. Newton's original Latin reads as follows: "Def 5 Vis est motus et quietis causale principium. Estque vel externum quod in aliquod corpus impressum motum ejus vel generat vel destruit, vel aliquo saltem modo mutat, vel est internum principium quo motus vel quies corpori indita conservatur, et quodlibet ens in suo statu perseverare conatur & impeditum reluctatur." (*Unpublished Scientific Papers of Isaac Newton*, 114.) Earlier, in the *Waste Book* of his student years, Newton set out a different general definition of force, one that accepts the mechanical's philosophy's insistence upon contact action: "Force is ye pressure or crouding of one body upon another." See Herival, *Background*, 138.

[93] In speaking of Newton's experimentalism or empiricism, I mean to contrast his approach to that pursued by thinkers such as Descartes. For Descartes, the laws of nature cannot be revised on the basis of any experience, since they have been derived *a priori* from God's nature. Newton, by contrast, claims to derive his laws from phenomena, and accordingly he considers them to be revisable. The revisability of the physical theory is set out explicitly in the *Principia*. Rule 4 seems to envision less dramatic revisions; further research may reveal the need to make the propositions "more exact", or show that they are "liable to exceptions". The possibility of more dramatic revisions is allowed in the Author's Preface, as Newton expresses the hope that his principles will shed light on this mode of philosophizing, or "some truer one" (*Principia*, 796 and 383.)

unintelligible prime matter, which should be eliminated, or to matter's essential nature, which is inaccessible. Instead they are unproblematic.

It is also notable that forces are responsible not only for changes of state, but also for the persistence of state. This means that in *De Gravitatione*, at least, the *vis inertiae* or force of inertia is a genuine force, as we shall see in more detail below.

A third notable point is that Newton has natural forces in mind here, that is, forces belonging to the created world. Yet an implication of Newton's definition is that there are both natural forces and the divine force, since God meets the definition of 'force'. Newton's God is an omnipotent creator, who brought the universe into existence, who impressed the planets' first transverse motions upon them, and who, Newton suggests in Query 31,[94] occasionally reforms the planetary orbits, which over time develop irregularities from the mutual actions of planets and comets.[95] Since God has caused and continues to cause motion, he is a "causal principle of motion and rest".[96] It therefore makes sense to call a natural force unreal if the effects once attributed to it are subsequently attributed instead to the divine force. I have in mind of course the case of gravity.

[94] Query 31 is an essay with much earlier roots. It appears in the English *Opticks* in 1717/18, but this version is a modification of Query 23, which appeared in the *Opticks* predecessor, the 1706 Latin *Optice*. Query 31/23, as it is sometimes known, was in turn was based on an essay written c. 1687). On this point see the commentary of Cohen and Westfall in *Newton: Texts, Backgrounds, Commentaries*, 5.

[95] "Some inconsiderable Irregularities...may have risen from the mutual actions of Comets and Planets upon one another, and...will be apt to increase, till this System wants a Reformation." Query 31 (*Opticks*, 402), but Query 23 in the edition upon which Leibniz was commenting. Newton's suggestion here was the probable provocation to Leibniz's charge, in his 1715 Letter 1, that Newton's God is like an imperfect watchmaker. See H. G. Alexander, *Leibniz-Clarke*, 11, n.*a*.

[96] The suggestion that God might qualify as a force raises a number of problems. Although *De Gravitatione*'s definition treats forces as causes in a quite general way—unlike the *Principia*'s definition of 'impressed force'—the notion that God is a force does not fit easily with either of the definition's two categories of force, namely, internal and external. God would not be a force internal to bodies in the sense of being properties of those bodies; in that sense, God would be external to the bodies. And spatially, God could not be clearly designated as either internal or external; being substantially omnipresent, God shares space with bodies, yet he is also present at their peripheries and beyond. There is also the question of whether Newton wants to retain *De Gravitatione*'s broad view of forces, in which the causes of changes in state are not the only forces. If in his mature writings he restricts forces to impressed forces, then all forces are causes, but not all causes are forces. This latter, more restrictive view would treat force as part of a physical view of the world, as opposed to part of a metaphysical picture, such as that we find in Leibniz. For Leibniz, forces at the phenomenal, or physical level, are not real because accelerations are not real; instead, forces belong to the metaphysical level, that is, to monads. Yet there are grounds for thinking that Newton might consider God as a force. In Query 28 (*Opticks*, 369, 370), Newton sketches a process of discovery in which by deducing causes from effects, we are eventually led to the first cause, that is, God. If God can in some sense be deduced from forces, then perhaps Newton allows forces to include causes other than those appearing in the *Principia*.

Force in the *Principia*

Force is prominent in the *Principia*'s section, Definitions, which defines the concepts that Newton considers less well known, which is to say the theoretical concepts that he introduces. A Scholium discusses some "very familiar" concepts, and while force is not explicitly among those very familiar concepts, it creates the need for the Scholium's explanations of space, time, and motion. I shall consider those very familiar concepts first, before turning to those defined in the Definitions, but as I cannot here engage the extensive literature about space and time, my comments will be brief.

The Scholium sets out the concepts of space, time, place, and motion that the *Principia* will use. Space, time, and motion themselves are not defined, since in Newton's view (carried over from *De Gravitatione*), duration and space are very familiar.[97] Elsewhere he has more to say about the nature of space, in that it is an emanative effect of God, but the Scholium's goal is to define the concepts needed for the *Principia*. These are the "absolute", "true" and "mathematical" senses of the terms 'space', 'time', 'place', and 'motion', and Newton distinguishes these from the commonly used senses of the terms, that is, the "relative", "apparent" and "common" senses, which depend upon perceived objects. Although the concepts of absolute space, time, and motion are critical to the *Principia*, it turns out that they are not different in kind from the relative or common concepts. Absolute space is three-dimensional and so too is relative or common space (though in the 17th century this went without saying, as the discovery of non-Euclidean geometries was a long way off). Relative, common spaces are "the same in species, and in magnitude",[98] Newton writes, which is to say that a relative space is three-dimensional and can be mapped directly onto a portion of absolute space. The difference is that absolute space is infinite and immobile, whereas relative space is finite and mobile, being conceived or determined in terms of perceptible objects. For example, the space in a room is determined by the room's walls,

[97] Newton prefaces the definitions stated in *De Gravitatione* by remarking, "The terms 'quantity', 'duration', and 'space' are too well known to be susceptible of definition by other words." (*Philosophical Writings*, 12.)

[98] Scholium to the Definitions, *Principia*, 409.

and it is finite in that it is bounded by those walls. It is mobile in that the room is part of a house that stands on a moving Earth, and indeed, everything that we perceive may be moving. As the Earth moves, relative space contained by the walls of the room does not remain the same "numerically",[99] for different parts of absolute space are being enclosed by the walls from moment to moment. Is relative or common space the relationist concept that Leibniz will defend?[100] There is no indication that Newton has this in mind, even though relative space is determined or known by perceptible objects. For while we mark out relative spaces by means of perceived objects, such as the walls of a room, Newton does not suggest that space is commonly conceived to arise as a result of those objects (or of possible objects, as Leibniz will hold).[101]

The concept of absolute place derives from absolute space—it is that part of absolute space that a body occupies. So a room in a house is continually changing one absolute place for another, for it occupies any given region of absolute space only momentarily, being located on a moving Earth.

Absolute time, like absolute space, has no reference to external objects or events. It "flows uniformly",[102] and thus even if the absence of any objects or events in the universe, there is such a thing as a time interval, and a given time interval will be equal to some time intervals but unequal to others.

Newton's concept of absolute motion, which depends upon the concepts of absolute space and place, is critical for his dynamics.[103] Absolute motion is "the change of position of a body

---

[99] *Ibid.*

[100] The debate with Leibniz's relationalist concepts of space and time is played out much later, with Samuel Clarke advancing a Newtonian position in the *Leibniz-Clarke Correspondence*.

[101] This point was first recognized by Howard Stein. See Stein's discussion in "Newtonian Space-Time".

[102] Scholium to the Definitions, *Principia*, 408.

[103] For an extensive discussion of this and related issues, see Stein, "Newtonian Space-Time", and also Robert DiSalle, "Newton's Philosophical Analysis of Space and Time". Building upon Stein's work, DiSalle argues that Newton's critics are mistaken in thinking that (i) he is trying to prove the existence of absolute space, time, and motion, (ii) that these are metaphysical concepts, and (iii) that he gives metaphysical arguments for them. DiSalle traces the critics' error to their assumption that an empiricist account of space and time must define motion as a change of relative place. Since Newton rejects that particular empiricist account, the critics presume that he is giving metaphysical arguments

from one absolute place to another",[104] and is thus a very different notion than Descartes' doctrine of relative motion. According to Descartes' philosophical sense of motion, the Earth is at rest even as it orbits the sun, because it remains contiguous to the fluid aether surrounding it. Since there is no relative motion between the Earth and the aether, the Earth is at rest. This sense of motion cannot facilitate the development of a dynamical physics, which requires being able to say that a force is acting when there is a change of motion. In the case of the Earth, saying that the Earth is subject to a force requires being able to say that it is drawn back from the tangent—it requires being able to say whether a given motion is rectilinear or not. For this, Newton employs the thought experiment of the bucket filled with water and set to spin, via the release of a twisted rope. As the bucket begins to spin, the relative motion between it and the sides of the bucket is great, but the height of the water at the edges of the bucket is small, which is to say that its inertial effects are small. By the time that the water and the bucket move more or less as one, with very little relative motion between them, the water has climbed farther up the edges of the bucket, exhibiting much greater inertial effects. Newton takes the water's inertial effects, as it tries, so to speak, to continue in rectilinear motion, though the edges of the bucket prevent that, to constitute absolute motion. Although we cannot perceive absolute motion or absolute space itself, we can say that the direction in which the water attempts to move (so to speak) is absolute, rectilinear motion. And this, unlike Descartes' philosophical sense of motion, enables Newton to say that a force is acting to prevent that rectilinear motion; the bucket supplies a force that prevents the water from moving inertially. Absent a concept of inertial frames, by which he

for metaphysical concepts of absolute space, time, and motion. In fact, DiSalle argues, Newton's concepts are not metaphysical; they are exemplars of empirical meanings assigned to theoretical notions. For Newton, to call a quantity absolute is not to infer that it is an existing substance. It is rather to say that the quantity can be defined by physical laws. Thus Newton is giving empirical definitions of space, time, and motion, in that these definitions are drawn from the laws of empirical science.

[104] Scholium to the Definitions, *Principia*, 409.

could identify accelerations by affixing a coordinate system to some body, he needs the notion of absolute space in order to identify when a force is acting.[105]

Turning to the Definition section itself, here we find eight "less familiar" terms. Newton begins with *quantity of matter*, which is "a measure of matter that arises from its density and volume jointly".[106] As mentioned above, Newton does not attempt to define matter itself. For one thing, he intends, as his title indicates, to restrict the *Principia* to the mathematical principles of natural philosophy. Additionally, however, he does not think the nature of matter is accessible to us, a point I shall discuss at greater length subsequently. *Quantity of motion* is next defined. It is "a measure of motion that arises from the velocity and the quantity of matter jointly",[107] and thus what subsequently came to be known as momentum. I set out the next three definitions, Definitions 3, 4, and 5, together with some of their explanatory remarks, as I shall refer to them subsequently.

> Definition 3. Inherent force of matter is the power of resisting by which every body, so far as it is able, perseveres in its state either of resting or of moving uniformly straight forward. This force is always proportional to the body and does not differ in any way from the inertia of the mass except in the manner in which it is conceived. Because of the inertia of matter, every body is only with difficulty put out of its state either of resting or of moving. Consequently, inherent force may also be called by the very significant name of force of inertia. Moreover, a body exerts this force only during a change of its state, caused by another force impressed upon it, and this exercise of force is, depending on the viewpoint, both resistance and impetus: resistance insofar as the body, in order to maintain its state, strives against the impressed force, and impetus insofar as the same body, yielding only with difficulty to the force of a resisting obstacle, endeavors to

[105] The concept of an inertial frame was introduced in 1884 by James Thomson, who referred to it as a 'reference frame'. Newton's Corollary 5 to the Laws of Motion begins to suggest the concept of inertial frames, by indicating that the laws of motion are the same for uniform rectilinear motion as for rest, and that these cannot be distinguished in a closed space: "Corollary 5. *When bodies are enclosed in a given space, their motions in relation to one another are the same whether the space is at rest or whether it is moving uniformly straight forward without circular motion.* For in either case the differences of the motions tending in the same direction and the sums of those tending in opposite directions are the same at the beginning (by hypothesis), and from these sums or differences there arise the collisions and impulses [literally, impetuses] with which the bodies strike one another. Therefore, by law 2, the effects of the collisions will be equal in both cases….On a ship, all the motions are the same with respect to one another whether the ship is at rest or is moving uniformly straight forward." (*Principia*, 423.) For a discussion of Corollary 5, see Janiak, *Newton as Philosopher*, 138-139. Janiak identifies a tension between Newton's concept of absolute space and his three laws, together with their corollaries. The concept of absolute space implies that bodies have true or absolute velocities; yet absolute velocity cannot be measured, according to Corollary 5, which is implied by the laws of motion.

[106] *Principia*, 403.

[107] *Ibid.*, 404.

> change the state of that obstacle. Resistance is commonly attributed to resting bodies and impetus to moving bodies; but motion and rest, in the popular sense of the terms, are distinguished from each other only by point of view, and bodies commonly regarded as being at rest are not always truly at rest.[108]
>
> Definition 4. *Impressed force is the action exerted on a body to change its state either of resting or of moving uniformly straight forward.* This force consists solely in the action and does not remain in the body after the action has ceased. For a body perseveres in any new state solely by the force of inertia. Moreover, there are various sources of impressed force, such as percussion, pressure, or centripetal force.[109]
>
> Definition 5. *Centripetal force is the force by which bodies are drawn from all sides, are impelled, or in any way tend, toward some point as to a center.* One force of this kind is gravity, by which bodies tend toward the center of the earth; another is the magnetic force, by which iron seeks a lodestone; and yet another is that force, whatever it may be, by which the planets are continually drawn back from rectilinear motions and compelled to revolve around curved lines.[110]

So the *vis inertiae* is introduced at least in name as a force, followed by impressed force and the centripetal force, of which gravity is an example. The term 'force' then figures in all of the remaining definitions: absolute quantity of centripetal force; accelerative quantity of centripetal force; and motive quantity of centripetal force. Yet no general definition of force is included in this list.

Is there reason to think that Newton has abandoned *De Gravitatione*'s general definition of 'force', either entirely or in part? He has not abandoned the fundamental claim that a force is a causal principle; he has merely put causal questions aside to focus upon mathematical ones. This is evident in his explanatory remarks to the motive quantity of centripetal force, (Definition 8): "This concept is purely mathematical, for I am not now considering the physical causes and sites of forces."[111] And in the Scholium to Section 11 of Book I, he explicitly presents the mathematical problem as a first stage, to be followed by an attack upon the physical problem.

---

[108] *Ibid.*, 404-405.

[109] *Ibid.*, 405.

[110] *Ibid.*

[111] Definition 8, *ibid.*, 407.

> Mathematics requires an investigation of those quantities of forces and their proportions that follow from any conditions that may be supposed. Then, coming down to physics, these proportions must be compared with the phenomena, so that it may be found out which conditions [or laws] of forces apply to each kind of attracting bodies. And then, finally, it will be possible to argue more securely concerning the physical species, physical causes, and physical proportions of these forces."[112]

If we focus upon the gravitational force (and in this passage Newton has gravity in particular in mind, for reasons to be discussed below), Newton appears to view the gravitational force largely as Kepler did. Kepler's goal, as we saw in chapter II, was to investigate the "physical cause" of the orbits and present his "physical conception" of the force "through calculation and geometry".[113] In the Principia, Newton presents the force "through calculation and geometry", but as his above-quoted remarks indicate, that knowledge of the mathematical proportions of the force is only one stage, while knowledge of the physical species and causes is another. So D*e Gravitatione*'s conception of force as a causal principle still stands. So too does another component of the manuscript's definition, namely, that some forces produce changes of state; that Newton retains this is obvious from his definition of 'impressed force'.

What about *De Gravitatione*'s position, however, that the principle causing the persistence of state is a force—does Newton abandon this? There is no clear indication that he does, but one suggestion that he does may be seen in the above-quoted explanatory remark to Definition 8. When he writes that "this concept" is purely mathematical and that he is "not now considering the physical causes and sites of forces", he is referring to the centripetal force, which is an impressed force. Perhaps he means here to identify impressed forces with forces generally, for though he is not considering the physical sites of "this concept", he has indicated the physical site of the *vis inertiae*. It is inherent in matter—it is a quality of matter. Yet this is hardly

[112] Book I: Section 11, Scholium, *ibid.*, 588.

[113] "I am much occupied with the investigation of the physical causes. My aim in this is to show that the celestial machine is to be likened not to a divine organism but rather to a clockwork...insofar as nearly all the manifold movements are carried out by means of a single, quite simple magnetic force...This physical conception is to be presented through calculation and geometry." (Letter to Herwart von Hohenburg, February 10, 1605, quoted in Holton, "Johannes Kepler's Universe: Its Physics and Metaphysics", 342.)

decisive, since Newton could easily be restricting his attention to the centripetal force while continuing to regard the *vis inertiae* as a force in virtue of its causing persistence of state. I do not have an answer to the question of whether Newton retains this aspect of *De Gravitatione*'s definition of 'force', though I think it is likely he does.[114] In any case, even if he does abandon that part of the general definition, it is possible that the *vis inertiae* would yet qualify as a genuine force, for reasons I explain next.

THE *VIS INERTIAE*

If we relied upon terminology alone, we might assume that the *vis inertiae* is a genuine force. For as noted earlier, Newton uses the Latin '*vis*' not only in his term for impressed forces—'*vis impressa'*—which clearly are genuine forces, but also in the phrases designating the *vis inertiae*—'*vis inertiae'* and '*vis insita*'. Similarly, Newton sometimes uses the term 'force' when writing in English about the *vis inertiae.*[115] This terminology is hardly decisive, however, for Newton sometimes adopts existing terms while endowing them with a new meaning. This is the case with the term '*impetus*', which in medieval usage referred to a conferred power that gradually diminishes, but which Newton uses to mean a momentary action that changes a body's state. Similarly, the term '*vis insita*', translated as "inherent force", is not one that Newton invents. As Newton found the term, it referred to an inherent or natural power as opposed to a "violent" one, the former being a power in accordance with the body's nature, and the latter a

[114] In this section, I have considered the suggestion that Newton retains *De Gravitatione*'s general definition of force. As Andrew Janiak pointed out to me, one might object to the suggestion on the grounds that Newton did not have the concept of mass in *De Gravitatione*; and that he is unlikely to retain a definition of force developed without the concept of mass. This objection merits further investigation. It also raises further questions, generated by questions about the concept of mass. If mass is resistance, for instance, as characterized by the three laws of motion, then Newton has made some steps toward a concept of mass by *De Gravitatione*, simply in virtue of sharing the widely acknowledged view of matter as resistive.

[115] In Query 31 for instance, Newton writes the following. "It seems to me farther, that these particles have not only a *vis inertiae*, accompanied with such passive laws of motion as naturally result from that force, but also that they are moved by certain active principles, such as is that of gravity, and that which causes fermentation, and the cohesion of bodies." Also, in an ultimately unpublished note for a future edition of the *Principia* (quoted in Cohen's "Guide", 404), he writes, "I do not mean Kepler's force of inertia, by which bodies tend toward rest, but a force of remaining in the same state either of resting or moving." (*Opticks*, 401.)

power opposed to it.[116] Newton adopts the term, endows it with his own meaning in Definition 3 of the *Principia*, and then states that he shall give his concept of inherent force an additional name: '*vis inertiae*'. Newton's thoughts about *vis inertiae* do not begin with the *Principia*, but have antecedents in *De Gravitatione*.

Vis Inertiae* in *De Gravitatione

In *De Gravitatione*, the *vis inertiae* is a genuine force. According to that manuscript's general definition, a force is a "causal principle of motion and rest", and the kinds of forces he distinguishes are external and internal. As seen in *De Gravitatione*'s Definition 5, quoted above, an internal principle of motion and rest is one that conserves existing motion or rest in a body and that causes a body to attempt to continue in its state, opposing resistance. What does Newton call this internal principle? He tells us in Definition 8 of *De Gravitatione*: '*inertia*', which he then refers to as '*vis'*. So this is the *vis inertiae*, or force of inertia.

> Definition 8. *Inertia* is the inner force of a body, lest its state should be easily changed by an external exciting force.[117]

Putting Definition 8 together with the relevant clause of Definition 5, *De Gravitatione*'s *vis inertia* is a force which is internal to a body, which conserves the body's existing state of motion or rest, and which causes the body to try to continue in its existing state by opposing any resistance. A similar definition may be found in the *Principia*'s near ancestor, *De Motu*.[118]

---

[116] See Cohen, "Newton's concepts of force and mass, with notes on the Laws of Motion", 60-61.

[117] *De Gravitatione*, *Philosophical Writings*, 36. Newton's original Latin reads as follows: "Def 8. Inertia est vis interna corporis ne status ejus externa vi illata facile mutetur." (*Unpublished Scientific Papers of Isaac Newton*, 114); and the Halls' translation reads: "*Inertia* is force within a body, lest its state be easily changed by an external exciting force." (*Ibid.,* 148.)

[118] Newton writes in *De Motu*: "*Definition* 2. And I call that the force of a body or the force innate in a body by reason of which it endeavors to persist in its motion along a straight line." (*Background*, 299.)

All of these effects of the *vis inertia* reappear in the *Principia*, however *De Gravitatione*'s general definition of 'force', which decides the *vis inertiae*'s status in that manuscript, does not.

Vis Inertiae* in the *Principia

In the *Principia*, the *vis inertiae* has three kinds of effects (or strictly speaking, only two, as we shall see).[119] One effect is the conservation of state—the conservation of the body's existing state of either motion or rest. Newton mentions this effect not in the *Principia*'s definition of *vis inertiae* (Definition 3), but his explanatory remarks to the definition of impressed force (Definition 4). There, Newton writes that an impressed force does not remain in the body once the action has ceased, indicating a crucial difference between this new concept of impressed force and the old, medieval concept of *impetus*. The medievals' concept, based on the old belief that any non-natural motion requires an external mover, was that of an externally conferred power that remains for some time in the body, diminishing only gradually. Newton distinguishes his quite different concept of an impressed force, writing that this force does not remain in the body to preserve the new state. Any state, once attained, is preserved not by an impressed force but by the *vis inertiae*: "For a body perseveres in any new state solely by the force of inertia."

The *vis inertiae*'s remaining effects, stated in the above-quoted Definition 3, are resistance and impetus—for though Newton rejects the medieval concept, he adopts the term 'impetus', endowing it with his own meaning. Resistance is the striving against an impressed force, as the body attempts to preserve its state; as Kepler remarked earlier, without resistance, matter could be accelerated to an infinite velocity by the slightest force. Impetus is the body's endeavor to change the state of an obstacle. Unlike the *vis inertiae*'s first effect, which operates continually to preserve the body's state in the absence of an impressed force, resistance and

[119] For an extended discussion of the functions of the *vis inertiae*, see McMullin, *Newton on Matter and Activity*, 36-42.

impetus are episodic, to borrow Stein's term.[120] They are exercised only when an impressed force is encountered.

Resistance and impetus are in reality one and the same. There is no real distinction between them, Newton writes, only a rational distinction, that is, a difference in viewpoint. When exercised, the *vis inertiae* of a given body, A, may be considered in terms of its effect upon A itself as it encounters the impressed force supplied by another body, B. When A's *vis inertiae* is considered in terms of its effect upon A, it is resistance. It is the striving by A to preserve its state as it encounters B's impressed force, a striving without which A could be infinitely accelerated by B's impressed force. A's *vis inertiae* may also be considered in terms of its effect upon the encountered obstacle, B; considered from this viewpoint, it is impetus, an endeavor to change B's state. Newton therefore appears to be suggesting that when exercised, the *vis inertiae* actually constitutes an impressed force. The exercised *vis inertiae* appears to be half of an action-reaction pair, since A's resistance, the reaction, may also be seen as its impetus, an action or impressed force, upon B. Likewise, B's *vis inertiae* may be considered in terms of itself, the body in which it is inherent, in which case it is resistance or reaction; or it may be considered in terms of its effect upon A, in which case it is impetus, that is, an action, or impressed force.[121]

---

[120] Stein, "Newton's Metaphysics", 284.

[121] In connection with this point, see Howard Stein and Lars-Göran Johasson. Stein writes: "Whereas the "force of inactivity" is a *permanent* attribute of a body—not always *exercised*, but always *present*—impressed force is by its nature *episodic*. The explanation ends with the remark, "Impressed forces are of different origins; as from percussion, from pressure, from centripetal force." ("Newton's Metaphysics", 284.) The phraseology here—a force is said to be "from" another (kind of) force as its "origin"—is rather odd. But the point is this: the "intrinsic force of matter" is, in Newton's terminology, one of the "natural powers" or forces of nature. The various "origins" of impressed forces, too, are natural powers: permanent features of material nature, not transient episodes. An *impressed* force is the *action* upon a body of one of these natural powers." See also Lars-Göran Johasson:

> In definitions III, IV and V Newton successively defines *vis insita, vis impressa*, and *centripetal force*; this suggests that they are different things. However, in the comment quoted above [i.e., Newton's explanatory remark in Definition III that the exercise of the *vis insita* may be considered both resistance and impetus] he writes that *vis insita* (i.e. inertia) and *vis impressa* (also called impulse) are in fact one and the same thing. The difference is whether the body in question is moving or at rest, and this difference is only a relative matter; it has to do with our choice of frame of reference, not with the objects described. ("An anti-Humean account of causation in classical physics", 10-11.)

Yet Johasson denies that the *vis insita* (*vis inertiae*) is an inherent quality of matter, as Newton describes it in Rule 3, writing that it denotes a change of motion (since it is identical to *vis impressa*), not the cause of that change:

The suggestion that the exercised *vis inertiae* is an impressed force has obvious implications for the *vis inertiae*'s status as a force. If this suggestion were indeed Newton's view, then the *vis inertiae* would qualify as a genuine force regardless of which of the two above-mentioned definitions of 'force' Newton accepted. If Newton accepts the definition of 'impressed force' as a definition of 'force' generally, then the *vis inertiae*, when exercised, would qualify, for when exercised it is an endeavor to change the obstacle's state, which is to say an impressed force. If, on the other hand, Newton retains *De Gravitatione*'s general definition of force, which classifies as a force not only that causing change of state but also that causing the persistence of state, then the *vis inertiae* would qualify twice over. For when exercised, it is an impressed force as well as resistance, and when unexercised, it causes the body's current state of either motion or rest to be preserved.

Nonetheless, I do not conclude that the *vis inertiae* is a genuine force, since the suggestion that when exercised it constitutes an impressed force is quite problematic, as a subsequent section will show. Before examining those problems, let us consider the relation of the *vis inertiae* to matter and to the laws of motion.

Relation of the *Vis Inertiae* to Matter and to the Three Laws of Motion

The *vis inertiae*'s relation to matter is indicated by its other name, indeed the name by which Newton first introduces it: 'inherent force of matter' ('*vis insita*'). Newton does not invent the term '*vis insita*', but he presumably uses it because he finds it apt. Thus the *vis inertiae* is inherent in, or inseparable from, matter. This accords with *De Gravitatione*'s earlier description of the *vis inertiae* as an "internal principle", and also with his later remarks in Rule 3, a rule

---

> The definition of *vis impressa* as 'that which changes the body's state of rest or uniform motion' suggests that *vis impressa* is the cause of changes. But the comment quoted above tells us that there is no real difference between *vis impressa* and *vis insita*; hence, since *vis insita* is not the cause of inertia but inertia itself, *vis impressa* cannot differ from the change of motion. Both expressions are in fact only different expressions signifying changes of motion, not the causes of these changes….It appears that Newton intended these three definitions as explications of concepts that are satisfied by one and the same force. (*Ibid.,*10.)

added for the 1713 edition.[122] This rule states the conditions for inferring the universal qualities of bodies, and thus for extending the qualities of observed bodies to unobserved ones. The resultant picture is one in which the micro world is much like the macro world, only smaller; observable bodies have are extended, massive, and hard because their unobservable, component particles are extended, massive, and hard.

> Rule 3. *These qualities of bodies that cannot be intended or remitted [i.e., qualities that cannot be increased and diminished] and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally*.[123]

Then in his explanatory remarks, Newton states that the *vis inertiae* is, unlike gravity, an inherent quality of matter, along with extension, hardness, impenetrability and mobility.[124]

> The extension, hardness, impenetrability, mobility, and force of inertia of the whole arise from the extension, hardness, impenetrability, mobility, and force of inertia of each of the parts; and thus we conclude that every one of the least parts of all bodies is extended, hard, impenetrable, movable, and endowed with a force of inertia…. I am by no means affirming that gravity is essential to bodies. By inherent force I mean only the force of inertia. This is immutable.[125]

---

[122] With the second edition of the *Principia*, published in 1713, Newton eliminates Hypothesis III, which stated, "Every body can be transformed into body of any other kind, and can assume successively all intermediate degrees of quality", and replaces it with Rule 3, which states the essential qualities of matter, and provides grounds for inferring the existence and qualities of unobservable particles of matter from those of observed bodies. This translation of Hypothesis III is by J.E. McGuire, who examines Newton's reasons for rejecting it in "Transmutation and Immutability: Newton's Doctrine of Physical Qualities"; see 262-263 in particular. See also Cohen, "Guide", 198-200.

[123] Book III, Rule 3, *Principia*, 795-96.

[124] It is interesting that in Query 23/31 (the slash indicating that Query 31 in the 1717/18 *Opticks* is a revision of the 1706 *Optice*'s Query 23), which contains an argument severely restricting the scope of motions explicable by passive principles, Newton does not include inertia in his list of the qualities endowed upon matter by God. There, Newton mentions the properties of Rule 3, minus inertia: "It seems probable to me, that God in the beginning formed Matter in solid, massy, hard, impenetrable, moveable Particles, of such Sizes and Figures, and with such other Properties, and in such Proportion to Space, as most conduced to the Ends for which he formed them; and that these primitive Particles being Solids, are incomparably harder than any porous Bodies compounded of them; even so very hard, as never to wear or break in Pieces: no ordinary Power being able to divide what God himself made one in the first Creation." (Query 31, *Opticks*, 400.)

[125] Rule 3, *Principia*, 795-796. The passage quoted concludes with the remark, "Gravity is diminished as bodies recede from the earth."

The constellation of terms that Newton associates with the *vis inertiae* while disassociating them from gravity—'inherent', 'essential', 'immutable'—raises some questions since those terms are not obviously synonymous with one another. For the moment, however, it is sufficient to note that the *vis inertiae* belongs to the least part of matter and is thus inseparable from matter. Does this inseparability explain its causal means of operation? Newton appears to think that no explanation is required; his remarks in an unpublished letter indicate that he regards manifest, inherent qualities of matter as primitives that require no explanation.[126]

The inherent *vis inertiae*, Newton writes in Query 31, is a "passive principle" that gives rise to the three laws of motion.[127] The laws are as follows.

> Law 1. Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed."
>
> Law 2. A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed."
>
> Law 3. To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction.[128]

---

[126] Newton to the Editor of the *Memoirs of Literature*, unpublished, written c. May 1712: "But Mr. Leibniz goes on. 'The ancients and the moderns, who own that gravity is an occult quality, are in the right, if they mean by it that there is a certain mechanism unknown to them whereby all bodies tend towards the center of the earth. But if they mean that the thing is performed without any mechanism by a simple primitive quality or by a law of God who produces that effect without using any intelligible means, it is an unreasonable and occult quality, and so very occult that it is impossible that it should ever be done through an angel or God himself should undertake to explain it.' The same ought to be said of hardness. So then gravity and hardness must go for unreasonable occult qualities unless they can be explained mechanically. And why may not the same be said of the *vis inertiae* [force of inertia] and the extention, the duration and mobility of bodies, and yet no man ever attempted to explain these qualities mechanically, or took them for miracles or supernatural things or fictions or occult qualities. They are the natural, real, reasonable, manifest qualities of all bodies seated in them by the will of God from the beginning of the creation and perfectly incapable of being explained mechanically, and so may be the hardness of primitive particles of bodies." (*Philosophical Writings*, 116-117.)

[127] In Query 31 Newton writes, "It seems to me farther, that these Particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles." (*Opticks*, 401). In draft material for the 1706 *Optice* (specifically, for Query 23), dated by McGuire as c. 1705, Newton is more specific, mentioning each of the three laws: "Matter is a passive principle & cannot move itself. It continues in its state of moving or resting unless disturbed. It receives motion proportional to the force impressing it, and resists as much as it is resisted. These are passive laws & to affirm that there are no other is to speak against experience. For we find in o^{r}selves a power of moving our bodies by o^{r} thought. Life & Will (thinking) are active Principles by wch we move our bodies, & thence arise other laws of motion unknown to us." (ULC, Add. 3970, fol. 619r, a draft variant of the 1706 *Optice*'s Query 23, written in English and quoted in McGuire, "Force, Active Principles, 171.)

[128] *Principia*, 417.

There is an evident connection between the *vis inertiae* and Law 1, which expresses the view adopted from Descartes' that uniform rectilinear motion is as natural as rest.[129] (It will also be noted that the states of rest and uniform motion mentioned in Law 1 are distinct, since Newton asserts absolute space and time, and thus absolute motion.) Law 1 is associated with the unexercised *vis inertiae*, for as stated in Definition 4, the unexercised *vis inertiae* preserves a body's state of motion or rest.[130] The second and third laws pertain to impressed force, and so are connected to the *vis inertiae* when exercised. In the next sections, I shall look a bit more closely at the *vis inertiae*'s relations to Law 1 and Law 3.

The *Vis Inertiae*, Law 1, and the Preservation of State

In saying that the unexercised *vis inertiae* preserves a body's state, I am rejecting Robin Collingwood's claim, later defended by Menno Hulswit.[131] They argue that Newton attributed the continuation of state to Law 1, but not to any cause, and that he therefore denied universal causation, holding that some events are law like but uncaused. (I take this to mean that some events have no *natural* cause; since everything that happens requires at least God's concurrence, God is in some sense the cause of everything.) In defending this claim, Hulswit draws upon a passage from the Scholium to the Definitions in which Newton distinguishes true (absolute) from relative motion. In the translation used by Hulswit, and with the latter's added italics, the passage reads as follows.

[129] In response to Leibniz's charge that he adopted his notion of inertia from Kepler, Newton drafts (though eventually discards) a clarificatory note distancing himself from Kepler's concept of inertia. See Cohen, "Guide", 404: "Newton's interleaved copy of ed. 2 adds the following, which was never printed: "I do not mean Kepler's force of inertia, by which bodies tend toward rest, but a force of remaining in the same state either of resting or moving."

[130] One difficulty here is that while Newton writes in Query 31 that all three laws of motion arise from the *vis inertiae*, Law 1 also helps explicate impressed force.

[131] See Hulswit, "A Short History of Causation", and Collingwood, "On the So-called Idea of Causation." For a similar view, see also Lars-Göran Johasson: "Uniform motion, i.e., change of position with constant velocity, is, according to Galileo and Newton a natural state which doesn't require a cause….A cause, i.e., a force, is needed only for the change of motion." ("An anti-Humean account of causation in classical physics", 15.)

> The *causes* by which true and relative motions are distinguished, one from the other, are the *forces* impressed upon bodies to generate motion. *True motion is neither generated nor altered, but by some force impressed upon the body moved;* but relative motion may be generated or altered without any force impressed upon the body. For it is sufficient only to impress some force on other bodes with which the former is compared, that by their giving way, that relation may be changed, in which the relative rest or motion of this body did consist. *Again, true motion suffers always some change from any force impressed upon the moving body*.[132]

Hulswit reaches his conclusion because he takes Newton to be defining 'cause' generally:

> Thus, Newton means by cause precisely the above mentioned (in the first two laws of motion) "motive force impressed upon" a body, which "compels" it to move differently. Put more precisely: *causes are forces or constraints that compel moving bodies to behave differently than they would have done without them*. Thus 'caused' means constrained or compelled. Newton used the expression "free" motion to refer to unconstrained motions. Thus Collingwood rightly concluded that "*in Newton there is no law of universal causation;* he not only does not assert that every event must have a cause, he explicitly denies it." Any movement that happens according to the first law of motion is an uncaused event. Thus if a body moves freely from A to B to C, the event which is the movement from A to B, is in no way the cause of the event which is the movement from B to C; it is not caused at all. The first law of motion is in fact a law of free or causeless motion (Collingwood [1938] 1991, 159; italics mine).[133]

Yet there is no indication in this Scholium passage that Newton is setting out a general definition of 'cause', nor does he define it elsewhere.[134]

Newton's point in the passage is this: the difference between a given body's true motion and its relative motion depends upon which bodies suffer the impressed force—that body itself, or the bodies to which it is related. Take a body A. How could true motion be generated in it, or

[132] Newton, *The Mathematical Principles of Natural Philosophy (Philosophiae Naturalis Principia Mathematica)*, 1726 edition, trans. A. Motte, 1729; Hulswit's italics. Cohen and Whitman translate the passage as follows: "The causes which distinguish true motions from relative motions are the forces impressed upon bodies to generate motion. True motion is neither generated nor changed except by forces impressed upon the moving body itself, but relative motion can be generated and changed without the impression of forces upon this body. For the impression of forces solely on other bodies with which a given body has a relation is enough, when the other bodies yield, to produce a change in that relation which constitutes the relative rest or motion of this body. Again, true motion is always changed by forces impressed upon a moving body, but relative motion is not necessarily changed by such forces." (*Principia*, 412.)

[133] Hulswit, "A Short History of Causation", 3.2.2.

[134] On this point, see Janiak: "Since Newton never defines 'cause,' or various related terms such as 'action,' and does not distinguish an ordinary from a more precise conception of causation, he apparently thinks that our ordinary conception is adequate for interpreting the *Principia*." ("Newton and the Reality of Force", 134.)

how could its existing true motion be altered? —Only by an impressed force upon that body, A. How could we generate *relative* motion in A, or alter A's existing *relative* motion? It would be sufficient to impress forces upon bodies *other than A*. So again, Newton's point has to do with which body suffers the impressed force. He is not making any claim about what qualifies as a cause. Specifically, he has not identified causes with impressed forces. There could be other kinds of causes, including the *vis inertiae*, which is not an impressed force (at least as unexercised), but to which Newton attributes the preservation of state, in his remarks in Definition 4 and elsewhere.

To obtain the Collingwood-Hulswit thesis, one would need to show that Newton identifies causes with impressed forces. Yet textual evidence runs against that identification. Newton consistently attributes the continuation of a body's state to the *vis inertiae*, which he considers to have causal efficacy. This is evident in the early manuscript, *De Gravitatione*, where he refers to it explicitly as a "causal principle", but also in the *Principia* itself. In the explanation of Rule 3 he writes, "That all bodies are movable and persevere in motion or rest by means of certain forces (which we call forces of inertia) we infer from finding these properties in the bodies that we have seen."[135] Over a long period of time, in texts stretching from *De Gravitatione* to later editions of the *Principia* and the *Opticks*, Newton attributes a body's persistence of state not directly to Law 1, but to the *vis inertiae* itself, as an inherent quality of matter.[136] So even if

[135] *Principia*, 795.

[136] The relevant texts include: *De Gravitatione*; *De Motu*; Definition 4 of the *Principia*; Rule 3 of the *Principia*; and Query 31 of the *Opticks*. In *De Motu* Newton writes: "*Definition* 2. And I call that the force of a body or the force innate in a body by reason of which it endeavors to persist in its motion along a straight line." (*Background*, 299.) In the explanation of Rule 3 he writes, "That all bodies are movable and persevere in motion or rest by means of certain forces (which we call forces of inertia) we infer from finding these properties in the bodies that we have seen." (*Principia*, 795.) In an ultimately unpublished note for a future edition of the *Principia* Newton writes, "I do not mean Kepler's force of inertia, by which bodies tend toward rest, but a force of remaining in the same state either of resting or moving." (This appears in Cohen, "Guide", 404.) In a Draft variant for the 1706 *Optice*, Newton writes, "Bodies (alone considered as long, broad & thick...) are passive. By their vis inertiae they continue in their state of moving or resting & receive motion proportional to ye force impressing it & resist as much as they are resisted." (ULC Add. 3970, folls. 620r, quoted in McGuire, "Force, Active Principles" 170-171.) Finally, in Query 31, Newton again attributes conservation of state, as well as opposition to resistance, to the inertial force: "The *Vis inertiae* is a passive Principle by which Bodies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the World." (*Opticks*, 397.)

Newton did not consider the *vis inertiae* to be a genuine force, he did consider the *vis inertiae* to have causal efficacy (in which case it would be a cause but not a force).

The *Vis Inertiae*, Law 3, and the Debt to Descartes

The third law concerns opposite and equal action-reaction pairs. As noted earlier, Newton holds that a body's resistance is only rationally distinct from its endeavor to change the state of an encountered obstacle, which suggests that he considers the exercised *vis inertiae* to be an impressed force upon the obstacle. I will subsequently discuss the reasons that this suggestion is problematic. First, however, I want to trace Newton's merely rational distinction between resistance and impetus, and also Law 3, to their conceptual basis in Descartes—specifically, to Descartes' rational distinction between action and passion.[137]

As we saw in chapter II, Descartes holds that action and passion are distinct only in reason,[138] a claim connected to his belief in a plenum. In a plenum, there is no space separating a body from other bodies, and so a body cannot be moved without moving some other bodies. The body expels the body contiguous to it on one side, and is expelled by that contiguous on the other side.[139] Under the assumption of a plenum, then, the body's being a mover cannot be conceived without its also being moved, and so there is only a rational distinction between mover and moved, that is, between action and passion.

If we turn to Descartes' discussion of motion in the strict sense, which is to say his doctrine of relative motion, we find the following principle of reciprocal action:

---

[137] I thank Alan Nelson for an influential discussion of the ideas in this section.

[138] Only substances can be really distinct, that is, able to exist apart from one another. See Descartes, *Principles of Philosophy*, II.60, CSM, 213.

[139] Descartes, *Principles of Philosophy*, II.3, CSM, 237: "*How in every case of motion there is a complete circle of bodies moving together.* I noted above that every place is full of bodies, and that the same portion of matter takes up the same amount of space, <so that it is impossible for it to fill a greater or lesser space, or for any other body to occupy its place while it remains there>. It follows from this that each body can move only in a <complete> circle <of mater, or ring of bodies which all move together at the same time>: a body entering a given place expels another, and the expelled body moves on and expels another, and so on, until the body at the end of the sequence enters the place left by the first body at the precise moment when the first body is leaving it."

> Transfer occurs from the vicinity not of *any* contiguous bodies but from the vicinity of those which 'are regarded as being at rest'. *For transfer itself is a reciprocal process*: we cannot understand that a body AB is transferred from the vicinity of a body CD without simultaneously understanding that CD is transferred from the vicinity of AB. *Exactly the same force and action is needed on both sides*. So if we wished to characterize motion strictly in terms of its own nature, without reference to anything else, then in the case of two contiguous bodies being transferred in opposite directions, and thus separated, we should say that there was just as much motion in the one body as in the other.[140]

The claims I have italicized may belong to a doctrine of relative motion. But this principle of reciprocal action—"Exactly the same force and action is needed on both sides"—will reappear in Newton's writings.

We know that Newton read Descartes' doctrine of relative motion very closely; a large portion of *De Gravitatione* is devoted to its refutation. And we know that Newton viewed Descartes' system with some animosity. In *De Gravitatione*, he positions himself dramatically against Descartes, declaring, "I shall venture to dispose of his fictions".[141] The fictions Newton proceeds to dispose of, there and in subsequent writings, include not only the doctrine of relative motion but also the material plenum, the vortical theory of gravity, Descartes' erroneous laws of collision, and the identification of matter with extension, which Newton considered a path to atheism. In the *Principia*, it is Galileo rather than Descartes whom Newton credits with discovering the inertial principle that he formulates as Law 1. So if Newton knowingly derived from Descartes the principle of reciprocal action, perhaps he would not have acknowledged it.[142] However, I shall not attempt the historian's task of tracing the causal path from Newton's reading of Descartes' rational distinction between action and passion and the associated principle of reciprocal action. It is sufficient to note that Newton did read the passages containing those ideas, and to show that they serve as a conceptual basis for some of Newton's fundamental ideas.

---

[140] *Ibid.*, II,.29, CSM 235. The second and third sets of italics are mine.

[141] *De Gravitatione* in *Philosophical Writings*, 14.

[142] However, in writing to Hooke, "If I have seen further it is by standing on the shoulders of giants", Newton acknowledges Descartes as one of those giants. See *Correspondence of Isaac Newton*, Vol. I, 416.

To make use of an idea, as opposed to adopting it wholesale, is to extract it from its current context, and put it to use in a different one. In the passages quoted above, Descartes considers cases of bodies sliding past one another, in the context of a doctrine of relative motion; he explains why, if motion is relative, we say of a body sliding along the earth that it is in motion, rather than saying that the earth is in motion. Newton has something else in mind. Rejecting Descartes' doctrine of relative motion along with the plenum, which together grounded Descartes' merely rational distinction between action and passion, Newton extracts the principle of reciprocal action and puts it to his own use. This principle becomes the conceptual basis for the exercised *vis inertiae* and for the closely related Law 3.

As discussed earlier, Newton sees no real distinction between a body's attempt to maintain its own state (resistance), and its attempt to change the state of the obstacle (impetus). If we consider the effect upon the one body, as it encounters an impressed force, it is exercising resistance, an attempt to maintain its prior state; but if we consider the effect upon the encountered body, the force of our original body is an impressed force, which the encountered body resists.

It seems then, that Newton has taken Descartes' principle of reciprocal action—"Exactly the same force and action is needed on both sides"—and used it to develop his concept of the inertial force. For if the force that one body exerts on another body is only rationally distinct from the effect it experiences itself, as it endeavors to maintain its own state, then "exactly the same force and action is needed on both sides", just as Descartes said. Law 3 generalizes the principle of reciprocal action, stating, "To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction."

But while Law 3 generalizes a principle drawn from the Cartesian system of action by contact, it does not itself imply action by contact. The law is neutral with respect to the question of whether forces act by contact or over a distance. One difficulty with the merely rational distinction between resistance and impetus—that is, with the suggestion that when exercised, the *vis inertiae* is an impressed force—is that it appears to presume action by contact.

Problematic Implications for the Rational Distinction between Resistance and Impetus

It is difficult to make sense of Newton's claim that there is no real distinction between a body's resistance and its "endeavors to change the state of that obstacle", if not by seeing the endeavor as an impressed force, yet there are serious problems with supposing that this is indeed Newton's meaning. First of all, if the exercised *vis inertiae* is an impressed force, what are we to make of Newton's explanatory remark, "This force is always proportional to the body"? We would need to suppose that the remark is incomplete, for the *vis inertiae* would be proportional not only to the body (the quantity of matter), but also to acceleration.

Second, the suggestion that a body's resistance is in reality identical to the force it impresses upon another body may be plausible for contact action, but it is implausible for forces that seem to act over distances. Impressed forces include not only percussion and pressure but also centripetal forces, and thus gravity. For gravity, the suggestion under consideration implies the following. When two bodies mutually gravitationally attract, the inertial resistance that each exercises is identical to the gravitational force it impresses upon the other body; the only difference between each body's resistance to the other body's force, and its attraction of the other body, is in how we conceive this. So, given bodies A and B, we could conceive A's inertia as its power of resisting B's attraction of it, or as its endeavor to attract B. If we consider a ball dropped near the surface of the earth, this interpretation implies that the ball's resistance to moving is only rationally distinct from the gravitational attraction by which it endeavors to change the earth's state. Yet the resistance that causes the ball to accelerate over time, as opposed to attaining infinite velocity and hitting the earth instantly, is not easily seen as an effort to change the earth's state.

Such an identity, a mere rational distinction, is not only implausible, it is contradicted by Rule 3, and this is a third problem. At the end of Rule 3, Newton states explicitly that the inertial force is inherent to matter, while the gravitational force is not. Indeed, he classifies only the *vis inertiae*, not gravity, as inherent because the latter varies with distance while the former does not. Clearly he does not consider gravity and the *vis inertiae*'s effect of resistance as two ways of conceiving a single force or effect. (And since gravity serves as the model for the additional distance forces about which Newton speculates, the problem extends to those forces as well.)

One possible explanation of these difficulties is that Newton developed the concept of the *vis inertiae* with contact action in mind. Yet this does not satisfactorily explain Newton's claim that resistance and impetus are merely rationally distinct, because there is one strong indication that Newton was satisfied with the claim: he carried it from the *Principia*'s first edition into later ones.

A Less Problematic Interpretation of the *Vis Inertiae*

One way out of these difficulties is to argue that Newton's *vis inertiae* is simply identical to mass. This view is defended by Cohen.

> He [Newton] identified mass and inertia. The *vis insita* of a body, he writes in Definition 3, "is always proportional to the body," that is, proportional to the mass. Furthermore, it "does not differ from the inertia of the mass" save for "the manner in which it is conceived." Hence, he writes, we may give *vis insita* a new and "very significant name," force of inertia (*vis inertiae*).[143]

The virtue of this view is that it avoids all the problems noted above. On this view the *vis inertiae* is proportional to body alone, not to body and acceleration both, and there is no counterintuitive identification between resistance and impressed forces such as gravity.

[143] Cohen, "Newton's concepts of force and mass, with notes on the Laws of Motion", 61.

Yet Cohen's view does not fit well with some of Newton's remarks. First of all, Newton does not say that the *vis inertiae* (*vis insita*) is identical to body (mass or quantity of matter), but merely that the two are proportional. Further, it is difficult to square Cohen's view with Newton's claim that resistance is only rationally distinct from a body's endeavor to change an obstacle's state. What could Newton mean by this, if he simply identified the *vis inertiae* with the quantity of matter? Also, Rule 3 presents the *vis inertiae* as a quality of matter, not as the quantity of matter.[144] I therefore do not think Cohen's view captures Newton's intent. The view seems best understood as a modification offered to Newton, though one that is more congenial than allowing the exercised *vis inertiae* to qualify as an impressed force.[145]

GRAVITY

The status of gravity as a force is not in question in the *Principia*, as noted earlier. Gravity is a centripetal force and thus an impressed force, so its status is not in question in this mathematical treatise, which does not attempt to explain gravity's causal means of action. Gravity's status as a force comes into question only once that causal question is considered. Yet even in the *Principia*, the causal question waits in the wings. This is in part because of Newton's positive claims about the gravitational force. Additionally, Newton provokes the question in his own mind in the way that Brahe provoked it for Kepler: by undermining an existing causal

[144] An additional question is raised by a speculation from Query 31. If the *vis inertiae* gives rise to the three laws of motion, but is itself simply mass (quantity of matter), must any matter God creates be described by the three laws of motion? To locate this question in the text, can we reconcile this interpretation of inertia with Newton's remark in Query 31 that God could have created matter having different densities and forces. (See *Opticks*, 403-404.) Elsewhere in Query 31, Newton speaks of inertia as a power of matter rather than as matter itself; inertia is something that the particles of matter "have", and the three laws of motion "result from that force". Then, in speculating that God could vary the laws of nature by creating matter of "different densities and forces", he seems to allow that God could create particles that lacked resistance, and had other traits instead. Is the way around this difficulty to consider Newton's use of the term 'force' redundant, adding nothing to his suggestion that God could vary the density of matter? For if inertia just is the quantity of matter, then by varying the density of matter, God would be varying the quantity of matter, which is to say, inertia. And particles of different densities, or different densities combined with other differences in properties, might obey different laws.

[145] Alternatively, one might defend Cohen's view—and without taking it as a modification of Newton's own view—by holding that the *vis inertiae* can be both a quality of matter, as Newton indicates in Rule 3, and the quantity of matter, as stated in Definition 1. As a person's height is both a quality of that person and a quantity that can be measured, mass could be both a quality and a quantity of matter. I thank Andrew Janiak for this point.

explanation. As Tycho Brahe disproved the crystalline sphere hypothesis, Newton attacks the material plenum critical to Descartes' vortex theory.

Newton's Attack on the Material Plenum

Earlier, in *De Gravitatione*, Newton attacked Descartes' identification of matter and extension. Then using realizations developed in *De Motu*,[146] he attacks Descartes' material plenum in Book II of the *Principia*. According to Descartes' mechanical explanation of celestial motions, a dense aether pushes celestial bodies along in their orbits. Newton, tackling problems of both celestial and terrestrial motion, shows that while celestial bodies conform to the predicted, idealized elliptical paths, terrestrial projectiles deviate from those idealized paths. He accounts for these deviations by assuming that atmospheric air provides resistance to the projectiles' motion. So, he assumes that the medium in which terrestrial projectiles travel provides resistance, but when treating celestial motion, he needs no such assumption. His results, in which only terrestrial bodies deviate from the idealized elliptical path, raise a problem for any Cartesian explanation of celestial motions that employs the notion of resistive matter.[147]

If Descartes' material fluid were dense enough to push the planets, it would produce enough resistance to make the planets deviate from Kepler's idealized elliptical paths, just as terrestrial projectiles do; indeed it would eventually bring the planets to a stop. Yet the planets do not deviate from those paths, and they are not brought to a stop, so such a dense medium must not exist. If, on the other hand, the material fluid were too rare to produce deviations from the elliptical paths, it would not be capable of pushing the planets. Thus the existence of a medium

[146] Westfall argues that a pendulum experiment c. 1679 convinced Newton that no material aether exists. See *Force*, 376-377.

[147] Defenders of Cartesian vortex theories might sidestep Newton's argument by denying the claim on which it depends, namely, that a material medium would be resistive and act by impact; defenders might hold that the vortical matter somehow carries the planets without pushing them. And Newton's arguments did not defeat vortical theories; they remained influential despite the *Principia*'s attack, with Leibniz, for one, inferring a material medium from his claim that action by contact belonged to the very nature of matter. Yet versions that sidestepped Newton's attack were still unable to explain Kepler's laws, the motion of comets, or the proportionality of the gravitational force to mass rather than surface area.

having enough resistance to push the planets is contradicted by observations; and a medium rare enough to conform to the observations could not perform the function Descartes assigns to it.[148]

However gravitational motions are caused, then, they cannot be caused by the impact of a material medium. As Newton writes to Leibniz in 1693, "The heavens are to be stripped as far as may be of all matter, lest the motions of planets and comets be hindered or rendered irregular".[149] This reopens the causal question, though Newton does not speculate about its answer in the *Principia.* (Apropos of that question, it is notable that Newton does not use the term 'void' to mean a space empty of all substance. This is not only because God is substantially present everywhere, but also because of the possibility of a very rare medium. In Definition 1, he does not deny the existence of an aether, he simply takes no account of it; if it exists, it has no sensible mass, and thus no relevance to his definition of mass. In Query 28, Newton reiterates that the heavens cannot contain a Cartesian, material medium, but he allows that there could be a medium lacking sensible resistance: "To make way for the regular and lasting Motions of the Planets and Comets, it's necessary to empty the Heavens of all Matter, except perhaps some very thin Vapours, Steams, or Effluvia…and from such an exceedingly rare Aethereal Medium as we described above."[150])

Gravity in the *Principia*: Some Central Claims

The *Principia* famously demonstrates that terrestrial projectile motion and celestial motions are explicable by the same principles, eventually overthrowing the Aristotelian distinction between the sublunary and superlunary realms. However, Newton does not initially

[148] On this point, see Brackenridge: "If Newton accounted for this celestial behavior by assuming that the ether was so diffuse that it caused no resistance, then he could no longer assume that the ether was dense enough to provide the mechanical collisions needed for the gravitational interaction. Such a conclusion would have called for a major revision in the way Newton saw the celestial world. It was not a step to be taken lightly. Nevertheless, Professor Jo Dobbs has recently argued that Newton did take such a step and that the exact nature of the area law played a major role in his decision to reject mechanical celestial collisions." (*The Key to Newton's Dynamics*, 23.)

[149] Newton to Leibniz, 1693 in *Philosophical Writings*, 108-109.

[150] Query 28, *Opticks*, 368..

identify the force that produces the orbits as gravity. In Book I, which analyzes motions resulting from a variety of forces, he refers to gravity as an example of a centripetal force; but thus far, gravity is only that force "by which bodies tend toward the center of the earth". The force that keeps the planets in their orbits, meanwhile, is simply a "centripetal force" throughout Books I and II. In Book III, Newton derives from observed phenomena his law of universal gravitation—the force of gravity between any two bodies is proportional to the product of their masses, divided by the square of the distance between them.[151] And it is not until Book III that he identifies the inverse square, centripetal force holding the planets in their orbits as gravity, that same force governing projectile phenomena on earth.

> Hitherto we have called "centripetal" that force by which celestial bodies are kept in their orbits. It is now established that this force is gravity, and therefore we shall call it gravity from now on. For the cause of the centripetal force by which the moon is kept in its orbit ought to be extended to all the planets, by rules 1, 2, and 4.[152]

Having identified the force responsible for the orbits with gravity, Newton asserts his principle of universal gravitation, and the proportionality of the gravitational force to mass in Book III, Proposition 7.

> Gravity exists in all bodies universally and is proportional to the quantity of matter in each.[153]

A corollary to Proposition 7 asserts that the gravity toward the whole arises from the gravity toward the individual parts. And since universal gravitation implies that any body, even an acorn, attracts the earth, Newton defends this against the charge of implausibility.

---

[151] Whereas Newton expresses his law in terms of proportionality, modern expression uses the gravitational constant.

[152] Book III, Prop 5, Scholium, *Principia*, 806.

[153] Book III, Prop 7, *ibid.,* 810.

> Therefore the gravity toward the whole planet arises from and is compounded of the gravity toward the individual parts. We have examples of this in magnetic and electric attractions. For every attraction toward a whole arises from the attractions toward the individual parts. This will be understood in the case of gravity by thinking of several smaller planets coming together into one globe and composing a larger planet. For the force of the whole will have to arise from the forces of the component parts. If anyone objects that by this law all bodies on our earth would have to gravitate toward one another, even though gravity of this kind is by no means detected by our senses, my answer is that gravity toward these bodies is far smaller than what our senses could detect, since such gravity is to the gravity toward the whole earth as [the quantity of matter in each of] these bodies to the [quantity of matter in the] whole earth.[154]

The claim that gravitational force is proportional to quantity of matter or mass—mass being a concept original to Newton[155]—is of course a clear departure from the Cartesian Tradition. If gravity were to operate by contact action, as the Cartesians held, its intensity would be proportional to surface area, rather than to the quantity of matter, compounded from a body's parts.[156] Much later, Newton would emphasize this point in the General Scholium added to the *Principia*'s 1713 edition.

> This force arises from some cause that penetrates as far as the centers of the sun and planets without any diminution of its power to act, and that acts not 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, and whose action is extended everywhere to immense distances, always decreasing as the squares of the distances. Gravity toward the sun is compounded of the gravities toward the individual particles of the sun, and at increasing distances from the sun decreases exactly as the squares of the distances.[157]

---

[154] Book III, Prop 7, Corollary 1, *ibid.*, 811.

[155] Although some of Newton's predecessors, including Galileo, William Gilbert, and Kepler, employed the term 'mass', they did not distinguish it from weight. As shall be discussed in a later chapter, Newton is the first to make that distinction. He defines 'body' or 'mass' as quantity of matter, and distinguishes it from weight by stating that it is "proportional" to weight. See Definition 1, *Principia*, 403.

[156] See *Principia*, Book I, section 12 and Book III, Propositions 8, 19, 20. See also Cohen, "Guide", 54-6.

[157] General Scholium, *Principia*, 943.

So matter is particulate,[158] and the heavens are nearly void of matter. Gravity is proportional to the quantity of matter rather than to surface area, and it decreases with distance in an inverse square relation. All of this suggests the possibility that material bodies may be causally affecting one another across empty space. (The theory also implies instantaneous action between bodies, but in the 17th century this was not regarded as problematic.[159])

Aware that he will be charged with allowing action at a distance, Newton carefully circumscribes the *Principia*'s goals. Of the two related problems he inherited from Kepler, the physical and the mathematical, it is only the latter that he claims to have solved. Thus in his Author's Preface to the Reader, Newton reiterates the point communicated already by his treatise's title: "our present work sets forth mathematical principles of natural philosophy."[160] He makes the same point again in connection with the centripetal force—of which gravity is of course an example—writing in his explanatory remarks for the definition of the centripetal force's motive quantity, (Definition 8): "This concept is purely mathematical, for I am not now considering the physical causes and sites of forces."[161] Furthermore, he continues, the term 'attraction' refers only to a "propensity toward a center". It does not define "a species or mode of action or a physical cause or reason"; the reader must "beware of thinking that....I am attributing

[158] Query 31 contains an atomist hypothesis, according to which God created primitive particles that cannot be divided by an ordinary power, but this is confined to a query because it is a hypothesis, meant to furnish experiments. Newton does not assert the existence of indivisible atoms; Rule 3 of the *Principia* allows for the possibility that the least parts of matter could turn out to be divisible.

[159] Hesse discusses the basis of this implication in Newton's treatment of Law 3: "Newton's own discussion of the third law is not quite satisfactory. He regards it as empirical in the case of collisions, and describes experiments by which he has established it, but he gives what appears to be a logical proof from the first law in the case of attractions….Furthermore, Newton assumes without comment that when bodies at a distance are moving relative to one another, the [third] law still holds, and this implies that action between them takes place instantaneously, for if the transmission takes time, the action of A on B may not be simultaneous with that of B on A and therefore in general not equal to it at all times." (*Forces and Fields*, 137.)

[160] Author's Preface to the Reader, 8 May, 1686, *Principia*, 382.

[161] Definition 8, *Principia*, 407.

forces in a true and physical sense to centers (which are mathematical points) if I happen to say that centers attract or that centers have forces".[162]

Following a discussion of terrestrial gravity and the laws of attraction in Section 11, Newton again distinguishes the mathematical from the physical problem, indicating that the *Principia*'s solution to the former problem sets conditions for the latter problem, whose solution has yet to be found.

> I use the word 'attraction' here in a general sense for any endeavor whatever of bodies to approach one another, whether that endeavor occurs as a result of the action of the bodies either drawn toward one another or acting on one another by means of spirits emitted or whether it arises from the action of aether or of air or of any medium whatsoever—whether corporeal or incorporeal—in any way impelling toward one another the bodies floating therein. I use the word 'impulse' in the same general sense, considering in this treatise not the species of forces and their physical qualities but their quantities and mathematical proportions, as I have explained in the definitions. Mathematics requires an investigation of those quantities of forces and their proportions that follow from any conditions that may be supposed. Then, coming down to physics, these proportions must be compared with the phenomena, so that it may be found out which conditions [or laws] of forces apply to each kind of attracting bodies. And then, finally, it will be possible to argue more securely concerning the physical species, physical causes, and physical proportions of these forces.[163]

What Newton's readers are intended to understand, especially in preparation for Book III, is that since he claims to have solved only the mathematical problem and not the physical one, the possibility that matter attracts across distances is only that, a possibility. Mathematics set out the proportions following "from any conditions that may be supposed", and provides one set of constraints; thus with the gravitational force, accelerations between bodies are constrained to be directly proportional to their masses and proportional to distance in the inverse square. Yet while mathematics provides one set of constraints upon what can be true, physical conditions may provide a further set of constraints, and those physical conditions may rule out action at a distance. The physical conditions could be such that gravitational effects are produced by some

[162] *Ibid.,* 408.

[163] Book I: Section 11, Scholium, *Principia*, 588.

immaterial agent or medium, but while Newton speculates about that elsewhere, he does not do so here.

Yet despite all the disclaimers, the possibility of action at a distance still looms large, in part because Newton does not strictly confine himself to mathematical propositions or to an acausal talk of "tendencies" (the only talk to which he is entitled, Bishop Berkeley will charge). At various points he indicates his belief in the causal efficacy of the gravitational force, saying for instance that gravity is the force "by which the moon is kept in its orbit".[164] Since he has eliminated the Cartesian causal explanation without providing anything in its place, action at a distance may be only a possibility, but it is the most obvious possibility.

Gravity's Relation to Matter

What exactly is the relationship of gravity to matter? Gravity is universal to matter, as Newton indicates in the above-quoted Proposition 7 of Book III. He reiterates this claim in his explanatory remarks to Rule 3 (also quoted above). At the same time, he states definitively that while the *vis inertiae* is an inherent quality of matter, gravity is not.

> If it is universally established by experiments and astronomical observations 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 so 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. 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. Yet I am by no means affirming that gravity is essential to bodies. By inherent force I mean only the force of inertia. This is immutable. Gravity is diminished as bodies recede from the earth.[165]

[164] Only in Book III does Newton identify the centripetal force keeping planets in orbit as gravity: "Hitherto we have called "centripetal" that force by which celestial bodies are kept in their orbits. It is now established that this force is gravity, and therefore we shall call it gravity from now on. For the cause of the centripetal force by which the moon is kept in its orbit ought to be extended to all the planets, by rules 1, 2, and 4." (Book III, Prop 5, Scholium, *ibid.,* 806.)

[165] Book III, Rule 3, *ibid.,* 795-96.

So gravity is universal but not inherent or essential to matter, and Newton remains consistent in this position over time.[166] To allow gravity as an inherent quality of matter would make the charge of action at a distance impossible to deny. However, Newton states a different reason for denying that gravity is inherent to matter. Gravity varies with distance, whereas the properties that Newton classifies as inherent and essential are immutable. Newton thus appears to accept the Scholastic classification of essential properties as those that cannot be "intended and remitted", that is, increased or decreased. Such properties are, in McMullin's terminology, intensity-invariant.[167]

Yet there is a potential problem with this classification, one that I shall say more about later. According to the classification Newton sets up, gravity differs from the inherent, essential properties, such as mobility, impenetrability, and hardness in that these latter qualities are immutable, while gravity is not. But is Newton's stated condition, immutability, really the classification condition he employs? He counts hardness as an inherent essential quality, but there are two problems with this. First, not all bodies are hard;[168] fluids for instance are not. Second, hardness is not immutable. A body's hardness may vary with pressure or with heat. Insisting upon the Scholastic condition of immutability therefore suggests that hardness should be removed from the list of inherent, essential qualities. Yet it remains on the list in Rule 3. (One

---

[166] See Newton's second letter to Bentley, Jan. 17, 1692/3: "You sometimes speak of Gravity as essential and inherent to Matter. Pray do not ascribe that Notion to me; for the Cause of Gravity is what I do not pretend to know." (*Correspondence of Isaac Newton,* 240.) See also the 1717 advertisement for the *Opticks*: "In this Second Edition of these Opticks I have omitted the Mathematical Traets publish'd at the End of the former Edition, as not belonging to the Subject. And at the End of the Third Book I have added some Questions. And to shew that I do not take Gravity for an essential Property of Bodies, I have added one Question concerning its Cause, chusing to propose it by way of a Question, because I am not yet satisfied about it for want of Experiments. July 16, 1717, I.N." (Advertisement II, *Opticks*, cxxiii.) The comparison with Roger Cotes' preface to the *Principia* is notable, for while Cotes does not use the terms 'inherent' or 'essential', he does state that gravity is a primary quality of matter: "Among the primary qualities of all bodies universally, either gravity will have a place, or extension, mobility, and impenetrability will not. And the nature of things either will be correctly explained by the gravity of bodies or will not be correctly explained by the extension, mobility, and impenetrability of bodies." (*Philosophical Writings,* 50.) However, Cotes' preface was not reviewed or approved by Newton prior to publication; see Westfall: "Newton declined even to see Cotes's preface because he feared being taxed with writing it. Cotes did eventually get Samuel Clarke to read over what he wrote." (*Never at Rest*, 749.)

[167] On this point, see McMullin, *Newton on Matter and Activity*, 58.

[168] See McMullin, *ibid.*, 22-23.

might reply that such variation is a property only of aggregate bodies, not of particles; and Newton does imply in Query 31 that particles are perfectly hard. Yet if sensible bodies are the basis for inferring the properties of insensible particles, then variations of aggregate bodies' hardness, due to pressure and heat, suggests that the hardness of particles may also be mutable.) This suggests that behind Newton's stated condition for classifying qualities as he does, there may be some other condition. Perhaps a belief that matter cannot act from a distance is behind his claim that hardness is inherent and essential while gravity is not. I will consider this possibility in the final chapter.

Newton's Relational Concept of Gravity

Newton conceives of gravity as a relational force. And since gravity is universal to matter, this force is an enormously complex relation, holding among all existent matter.[169] Using the simpler case of two bodies, Newton explains the force's relational character in *A Treatise of the System of the World*, a manuscript that, while published posthumously, dates from the first edition of the *Principia*. (Newton originally intended Book III to be accessible to a general readership, and this manuscript was the result. However, once he decided instead to exclude a general readership, however, he replaced it the more technical version that appeared in 1687.)

> Since the action of the centripetal force upon a body attracted is, at equal distances, proportional to the matter in this body, it accords with reason that it should be proportional also to the matter in the body attracting. For action is mutual, and [by the third Law of Motion] makes bodies by a mutual tendency approach one another, and hence must be conformable with itself in each body. *One body may be considered as*

[169] In draft material written prior to the *Principia*, "On the Motion of Bodies in Non-Resisting Mediums", Newton's work on orbits leads him to the following conclusion:

> "Each time a planet revolves it traces a fresh orbit, as happens also with the motion of the moon, and each orbit is dependent upon the combined motions of all the planets, not to mention their actions upon each other. Unless I am much mistaken, it would exceed the force of human wit to consider so many causes of motion at the same time, and to define the motions by exact laws which would allow of any easy calculation." (*Unpublished Scientific Papers of Isaac Newton*, 281.)

Commenting upon this passage, Cohen notes that Newton's recognition of orbital perturbations was an essential step toward the principle of universal gravitation. See Cohen, "Guide", 19.

> *attracting, another as attracted; but this distinction is more mathematical than natural. The attraction really is of each body towards the other,* and is thus of the same kind in each. *And hence it is that the attractive force is found in each*. The sun attracts Jupiter and the other Planets, Jupiter attracts the Satellites; and by parity of reason, the Satellites act among themselves reciprocally and upon Jupiter, and all the Planets mutually among themselves. *And though the mutual actions of two Planets may be distinguished from one another, and considered as two actions, by which each attracts the other: yet in so far as these [actions] are intermediate, they are not two, but a single operation between two terms.* By the contraction of a single interceding cord two bodies may be drawn each to the other. The cause of the action is twofold, indisputably [that cause is] the disposition of each body; the action is likewise twofold in so far as it is upon two bodies; but *as between two bodies it is sole and single. It is not one operation by which Jupiter attracts the Sun, but it is one operation by which the Sun and Jupiter mutually endeavor to approach one another.* By the action by which the Sun attracts Jupiter, Jupiter and the Sun endeavor to come nearer together [by the third Law of Motion] and, by the action by which Jupiter attracts the Sun, Jupiter and the Sun likewise endeavor to come nearer together: *but the Sun is not attracted towards Jupiter by a double action, nor Jupiter by a double action towards the Sun, but it is one intermediate action by which both approach nearer together.* Iron draws the loadstone as much as the loadstone draws the iron; for all iron in the neighborhood of the loadstone also draws other iron. *But the action between the loadstone and the iron is single, and is considered as single by the Philosophers*...Conceive a single operation arising from the conspiring nature of both to be exerted in this way between two Planets; and this will be disposed in the same way *towards* both: hence being manifestly proportional to the matter in one of them, it will be proportional to the matter in the other.[170]

Whereas the Aristotelians conceived gravity as an essential, monadic property of a single body, specifically the natural tendency of earthy bodies to seek the center of the universe, Newton asserts instead a relation. Gravity would exist if the universe contained only one aggregate body, since by the principle of universal gravitation, the component particles of the body would attract one another. However, there would be no gravity if the universe contained only a single particle. Without at least two relata, there can be no relation, and so without at least two particles in the universe there can be no gravitational force. The contributions of individual particles to this relation are their "dispositions".[171]

---

[170] Excerpt from: *De Mundi Systemate Liber* (London, 1728), translated by Howard Stein, with his explanatory comments in brackets and his italics in "Newton's Metaphysics", 287-288.

[171] In the first of four letters to Bentley, Newton speaks of gravitating powers arising not from dispositions but from the quantities of matter. He writes, "Ye Motions wch ye Planets now have could not spring from any naturall cause alone, but were imprest by an intelligent Agent." After providing a number of reasons, including that no natural cause could put the planets in the same plane, Newton concludes, "To make this systeme therefore wth all its motions, required a Cause wch understood & compared together *the quantities of matter* in ye several bodies of ye Sun & Planets & *ye*

What are these dispositions? Newton does not attempt to say. One might say that each particle is disposed to attract other particles, should they exist. This would not amount to saying that gravity itself is inherent and essential to matter, since as a relation, the force itself cannot be the quality of any single particle. So the view that particles have the disposition to attract other particles would be consistent with Newton's remarks in Rule 3. Yet the view would invite the charge that matter acts distantly in Newton's system.[172] So if Newton classifies gravity as he does in Rule 3 precisely to avoid that charge, a possibility I raised earlier, then he would not accept this view, despite its consistency with his remarks in Rule 3. The question of what these dispositions could be is part of the vexing question of what the "physical causes and sites"[173] of gravity might be, which raises the question of whether the force is real.

The Question of Gravity's Status as a Force

Although Newton sets causal questions aside in the *Principia*, he nonetheless speaks of gravity as a force that meets *De Gravitatione*'s conception of a force as a causal principle. He speaks of the Earth holding the moon in its orbit, and in the 1713 General Scholium, he affirms that gravity "really exists", and "suffices for all the motions for the heavenly bodies".[174]

---

gravitating powers resulting from thence." (Newton's first letter to Bentley, December 10, 1692, *Correspondence of Isaac Newton*, 235; italics added.)

[172] Would a claim that matter can act distantly in turn undermine Newton's view of gravity as a relation? It might initially seem so, for the following reason. A force arises from some substance or substances, and Newton's condition for a substance's existence is that it be spatially located and extended. Moreover, spatial continuity seems required for a substance to be unitary. Although we may speak of air as a substance, even though it is made up of spatially separated particles, we still consider those particles to be numerically distinct, and we consider the Sun and Jupiter to be numerically distinct from one another, because of their spatial separation. We might therefore think that the gravitational force between any two particles can exist as the single, intermediate action that Newton describes only if it exists at each point between the bodies, from center to center, with no spatial gaps. Thus we might think that if matter acted distantly, with particle A exerting its attractive power upon B, and B doing the same upon A, there would be two distinct actions, rather than a single, mutual action. Yet upon reflection, this does not follow. Although particle A could exist if particle B did not, the force could not in that case exist. Since the force can arise only if there are at least two material particles in the universe, and since it cannot happen that the one particle is accelerated while the other is not, there are grounds for denying that in acting distantly, the particles are the sources of two distinct forces.

[173] This phrase is from Newton's explanatory remarks to Definition 8 (*Principia*, 407), as he cautions that his concept of force is purely mathematical.

[174] For a recent and influential discussion of the question of whether and why Newton considers gravity to be a real force, despite the incomplete understanding of it, see Janiak, "Newton and the Reality of Force". Janiak argues that

> Thus far I have explained the phenomena of the heavens and of our sea by the force of gravity [*Hactenus phaenomena coelorum & maris nostri per vim gravitatis exposui*], but I have not yet assigned a cause to gravity. Indeed, this force arises from some cause that penetrates as far as the centers of the sun and the planets without any diminution of its power to act….I have not as get been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses [*hypotheses non fingo*]….And it is enough that gravity really exists [*Et satis est quod gravitas revera existat*], acts according to the laws that we have set forth, and suffices for all the motions of the heavenly bodies and of our sea [*&ad corporum caelestium & mari nostri omnes sufficiat*].[175]

Yet as he notes in the passage, he has not been able discover gravity's causal workings. The *Principia* both proves that gravitational effects cannot be produced by impact (material contact action), and raises the possibility that the causal explanation could be a power of material particles to affect one another at distances, without any intermediary to convey the force by impact. Newton's qualifying remarks in the *Principia* underscore his belief that the physical problem has not been solved, which is to say that matter acting distantly is not the answer. And

---

Newton's "mathematical treatment of force" should not be understood as providing a mere calculating device, as Clarke erroneously represents Newton as doing, but as identifying a force whose "physical characterization" has not yet been specified. Janiak argues that Newton takes himself to have identified a real force, as opposed to a mere calculating device, because he has shown that (i) a wide range of phenomena that previously seemed disparate in fact have the same cause; (ii) mass and distance are the only salient variables in the causal chain; and (iii) gravity is not a mechanical cause in the commonly accepted sense of operating by surface action.

[175] This translation of the General Scholium passage, by Janiak, appears in his article, "Newton and the Reality of Force", 129. I concur with Janiak's conclusions that though Newton cannot provide the causal story, he nonetheless regards gravity as causally efficacious. In support of that view, Janiak notes that while the Cohen and Whitman translation says gravity "is sufficient to explain all the motions of the heavenly bodies", Newton's Latin lacks a correlate for the verb 'explain'. Janiak notes that his more literal translation, that gravity "suffices for all the motions", presents the force as causally efficacious:

> The translation of the text is my own. In *Principia*, Cohen and Whitman translate Newton's phrase, '*&ad corporum caelestium & mari nostri omnes sufficiat*' as follows: 'and is sufficient to explain all the motions of the heavenly bodies and of our sea'….The notion that gravity *explains* the motions of the heavenly bodies and of the sea may accurately reflect Newton's view, but the verb itself is missing from the original Latin….Cohen's translation in this particular case may reflect his interpretation of the General Scholium, and of Newton's view of force more generally. (Janiak, *ibid.,* 129.)

For purposes of comparison, I include the translation of the entire passage by Cohen and Whitman:

> Thus far I have explained the phenomena of the heavens and or our sea by the force of gravity, but I have not yet assigned a cause to gravity. Indeed, this force arises from some cause that penetrates as far as the centers of the sun and planets without any diminution of its power to act….I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses….And it is enough that gravity really exists and acts according to the laws that we have set forth and is sufficient to explain all the motions of the heavenly bodies and of our sea. (*Principia*, 943.)

in a letter written to colleague and theologian Richard Bentley several years after the *Principia*'s publication, he appears to reject the possibility of distant action out of hand.[176]

> 'Tis unconceivable that inanimate brute matter should (without ye mediation of something else wch is not material) operate upon & affect other matter without mutual contact….That gravity should be innate inherent & essential to matter so yt one body may act upon another at a distance through a vacuum without the mediation of any thing else by & through wch their action or force may be conveyed from one to another is to me…an absurdity.[177]

Since Newton has proved that the heavens are void of any material medium, he appears to be faced with the following options. First, he could abandon the second part of Kepler's quest, that of understanding the physical means by which gravitational effects are produced, and treat the mathematical solution to the problem about the orbits as complete. In other words, he could leave off being a natural philosopher by abandoning the search for causes, and wholly affirm the new physics of mathematical deducibility. He could then take the goal of physics to be that of prediction, and the forces of this physics as mere predictive tools.

Such an option does not figure in Newton's thinking, however. He remains a natural philosopher, and the business of natural philosophy is, as he later writes in Query 28 of the *Opticks*, is "to deduce Causes from Effects, till we come to the very first Cause, which certainly is not mechanical; and…to unfold the Mechanism of the World."[178] For Newton the world has been causally ordered by God, that first cause, who certainly is not mechanical, and the task ahead is to understand the world's causal workings, including the causal workings of the gravitational force.

Second, since Newton retains his commitment to causal explanations, he could accept that matter acts distantly. Since material bodies seem to affect one another, and yet there could

[176] I say that Newton *appears* to reject the possibility of action at distance because some commentators, in particular John Henry, deny that interpretation. I examine Henry's very different interpretation in my final chapter.

[177] Newton's fourth letter to Bentley, Feb. 25, 1692/3, *Correspondence of Isaac Newton*, 253-254.

[178] *Opticks,* 369.

not be a material medium to convey the effects, Newton might simply conclude that bodies can and do accelerate one another without contact or a medium, even across millions of miles of empty space. This option might mean (but perhaps need not require[179]) rescinding Rule 3's claim that gravity is not an essential power of matter. Although Newton seems, *prima facie*, to reject the option of matter acting distantly, it merits closer examination.

Third, if Newton both retains the commitment to causal explanations and rejects action at a distance, he might take gravitational effects to be produced by primary causation, by which I mean God's direct action. This contrasts with secondary causation, in which God brings about events through the causal mechanisms or means he has instituted in the natural world, which is to say the created world. To say that gravitational effects are produced by primary causation would be to say that as a natural force, gravity is unreal. The gravitational force would be real in the sense of being part of the divine force, but it would not be a real physical force.[180] From here onward, when I speak of a force being unreal, I shall mean that as a physical force it is unreal.

Finally, if Newton retains his commitment to causal explanations, his apparent denial of action at a distance, and an expectation that gravity is a physical force, a means of producing accelerations that belongs to the natural or created world, then he will seek some immaterial medium that could be part of the causal story. Newton might avoid action at a distance if the immaterial medium were continuous, but would have difficulty doing so if it were particulate.

Since Newton does not consider the first option, it remains to investigate the remaining three, which I begin to do in the next chapter.

---

[179] See also John Henry, "God and Newton's Gravity"; I discuss Henry's view in the final chapter.

[180] Again, my suggestion that God might qualify as a force is subject to a number of difficulties, as mentioned in an earlier footnote.

REFERENCES

Alexander, H.G., The Leibniz-Clarke Correspondence: Together with Extracts from Newton's Principia and Opticks, Manchester: Manchester University Press, 1956.

Brackenridge, Bruce: The Key to Newton's Dynamics: The Kepler Problem and the Principia, Berkeley: University of California, 1995.

Cohen, I. Bernard, "A Guide to Newton's Principia", with contributions by Michael Nauenberg and George E. Smith, in Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I.Bernard Cohen and Anne Whitman, Berkeley: University of California Press, 1999.

Cohen, I. Bernard, "Newton's concepts of force and mass, with notes on the Laws of Motion", in I. Bernard Cohen and George E. Smith (eds.), Cambridge Companion to Newton, Cambridge: Cambridge University Press, 2002, 57-84.

Collingwood, Robin G., "On the So-called Idea of Causation." Proceedings of the Aristotelian Society 38 (1938). Reprinted in A.B. Schoedinger (ed.), Introduction to Metaphysics: The Fundamental Questions, Buffalo, New York: Prometheus Books, 1991, 145-162.

DiSalle, Robert, "Newton's Philosophical Analysis of Space and Time", in I. Bernard Cohen and George E. Smith (eds.), Cambridge Companion to Newton, Cambridge: Cambridge University Press, 2002, 33-56.

Downing, Lisa, "Berkeley's Natural Philosophy and Philosophy of Science", in K. P. Winkler (ed.), The Cambridge Companion to Berkeley, Cambridge: Cambridge University Press, 2005.

Herivel, John, The Background to Newton's Principia; A Study of Newton's Dynamical Researches in the Years 1664-84, Oxford: Clarendon Press, 1965.

Holton, Gerald: "Johannes Kepler's Universe: Its Physics and Metaphysics", American Journal of Physics 24 (1956), 340-351.

Hulswit, Menno, "A Short History of Causation", accessed April, 2007, <http://www.library.utoronto.ca/see/SEED/Vol4-3/Hulswit.htm>, a short version of chapter 1 of From Cause to Causation. A Peircean Perspective. Dordrecht, Kluwer Publishers, 2002.

Janiak, Andrew, "Newton and the Reality of Force", Journal of the History of Philosophy, vol. 45, no.1 (2007) 127-147.

Lars-Göran Johasson, "An anti-Humean account of causation in classical physics", delivered at the confrence, CENSS2002 Causation and Explanation in Natural and Social Sciences, Ghent University, 15 - 18 May 2002, and accessed February, 2008, <http://logica.rug.ac.be/censs2002/abstracts/Johansson.htm>.

McGuire, J. E., "Force, Active Principles, and Newton's Invisible Realm", Ambix 15 (1968), 154-208.

McMullin, Ernan, Newton on Matter and Activity, Notre Dame: University of Notre Dame Press, 1978.

Newton, Isaac, The Mathematical Principles of Natural Philosophy (Philosophiae Naturalis Principia, 1726), trans. A. Motte (1729), with an introduction by I. Bernard Cohen, London: Dawson, 1968.

Newton, Isaac, *Opticks*, Or A Treatise of the Reflections, Refractions, Inflections & Colors of Light, based on the fourth edition of 1730, New York: Dover, 1952.

Newton, Isaac, Correspondence of Isaac Newton, ed. by H.W. Turnbull et al., Cambridge: Cambridge, 1959-1971.

Newton, Isaac, *Unpublished Scientific Writings of Isaac Newton*, ed. A.R. Hall and Marie Boas Hall, Cambridge: Cambridge University Press, 1962.

Newton, Isaac, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I.Bernard Cohen and Anne Whitman, Berkeley: University of California Press, 1999.

Newton, Isaac: Newton: Philosophical Writings, ed. Andrew Janiak, Cambridge: Cambridge University Press, 2004.

Stein, Howard, "Newtonian Space-Time", in Robert Palter (ed.), The Annus Mirabilis of Sir Isaac Newton, 1666-1966, Cambridge, Mass.: MIT Press, 1970, 258-284.

Stein, Howard, "Newton's Metaphysics", in Cambridge Companion to Newton, I. Bernard Cohen and George E. Smith (eds.), Cambridge University Press, 2002, 256-307.

CHAPTER IV

SUBSTANCE AND GRAVITY

What is Newton's ontology of substance, what hypotheses does he consider for gravity's "physical cause", and which of those explanations involve action at a distance?

As we saw previously, Newton considers his solution to the problem of the planetary orbits incomplete because he has not discovered the causal means by which gravity acts. In this chapter, I examine the substances in Newton's ontology, especially those that he thinks might figure in gravity's causal story. Most of the hypotheses I consider are candidates for gravity's "physical cause", which is to say that they involve natural (created) substances. However, I also examine the possibility that Newton attributed gravitational effects directly to God. I first examine Newton's concepts of these various substances, and I then consider the related hypotheses about gravity's cause.

SUBSTANCE: MATTER AND SPIRITS

Newton recognizes several kinds of substance. If we consider the features that he attributes to all substances generally, we notice both epistemological and metaphysical departures from the Cartesian Tradition. Descartes held that substances are known through the understanding, but for Newton an epistemological feature common to all substances is that they cannot be known directly. We have access only to properties, and so in keeping with his experimentalism, Newton writes that we can only infer substances: "We do not know the substances of things. We have no idea of them. We gather only their properties from the phenomena and from the properties [we infer] what the substances may be."[181] Metaphysically, Descartes' system is characterized by its sharp distinction between spirit and matter, with only inert matter being spatially extended. Newton, however, rejects this, arguing in *De Gravitatione* that a metaphysical feature common to all substances, including God and minds, is spatial location.

> No being exists or can exist which is not related to space in some way. God is everywhere, created minds are somewhere, and body is in the space it occupies; and whatever is neither everywhere nor anywhere does not exist. And hence it follows that space is an emanative effect of the first existing being.[182]

Newton's ultimate response to a third Cartesian claim is less clear. According to Descartes, matter can both resist and transfer motion by contact, but it cannot initiate motion; in McMullin's terms, matter cannot act in the "full agent sense". Does Newton follow Descartes in thinking that matter cannot initiate motion? This question has no straightforward answer. I shall continue to address it, as it is bound up with the question of whether Newton considered or perhaps accepted distant action by matter as gravity's causal means.

---

[181]Draft Conclusion for the General Scholium, MS. C (MS. Add 3965 fols. 361-362), *Unpublished Scientific Papers of Isaac Newton*, 360. Newton left this Draft Conclusion unpublished, replacing it with his far more compressed General Scholium. It is worth quoting the passage at greater length, since Newton is expansive in his point that we cannot know substance directly:

> We do not know the substances of things. We have no idea of them. We gather only their properties from the phenomena and from the properties [we infer] what the substances may be. That bodies do not penetrate each other we gather from the phenomena alone; that substances of different kinds do not penetrate each other does not at all appear from the phenomena. And we ought not rashly to assert that which cannot be inferred from the phenomena. We know the properties of things from phenomena, and from the properties we infer that the things themselves exist and we call them substances: but we do not have any more idea of substances than a blind man has of colors. From the phenomena alone we gather that bodies do not penetrate each other; that substances of different kinds do not penetrate each other is not evident from the phenomena….From the phenomena we know the properties of things, and from the properties we infer that the things themselves exist and we call them substances: be we do not have any idea of substances. We see but the shapes and colours of bodies, we hear but sounds, we touch but external surfaces, we smell odours and taste flavours; but we know the substances or essences themselves by no sense, by no reflex action, and therefore we have no more idea of them than a blind man has of colours. And when it is said that we have an idea of God or an idea of body, nothing other is to be understood than that we have an idea of the properties or attributes of God or an idea of the properties by which bodies are distinguished from God or from each other. (Draft Conclusion for the General Scholium, *Unpublished Scientific Papers of Isaac Newton*, 360-62.)

[182] *De Gravitatione*, *Philosophical Writings*, 25. Hall and Hall translate the passage as follows: "No being can exist which is not in some way related to space. God is everywhere, created minds are somewhere, and body is in the space it occupies. Whatever is neither everywhere nor somewhere does not exist. Hence it follows that space is an effect arising from the first existence of being." (*Unpublished Scientific Papers of Isaac Newton*, 136.)

Matter

In keeping with the rules of his experimental philosophy, Newton develops his concept of body or matter by trying to derive its characteristics from phenomena rather than reason. While he defines mass or quantity of matter, and attributes to all matter a set of properties he claims to have reached by induction, he does not define matter itself, considering its essential nature to be inaccessible to us. Yet as we will see here and especially in later chapters, Newton does have some ideas about what matter's essential nature might be, and even though he does not assert them, those ideas guide his investigations.

Mass

In accordance with the intention of presenting the mathematical principles of natural philosophy, stated in his Author's Preface,[183] the *Principia* does not define matter, but rather quantity of matter, that is, mass.

> Definition 1. *Quantity of matter is a measure of matter that arises from its density and volume jointly.* If the density of air is doubled in a space that is also doubled, there is four times as much air, and there is six times as much if the space is tripled. The case is the same for snow and powders condensed by compression or liquefaction, and also for all bodies that are condensed in various ways by any causes whatsoever. For the present, I am not taking into account any medium, if there should be any, freely pervading the interstices between the parts of bodies. Furthermore, I mean this quantity whenever I use the term "body" or "mass" in the following pages. It can always be known from a body's weight, for—by making very accurate experiments with pendulums, I have found it to be proportional to weight.[184]

[183] Author's Preface, appearing first in the 1687 edition: "Since we are concerned with natural philosophy rather than manual arts, and are writing about natural rather than manual powers, we concentrate on aspects of gravity, levity, elastic forces, resistance of fluids, and forces of this sort, whether attractive or impulsive. And therefore our present work sets forth mathematical principles of natural philosophy. For the basic problem of philosophy seems to be to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces. For in book 3, by means of propositions demonstrated mathematically in books 1 and 2, we derive from celestial phenomena the gravitational forces by which bodies tend toward the sun and toward the individual planets. Then the motions of the planets, the comets, the moon, and the sea are deduced from these forces, by propositions that are also mathematical. If only we could derive the other phenomena of nature from mechanical principles by the same kind of reasoning!" (*Principia*, 382.)

[184] *Principia*, 403.

This concept of mass is original to Newton, for unlike Kepler and Galileo, Newton distinguishes mass from weight, the two being merely proportional rather than identical. Two events enabled Newton to distinguish mass from weight.[185] One was a discovery made during Jean Richer's 1672-73 scientific expedition to Cayenne. Weight is not invariant across terrestrial locations, Richer found, but rather depends upon latitude. (In addition to leading Newton toward the concept of mass, this discovery is incorporated directly in the *Principia*. In Book III, Proposition 20, Problem 4, Newton sets the problem of comparing the weights of bodies located at different regions of the earth.) A second influential event came in 1680 with the appearance of a comet. In studying the comet, Newton concluded that it was affected not only by the sun but also by the planets, and that the effect must occur in virtue of their quantity of matter.

Because he is defining quantity of matter rather than matter itself, Newton sets aside questions about an aether. An aether with sensible resistance does not exist, as he proves in Book II. If there is an aether pervading the pores of bodies, it is too rare for its resistance to be detected, and it therefore can be set aside.

The Concept of Matter (Body)

Although Definition 1 is confined to mass, some other passages and other texts state the properties of matter that Newton has determined. He first develops a concept of body or matter in *De Gravitatione*, and that concept persists in later texts, including the *Principia*. The concept is strongly empirical and otherwise anti-Cartesian. Descartes derived his concept of matter *a priori*, claiming matter and other substances are known through the understanding, and he identified matter with extension. Whereas Descartes defined matter itself, Newton does not. We can sense hardness and mobility, but if matter has some "essential and metaphysical constitution"[186] it is not

[185] On both of these events, see Cohen, "Guide", 19-20.

[186] *De Gravitatione*, *Philosophical Writings*, 27. This a view that Newton may never have abandoned, for it is suggested by his remark in Query 31 that God might vary the laws of nature by varying the forces and properties of matter. One might object, however, by arguing that to vary the forces and properties of matter would be to create a

accessible to us. In general, Newton will write in a later text, we have access only to properties, and so we can only infer substances from the sensed properties.[187] This means that if we were presented with two substances, one of which was a material body and the other of which shared matter's sensible properties while differing in its essential and metaphysical constitution, we would be unable to distinguish them. Therefore, instead of saying what bodies are, *De Gravitatione* identifies the characteristics of the things that we call bodies. Such things have powers to produce sensations in us, are mobile and impenetrable, and are reflected according to certain laws.[188] And instead of associating properties as the Aristotelians did with prime matter—an inaccessible substrate that persists through qualitative changes—he associates sensed properties with determined regions of space. "It is not necessary that we suppose some unintelligible substance to exist in which as subject there may be an inherent substantial form….Extension takes the place of the substantial subject in which the form of the body is conserved by the divine will."[189] So the notion of prime matter is eliminated, producing a concept of body that is strongly empirical—but not fully so, as explained below.

Since bodies are considered as regions of space associated with sensed properties, they are not identical to extension as Descartes thought, but instead have the power to produce sensations

---

substance that is not matter. Also, some commentators would object to my suggestion that Newton's skeptical stance toward matter's essence extends past *De Gravitatione*; a number of commentators interpret the *Principia* as asserting the essential qualities of matter. (And here I intend a strong sense of 'essential', such that to be an entity of a given kind, the entity must possess the essential property. I am not referring to the Scholastic sense of 'essential' that I take Newton to mean in Rule 3, which is, in McMullin's terms, "intensity-invariant.") For a discussion of matter's essence in that stronger sense, see Janiak, *Newton as Philosopher*, 118-129.

[187] In his Draft Conclusion for the General Scholium, Newton writes, "We do not know the substances of things. We have no idea of them. We gather only their properties from the phenomena and from the properties [we infer] what the substances may be." (Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 360-362), *Unpublished Scientific Papers of Isaac Newton,* 360-361.)

[188] "We can define bodies as *determined quantities of extension which omnipresent God endows with certain conditions*. These conditions are: (1) that they be mobile...(2) that two of this kind cannot coincide anywhere, that is, that they may be impenetrable, and hence that oppositions obstruct their mutual motions and they are reflected in accord with certain laws; (3) that they can excite various perceptions of the senses...in created minds and conversely be moved by them." (*De Gravitatione*, *Philosophical Writings*, 28-29.)

[189] *De Gravitatione* in *Philosophical Writings*, 29. (The Halls' translation, *Unpublished Scientific Papers of Isaac Newton,* 140, is identical.)

in us.[190] (For this reason Newton considers his concept of body to be immune to the charge of atheism which he leveled at Descartes. Descartes' concept faces the charge because space is the one thing that can be conceived without God, whereas Newton thinks bodies have powers to cause sensations, which we cannot conceive apart from God.) And while extension is continuous, matter is particulate. The heavens are nearly void of matter, and aggregate bodies have interstices or pores, as Newton frequently remarks.

How can we infer the existence of the particles comprising aggregate bodies? Since the particles or "least parts of matter" are unobservable, we need grounds for believing that they exist, and for accepting the properties Newton will attribute to them. The 1713 edition of the *Principia* provides these grounds with Rule 3. This new rule of reasoning is a rule of induction, permitting the inference to the existence and properties of unobservable particles of matter.

> Rule 3. The qualities of bodies that cannot be intended and remitted [i.e., qualities that cannot be increased and diminished] and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally....The extension, hardness, impenetrability, mobility, and force of inertia of the whole arise from the extension, hardness, impenetrability, mobility, and force of inertia of each of the parts; and thus we conclude that every one of the least parts of all bodies is extended, hard, impenetrable, movable, and endowed with a force of inertia....Further, from phenomena we know that the divided, contiguous parts of bodies can be separated from one another, and from mathematics it is certain that the undivided parts can be distinguished into smaller parts by our reason. But it is uncertain whether those parts which have been distinguished in this way and not yet divided can actually be divided and separated from one another by the forces of nature. But if it were established by even a single experiment that in the breaking of a hard and solid body, any undivided particle underwent division, we should conclude by the force of this third rule not only that divided parts are separable but also that undivided parts can be divided indefinitely.[191]

So according to Rule 3, we can infer the existence of particles—the "least parts of

[190] Referring to Descartes, Newton writes, "Let us abstract from body (as he demands) gravity, hardness, and all sensible qualities, so that nothing remains except what pertains to its essence. Will extension alone then remain? By no means. For we may also reject that faculty or power by which they [the qualities] stimulate the perceptions of thinking things. For since there is so great a distinction between the ideas of thought and of extension that it is not obvious that there is any basis of connection or relation [between them], except that which is caused by divine power, the above capacity of bodies can be rejected while preserving extension, but not while preserving their corporeal nature." (*De Gravitatione*, *Philosophical Writings*, 33-34.)

[191] *Principia*, 796.

matter"—because we have experience of being able to separate bodies into parts, and mathematical divisibility enables us to conceive of those parts being further divided. Newton is uncertain about whether the particles of matter can be indefinitely, that is, infinitely divided.[192] Mathematical divisibility is unlimited, but mathematical truths alone provide only one constraint upon facts about the world; there could be others. Thus an experiment demonstrating the actual divisibility of a particle would, together with infinite mathematical divisibility, establish the infinite divisibility of particles, but absent such an experiment, Newton considers the question undecided.[193] Accordingly, Newton's suggestion in the *Opticks* that the "primitive particles" of matter are so hard that only God is able to divide them is speculative, which is why it is confined to a Query.[194] Newton also speculates there that these primitive particles are "permanent", and that change is explicable through "the various separations and new associations and motions" of these particles, not through their destruction.[195]

Rule 3 also sets out the properties of these particles, which appear to be qualitatively identical to one another.[196] The set largely agrees with that given in *De Gravitatione*. The particles have extension, hardness, impenetrability, mobility, and the force of inertia. The stated

---

[192] See Cohen, "Guide", for a view that there is no distinction between the concepts of indefinite and infinite divisibility.

[193] *Principia*, 796.

[194] It is "probable" that God formed particles so hard that "no ordinary power" can divide; see Query 31, *Opticks,* 400.

[195] See Query 31: "That Nature may be lasting, the changes of corporeal Things are to be placed only in the various separations and new Associations and Motions of these permanent Particles." (*Opticks*, 400.)

[196] On this point, see Westfall: "Matter was qualitatively neutral and homogeneous, differentiated solely by quantity." (*Force*, 346.) Still, Newton's remarks about the transformability of bodies raise some questions about whether he consistently takes all particles to be qualitatively identical. In Query 30, Newton suggests that light and matter might be tranformable into one another: "Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter into their composition? For all fixed Bodies being heated emit Light, so long as they continue sufficiently hot." (*Opticks*, 374.) This suggestion has an antecedent in Hypothesis III, which appears in the *Principia*'s first edition but is eliminated from the second and there replaced by Rule 3. (For a discussion of Newton's reasons for eliminating Hypothesis III, see McGuire, "Transmutation and Immutability: Newton's Doctrine of Physical Qualities".) Hypothesis III asserted that a body of any kind can be transformed into a body of any other kind: "Every body can be transformed into a body of any other kind whatever and endued successively with all the intermediate grades of qualities" (quoted in Westfall, *Force*, 388). Is Newton referring here to any body, including particles, or only to aggregate bodies? If the former, are we to think that there are intermediate grades of qualities between a particle of matter and a particle of light? If the latter, are light particles just particles of normal matter, and is that the reason that only aggregate bodies could pass through intermediate grades of qualities? We cannot answer these questions, because Newton is not certain about the nature of light.

basis for this inference is that (a) these properties cannot be intended or remitted, that is, they are immutable and cannot vary in intensity, and (b) they are known to belong universally to all bodies on which experiments can be made. We might question whether (b) justifies the inclusion of the *vis inertiae* on the list of inherent and essential properties, for we do not observe bodies moving inertially or resting (though some bodies appear to rest), without being subject to impressed forces. This raises questions about the extent to which the phenomena that Newton appeals to are in fact bound up with his theory. As for (a), we saw a problem with this condition earlier. Again, Newton closes his explanatory remarks to Rule 3 by emphasizing that while gravity is universal to matter, it is not inherent or essential to it. The suggestion made earlier was that Newton's apparent reluctance to believe that matter could act distantly might be behind his classification. For again, not all of the properties that he classifies as inherent and essential are in fact immutable; hardness was the problematic case discussed in chapter III.

By denying that gravity is inherent and essential to matter, Newton leaves open the possibility that bodies might gravitate in virtue of some immaterial substance that acts upon them—a possibility that would preserve the expectation that matter is passive. In a later chapter, I will consider what I shall call the 'principle of the passivity of matter' (PPM) more closely, arguing that (i) it means that matter can neither change its own state nor initiate new motion in other matter, and (ii) it is a metaphysical principle for Newton, since he lacks empirical grounds for it. However, I shall simply assume (i) throughout this chapter.

Why is Newton Drawn to the Principle that Matter is Passive?

Why does Newton even try to retain the claim that matter is passive in the sense of being unable to initiate action? One might argue, with McMullin, that the notion of active matter conflicts with Christianity's tenet that everything depends upon God for its existence; to say that matter can act in the full sense of initiating motion would amount to saying that it is independent of God. According to McMullin, this diagnosis of Newton's reasoning is supported by a remark from *De Gravitatione*: "We find almost no other reason for atheism than this notion of bodies having, as it were, a complete, absolute and independent reality in themselves...so that it is only verbally that we call bodies created and dependent."[197] Yet this particular remark does not support McMullin's diagnosis, as an examination of the passage containing it reveals. Throughout the passage in question, the notion that matter could be active is not Newton's target. While Newton is attacking Descartes' concept of body as a path to atheism, he does not mention activity. It is Descartes' identification of body with extension that implies that bodies could exist independently of God. Extension (space) has existed eternally, and so to identify body with extension is to imply that body is not dependent upon God, and could exist if God did not.[198] Space is the one thing we could conceive independently of God, since space would be the effect of any first existent, be that God or particle.

Yet McMullin has another reason for his diagnosis: "To locate the active principles responsible for motion in matter, as Leibniz did, was to make matter, once created, a self-sufficient entity."[199] This claim is more difficult to evaluate. On the one hand, no created thing is fully self-sufficient. All things are sustained by God to the extent that their continued existence requires his concurrence. And direct divine intervention would still be required for some

---

[197] *De Gravitatione*, Halls' translation (*Unpublished Scientific Papers of Isaac Newton,* 144.) The Halls' translation is the one that McMullin cites in *Newton on Matter and Activity*, however the translation by Johnson et al. (*Philosophical Writings,* 32) is identical for the quoted passage.

[198] In the Halls' translation, which McMullin cites, the passage reads as follows: "If we say with Descartes that extension is body, do we not manifestly offer a path to Atheism, both because extension is not created but has existed eternally, and because we have an absolute idea of it without any relationship to God, and so in some circumstances it would be possible for us to conceive of extension while imagining the non-existence of God?" (*Unpublished Scientific Papers of Isaac Newton,* 142-143). The translation by Johnson et al. does not differ significantly: "If we say with Descartes that extension is body, do we not manifestly offer a path to atheism, both because extension is not created but has existed eternally, and because we have an idea of it without any relation to God, and so in some circumstances it would be possible for us to conceive of extension while supposing God not to exist?" (*Philosophical Writings*, 31.)

[199] McMullin relies not only upon the passage from *De Gravitatione*, but also points to other influences: "The second consideration which may have influenced Newton in his decision to make matter as inert a principle as a consistent mechanics would allow was specifically theological in its inspiration. He believed the Christian doctrine of Creation to imply the total dependence of the world on God's activity, and he often tended to interpret this to mean that the activity in the world had to come directly from God, without any secondary intermediary. To locate the active principles responsible for motion in matter, as Leibniz did, was to make matter, once created, a self-sufficient entity….Cudworth in his *True Intellectual System of the Universe* (1678) argued against atomists and atheists (who find, he says, only "passive principles" in the universe) the need for active principles to explain the various sorts of change. Newton read and annotated this work and was undoubtedly influenced by it." (*Newton on Matter and Activity*, 54-55 and n.103.)

processes even if matter possessed active powers; for gravity alone is not sufficient to preserve the orbits without God's occasional intervention to reform them.[200] Yet Newton may not have thought that matter could be as independent of God as minds are.

Thus one possible reason that Newton is reluctant to believe that matter has active powers is that doing so would come too close to erasing the distinction between bodies and minds. Newton does not accept the Cartesian's sharp distinction between matter and spirits, as we will see shortly.[201] Yet he might still expect minds to be distinguished from bodies by their ability to initiate motion. In *De Gravitatione*, Newton suggests that when we move our bodies, we imitate God's power of creation; God makes certain region of space impenetrable by creating bodies to fill them, and we make certain regions of space impenetrable by moving existing bodies into those regions. To attribute active powers to "inanimate brute matter"[202] would amount to saying that bodies too can imitate God's power of creation in this way.

Spirits

Newton speaks about both perceiving spirits, namely God and minds, and non-perceiving spirits, namely the electric spirit and the aether. Newton is confident that God and minds exist; yet the other two spirits (if they are indeed two distinct spirits, for that is a point of controversy) remain speculative. (In an early text, he also speaks of light as a spirit, but later suggests that it consists in corpuscles, like all bodies.[203])

While Newton is influenced by the Cartesian distinction between matter and spirits, he does not sharply distinguish them by denying that they share any properties. For Descartes, matter is identical to extension, while spirits are unextended. Newton, however, takes spatial location to

[200] Query 31, *Opticks*, 402.

[201] On this point, see McMullin, *Newton on Matter and Activity*, 55.

[202] This phrase, contained in Newton's earlier-quoted letter to Bentley, actually originates with Bentley, in the letter to which Newton is responding. I discuss this in my final chapter.

[203] "All Bodies seem to be composed of hard Particles....Even the Rays of Light seem to be hard Bodies; for otherwise they would not retain different Properties in their different Sides." (Query 31, *Opticks*, 389.)

be a condition of existence, and he therefore considers not only matter but also spirits to be spatially located and extended. Descartes also takes matter to be passive, attributing activity to spirits alone; only spirits are capable of self-motion and the initiation (as opposed to transfer) of motion in bodies. Newton, however, as I argue in a later chapter, lacks the evidence to assert this view, though he is drawn to it.

Another similarity between matter and at least some spirits is that Newton expects them to be particulate. Vapors and exhalations appear to be particulate, as does the aether if it exists. It is extremely subtle, which is to say that its particles are very small,[204] and also extremely rare, which is to say that its particles are very few.[205] (Newton also refers to the magnetic "effluvia" as being "rare and subtile", but these are material.[206]) The nature of the electric spirit, on the other hand, is not always clear. At one point (in the Draft Conclusion), Newton says that it is continuous[207], while at some points (e.g., Query 22), he says it is "rare and subtile", terms he does

[204] In *De Gravitatione*, Newton tells us that for a fluid to be 'subtle' is for it to be divided: "If the aether were a corporeal fluid entirely without vacuous pores, however subtle its parts are made by division, it would be as dense as any other fluid." (*Philosophical Writings*, 35.)

[205] In *De Gravitatione*, Newton holds that an aether would have to have vacuous pores, for otherwise it would have inertial properties that would slow bodily motions, contra experience: "It should be observed from what was said earlier that there are empty spaces in nature. For if the aether were a corporeal fluid entirely without vacuous pores, however subtle its parts are made by division, it would be as dense as any other fluid, and it would yield to the motion of passing bodies with no less inertia; indeed with a much greater inertia if the projectiles were porous, because then the aether would enter its internal pores, and encounter and resist not only the whole of its external surface, but also the surfaces of all the internal parts. Since the resistance of the aether is on the contrary so small when compared with the resistance of quicksilver as to be over ten or a hundred thousand times less, there is all the more reason for thinking that by far the largest part of the aetherial space is empty, scattered between the aetherial particles." (*De Gravitatione* in *Philosophical Writings*, 35.)

[206] Newton follows Boyle in supposing the magnetic force to be communicated by some material effluvia. Concerning Boyle, see Boas: "Boyle, of course, recognized the existence of magnetic attraction, but he was convinced that it too could be explained mechanically, by means of the emission of corporeal effluvia from the loadstone." ("The Establishment of the Mechanical Philosophy, 480; Boas references Boyle, *Mechanical Production of Magnetism*, 1675; *Works* IV, 340-45.) To suppose that Newton too thought the magnetic effluvia to be a material conveyer of the force explains why he remarks in draft material for the *Principia,* "Magnetic force is communicated by contact; the other forces are not." For this remark, see A Draft Conclusion to the *Principia* (ULC MS Add. 3965, fols. 351-352; MS 3970, fols. 602-604, c. 1704–1712) translated by Cohen, "Guide", 287.

[207] See A Draft Conclusion to the *Principia*, *ibid.*, 292: "Hence also the heat of a body is most easily and most quickly propagated into contiguous bodies. For when the electric spirit that lies hidden in two bodies (a hot body and a cold body) becomes continuous through the contact of the bodies, its vibrations in the hot body will not be reflected at the common surface of the bodies but will be propagated into the second body through the continuous spirit."

not associate with those spirits that clearly are not particulate, God and minds.[208]

Still, all of these spirits differ from matter in some ways. God and minds lack hardness, impenetrability, and resistance.[209] God poses no resistance to bodies,[210] Newton writes, and the same should be true of minds, given that they are unified with bodies. The speculated spirits, including the electric spirit, the spirit or vapor emitted by comets (which, Newton suggests in the *Principia*, makes up the most subtle part of our air[211]), and the non-Cartesian aethers lack at least *sensible* resistance. The aether, if it exists, is particulate, but again, it is extremely subtle and rare. Indeed, the lack of sensible resistance is the reason that Newton excludes it from Definition

[208] The description appears in Query 22: "If any one would ask how a Medium [the very rare, elastic aether described in Queries 21-22] can be so rare, let him tell me how the Air, in the upper parts of the Atmosphere, can be above an hundred thousand times rarer than Gold. Let him also tell me how an electrick Body can by Friction emit an Exhalation so rare and subtile, and yet so potent, as by its Emission to cause no sensible Diminution of the weight of the electrick Body, and to be expanded through a Sphere, whose Diameter is above two Feet, and yet to be able to agitate and carry up Leaf Copper, or Leaf Gold, at the distance of above a Foot from the electrick Body? And how the Effluvia of a Magnet can be so rare and subtile, as to pass through a Plate of Glass without any Resistance or Diminution of their Force, and yet so potent as to turn a magnetick Needle beyond the Glass?" (*Opticks*, 353.) On the question of whether the electric spirit is particulate, see McMullin: "In the General Scholium there is no hint of the electric spirit's itself being particulate….In Query 22, however…the "exhalation" is represented in corporeal terms with some suggestion of its being particulate ('subtle' was most often used to emphasize the small size of constituent particles). Newton quite evidently moved easily from one to the other model, which is not too surprising since he regarded them both as quite speculative." (*Newton on Matter and Activity*, 149.)

[209] While this is so of God and minds, Newton speculates that other entities that he classifies as (non-perceiving) spirits might gain or lose resistance if they change "in respect of their forms". Thus Newton continues to speculate about the transformability of matter:

> Body I call everything tangible which is resisted by tangible things...Vapors and exhalations on account of their rarity lose almost all perceptible resistance, and in the common acceptance often lose even the name of bodies, and are called spirits. And yet they can be called bodies if they are the effluvia of bodies and have a resistance proportional to density. But *if the effluvia of bodies were to change thus in respect of their forms so that they were to lose all power of resisting* and cease to be numbered among the phenomena, these I would no longer call bodies, for I speak with the common people. (ULC, Add. 396, f. 437v, quoted by McMullin, *Newton on Matter and Activity*, 100, and identified by him as a definition of 'body' drafted for the *Principia*'s third edition but not ultimately included; my italics.)

Matter is resistive, but Newton appears here to be speculating that some material effluvia might lose that quality. Would the result be matter in a different form, or something immaterial? The passage in any case indicates the indistinct boundary between at least some matter and some spirits.

[210] "He is omnipresent not only virtually but substantially, for virtue cannot subsist without substance, the substance is already imagined. In him are all things contained and moved, yet God and matter do not interfere. God suffers nothing from the motions of bodies, and these suffer no resistance from the omnipresence of God." (Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 361-362), *Unpublished Scientific Papers of Isaac Newton*, 359-360.)

[211] In Book III, Proposition 41, Newton indicates that comets might supply the spirit needed for life on earth: "For the conservation of the seas and fluids on the planets, comets seem to be required, so that from the condensation of their exhalations and vapors, there can be a continual supply and renewal of whatever liquid is consumed by vegetation and putrefaction and converted into dry earth….the bulk of dry earth is increased from day to day, and fluids—if they did not have an outside source of increase—would have to decrease continually and finally to fail. Further, I suspect that that spirit which is the smallest but most subtle and most excellent part of our air, and which is required for the life of all things, comes chiefly from comets." (*Principia*, 926.)

1 of the *Principia*. (Of course, it remains possible that while the aether lacks *sensible* resistance, because it is so rare and subtle, its particles are nonetheless material, in which case it would have some resistance that we failed to sense; Newton does not claim to know the aether's nature, or whether it exists.)

Below, I examine three spirits, asking which Newton considers in seeking gravity's causal story. Before proceeding, a general problem should be noted. There will be no obvious means of providing a naturalistic explanation of gravitational effects that avoids action at a distance. If action at a distance is to be avoided, then the spirit would need to act by contact. (I will explain what action by contact amounts to in the final chapter.) Most of Newton's speculations about non-perceiving spirits suggest a particulate spirit rather than a continuous one. Moreover, the aether appears to act distantly, with the particles repelling one another. To invoke a further particulate medium to explain the apparently distant action of the first might invite a regress. Action at a distance could be eliminated via a continuous medium, and Newton does speak about the electric spirit as being continuous. Yet the notion of a continuous medium filling the heavens also does not seem to fit well with Newton's atomism, and it is even farther removed from sensible phenomena than is the (speculated) particulate aether, which is at least an extrapolation from sensible particulate media such as air.

God, the Infinite Spirit

Newton's God is the infinite spirit, the perfect, necessarily existing, active substance who created the world and continually sustains it. This active God is both the temporally first cause, but also the most fundamental level of explanation, as indicated by Newton's Query 31 remarks about the method of analysis. That method will lead us from motions to the forces producing them, "from particular Causes to more general ones, till the Argument end in the most general", and to the first cause, God.[212] Space is an "emanative effect"[213] of God, and as noted earlier, God poses no resistance to matter, though he is spatially extended: "In him are all things contained and moved, yet God and matter do not interfere. God suffers nothing from the motions of bodies, and these suffer no resistance from the omnipresence of God."[214]

In asserting that God is spatially extended, Newton departs from the prevailing view that God is only virtually omnipresent. On that prevailing view, God can be outside space and time, and thus not substantially omnipresent, while yet being omnipotent, for it is not God himself that is omnipresent but his *virtus* or active power. Aquinas explains this in part as the reach of God's knowledge—all things are subject to God's inspection—and in part by the reach of God's power. For the latter he gives this analogical example: "A king, for example, is said to be in the whole kingdom by his power, although he is not everywhere present."[215] On Newton's view, however, it is not only God's active power that is everywhere present, it is God himself, the divine substance: "He is omnipresent not only *virtually* but also *substantially*; for action requires

---

[212] Query 31: "By this way of Analysis we may proceed from…Motions to the Forces producing them; and in general, from Effects to their Causes, and from particular Causes to more general ones, till the Argument end in the most general. This is the Method of Analysis: And the Synthesis consists in assuming the Causes discover'd, and establish'd as Principles, and by them explaining the Phaenomena proceeding from them, and proving the Explanations....For so far as we can know by natural Philosophy what is the first Cause…so far our Duty towards him…will appear to us by the Light of Nature." (*Opticks*, 404-405.) Similarly, in Query 28, Newton asserts that that the business of natural philosophy is to use phenomena to deduce causes from effects, until one reaches "the very first Cause, which certainly is not mechanical". (*Opticks*, 369.) While Newton's references to God are clear, Cotes does not mention God when referring to Newton's expectation of compound causes being explained by simpler ones. See his preface to the 1713 edition of the *Principia*: "For causes generally proceed in a continuous chain from compound to more simple; when you reach the simplest cause, you will not be able to proceed any further. Therefore no mechanical explanation can be given for the simplest cause; for if it could, the cause would not yet be the simplest." (*Philosophical Writings*, 51.) A few other divergences may be found between Newton's writings and Cotes' preface; according to Westfall, *Never at Rest*, 749, Newton chose not to review Cotes' preface prior to publication.

[213] *De Gravitatione*, *Philosophical Writings,* 21. Space would be the effect of any first existent. God exists necessarily, and space is an emanative effect of this necessarily existing being. Newton also speaks of space as "an affection of every kind of being", which is to say that it is not peculiar to any kind of being, as the affection of thought is peculiar to minds, and motions to bodies. For a discussion of the ontology of space, including how Newton takes an affection to differ from both substances and attributes, see Janiak, *Newton as Philosopher*, 139-150.

[214] "He is omnipresent not only virtually but substantially, for virtue cannot subsist without substance, the substance is already imagined. In him are all things contained and moved, yet God and matter do not interfere. God suffers nothing from the motions of bodies, and these suffer no resistance from the omnipresence of God. By the same necessity he is always and everywhere the same. He is wholly like to himself." (Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 361-362), *Unpublished Scientific Papers of Isaac Newton,* 359-360.)

[215] Aquinas, *Summa Theologica*, I. 8. 3.

substance [*lit.* for active power [virtus] cannot subsist without substance.]"[216] Since God is present at the site of every effect, he is an obvious means by which Newton could give a causal explanation of gravitational effects without saying that matter acts distantly.

Newton is often described as a voluntarist, as he thinks God at least sometimes acts directly in the world. Most notably, God occasionally reforms the planetary orbits, Newton suggests in Query 31. The claim that God causes gravitational effects directly would be consistent with this understanding of God, but the scope of God's direct action—his primary causation—remains in question. I shall take up that question in the section about causal hypotheses for gravity's cause.

Minds

In *De Gravitatione*, Newton rejects Descartes' conception of mind on two grounds. Descartes takes the mind to be unextended, being only virtually present in the body, but this conception of mind fails Newton's existence condition, which is spatial location; Newton takes minds to be "diffused through space".[217]

Second, to hold that minds are unextended makes the interaction between mind and body unintelligible.

> If we say with Descartes that extension is body, do we not manifestly offer a path to atheism....Nor is the distinction between mind and body in his philosophy intelligible, unless at the same time we say that mind has no extension at all, and so is not substantially present in any extension, that is, exists nowhere; which seems the same as if we were to say that it does not exist, or at least renders its union with body thoroughly unintelligible and impossible.[218]

So Newton takes the mind to be substantially present, and if it is united with the body, then

[216] General Scholium, *Principia*, 941. The italics are Newton's.

[217] "Just as we understand the moment of duration to be diffused throughout all spaces, according to its kind, without any concept of its parts: so it is no more contradictory that mind also, according to its kind, can be diffused through space without any concept of its parts." (*De Gravitatione*, *Philosophical Writings*, 26.)

[218] *Ibid.*, 31.

substantially present in the body, though he does not claim to know the nature of the substance.[219] He does not claim to know how mind-body interaction works, but this mystery does not make parallelism a temptation; whereas a parallelist considers mind-body interaction to be merely an appearance, Newton takes it to be real. The mind, like God, is active, and able to move bodies: "We find in o^{r}selves a power of moving our bodies by o^{r} thought. Life & Will (thinking) are active Principles by w^{ch} we move our bodies, & thence arise other laws of motion unknown to us."[220] In *De Gravitatione,* Newton casts our ability to move our bodies as a analogue of God's activity of creating bodies; God makes certain areas of space impenetrable by creating bodies, and we make certain areas of space temporarily impenetrable to other bodies by moving our bodies into those areas of space. So we know that we can move our bodies, though we do not know the laws by which the mind can move the body.[221]

At various points, Newton attempts to determine the means by which the mind moves the body, suggesting in the General Scholium that it might be done by means of some further substance, an electric spirit.[222] Although minds are spatially extended, they sufficiently different from bodies, being penetrable and non-massive, that we may speak of a mind-body dualism. Yet

---

[219] Newton writes in *De Gravitatione*, "It would be rash to say what is the substantial foundation of minds" (translation by Stein in "Newton's Metaphysics", 281.) Stein takes this phrase, "the substantial foundation of minds", to refer to the mind-body problem of understanding the relation between mental attributes and corporeal ones: "When these relations are sufficiently understood, Newton implies, we may expect to know all that there is to know about the 'substantial foundation of minds'." (*Ibid.,* 282.)

[220] ULC, Add. 3970, fol. 619r, identified by McGuire as draft material for the *Optice* and quoted in "Force, Active Principles", 171.

[221] "The same question [about how God imparts] arises with regard to the way we move our bodies, and nevertheless we do believe that we can move them. If that were known to us, by like reasoning we should also know how God can move bodies, and expel them from a certain space bounded in a given figure…that is, cause that space to be impenetrable and assume the form of body…..but we only move bodies; and at that not any we choose, but only our own bodies, to which we are united not by our own will, but by divine constitution; nor can we move bodies in any way but only in accord with those laws which God has imposed on us." (*De Gravitatione*, *Philosophical Writings*, 29.)

[222] "A few things could now be added concerning a certain very subtle spirit pervading gross bodies and lying hidden in them; by its force and actions, the particles of bodies attract one another at very small distances and cohere when they become contiguous; and electrical [i.e. electrified] bodies act at greater distances, repelling as well as attracting neighboring corpuscles; and light is emitted, reflected, refracted, inflected, and heats bodies; and all sensation is excited, and the limbs of animals move at command of the will, namely, by the vibrations of this spirit being propagated through the solid fibers of the nerves from the external organs of the senses to the brain and from the brain into the muscles. But....there is not a sufficient number of experiments to determine and demonstrate accurately the laws governing the actions of this spirit." (*Principia,* 943-944.)

Newton's dualism does not produce the same conflict found in Descartes, since he does not assert that the quantity of motion in the world is preserved by contact transfer. In Descartes' system, the actions that minds induce in bodies appear to disrupt the quantity of motion in the world, which he takes to be constant. Newton, however, speculates (albeit forcefully) in Query 31 that the quantity of motion in the world is not constant, and that new motion must be introduced by some "active principles" to replace that which decays. Since he denies that the quantity of motion is constant, there is no difficulty in saying that minds introduce new motion when they act on bodies, changing the total quantity of motion in the world. Questions do arise, however, about Law 3 of the *Principia*. It is not clear whether Law 3 applies when the interacting substances are mind and body, and if so, what sort of reaction the body produces in the mind, and vice versa.[223]

Since the mind plays no part in Newton's attempts to explain gravity's physical cause, except indirectly as an example of something that is active and that acts locally, I will have no more to say about it. In the next section, I will discuss in more detail those substances that figure in Newton's attempts to discover gravity's "physical cause".

HYPOTHESES FOR GRAVITY'S CAUSE

Newton attempts to discover gravity's "physical cause" over a period of decades. The one hypothesis that he definitively rejects is a material, Cartesian aether having inertial properties. The other hypotheses that he might consider include primary causation, which is to say direct action by God; matter that has active powers and acts distantly; an immaterial natural medium such as the electric spirit or an aether; light; and some sort of "active principle". Since an active principle is not a substance, I reserve most of my discussion of it for later chapters, focusing here upon the other hypotheses mentioned. I begin with the hypothesis about God, turning afterward to the hypotheses about natural (created) substances.

[223] *Prima facie*, it seems that the laws of motion would not apply to minds, which are non-massive and impenetrable. For a discussion of such problems, see Alan Gabbey, "Newton, active principles, and the mechanical philosophy", 348-350. See also Liam Dempsey, "Written in the flesh: Isaac Newton on the mind–body relation". Dempsey argues that Newton took the power of moving the body to belong to the same class of forces as gravity and the electrical force.

God's Primary Causation

God is one obvious answer to Newton's question about what gravity's cause might be, and since God is omnipresent, it is an answer that would avoid action at a distance. Yet this answer would imply that gravity's cause is not physical;[224] bodies do not really accelerate one another in proportions dependent upon their masses and distance, but are instead predictably moved according to those proportions by God.[225] So according to this answer, gravity considered as a physical force is unreal.

Our question in this section is not whether Newton accepts primary causation at all. He clearly thinks that God acts directly in the world at least sometimes. The basis of Leibniz's complaint that Newton's God is like an imperfect watchmaker, for instance, is Query 31's remark that God directly reforms the planetary orbits: "Some inconsiderable Irregularities...may have risen from the mutual Actions of Comets and Planets upon one another, and...will be apt to increase, till this System wants a Reformation."[226] Our question, then, is about the extent of God's primary causation. We want to know whether the range of God's direct action includes ordinary gravitational effects.

Several passages from some unpublished manuscripts suggest that Newton does take God to cause the planetary orbits by direct and continual action, or at least considers the hypothesis very seriously. The most striking passage is one written in the1690's. There, Newton denies that spatially separated bodies can attract one another except by the mediation of some "active

[224] How to understand this term (and to do so while avoiding anachronism) is a question. The physical cannot be distinguished from the non-physical by a spatial criterion, for instance, since Newton takes God and minds to be spatially extended. Is the physical then that which is empirically accessible? Presumably not, since Newton considers the design of beasts and other phenomena to constitute empirical evidence for God.

[225] Predictability has its limits, of course. Newton writes that due to universal gravitation, the planets trace new orbits with each revolution, and understanding the full complexity of those orbits is "beyond human wit." See *De Motu Corporum* (translated as *On the Motion of Bodies*): "Each time a planet revolves it traces a fresh orbit, as happens also with the motion of the Moon, and each orbit is dependent upon the combined motions of all the planets, not to mention their actions upon each other. Unless I am much mistaken, it would exceed the force of human wit to consider so many causes of motion at the same time and to define the motions by exact laws which would allow of an easy calculation." (*Unpublished Scientific Papers of Isaac Newton*, 280-281.)

[226] Query 31, *Opticks*, 402 (but Query 23 in the edition upon which Leibniz was commenting). As H. G. Alexander notes, Newton's suggestion here was the probable provocation to Leibniz's charge, in his 1715 Letter 1, that Newton's God is like an imperfect watchmaker; see *Leibniz-Clarke,* 11, n.*a*.

principle" that propagates the force; and ascribing that view to the ancients with clear approbation, he suggests that that active principle might be God.

> For two planets separated from each other by a great expanse of void do not mutually attract each other by any force of gravity or act on each other in any way except by the mediation of some active principle that stands between them by means of which force is propagated from one to the other. [According to the opinion of the ancients, this medium was not corporeal since they held that all bodies by their very natures were heavy and that atoms themselves fall through empty space toward the earth by the eternal force of their nature without being pushed by other bodies.] Therefore the ancients who grasped the mystical philosophy more correctly taught that a certain infinite spirit pervades all space, and contains and vivifies the entire world; and this supreme spirit was their numen; according to the poet cited by the Apostle: In him we live and move and have our being. Hence the omnipresent God is recognized, and by the Jews is called 'place'. To the mystical philosophers, however, Pan was that supreme numen...By this symbol, the philosophers taught that matter is moved in that infinite spirit and by it is driven, not at random, but harmonically, or according to the harmonic proportions as I have just explained.[227]

Another suggestive assertion is a revision that Newton drafted for the *Principia*'s Proposition 6, a proposition asserting that all bodies gravitate toward each of the planets.[228] An ultimately unpublished corollary reads as follows: "Corol. 9. There exists an infinite and omnipresent spirit in which matter is moved according to mathematical laws.'"[229]

A number of commentators have appealed to passages such as the above in defense of the claim that Newton attributed all gravitational effects to God. The variants of this position include both the claim that Newton consistently attributed to God all effects involving forces that appear to act across distances, and claims of more limited scope. Richard Westfall concludes that privately, Newton believed that God caused the planetary motions directly, and that therefore the

---

[227] ULC Ad. 3965.6 f.269, quoted in Westfall, *Force*, 397-98. McGuire dates this passage to "a manuscript probably related to the "classical" scholia of the abortive 1690's edition of the *Principia*." See McGuire, "Force, Active Principles", 196.

[228] In the third edition, Proposition VI of Book III reads, "All bodies gravitate toward each of the planets, and at any given distance from the center of any one planet the weight of any body whatever toward that planet is proportional to the quantity of matter which the body contains." (*Principia*, 806.)

[229] See Westfall: "Among the new corollaries to Proposition VI that he planned was a direct assertion of God's causative role: 'Corol. 9. There exists an infinite and omnipresent spirit in which matter is moved according to mathematical laws.'" (*Never at Rest*, 509, and quoting Newton, ULC, *Add MS* 396.6, f. 266v.)

gravitational force was not real.[230] Westfall relies in particular upon the first passage quoted above, but also takes the planned but ultimately unpublished corollary as reason to think Newton assigned ordinary gravitational effects to primary causation. Betty Jo Teeter Dobbs also attributes a consistent private view to Newton, and one that implies that as a physical force, gravity is unreal. Yet she does not read Newton as obviously attributing gravitational effects directly to God; more probably he attributes them to Christ. Drawing upon Newton's alchemical writings, Dobbs argues that Newton consistently denied that matter could be active, and that he is best understood as taking all forces, spirits, or principles to be the work of "God's viceroy, the Christ."[231] According to Dobbs then, God's providential action could be indirect, in that God could be acting through a divine spirit or through Christ as his agent.[232]

J.E. McGuire's view is similar to Westfall's, but he limits the scope by time. Newton attributed all effects associated with distance forces to God during the post-*Principia* period (i.e.,

---

[230] On the basis of ULC Ad. 3965.6 f.269 (see note above), Westfall concludes that Newton did not consider (distance) forces to be real: "From the point of view of Newton's ultimate metaphysics, then, forces were no more real entities in the universe than they were from the point of view of orthodox mechanical philosophy. In the one case, apparent attractions and repulsions were the effects of invisible mechanisms, aetherial effluvia of one sort or another which pushed bodies about and created the appearance of attractions and repulsions. In the other case, they were the effects of an incorporeal medium, the infinite God who, in His sensorium, controls and moves the material world even as we control and move our bodies. As Newton said in the General Scholium, 'a being, however perfect, without dominion, cannot be said to be Lord God.' Dominion his God assuredly had—every movement in the world was the immediate effect of His power." (Westfall, *Force*, 398.) See also *Force*, 400: "He had abandoned the mechanisms of a material aether in favour of the Divine Medium who moves bodies as though they attract each other according to mathematical laws."

[231] See Dobbs: "The alchemical process...he saw...as the epitome of God's providential, nonmechanical action in the world.....The 1674 treatise on vegetation, in which Newton makes explicit the relationships between vegetable and mechanical chemistry, makes it possible to trace an evolutionary process in which alchemy and corpusculareanism interact to produce his published theory of matter....The active principles that operate between and among the small particles of matter in the *Opticks* are identical with those that so operate in the alchemical papers. Whether they be called forces, virtues, media, principles, or spirits, and whether they operate by corporeal or incorporeal means...is in the end only of secondary importance, for activity requires divinity, and nonmechanical action indicates the presence of the divine in the natural order. Universal gravity demonstrates the omnipresence of God the Father; vegetable actions in micromatter indicate continuing supervision of the world by God's viceroy, the Christ. But now perhaps Newton has finally said enough for us to grasp his meaning...'And thus much concerning God; to discourse of whom from the appearances of things does certainly belong to Natural Philosophy.'" ("Newton's Alchemy and His Theory of Matter", 528.)

[232] Dobbs writes, "Whether they [the active principles] be called forces, virtues, media, principles, or spirits, and whether they operate by corporeal or incorporeal means...is in the end only of secondary importance, for activity requires divinity, and nonmechanical action indicates the presence of the divine in the natural order.") In keeping with these priorities, Dobbs allows that the divine action could be indirect, but she holds that even an indirect cause would have to be a divine spirit or agent: "When Newton said 'active' in his discussions of forces, we really should understand that a divine spirit is at work either directly or indirectly." (*Ibid.,* 526.)

the 1690's), he argues, but by 1705 sought an explanation within the natural order.[233] From the time of the second English edition of the *Opticks*, in 1706, McGuire argues, Newton shifted toward the view that God employed secondary causation more, with natural agents being the source of much activity.[234] All of these views take Newton to deny that matter could be active or act distantly, but another commentator takes a different view. Joan Hawes takes Newton to attribute some effects consistently to primary causation, but she limits the scope of God's direct action by the type of force or phenomena. She argues that Newton consistently attributed gravitational effects to God, but allowed action at a distance for certain electrical effects, as we shall see in a subsequent section.

It seems clear that Newton seriously considered the hypothesis that gravitational effects are produced directly by God, yet the texts indicate that he considered the force to be real. Here I

---

[233] See McGuire: "Newton is against any form of mechanical or fluid aether on grounds of reason and evidence. Thus, though he remained interested in the possibility of a mechanical explanation of gravity, he seemed more inclined to think that it was a manifestation of the Divine presence in nature. By the end of the 1690's, his ideas began to crystallize in favour of the latter opinion.....In draft scholia intended for Proposition IV to IX of the Third Book of the *Principia*, Newton hoped to show that the ancients had anticipated the doctrines contained in these Propositions….these scholia were used to establish four basic theses which Newton attributed to antiquity: that matter is atomic in structure and moves by gravity through an infinite void; that gravitational force acts universally: that its action diminishes as the inverse square of the distance between bodies: and that God's direct action is the true cause of gravity. This material confirms our interpretation of Newton's opinion regarding the causative nature of gravity in the nineties, namely, God himself who is ubiquitously present in space." ("Force, Active Principles", 163-164.) McGuire continues this thread of argument in subsequent pages: "In a manuscript probably related to the 'classical' scholia of the abortive 1690's edition of the *Principia*, Newton was quite unambiguous about the status of active principles....In this passage, which strongly emphasises the existence of divinity in nature, Newton unmistakenly refers to God, as the cause of the 'force of gravity', by means of the term 'active principle'.....In 1705 in a draft for Query 23 of the *Optice*, he still exclusively used the term in referring to God: 'Life and will are active principles' and 'if there be an universal life and all space be the sensorium of a thinking being...then laws of motion arising from life or will may be of universal extent.' Without doubt Newton's voluntarist theology is to the fore." (*Ibid.,* 195-196. Here McGuire is commenting upon ULC Ad. 3965.6 f.269, in which Newton writes, "By this symbol, the philosophers taught that matter is moved in that infinite spirit and by it is driven, not at random, but harmonically".)

[234] McGuire's chronology of the periods during which Newton favored natural hypotheses, as opposed to occasionalism, may be found in "Force, Active Principles". According to McGuire, Newton tended to attribute gravitational effects directly to God during the period following the *Principia*, from the 1690's to just 1705 (i.e., until just before the 1706 *Optice*, which included an expanded number of queries, including Query 23, which would become Query 31 in the 1717/18, second English translation which contained still more queries). During these years, McGuire argues, Newton tended to attribute gravitational effects directly to God because Newton at this time emphasized void space. Subsequently, McGuire argues, during the period from the 1716 *Optice* to 1718, the time of the second English edition of the *Opticks*, Newton restricted the scope of God's direct action, attributing more phenomena, including most gravitational effects, to God's secondary causes, natural agents. As a voluntarist, Newton still held that God sometimes acts directly, via his *potentia absoluta*, for instance when he acts occasionally to reform the orbits, as Newton asserts in Query 31. During this later period, McGuire argues, Newton was strongly influenced by chemical phenomena as he tried to explain the small forces of nature operating at the level of unobservable particles (and also considered explanations of those forces in terms of electricity, magnetism, and light.) McMullin, however, rejects McGuire's "neat periodization", arguing that Newton never repudiated any of the explanatory models he considered, and continued to explore all of them; see McMullin, *Newton on Matter and Activity*, 79.

intend the first of the two senses I distinguished in the previous chapter, such that a real force is due to secondary rather than primary causation.[235] Even during the post-*Principia* period, Newton repeatedly treats the gravitational force as something that requires nothing more than divine concurrence, and operates independently of God. This is indicated by his response to a question about whether the gravitational force could lead to collapse. Once people came to accept an attractive force between the sun and the planets, a question arose about the "fixed stars"—fixed because the stars were believed to lack the planets' transverse motions.[236] Why does the universe not collapse—why are the fixed stars and the sun not pulled together by the gravitational force? Newton replies to this question in several ways, all of which imply that the gravitational force is real. When Bentley raises this question to Newton in 1692, Newton explains that the system will not collapse so long as space is infinite.[237] (He reiterates this explanation in the General Scholium,[238] writing that God has placed the stars at immense distances from one another to

---

[235] As noted in chapter III, I also defend the view that Newton takes the gravitational force to be real in the second sense of having genuine causal efficacy. In a subsequent chapter, I present textual evidence in favor of the view that Newton considered the gravitational force to be causally efficacious, rather than the mere instrumental device that Berkeley took it to be. As noted previously, I do not address the question of *how* Newton could hold that view. Andrew Janiak addresses that question in chapter 3 of *Newton as Philosopher*, and in "Newton and the Reality of Force".

[236] See, for example, the Phenomena at the beginning of *Principia*, Book III, which mention the fixed stars. Phenomenon 1, for example, states, "The circumjovial planets [or satellites of Jupiter], by radii drawn to the center of Jupiter, describe areas proportional to the times, and their periodic times—the fixed stars being at rest—are as the 3/2 powers of their distances from that center." (*Principia*, 797).

[237] In his first letter to Bentley, December 10, 1692, Newton writes that collapse would happen only in a finite space, not in an infinite one: "If the matter of our Sun & Planets & all ye matter in the Universe, were evenly scattered throughout all the heavens, & every particle had an innate gravity towards all the rest & the whole space throughout wch this matter was scattered, was but finite; the matter on ye outside of this space would by its gravity tend towards all ye matter on the inside & by consequence fall down into the middle of the whole space & there compose one great spherical mass. But if the matter was evenly diffused through an infinite space, it would never convene into one mass but some of it would convene into one mass & some into another so as to make an infinite number of great masses scattered at great distances from one to another throughout all yt infinite space. And thus might ye Sun and Fixt stars be formed supposing the matter were of a lucid nature. But how the matter should divide it self into two sorts & that part of it wch is fit to compose an opake body, should coalesce, not into one great body like ye shining matter but into many little ones...I do not think explicable by mere natural causes, but am forced to ascribe it to ye counsel and contrivance of a voluntary Agent." (*Correspondence of Issac Newton*, 234.)

[238] "So that the systems of the fixed stars will not fall upon one another as a result of their gravity, he [God] has placed them at immense distances from one another." (General Scholium, *Principia*, 940.) In Query 28, Newton infers the existence of a designer from the fact that the stars do not aggregate together. He does not tell us whether collapse is prevented through direct or indirect action, but again the gravitational force is implied to be something distinct from divine action, in that some of its effects may need to be countered by divine action: "What hinders the fix'd Stars from falling upon one another?....Does it not appear from Phenomena that there is a Being incorporeal, intelligent, omnipresent?" (Query 28, *Opticks*, 369-370.)

prevent their collapse under gravity, and again in Query 28.) If God were producing all gravitational effects, directly, then the lack of collapse would be explained simply by God's will, not by any feature of the universe. Thus by saying that the stars do not collapse into the sun because they are in infinite space, Newton implies that there is a real force of attraction between the bodies. Another of Newton's replies is recorded in David Gregory's 1694 *Memoranda* from his conversations with Newton. Gregory attributes to Newton the claim "that a continual miracle is needed to prevent the Sun and the fixed stars from rushing together through gravity".[239] If we can accept the veracity of the *Memoranda*, Newton is again implying a distinction between the gravitational force, which could cause the system to collapse absent divine action, and the divine action that does in fact prevent it. If there were no physical force of attraction among the bodies, and instead only God's action, no such distinction would need to be drawn. In short, if God were moving the celestial bodies directly, he would not need to *prevent* collapse; he would simply need to refrain from pushing the stars into the sun. Even during the 1690's, then, the period to which McGuire's chronology dates Newton's strongest attraction to the primary causation hypothesis, Newton takes the gravitational force to operate independently of God.[240]

There are other indications that Newton limits the extent of primary causation. The following excerpt from the 1694 Gregory *Memoranda* suggests that in the usual course of events, God merely sustains or cooperates with the secondary causes he has instituted, acting directly only relatively rarely: "And [God is] constantly co-operating with all things according to accurate laws, as being the foundation and cause of the whole of nature, except where it is good to act otherwise."[241] And in a 1692 letter to Bentley, Newton explains that the planetary orbits

---

[239] 446 Memoranda of David Gregory, 5, 6, 7 May 1694, *Correspondence of Isaac Newton*, Latin original at 3:334 and translation at 3:336. Interestingly, the notion that there could be a continual miracle is at odds with the notion of a miracle found in Clarke's letters; since all activity derives from God, Clarke classifies unusual events as miracles, and regular events as natural.

[240] Once again, by 'independent' I mean that it requires nothing more than that required by all natural phenomena, namely, God's concurrence.

[241] David Gregory MS. 245, fol. 14a, Latin original published in Crauford Gregory's article, "Notice concerning an autograph manuscript of Isaac Newton", and quoted by McGuire, "Force, Active Principles", 190.

could not result from "natural cause *alone*" (my emphasis), since, among other things, the planets lie in the same plane. He then continues,

> To make this systeme therefore wth all its motions, required a Cause wch understood & compared together *the quantities of matter* in ye several bodies of ye Sun & Planets, *& ye gravitating powers resulting from thence*.[242]

This remark—"gravitating powers" result from the "quantities of matter"—is again suggestive of secondary rather than primary causation.

The view that in the normal course of events, the planetary system is self-sustaining, via secondary causation, is again evident in this unpublished letter, c. 1712.

> Certainly God could create planets that should move round of themselves without any other cause than gravity that should prevent their removing through the tangent. For gravity without a miracle can keep the planets in. And to understand this without knowing the cause of gravity, is as good a progress in philosophy as to understand…the frame of the bones and muscles and their connection in the body of an animal and how the bones are moved by the contracting or dilating of the muscles without knowing how the muscles are contracted or dilated by the power of the mind, is [in] the philosophy of animal motion.[243]

Newton reiterates this position in the 1713 General Scholium, writing, "They will indeed persevere in their orbits by the laws of gravity." So while the planets acquired their co-planar positions through divine action, this is not the means by which they maintain those positions and orbits. Finally, the General Scholium contains a remark that bears on a passage to which Westfall appeals in supporting the primary causation hypothesis. Newton at one point speaks of space as God's "sensorium", and in the General Scholium he writes, "In him all things are

---

[242] The first letter to Bentley, December 10, 1692, *Correspondence of Isaac Newton*, 235.

[243] Newton to the Editor of the *Memoirs of Literature*, unpublished, written c. May 1712, *Philosophical Writings*, 116-117. This passage is a bit tricky because of Newton's use of the word 'miracle'. Samuel Clarke, the expositor of Newton's position in the *Leibniz-Clarke Correspondence*, rejects Leibniz's notion of a miracle as direct action by God, countering that all events are caused directly by God, and thus the term 'miracle' simply refers to the unusual events among them. Yet we cannot assume that Clarke always represents Newton's own views, and in this letter Newton rejects the view that gravity is due to primary causation, for he says that its cause is unknown.

contained and move, but he does not act on them nor they on him."[244] This supports a literal reading of Newton's draft Corollary, which reads, "There exists an infinite and omnipresent spirit in which matter is moved according to mathematical laws."[245] While it does assert the existence of God, this statement says that matter is moved *in* that spirit, not *by* it.

Thus I reject the view that Newton attributed gravitational effects to primary causation, and I reject both the limited and the broad versions of the view. In his specific discussions of the gravitational force, Newton treats it as real, and in general he tends toward thinking God works largely through secondary causation.[246] One reason that Newton might be hesitant to attribute gravitational effects to God's direct action is that doing so would significantly limit the domain of secondary causation. As we will see in the next chapter, Newton classifies not only gravity but also a vast range of phenomena as "new motions". Therefore, if Newton attributed gravitational effects directly to God, there would be no reason to conceive of other sources of new motion differently; it would instead make sense to attribute all new motions to primary causation. This would leave very little to secondary causation, saddling God with all the mundane chores of the world. The view that God often works through secondary causes creates a pressure to deny that gravitational effects are produced by primary causation.

Active Powers in Matter

Does Newton attribute active powers of attraction and repulsion to matter, including the power of gravitational attraction? Such an attribution would mean abandoning the principle of the passivity of matter and also allowing action at a distance. In this section I consider texts in

---

[244] General Scholium: "He is omnipresent not only *virtually* but also *substantially*; for action requires substance. In him all things are contained and move, but he does not act on them nor they on him. It is agreed that the supreme God necessarily exists, and by necessity he is *always* and *everywhere*." (*Principia*, 940-942.)

[245] Newton's draft Corollary, from ULC, *Add MS* 396.6, f. 266v, is discussed by Westfall: "Among the new corollaries to Proposition VI that he planned was a direct assertion of God's causative role: 'Corol. 9. There exists an infinite and omnipresent spirit in which matter is moved according to mathematical laws.'" (*Never at Rest*, 509.)

[246] Newton's letter to Burnet, 1680-81: "Where natural causes are at hand God uses them as instruments of his work." (*Correspondence of Isaac Newton*, 2.334 and quoted in McGuire, "Force, Active Principles", 206.)

which he initially appears to allow this, and I argue that despite those appearances, he at most allows the possibility that such powers belong directly to particles, such that no intermediary is needed for affecting other, spatially removed matter. (In the final chapter, I consider the narrower proposal that Newton accepts active powers as inessential properties of matter.)

Although Newton appears in his letter to Bentley to reject the notion that distant bodies could causally interact without a medium, in some texts he appears to attribute forces directly to matter. In the unpublished *Conclusio* (c. 1687), for instance, he suggests, "Almost all the phenomena of nature will depend on the forces of particles, if only it be possible to prove that forces of this kind do exist."[247] Newton again attributes forces directly to particles in *De Natura Acidorum*, c. 1692: "The particles of acids are coarser than those of water and therefore less volatile; but they are much finer than those of earth, and therefore much less fixed than they. They are endowed with a great attractive force and in this force their activity consists by which they dissolve bodies and affect and stimulate the organs of the senses."[248] And Query 31 opens by suggesting that particles have powers or forces, by which they act at a distance: "Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phenomena of Nature?"[249]

Yet the passage does not end there, as we shall see shortly, and in general, there are difficulties in supposing that Newton is allowing that the causal interaction between the spatially

---

[247] *Unpublished Scientific Papers of Isaac Newton*, 345.

[248] "The particles of acids are coarser than those of water and therefore less volatile; but they are much finer than those of earth, and therefore much less fixed than they. They are endowed with a great attractive force and in this force their activity consists by which they dissolve bodies and affect and stimulate the organs of the senses. They are of a middle nature between water and [terrestrial] bodies and they attract both. By their attractive force they surround the particles of bodies by they stony or metallic, and they adhere to them very closely on all sides, so that they can scarcely be separated from them by distillation or sublimation. When they are attracted and gathered together on all sides they raise, disjoin and shake the particles of bodies one from another, that is, they dissolve the bodies; and by their force of attraction by which they rush to the [particles of] bodies, they move the fluid and excite heat and shake asunder some particles to such a degree as to turn them into air and generate bubbles: and this is the reason of dissolution and violent fermentation." (*De Natura Acidorum*, c. 1692 in *Newton: Texts, Backgrounds, Commentaries*, 312.)

[249] Query 31, *Opticks*, 375-376.

separated particles takes place without any spatial intermediary, such as God or an immaterial medium. One problem is that these seeming attributions of active powers to matter are counterbalanced by suggestions that matter is passive. Newton's 1693 description of matter as "inanimate" and "brute" is echoed in draft material for the 1706 *Optice*, where Newton writes that matter is a "passive principle", and that Bodies "alone considered" are passive.

> Matter is a passive principle & cannot move itself. It continues in its state of moving or resting unless disturbed. It receives motion proportional to the force impressing it, and resists as much as it is resisted.[250]
>
> For Bodies (alone considered as long, broad & thick...) are passive. By their vis inertiae they continue in their state of moving or resting & receive motion proportional to ye force impressing it & resist as much as they are resisted; but they cannot move themselves; & without some other principle than the vis inertiae there could be no motion in the world.[251]

Similarly, while Query 31 opens by seemingly attributing active powers to particles, it refrains from attributing active powers directly to matter, attributing only the *vis inertiae* directly to matter. There must be some active principle, he writes, for by the *vis inertiae* alone, "there never could have been any motion in the world".[252] And while the particles "have" the passive principle

[250] ULC, Add. 3970, fol. 619r, written in English and quoted by McGuire in "Force, Active Principles", 170-171, and identified by him as draft variants of 1706 *Optice*. As the passage continues, Newton points to life and will as active principles, in contrast to matter: "These are passive laws & to affirm that there are no other is to speak against experience. For we find in o[r]selves a power of moving our bodies by o[r] thought. Life & Will (thinking) are active Principles by wch we move our bodies, & thence arise other laws of motion unknown to us." (*Ibid.*)

[251] ULC Add. 3970, folls. 255r-256r, draft variants of 1706 *Optice*, in McGuire, *ibid*. The more extended passage (from ULC, Add. 3970, fol. 620r) closes with a vitalist suggestion: "If there be another Principle of motion there must be other laws of motion depending on that Principle. And the first thing to be done in Philosophy is to find out all the general laws of motion (so far as they can be discovered) on which the frame of nature depends....We find in o[r]selves a power of moving our bodies by o[r] thoughts (but the laws of this power we do not know & see y[e] same power in other living creatures but how this is done & by what laws we do not know. And by this instance & that of gravity it appears that there are other laws of motion (unknown to use) than those wch arise from Vis inertiae (unknown to us) wch is enough to justify & encourage o[r] search after them. We cannot say that all nature is not alive." (*Ibid.*)

[252] "The *Vis inertiae* is a passive principle by which Bodies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the world. Some other Principle was necessary for putting bodies into Motion; and now they are in Motion, some other Principle is necessary for conserving the Motion." Query 31, *Opticks*, 397.)

of the *vis inertiae*, they "are moved by" active principles.[253] This allows that the active principle does not belong to matter, but is instead something external to it. Yet these passages are not decisive. For one thing, the phrase "are moved by" merely suggests that active principles do not belong to matter; it does not close the door to the possibility that they do. (Additionally, Newton writes in the *Optice* draft that "bodies *alone considered*" are passive, thereby raising the possibility that he attributes *inessential* active powers to matter. I delay an examination of this suggestion until the final chapter.)

A second difficulty with supposing that Newton attributes active powers directly to particles is that most of the remarks that might be construed to that effect have the following in common. They speculate about the existence of "lesser forces" to explain phenomena such as cohesion and fermentation (chemical reactions) –and they do so by taking gravity, along with electricity and magnetism, as a model. Thus in the *Conclusio*, Newton invokes the "conformity of Nature" as a reason for thinking gravitational attractions may have analogues in "lesser forces" between unobserved particles.

> There are, however, innumerable other local motions which on account of the minuteness of the moving particles cannot be detected, such as the motions of the particles in hot bodies, in fermenting bodies, in putrescent bodies, in growing bodies, in the organs of sensation and so forth. If anyone shall have the good fortune to discover all these, I might almost say that he will have laid bare the whole nature of bodies so far as the mechanical causes are concerned.... Nature is exceedingly simple and conformable to herself. Whatever reasoning holds for greater motions should hold for lesser ones as well. The former depend upon the greater attractive force of larger bodies, and I suspect that the latter depend upon the lesser forces, as yet unobserved, of insensible particles.[254]

Gravity is the model in draft material for a projected Book IV of the *Opticks*, written in the early

---

[253] "It seems to me farther, that these Particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity." (Query 31, *Opticks*, 401.)

[254] Draft of *Conclusio* for *Principia* I, in *Unpublished Scientific Papers of Isaac Newton*, 333, and quoted by McMullin, *Newton on Matter and Activity*, 50.

1690's but not ultimately included.[255]

> Hypoth 2   As all the great motions in the world depend upon a certain kind of force (w^{ch} in this earth we call gravity) whereby great bodies attract one another at great distances: so all the little motions in y^{e} world depend upon certain kinds of forces whereby minute bodies attract or dispell one another at little distances. How the great bodies of y^{e} Earth Sun Moon & Planets gravitate towards one another what are y^{e} laws & quantities of their gravitating forces at all distance from them & how all y^{e} motions of those bodies are regulated by their gravities I shewed in my Mathematical Principles of Philosophy to the satisfaction of my readers. And if Nature be most simple & fully consonant to her self she observes the same method in regulating the motions of smaller bodies w^{ch} she doth in regulating those of the greater.[256]

And again in Query 31:

> For it's well known, that Bodies act one upon another by the attractions of Gravity, Magnetism, and Electricity; and these Instances show the Tenor and Course of Nature, and make it not improbable but that there may be more attractive Powers than these. For Nature is very consonant and conformable to herself.[257]

So gravity is the model for the speculated short-range, lesser forces (which many commentators refer to as 'interparticle forces', though that appellation describes gravity as well). But if gravity is a basis for inferring the existence of lesser forces, then to suppose that Newton takes these lesser forces to be powers that belong directly to matter and which can affect distant matter without an intermediary presumes that gravity is already accepted as itself being such a power of matter.

There is one text in which Newton at first glance appears to be saying just that. In the carefully composed[258] but ultimately unpublished Draft Conclusion to the *Principia*, Newton

---

[255] See Westfall: "The *Opticks* that Newton published in 1704 was not the *Opticks* he had planned in the early 1690's. That work had reached its climax in a Book IV dedicated to the demonstration that forces that act at a distance exist....In the *Opticks* he did publish, he eliminated Book IV and focused the work sharply on optical problems." (*Never at Rest*, 640.)

[256] Hypothesis 2 is ULC Add. MS. 3970.3, ff. 338-8v, and appears in Westfall, *Force*, 379. (Westfall notes that the bracketed words are his reconstructions, due to damage to the paper; *ibid.*, 411, n.128.)

[257] Query 31, *Opticks*, 376.

[258] See Cohen, "Guide", 283: "Most of this document is written neatly (in Newton's hand) and is not a rough draft with passages crossed out and rewritten, although the very last part is more tentative."

compares gravity to the electrical and magnetic forces, and makes this dramatic statement: "Magnetic force is communicated by contact; the other forces are not."[259] Is Newton asserting here that gravity and the electrical force involve action at a distance, without any medium between causally interacting bodies? Despite initial appearances, it seems that he is not. It was accepted in the 17th century that magnetic bodies emit material effluvia, which act as a medium within the area to which they reach.[260] In saying that the magnetic force is communicated by contact, then, Newton means that the force is communicated by the magnetic body's *material* effluvia. Against this he contrasts gravity and the electrical force. These do not operate by the contact of material effluvia. Yet they might operate by the contact of some *immaterial* medium. Newton's above-quoted remark does not exclude that possibility, and a later passage in the text supports it. Later in the Draft Conclusion he writes,

> By these experiments it is fully enough clear that glass at small distances always abounds in electric force, even without friction, and therefore abounds in an electric spirit which is diffusd through its whole body and always surrounds the body with a small atmosphere, but never goes out far into the air unless stirred up by friction.[261]

Thus from the fact that glass attracts light bodies at small distances, even without friction, he infers the existence of a short-range medium, namely the electric spirit, which is immaterial. The inference depends upon an assumption that the material bodies do not act distantly; without that assumption, there is no basis for inferring the existence of the electric spirit.

---

[259] A longer excerpt reads, "I have now set forth the forces, properties, and effects of gravity. It is most certain from phenomena that electric and magnetic attractions also exist. But the laws of these [attractions] are very different from the laws of gravity. Electrical and magnetic attractions are intended and remitted; gravity cannot be intended and remitted. Magnetism and electricity sometimes attract and sometimes repel; gravity always attracts. They act at small distances, gravity at very great distances. Magnetic force is communicated by contact; the other forces are not." (A Draft Conclusion to the *Principia*, Cohen, "Guide", 292.)

[260] See Hawes, "Newton and the 'Electrical Attraction Unexcited'", 122.

[261] A Draft Conclusion to the *Principia*, Cohen, "Guide", 289.

Additionally, Newton denies knowing gravity's causal story. In a 1693 letter to Leibniz, he implicitly indicates that he does not know gravity's causal story; for after asserting that the celestial motions and the tides "follow from" gravity, he adds that he will not object if someone can show that gravity and its laws are explained by the action of "some subtle matter".[262]

We find the same position much later in Newton's 1712, unpublished response to Leibniz's charges. In that letter, he states that it is within God's power to create a world in which the planets could move by gravity alone. "Certainly God could create planets that should move round of themselves without any other cause than gravity that should prevent their removing through the tangent. For gravity without a miracle can keep the planets in."[263] Here Newton indicates that gravity is real in the second sense that I distinguished earlier; gravity can keep the planets in, and thus the force itself has causal efficacy. But if we think he means to close the causal question about gravity by attributing attractive powers directly to matter, Newton immediately disabuses us of this, writing that the gravitational force has some cause yet to be discovered:

> And to understand this without knowing the cause of gravity, is as good a progress in philosophy as to understand to understand….how the bones are moved by the contracting or dilating of the muscles without knowing how the muscles are contracted or dilated by the power of the mind, is [in] the philosophy of animal motion.[264]

[262] "Since all the phenomena of the heavens and of the sea follow precisely, so far as I am aware, from nothing but gravity acting in accordance with the laws described by me; and since nature is very simple, I have myself concluded that all other causes are to be rejected and that the heavens are to be stripped as far as may be of all matter, lest the motions of planets and comets be hindered or rendered irregular. But if, meanwhile, someone explains gravity along with all its laws by the action of some subtle matter, and shows that the motion of planets and comets will not be disturbed by this matter, I shall be far from objecting." (Newton to Leibniz, 1693, *Philosophical Writings*, 108-109.) The phrase "subtle matter" raises some questions. If Newton is thinking of a very rare material medium, it would have to act by some means other than impact, for Newton has disproved the existence of a material medium having sufficient inertial properties to push the planets. We cannot simply assume that the phrase is just a manner of speaking, one that because of that disproof must refer to an immaterial medium. One reason is that this letter to Leibniz was written not long after the first edition of the *Principia*, which contained a hypothesis eliminated from the second, 1713 edition. This is Hypothesis III, which asserts the transformability of matter.

[263] Newton to the Editor of the *Memoirs of Literature*, unpublished, written c. May 1712, *Philosophical Writings*, 116-117. Newton is responding to criticism that Leibniz stated in a letter originally written to Nicholas Hartsoeker, and later published in the *Memoirs of Literature*.

[264] "And to understand this without knowing the cause of gravity, is as good a progress in philosophy as to understand the frame of a clock and the dependence of the wheels upon one another without knowing the cause of the gravity of the weight which moves the machine is in the philosophy of clockwork; or the understanding of the frame of the bones

This position is restated in the 1713 General Scholium, as we saw. There, Newton asserts that "gravity really exists" and that its laws are sufficient for the planets to "persevere in their orbits", but he has not assigned it a cause.[265]

Finally, Newton's seemingly direct attribution of active powers to matter in Query 31 is almost immediately followed by one of his characteristic qualifying remarks: "How these Attractions may be perform'd, I do not here consider. What I call Attraction may be perform'd by impulse, or by some other means unknown to me."[266] While one might think this comment is simply a stratagem, intended to deflect criticism about his acceptance of action at a distance, I think there is a better way to understand it, a way that makes sense of the difficulties I have been discussing.

In the texts containing the most provocative suggestions that matter possesses active forces, virtues, or powers by which it acts distantly, Newton is speculating about the existence of "lesser forces". Just as there were two problems to solve when Newton began his work on gravity—that of presenting the force "through calculation and geometry", as Kepler put it, and that of finding the physical, causal explanation—so there are two problems for the cohesion and chemical phenomena. Whereas only the physical, causal problem remains outstanding in the case of gravity, both problems remain outstanding for these other phenomena. In Query 31 and elsewhere, Newton speculates that these phenomena might be due to some lesser forces.

---

and muscles and their connection in the body of an animal and how the bones are moved by the contracting or dilating of the muscles without knowing how the muscles are contracted or dilated by the power of the mind, is [in] the philosophy of animal motion." (Newton to the Editor of the *Memoirs of Literature*, *ibid.*)

[265] General Scholium: "They [the celestial bodies] will indeed persevere in their orbits by the laws of gravity, but they certainly could not originally have acquired the regular position of the orbits by these laws….I have explained the phenomena of the heavens and of our sea by the force of gravity, but I have not yet assigned a cause to gravity.....It is enough that gravity really exists and acts according to the laws that we have set forth and is sufficient to explain all the motions of the heavenly bodies and of our sea." (*Principia,* 940 and 943.)

[266] Query 31, *Opticks*, 376.

If we suppose that in Query 31 and the other texts noted above, Newton is trying to answer the physical, causal question, then he appears to suggest as an answer that matter possesses powers to act distantly; and he then appears to retract that answer a few sentences later, by saying that he is not considering how the attractions may be performed.[267] All this supposes that Newton thinks it proper to proceed to the physical, causal question without having answered the mathematical one; for while he speculates that there may be some forces analogous to gravity, in that they act between spatially separated particles, he does not yet know their "mathematical proportions". For example, he cannot specify how the speculated force of cohesion might vary with distance. (Perhaps it varies with the inverse cube, for instance, as Newton finds to be approximately the case for the magnetic force.) Nor can he say whether one force or many are at work. It might be only a single, dual-natured force that is attractive at some distances but repulsive at others; for he speculates in Query 31, that as numbers pass from negative to positive, so a force might pass from repulsive to attractive.[268]

---

[267] *Ibid.*

[268] "As in Algebra, where affirmative Quantities vanish and cease, there negative ones begin; so in Mechanicks, where Attraction ceases, there a repulsive Virtue ought to succeed. And that there is such a Virtue, seems to follow from the Reflexions and Inflexions of the Rays of Light....It seems also to follow from the Emission of Light; the Ray so soon as it is shaken off from a shining Body by the vibrating Motion of the Parts of the Body, and gets beyond the reach of Attraction, being driven away with exceedingly great Velocity....It seems also to follow from the production of Air and Vapour. The Particles when they are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of the Attraction of the Body, recede from it, and also from one another with great Strength, and keep at a distance, so as sometimes to take up above a Million of Times more space than they did before in the form of a dense Body. Which vast Contraction and Expansion seems unintelligible, by feigning the Particles of Air to be springy...or by any other means than a repulsive Power." (Query 31, *Opticks*, 395.) There is disagreement among commentators about whether Newton is here suggesting a dual-natured force. Joan Hawes and also the Halls read Newton as making that suggestion. See the Halls' commentary:

> His general theory of matter postulated the existence of both repulsive and attraction forces in all phenomena except gravitation, which was unique; as he put it vividly in *Quaery* 31, 'as in algebra where affirmative quantities vanish and cease, there negative ones begin: so in mechanicks where attraction ceases, there a repulsive virtue ought to succeed'. Electrical phenomena offered a particularly significant combination of the two kinds of force. (It was a more significant example than the case of magnetism, which was specialized and limited to one kind of matter) This duality of force remained a perpetual problem. In his mathematical treatment of the force of gravity in the *Principia* it did not concern him, except in Book II, Proposition XXII....In other cases, in the qualitative discussions of cohesion, capillary attraction, solution, and so forth, Newton could do no more than merely assert the simultaneous existence of dual forces without further reconciling them; it was without doubt one of the merits of the aether hypothesis that it seemed to offer some possibility of doing this. (*Unpublished Scientific Papers of Isaac Newton,* 210-11.)

Marie Boas, however, appears to interpret this passage as indicating regions of attraction and repulsion, rather than a single, dual-natured force. Commenting upon the passage from Query 31, she writes, "Each particle was surrounded by

Yet in general, Newton does not recommend answering the physical, causal question first. In the Scholium to Book I, Section 11, Newton writes that we must first investigate the "quantities of forces and their proportions that follow from any conditions that may be supposed". It is only after this that we can "come down to physics" and begin to determine, among other things, the "physical species"[269] and "physical causes" of the forces. The mathematical problem is the first stage, then. So instead of supposing that he is leapfrogging over the mathematical problem and speculating about the physical, causal problem, we should understand his remarks in Query 31 as addressing the prior, mathematical problem. Understood this way, Newton is not making a physical, causal claim only to retract it. He is beginning with the mathematical problem, by speculating that phenomena such as cohesion might be due to forces that act between spatially separated particles. Those forces might be distance-variant, as opposed to ones acting by contact. To discover the distance relations between particles undergoing attraction or repulsion would constitute progress on the mathematical problem. His subsequent remark, to the effect that he is not here considering how the attractions might be performed, indicates that his speculations are confined to this first, mathematical stage, and do not address the physical, causal problem.

The Electric Spirit

In the 1713 General Scholium, Newton writes that gravity's cause, whatever it may be, "penetrates as far as the centers of the sun and planets."[270] He then goes on to speculate about a

---

a sphere or area of attraction; where this stopped, a sphere of repulsion succeeded; beyond this again, there was a second sphere of attraction, that of gravitation, extending outward indefinitely." ("The Establishment of the Mechanical Philosophy", 516.) Since Newton clearly takes the gravitational force to reach to the very center of bodies, Boas presumably means that within a certain region, a repulsive force is dominant, counteracting the effects of the gravitational force. Since she sees no reason to state that the gravitational force is thus distinct from the repulsive force, she presumably thinks that the repulsive force may also be distinct from the attractive force operating at the inner sphere around the particle (i.e., the cohesive force).

[269] For a discussion of the physical species of force, see Janiak, *Newton as Philosopher*, 58-65.

[270] General Scholium: "I have not yet assigned a cause to gravity. Indeed, this force arises from some cause that penetrates as far as the centers of the sun and planets without any diminution of its power to act, and that acts not in

"very subtle spirit" that initially appears to meet this condition, because it pervades the pores of bodies.

> A few things could now be added concerning a certain very subtle spirit pervading gross bodies and lying hidden in them; by its force and actions, the particles of bodies attract one another at very small distances and cohere when they become contiguous; and electrical [i.e. electrified] bodies act at greater distances, repelling as well as attracting neighboring corpuscles; and light is emitted, reflected, refracted, inflected, and heats bodies; and all sensation is excited, and the limbs of animals move at command of the will, namely, by the vibrations of this spirit being propagated through the solid fibers of the nerves from the external organs of the senses to the brain and from the brain into the muscles. But....there is not a sufficient number of experiments to determine and demonstrate accurately the laws governing the actions of this spirit.[271]

Although the General Scholium does not identify this subtle spirit, most commentators agree that it is the electric spirit.[272] This identification is based upon draft materials, including the Draft Conclusion to the *Principia* (c. 1704-1712),[273] which both names the electric spirit and discusses

---

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, and whose action is extended everywhere to immense distances, always decreasing as the squares of the distances." (*Principia*, 943.)

[271] *Ibid.*, 944.

[272] This identification was first made by Hall and Hall in *Unpublished Scientific Papers of Isaac Newton*, 1962, based upon unpublished drafts. The identification of the subtle spirit as an electrical spirit gains additional support from A Draft Conclusion to the *Principia* (ULC MS Add. 3965, fols. 351-352; MS 3970, fols. 602-604, c. 1704–1712), translated by Cohen, "Guide", 287-292. Joan Hawes, writing long before the publication of the Draft Conclusion, but after the Halls, rejects their identification of the spirit as electric. Hawes argues that the 'subtle spirit' of the General Scholium is not the electric spirit discussed in the draft manuscripts, but is instead an aether. She holds that aether is not the same as the aether in the Boyle letter, but is similar to it in one important respect: in both cases, an aether is used to explain inter-particulate forces:

> I expressed doubt on the possible identification of the subtle spirit, described in the *Scholium Generale* of the 1713 edition of the *Principia*, with the electric spirit described in some of its draft manuscripts. If one believes that at this stage Newton considered that particle forces were explicable in terms of electrical forces of repulsion and attraction, evident without friction, and independent of the electric spirit, then there is no doubt as to the non-equivalence of the two entities. For, in the *Scholium Generale* as printed in 1713, particle phenomena are effected 'by the force and action' of the subtle spirit. It is generally agreed, I think, that the 'Aethereal Medium' of the *Opticks* was a development of the aetherial conjecture about gravity with which Newton concluded his letter to Boyle (although the concept of an aether composed of mutually repulsive particles, introduced in *De Aere et Aethere*, has its importance.) I doubt, however, that anyone would suggest the equivalence of the aether hypotheses contained in the two works, even if Newton had re-written the entire letter using the concept of an aether of continually variable density. This is because, in the latter work, particle forces had an aetherial explanation, whereas the *Opticks* is renowned for its non-aetherial explanation of particle forces. On the other hand, the similarity between the aether of Boyle's letter and the subtle spirit of the *Scholium Generale*...is remarkable for the fact that in both works the inter-particulate forces are explained through the action of an aether. ("Newton and the 'Electrical Attraction Unexcited'", 129-130.)

[273] Cohen, "Guide", 283.

it in much greater detail than the brief paragraph quoted above. (This paragraph was omitted from the *Principia*'s third edition, perhaps because it is speculative, and perhaps also because after the second edition, Newton's hopes for the electric spirit begin to wane.) Though the Draft Conclusion remained unpublished, much of it was nearly prepared for publication, so it probably expresses thoughts that, while speculative, were nonetheless carefully considered.[274] In the period that the Draft Conclusion was composed, Newton was strongly impressed by some experiments by Francis Hauksbee, including that of an evacuated, rotating globe made to glow by friction. Newton attributed this effect, as well as capillary action, to an electric spirit,[275] and began to consider the electrical spirit as an explanation for a wide range of phenomena.

Reductionism and the Phenomena Associated with the Electric Spirit

In the Draft Conclusion, Newton attributes to this spirit the capacity to produce light and thereby to heat bodies, to change the trajectory of light, and to cause sensation by vibrating in the nerves and organs that connect the brain and muscles. He also suggests the electric spirit as the answer to a problem that the ancient atomists had failed to solve, cohesion. Newton remarks in Query 31 that their solution of hooked atoms begs the question.[276] (If the atoms do not enclose one another but instead have hooks, such that they can separate from old aggregates to form new ones, one may wonder how they then stay in these new aggregates.)

If the electric spirit were continuous and pervaded the entire heavens, it might produce or convey gravitational effects by contact, avoiding action at a distance. Yet Newton does not intend

---

[274] *Ibid.*

[275] *Ibid.*, 286.

[276] "The Parts of all homogeneal hard Bodies which fully touch one another, stick together very strongly. And for explaining how this may be, some have invented hooked Atoms, which is begging the Question; and others tell us that Bodies are glued together by rest, that is, by an occult Quality, or rather by nothing; and others, that they stick together by conspiring Motions, that is, by relative rest among themselves. I had rather infer from their Cohesion that their Particles attract one another by some Force, which in immediate Contact is exceeding strong, at small distances performs the chymical Operations above-mention'd, and reaches not far from the Particles with any sensible Effect." (Query 31, *Opticks*, 388-389.)

the electric spirit as a hypothesis for gravity's physical cause.[277] (One wrinkle that I will not explore is the possibility that Newton's electrical spirit is identical to the aether of the *Opticks*, which figures in Query 21's aethereal hypothesis about gravity.[278]) Neither the General Scholium's abbreviated discussion nor the much lengthier Draft Conclusion lists gravity among the phenomena that might be caused by the electric spirit.[279] Moreover, the electric spirit does not meet the condition Newton sets upon gravity's cause. While it does pervade gross bodies, it does not fill the heavens, reaching to the very centers of the sun and planets. It pervades some bodies, but its reach is limited. It surrounds glass bodies, for instance, but it does not reach far from them, even with friction.[280]

---

[277] Concurring with this assessment are McGuire ("Force, Active Principles", 175), and Hawes ("Newton's Two Electricities", 102). According to McGuire, Newton thought of the electric force during this period (1706-1713) as a "primordial agent or spirit" responsible for motions taking place at the level of unobservable particles; the range of phenomena to be unified by this spirit, however, does not include gravity. Cohen at one point suggests that around the period of the General Scholium, Newton did hope to explain gravity by electrical phenomena, but he later makes the weaker claim that Newton hoped that electrical phenomena would lead to a better understanding of attractive forces generally. See Cohen: "By the time of the third edition, Newton seems to have abandoned his earlier attempts to explain the action of gravity by reference to electrical phenomena and had come rather to hope that an explanation might be found in the actions of an "aethereal medium" of varying density." See also "Guide", 286: "In this presentation [i.e., the Draft Conclusion], as in the General Scholium, Newton does not include the force of gravity among the actions of this [electric] spirit. The final impression given a reader is that if more were known about the action of this spirit, then we would understand the nature of attractive forces in general and so be in a better position to understand the action of gravity." ("Guide", 25.)

[278] Cohen notes that some scholars identify the electric spirit with the *Opticks*' aether, though he rejects that identification: "Some four years after the second edition of the *Principia*, Newton published the second edition of the *Opticks* (London, 1717/18), in which he explored the properties and effects of an 'aethereal medium,' a somewhat different entity from the Cartesian or dense aether which he had rejected earlier. Scholars are divided in their judgment concerning whether this aethereal medium is identical with the electric spirit. An exploration of that question would take us far afield. What is of concern here is not so much to explore all of Newton's speculations about spirit and force, but rather to understand what Newton had in mind when he wrote the paragraph of the General Scholium with which the later editions of the *Principia* conclude. As the draft conclusion printed here shows plainly, and as the documents published by the Halls made clear, Newton's 'spirit' is an 'electric spirit,' whose properties were demonstrated to him by Hauksbee." ("Guide", 287.)

[279] Similarly, in draft material that McGuire interprets as relating to some proposed new queries for the *Opticks*, Newton again lists a range of phenomena that the electric spirit might explain, without including gravity; see "Force, Active Principles", 176. In a draft that McGuire interprets as something Newton probably intended to follow one of the new Queries for the 1717/18 *Opticks*, (specifically, a proposed successor to the last of the new Queries, numbers 17-24), Newton again lists a range of phenomena that the electric spirit might explain, without including gravity: "Do not all bodies therefore abound with a very subtile, but active, potent, electric spirit by w[ch] light is emitted, refracted. & reflected, electric attractions and fugations are performed, & the small particles of bodies cohere when contiguous, agitate one another at small distances...For electric...uniting the thinking soul & unthinking body. This spirit may also be of great use in vegetation, wherein three things are to be considered, generation, nutrition & preparation of nourishment." (U.L.C. Add. 3970, fols. 235v, in McGuire, *ibid.,* 176).

[280] "By these experiments it is fully enough clear that glass at small distances always abounds in electric force, even without friction, and therefore abounds in an electric spirit which is diffusd through its whole body and always

So the electric spirit is not a candidate for gravity's cause, and the connection between the two forces is that both are distance forces, which is to say that they operate between spatially separated bodies, without the contact of any material effluvia. Newton also remarks upon an intriguing similarity in the forces' proportions, describing an experiment in which the electric force varied almost with the inverse square of distance.[281] Then, having explained cohesion in terms of the electric force, he compares the shape it produces in a drop of liquid to that produced by the gravitational force in a planet: "Just as the earth takes on a spherical shape by the gravity of its parts toward the center, so the drops of liquid constantly affect spherical shapes by the electrical attraction of their parts toward themselves."[282]

Yet there are also notable differences between the forces, so while Newton is hoping that a range of phenomena might be attributed to the electric spirit, and several forces reduced to the electric force associated with that spirit, gravity is not among them. The Draft Conclusion to the *Principia* begins by emphasizing the differences between gravity and the electric and magnetic forces. He writes, for example, "Electrical and magnetic attractions are intended and remitted; gravity cannot be intended and remitted."[283] Gravity's intensity depends only upon distance, that is, whereas the electrical force can be increased by friction or impeded by the interposition of bodies (a difference he notes somewhat later in the Draft Conclusion to the *Principia*). Another notable difference is that the gravitational force only attracts, whereas the electrical and magnetic forces "sometimes attract and sometimes repel." Newton elsewhere tries to explain this by suggesting what commentators have termed the 'duality of force'[284]; the electric force might

---

surrounds the body with a small atmosphere, but never goes out far into the air unless stirred up by friction." (A Draft Conclusion to the *Principia*, Cohen "Guide", 289.)

[281] "In the latest experiment, the force of attraction came out very nearly inversely in the ratio of the square of the distance." (*Ibid.*)

[282] *Ibid.*, 290.

[283] A Draft Conclusion to the *Principia*, Cohen, "Guide", 287.

[284] The Halls comment on the oddness of the suggestion:

attract at some distances but become a repulsive force at other distances, he suggests in Query 31, just as numbers pass from positive to negative.[285] The attribution of this duality to the electrical force would pose an obstacle to unifying it with the gravitational force, which is only attractive, and there is no indication that Newton expects to unify these two forces. His aim in the Draft Conclusion instead seems to be the same one expressed much earlier, in his Author's Preface to the 1687 *Principia* and in his unpublished *Conclusio* (also written in 1687). There, he hoped that understanding the "lesser forces" holding among "insensible particles" would illuminate phenomena other than gravity, and he treated the gravitational force not as something that could be reduced to the lesser forces but as a basis for inferring their probable existence.[286] His discussion of the electric force decades later is consistent with that expectation.

> The propositions [from a draft for the General Scholium, Section IV, no. 8, MS.C, *ibid.,* 355-364] are Newton's last private thoughts upon the origin of the natural forces by which particles are moved and visible phenomena occasioned, and they are very hard to interpret. The electric spirit is the cause of cohesion, for it causes a strong attraction between contiguous particles; at the same it causes repulsion at greater distances....Newton appears to suggest that whereas in experiments in electricity large forces give rise to conspicuous effects of attraction, repulsion and luminous discharge, in the minute world of material particles electric forces might cause the invisible motions of the particles that are sensed as heat, light, or chemical change. But it is hard to understand how Newton could imagine that the electric force between particles which is a force of attraction at microscopic distances could become a force of repulsion between bodies at macroscopic distances, if that is what he means. (*Unpublished Scientific Papers of Isaac Newton*, 209.)

See also Hawes:

> The accompanying experiment [to Proposition 5], 'On the solution of metals', is, of course, well known for its postulate of attraction and repulsion between material particles. The interesting point now seems to be, that both particle attraction and repulsion, originate in electrical forces. In other words, the particles of matter are endowed with an electric force (evident without excitation by friction) which can be simultaneously attractive and repulsive. Now, force duality concepts in the explanation of natural phenomena are not an innovation in Newton's writings, for in the suppressed *Conclusio*, intended for publication in the 1687 edition of the *Principia*, Newton writes concerning the immiscibility of oil and water as follows: 'There must be one force whereby particles of oil attract each other, and another whereby they repel the particles of water'....Newton has often incorporated the idea of one entity endowed with the double force of attraction and repulsion. ("Newton's Two Electricities", 127-128.)

[285] Query 31, *Opticks*, 395. Again, see the Halls' discussion of this passage, and also that of Boas, mentioned earlier in note 266.

[286] See the Author's Preface, written c. 1687: "Then the motions of the planets, the comets, the moon, and the sea are deduced from these forces, by propositions that are also mathematical. If only we could derive the other phenomena of nature from mechanical principles by the same kind of reasoning!" (*Principia*, 382.) See also the unpublished *Conclusio*, written in the same period: "There are, however, innumerable other local motions which on account of the minuteness of the moving particles cannot be detected, such as the motions of the particles in hot bodies, in fermenting bodies, in putrescent bodies, in growing bodies, in the organs of sensation and so forth. If anyone shall have the good fortune to discover all these, I might almost say that he will have laid bare the whole nature of bodies so far as the mechanical causes are concerned....Nature is exceedingly simple and conformable to herself. Whatever reasoning holds for greater motions should hold for lesser ones as well. The former depend upon the greater attractive force of

The Nature of the Electric Spirit and the Question of Distant Action

It is difficult to tell whether Newton considers the electric spirit to be continuous or particulate. Some of his remarks about heat transfer might suggest a continuous spirit.

> Hence also the heat of a body is most easily and most quickly propagated into contiguous bodies. For when the electric spirit that lies hidden in two bodies (a hot body and a cold body) becomes continuous through the contact of the bodies, its vibrations in the hot body will not be reflected at the common surface of the bodies but will be propagated into the second body through the continuous spirit.[287]

Yet perhaps Newton's point here is not that the spirit itself is continuous, but that a cloud of the particulate spirit surrounding one body may come to abut or intersect the cloud surrounding another body. For in Query 22 he refers to the electric spirit as being "rare and subtile", which is to say having very fine particles[288] and a very low density.[289]

Does Newton ever allow that particles that accelerate one another by the electric force are acting distantly upon one another? That is, whatever the nature of the electric *spirit* may be, do particles themselves possess the power to attract and does the electric force ever involve distant action? Some texts appear to imply that it does. In Query 31, Newton writes, "Perhaps electrical

---

larger bodies, and I suspect that the latter depend upon the lesser forces, as yet unobserved, of insensible particles." (*Unpublished Scientific Papers of Isaac Newton*, 333.)

[287] A Draft Conclusion to the *Principia*, Cohen, "Guide", 287.

[288] Newton indicates that for a fluid to be 'subtle' is for it to be divided: "If the aether were a corporeal fluid entirely without vacuous pores, however subtle its parts are made by division, it would be as dense as any other fluid." (*De Gravitatione*, *Philosophical Writings*, 35.)

[289] See Query 22: "An electrick Body can by Friction emit an Exhalation so rare and subtile, and yet so potent, as by its Emission to cause no sensible Diminution of the weight of the electrick Body." (*Opticks*, 353.) This unpublished passage also suggests that the electric spirit is particulate, since it can be rarefied: "Friction may rarefy the [electric] spirit, not of all the particles in the electric body, but of those which are on the outside of it." (ULC, Add. 3970, f. 235r, an early draft for the last set of queries that Newton wrote, in McMullin, *ibid.*, n.98.) McMullin notes the disparity between the passages suggesting a particulate electric spirit, and the General Scholium, which gives no such indication: "In the General Scholium there is no hint of the electric spirit's itself being particulate….[but in Query 22] the "exhalation" is represented in corporeal terms with some suggestion of its being particulate ('subtle' was most often used to emphasize the small size of constituent particles). Newton quite evidently moved easily from one to the other model, which is not too surprising since he regarded them both as quite speculative." (*Newton on Matter and Activity*, 149.)

Attraction may reach to such small distances [as escape Observation], even without being excited by Friction."[290] In draft material for the General Scholium, we find an elaboration of that thought.

> As the System of the Sun, Planets and Comets is put in motion by the forces of gravity and its parts persist in their motions, so also the smaller systems of bodies seem to be set in motion by other forces and their particles to be moved among themselves in different ways, and especially by the electric force. For the particles of very many bodies seem to be endowed with an electric force and to act upon each other at small distances even without friction, and those which are most electric, through friction, emit a spirit to great distances, by means of which straws and light bodies are now attracted, now repelled and now moved in diverse ways.[291]

We might initially think that Newton is reasoning as follows: If an emitted spirit conveys the force with friction, yet the force acts over shorter distances without friction, then without friction the particles may be acting upon one another without any intervening medium.[292]

Yet closer inspection of this and other texts indicates that Newton is not attributing the attractive powers directly to material particles, nor asserting action without any medium. The two passages just quoted leave open the possibility that even without friction, it is the electric spirit that communicates the force. The absence of friction does not entail the absence of a medium, thus Query 31's remark leaves the possibility of a medium open; and so does the longer draft passage just quoted, for there Newton says only that the bodies *seem* to be endowed with an electric force. Moreover, in other texts Newton affirms this possibility; in the absence of friction, it is still the electric spirit that communicates the force. In the Draft Conclusion he writes, "the

---

[290] Query 31, *Opticks*, 376.

[291] *Unpublished Scientific Papers of Isaac Newton*, 353-54.

[292] Hawes argues that Newton accepts two distinct electric forces, one of which belongs directly to particles and involves distant action by matter, without a medium: "It is to this draft of the *Scholium Generale* that we must look for the source of the amendment to the 31st Query, as outlined above. [i.e., the additional phrase, "perhaps electrical Attraction may reach to such small distances, even without being excited by Friction."] But more important here, is Newton's suggestion that the particles themselves possess an electric force which is effective over small distances and is active without the medium of an electric spirit: for the latter spirit is only manifest when electric bodies are excited by friction and when greater distances are involved....If, then, Newton has dispensed with the aether hypothesis for the explanation of inter-particulate forces, he must now be supposing that these forces act at a distance, without the operation of an intervening medium." ("Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", 205-206.) See also Hawes, "Newton's Two Electricities", 95, where she again emphasizes two distinct kinds of electrical attraction.

same spirit constantly attracts bodies at small distances from the electric body, even without friction and heat".[293] Later in the same text he indicates that the electric spirit is a medium communicating the force. The glass "abounds in an electric spirit"; this spirit "surrounds the body" and is "diffused through" the body, even without friction. Finally, in drafts that McGuire identifies as versions of the new *Opticks* Queries,[294] Newton suggests that friction does not cause bodies to emit the electric spirit, but only causes the expansion of the spirit that already surrounds the body: "that virtue may not be *generated* by friction but only *expanded*" (italics added).[295] Despite initial appearances in Query 31, then, the electric force does not belong directly to particles, but instead operates through the electric spirit.

The Aether

At various points in his investigations, Newton considers different aether hypotheses, and often the aether is, like the electric spirit,[296] an attempt to reduce many phenomena to the action

[293] "That same spirit is also emitted from some bodies (as from electrum [i.e., amber] and adamant [i.e., the hardest substance, diamond]) by heat alone without friction, and attracts small light bodies. Furthermore, *the same spirit constantly attracts bodies at small distances from the electric body*, even without friction and heat, for stagnant liquids ascend in thin glass tubes immersed into them to their lowest parts, and do so in a vacuum just exactly as in open air." (A Draft Conclusion to the *Principia*, Cohen, "Guide", 288; my italics.)

[294] Queries 17-24 were written last and then inserted between versions of queries written earlier; see Westfall, *Never at Rest*, 644.

[295] The extended passage (U.L.C. Add. 3970, fol. 235v) appears in Westfall, *Force*, 394: "Quaest. 24. May not the forces by w^{ch} the small particles of bodies cohere & act upon one another at small distances for producing the above mentioned phenomena of nature be electric? For altho electric bodies do not act at a sensible distance unless their virtue be excited by friction, yet that virtue may not be generated by friction but only expanded. For the particles of all bodies abound with an electric spirit w^{ch} reaches not to any sensible distance from the particles unless agitated by friction or by some other cause & rarified by the agitation. And the friction may rarify the spirit not of all the particles in the electric body but of those only w^{ch} are on the outside of it: so that the action of the particles of the body upon one another for cohering & producing the above-mentioned phenomena may be vastly greater than that of the whole electric body to attract at a sensible distance by friction. And if there be such an universal electric spirit in bodies, certainly it must very much influence the motions & actions of the particles of the bodies amongst one another, so that without considering it, philosophers will never be able to give an account of the Phaenomena arising from those motions & actions. And so far as these phaenomena may be performed by the spirit w^{ch} causes electric attraction it is unphilosophical to look for any other cause."

[296] As noted earlier, some commentators take the electric spirit to be identical with the aether of at least some of Newton's hypotheses.

of a single substance.[297] In an early manuscript about alchemy, *On Nature's Obvious Laws in Vegetation* (c. 1669), Newton suggests that an aether might explain fermentation (i.e., chemical reactions[298]) and vegetative action; a "subtile spirit" might enter into the pores of bodies and divide their parts. At this early point, he does not attempt to explain light behavior in terms of an aether, but instead suggests that the aether might be only "a vehicle to some more active spirit", with light being one possibility for that more active spirit. Later, in the *Opticks*' queries, however, he casts the relationship between the aether and light the other way around, suggesting that the aether may be responsible for light refraction and diffraction. (Historically, the aether hypothesis would endure longest as an expected medium for light waves, however Newton thinks light consists in particles.) Cohesion might also be caused by an aether, Newton sometimes speculates, writing in a drafted revision to Query 31, that the aether is an "agent in Nature" that makes particles stick together.[299] Finally, Newton provides two aethereal hypotheses for gravity.

The first of these two aethereal hypotheses about gravity is set out in the 1679 Letter to Boyle, and thus well before the *Principia*'s assertion that matter universally gravitates. In the letter, Newton tentatively suggests that gravitational effects are produced by an aether comprising particles of varying size. The finer particles are more apt to lodge in a body's pores than the grosser particles, and the grosser particles move away from the Earth in order to make way for the

[297] See McGuire, "Force, Active Principles", 156. See also Hall and Hall: "In *De Aere et Aethere* the particles of air are, so to speak, active agents in phenomena in virtue of their intrinsic repulsive force. In the *Letter to Boyle*, this is no longer the case: particles of air or of other matter, even light-rays, are passively subjected to the force exerted by aether particles, to which the intrinsic repulsive force has now been transferred. Some economy of explanation is gained by the change. For instead of supposing that material particles are endowed with a variety of forces, gravitational, chemical, electrical and so forth, it may be possible to reduce all these to one force in the aether—but unfortunately for economy, Newton did not succeed in this. On the other hand, there has necessarily been a multiplication of entities in a fashion to invite the slash of Ockham's razor. One does not make much progress by supposing that repulsion between material particles is caused by the repulsion between aetherial particles, for this leave the latter just as unexplained as the former was previously." (*Unpublished Scientific Papers of Isaac Newton,* 189.)

[298] Newton uses the term 'fermentation' to refer to chemical phenomena generally. See Hesse, *Forces and Fields*, 154-155.

[299] "There are, therefore, agents in Nature able to make the particles of bodies attract one another very strongly to stick together strongly by those attractions. One of the agents may be the aether above-mentioned, whereby light is refracted. Another may be the agent or spirit which causes electrical attraction....And as there are still other mediums which may cause attractions such as are the magnetic effluvia, it is the business of experimental philosophy to find out all these mediums with their properties." (ULC, Add. 3970, f. 622r, in McMullin, *Newton on Matter and Activity*, 97. McMullin identifies the passage as a revision of Query 31; *ibid.*, 149).

finer particles; bodies above the Earth must move downward in order for this rearrangement to take place.[300] What is the nature of this aether? Air and vapors, which comprise the atmosphere, are material; these are "nothing else but the particles of all sorts of bodies, of which the earth consists, separated from one another, and kept at a distance " by their tendency to recede from one another.[301] The 1679 aether is similar to air in at least two respects. First, it is capable of contraction and dilation; the difference is in degree, since it is more strongly elastic than air. Second, it is material. In the letter Newton writes that the aether is "much like air in all respects, but far more subtle";[302] and chapter two of *De aere et aethere* states explicitly that just as air comprises particles broken away from bodies, the aether comprises broken particles of air.[303] Moreover, prior to asserting the universal gravitation of matter, Newton has no reason to think that an aether would be immaterial—but subsequent to that assertion he may, as I explain below.

The other aethereal hypothesis for gravitational effects is the one set out much later in Query 21. Like the aether of the Boyle letter, the Query 21 aether is particulate and very elastic. But while the aether of the Boyle letter comprised particles of varying size, whose tendencies to

---

[300] "I will set down one more conjecture....It is about the cause of gravity. For this end I will suppose aether to consist of parts differing from one another in subtlety by indefinite degrees: that in the pores of bodies there is less of the grosser aether, in proportion to the finer, than in open spaces, and consequently that in the great body of the earth there is much less of the grosser aether, in proportion to the finer, than in the regions of the air: and that yet the grosser aether in the air affects the upper regions of the earth, and the finer aether in the earth the lower regions of the air, in such a manner that from the top of the air to the surface of the earth, and again from the surface of the earth to the centre thereof, the aether is insensibly finer and finer. Imagine now any body suspended in the air, or lying on the earth, and the aether being by the hypothesis grosser in the pores, which are in the upper parts of the body, than in those which are in its lower parts, and that grosser aether being less apt to be lodged in those pores, than the finer aether below, it will endeavour to get out and give way to the finer aether below, which cannot be without the bodies descending to make room above for it to go out into." (Newton to Boyle, 28 February 1678/9, *Philosophical Writings*, 10.)

[301] Newton to Boyle, *ibid.,* 4. A similar view of air and vapors may be found in Query 31. There, Newton indicates that they are produced as fine particles are shaken off of bodies; then as they become very small, they acquire a tremendous repulsive power that produces the spring of the air: "That there is such a [repulsive] Virtue, seems to …follow from the Emission of Light; the Ray so soon as it is shaken off from a shining Body by the vibrating Motion of the parts of the Body, and gets beyond the reach of Attraction, being driven away with exceedingly great Velocity....It seems also to follow from the production of Air and Vapour. The Particles when they are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of the Attraction of the Body, recede from it." (Query 31, *Opticks*, 395.)

[302] Newton to Boyle, 28 February 1678/9, *Philosophical Writings*, 1.

[303] The Halls conclude that *De aere et aethere* was composed c. 1673-1675, and thus prior to the Boyle letter; see *Unpublished Scientific Papers of Isaac Newton*, 189. Westfall, however, takes *De aere et aethere* to have been written after the Boyle letter, as an attempt to systematize the thoughts expressed earlier in the Boyle letter. See Westfall, *Force*, 373 and 374 respectively concerning the dating and the nature of the aether.

lodge in the pores of bodies varied according to size, this new aether comprises uniformly fine particles. These particles repel one another with a tremendous force, and extend in a density gradient outward from the sun.[304] The pressure from the density gradient pushes the planets inward toward the sun, where the aether is rarer.

> Qu.21. Is not this Medium [the Aethereal Medium] much rarer within the dense Bodies of the Sun, Stars, Planets and Comets, than in the empty celestial Spaces between them? And in passing from them to great distances, doth it not grow denser and denser perpetually, and thereby cause the gravity of those great Bodies towards one another, and of their parts towards the Bodies; every Body endeavoring to go from the denser parts of the Medium towards the rarer? For if this Medium be rarer within the Sun's Body than at its Surface, and rarer there than at the hundredth part of an Inch from its Body, and rarer there than at the fiftieth part of an Inch from its Body, and rarer there than at the Orb of *Saturn*; I see no reason why the Increase of density should stop any where, and not rather be continued through all distances from the Sun to *Saturn*, and beyond. And though this Increase of density may at great distances be exceeding slow, yet if the elastick force of this Medium be exceeding great, it may suffice to impel Bodies from the denser parts of the Medium towards the rarer, with all that power which we call Gravity. And that the elastick force of this Medium is exceeding great, may be gather'd from the swiftness of its Vibrations....As Attraction is stronger in small Magnets than in great ones in proportion to their Bulk, and Gravity is greater in the Surfaces of small Planets than in those of great ones in proportion to their bulk, and small Bodies are agitated much more by electric attraction than great ones; so the smallness of the Rays of Light may contribute very much to the power of the Agent by which they are refracted. And so if any one should suppose that *Aether* (like our Air) may contain Particles which endeavor to recede from one another (for I do not know what this *Aether* is) and that its Particles are exceedingly smaller than those of Air, or even than those of Light: The exceeding smallness of its Particles may contribute to the greatness of the force by which those Particles may recede from one another, and thereby make that Medium exceedingly more rare and elastick than Air, and by consequence exceedingly less able to resist the motions of Projectiles, and exceedingly more able to press upon gross Bodies, by endeavoring to expand itself.[305]

[304] This aether is not a "mechanical aether", such as the one that Richard Bentley rejects in his Seventh Boyle Lecture. It bears more resemblance to a hypothesis discussed by Hooke. In his *Micrographia*, Hooke asks "whether the Phaenomena of gravity might not by this means be explained, by supposing the Globe of Earth, Water, and Air to be included with a fluid, heterogeneous to all and each of them, so subtil as not only to be every where interspersed through the Air (or rather the air through it), but to pervade the bodies of Glass, and even the closest Metals, by which means it may endeavor to detrude all earthly bodies as far from it as it can; and partly thereby, and partly by other of its properties, may move them towards the Center of the Earth." (*Micrographia*, quoted in Henry, "Occult Qualities and the Experimental Philosophy", 347-48.) Commenting upon this passage, Henry remarks (*ibid.*, 348), "This universal incongruous subtle fluid may well have provided a model for Newton's aether speculations." Henry also speaks of Hooke's subtle fluid as having an "occult power of detrusion or repulsion", similar to the repulsive action in Newton's aether. This is not a flight of fancy, Henry writes, for Hooke had a "familiar exemplar of a fluid whose parts seemed to detrude one another to a remarkable extent", namely air. When placed in a Torricellian vacuum, a sheep's bladder filled with air would expand to become taut. "So began a major effort to understand the mysteries of the 'spring' of the air." (Henry, *ibid.*)

[305] Query 21, *Opticks*, 350-352.

Most commentators deny that Newton intended this as a hypothesis to be seriously investigated (for the purpose of hypotheses, Newton writes, is to "furnish experiments"[306]). Since the hypothesis has serious conceptual difficulties, some commentators argue that Newton probably intended it only as a means of silencing his critics, who charged him with accepting action at a distance.[307] And the Halls argue that to suppose that Newton took the aether hypothesis seriously is to suppose that he did not take the gravitational force to be real.[308] Against this position, Andrew Janiak argues that Newton was justified in thinking that his mathematical characterization of gravity identified a real force, one with causal efficacy, even though he had not discovered its physical characterization. To note just one point of Janiak's argument, even if gravity's physical characterization turned out to involve an aether, it would remain true that the only salient variables in the accelerating bodies would be their masses and distance of separation.[309]

---

306 Newton to Oldenburg, for Pardies, 10 June, 1672, *Philosophical Transactions* 85, 5014, quoted in Harper and Smith, "Newton's New Way of Inquiry", 120.

307 See McGuire ("Force, Active Principles", 187) and Hawes ("Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", 209-210); Hawes argues that Newton simply wished to end the disputes over Leibniz's charges. A dissenting voice come from Laudan, who argues that Newton did accept the aethereal speculations of the *Opticks*. Yet as McMullin notes (*Newton on Matter and Activity*, 151), Laudan's discussion of the *Opticks* aether focuses upon optical and chemical phenomena, not upon the Query 21 hypothesis about gravitation.

308 See Hall and Hall: "The main objection to wholehearted endorsement of the view that Newton was (at best) a discreet aetherist, is the obvious fact that it makes a nonsense of the *Principia* and of all of that achievement in mechanics for which Newton has been venerated above all. For...*if* Newton meant what he said when he spoke of forces in physics (in the *Principia* texts as printed, and in so many manuscript passages), then he was indeed introducing a great new idea, analogous to and preparing the way for that of the field in nineteenth century physics. The force concept introduced by Newton enabled him to transcend Cartesian, billiard-ball mechanism, the mechanism of impact. If particle A moves, it is not necessarily because it has been struck by particle B; it may be that a force (which is gravitational, magnetic, electrical, or chemical in nature) has acted upon it. It was this second-order mechanism that permitted Newton to extend the mathematization of physics so far, to construct celestial mechanics, and to reestablish the void. In fact it enabled Newton to reestablish atomism by returning to concepts closer to those of Epicurus than was the corpuscularian mechanism of the Cartesians; it was precisely the addition of the idea of force that made *mathematical* atomism feasible....Newton's late discovery of the true power of the law of gravitation—after 1680—was a blow to his aetherial hypotheses….With the law came the intersteller vacuum." ("Newton and the Theory of Matter", *Newton: Texts, Backgrounds, Commentaries* 79-83.)

309 For this argument against the Halls' position, and a concomitant supposition that Newton did take Query 21's aether hypothesis seriously, see Janiak, "Newton and the Reality of Force".

It is difficult simply to dismiss Query 21's hypothesis as simply a method of silencing critics. For one thing, it is difficult to dismiss any of Newton's published claims, given that he was so cautious, holding so much back from publication and so carefully drafting and redrafting what he did publish. Additionally, it would leave Newton's reasons for including Query 21 unexplained. Its hypothesis about gravity was unlikely to placate his critics, since instead of doing away with action at a distance; it merely replaced long-range attractions among the celestial bodies with shorter-range repulsions among the aethereal particles.[310]

Still, the hypothesis is at best extremely puzzling. The difficulty is not that Newton is explaining gravitational effects by surface action, as some commentators have suggested.[311] The hypothesis does not repudiate the General Scholium's remark that gravity acts in proportion to the quantity of solid matter rather than in proportion to the bodies' surfaces. To repudiate that claim would require saying that the aether is stopped at the bodies' surfaces, but even though Newton writes that the aether an "press upon gross bodies", he also writes that it penetrates the bodies' pores. So the hypothesis does not propose an operation by or proportional to surface action. Yet even so, it is difficult to see how the hypothesis could bear out the result that gravity is a function of mass. If we consider two planets, located at the same distance from the sun and having the same volume but different densities, the denser one would have fewer pores; it therefore might contain fewer aether particles (assuming for the moment that the aether particles could only be lodged in the pores, as opposed to penetrating the hard particles of matter). Without some addition to the story, this denser and more massive planet would seem to be subject to a lesser gravitational force, rather than the greater force expected in virtue of its greater mass.

[310] If Newton did consider the hypothesis seriously, perhaps it is connected to Query 30's speculations about the transformability of light and matter. Could his long-standing speculations about such transformations be the source of his speculation that as light diffuses, in an inverse-square relation, in proceeding outward from the sun, a density gradient of aethereal particles increases? The evidence seems too thin to pursue such questions, yet so long as they persist it is difficult to dismiss Query 21 entirely.

[311] See Hawes: "The larger the surface area of the gravitating body, the greater the force that would act on it because of the increase in the quantity of the surrounding aether." ("Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", 210.)

A further difficulty is that the density gradient does not account for universal gravitation. By universal gravitation, accelerations should occur not only between, say, a pair of bodies lying along the density gradient, such as the sun and the Earth, but also between a pair of bodies lying perpendicular to the gradient. If these bodies lying perpendicular to the gradient gravitate toward one another, it is not in virtue of Query 21's density gradient, for that impels the bodies only inward, toward the area of lesser aethereal density, not toward one another. Might there be additional gradients to explain these cases, in the manner of Descartes' minor vortices? This is difficult to conceive; since gravitation is universal, some gradient would be required between any given pair of particles. Another possibility is that the mutual accelerations of bodies not lying along the gradient have a different cause than those lying along the gradient. Yet it would be quite unsatisfactory to invoke two distinct causes of gravitational phenomena.

It is also notable that Query 21's hypothesis does not do away with action at a distance, since the aether is mostly empty space, and the aethereal particles repel one another. It therefore would not preserve the expectation that all causation is local, unless there existed a further, continuous medium that caused the repulsions among the aethereal particles. Yet if Newton were to invoke a continuous medium at that level, to avoid distant action among the aethereal particles, why not posit the continuous medium from the outset, without invoking an immaterial aether? Without any further, continuous medium, the most that the Query 21 hypothesis could preserve is the expectation that *matter* cannot act distantly. To do that, however, one would need to hold that the aethereal particles are not material.

One reason to hold that the aethereal particles, if they exist, are not material is this: to explain gravitational effects via a material aether invites a regress. For if the aethereal particles are material, then by universal gravitation, they too must gravitate. Some further substance must then be invoked to explain the approach of the aethereal particles toward one another, but if it too must be material, then it too will gravitate, requiring a further substance. Newton was well aware that regress would ensue, and in the first edition of the *Principia* used the consequence of a regress in arguments to show that one cannot explain gravitational effects by invoking an aether that either lacks gravity or has a lesser tendency to gravitate, in proportion to its quantity of matter.[312] Might one try to block the regress by arguing that the aether particles have sufficient repulsive force to counteract their gravitational tendency to approach one another? No, for even if the effects of the gravitational tendency of the particles to approach one another were obscured by their repulsive force upon one another, the tendency itself would still require explanation.

To suppose an *immaterial* aether is also problematic, however. Without matter's sensible effects, such as resistance, it is difficult to see how an immaterial aether could have any basis in the phenomena. This is a problem I explore in detail in my final chapter.

Concluding Remarks

I have argued that despite Newton's expectation that matter is passive and unable to act distantly, he does not attribute gravitational effects to primary causation. He instead treats gravity as a real physical force, and seeks the cause of gravitational effects in the natural order. I have also argued that despite initial appearances, we cannot conclude that Newton attributes active powers of attraction or repulsion directly to the particles of matter, such that no intermediary is

---

[312] For the 1713 edition of the *Principia*, Newton writes but ultimately does not publish a corollary setting out the regress argument. In all editions of the *Principia*, Corollary 1 to Proposition 6 of Book III states that the weights of bodies depend only upon the quantity of matter, not upon forms or textures. In the 1687 edition, Corollary 2 then states that there cannot be a material aether, or any other matter, that either fails to gravitate or else gravitates less in virtue of its form (and here Newton presumably means the fineness of its particles). Newton's reasoning here depends upon a hypothesis that he will eliminate for successive editions of the *Principia* (i.e., Hypothesis III, which states: "Every body can be transformed into body of any other kind, and can assume successively all intermediate degrees of quality.") In accordance with the elimination of that hypothesis, Newton revises Corollary 2 for the 1713 edition, but the content of the Corollary remains much the same. Another revision—a further corollary that he writes but ultimately does not include—states the regress argument about the aether. Any attempt to explain gravitational effects by postulating a rare material medium that lacks gravity or has a lesser gravitational tendency will end in a regress:

> If anyone should deny these Hypotheses and have recourse to a third hypothesis, namely, that one admit some matter with no gravity by which the gravity of the perceptible matter may be explained; it is necessary for him to assert two kinds of solid particles which cannot be transmuted into one another: the one [kind] of denser [particles] which are heavy (have gravity) in proportion to the quantity of matter, and out of which all matter with gravity and consequently the whole perceptible world is compounded, and the other [kind] of less dense particles which have to be the cause of the gravity of the denser ones but themselves have no gravity, lest their gravity might have to be explained by a third kind and that (again by a fourth) and so on to infinity. (MS. U.L.C. Add. 3965.6, folio 267^{r}; the passage appears in McGuire, "Transmutation and Immutability: Newton's Doctrine of Physical Qualities", 264.)

required for bodies to affect one another. The possibility does remain though, in particular the possibility that he attributes *inessential* active powers to matter, and I address that possibility in the final chapter. The electric spirit does not extend through the heavens, and is not a hypothesis for the physical cause of gravitational effects. The aether of the Query 21 is presented as such a hypothesis, but as presented, it would not account for universal gravitation. Concurrently, then, Newton continues to explore the notion of some "active principles", which since they are not substances will be considered in the next chapters.

The discussion of active principles will show just how pressing the problem about gravity is. Although in one respect the gravitational force stands alone, differing from the electrical and magnetic forces in being only attractive, in another respect it is not *sui generis*. Newton speculates that nearly all the motion we observe is "new motion", that is, motion that is generated by some active source. Gravitational effects are just one kind in a vast class of new motions.

REFERENCES

Alexander, H.G., ed., *The Leibniz-Clarke Correspondence*, Manchester: Manchester University Press, 1956.

Aquinas, Thomas, *Summa Theologica*, in Anton Pegis (ed.), *Basic Writings of Saint Thomas Aquinas*, New York: Random House, 1945.

Boas, Marie, "The Establishment of the Mechanical Philosophy", *Osiris* 10 (1952), 412-54.

Cohen, I. Bernard, "A Guide to Newton's *Principia*", with contributions by Michael Nauenberg and George E. Smith, in Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I.Bernard Cohen and Anne Whitman, Berkeley: University of California Press, 1999.

Dempsey, Liam, "Written in the flesh: Isaac Newton on the mind–body relation", *Studies in History and Philosophy of Science* 37:3 (2006), 420-441.

Dobbs, Betty Jo Teeter, "Newton's Alchemy and His Theory of Matter", *Isis* 73 (1982), 512-28.

Hawes, Joan L., "Newton and the 'Electrical Attraction Unexcited'", *Annals of Science* 24:2 (June, 1968), 121-130.

Hawes, Joan L., "Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", *Notes and Records of the Royal Society of London* 23:2 (Dec., 1968), 200-212.

Hawes, Joan L., "Newton's Two Electricities", *Annals of Science* 27:1 (March, 1971), 95-103.

John Henry, "Occult Qualities and the Experimental Philosophy", *History of Science* 24 (1986), 335-381.

Janiak, Andrew, "Newton and the Reality of Force", *Journal of the History of Philosophy* 45 (2007), 127-47.

Janiak, Andrew, *Newton as Philosopher*, Cambridge: Cambridge University Press, 2008.

McGuire, J.E., "Transmutation and Immutability: Newton's Doctrine of Physical Qualities", reprinted in J.E. McGuire, *Tradition and Innovation: Newton's Metaphysics of Nature*, Boston: Kluwer Academic Publishers, 1995.

McMullin, Ernan, *Newton on Matter and Activity,* Notre Dame: University of Notre Dame Press,1978.

Newton, Isaac, *Unpublished Scientific Writings of Isaac Newton*, ed. A.R. Hall and Marie Boas Hall, Cambridge: Cambridge University Press, 1962.

Newton, Isaac, *Correspondence of Isaac Newton*, ed. H.W. Turnbull *et al*., Cambridge: Cambridge, 1959-1971.

Newton, Isaac, *Newton: Texts, Backgrounds, Commentaries*, ed. I. Bernard Cohen and Richard S. Westfall, New York: W.W. Norton & Co., 1995.

Newton, Isaac: *The Principia: Mathematical Principles of Natural* Philosophy, trans. I Bernard Cohen and Anne Whitman, Berkeley: University of California Press, 1999.

Newton, Isaac: *Newton: Philosophical Writings*, ed. Andrew Janiak, Cambridge: Cambridge University Press, 2004.

Smith, George and Harper, W., "Newton's New Way of Inquiry", in Jarrett Leplin, (ed.), *The creation of ideas in physics: studies for a methodology of theory construction*, Boston: Kluwer Academic Publishers, 1995.

Stein, Howard, "Newton's Metaphysics", in *Cambridge Companion to Newton*, I. Bernard Cohen and George E. Smith (eds.), Cambridge University Press, 2002, 256-307.

Westfall, Richard S., *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century*, London: Macdonald and Co.; New York: American Elsevier Publishing Company, 1971.

Westfall, Richard S., *Never at Rest: a Biography of Isaac Newton*, New York: Cambridge University Press, 1980.

CHAPTER V

NEW MOTION AND ACTIVE PRINCIPLES

Why does Newton suggest that the universe contains an active source of new motion, how are active principles related to distance forces, and what might active principles be?

Impressed by what William Thomson would in the next century call "the universal tendency in nature to the dissipation of mechanical energy"[313], but lacking the concept of energy, Newton writes in Query 31, "Motion is much more apt to be lost than got, and is always upon the Decay."[314] He goes on to argue that passive principles alone cannot explain the phenomena, and that the universe must contain some sort of active principles—some generative source of new motions. Since these arguments are confined to one of the *Opticks*' queries, they have the status of hypotheses, intended only "to furnish experiments".[315] (This should be borne in mind, though for convenience I often use phrases such as 'Newton argues' and 'Newton concludes'.) Yet Newton's tone is strikingly confident, and it is clear that he expects active principles to be fundamental to the workings of nature. In this chapter, I examine Newton's reasons for thinking that the universe contains some generative source of new motion—some "active principles". I then examine the relationship between distance forces and active principles, and I ask what these active principles might be.

---

313 William Thomson (the future Lord Kelvin), 1852, quoted in Price, *Time's Arrow and Archimedes' Point*, 24.

314 Query 31, *Opticks*, 398.

315 As Newton wrote to Oldenburg (1672), hypotheses were valuable only "in so far as they may furnish experiments". (Letter to Oldenburg, *Newton's Philosophy of Nature: Selections from his Writings*, 6.)

THE ARGUMENT FOR NEW MOTION

Although Newton has a principle of conservation of motion, he does not have additional concepts that might prevent him from concluding that the universe contains an active source of new motion. He does not share Descartes' metaphysically based belief that the universe's quantity of motion must remain constant, nor does he have the principle of the conservation of angular momentum or a concept of energy. The concepts that he lacks are factors external to his reasoning process, and a full discussion of them, in particular of energy, would lead us into the complex debate about *vis viva*. I focus instead upon the internal reasoning by which Newton defends a belief in active principles.

The Principle of Conservation of Motion (Linear Momentum)

In developing his principle of the conservation of motion, Newton has Descartes' work on collisions and motion to use as a foil or at least as a point of reference. Descartes' incorrect laws of collision must have been useful to Newton, for as clearly articulated claims, they could be evaluated and overturned.[316] Descartes also set out a principle that he derived from God's immutable nature: that the quantity of motion in the universe remains constant. Newton will draw upon this principle but ultimately reject it, and I shall therefore distinguish Newton's own principle of the conservation of motion from Descartes' principle by calling the latter 'the principle of the preservation of motion'. According to Descartes, a body can lose motion only by transferring it to other bodies, and motion can no more be generated than lost (except insofar as the entire universe is continually recreated by God[317]). So as bodies collide with one another, the quantity of motion remains constant.

---

[316] See Herivel: "The laws of collision given by Descartes in Part II of his *Principia* were notoriously full of error. Nevertheless they represented the first widely known published attack on the problem based on the notion of momentum and its conservation, and as such would inevitably influenced Newton's approach, if only indirectly." (*Background*, 52.)

[317] As noted in chapter II, this position has led some commentators to attribute occasionalism to Descartes. That view is explored and opposed by Daniel Garber; see *Descartes' Metaphysical Physics*, especially 301-302.

Descartes construes motion in terms of speed and volume—speed because he does not have the concept of vector quantities, and volume because he lacks the concept of mass. Let us suppose a universe comprising two identical bodies, which approach one another at equal speeds and then come to a stop upon collision. This supposition would conflict with Descartes' principle of the preservation of motion. If motion is a scalar quantity, the claim that the total quantity of motion is preserved conflicts with the claim that there is a positive quantity of motion prior to the collision but zero motion afterward. So if one insists upon Descartes' principle of the preservation of motion, one must conclude that in this two-body universe, the motion has not been extinguished but only transferred, presumably to the level of unobservable bits of matter. In our actual universe, which comprises many bodies, we observe a positive quantity of motion, and by Descartes' principle, this scalar quantity motion of motion cannot be changed. Motion can only be transferred, so the universe cannot run down.

Newton, however, understands motion as the vector quantity that we know as 'linear momentum'. As Newton states in Definition 2 of the *Principia*, the quantity of motion is the measure of motion arising "from the velocity and the quantity of matter jointly." Corollary 3 to Law 3 indicates that velocity and thus motion is a vector quantity.

> Corollary 3. The quantity of motion, which is determined by adding the motions made in one direction and subtracting the motions made in the opposite direction, is not changed by the action of bodies on one another.[318]

Corollary 4 then tells us that the center of gravity of a system is not changed by the actions of its bodies upon one another.[319]

[318] *Principia*, 420.

[319] Corollary 4 appeared earlier as Law 4 in *De Motu*, the draft that served as the basis for the *Principia*. See *De Motu*: "*Law* 4. By the mutual actions between bodies the common centre of gravity does not change its state of motion or rest. It follows from Law 2." (*Background*, 299.)

> Corollary 4. The common center of gravity of two or more bodies does not change its state whether of motion or of rest as a result of the actions of the bodies upon one another, and therefore the common center of gravity of all bodies acting upon one another (excluding external actions and impediments) either is at rest or moves uniformly straight forward.[320]

Because Newton understands velocity as a vector quantity, his principle of the conservation of motion is crucially different from Descartes' preservation principle. The supposition that the two bodies mentioned in our earlier supposition come to a halt upon collision does not conflict with Newton's principle of the conservation of motion. Since velocity and thus momentum are vector quantities, the total momentum of the system is zero both before and after collision. So Newton's principle is not by itself sufficient to guarantee that the universe will not run down.

In Query 31, Newton contests the related Cartesian claims that (a) a body can lose motion only by transferring that motion to other bodies; and (b) the quantity of motion in the universe remains constant. He first presents a thought experiment designed to show that motion can be lost and gained, and he then presents cases involving collisions designed to show that motion decays.

Losses and Gains by the Composition of Motion: Query 31's Two-Globe Case

It is "very certain" from the composition of motions, Newton argues in Query 31, that the quantity of motion in the world is not constant. To show this, he presents the following thought experiment, involving a system of two globes connected by a rod (a dumbbell), which rotates as its center of gravity moves in a right line. So it rotates while moving in absolute translation across absolute space.

> For from the various Composition of two Motions, it is very certain that there is not always the same quantity of Motion in the world. For if two Globes joined by a slender Rod revolve about their common Centre of Gravity in an uniform Motion, while that Centre moves on uniformly in a right Line drawn in the Plane of their circular Motion, the Sum of the Motions of the two Globes, as often as the Globes are in the right Line described by their common Centre of Gravity, will be bigger than the Sum of their

[320] *Principia*, 421.

> Motions, when they are in a Line perpendicular to that right Line. By this Instance it appears that Motion may be got or lost.[321]

This conclusion, that the quantity of motion is greater when the rod is aligned with the right line motion than it is when perpendicular to it, has an interesting irony. Much earlier, in *De Gravitatione*, Newton leveled the following criticism as a reason to reject Descartes' doctrine of relative motion: "It follows from the Cartesian doctrine that motion can be generated where there is no force acting."[322] Yet with Query 31's two-globe case, Newton seems to abjure that criticism; since the result of a changing quantity of motion is generated by the composition of motions, Newton implies that motion can be generated without force.

The case is puzzling for another reason: we cannot produce Newton's result of unequal values for the two orientations if we take him to be performing a vector sum. If we assume he is performing a vector sum, the quantities of motion are equal for the two orientations of the rod. (See Appendix for details.) If, however, we suppose instead that Newton is performing a numerical sum,[323] first taking the magnitude of each globe's motion (momentum) and then adding them, we do produce Newton's result. (See Appendix for details.) The numerical sum is greater when the rod connecting the globes lies with the right line of absolute translation rather than perpendicular to it.

As the dumbbell rotates while moving along a right line, then, the quantity of motion changes; motion is "got and lost". The case therefore contests both of the Cartesian claims

---

[321] Query 31, *Opticks*, 397-398.

[322] See *De Gravitatione*: "It follows from the Cartesian doctrine that motion can be generated where there is no force acting. For example, if God should suddenly cause the spinning of our vortex to stop, without applying any force to the earth which could stop it at the same time, Descartes would say that the earth is moving in a philosophical sense—on account of its translation from the vicinity of the contiguous fluid—whereas before he said it was at rest, in the same philosophical sense....It also follows from the same doctrine that God himself could not generate motion in some bodies even though he impelled them with the greatest force. For example, if God impelled the starry heaven together with all the most remote part of creation with any very great force so as to cause it to revolve around the earth (suppose with a diurnal motion): yet by this, according to Descartes, the earth alone and not the sky would be truly said to move (Part III, article 38), as if it would be the same whether, with a tremendous force, he would cause the skies to turn from east to west, or with a small force turn the earth in the opposite direction. But who will suppose that the parts of the earth endeavor to recede from its center on account only of a force impressed upon the heavens?" (*Philosophical Writings*, 18.)

[323] I thank Lon Becker for suggesting this possibility.

mentioned above. Contra (b), the quantity of motion in the universe does not remain constant, since contra (a), each globe loses motion at various points in the rotation, but does so without communicating that motion to another body. This result is consistent with that part of Newton's Corollary 3 which states, "the quantity of motion...is not changed by the action of bodies on one another", since the losses (and gains) of motion do not result from any action between the bodies. They result from the "composition of two motions".

The notable point about the two-globe case is that Newton does have a means of supporting rather than denying Descartes' claim that the quantity of motion in the universe remains constant. If he were inclined to accept that claim, he could support it by taking the vector sum.[324] Instead, he takes the numerical sum, and concludes that the universe's quantity of motion is not constant. This conclusion is especially striking because allowing that the quantity of motion in the universe can change as a result of the composition of motions, rather than by a force, makes him guilty of the same charge he leveled at Descartes much earlier, as noted above. All of this suggests that Newton's expectation that the universe contains some active source of new motion is very strong.

Losses of motion in collisions: the weakness of elasticity of solids

As Newton understands the two-globe case, it tells against the previously mentioned Cartesian claims that (a) a body can lose motion only by transferring that motion to other bodies; and (b) the quantity of motion in the universe remains constant. He continues his attack upon these claims in the following passage.

[324] *Vis viva* offers another means of emphasizing that which is constant. Newton does not address the *vis viva* debate, and so he does not bring the developing concept of energy into his analysis. If one makes use of Huygens and Leibniz's *vis viva*— mv^2 and thus kinetic energy but for the factor 1/2—there is no inequality between the right and perpendicular orientations of the rotating dumbbell. The controversy about *vis viva* began with Leibniz's work on collisions, specifically with his 1686 publication in *Acta Eruditorum* of "A Brief Demonstration of a Notable Error of Descartes and Others Concerning a Natural Law." Leibniz noticed that the sums of bodies' *vis viva*, that is, mv^2, is conserved in elastic collisions. This was a significant step toward a general principle of conservation of energy. However, the debate was complex and focused largely upon the question of whether the true measure of force was *vis viva*, or change of momentum. Newton became aware of the debate at some point following the first edition of the *Principia*, but did not address it in later editions. On the history of the *vis viva* controversy, see George Smith: "The *vis viva* dispute: A controversy at the dawn of dynamics", 31.

> But by reason of the Tenacity of Fluids, and Attrition of their Parts, and the Weakness of Elasticity in Solids, Motion is much more apt to be lost than got, and is always on the Decay. For Bodies which are either absolutely hard, or so soft as to be void of Elasticity, will not rebound from one another. Impenetrability makes them only stop. If two equal Bodies meet directly *in vacuo*, they will by the Laws of Motion stop where they meet and lose all their Motion, and remain in rest, unless they be elastick and receive some new Motion from their Spring. If they have so much Elasticity as suffices to make them rebound with a quarter, or half, or three quarters of the Force with which they come together, they will lose three quarters, or half, or a quarter of their Motion. And this may be tried, by letting two equal Pendulums fall against one another from equal Heights. If the Pendulums be of Lead or soft Clay, they will lose all or almost all their Motions: If of elastick Bodies, they will lose all but what they recover from their Elasticity. If it be said, that they can lose no Motion but what they communicate to other Bodies, the consequence is, that *in vacuo* they can lose no Motion, but when they meet they must go on and penetrate one another's Dimensions.[325]

Here Newton mentions several causes of the decay of motion, including the weakness of elasticity in collisions, and he concludes the passage with the following argument against the above-noted Cartesian claim (a). If the Cartesians were correct in saying that a body loses only the motion that it communicates to other bodies, then colliding bodies that do not communicate motion to one another should instead pass through one another. Thus partially elastic bodies, which lose some of their motion, should partially interpenetrate one another, and bodies that lose all of their motion should fully interpenetrate, and then pass through one another. Yet this does not happen. Colliding bodies that fail to communicate motion to one another do not pass through one another; pendulums made of clay, for example, simply stop. So contra the Cartesians, a body can lose motion without communicating it to another body. In the two-globe case, such losses were a result of the composition of motions, but here the losses result from the weakness of elasticity.

The case accords with Newton's principle of conservation of motion; in accordance with Corollary 3, the pre- and post-collision momenta are equal. But like the two-globe case, it does not agree with Descartes' preservation principle, for the world is very different after the collision

[325] Query 31, *Opticks*, 398.

than it was before. This is underscored in the cases of absolutely hard bodies, and bodies so soft as to be void of elasticity,[326] since prior to the collisions there was absolute motion, but afterward there is absolute rest. (I am disregarding, of course, the earth's motion, and that "bodies commonly regarded as being at rest are not always truly at rest".[327]) The tenacity of fluids accounts for further decay of motion.[328] With enough such cases, the world would run down, absent anything to provide new motion, and this is the claim toward which Newton is heading.

Yet just as in the two-globe case, Newton could avoid the conclusion that motion decays, if he were so inclined. If he hoped to preserve Descartes' claim that the quantity of motion in the universe remains constant, he could speculate that the losses of motion from friction and collisions are only apparent. In reality, he could argue, motion lost at the macro level has simply been transferred to the micro level, as heat. Such an argument had precedents, for instance in Boyle.[329] Yet Newton does not take that path, and instead associates heat with forces that appear to act at a distance, and concomitantly with active principles.

---

[326] Bodies that are hard but not perfectly so are elastic, as is evident in the following passage from the *Conclusio*: "Just as that vibratory motion of which sound consists is as well propagated through wood and other long solid bodies by transmission through their contiguous parts as through air by transmission through the forces of non-contiguous particles; so the vibratory motion of which heat possibly consists can be propagated as well through the forces of non-contiguous parts as through the impulses of contiguous ones. For all bodies when they have become sufficiently hard are elastic and hence, as it seems to me, if fluids are composed of hard particles these also will be elastic." (*Conclusio*, c. 1687, in *Unpublished Scientific Papers of Isaac Newton,* 346-47) However, Newton classifies the idealized case of perfectly hard bodies together with soft bodies. Both, he indicates in Query 31, will fail to rebound, which is to say that they are inelastic. Wilson Scott and Christian Boudri have argued that Newton's definition of hardness as an inability to rebound weighed against acceptance of the view that mv^2, known as *vis viva*, was conserved, and thus hindered progress toward a principle of conservation of kinetic energy. See Scott, *The Conflict between Atomism and Conservation Theory (1644-1860).* See also Christian Boudri, *What was Mechanical about Mechanics? The Concept of Force between Metaphysics and Mechanics from Newton to Lagrange*, 105-106

[327] *Philosophical Writings*, 60.

[328] "If three equal round Vessels be filled, the one with Water, the other with Oil, the third with molten Pitch, and the Liquors be stirred about alike to give them a vortical Motion; the Pitch by its Tenacity will lose its Motion quickly, the oil being less tenacious will keep it longer, and the Water being less tenacious will keep it longest, but yet will lose it in a short time. Whence it is easy to understand, that if many contiguous Vortices of molten Pitch were each of them as large as those which some suppose to revolve about the Sun and fix'd Stars, yet these and all their Parts would, by their Tenacity and Stiffness, communicate their Motion to one another till they all rested among themselves. Vortices of Oil or Water, or some fluider Matter, might continue longer in Motion; but unless the Matter were void of all Tenacity and Attrition of Parts, and Communication of Motion, (which is not to be supposed,) the Motion would constantly decay." (Query 31, *Opticks,* 398-399.)

[329] See Boas, citing Boyle: "He noted that, 'When a hammer striking on a nail, makes the head of it grow hot, the hammer is but a purely mechanical agent, and works by local motion' ([Boyle], 209). But the hammer did not make the nail grow hot as long as its force served to drive the nail into the wall; it was only when the nail itself could no longer

Now admittedly, in considering heat and heat transfer, Newton does suggest that heat is the vibrating motion of particles. In Query 5, for instance, he writes that light upon bodies "puts their parts into a vibrating motion wherein heat consists."[330] However, Newton also clearly associates heat with activity. According to Query 30, light is the source of a great deal of activity, and the emission of light by heated bodies is offered as evidence of this.[331] Moreover, he long ago began trying to explain heat transfer in terms of distance forces. In the unpublished, 1687 *Conclusio*, he suggests that while the vibrations constituting heat may be transferred among contiguous particles by impulse, they are transferred among non-contiguous particles by forces:

> Just as that vibratory motion of which sound consists is as well propagated through wood and other long solid bodies by transmission through their contiguous parts as through air by transmission through the forces of non-contiguous particles; so the vibratory motion of which heat possibly consists can be propagated as well through the forces of non-contiguous parts as through the impulses of contiguous ones. For all bodies when they have become sufficiently hard are elastic and hence, as it seems to me, if fluids are composed of hard particles these also will be elastic.[332]

Much later, in Query 18 of the *Opticks*, he suggests that heat is transferred by an aether, and since the aether of the *Opticks* operates by repulsive forces, he is again associating heat with distance forces.[333] It seems then that Newton does not consider heat transfer as a means of avoiding the

---

move that the force of the hammer, now moving the particles composing the nail, made the nail grow hot." ("The Establishment of the Mechanical Philosophy", 471.)

[330] See for instance, Query 5: "Do not Bodies and Light act mutually upon one another....Light upon Bodies for heating them, and putting their parts into a vibrating motion wherein heat consists?" Also, in Query 28, Newton writes, "A dense fluid [i.e., such as the Cartesians propose] can be of no use for explaining the Phaenomena of Nature, the Motions of the Planets and Comets being better explain'd without it. It serves only to disturb and retard the Motions of those great Bodies, and make the Frame of Nature languish: And in the Pores of Bodies, it serves only to stop the vibrating Motions of their Parts, wherein their Heat and Activity consists." (*Opticks*, 368.)

[331] "Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter into their Composition? For all fixed Bodies being heated emit Light so long as they continue sufficiently hot, and Light mutually stops in Bodies as often as its Rays strike upon their Parts, as we shew'd above. I know no Body less apt to shine than Water; and yet Water by frequent Distillations changes into fix'd Earth, as Mr. Boyle has try'd; and then this Earth being enabled to endure a sufficient Heat, shines by Heat like other Bodies." (Query 30, *Opticks*, 374.)

[332] *Unpublished Scientific Papers of Isaac Newton*, 346-47.

[333] "Is not the Heat of the warm Room convey'd through the *Vacuum* by the Vibrations of a much subtiler Medium than Air, which after the Air was drawn out remained in the *Vacuum*? And is not this Medium the same with that Medium

acceptance of active principles, because he has already associated heat with activity and with distance forces. So just as in the two-globe case, Newton passes up opportunities to deny that motion is genuinely lost, and thus to deny the existence of new motion.

The Inference to a Generative Source of New Motion

Unlike the two-globe case, cases involving collisions and friction do not have a built-in means of compensating losses of motion with gains. In the two-globe cases, there was a cycle of losses and gains in motion, both explained by the composition of motions. The cases of collisions and friction produce only the decay of motion, which means that if lost motion is to be replenished by new motion, that new motion must have some independent source. Newton argues in Query 31 that the source of this new motion cannot be the "passive principles" by which bodies persist in their state, receive motion in proportion to impressed forces, and resist as much as they are resisted. In other words, the source of new motion cannot be the three laws of motion. There must be some further principle that both produces and conserves motion.

> Nature will be very conformable to herself and very simple, performing all the great Motions of the heavenly Bodies by the Attraction of Gravity which intercedes those Bodies, and almost all the small ones of their Particles by some other attractive and repelling Powers which intercede the Particles**.** The *Vis inertiae* is a passive Principle by which bodies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the World. Some other Principle was necessary for putting bodies into Motion; and now they are in Motion, some other Principle is necessary for conserving the Motion.[334]

---

by which Light is refracted and reflected, and by whose Vibrations Light communicates Heat to Bodies, and is put into Fits of easy Reflexion and easy Transmission? And do not the Vibrations of this Medium in hot Bodies contribute to the intenseness and duration of their Heat? And do not hot Bodies communicate their Heat to contiguous cold ones, by the Vibrations of this Medium propagated from them into the cold ones? And is not this Medium exceedingly more rare and subtile than the Air, and exceedingly more elastick and active? And doth it not really pervade all Bodies? And is it not (by its elastick force) expanded through all the Heavens?" (Query 18, *Opticks*, 348-49.)

[334] Query 31, *Opticks*, 397.

As the passage continues, Newton calls these further principles "active principles", and he attributes a vast and diverse class of phenomena to them.

> Seeing therefore the variety of Motion which we find in the World is always decreasing, there is a necessity of conserving and recruiting it by active Principles, such as are the cause of Gravity, by which Planets and Comets keep their Motions in their Orbs, and Bodies acquire great Motion in falling; and the cause of Fermentation, by which the Heart and Blood of Animals are kept in perpetual Motion and Heat; the inward Parts of the Earth are constantly warm'd...and the Sun continues violently hot and lucid, and warms all things by his Light. For we meet with very little Motion in the World, besides what is owing to these active Principles. And if it were not for these Principles, the Bodies of the Earth, Planets, Comets, Sun, and all things in them, would grow cold and freeze, and become inactive Masses; and all Putrefaction, Generation, Vegetation and Life would cease, and the Planets and Comets would not remain in their Orbs....It seems to me farther, that these particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity, that which causes Fermentation, and the Cohesion of Bodies."[335]

What exactly does Newton mean by saying that we meet with very little motion except that due to active principles? I take up this question in my final chapter. There, I argue that Newton does not expect the scope of the collision model merely to be reduced. In Cartesian systems, which have come to be known as the orthodox mechanical philosophy, collisions served as the model for causal interactions among material bodies. Motion could be transferred in collisions, but could not be generated and destroyed; and these collisions were assumed to operate by contact action. I will argue that Newton's departure from this mechanical philosophy is more radical than has previously been recognized, because his speculations about collisions indicate that he expects even these to operate by distance forces, force that, whatever their causal story may be, do not act by material contact. Indeed, I will argue, Newton expects all motions other than the absolute translations caused by the *vis inertiae* to be due to active principles. At the moment, however, I turn to the question of what these active principles might be.

[335] Query 31, *Opticks*, 399-401.

ACTIVE PRINCIPLES

Newton's speculations about active principles begin at an early point. Although he is strongly influenced by the Cartesian mechanical philosophy, which attempted to eliminate animistic elements from the material world, mechanical explanations in terms of surface impacts had difficulty with a range of phenomena. Not only did vortex theories, which were based upon the impact model, founder with Kepler's laws, comets, and the proportionality of gravity to mass rather than surface area, the impact model seemed inapplicable to magnetic effects, the cohesion of bodies, and the spring of the air. (For it was known that a sheep's bladder filled with air would expand once placed in a vacuum, indicating that the air particles endeavor to recede from one another.) Even more difficult to reconcile with the reduction of all material processes to surface impacts were biological processes and chemical reactions, which do not appear to operate by a Cartesian-style transfer of motion. The strongest adherents of the orthodox mechanical philosophy were typically those who did not attempt to solve the riddles of biological and chemical processes. And when orthodox mechanical philosophers did apply themselves to such problems, they often turned to disguised animistic elements, as Westfall has observed.[336] Newton attempts to understand chemical and biological phenomena, and in doing so he invokes active principles directly. In doing so, he is influenced by several sources. These include the alchemical treatises that he studied carefully in his early years and also the neo-Platonist ideas of Henry More and Ralph Cudworth.[337] Newton is also familiar with the view, developed by some elder English thinkers and articulated most clearly by legal theoretician Mathew Hale, that matter has some inessential active powers.[338] That view implies that matter can act distantly, and I shall

---

[336] As an example, Westfall mentions John Mayow's theory: "His nitro-aerial particles were the source of all activity in nature—of animal life, animal motion, vegetable life, elasticity, and much else. Without facing the question of what an active principle could be in a mechanical universe, he had merely tricked it out in a particulate costume and deluded himself that the issue was solved." (*Force*, 367.)

[337] See McGuire, "Force, Active Principles", 204; see also McMullin, *Newton on Matter and Activity*, 43-44.

[338] Concerning the influence of Hale and Charleton on Newton, see Henry, "Occult Qualities and the Experimental Philosophy"; see also Westfall, "The foundations of Newton's philosophy of Nature", 171-82.

address it in my final chapter. Here I focus upon the influences from Cudworth and from alchemy.

In the early stages of his thought, Newton's ideas about active principles focus upon a search for active substances. Later, distance forces come to dominate his understanding of natural phenomena, and he connects active principles to these distance forces. The search for an active substance continues, however, for as Newton writes in another context, "action requires substance".[339] The effort to provide a causal story for distance forces is thus an effort to discover which substances communicate the action and how they do so. As Newton attempts to discover what active principles might be, his thoughts remain extremely speculative, as we shall see.

Early Influences: Cudworth's Plastick Natures

In his *True Intellectual System of the Universe*, Cudworth reacts against a number of views he considers atheistic, including that of Thomas Hobbes, which allows matter to have life. His own account of natural phenomena sharply distinguishes passive matter from active spirit, soul or life. Contrasting passive and active powers, he writes,

> To the latter of which belongs both cogitation, and the power of moving matter, whether by express consciousness or no. Both of which together may be called by one general name of life; so that they made these two general heads of being or entity, passive matter or bulk, and self-activity or life. The former of these was commonly called by the ancients…'that which suffers and receives' and the latter…'the active principle'.[340]

Motions and other changes in matter are produced as living or active principles act upon it. Matter, being passive, is lower in the chain of being than are all of the active principles or spirits that Cudworth classifies together under the name 'life'. This category includes not only God and minds, but also an immaterial "plastick nature" to which Cudworth attributes all the mundane

[339] General Scholium, *Principia*, 941. In the General Scholium, Newton contests the prevailing view that God is only virtually present throughout space, arguing that since action requires substance, God is also substantially present throughout space.

[340] Ralph Cudworth, *The True Intellectual System of the Universe*, quoted in McGuire, "Force, Active Principles", 204.

workings of the created world. Cudworth employs this plastick nature as a means of explaining natural phenomena while avoiding both the Scylla of Hobbes and the Charybdis of occasionalism. Hobbes allows matter to be alive, and that atheistic path is to be avoided. So too is occasionalism, a doctrine holding that only God can be truly active, and thus that God directly causes each event in the universe. Cudworth takes occasionalism to be unseemly for the deity; as Descartes remarked, we should not believe that God "employs his own hands…to hurl lightning upon rocks".[341] So Cudworth's plastick nature is not identical to God's will. It is instead something distinct from God, having been created by him to bring about mundane effects.

What exactly is this plastick nature? Although it is a law, or set of laws, it is not propositional. It is not a verbal command.

> The Laws or Commands of the Deity, concerning the Mundane Oeconomy (they being really the same thing) ought not to be looked upon, neither as *Verbal things*, nor as mere *Will* and *Cognition* in the Mind of God; but as an *Energetical and Effectual Principle*, constituted by the Deity, for the bringing of decreed things to pass.[342]

The immaterial plastick nature is simultaneously a spirit that acts upon matter—as indicated by the term 'immaterial'—and the laws governing the world. Thus Cudworth does not take laws to be verbal commands or descriptions, but in his time this was not surprising. Whereas we now take laws to be propositional, earlier conceptions differed. Francis Bacon uses the term 'law' to refer to a medieval concept of essence,[343] and one of Leibniz's conceptions of a law is a substance's internal principle of action, by which its changes are realized. Cudworth takes the plastick nature to be a law, but while Leibniz will locate such an efficacious power in each substance, Cudworth, like Henry More, identifies the efficacious power as the immaterial spirit

[341] Descartes, AT VI 231, translation by David Cunning, "Systematic Divergences in Malebranche and Cudworth", 345.

[342] Cudworth, *The True Intellectual System of the Universe*, 161 and quoted in Cunning, *op.cit.*, 353; Cunning also refers the reader also to 150, 162, and 680-81 in Cudworth.

[343] See Edgar Zilsel, "The Genesis of the Concept of Physical Law", 260-261.

that acts upon matter.[344] So the plastick nature is a law without being propositional, and it is efficacious without being identical to God's will. It is an active, efficacious spirit that is distinct from God, having been created to carry out the events that God wills. Notably, this immaterial spirit is not conscious. Cudworth compares its action to habits, which are unthinkingly performed.[345]

In asking whether Newton's search for a causal account of gravity and the speculative distance forces was influenced by Cudworth, we can identify some broad similarities. Like Cudworth, Newton tries to explain the mundane workings of the world in terms of secondary rather than primary causation, and as we shall see, in one text Newton identifies active principles with laws. Newton also allows for non-perceiving, active substances that might be immaterial, including the electric spirit, the aether, and possibly light (though these latter two, and especially light, might after all be material.) For both Newton and Cudworth, the expectation that matter is passive motivates the speculations about active spirits. Yet unlike Cudworth, Newton will not preserve that belief by simply postulating the active spirit needed to do so. He seeks instead to derive his conclusions from the phenomena.

---

[344] Henry More describes his Spirit of Nature as follows: ""[It is] a substance incorporeal, but without Sense and Animadversion, pervading the whole Matter of the Universe, and exercising a Plastical power therein according to the sundry predispositions and occasions in the parts it works upon, raising such Phaenomena in the world, by directing the parts of the Matter and their Motion, as cannot be resolved into mere Mechanical powers." (*The Immortality of the Soul*, II.12.1, 1662, and quoted in Steven Nadler, "Doctrines of Explanation", 533-534.)

[345] In the following passages, Cudworth emphasizes that the plastick nature operates without consciousness or intention.

> [A plastic nature] is not *Master* of that *Reason* and *Wisdom* according to which it acts, nor does it properly *Intend* those *Ends* which it acts for, nor indeed is it Expressly Conscious of what it doth, it not *Knowing* but only *Doing*. (*True Intellectual System of the Universe*, 162).
>
> But because this may seem strange at first sight, that Nature should be said to Act *for the sake of ends*, and *Regularly* or *Artificially*, and yet be itself devoid of *Knowledge* and *Understanding*, we shall therefore endeavour to persuade the *Possibility*, and facilitate the Belief of it, by some other Instances; and first by that of *Habits*, particularly those Musical ones of Singing, Playing upon Instruments, and Dancing. (*Ibid.*, 157).
>
> [There is] no Reason, why this *Plastick Nature* (which is supposed to move Body *Regularly* and *Artificially*) should be thought to be an Absolute Impossibility, since *Habits* do in like manner, *Gradually Evolve* themselves, in a long Train or Series of *Regular* and *Artificial Motions*, readily prompting the doing of them, without comprehending that *Art* or *Reason* by which they are directed. (*Ibid.*, 157).

For these passages and Cunning's discussion, see "Systematic Divergences in Malebranche and Cudworth", 351.

Early Influences: Alchemy

According to the alchemical treatises that Newton studied carefully, matter could be transformed and activated by various animating principles or substances. Neo-Platonism similarly distinguished active and passive principles, as we saw earlier with Kepler, and construed light as a source of activity. Newton's early investigations with chemical phenomena, light and heat, reflect the alchemy's tradition of active and passive principles, as well as the belief that light is a generative source of activity. In his 1669 manuscript, *On Nature's Obvious Laws in Vegetation*, he suggests that the Earth is like an "inanimate vegetable" whose processes require some subtle spirit or principle of vegetation that activates the "material soul" of matter. An aether is one candidate for this activating substance, but Newton also suggests that the aether might be only a vehicle to a more active substance. Given its connection with heat and necessity for growth, that more active substance could be light.[346] Later, in *An Hypothesis Explaining the Properties of Light*, which Newton presented to the Royal Society in 1675, he again appeals to active principles in connection with light and chemical phenomena. In this early work, then, active principles are associated only with substances, and not with the distance forces that later dominate his natural philosophy.

[346] "This Earth resembles a great animall or rather inanimate vegetable, draws in aethereall breath for its dayly refreshment and vital ferment and transpires again with gross exhalations….This is the subtil spirit which searches the most hiden recesses of all grosser matter which enters their smallest pores.…And thus perhaps a great part…of sensible matter is nothing but Aether congealed and interwoven into various textures….Note that tis more probable the aether is but a vehicle to some more active spirit….This spirit perhaps is the body of light 1 becaus both have a prodigious active principle both are perpetuall workers 2 because all things may bee made to emit light by heat, 3 the same cause (heat) banishes also the vitall principle. 4 Tis suitable with infinite wisdom not to multipy causes without necessity 5 Noe heat is so pleasant and brigh as the suns, 6 light and heat have a mutual dependence on each other and noe generation without heat. heat is a necessary condition to light and vegetation. heate excites light and light and light excites heat, heat excites the vegetable principle and that increaseth heat. 6 Noe substance soe indifferently, subtily and swiftly pervades all things as light." (*On Nature's Obvious Laws in Vegetation* , c. 1669, *Newton: Texts, Backgrounds, Commentaries*, 304-305.)

The Association among Active Principles, Spirits, and Distance Forces

By the publication of the *Principia* in 1687, Newton's thought has been redirected toward distance forces. The connection between distance forces and active principles, however, is not evident in the *Principia* because there his references to active principles are oblique.[347] He suggests that life on earth requires the vapor from comet tails,[348] and that such vapors may be transformed into salts and sulphurs, mud and clay, stones and other earthy substances.[349] The point about the transmutation of a comet's vapor, retained in all editions of the *Principia*, is an instance of a more general hypothesis that appears in only the 1687 edition. That more general hypothesis is the afore-mentioned Hypothesis III,[350] the suggestion that a body of any kind can be transmuted into a body of any other kind, and Newton may be thinking that some active substance is required for the transformation. His ideas about this possibility are not transient; while Hypothesis III would be eliminated by the 1713 edition of the *Principia*, a narrower claim

---

[347] McGuire writes that active principles are discussed at the end of Book III in the first edition of the *Principia*. He seems to be referring to Newton's claim that the vapours from comets have a high degree of causal efficacy, that they are required for nourishing vegetables and replenishing rivers, and can be transmuted into other substances by slow heat, including water, salts, mud and stones. This is indeed much less direct than the discussion one finds in the *Opticks*. However, McGuire speaks as though Newton discusses active principles more directly at the end of Book III in the 1687 edition. (See "Transmutation and Immutability: Newton's Doctrine of Physical Qualities", 263 and 275-276, where McGuire notes that the claims about comets supplying replenishing vapours that can be transmuted into other substances is present in all editions of the Principia.)

[348] This suggestion is reminiscent of Aristotle's belief that motion in the sublunary realm would cease if not for some source in the superlunary realm.

[349] Newton suggests in Book III, Proposition 41 that comets might supply the spirit needed for life on earth: "Just as the seas are absolutely necessary for the constitution of this earth, so that vapors may be abundantly enough aroused from them by the heat of the sun, which vapors either—being gathered into clouds—fall in rains and irrigate and nourish the whole earth for the propagation of vegetables, or—being condensed in the cold peaks of mountains (as some philosophize with good reason)—run down into springs and rivers; so for the conservation of the seas and fluids on the planets, comets seem to be required, so that from the condensation of their exhalations and vapors, there can be a continual supply and renewal of whatever liquid is consumed by vegetation and putrefaction and converted into dry earth. For all vegetables grow entirely from fluids and afterward, in great part, change into dry earth by putrefaction, and slime is continually deposited from putrefied liquids. Hence the bulk of dry earth is increased from day to day, and fluids—if they did not have an outside source of increase—would have to decrease continually and finally to fail. Further, I suspect that that spirit which is the smallest but most subtle and most excellent part of our air, and which is required for the life of all things, comes chiefly from comets." (*Principia*, 926; see also 938.)

[350] Again, Hypothesis III appears only in the 1687 edition of the *Principia*. It asserts that all matter is the same, and so any body can be transformed into a body of any other kind: "Every body can be transformed into a body of any other kind whatever and endued successively with all the intermediate grades of qualities." The *Conclusio*, written c. 1687 for the *Principia* but suppressed, makes a similar claim: "The matter of all things is one and the same, which is transmuted into countless things by the operation of nature." Both passages appear in Westfall, *Force*, 388.

about transmutability would appear in Query 30 of the *Opticks*,[351] now paired with a claim about activity. Thus Query 30 begins by asking, "Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter into their Composition?"[352] But while the association between light and activity persists, Newton does not associate activity exclusively with light. This is not surprising, since light is a poor candidate for explaining some new motions, in particular gravitational effects, which depend upon mass rather than light distribution.[353] Increasingly, Newton associates activity with distance forces.

Now, active powers and distant action are conceptually distinct. There is no conceptual obstacle to supposing, for instance, that two entities possessing active powers could affect one another while contiguous. There is nothing incoherent, for instance, about the hypothesis that certain chemicals have active powers, that when combined, their parts become contiguous, and that upon becoming contiguous these parts generate new motion in one another, producing an explosion. And in any case, there is no indication that Newton amasses conceptual reasons for associating active principles with distance forces (nor would we expect such reasons.) The association between active principles and distance forces instead arises as Newton's investigations lead him to conjecture that in fact, nearly all motion is new motion, that is, motion due to active principles; and in fact, nearly all phenomena are due to distance forces rather than to material contact.

---

[351] "Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter into their Composition? For all fixed Bodies being heated emit Light so long as they continue sufficiently hot, and Light mutually stops in Bodies as often as its Rays strike upon their Parts, as we shew'd above. I know no Body less apt to shine than Water; and yet Water by frequent Distillations changes into fix'd Earth, as Mr. Boyle has try'd; and then this Earth being enabled to endure a sufficient Heat, shines by Heat like other Bodies. The changing of Bodies into Light, and Light into Bodies, is very conformable to the Course of Nature, which seems delighted with Transmutations. Water, which is a very fluid tasteless Salt, she changes by Heat into Vapour, which is a sort of Air." (Query 30, *Opticks*, 374.)

[352] *Ibid*.

[353] Cohen makes this point in his "Guide", while McMullin disagrees, claiming that light was one of Newton's four explanatory models for gravitational phenomena; see *Newton on Matter and Activity*, 79.

The connection between active principles and distance forces is evident in Query 31. Indeed, two of its related goals are to propose that phenomena such as cohesion and chemical reactions are produced by distance forces operating between the particles of matter, and that most motion is due to active principles. These ideas, as published in the 1717/18 *Opticks*, reach back to the *Principia* period or earlier. This is evident from Query 31's roots; an earlier version of it appeared as Query 23 of the 1706 *Optice*, and that version in turn had a predecessor, composed c. 1687. The connection between active principles and distance forces is also evident in the draft *Conclusio* for the *Principia*, composed c. 1687 but ultimately unpublished. "There are innumerable other local motions", Newton suggests in the *Conclusio*, that cannot be detected due to "the minuteness of the moving particles".[354] These local motions, he continues, may be the source of fermentation (chemical phenomena), growth and putrescence, and sensation—the same phenomena that Query 31 attributes to active principles. How do these local motions work? Although Newton cannot provide the details, he suggests in the *Conclusio* that they operate by distance forces: "Whatever reasoning holds for greater motions should hold for lesser ones as well. The former depend upon the greater attractive force of larger bodies, and I suspect that the latter depend upon the lesser forces, as yet unobserved, of insensible particles."[355] If contact action is associated with passivity, then, distance forces are associated with activity.

What Might Active Principles Be?

What might these active principles be? In trying to answer this question, we might first consider the phrase itself, 'active principle'. The term 'active' tells us that they generate new

[354] *Conclusio*, *Unpublished Scientific Papers of Isaac Newton,* 333.

[355] "There are, however, innumerable other local motions which on account of the minuteness of the moving particles cannot be detected, such as the motions of the particles in hot bodies, in fermenting bodies, in putrescent bodies, in growing bodies, in the organs of sensation and so forth. If anyone shall have the good fortune to discover all these, I might almost say that he will have laid bare the whole nature of bodies so far as the mechanical causes are concerned....Nature is exceedingly simple and conformable to herself. Whatever reasoning holds for greater motions should hold for lesser ones as well. The former depend upon the greater attractive force of larger bodies, and I suspect that the latter depend upon the lesser forces, as yet unobserved, of insensible particles." (Draft of *Conclusio* for *Principia* I, c. 1687, *Unpublished Scientific Papers of Isaac Newton*, 333.)

motion, as opposed to transferring motion from one body to another. The term 'principle' does not provide much guidance, however, for it is notoriously vague. For the ancients, 'principle' could mean a source, a destination, or a fundamental constituent, which is to say a material cause. In Newton's time, the term might refer to a proposition, but might also refer either to a material cause or fundamental constituent, or to a fundamental cause of phenomena.[356] Probably the term 'principle' is serviceable to Newton in part because it is equivocal, and therefore can be applied to an ill-formed concept. As he writes in an unpublished draft of Query 31, he finds active principles and their means of affecting matter mysterious.

> Without some other principle than the vis inertiae there could be no motion in the world. (And what that Principle is & by (means of) laws it acts on matter is a mystery or how it stands related to matter is difficult to explain). And if there be another Principle of motion there must be other laws of motion depending on that Principle.[357]

Yet he is confident in Query 31 that active principles exist. Perhaps his remarks there suggest some possibilities as to what they might be.

> ....It seems to me farther, that these particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity, that which causes Fermentation, and the Cohesion of Bodies. These Principles I consider, not as occult Qualities, supposed to result from the specifick Forms of Things, but as general Laws of Nature, by which the Things themselves are form'd; their Truth appearing to us by

---

[356] In distinguishing these senses of 'principle', I am following McGuire, who writes, "In the late seventeenth century, three traditional distinctions were still current: a principle could mean [(i)] something formulated or asserted: [(ii)] the primitive *arche* out of which all things were thought to originate: or [(iii)] the primary cause of existing phenomena as, for example, the "principles of matter and motion" celebrated in the mechanical philosophies. The second sense of the term embodies the notion of being prior in time....The first sense ranged from primary truths and mathematical propositions through normative expressions, to laws of nature. " (McGuire, "Force, Active Principles, 194) McGuire finds the first and third senses of the term in Query 31 and its predecessor, Query 23 of the 1706 *Optice*. He goes on to argue (*ibid.*, 194-196) that in these texts Newton considered active principles to be natural agents, whereas prior to the *Optice* he used 'active principle' to refer only to God. I have opposed McGuire's view that Newton attributed gravitational effects to God during that earlier period.

[357] ULC, Add. 3970, fol. 620r. McGuire dates this passage to 1705, and notes that it was written in English. As the passage continues, Newton cites the mind's power to move the body as model of the active production of new motion and continues with a vitalist speculation: "We cannot say that all nature is not alive." By the published, 1717/18 version of Query 31, Newton has eliminated these vitalist connotations, but in the unpublished manuscript remarks (quoted in McGuire, "Force, Active Principles", 171), Newton's thinking about active principles shows the continued influence of thinkers such as Cudworth.

> Phaenomena, though their Causes be not yet discover'd. For these are manifest Qualities, and their Causes only are occult. And the *Aristotelians* gave the Name of occult Qualities, not to manifest Qualities, but to such Qualities only as they supposed to lie hid in Bodies, and to be the unknown Causes of manifest Effects: Such as would be the Causes of Gravity, and of magnetick and electrick Attractions, and of Fermentations, if we should suppose that these Forces or Actions arose from Qualities unknown to us, and uncapable of being discovered and made manifest....To tell us that every Species of Things is endowed with an occult specifick Quality by which it acts and produces manifest Effects, is to tell us nothing: But to derive two or three general Principles of Motion from phaenomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the causes of those Principles were not yet discover'd: And therefore I scruple not to propose the Principles of Motion above-mention'd, they being of very general Extent, and leave their Causes to be found out.[358]

This passage suggests several ways of understanding active principles. First, active principles might be identical to distance forces. A central aim of Query 31 is to propose that forces analogous to gravity may produce phenomena such as cohesion and fermentation. As examples of active principles, Newton cites gravity and these other forces; particles are moved by "certain active principles, such as is that of gravity, and that which causes fermentation, and the cohesion of bodies". This suggests that active principles just are distance forces. Second, active principles might be identical to laws, for Newton considers these principles "as general laws of nature". Third, active principles might be something that figures in the causal story of distance forces, without being identical to the forces themselves. This possibility arises from Newton's remark, toward the end of the passage, that the causes of these manifest principles of motion have not yet been discovered. We could understand this to mean that something causes the active principles that in turn cause the motions, and that our search is for the cause of the active principles. Yet it seems doubtful that this literal reading is what Newton has in mind. After all, he has already said that active principles are mysterious, and that they are causally efficacious. So it seems that they, and not their cause, are the objects of his search. A better way to understand this remark, then, is to suppose that the mysterious active principles figure in the causal story of distance forces, which is the third possibility just noted. Let us consider these possibilities in more detail.

[358] Query 31, *Opticks*, 402.

Might active principles be identical to distance forces? This possibility is suggested, as mentioned above, by the examples Newton gives of active principles, namely, gravity and the cause of cohesion. We might therefore think that active principles are only rationally distinct from distance forces. They are forces as we attend to their mathematical proportions, but active principles as we attend to their causal means of action. This suggestion respects *De Gravitatione*'s general definition of force as a causal principle of motion and rest, since according to Newton's speculations, active principles are causally efficacious in producing new motions.[359] Yet at best the identification is uncertain, for elsewhere we find Newton distinguishing between forces and active principles. In a draft for the 1706 *Optice*, for example, he writes, "These Forces may be reckoned among the laws of motion (& referred to an active principle) but whether they depend on bodies alone may be a question."[360] So here the forces are not identical to active principles, but are rather "referred to" them. In any case, to identify forces with active principles would be uninformative. The goal is to discover the causal means by which distance forces act, and allowing that these forces also have the name 'active principles' does not provide any details about the causal story. We are still left with the question of which substances figure in producing the effects attributed to distance forces, and how it all works.

The second possibility raised by the above quoted passage is that active principles are identical to laws. At one point, Newton writes that active principles are not "occult qualities", the

[359] I suggested in chapter III that Newton might retain *De Gravitatione*'s general definition of force, however there are difficulties with that suggestion, as a note in that earlier chapter indicates. As Andrew Janiak pointed out to me, one might object to the suggestion on the grounds that Newton did not have the concept of mass in *De Gravitatione*; and that he is unlikely to retain a definition of force developed without the concept of mass. This objection merits further investigation. It also raises further questions, generated by questions about the concept of mass. If mass is resistance, for instance, as characterized by the three laws of motion, then Newton has made some steps toward a concept of mass by *De Gravitatione*, simply in virtue of sharing the widely acknowledged view of matter as resistive.

[360] In a draft for the 1706 *Optice*, Newton identifies forces with laws, and then writes that these may be "referred to an active principle". He writes, "I have hitherto been arguing from the effects to their causes & carried the argument (as high as) up to certain forces (the powers) by wch little bodies act on one another at small distances. These Forces may be reckoned among the laws of motion (&referred to an active principle) but whether they depend on bodies alone may be a question." (ULC, Add. 3970, fol. 620r, quoted by McGuire "Force, Active Principles", 170-171; McGuire notes that these variants were written in English.)

ad hoc tendencies that the Aristotelians assigned to each kind of substance or object,[361] but are instead "general principles" that have been derived from the phenomena, and "general laws of nature". But what does Newton mean by saying that active principles are laws? In identifying active principles with laws, is he suggesting that laws are causally efficacious? This depends upon what he understood a law to be. If a law is a description, then it is not the sort of thing to be causally efficacious. Contemporary dispositionalist accounts of laws, for instance, take laws simply to express or describe the phenomena produced by the dispositions. The causal efficacy lies not in the laws, but in the dispositions of bodies or systems to behave in certain ways, as copper is disposed to conduct electricity under certain conditions.

Yet not all conceptions of laws take them to be descriptions. At least three alternative conceptions of laws were available to Newton, all of which took laws to be causally efficacious. First, one might conceive of the laws of nature as being only rationally distinct from God's will. This is the sort of view one finds in Malebranche, at least on some commentators' interpretations. According to Nicholas Jolley, the laws of nature are the propositional contents of God's volitions. More specifically, the laws are God's general volitions or ideas, ideas that bear more resemblance to Platonic forms than to Cartesian thoughts.[362] Jolley intends this notion of general volitions to construe laws as structural features of the created world, as opposed to individual divine desires, even though they are ontologically indistinct from God and thus primary rather than secondary causes.[363] On this reading of Malebranche, God's general volitions applied to the initial conditions created by God are sufficient to bring about events, and so the laws of nature are causally efficacious. This cannot be what Newton has in mind, however, when he writes that active principles are laws of nature. Gravity is one of Query 31's examples of active principles, and as I argued earlier, Newton repeatedly treats the gravitational force as something that God

[361] For a discussion of the many qualities introduced by the late Scholastics, see Nadler, "Doctrines of Explanation in Late Scholasticism and in the Mechanical Philosophy", III-IV.

[362] Jolley, "Occasionalism and Efficacious Laws in Malebranche", 255.

[363] *Ibid.*, 252.

must oppose and hence as something that is ontologically distinct from God. This same position is evident in Query 31.

> Now by the help of these Principles, all material Things seem to have been composed of the hard and solid Particles above-mention'd, variously associated in the first Creation by the Counsel of an intelligent Agent. For it became him who created them to set them in order.[364]

Here active principles are God's tools; it is "by the help of these principles" that God sets things in order. So the active principles associated with gravity and the forces causing fermentation and cohesion are secondary causes. They are not simply rationally distinct from God. They are really distinct.

A second conception of causally efficacious laws takes them to be the essences or internal principles belonging to matter, and thus to be only rationally distinct from matter. According to Leibniz, who resurrects Aristotle's substantial forms, primary matter is passive; yet matter as we know it is active, since God creates substances out of primary matter. He does this by impressing upon matter "a soul or a form analogous to a soul, or a first entelechy, that is, a certain urge [*nisus*] or primitive force of acting, which itself is an inherent law".[365] So a law is not a description but is instead an internal essence. The laws or essences of substances do not causally interact with one another, according to Leibniz's doctrine of pre-established harmony; a substance's changes do not follow from any "influx", that is, causal interactions with other things. Instead, a substance's changes follow from "the inherent force and laws of its own nature".[366] On this view, then, laws are causally efficacious in virtue of being these active internal essences, and

---

[364] Query 31, *Opticks*, 402.

[365] Leibniz, "On Nature Itself", published in the September 1698 issue of the *Acta Eruditorum* and reprinted in *Philosophical Essays*, 162-163.

[366] *Ibid.*, 161. Leibniz refers to his doctrine of pre-established harmony in the 1711 Letter to Hartsoeker that was published in *Memoirs of Literature*. (Newton's unpublished response, discussed earlier, does not mention the doctrine.)

they are also genuine secondary causes. It is likely that this Leibnizean view was known to Newton, since Clarke discusses it in his correspondence with Leibniz.[367]

Since Newton takes active principles to be secondary causes, the Leibnizean view is congenial to him in this respect. Yet the view is not congenial to Newton in another respect, as we see by considering causal interactions among bodies. Suppose for the moment that Newton accepted the doctrine of pre-established harmony. Doing so would undermine his relational conception of the gravitational force. If gravitating bodies did not causally interact, but instead moved because of their internal principles, attraction would be two distinct actions instead of the single, mutual action that Newton compares to the contraction of a rope. And in any case, Newton thinks that causal interactions among bodies are genuine. What does a Leibnizean conception of laws imply when combined with this realism about causal interactions? To the extent that we can make sense of the combination, it too implies that the gravitational force is not a single mutual action, but is rather two distinct forces, one contained in each body. And absent any addition to the story, it also implies action at a distance, with each body attracting the other across empty space, in virtue of its internal essence. So the view that the laws are only rationally distinct from matter is perhaps more alien to Newton than the view that they are only rationally distinct from God.

Between the extremes of laws being in matter and laws being in God, there is a third option for Newton—that suggested by Ralph Cudworth. As we saw earlier, Cudworth identifies laws with an immaterial plastick nature—an "energetical principle" or living spirit that causes the mundane motions that God should not stoop to perform. Since the laws as Cudworth conceives them just are the immaterial plastick nature that causes mundane motions, they are causally efficacious. We already saw some points of resemblance between this view and Newton's ideas. Cudworth's plastick spirit is active, immaterial, and non-perceiving, and Newton allows for such

[367] See Alexander, *Leibniz-Clarke*. I was unable to locate any explicit references to the view in Newton's own writings, however Newton knew a good deal about Leibniz's views by the time of the priority dispute over calculus, c. 1708.

spirits too. His electric spirit is active and non-perceiving, and it is immaterial as well. In saying that only the magnetic force operates by contact—by the contact of *material* effluvia, that is—Newton implied the electric spirit to be immaterial. The aether, if it exists, is active and non-perceiving, and though it might be material, it also might not. Although he clearly takes it to be material in some texts, notably the pre-*Principia* manuscript, *De aere et aethere*, the *Principia*'s claim of universal gravitation creates pressure to say that if an aether exists and can explain gravity, it must be immaterial on pain of regress.

Yet these similarities are thin, and Newton's discussion of laws does not follow Cudworth. Whereas Cudworth identifies his plastick spirit with the laws, Newton never identifies any substance, such as the aether or the electric spirit (or light), with laws. And while his remark that active principles are general laws of nature suggests that the laws are causally efficacious—active—elsewhere in Query 31 he distinguishes laws from causal efficacy. In explaining that he does not know how the attractions between spatially separated particles are performed, he writes that we must first learn "the Laws and Properties of the Attraction, before we enquire the Cause by which the Attraction is perform'd".[368] So to learn the laws is not to discover the attraction's causal story, which is to say that the causally efficacious active principles are not the laws.

The third possibility mentioned for active principles is that they figure in the causal story of distance forces without being identical to those forces. If active principles are neither in matter nor in God, perhaps they are the properties or powers of an immaterial substance. But while Cudworth is willing to postulate a spirit in order to preserve his principle that God does not perform mundane tasks with his own hands, Newton is not willing to do the same in order to preserve the metaphysical principles to which he is drawn. In the closing chapter, I consider the difficulties Newton faces in trying to discover the location of active powers, and this in trying to discover gravity's causal story.

[368] Query 31, *Opticks*, 376.

REFERENCES

Alexander, H.G., ed., *The Leibniz-Clarke Correspondence*, Manchester: Manchester University Press, 1956.

Boas, Marie, "The Establishment of the Mechanical Philosophy", *Osiris* 10 (1952), 412-54.

Boudri, Christian: *What was Mechanical about Mechanics? The Concept of Force between Metaphysics and Mechanics from Newton to Lagrange*, trans. Sen McGlinn, Dordrecht: Kluwer Academic Publishers, 2002.

Boyle, Robert, *Mechanical Origin of Heat*; *Works* IV (1675), in *The Works of the Honourable Robert Boyle. In Six Volumes. To which is Prefixed the Life of the Author,* London: Thomas Birch, 1772.

Cudworth, Ralph, *The True Intellectual System of the Universe*, Stuttgart-Bad Cannstatt: Fr. Fromann Verlag, 1964 (reprint of the 1678 edition printed for R. Royston, London).

Cunning, David, "Systematic Divergences in Malebranche and Cudworth", *Journal of the History of Philosophy* 41:3 (2003), 343-63.

Garber, Daniel, *Descartes' Metaphysical Physics*, Chicago: The University of Chicago Press, 1992.

John Henry, "Occult Qualities and the Experimental Philosophy", *History of Science* 24 (1986), 335-381.

Herivel, John, *The Background to Newton's Principia; A Study of Newton's Dynamical Researches in the Years 1664-84*, Oxford: Clarendon Press, 1965.

Hutton, Sarah, 2007, "The Cambridge Platonists", *The Stanford Encyclopedia of Philosophy* (Spring 2007 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/spr2007/entries/cambridge-platonists/>.

Jolley, Nicholas (2002), "Occasionalism and Efficacious Laws in Malebranche", *Midwest Studies in Philosophy* 26 (2002), 245-257.

Leibniz, Gottfried Wilhelm, "On Nature Itself", published in the September 1698 issue of the *Acta Eruditorum* and reprinted in Roger Ariew and Daniel Garber (eds. and trans.), *Philosophical Essays*, Indianapolis, Hackett Publishing Company, 1989.

McGuire, J. E., "Force, Active Principles, and Newton's Invisible Realm", *Ambix* 15 (1968), 154-208.

McMullin, Ernan, *Newton on Matter and Activity,* Notre Dame: University of Notre Dame Press, 1978.

Nadler, Steven (1998) "Doctrines of Explanation in Late Scholasticism and in the Mechanical Philosophy", in Daniel Garber and Michael Ayers (eds.), *The Cambridge History of Seventeenth Century Philosophy*, Vol. 1, Cambridge: Cambridge University Press, 1998, 513-552.

Newton, Isaac, *Opticks, Or A Treatise of the Reflections, Refractions, Inflections & Colors of Light*, based on the fourth edition of 1730, New York: Dover, 1952.

Newton, Isaac, *Newton's Philosophy of Nature: Selections from his Writings*, New York: Hafner Publishing Co., 1953.

Newton, Isaac, *Unpublished Scientific Writings of Isaac Newton*, ed. A.R. Hall and Marie Boas Hall, Cambridge: Cambridge University Press, 1962.

Newton, Isaac, *Newton: Texts, Backgrounds, Commentaries*, ed. I. Bernard Cohen and Richard S. Westfall, New York: W.W. Norton & Co., 1995.

Price, Huw, *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time*, New York: Oxford University Press, 1996.

Scott, Wilson: *The Conflict between Atomism and Conservation Theory (1644-1860),* New York: Elsevier, 1970.

Smith, George: "The *vis viva* dispute: A controversy at the dawn of dynamics", October 2006, accessed April, 2007, <http://www.physics.odu.edu/~kuhn/PHYS101/VisViva.html>.

Westfall, Richard S., "The foundations of Newton's philosophy of Nature", *British Journal for the History of Science* 1:2 (Dec., 1962), 171-182.

Zilsel, Edgar, "The Genesis of the Concept of Physical Law", *The Philosophical Review* 51:3 (May, 1942), 245-279

CHAPTER VI

GRAVITY, METAPHYSICAL PRINCIPLES, AND NEWTON'S SUBSTANCE COUNTING PROBLEM

How do metaphysical principles intersect with Newton's empiricism to generate the problem about gravity, and can that problem be solved?

Introduction

In the history of physics, metaphysical principles have seen changing fortunes. Such principles, which have intuitive appeal but cannot or else simply have not been adduced from evidence, might function as explicit and absolute constraints upon a physical theory, or they might serve merely as guidelines for interpretation.[369] Today, metaphysical principles tend to play the lesser role, with the principle of local causation, for instance, motivating some interpretations of quantum mechanics. Looking back to the time before physics had emerged from natural philosophy, however, we often find metaphysical principles playing the greater role. For Leibniz there can be no void because the perfection of the world implies a plenum, and for Descartes, the preservation of motion is a metaphysical principle, derived from God's

[369] When I speak of metaphysical principles, I mean to contrast them with empirically supported propositions. This is not the sense of the term 'metaphysical' that Newton employs in A Draft Conclusion to the *Principia*. There, he holds that a proposition may be part of both metaphysics, which was in his time understood either as the study of being *qua* being, or as the study of that which is not physical, and physics; if it is derived from phenomena, it belongs to physics, even if it is about something immaterial. In this way, immaterial God can be part of natural philosophy, as Newton says in the General Scholium that he is. Thus the sense of 'metaphysical' that I have in mind is that which Newton refers to as 'dreaming' in this passage from the Draft Conclusion: "What is taught in metaphysics, if it is derived from divine revelation, is religion; if it is derived from phenomena through the five external senses, it pertains to physics ["ad Physicam pertinet"]; if it is derived from knowledge of the internal actions of our mind through the sense of reflection, it is only philosophy about the human mind and its ideas as internal phenomena likewise pertain to physics. To dispute about the objects of ideas except insofar as they are phenomena is dreaming. In all philosophy we must begin from phenomena and admit no principles of things, no causes, no explanations, except those which are established through phenomena. And although the whole of philosophy is not immediately evident, still it is better to add something to our knowledge day by day than to fill up men's minds in advance with the preconceptions of hypotheses." (Unpublished Preface to the *Principia*, ULC MS Add. 3968, fol. 109, Cohen, "Guide", 54.)

immutability. Indeed, Descartes assigns such principles their greatest power yet, deriving the whole of physics from a metaphysics esteemed as the first philosophy. With Newton, however, matters are more complex. Turning his back upon the Cartesian program, he famously writes that he feigns no hypotheses, and he often evinces great confidence that the method of experimental philosophy can by itself reveal the causal workings of the universe. It is from the phenomena, his preface to the *Principia* explains, that one discovers the forces of nature. Yet the gravitational force is a persistent problem for Newton. His gravitational theory raises the spectre of matter acting at a distance, with sun and planets attracting one another across empty space, yet as he writes to theologian Richard Bentley, he considers such unmediated action absurd.

What exactly is so vexing to Newton about the gravitational force, and how do metaphysical principles intersect with his empiricism[370] to generate the problem? I examine three explanations of Newton's view of gravity, matter, and action at a distance, all of which suppose that there is a genuine problem for him about the role of metaphysical principles in natural philosophy. That problem would dissolve if he drew a sharp line between physics and metaphysics by attributing such troublesome phenomena as gravitational effects to God. After setting out the focal remarks from Newton's letters to Bentley, I therefore briefly present considerations against that position. I then turn to the three explanations. According to the first argument I examine, the gravitational force was in fact for Newton no problem at all; although he denied that matter essentially possessed the power to attract across distances, he accepted it as an

[370] When I speak of Newton's experimentalism or empiricism, I intend to contrast his approach to the *a priori* or metaphysical approach to physics pursued by Descartes and Leibniz. Descartes derives the laws of nature from an *a priori* understanding of God, and Leibniz derives the existence of a material vortex to explain gravitational effects from his metaphysical principle that by their nature, bodies act only upon contiguous bodies by surface action. The laws of nature that Descartes and Leibniz ground in metaphysical principles are not revisable, precisely because of that ground. Newton, by contrast, claims to derive his laws and propositions from phenomena. This is not to say that he fully frees himself of metaphysical principles; I argue that certain metaphysical principles guide his physical investigations. Nor is it to say that his empiricism resembles that championed by the logical positivists, who attempted to take sense experience as foundational and as independent of theory. Law 1, for instance, is not derived from perceptions of bodies free of impressed forces, and the law of universal gravitation indicates that we encounter no such bodies. In general, the phenomena from which Newton derives his propositions could be termed theory-laden. The point is that Newton considers the laws and propositions he derives from phenomena to be revisable. With Rule 4, Newton allows that further investigation may reveal the need to make the propositions "more exact", or show that they are "liable to exceptions"; and in his Author's Preface to the *Principia*, he allows for more dramatic revisions, writing that perhaps his work will shed light on this mode of philosophizing, or upon "some truer one".

inessential or superadded property, endowed upon matter by God. Against this, I argue that Newton's empiricism does not sit easily with this thesis of superaddition or its concomitant strong sense of essential properties. Still, even as Newton abstains from assertions about matter's essence, he reveals some opinions, notably that matter cannot act where it is not. Thus the closely related second and third explanations I consider are that Newton accepts a general principle of local causation, and that he accepts the principle that matter is passive. Since he lacks empirical warrant for these principles, they should serve only as guides as he searches for an immaterial medium, hoping to locate the active principles he associates with gravitational effects outside of matter. Still, the principle of local causation exerts a strong influence in that it determines the nature of the only available models for an inanimate immaterial medium, God and minds. Is there any means, however, of inferring the existence of such an immaterial substance as the medium, and if there were, would it be possible to associate active powers with it rather than with matter? I argue that there would not. I identify what I call 'Newton's Substance Counting Problem' as the source of the difficulty, and I argue that as Newton conceives it, his problem of finding a complete causal explanation of gravity is one that cannot be solved.

Two preliminary remarks are in order. First, I use the term 'distance forces' to refer to forces that appear to involve action at a distance, because they operate between spatially separated bodies. But while their mathematical expressions tell us the relations between bodies as functions of distance, the causal means by which these forces operate is very much in question, and I therefore intend the term 'distance force' to be neutral. Second, Newton distinguishes speculations and hypotheses from asserted propositions, that is, propositions he considers to be derived from phenomena. Texts such as the *Principia* and the body of the *Opticks* contain asserted propositions, while hypotheses are confined to speculative writings. Much of Newton's discussion of the problem about gravity is to be found in his speculative writings, a class including his unpublished manuscripts, the queries of the *Opticks*, and also his letters to Bentley, to which I now turn.

Newton's Remarks to Bentley

Newton's most vehement remarks on the question of whether matter could act at a distance are contained in his letters to theologian Richard Bentley, some five years after the *Principia*'s first edition. The exchange between the two men was occasioned by Bentley's desire to understand the central points of the *Principia*, for the late Robert Boyle had endowed a lecture series in defense of the Christian faith, and Bentley was preparing to publish his aptly entitled sermons, "A Confutation of Atheism from the Origin and Frame of the World". Newton had advised Bentley about which parts of the *Principia* to read. Then in the epistolary exchange that followed Bentley's oral delivery of his lectures, Newton replied to questions about the theological implications of his view, and commented upon Bentley's draft of his Seventh Boyle Lecture, which Bentley was preparing for publication. Thus the oral versions of Bentley's lectures precede his correspondence with Newton, and his altered, published versions of those lectures follow that correspondence.[371] Bentley preserved all four of Newton's letters, but only one of Bentley's letters is extant, that containing the abstract or draft of his seventh lecture.

It seems that in a letter that did not survive, Bentley misrepresented Newton's views on gravity, and in his response, Newton protests; he denies knowing gravity's cause, and denies that gravity is essential to matter.

---

[371] The chronology of events (omitting mention of those letters of Bentley's that are not extant) is as follows.

November, 1692: Bentley delivers some version of what is later published as his 7th Lecture.
December 5, 1692: Bentley delivers some version of what is later published as his 8th Lecture.
December 10, 1692: Newton's first letter to Bentley.
January 17, 1692/3: Newton's second letter to Bentley, asserting that gravity is not essential to matter.
February 11, 1692/3: Newton's third letter to Bentley.
February 18, 1692/3: Bentley's letter to Newton, containing an "abstract and thread" of his then-unpublished Seventh Boyle Lecture.
February 25, 1692/3: Newton's fourth letter to Bentley, containing his remarks about matter acting without mediation.
1693: The published versions of Bentley's lectures appear.
1756: Newton's letters to Bentley are first published, as *Four Letters from Sir Isaac Newton to Doctor Bentley.*

The letters written during January and February are written with a slash between the years 1692 and 1693 because of a change in custom for marking the new year. According to an older tradition, the new year did not begin until March 25th, with the Feast of the Annunciation. The newer practice, ushered in with the change from the Julian to the Gregorian calendar (a change made in England in 1752), was to take January 1st as the beginning of the new year. Documents written during the transitional period before this new custom had fully taken hold, and between January 1st and March 25th, are often dated with a slash between the years.

> You sometimes speak of Gravity as essential and inherent to Matter. Pray do not ascribe that Notion to me; for the Cause of Gravity is what I do not pretend to know, and therefore would take more Time to consider it.[372]

In a subsequent letter commenting upon the draft of a lecture that Bentley has sent him, Newton makes his now-famous remarks about matter acting at a distance.

> The last clause of your second Position I like very well. Tis unconceivable that inanimate brute matter should (without ye mediation of something else wch is not material) operate upon & affect other matter without mutual contact; as it must if gravitation in the sense of Epicurus be essential and innate in it. And this is one reason why I desired you would not ascribe innate gravity to me. That gravity should be innate inherent & essential to matter so yt one body may act upon another at a distance through a vacuum without the mediation of any thing else by & through wch their action or force may be conveyed from one to another is to me so great an absurdity that I believe no man wh has in philosophical matters any 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 is a question I have left to ye consideration of my readers.[373]

Physics Divorced from Metaphysics: Primary Causation and Gravitational Effects

According to a number of commentators, Newton is merely being coy with this last remark; while he leaves his readers to consider whether gravity's cause is material or immaterial, he privately attributes the planetary motions directly to God, that immaterial being who is substantially present throughout all of space. There is no action by matter, since the immaterial deity produces the actions, and no action at a distance, since the extended deity is present at the site of the bodies he moves.

It is uncontroversial that Newton's God sometimes acts directly in the world; he acts directly to reform the planetary orbits, for instance, which the mutual actions of planets and comets render irregular over time.[374] I shall use the term 'primary causation' to refer to such

[372] Newton's second letter to Bentley, Jan. 17, 1692/3, *Correspondence of Isaac Newton*, 240.

[373] Newton's fourth letter to Bentley, Feb. 25, 1692/3, *ibid*., 253-254.

[374] "Some inconsiderable Irregularities...may have risen from the mutual Actions of Comets and Planets upon one another, and...will be apt to increase, till this System wants a Reformation." (Query 31, *Opticks*, 402, but Query 23 in

direct actions by God, and the term 'secondary causation' to refer to natural causes, that is, the means that God has established in the created order. It is the range of primary causation that is controversial. Some commentators argue that Newton ultimately explained gravity in terms of primary causation, and this view has a number of variants. Joan Hawes limits the range of phenomena for which Newton accepted primary causation; she argues that Newton attributed gravitational effects directly to God, but allowed action at a distance for the electric force.[375] J.E. McGuire limits the time during which Newton accepted primary causation; he argues that Newton held the view during the post-*Principia* period, but after the 1706 *Optice* pushed distance forces into the realm of secondary causation, believing that gravity and the other distance forces about which he speculated had causes within the natural order.[376] Richard Westfall, by contrast, sees no such limitations. He argues that privately, Newton believed that all of the "new motions" associated with distance forces were in reality the effects of God's direct and immediate action. The implication of Westfall's view, then, is that physics is cordoned off from metaphysics. The metaphysical story, about causal efficacy, is a story of God's primary causation; apart from the "passive principles" of the *vis inertiae* and the three laws of motion arising from it, which Newton believes to explain very little motion, secondary causes are rejected. Here we are reminded of Leibniz, who allows forces and bodies at one level of description, but avoids problems about causation by ultimately restricting his ontology to percipients, denying causal interaction among the monads, and attributing all activity to God. If Westfall's interpretation is correct, then Newton similarly drew a sharp line between physics and metaphysics by explaining distance forces in terms of primary causation.

---

the edition upon which Leibniz was commenting.) Newton's suggestion here was the probable provocation to Leibniz's charge, in his 1715 Letter 1, that Newton's God is like an imperfect watchmaker. See H. G. Alexander, *Leibniz-Clarke*, 11, n.*a*.

375 Hawes, "Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", 205.

376 See McGuire, "Force, Active Principles", 207-208.

Although Newton's unpublished manuscripts indicate that he considered the path these commentators suggest, and did so very seriously, I do not think the texts support any stronger conclusion. Two considerations will have to suffice here. First, Query 31 clearly presents distance forces as God's tools. There, Newton identifies the active principles he associates with distance forces as "general laws of nature, by which the things themselves are formed"; and, he continues, referring to the speculated force of cohesion, God composes bodies "by the help of these principles". Thus in Query 31, distance forces, or at least the active principles associated with them,[377] are secondary causes. Second, even in the post-Principia period, when Newton sometimes suggests God as the explanation of gravity, he also repeatedly treats the gravitational force as something that God must work against, and thus as independent of God; God works against the gravitational force, for instance, to prevent the stars from collapsing into the sun.[378] The first claim weighs against Westfall's stronger conclusion, while the second weighs against both that and the more limited conclusions of Hawes and McGuire. If on the basis of such claims

[377] As noted in the previous chapter, active powers and distance forces are conceptually distinct. There is nothing incoherent, for instance, about supposing that certain chemicals possess active powers of generating new motion, and that they do so when combined because in combination their parts become contiguous. Yet Newton does associate active principles with distance forces. This association arises from his dual conjectures that nearly all motion is new motion, that is, motion due to active principles, and that nearly all phenomena are due to distance forces rather than to material contact. (These phenomena may be due to the contact of some immaterial medium, however. Again, I use the term 'distance force' to refer to any force operating between spatially separated bodies, and the term does not imply the absence of an immaterial medium.)

[378] In the first of his four letters to Bentley, Newton explains that the system will not collapse so long as space is infinite. This claim suggests a belief that the gravitational force is real. If God were producing all gravitational effects, directly, then no explanation would be needed to explain why the system does not collapse, beyond God's will. By suggesting that if space were not infinite, the stars would collapse upon the sun, and that they do not only because space is infinite, Newton implies that the heavenly bodies really do attract one another. (See Newton to Bentley, December 10, 1692, *Philosophical Writings*, 95-96.) Similarly, David Gregory's 1694 *Memoranda* attributes to Newton the claim "that a continual miracle is needed to prevent the Sun and the fixed stars from rushing together through gravity". Interestingly, the notion that there could be a continual miracle is at odds with the notion of a miracle found in Clarke's letters; since all activity derives from God, Clarke classifies unusual events as miracles, and regular events as natural. The central point here, however, is that Newton implies a distinction between the gravitational force, which could cause the system to collapse absent divine action, and the divine action that does prevent it. If there were no attractions, but only God's action, no such distinction would need to drawn. Indeed, if God caused all these motions directly, no positive action would be needed to prevent collapse; God would simply fail to push the stars into the sun. (See 446 Memoranda by David Gregory, 5, 6, 7 May 1694, *Correspondence of Isaac Newton,* 3:334 original and 3:336 translation.) The same distinction between the gravitational force and the action God takes to counter it is also evident in later writings, specifically the General Scholium assertion that God has placed the stars at immense distances from one another to prevent their collapse under gravity (*Principia*, 940), and again in Query 28. In Query 28, Newton infers the existence of a designer from the fact that the stars do not aggregate together. He does not tell us whether collapse is prevented through direct or indirect action, but again the gravitational force is implied to be something distinct from divine action, in that some of its effects may need to be countered by divine action: "What hinders the fix'd Stars from falling upon one another? How came the Bodies of Animals to be contrived with so much Art....Does it not appear from phenomena that there is a Being incorporeal, intelligent." (*Opticks*, 369.)

we take Newton's natural philosophy to include secondary causes, as I shall now do, we then face the question of whether he allowed metaphysical principles to play any role in determining what the secondary causes of gravitational and other phenomena might be.

THE ATHEISTIC THREAT AND SUPERADDED ACTIVE POWERS

Was Newton's concern about the gravitational force that it carried the threat of atheism? In the early modern period, the investigations of nature that constituted natural philosophy often included or in some cases were dominated by considerations about God.[379] Descartes attempted to derive the laws of nature from the nature of God,[380] and though Galileo eschewed that *a priori* approach to natural philosophy, he understood his investigations as an inquiry into God's creation. Those defending corpuscular theories of matter, such as Gassendi and Boyle, typically avoided citing their ancient atomist predecessors, such as Democritus and Epicurus, because these figures were associated with atheism. Since the doctrines attributed the atoms' motion to their own nature, rather than to a deity's guidance, those doctrines were suspect. As an atomist, Newton might be expected to share Gassendi's and Boyle's concerns.

Such concerns do figure in one of the charges Newton brings against the Cartesian theory of matter in the unpublished, pre-*Principia* manuscript, *De Gravitatione*. In reference to Descartes' identification of matter with extension, Newton writes, "However we cast about we find almost no other reason for atheism than this notion of bodies having, as it were, a complete, absolute, and independent reality in themselves."[381] According to Newton, extension—space—would be the effect of anything that existed, and since we therefore can have

[379] For a discussion of seventeenth century attitudes toward the proper stance of natural philosophy with respect to God, see Grant, *A History of Natural Philosophy*, 293-302.

[380] As a practical consideration, Descartes had Galileo's treatment at Rome in mind when he suppressed *Le Monde* and wrote that strictly speaking, the earth is always at rest, since it remains contiguous to neighboring celestial matter even as it orbits the sun.

[381] *De Gravitatione*, *Philosophical Writings,* 32. Newton brings this charge not only against the Cartesian view of matter but also against the idea of prime matter, though he considers the notion of prime matter "unintelligible".

an idea of extension without an idea of God, the Cartesian concept of matter sets a path to atheism.[382]

Yet Newton's own results in the *Principia* had the potential to raise the threat of atheism in a new way. If the gravitational force is a mutual attraction universal to matter, then the atheist might attempt to explain the present state of the universe without appeal to God. Atoms might accrete into bodies, the atheist could say, by means of their intrinsic power to attract one another.

Richard Bentley's View: Superaddition and Action at a Distance

This was a threat that Richard Bentley considered serious enough to challenge, and in the published version of his Seventh Boyle Lecture, he sets out the threat. The Epicurean theory of gravity, Bentley notes, without naming it as such, would not serve the atheist's purpose. A tendency for atoms to veer away from a perpendicular and tend toward a vacuum, or toward nothing in specific, would not explain the accretion of atoms into bodies. But if gravity is mutual attraction, the atheist might argue that matter has an inherent, essential power to unite to other matter, creating the celestial bodies we observe.

Having identified the threat, Bentley counters it by arguing that mutual attraction could not be eternal to matter nor could it be acquired by matter of its own accord; it could only have been infused into matter by God. According to Bentley's supposition, the atheist suggests that particles once in chaos convened into bodies by their mutual powers of attraction. Yet this could not be, Bentley argues, taking tutelage from Newton's letters, for if mutual attraction were inherent in eternally existing particles, those particles would always have gravitated and so never could have been in chaos. Ignoring the possibility of eternally existing aggregate bodies, Bentley concludes that gravity could not have been eternal to matter. He then attempts to show that far from abetting atheism, the mutual attraction of matter proves God's existence. In support of this

[382] "If we say with Descartes that extension is body, do we not manifestly offer a path to atheism, both because extension is not created but has existed eternally, and because we have an idea of it without any relation to God, and so in some circumstances it would be possible for us to conceive of extension while supposing God not to exist?" (*Ibid*., 31.)

claim, Bentley recrafts a sentence from his one extant letter to Newton—"'Tis unconceivable, yt inanimate brute matter should (without a divine impression) operate upon & affect other matter without mutual contact: as it must, if gravity be essential and inherent in it"—replacing his own phrase, "divine impression", with the phrase Newton used in his reply, "mediation". And so Bentley's published Seventh Lecture contains the following passage.

> 'Tis utterly unconceivable, that inanimate brute Matter (without the mediation of some Immaterial Being) should operate upon and affect other Matter without mutual Contact; that distant Bodies should act upon each other through a *Vacuum* without the intervention of something else by and through which the action may be conveyed from one to the other....Now mutual Gravitation or Attraction...is the same thing with This: 'tis an operation or vertue or influence of distant Bodies upon each other through an empty Interval, without any *Effluvia* or Exhalations or other corporeal Medium to convey and transmit it. This power therefore cannot be innate and essential to Matter. And if it be not essential; it is confrequently most manifest (seeing it doth not depend upon Motion or Rest or Figure or Position of Parts, which are all the ways that Matter can diversify itself) that it could never *supervene* to it, unless impress'd and infused into it by an immaterial and divine Power.[383]

It is notable, for reasons I shall indicate subsequently, that at the end of this passage, Bentley strays away from Newton's term, 'mediation', and back to his own, earlier talk of God impressing gravity into matter. In the published version of his Eighth Lecture—a lecture for which Newton did not review a draft—Bentley states his view of gravity explicitly: "Gravitation…is a constant Energy infused into Matter by the Author of all things."[384] Here we have Bentley's thesis of superaddition; gravity is an active power that is not part of matter's essential nature but was superadded by God.

The implication of Bentley's superaddition thesis is of course that matter can act at a distance. Although matter's essential nature does not include active powers of attraction, God has

[383] *Papers and Letters,* 340-341.

[384] Bentley, "Eighth Boyle Lecture", preached December 5, 1692 and published 1693, *Papers & Letters*, 363. The passage continues as follows: "But now admitting that Gravity may be essential to Matter; and that a transverse Impulse might be acquired too by Natural Causes, yet to make all the Planets move about the Sun in circular Orbs; there must be given to each a determinate Impulse...." (*Ibid.*) However, the context indicates that this is intended as a counterfactual, not a possibility. Earlier, Bentley stated that he has proved that gravity cannot be innate, in a sentence showing the style in which he poses counterfactuals: "Now although Gravity could be innate (which we have proved that it cannot be)." (*Ibid.,* 347.)

infused matter with those inessential powers, thereby enabling the sun and planets to affect one another across vast reaches of empty space, without any intervening medium to convey the effect.

John Henry's Argument: Bentley as Newton's Spokesman

Did Newton share Bentley's position? In some texts, Newton does seem to allow the possibility of action at a distance. The opening of Query 31 is enough to raise eyebrows: "Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance...For it's well known, that Bodies act one upon another by the attractions of Gravity, Magnetism, and Electricity...and make it not improbable but that there may be more attractive Powers than these." Yet Newton immediately disclaims knowing the causes of these attractive powers.[385] His point seems to be that in formulating hypotheses for unsolved problems, such as cohesion, we can draw only upon what is known about gravity, which is to say its mathematical proportions. The analogy of nature supports only this much, since we are ignorant of gravity's cause.[386] This is consonant with one of Query 31's goals, which is to show that many phenomena may be produced by short range forces analogous to gravity, which is to say forces acting between spatially separated bodies; but as we are ignorant of gravity's full causal story, we have no full causal story to extend to these speculated forces.

To say that Newton allowed even the possibility of matter acting distantly is to invite controversy. To say that despite his remonstrance to Bentley and his repeated denials of knowing

---

[385] I refer to the following remark from Query 31: "How these Attractions may be perform'd, I do not here consider. What I call Attraction may be perform'd by impulse, or by some other means unknown to me. I use that Word here to signify only in general any Force by which Bodies tend towards one another, whatsoever be the Cause." (*Opticks* 376.)

[386] As Query 31 continues, Newton speculates that electrical attraction may reach to small distances even without friction, and this remark initially suggests action at a distance. It initially suggests that if an emitted spirit conveys the force with friction, yet the force acts over shorter distances without friction, then without friction the particles may be acting upon one another without any intervening medium. However, examination of related texts reveals this not to be the case. Newton holds that there is a spirit that abounds even without friction, and that friction simply extends its range. So there is a medium, both with and without friction, by which the electrical attraction is conveyed. The relevant passage is contained in A Draft Conclusion to the *Principia*: "By these experiments it is fully enough clear that glass at small distances always abounds in electric force, even without friction, and therefore abounds in an electric spirit which is diffusd through its whole body and always surrounds the body with a small atmosphere, but never goes out far into the air unless stirred up by friction." ("Guide", 289.)

gravity's physical cause, Newton wholeheartedly accepted action at a distance would be quite a dramatic claim. One commentator defends such a view, however, taking Bentley and also John Locke as Newton's spokesmen. John Henry interprets Newton as consistently allowing action at a distance by matter, by considering activity to be a superadded, which is to say inessential, property of matter. Newton considered it theologically problematic to allow gravity as an essential property, Henry argues, since doing so would abet the atheist's claim that the particles of matter could have accreted into large bodies without God; the clue to Newton's theological concern is his mention of Epicurus in the earlier-quoted remarks to Bentley. The notion of superadded active powers, a view held by Newton's elder English contemporaries, alleviated Newton's theological concerns, and so he accepted activity as an inessential but internal power of matter, superadded to it by God.

> When Newton said 'Pray do not ascribe that notion to me', the notion he was objecting to was not that gravitational attraction might be a property of matter, but that gravitational attraction might be held to be an essential property of matter, in the way that extension was held to be. Extension was generally agreed to be an essential attribute of matter. Matter could not be conceived of without extension but it could easily be conceived of without gravitational attraction.[387]
>
> Gravity was not to be seen as a property which was logically entailed by the nature of matter itself, in the way that extension was.[388]

If Newton believed that matter had superadded active powers, why did he deny knowing gravity's cause, most famously in the General Scholium, but also in Query 31 and elsewhere? Henry explains this by attributing a disjunctive belief to Newton: God has added an active principle to matter, "either to all matter, or merely to the matter of the aether, depending upon which speculation Newton favoured at the time".[389] So Newton is uncertain about which sort of matter has superadded active powers, but he is confident that some sort does, and thus that matter can act

---

[387] Henry, "God and Newton's Gravity", 128.

[388] *Ibid*., 131.

[389] *Ibid*., 133.

distantly. What are we to make of Newton's remark to Bentley that the gravitational effects could not occur without the "mediation" of something that conveys the force and action? According to Henry, Newton's meaning is this: by endowing matter with active powers, God mediated between the way matter is essentially, and the way he actually created it.[390]

A Critical Look at Henry's Argument: Superaddition and Newton's Empirical Concept of Matter

There are a number of problems with trying to infer Newton's view from Bentley's.[391] The main questions, however, are whether Newton's central concern about gravity was the atheistic threat that Bentley identifies, and whether the notion of superaddition is consistent with Newton's concept of matter. It is certainly true that Newton would not want his views associated

[390] "For both Newton and Bentley, God was the immaterial mediator whose omnipotence enabled him to impose upon matter an agent of gravitational attraction which acts constantly according to certain laws." (*Ibid.,* 130.)

[391] To infer Newton's views from Bentley's is to infer that Newton was fully confident that God infused active powers directly into the particles of ordinary matter, so that they could causally affect one another from a distance. And that of course conflicts with Newton's repeated statements that he does not know gravity's cause.

There are further difficulties in trying to infer Newton's views from Bentley's claims. First of all, Bentley's most explicit statement is made in the published version of Lecture Eight. We have no reason to think that Newton ever saw or approved the published version of Lecture Seven, for which he had seen Bentley's abstract, let alone the published version of Lecture Eight. At the time of the their correspondence, Bentley has not sent his lectures to the publisher. He is still revising them, it seems. Clearly he is doing so partly in response to Newton's comments, but since the correspondence shows him to be someone introducing his own questions and ideas, and pursuing his own project, we must allow that his ideas might differ from some of Newton's. Where Newton expressed uncertainty, or left room for several interpretations, Bentley may have opted for the interpretation that best suited the goals of his lectures. It is the texts that serve as the evidence.

Henry overstates the importance of Newton's mention of Epicurus because he suggests that Newton is the one to introduce the notion of gravity associated with Epicurus; Henry writes that Bentley is "following Newton's lead" when he attacks the Epicurean notion of gravity in his published lecture. It is true that Newton is the first to mention Epicurus by name, as he does in his fourth letter, and it is true that Bentley's published Seventh Lecture names Epicurus in connection with the theory that Bentley and Newton have been discussing. However, it is Bentley who first introduces the theory, together with a variation on it. He does this in his one extant letter to Newton; it is to this letter, which contains the draft of his Seventh Lecture, that Newton replies when he mentions Epicurus by name.

As a point of clarification, Newton's mention of Epicurus is not intended as a reference to Epicurus' own theory. When Newton writes that it is inconceivable that inanimate matter should, without the mediation of something not material, "affect other matter without mutual contact, as it must be if gravitation in the sense of Epicurus be essential and innate in it", he is referring to a hybrid hypothesis that Bentley attacks—hybrid in that it combines an Epicurean element (the claim that gravity, whatever it is, is essential to matter) with Newton's concept of gravity as mutual attraction. Thus Newton is referring to the atheistic hypothesis that atoms could have an essential and innate quality of mutual attraction, and not to Epicurus' own theory, which does not assert mutual attraction among the particles. (This is clear from the context, for Newton explicitly notes that he is responding to Bentley's second point, and thus not to the first one, in which Bentley discusses Epicurus' theory of gravity as "common motion without attraction". Moreover, Newton's next remark indicates that he cannot be referring to Epicurus' own theory. He says, "And this is one reason why I desired that you would not ascribe innate gravity to me." Clearly he does not think Bentley would attribute Epicurus' own theory of gravity to him, for Epicurus did not defend mutual attraction. What he does not want attributed to him, then, is a theory of mutual attraction that includes the claim that gravity is essential, inherent or innate.) The central point, however, is the one that I have already made, namely that Newton does not use the term 'essential' in the way needed for Henry's interpretation.

with atheism, and as we saw earlier, one charge he brought against Descartes' theory of matter in *De Gravitatione* was that it led to atheism. (Newton considers his own concept of matter in that manuscript, which antedates his theory of gravitation and concept of mass, to be immune from the charge of atheism. Only extension can be conceived without God, and bodies are not identical to extension; an entity qualifies as a body only if it has powers to produce sensations in us.[392]) Does Newton think that the concept of gravity as mutual attraction would likewise set a path to atheism? No, for as his letters to Bentley and other texts indicate, gravity alone could not explain the present state of the universe, even if material particles had existed eternally and had inherent powers of gravitational attraction. To explain the planets' transverse motions and the fact that they lie in the same plane, one must invoke God. So the threat identified by Bentley is not the source of Newton's concern about gravity.

This does not show, however, that Newton did not for some other reason accept the thesis of superaddition. A belief that God could bestow active powers upon matter is certainly consistent with Newton's belief in an omnipotent deity. It is also clear that Newton was acquainted with the doctrine of superaddition, including the clearly ontological version set out by legal theoretician Matthew Hale[393], and the version defended by his friend John Locke, which I shall discuss in more detail below. For the moment, let us consider a suggestion implicit in Henry's remarks.

In passages quoted earlier, Henry writes that gravity was not considered a property "logically entailed by the nature of matter itself", and that matter could be "conceived of without gravitational attraction", but not without extension. Yet is it extension against which Newton

[392] For this argument, see *De Gravitatione*, *Philosophical Writings*, 33-34.

[393] For Matthew Hale, the claim that matter has superadded active powers is clearly ontological. He writes, "Matter it self simply considered as such, though it be susceptive of Motion (as we daily see) is not the immediate principle of Motion in those subjects that seem to be self-moving....And this entity I call *Vis* or *Virtue activa*, superadded to Matter, and giving immediately those motions to it…without which, Matter would be stupid, dull, unactive, and alwayes at rest in its self unless accidentally moved *ab extrinseco*." (*Observations touching the principles of natural motions*, quoted in Henry, "Occult Qualities and the Experimental Philosophy", 342.) Research by Henry (*ibid*.) and also by Westfall ("The foundations of Newton's philosophy of Nature") reveals that Newton was acquainted with doctrines of superaddition that antedated Locke's expression of it.

contrasts gravity? Is logical implication, in the sense of what we can conceive, Newton's ground for calling a property essential, and has he thus reached his concept of matter *a priori*?

By 1713 at least, the answer to these questions is clearly no. In the second edition of the *Principia*, a new rule of reasoning, Rule 3, appears. This rule explains how to reason inductively about qualities that cannot be increased or decreased, and the explanatory remarks following the rule answer the first question noted above. It is not extension against which Newton contrasts gravity, but the *vis inertiae*, or 'force of inertia' as it is translated:[394] "I am by no means affirming that gravity is essential to bodies. By inherent force I mean only the force of inertia. This is immutable. Gravity is diminished as bodies recede from the earth."[395] This by itself begins to answer the second question noted above. For Newton's force of inertia, by which bodies persevere in their states of rest or motion,[396] according to the *Principia*'s Definition 4, is not logically implied by the concept of matter. Matter could be and until the 17th century was conceived to exist without Newton's force of inertia; Kepler for instance imagined matter to have a very different property of inertia, namely, a tendency toward rest.[397]

[394] I do not here address the question of whether Newton considered the *vis inertiae* to be a genuine force. He does use the term 'force' to refer to it in some of his English writings, for instance in Query 31 of the English edition of the *Opticks* (see *Philosophical Writings*, 137 for instance.) However as Cohen explains in "Newton's concepts of force and mass" (*Cambridge Companion*, 60 in particular), Newton adopted a term already in use, *vis insita*, assigned it his own meaning, and then introduced *vis inertiae* as a co-referring term. The issue is more complex than this, however, because Newton's definition of the *vis inertiae* is subject to different interpretations.

[395] Rule 3, *Principia*, 795-796.

[396] In the unpublished pre-*Principia* manuscript, *De Motu*, the suggestion that the innate force, or force of inertia, causes the persistence of state, is even more pronounced. Using the Aristotelian term 'endeavor', Newton writes, "*Definition* 2. And I call that the force of a body or the force innate in a body by reason of which it endeavors to persist in its motion along a straight line. (*Background*, 299).

[397] Here one might object that since inertia is essential to matter, then while thinkers who lacked an understanding of inertia might have applied the term 'matter' to matter, they could not have been conceiving of matter without inertia, but must rather have been conceiving of something other than matter. (I do not mean to suggest that Newton's predecessors, including Kepler, applied the term 'matter' to all matter; Kepler did not apply the term to the sun, for instance.) And so, to continue the objection, the concept of matter does in fact logically imply inertia (if not the force of inertia). One might then defend Henry by attributing to him the claim that Newton's concept of matter was empirical, and then interpreting Henry's talk of what the concept of matter logically implies as follows: to say that a trait is logically implied by a concept is not to say it was derived *a priori*, but rather to say that it is essential rather than accidental, and known to be such empirically. This line of thinking brings us directly to the question of whether Newton has any basis for claiming a distinction between properties that are essential and those that are inessential but universally realized. I address this question in a subsequent section.

Descartes, of course, did derive his concept of inertia by reason,[398] however Rule 3 indicates that Newton considers his own grounds to be empirical. His list of the properties that are inherent and essential includes extension, hardness, impenetrability, mobility and the force of inertia; and the explanatory comment of the *Principia*'s Rule 3 unequivocally states that the ground for concluding these properties—even extension—to be inherent and essential to matter is not reason but the senses.[399] Of extension and impenetrability, for instance, he writes, "The extension of bodies is known to us only through our senses....That all bodies are impenetrable we gather not by reason but by our senses. We find those bodies to be impenetrable, and hence we conclude that impenetrability is a property of all bodies universally."[400]

Gravity is distinguished from essential properties, such as extension and hardness, not on the basis of an *a priori* examination of how matter can be conceived, but because it varies with distance.[401] Newton considers extension, hardness, and the like to be intensity-invariant, to borrow Ernan McMullin's term, and he has adopted the Scholastic classification of essential properties as those that cannot be "intended or remitted", that is, increased or decreased.[402]

---

[398] "That it is in the very nature of motion to come to an end, or to tend towards a state of rest….is utterly at variance with the laws of nature; for rest is the opposite of motion, and nothing can by its own nature tend towards its opposite, or towards its own destruction." (*Principles of Philosophy*, II.37, CSM, 241.)

[399] Which properties Newton considers essential is a matter of controversy. Some commentators (McMullin) argue that Newton considered only inertia to be essential to matter, while other commentators (McGuire, Koyre) argue that Newton considered the larger set, including extension, hardness, and impenetrability, to be essential properties. Janiak also accepts the latter view; see *Newton as Philosopher*, 113.

[400] The claim that it is only from phenomena that we learn that bodies do not penetrate one another also appears in his Draft Conclusion for the General Scholium: "We do not know the substances of things. We have no idea of them. We gather only their properties from the phenomena and from the properties [we infer] what the substances may be. That bodies do not penetrate each other we gather from the phenomena alone; that substances of different kinds do not penetrate each other does not at all appear from the phenomena. And we ought not rashly to assert that which cannot be inferred from the phenomena." (Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 360-362), *Unpublished Scientific Papers of Isaac Newton*, 360-361.)

[401] Although Newton claims an empirical basis for concluding all bodies, including each atom, to possess the properties he lists in Rule 3, one may question his claim. For a discussion of this point, see McMullin, *Newton on Matter and Activity*, 22-27. See also my discussion in chapter IV.

[402] We might question whether all of these properties are indeed either universally experienced in bodies or intensity-invariant. One might argue that hardness, for instance, is not. On this point, see McMullin, *Newton on Matter and Activity*, 1.4, especially 22-26.

Rule 3 was written long after Newton's letter to Bentley, however. Might Newton have accepted the notion of superaddition earlier? In *De Gravitatione*, written long before the exchange with Bentley,[403] things are trickier, in part because extension—space—does have a unique status. Space would be the effect of any first existing thing, whether that first existent be God, mind, or matter; and so, Newton writes, space is the one thing that could be conceived independently of God.[404] Additionally, Newton uses the term 'essential' differently here than he does later in Rule 3, allowing that bodies might have a real essence—some "essential and metaphysical constitution".[405] It is possible, then, that matter has some real essence, and that extension belongs to its essence, just as extension belongs to all existents in *De Gravitatione*.

Still, Newton's concept of matter or body in this early manuscript is already strongly empirical. To develop a concept of body or matter, Newton begins with ordinary bodies and determines what they are like—what properties they have, and what laws they obey. We call something a body, he writes, if it has powers to produce sensations in us, is mobile and impenetrable, has resistance, and is reflected in accordance with certain laws.[406] And it is clear

---

[403] The manuscript is undated. The Halls argue that it belongs to a very early period, c. 1664-1668 (see *Unpublished Scientific Papers of Isaac Newton,* 89). B.J. T. Dobbs argues for a much later date, shortly before *Principia*. Stein's remarks in "Newton's Metaphysics" weigh against Dobbs, and in favor of an earlier dating. According to Stein, the Halls' translation of *De Gravitatione* contains a number of errors, including an incorrect suggestion that in the opening sentence, Newton indicates that he will discuss a "science of gravity". Relying upon this, Dobbs concludes that the manuscript represents, as Stein puts it, "an abortive draft of an introduction to Newton's *Principia*." In fact, Stein writes, "Newton's phrase has nothing to do with a 'science of gravity'; he is speaking of the *weight* of fluids and of solids in fluids, which is the exact subject of the classic treatise, 'On Floating Bodies' of Archimedes." (Stein, "Newton's Metaphysics", 298-299, n. 27; see also 302-303, n.39.)

[404] This follows from two passages in *De Gravitatione.* Newton states that space is the effect of the first existent: "No being exists or can exist which is not related to space in some way. God is everywhere, created minds are somewhere, and body is in the space it occupies; and whatever is neither everywhere nor anywhere does not exist. And hence it follows that space is an emanative effect of the first existing being." (*Philosophical Writings*, 25.) Subsequently, in charging Descartes' concept of matter as paving the way to atheism, Newton states that space can be conceived without God: "If we say with Descartes that extension is body, do we not manifestly offer a path to atheism, both because extension is not created but has existed eternally, and because we have an idea of it without any relation to God, and so in some circumstances it would be possible for us to conceive of extension while supposing God not to exist?" (*Philosophical Writings*, 31.)

[405] *De Gravitatione*, *ibid.*, 27.

[406] "We can define bodies as *determined quantities of extension which omnipresent God endows with certain conditions*. These conditions are: (1) that they be mobile...(2) that two of this kind cannot coincide anywhere, that is, that they may be impenetrable, and hence that oppositions obstruct their mutual motions and they are reflected in accord with certain laws; (3) that they can excite various perceptions of the senses...in created minds and conversely be moved by them." (*Ibid*., 28-29.)

from the context that Newton is not attempting to say what bodies *are*, essentially, but is rather identifying the characteristics of those things that we *call* bodies, in virtue of the properties we perceive. Newton is here setting out a view that he will articulate again in much later texts: we have access only to properties, and so we must infer substances from properties.[407] Thus we could never distinguish between two entities that differed in their essential or metaphysical constitution, but shared all their perceptible properties.[408] The basis for classifying something as a body—as matter—is not anything derivable *a priori*. It is a set of properties accessible by sense rather than reason, just as it is later, in Rule 3. Both before and after his letters to Bentley, then, Newton considers his concept of matter to be empirical. He is not investigating the essential and metaphysical nature of bodies that the notion of superaddition seems to presume.

Yet showing that Newton's concept of matter was empirical does not immediately close the discussion of superaddition. For Locke too considered his concept of matter empirical, and yet came to believe that gravity was a superadded power of matter. So Locke's thoughts about superaddition merit a closer look.

---

[407] In the his Draft Conclusion for the General Scholium, Newton writes, "We do not know the substances of things. We have no idea of them. We gather only their properties from the phenomena and from the properties [we infer] what the substances may be." (Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 360-362), *Unpublished Scientific Papers of Isaac Newton*, 360-361.)

[408] This view is further suggested by the rest of the passage from *De Gravitatione*: "Although it scarcely seems credible that God could create beings similar to bodies which display all their actions and exhibit all their phenomena, and yet would not be bodies in essential and metaphysical constitution, as I have no clear and distinct perception of this matter I should not dare to affirm the contrary, and hence I am reluctant to say positively what the nature of bodies is, but I would rather describe a certain kind of being similar in every way to bodies." (*Philosophical Writings*, 27.) The view suggested here is one that Newton may never have abandoned, for it reappears in the Query 31 remark that God might vary the laws of nature by varying the forces and properties of matter. One might object, however, by arguing that to vary the forces and properties of matter would be to create a substance that is not matter. Also, some commentators would object to my suggestion that Newton's skeptical stance toward matter's essence extends past *De Gravitatione*; a number of commentators interpret the *Principia* as asserting the essential qualities of matter. (And here I intend a strong sense of 'essential', such that to be an entity of a given kind, the entity must possess the essential property. I am not referring to the Scholastic sense of 'essential' that I take Newton to mean in Rule 3, which is, in McMullin's terms, "intensity-invariant.") For a discussion of matter's essence in that stronger sense, see Janiak, *Newton as Philosopher*, 118-129.

A Closer Look at Superaddition

The essence of matter, Locke explains to Stillingfleet, is solidity and extension, however an omnipotent God may do anything that is not contradictory, including superadding inessential qualities to matter.[409] One such superadded quality might be thought; our inability to understand how matter could think does not show that it cannot do so. Motion is another quality superadded to some bodies but not others. And after initially holding that all motion must be communicated by impulse,[410] because only that can be derived from our idea of body, Locke accepts gravity as a superadded quality of matter. We do not understand how matter attracts matter at a distance, "much less at the distance of 1,000,000 miles",[411] however "Mr. Newton's incomparable book" has convinced Locke that it does so.

> The gravitation of matter towards matter, by ways inconceivable to me, is not only a demonstration that God can, if he pleases, put into bodies powers and ways of operation, above what can be derived from our idea of body, or can be explained by what we know of matter, but also an unquestionable and every where visible instance, that he has done so.[412]

According to Locke, then, matter does act upon other matter from a distance, but this is not essential to its nature. God might have made a world containing matter, without including any thought, motion, or gravitational attractions among bodies.[413]

---

[409] "The idea of matter is an extended solid substance; wherever there is such a substance, there is matter, and the essence of matter, whatever other qualities, not contained in that essence, it shall please God to superadd to it. For example, God creates an extended solid substance, without the superadding anything else to it, and so we may consider it at rest: to some parts of it he adds motion….It is farther urged, that we cannot conceive how matter can think. I grant it; but to argue from thence, that God therefore cannot give to matter a faculty of thinking, is to say God's omnipotency is limited." (*Locke to Stillingfleet.*)

[410] The first three editions of *An Essay Concerning Human Understanding* contained these lines: "How bodies operate one upon another...is manifestly by impulse and nothing else. It being impossible to conceive that body should operate on *what it does not touch*." (*Essay*, II.viii.11, 171; see Fraser's annotations.)

[411] *Locke to Stillingfleet, The Works of John Locke*, Vol. 3, 467.

[412] *Ibid.*

[413] Locke writes that the essence of matter is solid extended substance, saying nothing of mass. Yet Roger Woolhouse argues in "Locke and the Nature of Matter" that Locke does take bodies to be massive. As Andrew Janiak pointed out to me in an influential discussion, Woolhouse's interpretation makes it difficult to see how Locke could conceive

The notion of superadded thought commands the bulk of Locke's attention, as that is the notion most provoking to Stillingfleet. However, it is the suggestion of superadded motion and gravitational powers that is more difficult to reconcile with Locke's empiricist program. For Locke appears to speak of superadded qualities in two ways. First, to classify properties as superadded is to say that "matter in general, or every part of matter, *as matter*, has them not", which is to say that the properties do not belong to matter by its nature. Second, superadded properties are those "which matter *in general* has not",[414] which is to say that these properties are possessed by some bodies but not by all. Close examination of the text indicates that Locke in fact has only the first definition in mind, but it will nonetheless be instructive to consider both definitions. I begin with the second: superadded qualities are those *not possessed by matter in general*. According to this condition, solidity and extension are essential, because they are possessed by matter in general, but thinking is superadded, since we have experience of bodies that show no signs of thinking. But what about motion and gravitation—do we have experiences of bodies that are not in motion, or that do not gravitate, as is required for superadded status under the condition we are presently considering? As a self-appointed under laborer of Newton, Locke means to bring his own beliefs into line with Newton's *Principia*. Yet as Newton wrote in the Scholium to the *Principia*'s definitions, many bodies that seem to be at rest are not really at rest, and "it is possible that there is no body truly at rest".[415] If we cannot confidently claim to have experience of any bodies truly at rest, and thus cannot claim that only some bodies move, we could not employ the second condition to claim that motion is a superadded property. By the

worlds having matter that did not gravitate. It is easier to see how Locke thinks there could be such worlds if Locke does not think of bodies as essentially massive. See *Newton as Philosopher*, 120-122, for Janiak's discussion of Woolhouse's interpretation and more generally of superaddition in Locke.

[414] "The superinducement of greater perfections and nobler qualities destroys nothing of the essence or perfections that were there before, unless there can be shown a manifest repugnancy between them; but all the proof offered for that, is only, that we cannot conceive how matter, without such superadded perfections, can produce such effects; which is, in truth, no more than to say, *matter in general, or every part of matter, as matter, has them not*; but is no reason to prove that God, if he pleases, cannot superadd them to some parts of matter: unless it can be proved to be a contradiction, that God should give to some parts of matter qualities and perfections, *which matter in general has not*." (Italics added. *Locke to Stillingfleet, The Works of John Locke*, Vol. 3.)

[415] *Principia*, 411.

same token, if essential properties are those possessed by matter in general, then since all matter gravitates, the condition under consideration implies that gravity is an essential property rather than a superadded one. Now, this difficulty is no doubt one reason that Locke does not classify superadded qualities according to the condition just examined. The condition that he does suggest, however, the first one noted earlier, raises its own difficulties.

According to the first condition, qualities are superadded if "matter in general, or every part of matter, *as matter*, has them not". This condition suggests a distinction between qualities that are essential to matter, "as matter", and those that are universally realized by all matter but inessential, in that matter could exist without them. With that distinction in hand, one might classify not only thought, but also motion and gravitation as inessential properties superadded to matter; unlike thought, gravitation is universal to matter, but if it does not belong to matter *as matter*, then it is superadded, just like thought. What might be the empirical basis, however, for distinguishing essential properties—properties belonging to matter *as matter*—from those that are merely universally realized? It is difficult to see what the basis might be. For Locke, the problem might be resolved by supposing that his claims about superaddition are not intended as an ontological thesis, about the real essence of matter, but rather as an epistemic thesis about the limits of our understanding.[416]

For Newton, however, what is at issue is an ontological thesis of superaddition, and that thesis is not easily reconciled with his views. His empiricism permits superaddition only according to the second condition identified above, on which superadded properties are those not possessed by matter in general; yet such a claim would classify gravity as essential rather than superadded. His empiricism does not permit superaddition according to the first condition identified above; it does not permit the strong view of essential properties needed to say that gravity could be universal to matter and yet inessential or superadded. For just as with Locke, it

[416] On this issue, see Margaret Dauler Wilson, "Superadded Properties: The Limits of Mechanism in Locke"; James Hill, "Locke's Account of Cohesion", 627.

is difficult to see what empirical grounds Newton could find for claiming that gravity is universally realized, yet inessential in the sense that matter could exist without it. As we have seen, Newton makes no official claim about what matter is "essentially and metaphysically".[417] He does not assert anything about matter's nature in his non-speculative writings, such as the *Principia*, and his view, set out initially in *De Gravitatione* and reiterated in a much later text,[418] is that we can only infer substances, since we have access only to properties.

If we look to Newton's official position, then, we can reject both the notion of superaddition and Henry's concomitant sense of 'mediation', in which God mediates between the way matter is essentially and the way God actually created it. Still, I will need to return to questions about the essential nature of matter, for though Newton officially makes no assertions about it, in texts that must be classified as speculative, including the letter to Bentley, Newton seems very much concerned with matter's essential and metaphysical nature. I postpone those considerations, however, since a closer look at Newton's letter indicates that he has spatial mediation in mind.

Spatial Mediation and the Principle that Matter Cannot Act Where It Is Not

When Newton writes that it is inconceivable that matter could affect other matter without mutual contact, unless by the mediation of something immaterial, he is not simply paraphrasing Bentley's own words, for he makes a crucial modification. Bentley himself had said that such distant action by matter is inconceivable without a "divine impression" and in his published lectures he continues to speak of God "impressing" active powers upon matter, and "infusing"

[417] Here I am paraphrasing a comment from *De Gravitatione*. Newton allows that matter has some "essential and metaphysical constitution", but does not attempt to say what that is. See *Philosophical Writings,* 27.

[418] "We do not know the substances of things. We have no idea of them. We gather only their properties from the phenomena and from the properties [we infer] what the substances may be. That bodies do not penetrate each other we gather from the phenomena alone; that substances of different kinds do not penetrate each other does not at all appear from the phenomena. And we ought not rashly to assert that which cannot be inferred from the phenomena." (Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 360-362), *Unpublished Scientific Papers of Isaac Newton*, 360-361.)

matter with energy. This sort of language expresses Bentley's thesis of superaddition by suggesting a single divine action. In repeating Bentley's words back to him, however, Newton uses a term that does not suggest a single action. He speaks not of a divine impression but of the "mediation" of something immaterial: it is absurd, he writes, to suppose "yt one body may act upon another at a distance through a vacuum without the mediation of any thing else by & through wch their action or force may be conveyed from one to another". Evidently, Newton has spatial mediation in mind.[419] This is the natural way to understand the term 'mediation' in this context, since that which mediates conveys the force or action from one point in space to another, for instance from the center of the sun to the center of Jupiter.[420] In other words, there must be some entity that occupies the space between the bodies and conveys their gravitational effects upon one another. To think otherwise is an absurdity, which is to say a contradiction.

What exactly is contradicted? One possibility is suggested by the subsequent section of Newton's letter, which speaks of a "contradiction in nature" as something that is not "really in nature".[421] So perhaps the notion of matter acting at a distance is not an impossibility, but something that just as a matter of fact is not really in nature. But this raises the question of

[419] This spatial interpretation of the term 'mediation' is the prevailing interpretation. See for example McMullin, *Newton on Matter and Activity*, 59.

[420] Additionally, if Newton were trying to make the point that Henry attributes to him, namely, that God infused matter with active powers, thereby mediating between the nature it would have had, had it existed in a godless universe, and the nature it actually has as God created it, there were ways to make the point more directly. After all, both Hale, whom Henry elsewhere explains that Newton read, and Bentley, manage to explain very clearly that they think that active powers have been "superadded" or "infused" in matter by God, and their remarks do not suggest spatial mediation, as do Newton's. The spatial interpretation of the term 'mediate' that I defend reflects Newton's use of the related word 'intermediate', as he describes the gravitational force in the posthumously published *A System of the World*. At several points, Newton speaks of the force that is intermediate between two bodies, and clearly the force is spatially intermediate, for he gives the analogy of a rope connecting the bodies. The passage I reference appears in Stein, "Newton's Metaphysics", 288, and is quoted elsewhere in this chapter.

[421] In the next section of his fourth letter, Newton comments upon one of Bentley's earlier suggestions, explaining that he has failed to prove as "absurd" the claim "that there should be positively an infinite sum or number". It can happen, Newton explains, that a "contradiction in terms", which is "an impropriety in speech", may be used to refer to something that is not a "contradiction in nature". Two examples Newton gives are a silver inkhorn and an iron whetstone. The names imply, respectively, an object that is made of horn yet made of silver, and an object that is made of iron yet made of stone. Yet the actual objects referred to by these phrases are made only of silver in the one case, and only of iron in the other. So while "contradictious phrases" are used to name these objects, those objects are not contradictions in nature because they are "really in nature". Newton begins his discussion of contradictions in nature with a mathematical example, which raises the intriguing question of whether Newton thought of mathematical truths as being part of nature, in the sense that their truth status would be dependent upon God.

evidence. What is the ground for saying that matter does not in fact act at a distance? The *Principia* implies the possibility that bodies can without any intermediary affect one another across empty space, and although Newton is profoundly dissatisfied with that possibility, he has not found an alternative causal explanation. Is Newton, who would go on to write in the 1713 General Scholium that he does not feign hypotheses, here declaring, as a metaphysical principle, the Scholastic maxim, *matter cannot act where it is not*?[422]

Before investigating that question, let us consider this principle more closely, as it appears to be a derived principle. It might be derived from a general principle of local causation (PLC):

PLC: Nothing can act where it is not.

We can see this principle operating in one interpretation of Samuel Clarke's remarks about action at a distance. Clarke, who defends a Newtonian position in the exchange that became known as the Leibniz-Clarke Correspondence, writes in his Fourth Reply: "That one body should attract another without any intermediate means, is indeed not a miracle but a contradiction: for 'tis supposing something to act where it is not."[423] Since Clarke speaks generally about "something", rather than about matter in particular, we might understand him to mean that all causation must be local. The contradiction he sees in the notion of matter acting at a distance would then be as follows. To say that a thing acts implies that it is present at the site of the effect, and so to say

[422] As Mary Hesse notes in "Action at a Distance in Classical Physics", 337, "matter cannot act where it is not" is a metaphysical principle of the Scholastics. Its history extends back to the ancients, however.

[423] "That one body should attract another without any intermediate means, is indeed not a miracle but a contradiction: for 'tis supposing something to act where it is not. But the means by which two bodies attract each other, may be invisible and intangible, and of a different nature than mechanism; and yet, acting regularly and constantly, may well be called natural; being much less wonderful than animal-motion, which yet is never called a miracle." (Clarke's fourth reply, *Leibniz-Clarke*, 53.)

that a thing acts at a distance without any intermediate means is to imply that it both is and is not located at a given place.[424] So PLC is one potential source of Newton's objection.

Another fundamental principle is suggested, however, by Newton's remark in draft material relating to the *Optice*, "Matter is a passive principle, and cannot move itself".[425] This suggests a general principle of the passivity of matter (PPM).

PPM: Matter is passive, and cannot move itself.

---

[424] A different interpretation of this passage, together with Clarke's subsequent remarks in his Fifth Reply, is given by John Henry in "God and Newton's Gravity". On Henry's reading, Clarke can be understood as accepting the same position that Henry attributes to Newton, namely, that matter has active powers that were superadded by God; for Clarke does not name God as the cause of gravitational motions, and instead changes the subject, to the question of whether there could be an effect without a cause. I disagree with this interpretation, for the following reasons. When Clarke takes up the issue of action at a distance again in his Fifth Reply, there is no indication that he has abandoned this principle, but the main question he is answering now is, are we justified in claiming to know that bodies attract one another, even if we cannot specify the causal means by which this happens? He says that "the sun attracts the earth through the intermediate void space", however he then explains that the claim that the space is void is simply an experimental result, in that nothing having sensible resistance has been detected in that space. (This is consistent with Newton's use of the term 'void'.) There must be some means that produces this effect, but even if we cannot find the cause, we still have sufficient evidence to claim to know the effect.

> That the sun attracts the earth...and that the space betwixt them is void, that is, hath nothing in it which sensibly resists the motion of bodies passing transversely through: all this, is nothing but a phenomenon, or actual matter of fact, found by experience. That this phenomenon is not produced *sans moyen*, that is without some cause capable of producing such an effect; is undoubtedly true. Philosophers therefore may search after and discover that cause, if they can; be it mechanical or not mechanical. But if they cannot discover the cause; is therefore the effect itself, the phenomenon, or the matter of fact discovered by experience , (which is all that is meant by the words attraction and gravitation) ever the less true? Or is a manifest quality to be called *occult*, because the immediate efficient cause of it (perhaps) is occult, or not yet discovered? (Clarke's fifth reply, *Leibniz-Clarke*, 118.)

Henry notes (*ibid.*, 137) that Clarke does not name God as the direct cause, "nor any kind of immaterial entity". This is true, but he does not rule these things out either (and God always remains an option, given that in objecting to the claim that Newton's gravity is due to a miracle, Clarke explains that there is no difference between the natural and the miraculous, except that the former is common and the latter unusual.) While it is possible that Clarke has abandoned his earlier claim that there must be some intermediate means, on pain of contradiction, there is no indication that he has; the point he is emphasizing is that we call the space a void because we have no evidence of a medium, but that does not indicate there is none.

[425] "Whence it seems to have been an ancient opinion that matter depends upon a Deity for its (laws of) motion as well as for its existence. The Cartesians make God the author of all motion & its as reasonable to make him the author of the laws of motion. Matter is a passive principle & cannot move itself. It continues in its state of moving or resting unless disturbed. It receives motion proportional to the force impressing it, and resists as much as it is resisted. These are passive laws & to affirm that there are no other is to speak against experience. For we find in o^r^selves a power of moving our bodies by o^r^ thought. Life & Will (thinking) are active Principles by wch we move our bodies, & thence arise other laws of motion unknown to us." (ULC, Add. 3970, fol. 619r, quoted in McGuire, "Force, Active Principles", 171.)

Newton might accept one of these principles, both, or neither, and his grounds might or might not be empirical. In the next sections, I shall consider more carefully what each of these principles might mean for Newton, and what grounds he might have for holding them.

LOCAL CAUSATION

What exactly constitutes local causation? Since Newton's ontology includes spirits as well as matter, the answer to this question depends upon the sorts of entities involved.

Interactions between Material Bodies

Material bodies cannot interpenetrate.[426] In cases involving material bodies alone, therefore, a causal interaction is local if it occurs by contact between the bodies' surfaces. To this extent, Newton may be said to agree with Descartes. As will become evident later, however, Newton expects only a strikingly small range of effects to be explained in this way.

Interactions between Material and Immaterial Entities

For causal interactions involving both material and immaterial entities, we should not expect surface action to be the means. The explanation here is decidedly un-Cartesian. According to a Cartesian, the reason that immaterial and material entities could not causally interact by surface action is that immaterial entities, being unextended, have no surfaces. Thus for a Cartesian, no two things of any kind can be in the same place at the same time. Two bodies, being identical with extension, exclude one another;[427] and as for entities of different kinds, an

---

[426] See *De Gravitatione*; Rule 3 of the *Principia*; Query 31 of the *Opticks*.

[427] As Descartes explicates the Scholastic view that two bodies cannot be in the same place at the same time, impenetrability is implied by the essence of extension. Responding to Henry More's claim that they are separable, Descartes writes, "We cannot even understand one part of an extended thing penetrating another part equal to it without understanding by that very fact half of that extension eliminated or annihilated. But what is annihilated does not penetrate another thing. And thus, in my judgment, it is demonstrated that impenetrability pertains to the essence of extension." (Quoted in Garber et. al., "New Doctrines of Body and its Powers, Place and Space", *The Cambridge History of Seventeenth Century Philosophy*, Vol. 1, 579.)

immaterial entity can neither exclude a material body nor share its spatial location. Newton's view is quite different. While he agrees that no two bodies can be in the same place at the same time, the same cannot be said for entities of different kinds.

According to Newton, everything that exists is extended. Spatial location is a condition of existence, he writes in *De Gravitatione*; that which is neither everywhere nor somewhere does not exist.[428] God is everywhere, which is to say that God is substantially present throughout all of infinite space; for as related below, Newton argues that it is not only God's *virtus* or active power but also God himself that is omnipresent. Minds are somewhere; they too are extended, being "diffused through space".[429] For to say that the mind is not substantially present in any extension—insofar as this is even intelligible, Newton writes—is to say that it does not exist.[430] Although Newton has relatively little to say about minds in his later writings, there is no reason to think that he strays from this early view, and he clearly retains the belief that God is substantially present throughout space.

Since bodies and minds are somewhere but God is everywhere, it follows that two things will be in the same place at the same time if one of those things is God. God shares the places occupied by all other existents, and this means that in acting locally, God is not restricted to acting only upon a body's surface. Whereas each of two material bodies is stopped at the surface of the other, omnipresent God can act locally by penetrating to the very centers of material bodies.

---

[428] "No being exists or can exist which is not related to space in some way. God is everywhere, created minds are somewhere, and body is in the space it occupies; and whatever is neither everywhere nor anywhere does not exist. And hence it follows that space is an emanative effect of the first existing being." (*De Gravitatione*, *Philosophical Writings*, 25.)

[429] "Just as we understand the moment of duration to be diffused throughout all spaces, according to its kind, without any concept of its parts: so it is no more contradictory that mind also, according to its kind, can be diffused through space without any concept of its parts." (*Ibid.*, 26.)

[430] "Nor is the distinction between mind and body in his philosophy intelligible, unless at the same time we say that mind has no extension at all, and so is not substantially present in any extension, that is, exists nowhere; which seems the same as if we were to say that it does not exist, or at least renders its union with body thoroughly unintelligible and impossible." (*Ibid.*, 31.)

If additional immaterial substances exist, ones that are inanimate such as an electric spirit or immaterial aether, then these too might be able to act locally by co-occupying place with material bodies. We have no empirical grounds for denying this, Newton writes in the ultimately unpublished Draft Conclusion to the General Scholium: "That substances of different kinds do not penetrate each other does not at all appear from the phenomena. And we ought not rashly to assert that which cannot be inferred from the phenomena."[431]

So, local causation for material bodies involves surface action, but local causation between material and immaterial entities may involve the sharing of spatial location, as the immaterial entity penetrates the particles of matter that are impenetrable by one another. It is the latter sort of local causation that Newton has in mind as he states the condition for gravity's cause in the General Scholium.

> This force arises from some cause that penetrates as far as the centers of the sun and planets without any diminution of its power to act, and that acts not in proportion to 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.[432]

This condition of local causation would be fulfilled by God, clearly enough, but might also be fulfilled by some inanimate (or at least non-perceiving) immaterial substance.[433] Newton continues to speculate about such substances, notably the aether. But while such substances

[431] Draft Conclusion for General Scholium, MS. C (MS. Add 3965 fols. 360-362), *Unpublished Scientific Papers of Isaac Newton*, 360-361.

[432] General Scholium: "This force arises from some cause that penetrates as far as the centers of the sun and planets without any diminution of its power to act, and that acts not in proportion to 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*, 943.) In a draft for the General Scholium, Newton makes the same point: "[Gravity] proceeds from some cause that penetrates to the very centers of the Sun and Planets without any diminution of its virtue, and which acts not on the surfaces of particles alone, but on all matter to the very centre since its action is proportional to the quantity of matter in all bodies. It proceeds from a cause by which the single particles of bodies act at immense distances with a virtue decreasing in the duplicate ratio of the distances reciprocally." (*Unpublished Scientific Papers of Isaac Newton*, 353.)

[433] I add this parenthetical note, distinguishing non-perceiving substances from inanimate ones, because in keeping with the vitalist strain of influence upon his thinking, Newton does at some points speculate that "all nature" might be "alive". See ULC, Add. 3970, fol. 620r, quoted in McGuire: "It appears that there are *other laws of motion (unknown to us) than those wch arise from Vis inertiae* (unknown to us) wch is enough to justify & encourage o[r] search after them. We cannot say that all nature is not alive." ("Force, Active Principles", n.52.)

might, if they are immaterial, be capable of acting locally by penetrating material particles, this does not imply that they cannot also act non-locally. This will become evident in the next section, which examines the question of whether Newton adheres strictly to a general principle of local causation.

Newton's Commitment to the Principle of Local Causation

Does Newton accept the general principle, PLC, that regardless of the kinds of entities involved, all causation must be local? He does not *assert* PLC, nor any other principles he recognizes as hypotheses; it does not appear in the *Principia*, for instance. Yet we can still ask about the status of PLC in writings that may be classified as speculative, including unpublished manuscripts, the *Opticks* queries, and the letters to Bentley. The remarks to Bentley are inconclusive. Since Newton speaks there only of interactions between material bodies, it is possible that he allows distant action by immaterial substances, but it is also possible that he accepts PLC, on the grounds that non-local causation is unintelligible.

One text initially seems to dispense with the sorts of intelligibility requirements seen in Descartes and Leibniz. Descartes rejected action at a distance on the grounds that it implicitly attributes to bodies an awareness of one another's existence,[434] and Leibniz charged Newton's theory with failing to provide an understandable story about how gravitational effects are produced. One of Newton's responses initially appears to suggest that since an omnipotent God could endow matter with active powers of attracting or repelling other matter at distances, there is nothing further to understand. "Certainly God could create planets that should move round of themselves without any other cause than gravity that should prevent their removing through the tangent", he writes, in an ultimately unpublished letter responding to Leibniz's charges.[435] And

[434] On this point, see Jammer, *Concepts of Force,* 104. For a discussion of Descartes' criticism of Roberval's explanation of the solar system, which employed attractions acting at a distance, see Westfall, *Force*, 86-87.

[435] Newton to the Editor of the *Memoirs of Literature*, unpublished, written c. May 1712, *Philosophical Writings*, 116-117.

while Leibniz expects some further explanation of gravity, beyond a law of God or a primitive quality, Newton at one point seems to allow primitive qualities as the end of the explanation; gravity is no more occult than hardness, he writes, for neither one can be explained mechanically.[436] Yet the letter's full remarks clearly indicate that Newton is not allowing gravitational attraction as a primitive. It is progress to know that gravity can keep the planets in, even if we do not know its cause, he writes, implying that since the cause remains to be discovered, gravity is not a primitive.[437] Since Newton thinks there remains something to be discovered, namely the causal story how gravitational effects are produced, he does not take gravitational attraction to be a primitive power. So the text in the end is fully consistent with PLC.

Newton's commitment to PLC does come into question, however, when we examine the aether of the *Opticks*. In the final set of queries that he wrote for the *Opticks*, queries 17-24,[438] Newton again speculates about an aether that might explain a wide range of phenomena, including light behavior, heat transfer, and more dubiously, gravitational effects.[439] The

---

[436] "No man ever attempted to explain these qualities [i.e., the *vis inertiae*, the extention, the duration and mobility of bodies] mechanically, or took them for miracles or supernatural things or fictions or occult qualities. They are the natural, real, reasonable, manifest qualities of all bodies seated in them by the will of God from the beginning of the creation and perfectly incapable of being explained mechanically, and so may be the hardness of primitive particles of bodies. And therefore if any man should say that bodies attract one another by a power whose cause is unknown to us, or by a power seated in the frame of nature by the will of God, or by a power seated in a substance in which bodies move and float without resistance and which has therefore no *vis inertiae* but acts by other laws than those that are mechanical: I know not why he should be said to introduce miracles and occult qualities and fictions into the world. For Mr. Leibniz himself will scarce say that thinking is mechanical as it must be if to explain it otherwise be to make a miracle, an occult quality, and a fiction." (Newton to the Editor of the *Memoirs of Literature*, unpublished, written c. May 1712, *Philosophical Writings*, 116-117.)

[437] "Certainly God could create planets that should move round of themselves without any other cause than gravity that should prevent their removing through the tangent. For gravity without a miracle can keep the planets in. And to understand this without knowing the cause of gravity, is as good a progress in philosophy as to understand…the frame of the bones and muscles and their connection in the body of an animal and how the bones are moved by the contracting or dilating of the muscles without knowing how the muscles are contracted or dilated by the power of the mind, is [in] the philosophy of animal motion." (*Ibid.*)

[438] Queries 17-24 were written last, and inserted between some earlier queries for the 1717/18 English edition of the *Opticks*. What became Query 31 for the 1717/18 edition was a revision of the essay that had appeared in the 1706 *Optice* as Query 23; and the version in the 1706 edition was itself a revision of an earlier essay. On this point, see Westfall, *Never at Rest*, 644. The reader is also referred to McGuire, "Force, Active Principles", for an extensive discussion of differences between the earlier and later versions of Query 23/31.

[439] It would at best fail to explain the universal gravitation among ordinary particles of matter, and at worse, violate that conclusion from the *Principia*. Some commentators hold that Newton meant the aether more seriously as an

extremely rare aether that figures in Query 21's hypothesis about gravity operates by repulsive action among the aethereal particles, whose elastic force is "exceedingly great". Increasing in density as it extends outward from the sun, the aether sets up a pressure gradient that impels the planets inward toward the sun. As an explanation of gravity, the hypothesis is quite tenuous. The point here, however, is that in speculating about the tremendous elastic force by which the aethereal particles "endeavor to recede from one another", Newton suggests a picture of aethereal particles acting upon one another from a distance.[440]

This result could be avoided if the repulsive action of the aethereal particles were due to some further medium, a continuous one that operated by contact. During the period of the 1713 General Scholium, Newton had high hopes for the electric spirit, which in one text he takes to be continuous.[441] Yet when speculating about the repulsive forces in a particulate aether, Newton does not mention the need for a continuous spirit. One possible explanation weighs against PLC: invoking a continuous medium would make the aether superfluous. If the goal were to preserve PLC, one could postulate a continuous medium as a direct explanation for light behavior, heat transfer, and gravitational effects, cutting out the aethereal middleman. It is also notable that the

---

explanation of optical phenomena than he did for gravitational effects. Laudan argues that Newton did accept the aethereal speculations of the *Opticks*, however as McMullin notes, Laudan's discussion of the *Opticks* aether focuses upon optical and chemical phenomena, not upon the Query 21 hypothesis about gravitation. See McMullin, *Newton on Matter and Activity*, 151.

440 Some commentators think that the aethereal particles act distantly (Cohen; Hawes), while others disagree (Halls, *Unpublished Scientific Papers of Isaac Newton*, 207). Janiak, tending toward the latter view, suggests that the aether might operate locally: "The aether's ubiquity throughout space might ensure that its action is only local in character." See Janiak's Introduction, *Philosophical Writings*, xxiv. We know from the Draft Conclusion to the General Scholium (*Unpublished Scientific Papers of Isaac Newton*, 360-361) that Newton thinks substances of different kinds might be able to penetrate one another, and in accordance with this, Janiak notes that the aether particles might be able to penetrate the particles of matter. It is not clear how this suggestion could dispel the appearance of action at a distance among the aethereal particles themselves, however, given that the aether is both extremely rare, and extremely elastic, with the fine particles having tremendous repulsive force. It is difficult to see how the aethereal particles' elastic motions could be explained by contact; they lack resistance, and even if they could collide, Newton's explanation of elastic collisions itself involves distance forces.

441 In that same text, Newton also writes that the electric force is not communicated by contact. Initially, this is puzzling. Why would the spirit not act by contact, if it is continuous? The answer is that Newton means that the spirit does not act by *material* contact. He is comparing it to the magnetic force, which he says does act by contact, and which was widely accepted in Newton's time to act by means of material effluvia. See my earlier discussion in chapter IV. The relevant passage appears in A Draft Conclusion to the *Principia*: "Magnetic force is communicated by contact; the other forces are not." (Cohen, "Guide", 287-292.)

suggestion Newton gives for the strength of the aether's repulsive force does nothing to preserve PLC: he attributes it to the smallness of the aethereal particles.

Is Newton invoking action at a distance in one arena in order to avoid it in another? He seems to be doing just that, not only in Query 21, which invokes an aether to explain away the apparent distant action by sun and planets upon one another, but also in Query 18's speculations about heat transfer. In that latter query, Newton describes an experiment in which two thermometers are placed in glass cylinders, one evacuated of air and the other not. When the cylinders are carried from a cold place into a warm one, Newton writes, the thermometers will grow warm at nearly the same rate; and will cool at nearly same rate when taken back to a cold place. Newton infers that there might exist some very subtle, vibrating medium that can travel through the glass and communicate heat from the air to the thermometer.[442] (And presumably the aether, rather than the air, would effect the heat transfer in the case of the unevacuated cylinder, as well as the evacuated one.) Thus he seems to be invoking the aether in part to avoid the result that the air outside the cylinder is affecting the thermometer within it from a distance.[443]

There is, however, an obvious means of avoiding the unsatisfactory result that Newton is both allowing and trying to avoid action at a distance. Perhaps he does not object to non-local causation generally, but only to distant action by *matter*. (Indeed, he may object to any action by matter, as we shall see in a later section.) In other words, it is not PLC that he aims to preserve, but only the narrower principle identified earlier, namely, that *matter* cannot act where it is not. In support of this, we may point to Newton's uncertainty about the aether's nature; it might well be

---

[442] See Query 18, *Opticks*, 348-349.

[443] The aether also has reductionist appeal. It potentially offers a means of explaining a wide range of phenomena by means of a single substance. However, the same reductionist goals might be accomplished by the dual-natured force that Newton speculates about in Query 31—a force that attracts at some distances, but repels at others. So one means of reducing the number of forces would be to attribute this dual-natured force directly to the particles of matter. Since the aether is not the only hope of achieving the reductionist goal, it is reasonable to think that it is appealing in part as a means of avoiding the result that matter acts distantly.

immaterial, in which case there could be action at a distance, but only by an immaterial substance.[444]

Still, attributing the narrower principle to Newton avoids one oddity only by ushering in another. If we suppose that Newton allows distant action by an immaterial aether, then since he has no direct evidence of this aether, we should expect it at least to resemble his models of immaterial substances. Yet the immaterial substances that Newton considers better known, minds and God, do not provide a model for distant action by an inanimate immaterial substance—for Newton considers minds and God to act locally, as I explain in the next section.

Models for Local Causation

It is difficult to find an unproblematic case of local causation. Collisions between material bodies served for some time as exemplars, however as I show in a subsequent section, Newton speculates that the explanation of elastic collisions between aggregate bodies will involve distance forces, specifically the force of cohesion. How might one explain phenomena involving distance forces, such as gravity and the cohesive force, without abandoning either secondary causation or the principle of local causation? The natural step is to seek an immaterial medium that could act locally. If there is no direct evidence of such a medium, one might provide some grounding for the hypothesis by looking to other immaterial substances as models. The immaterial substances in Newton's ontology are God and, though he does not claim to know their substantial nature,[445] probably minds as well.

The mind is an abstraction from experience, and as Locke points out in his *Essay*, the first notion of active power comes from the experience of moving one's body. If one takes minds to be substances, this experience provides empirical support for the claim that the mind is an active

---

[444] The nature of the aether is unclear; Newton states directly in Query 21, "I do not know what this *Aether* is." (*Opticks, 352.)*

[445] *De Graviatione*, *Philosophical Writings*, 33.

substance. But is there empirical support for saying that in moving the body, the mind acts locally? Newton has relatively little to say about minds, but the early manuscript, *De Gravitatione* does suggest that the mind is extended. Why should we think that the mind is extended? It must be extended he writes, in order to be unified with the body. To say the mind is unextended "renders its union with the body thoroughly unintelligible and impossible."[446] This suggests that causation is local, but it also suggests that Newton's belief in local causation is driving the view of the mind rather than the other way around. Only if the mind is extended could it be located where the body is located, as it must be to be unified with and to move the body. This is not empirical.

Neither is Newton's reasoning about God's substantial omnipresence empirical. He does claim empirical evidence of God's existence; he claims that in the design of animals and the planets' orbital planes. He does not, however, have empirical evidence that God himself is present at all points in space, that is, that God is substantially omnipresent. While it was universally accepted that God is virtually omnipresent—which is to say that God's *virtus* or active power reaches to all points in space—Newton argues for the unorthodox claim that God is also substantially omnipresent. In the General Scholium, he writes of God, "He is omnipresent not only *virtually* but also *substantially*; for action requires substance [*lit.* for active power [virtus] cannot subsist without substance.]"[447] Having assumed the universally shared belief in God's virtual omnipresence, Newton here argues that God himself must also be omnipresent, and he reaches that conclusion on the grounds that an active power cannot subsist without substance. If we ask how exactly this reason is meant to show that God is omnipresent, however, we find the assumption that causation must be local. We know that Newton shares the general view that

[446] *Ibid.*, 31.

[447] General Scholium, *Principia*, 941. In his exchange with Leibniz, Clarke similarly holds that in virtue of his immensity, God is substantially omnipresent; see *Leibniz-Clarke*.

there cannot be properties without substances.[448] But why does Newton think that in order for God's power to be omnipresent, the substance, God himself, must be present everywhere in space? The answer, it appears, is that Newton assumes that a substance must be present where it acts.[449] For a third alternative to both the view that God is not spatially extended and the view that he is spatially omnipresent is the claim that God is spatially extended in only in a limited area of space. (And that claim would meet Newton's condition that existence requires spatial extension.) Yet Newton disregards that alternative, instead taking God to be omnipresent.[450] As with minds, then, the principle of local causation determines God's nature, driving the view that God exists at all points in space.[451]

At least with respect to minds and God, then, the principle of local causation appears to be a metaphysical principle. This produces a tension. To the extent that God and minds are active immaterial substances, they are the only available models for speculation about inanimate immaterial substances. Yet in keeping with his experimental method, Newton does not transplant his reasoning about them into his effort to explain gravity; he does not postulate a continuous

---

[448] See *De Gravitatione*: "The idea of accident involves the concept of created substance." (*Philosophical Writings*, 32.)

[449] Howard Stein takes Newton's reasoning to be empirical: "It might well be asked how *experience* could be said to ground Newton's assertion that "God is everywhere." But first—although the claim that God is everywhere *present in space* was a controversial one, and even somewhat dangerous to advocate—Newton thought the doctrine of the *ubiquity* or *omnipresence* of God amply founded in the tradition of revealed truth; and second, he clearly thought experience shows that *minds* can act only *where they are*; so the doctrine of God's omnipotence (likewise founded in revelation) itself entails his omnipresence." ("Newton's Metaphysics", 270.) Yet how would God's omnipotence entail his omnipresence? Revelation seems to provide no claims that, together with omnipotence, would entail omnipresence (for as Stein notes, Newton's claim that God is substantially omnipresent was controversial). It appears, then, that as I have argued, God's omnipresence is entailed not by the claim of omnipotence alone, but by that claim together with an assumption of local causation.

[450] One might resist my claim that Newton assumes God to act locally via the following reasoning. Given that Newton takes action to require substance, and on this basis thinks that God must be spatially extended, he could hold that God is extended in only a limited part of space. Yet to say that an extended God has only limited extension is incompatible with God's infinity. And so if Newton takes God to be extended at all, then so long as he takes God to be infinite, he must take God to be infinitely extended and thus omnipresent. So, it is not an assumption of local causation that determines God's omnipresent nature, it is the combined claims that there cannot be action without substance and that God is infinite. While I allow this possibility, I still think that Newton may be relying upon an assumption of local causation, since he does so in reasoning about the mind's extended nature. Again, in defense of his claim that the mind is extended, Newton suggests that only an extended mind could be unified with the body, and the notion that the mind must be unified with the body in order to move it suggests that the mind could move the body only by acting locally upon it.

[451] I thank Andrew Janiak for a discussion of these issues.

spirit in order to do away with action at a distance. Instead, the intuitively appealing principle of local causation lingers as a desirable result that he hopes the phenomena will support. Let us now turn to the principle of the passivity of matter.

THE PASSIVITY OF MATTER

For Descartes, there is in general no difference between action and passion; a single event will be an action with respect to one thing, but a passion with respect to some other thing.[452] In the realm of material substance, this must be so, because Descartes asserts a material plenum. Since matter is identical to extension or space, there is no such thing as empty space between any particle—any area of extension—and its neighbors. Therefore, a particle that is pushed by the neighbor on its right must inevitably push against the neighbor on its left, and is simultaneously both active and passive. It is passive with respect to the particle pushing it, and active with respect to the one it in turn pushes.

Newton, however, rejects Descartes' material plenum. His investigations also extend to a great range of phenomena, including "fermentations" or chemical reactions, which appear to involve the spontaneous generation of motion. Lacking a concept of energy, Newton concludes that to replenish the motion that is "always on the decay", the natural order must contain some active principles that generate "new motions", a vast class of phenomena that includes gravitational attractions, electrical and magnetic effects, growth, and chemical reactions. Now, the belief in a material plenum and the belief that the quantity of motion in the world remains constant are the supports of Descartes' merely rational distinction between action and passion. Having rejected those beliefs, Newton sees a real distinction between action and passion. And so active principles could not belong to matter if matter is passive. Yet what exactly does it mean

[452] "What is a passion with regard to one subject is a always an action in some other regard....Although an agent and patient are often quite different, an action and passion must always be the same thing which has these two names on account of the two different subjects to which it may be related." (*The Passions of the Soul*, I.1, CSM, 328.)

for matter to be passive, and which phenomena does Newton expect to be explained by matter alone?

The Meaning of Passive Matter in Newton's System

As we saw earlier, Newton writes in some 1706 draft material, "Matter is a passive principle and cannot move itself", and this gave us an initial definition of passivity. To spell out the details of what this could mean, however, it will be helpful to review a number of possibilities.

(1) *Matter is passive if it plays no role in causing changes of state in itself or in anything else.*

There are a number of ways of understanding this definition, all of which Newton rejects. One might understand it as a claim that matter is unable to act upon anything, either by causing other matter to move or by exciting sensations or perceptions in us. Newton sees the second disjunct as an unsatisfactory consequence of the Cartesian identification of matter with extension, and thus a reason to reject the Cartesian view. A substance, Newton writes in *De Gravitatione*, is an entity that acts upon things. We would not consider something a body if it could not move or excite sensations and perceptions in minds.[453]

One might also understand the definition in terms of a materialist version of pre-established harmony; created entities do not causally affect one another, but only appear to do so, as each carries through its divinely prescribed set of changes. Or one might understand it as an assertion that all causation is primary causation, that is, the direct action by God. Malebranche's version of this holds that only God can produce effects, and though bodies appear to cause effects in one another, as they collide, in fact God is at each instant recreating the bodies, at different points in space.

[453] "Although philosophers do not define substance as an entity that can act upon things, yet everyone tacitly understands this of substances….They would hardly allow that body is a substance if it could not move, nor excite any sensation or perception in any mind whatsoever." (*De Gravitatione*, *Philosophical Writings*, 21-22.)

As we saw earlier, however, Newton inclines strongly toward secondary causation. Although God sometimes intervenes in the established order, to reform the planetary orbits for instance, God accomplishes most of his ends through secondary causation. Newton usually tries to explain even distance forces as secondary causes, and the *vis inertiae*, which gives rise to the three passive laws of motion is consistently a secondary cause. The subsequent possibilities I consider therefore assume secondary causation, each telling us what it might mean for matter to be passive if matter still plays some part in the story of causal interactions.

(2) *Matter is passive if it cannot resist any attempt to change its state.*

As Kepler noted, "If the matter of the celestial bodies were not endowed with inertia, something similar to weight...the smallest motive force would suffice to impart to them an infinite velocity."[454] Such effects are contrary to observations, and we therefore do not find any of Newton's predecessors or contemporaries directly asserting that bodies may be accelerated to infinite or arbitrary velocities. Such was the unintended consequence, however, of any view that made no specific provision for resistance. Locke, for example, takes the primary qualities of body to be solidity, extension, figure, and mobility,[455] but while solidity suggests that a body colliding with an obstacle cannot pass through it, these qualities are still consistent with the result that Kepler wants to rule out, namely, that the body could accelerate the obstacle to an infinite velocity. Newton, like the Scholastics, Kepler, and Descartes, attributes a resistive power to matter, and having distinguished weight from mass, he connects matter's resistive power to its quantity, that is, to its mass.

(3) *Matter is passive if it cannot change its own state.*

In Query 31, Newton writes of his three laws of motion as "passive laws of motion" that

[454] Kepler, *De causis planetarum*; the passage appears in Jammer, *Concepts of Mass*, 55.

[455] *Essay*, I.viii.9, 170.

result from the *vis inertiae*, or force of inertia.[456] According to these laws, a material particle cannot change its own state; it cannot accelerate itself by redirecting any motion it has or by changing its speed, and will remain in its state unless some impressed force is exerted upon it. So a particle's inability to accelerate itself is part of the meaning of passivity. Matter cannot move itself in the sense that one bit of matter cannot move itself.

However, the three laws just by themselves leave open the possibility that matter could move itself in another sense. The three laws do not rule out the possibility that one bit of matter could move another bit of matter. One bit of matter could move another if it could impress a force upon it. Now as Newton tells us in Definition 4, there are different kinds of impressed forces, including not only percussion and pressure, but also centripetal forces, including gravity. And as Newton makes plain in Query 31 and elsewhere, he does not consider gravity to be passive. The gravitational force is either identical to, or caused by, some "active principle", for it is a generative source of new motions. Since Newton considers the generation of new motion to be incompatible with passivity, we need to supplement our definition.

(4) *A material particle is passive if it cannot change its own state, and it cannot generate "new motion" in other matter.*

According to this definition, matter alone cannot generate new motion, so matter alone cannot explain gravitational effects, or the sudden accelerations of resting particles away from one another, as might occur in some "fermentations", that is, chemical reactions. If matter is passive, then the generation of new motion indicates that some active entity, and thus something other than matter, is at work.

---

[456] In Query 31, Newton writes, "It seems to me farther, that these particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles." (*Opticks*, 401.) In draft material for the1706 *Optice* (Query 23/31), dated by McGuire as c. 1705, Newton is more specific, mentioning each of the three laws: "Matter is a passive principle & cannot move itself. It continues in its state of moving or resting unless disturbed. It receives motion proportional to the force impressing it, and resists as much as it is resisted. These are passive laws & to affirm that there are no other is to speak against experience. For we find in o[r]selves a power of moving our bodies by o[r] thought. Life & Will (thinking) are active Principles by wch we move our bodies, & thence arise other laws of motion unknown to us." (ULC, Add. 3970, fol. 619r, a draft variant of the 1706 *Optice*'s Query 23, quoted in McGuire, "Force, Active Principles", 171.)

I take this definition to be the meaning of the earlier-stated principle of the passivity of matter, and with this refinement, we can restate the principle of the passivity of matter (PPM) as follows.

> PPM: Matter is passive, in that a particle of matter can neither change its own state, nor generate new motion in other matter.

Let us now consider what passive matter could do. Specifically, we want to know whether a passive material body could communicate its own motion to another body, or redirect existing motion in another body. Such communication of existing motion will be compatible with the passivity of matter, obviously, only if it is genuine communication, as opposed to the mere appearance of communication that in fact involves the generation of new motion. Newton tells us in Query 31 that we meet with very little motion in the world except that caused by active principles, and that if the world contained only passive principles, the sun would become a cold inactive mass, life would cease, and the planets would not remain in their orbits.[457] Is he thinking that the only motions explicable in terms of matter alone are the absolute translations caused by the *vis inertiae*, that is, the constant rectilinear motions across absolute space?

What Can Passive Matter Do?

What can a material particle do while still qualifying as passive? We know that by its *vis inertiae*, it can remain in a state of absolute rest, that is, rest in absolute space, or in a state of absolute translation across space. It can also resist impressed forces. Can it redirect the motion of other matter, or communicate its own motion to other matter? Perhaps if it could do this by contact—perhaps if the impressed forces of pressure or percussion operated by contact—matter

[457] "For we meet with very little Motion in the World, besides what is owing to these active Principles. And if it were not for these Principles, the Bodies of the Earth, Planets, Comets, Sun, and all things in them, would grow cold and freeze, and become inactive Masses; and all Putrefaction, Generation, Vegetation, and Life would cease, and the Planets and Comets would not remain in their Orbs." (Query 31, *Opticks*, 399-400.)

would still qualify as passive. How exactly could a body communicate its own motion to another body, however?

Henry More tried to dispel the mystery with a metaphor, suggesting that one body rouses the other, as if from sleep, and Locke remarked upon the puzzle in his *Essay*; experience makes the communication of motion by impulse familiar to us, yet the causes and manner of production are obscure.[458] Leibniz explained the communication of motion in terms of the active *vis viva*.

Does Newton think that it is possible for motion to be communicated from one body to another, so that the causal story of collisions includes only passive matter? Or does the apparent communication of motion really boil down to the decay of one motion, and the generation of a new motion by some active entity? There are two cases to consider here: collisions between aggregate bodies, and collisions between individual particles.

Newton's remarks in Query 31 suggest that when aggregate bodies collide, their rebounding motions are not transferred motion but new motion.

> If two equal Bodies meet directly *in vacuo*, they will by the Laws of Motion stop where they meet and lose all their Motion, and remain in rest, unless they be elastick and receive some new Motion from their Spring....This may be try'd, by letting two equal Pendulums fall against one another from equal heights...if of elastick bodies, they will lose all but what they recover from their Elasticity.[459]

So the elastic bodies receive "new motion" from their spring. While Newton's subsequent use of the term 'recover' might seem to undermine this interpretation, because it arguably connotes preserved motion, in other texts he attributes elasticity or "springiness" to the distance forces he associates with activity and new motion. In some drafts for a projected (but ultimately unpublished) Book IV of the *Opticks*, which McGuire dates to the early 1690's,[460] he considers it

[458] Locke, *Essay*, II.xxiii.28.

[459] Query 31, *Opticks*, 398.

[460] See McGuire, "Force, Active Principles", 165.

"very probable" that a great number of phenomena in nature "depend upon certain kinds of forces whereby minute bodies attract or dispell one another at little distances". Among these phenomena he includes "y^{e} springiness or elasticity of hard bodies".[461]

Let us consider how "ye springiness" of aggregate bodies could be new motion produced by distance forces. Aggregate bodies have pores and are made up of many particles.[462] Newton speculates that these particles are held together by a force that has some sensible effect at short distances from the particles, and is exceedingly strong once the particles are in immediate contact.[463] Thus according to Newton's speculations, a single force performs at least these two functions, impelling separated but near particles toward one another, and then binding them once they are contiguous.[464] In virtue of its impelling function, this is a distance force, and Newton

---

[461] "Hypoth 2 As all the great motions in the world depend upon a certain kind of force (w^{ch} in this earth we call gravity) whereby great bodies attract one another at great distances: so all the little motions in y^{e} world depend upon certain kinds of forces whereby minute bodies attract or dispell one another at little distances. How the great bodies of y^{e} Earth Sun Moon & Planets gravitate towards one another what are y^{e} laws & quantities of their gravitating forces at all distance from them & how all y^{e} motions of those bodies are regulated by their gravities I shewed in my Mathematical Principles of Philosophy to the satisfaction of my readers. And if Nature be most simple & fully consonant to her self she observes the same method in regulating the motions of smaller bodies w^{ch} she doth in regulating those of the greater. This principle of nature being very remote from the conceptions of Philosophers I forbade to describe it in that Book leas[t it] should be accounted an extravagant freak & so prejudice my Readers against all those things w^{ch} were y^{e} main designe of the Book: & yet I hinted [at them] both in the Preface & in y^{e} book it self where I speak of the [refraction] of light & of y^{e} elastick power of y^{e} Air: but [now] the design of y^{t} book being secured by the approbation of Mathematicians, [I have] not scrupled to propose this Principle in plane words. The truth of this Hypothesis I assert not because I cannot prove it, but I think it very probable because a great part of the phaenomena of nature do easily flow from it w^{ch} seem otherwise inexplicable: such as are chymical solutions precipitations philtrations, detonizations, volatizations, fixations, rarefactions, condensations, unions, separations, fermentations: the cohesion texture firmness fluidity & porosity of bodies, the rarity & elasticity of air, the reflexion & refraction of light, the rarity of air in glass pipes & ascention of water therein, the permiscibility of some bodies & impermiscibility of others, the conception & lastingness of heat, the emission & extinction of light, the generation & destruction of air, the nature of fire & flame, y^{e} springiness or elasticity of hard bodies." (ULC Add. MS. 3970.3, ff. 338-8v, in Westfall, *Force*, 379; his reconstructions of text that is missing due to damage to the paper appear in brackets, as he indicates, *ibid.*, 411, n.128.) For a discussion of this passage, see also McGuire, "Force, Active Principles", 165; McGuire dates this draft to the early 1690's.

[462] Query 31, *Opticks*, 394.

[463] "The Parts of all homogeneal hard Bodies which fully touch one another, stick together very strongly. And for explaining how this may be, some have invented hooked Atoms, which is begging the Question; and others tell us that Bodies are glued together by rest, that is, by an occult Quality, or rather by nothing; and others, that they stick together by conspiring Motions, that is, by relative rest amongst themselves. I had rather infer from their Cohesion, that their Particles attract one another by some Force, which in immediate Contact is exceeding strong, at small distances performs the chymical Operations above-mention'd, and reaches not far from the Particles with any sensible Effect." (Query 31, *Opticks*, 388-389.)

[464] Passages suggesting this may be found in the General Scholium, in the unpublished Draft Conclusion for the General Scholium, and in Query 31. In the General Scholium, Newton writes:

speculates that it may explain elasticity and thus the rebounding motions in elastic collisions. In a collision, the cohesive force prevents the particles comprising an aggregate body from sliding away from one another, so that instead of deforming, the body springs back by returning to its original shape.[465] (Since an aggregate body is porous, it might deform without the particles losing contact with one another; the areas between the body's parts could diminish, for instance.) Since Newton has speculated that a single force both impels particles toward one another when they are separated but near, and then binds them together once they are contiguous, it seems that impacts between aggregate bodies involve the operation of distance forces.[466]

> A few things could now be added concerning a certain very subtle spirit pervading gross bodies and lying hidden in them; by its force and actions, the particles of bodies attract one another at very small distances and cohere when they become contiguous. (*Principia*, 943-944.)

Similarly, he writes in the Draft Conclusion for the General Scholium,

> Proposition 1. That very small particles of bodies, whether contiguous or at very small distances, attract one another.
> Proposition 2. Or Scholium. That attraction is of the electric kind.
> Proposition 3. That attraction of particles at very small distances is exceeding strong (by Experiment 5) and suffices for the cohesion of bodies. (*Unpublished Scientific Papers,* 361.)

And in Query 31 he speculates,

> The Parts of all homogeneal hard Bodies which fully touch one another, stick together very strongly. And for explaining how this may be, some have invented hooked Atoms, which is begging the Question; and others tell us that Bodies are glued together by rest, that is, by an occult Quality, or rather by nothing; and others, that they stick together by conspiring Motions, that is, by relative rest amongst themselves. I had rather infer from their Cohesion, that their Particles attract one another by some Force, which in immediate Contact is exceeding strong, at small distances performs the chymical Operations above-mention'd, and reaches not far from the Particles with any sensible Effect. (*Opticks*, 388-389.)

465 "If a Body is compact, and bends or yields inward to pressure without any sliding of its Parts, it is hard and elastic, returning to its Figure with a Force arising from the mutual attraction of its Parts. If the Parts slide upon one another, the Body is malleable or soft." (Query 31, *Opticks*, 394.)

466 This has implications for a definition of activity, since it might turn out that distinct forces perform the binding and impelling functions, rather than a single force, as Newton supposes.

Statics presents cases in which forces act, yet because the net force is zero there is no acceleration or in some cases no motion at all. For example, we can suppose a cold universe containing a single, aggregate body, at absolute rest in space. If we suppose the body to be cold, then none of its particles vibrates with heat, and if we suppose the body to be perfectly hard, so that its particles are in contact with one another, then none of the particles moves toward another or is in any other way in motion. There is a force acting, however, for this is an aggregate body whose constituent particles are not merely contiguous but held in contact with one another by the cohesive force. (The gravitational force acts as well, between the centers of any two particles, but let us focus upon the cohesive force.)

As noted above, Newton speculates that a single force performs both the function of impelling distant particles toward one another, and the function of binding them strongly once they become contiguous. So we can classify the cohesive force as a distance force on the basis of a counterfactual: if any particles were to become separated, the force would act across the distance, to impel them back toward one another. As a distance force, the cohesive force is associated with activity, so we seem to have a situation in which there can be activity without any new motion. Yet there should be no oddity in this precisely because the force is a distance force. Although its cohesive function may be

What about the case of individual particles? Here the cohesive force is not a factor. We might therefore expect Newton to say that if a moving particle collides with a resting one, the former communicates motion to the latter by contact. That does not appear to be Newton's view, however. He suggests in Query 31 that like soft bodies, bodies that are absolutely hard will not rebound from one another. "Impenetrability makes them only stop", he writes.[467] He also suggests that particles are hard and impenetrable.[468] Since they have no pores, we may presume that he considers them absolutely hard. This suggests that the impact of two hard particles will not produce an elastic rebound. Without any cohesive force operating, the particles will simply stop. Instead of communicating motion, the impact between individual particles produces a decay of motion. This decay of motion is the strikingly small range of effects due to contact action, mentioned earlier.

According to the picture sketched here, then, what appears in elastic collisions to be the communication of motion from one body to another is in fact the decay of motion followed by the generation of new motion. This picture is consistent with Newton's reference to elastic rebounds

---

performed at absolute rest, it also has the ability to draw particles together should they become separated, and thus to generate new motion.

What if the force that makes particles cohere turns out to be distinct, however, from the force that impels separated particles together? In Newton's speculations, a single force performs these two functions, acting both when the particles are spatially separated and when they are in contact. Since these are only speculations, however, it is also possible that two distinct forces are responsible for these distinct functions—one force impelling particles toward one another when they are separated but near, and another holding them together once they are in contact. On this supposition, the cohesive force would act only upon particles in contact, and therefore could not be considered a distance force in virtue of action it would take upon spatially separated particles. Yet it prevents the separations that would occur if the particles were merely contiguous, and were subjected to an impressed force. Since Newton does not consider the cohesive force as performing only that one function, we cannot point to any texts to say that he would still classify it as active, yet it seems fair to say that he would. If so, this suggests that there can be activity even though the only force operating lacks the ability to generate new motion.

Whether this result is odd or not really depends, however, upon where the causal efficacy lies. If the causal efficacy lies in the forces, then it might be odd to consider a force to be active or an "active principle" (for at one point in Query 31, Newton identifies active principles with gravity and the forces causing cohesion and fermentation) if it lacks the ability to generate new motion. If the causal efficacy lies in a substance, however, and the forces are distinct only to the extent that they represent distinct functions performed by that substance, then since that substance has the ability to accelerate particles as well as make them cohere, we can retain the identification of activity with the ability to generate new motion.

[467] Query 31, *Opticks*, 398.

[468] Query 31, *Opticks*, 394.

in Query 31 as the "new motion" that bodies gain from their spring,[469] and it agrees with his explicit remark there that we meet with very little motion in the world, except that due to active principles.[470] If matter is passive, and thus is not the bearer of these active principles, then the only motions explicable in terms of matter alone are the absolute translations caused by matter's *vis inertiae*.

This is a dramatic departure from the orthodox mechanical philosophy, in which collisions served as a model for causal interactions among material bodies. That picture involved two claims. First, motion could be only transferred in collisions, as opposed to being extinguished and then generated anew, and second, the transfer of motion was effected by contact. According to the interpretation I have sketched here, Newton expects the mechanical philosophy's model of material contact action to be overthrown for nearly all phenomena, for he expects that not even elastic collisions transfer motion or operate by material contact. The details of Newton's replacement model are not known, of course, because the means by which distance forces operate remains unknown. But if their operation is by contact, it will be by the contact of some immaterial substance.

Newton's Commitment to the Principle of the Passivity of Matter

Does Newton accept PPM, at least in his speculative writings? One complication for answering this question is that Newton is uncertain about the nature of the aether, if it exists. He considers it active,[471] if it exists, and at various points he seems to suppose that if it exists, it is

[469] "If two equal Bodies meet directly *in vacuo*, they will by the Laws of Motion stop where they meet and lose all their Motion, and remain in rest, unless they be elastick and receive some new Motion from their Spring....This may be try'd, by letting two equal Pendulums fall against one another from equal heights...if of elastick bodies, they will lose all but what they recover from their Elasticity." (Query 31, *Opticks*, 398.)

[470] "We meet with very little Motion in the World, besides what is owing to these active Principles." (Query 31, *Opticks*, 399.)

[471] In Newton's pre-*Principia* alchemical writings, the aether is active, and remains so in later speculations. In Query 18, for instance, Newton writes, "Is not the Heat of the warm Room convey'd through the *Vacuum* by the Vibrations of a much subtiler Medium than Air.…And is not this Medium exceedingly more elastick and active?" (*Opticks*, 349.)

material. And in the later queries, he returns to some earlier speculations about the transformability of matter. Yet there are reasons for thinking that Newton at least sometimes speculated about an immaterial aether. For one thing, in Query 21's speculative aethereal explanation of gravitational effects, he writes that he does not know what this aether is. Additionally, to invoke a material aether in order to explain gravitational effects would threaten a regress, as discussed earlier, since the material particles of that aether would themselves gravitate.[472]

If we set aside the aether and consider ordinary matter, Newton is strongly drawn to PPM, asserting it directly in some texts, as we have seen. He approvingly adopts Bentley's phrase, 'inanimate brute matter', and in draft material for the 1706 *Optice*, he confines activity to spirits, writing, "Matter is a passive principle, and cannot move itself....Life and will (thinking) are active principles, by which we move our bodies."[473] All matter is attended with signs of life,

---

[472] As noted in an earlier chapter, Newton is well aware of the regress threat. For the 1713 edition of the *Principia*, he writes but ultimately does not publish a corollary setting out the regress argument. In all editions of the *Principia*, Corollary 1 to Proposition 6 of Book III states that the weights of bodies depend only upon the quantity of matter, not upon forms or textures. In the 1687 edition, Corollary 2 then states that there cannot be a material aether, or any other matter, that either fails to gravitate or else gravitates less in virtue of its form (and here Newton presumably means the fineness of its particles). Newton's reasoning here depends upon a hypothesis that he will eliminate for successive editions of the *Principia* (i.e., Hypothesis III, which states: "Every body can be transformed into body of any other kind, and can assume successively all intermediate degrees of quality.") In accordance with the elimination of that hypothesis, Newton revises Corollary 2 for the 1713 edition, but the content of the Corollary remains much the same. Another revision—a further corollary that he writes but ultimately does not include—states the regress argument about the aether. Any attempt to explain gravitational effects by postulating a rare material medium that lacks gravity or has a lesser gravitational tendency will end in a regress:

> If anyone should deny these Hypotheses and have recourse to a third hypothesis, namely, that one admit some matter with no gravity by which the gravity of the perceptible matter may be explained; it is necessary for him to assert two kinds of solid particles which cannot be transmuted into one another: the one [kind] of denser [particles] which are heavy (have gravity) in proportion to the quantity of matter, and out of which all matter with gravity and consequently the whole perceptible world is compounded, and the other [kind] of less dense particles which have to be the cause of the gravity of the denser ones but themselves have no gravity, lest their gravity might have to be explained by a third kind and that (again by a fourth) and so on to infinity. (MS. U.L.C. Add. 3965.6, folio 267^r; the passage appears in McGuire, "Transmutation and Immutability: Newton's Doctrine of Physical Qualities", 264.)

To block the regress, one could of course suppose that the actions of the material aether particles are due to some further medium, one that was immaterial and therefore did not gravitate. But such a move would render the aether superfluous; since there is no more evidence for an aether than for this further, immaterial medium, one might just as well invoke the immaterial medium from the outset to explain gravitational effects, cutting out the aethereal middleman.

[473] "Whence it seems to have been an ancient opinion that matter depends upon a Deity for its (laws of) motion as well as for its existence. The Cartesians make God the author of all motion & its as reasonable to make him the author of the laws of motion. Matter is a passive principle & cannot move itself. It continues in its state of moving or resting

he writes, in more draft material for the *Optice*, suggesting by the term 'attended' that this life is external rather than internal to matter.[474]

One might argue that there is a shift in tone by Query 31, as revised for the 1717/18 *Opticks*. Whereas Newton's draft material for the 1706 *Optice* states that matter is a passive principle, in Query 31, it is no longer matter itself, but matter's inherent force of inertia that is the passive principle: "The *Vis inertiae* is a passive Principle by which Bodies persist in their motion or rest."[475] Drawing upon that remark, one might read Newton as suggesting that while matter possesses a passive principle, namely, the *vis inertiae*, it might also possess an active principle. And one might then see that possibility sketched in this draft passage for the General Scholium: "The particles of very many bodies seem to be endowed with an electric force and to act upon each other at small distances even without friction".[476]

---

unless disturbed. It receives motion proportional to the force impressing it, and resists as much as it is resisted. These are passive laws & to affirm that there are no other is to speak against experience. For we find in o^{r}selves a power of moving our bodies by o^r thought. Life & Will (thinking) are active Principles by wch we move our bodies, & thence arise other laws of motion unknown to us." (ULC, Add. 3970, fol. 619r, a draft variant of the 1706 *Optice*'s Query 23, quoted in McGuire, "Force, Active Principles, 171.)

[474] "Life & will are active Principles by w^{ch} we move our bodies, & thence arise other laws of motion unknown to us. And since all matter duly formed is *attended with signes of life* & all things are framed wth perfect art & wisdom & Nature does nothing in vain: if there be an universal life & all space be the sensorium of a thinking being who by immediate presence perceives all things in it...the laws of motion arising from life or will may be of universal extent." (Draft material for Query 23 of the *Optice*, ULC Ad. 3970.9 f.619, *Force*, 397; my italics.) In addition to Westfall's discussion of this passage (*ibid.*), see McMullin, *Newton on Matter and Activity*, 80, and McGuire, "Force, Active Principles", 205.

[475] "Nature will be very conformable to herself and very simple, performing all the great motions of the heavenly Bodies by the Attraction of Gravity which intercedes those Bodies, and almost all the small ones of their Particles by some other attractive and repelling Powers which intercede the Particles**.** The *Vis inertiae* is a passive Principle by which Bodies persist in their motion or rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted." (Query 31, *Opticks*, 397.)

[476] Draft material for the General Scholium appears to attribute electric forces to particles, which is to say to matter:

> As the System of the Sun, Planets and Comets is put in motion by the forces of gravity and its parts persist in their motions, so also the smaller systems of bodies seem to be set in motion by other forces and their particles to be moved among themselves in different ways, and especially by the electric force. For the particles of very many bodies seem to be endowed with an electric force and to act upon each other at small distances even without friction, and those which are most electric, through friction, emit a spirit to great distances, by means of which straws and light bodies are now attracted, now repelled and now moved in diverse ways. (*Unpublished Scientific Papers of Isaac Newton*, 353-54.)

See also Hawes, "Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", 205. On the basis of the quoted passage and similar texts, Hawes argues that Newton accepted action at a distance via the electric force, while rejecting it for gravitational effects.

At first glance, this remark does appear to suggest action at a distance; it appears to suggest that while friction produces an electric spirit that conveys the electric force, the force acts over shorter distances without friction, and thus without the electric spirit as a medium. Yet a look at the Draft Conclusion to the *Principia* indicates that this is not what Newton has in mind. He does not credit friction with producing the electric spirit, but only with expanding its range. Without friction, the electric spirit still abounds, it simply does not reach as far.[477] And as mentioned earlier, while Newton opens Query 31 by asking whether particles of matter have powers or forces by which they act on one another at a distance, he soon adds that he does not know how such attractions between spatially separated bodies are performed.

At bottom, the dominant tone in Query 31 is uncertainty, and PPM seems to be driving that uncertainty, as Newton leaves the question of where active principles or powers are located unanswered. In earlier draft material, Newton wrote that the nature of the active principle, and its relation to matter, was mysterious,[478] and by Query 31 the mystery remains unsolved. Newton continues to speak of active principles as something extrinsic to matter, but without assigning them any definite location.[479]

---

477 Thus Newton's point in the following passage is that while particles act upon one another at greater distances with friction than without, in both cases an electric spirit is present that conveys the force. "By these experiments it is fully enough clear that glass at small distances always abounds in electric force, even without friction, and therefore abounds in an electric spirit which is diffused through its whole body and always surrounds the body with a small atmosphere, but never goes far out into the air unless it is stirred up by friction. And the case is the same for other electric bodies." (A Draft Conclusion to the *Principia*, Cohen, "Guide", 289.)

478 "Without some other principle than the vis inertiae there could be no motion in the world. (And what that Principle is & by (means of) laws it acts on matter is a mystery or how it stands related to matter is difficult to explain)." (ULC Add. 3970, folls. 255r-256r, quoted by McGuire, "Force, Active Principles", 170-171.) The passage, which was written in English, is from a draft variant of the 1706 *Optice*'s Query 23, a revised version of which would later become Query 31. McGuire dates this draft material, which was written in English, to c. 1705.

479 Whereas the particles of matter possess the *vis inertiae*, which gives rise to the three passive laws of motion, they are "moved by" active principles: "It seems to me farther, that these particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity, that which causes Fermentation, and the Cohesion of Bodies. These Principles I consider, not as occult Qualities, supposed to result from the specifick Forms of Things, but as general Laws of Nature, by which the Things themselves are form'd; their Truth appearing to us by Phaenomena, though their Causes be not yet discover'd." (Query 31, *Opticks*, 401.)

Grounds for the Principle of the Passivity of Matter

What grounds might Newton have for PPM? He does not seem to have inductive warrant for it. Inductive warrant for the three laws of motion does not constitute inductive warrant for PPM, since as we saw earlier, PPM is more restrictive upon matter than are the three laws of motion; the three laws tell us that a bit of matter cannot alter its own state, but they do not rule out the possibility that one particle of matter might have an attracting power by which it can generate motion in another particle.

One might ask why Newton does not assert PPM, given that he does assert the laws of motion—and yet those laws are not based upon uninterpreted experience. Law 1, for instance, is not derived from any theory-free observations, for we do not have experience of any bodies that are wholly free of impressed forces. PPM consists in a conjunction, and Newton asserts the first conjunct—that a particle of matter cannot change its own state—for that boils down to the laws of motion. The second conjunct—that a particle of matter cannot generate new motion in other matter—he does not assert. Why does Newton not assert the second conjunct as well as the first, given that he accepts interpreted observations as an empirical basis for his propositions? The answer, I think, is that the first conjunct is necessary for doing dynamics, whereas the second is not.[480] To do dynamics, Newton needs the laws of motion, but he does not need the claim that matter cannot initiate new motion in other matter; while he gravely doubts that matter could act distantly without a medium, or otherwise generate new motion, his ability to derive forces from effects and to predict further effects from those forces would be untouched by an acceptance of action at a distance. The laws of motion, and thus the first claim comprising PPM, have empirical *bona fides* that the second claim lacks, such as the successful predictions of further effects. Newton does not have inductive grounds for PPM considered as a whole, then, and he confines it to his speculative writings because it is a hypothesis.

[480] My response draws upon DiSalle's work in *Understanding Space-Time.*

CONCLUSION

In this final section, I briefly review some conclusions from the foregoing sections. Then drawing upon those conclusions, I argue that Newton's problem about gravity is a problem about counting substances and apportioning properties to substances. I show how that problem arises from the empirical and metaphysical elements of his thought, and I argue that by its nature, the problem as Newton conceives it cannot be solved.[481]

A Brief Review

Newton does not allow gravity as a superadded property of matter, and in general, it is difficult to see how his empiricism could accommodate an ontological thesis of superaddition for gravity. For to defend such a thesis empirically would require an empirical means of distinguishing between properties that are essential in the strong sense that matter could not exist without them, and properties that are inessential or superadded, though universally realized. Accordingly, Newton does not claim to know which properties are essential to matter in that strong sense. When he denies that gravity is essential to matter, in Rule 3, he employs a different sense of 'essential', classifying gravity as inessential on the grounds that its intensity varies with distance. But while Rule 3's sense of 'essential' purports to be the empirically defensible condition of being intensity-invariant, not all properties that Newton classifies as essential clearly fulfill that condition, hardness being one problematic case. This suggests that Newton's classification, which isolates gravity as universal but inessential to matter, may be driven by some non-empirically based beliefs about matter's essential nature, in the strong sense of 'essential'.

Newton allows that matter has an "essential and metaphysical nature", and though he makes no assertions about what that nature is, his beliefs about matter's nature in this strong sense

[481] Since my arguments concern the problem as Newton conceives it, I shall not be concerned with factors external to his reasoning process. An analysis of factors external to his reasoning might point to his atomism and his lack of a full-fledged field concept as the obstacles to solving the problem about gravity. For he takes atoms to be the fundamental constituents of nature, and while he advances toward a field concept, those advances do not include the requirement that effects be transmitted over time; the notion that gravitational effects could be transmitted instantaneously is still unproblematic in the 17th century.

of 'essential' are evident in his letters to Bentley. In that letter, which may be classified as a speculative text, Newton indicates his belief in what appears to be the metaphysical principle, *matter cannot act where it is not*. He is also drawn to two more fundamental principles from which that narrower principle may derive, a general principle that all causation must be local, and a principle that matter is passive. Yet he asserts none of the three principles, lacking empirical warrant for them. The principle that matter is passive, in that it can neither change its own state nor generate new motion in any other matter is not empirically warranted. This principle is more restrictive upon matter than the three laws of motion, and moreover, the attractions and repulsions of gravitational, electrical, and magnetic phenomena, together with the seemingly spontaneous generation of motion in biological and chemical phenomena, suggest that matter might not obey the principle. The principle that all causation is local similarly lacks empirical warrant. Even collisions fail to provide a model of local causation; for Newton speculates that they may involve distance forces and the generation of new motion, and he has no empirical evidence of the continuous medium needed to deny all action at a distance.

His speculations about a particulate medium, namely the aether, suggest a means of maintaining the narrower principle that *matter* at least cannot act distantly; for while the aethereal particles seem to repel one another by distance forces, they could be immaterial. If we suppose Newton to be guided by this narrower principle, rather than by the general principle that all causation must be local, then it becomes understandable that he would try to avoid action at a distance in such phenomena as heat transfer and gravitational effects by speculatively invoking a distantly acting aether. For if the aether were immaterial, these speculations would preserve the narrower principle.

Yet this narrower principle does not sit easily with some aspects of Newton's thought. Specifically, it is odd to suppose that an immaterial substance is more likely to act distantly than a material one, given that God and minds, which are positioned firmly in Newton's ontology and are the only available models for inanimate immaterial substances, act locally. And indeed as we saw, it is the general principle of local causation that seems to determine the nature of Newton's God and minds, rather than the other way around.

Finally, we saw that animate immaterial substances act locally upon material entities not by surface action but by the co-occupation of place. The same could be true of inanimate immaterial substances, and this sharing of place is the condition upon gravity's cause that Newton states in the General Scholium and elsewhere—it penetrates to the very center of material particles.

Gravity and Newton's Substance Counting Problem

At one level, Newton's problem about gravity is the problem of discovering some immaterial substance that might possess active powers to produce gravitational effects. So it is a problem about finding a suitable substance in which to locate active powers. Yet there is a deeper problem. The claim that substances of different kinds may be able to co-occupy place leads to an epistemological problem, namely, that he has no means of determining how many kinds of substance to infer from a set of properties. I shall call this problem 'Newton's Substance Counting Problem'. There is therefore no means of apportioning properties—most notably active powers—among substances. Let us see how Newton's Substance Counting Problem arises.

Newton does not want to say that God is the active power causing gravitational effects. He thinks that the gravitational force is real, and that gravity's cause is something in the natural world. Nor does he want to say that the active powers belong to material particles. To say that would mean giving up his expectations that matter is passive, and that it cannot act at a distance without any medium. To preserve these expectations, he needs to find some immaterial medium that bears the active powers, and acts locally upon matter.

For an immaterial medium to act locally upon matter might mean co-occupying space with matter. The animate, known spirits (God and minds) act locally upon matter by co-occupying space with it, and Newton allows that an inanimate immaterial medium, such as an aether, might also penetrate matter and share space with it. His grounds for this possibility are inductive, in that it is not ruled out by any known phenomena. A metaphysical principle helped generate this possibility, in that the model for additional, locally acting substances is God, whose extended nature is driven by the principle of local causation; and induction keeps the possibility in play.

Now as we saw earlier, Newton thinks we have no direct access to substances, and must infer them from perceived properties. We infer a body by associating perceived properties with regions of space. Again, this is Newton's means of dispensing with the notion of prime matter; it becomes "unnecessary to feign some unintelligible substance....Extension takes the place of the substantial subject in which the form of the body is conserved by the divine will."[482] Newton's attention is here confined to bodies, and if we suppose that only bodies exist, we have a clear means of counting bodies. If we want to know how many substances are present, given the properties we observe, and if we expect only material bodies to exist, we can individuate and count bodies by using a spatial criterion. When we perceive properties such as color, hardness and impenetrability in one region of space, we say there is one billiard ball, or one planet; and when we perceive those sorts of characteristics in two regions of space, we say that there are two billiard balls, or two planets. But this method of counting bodies works only because bodies are impenetrable by one another.

If we allow more kinds of substances into our ontology, and if we further allow Newton's possibility that two things can be in the same place at the same time, we face an obstacle in trying to individuate and count substances. For again, all substances are spatially extended; God and minds do share space with material bodies; and according to Newton's speculations, there could be yet more substances of different kinds, able to penetrate one another to share the same region of space. Once this is allowed, how could we know how many substances to infer from a set of

[482] *De Gravitatione*, *Philosophical Writings*, 29. (The Halls' translation, *Unpublished Scientific Papers of Isaac Newton,* 140, is identical.)

properties experienced in a single spatial region? When we perceive the properties we associate with a billiard ball, there are at least two substances occupying that space, the material billiard ball, and God,[483] and there might be yet another—an inanimate immaterial substance such as an aether. Since even such inanimate immaterial substances might be able to co-occupy place with matter, we cannot determine how many substances are present by associating properties with different regions of space. Since properties belonging to different substances might be present in the very same region of space, we can no longer employ the spatial criterion mentioned above for individuating and counting substances; a set of properties located in a given region of space might belong to several substances rather than to one alone. This is Newton's Substance Counting Problem.

A further problem is this. Even if we somehow knew the number of substances present in a given region of space, how would we know which properties belonged to which substance? Once again, if the substances shared the same place, we could not employ a spatial criterion for apportioning properties to substances. When two particles attract one another, should the power to generate that motion be associated with the particles themselves, or with some substance that shares their spatial location? When two chemicals are combined and produce an exothermic reaction, there appears to be the spontaneous generation of motion. Should the power to produce this motion be associated with the material chemicals, or with some immaterial substance that shares their spatial location? These are crucial questions for which Newton has no resources to answer; the possibility that different kinds of substance could co-occupy place blocks an answer, so long as he retains an allegiance to empiricism.

If Newton were willing to base his physics upon metaphysical, that is, non-empirical, principles, he could solve his problem about gravity by simply asserting that PPM and PLC were true. He could then postulate the active immaterial substance needed to explain away the

[483] In any region of space, there is at least one substance, immaterial God. If we perceive resistance, hardness, and impenetrability, we say there is another substance, matter, that is, body. (If the body is a human body, then there is an additional substance, mind.) And there could be yet another immaterial substance, such as an immaterial aether.

appearance of sun and planets attracting one another across empty space, much as Leibniz postulates a material vortex by employing his principle that bodies by nature can act only upon contiguous bodies. If Newton could take it as given that matter is unable to generate new motions such as gravitational attractions, and unable to act across empty space, this together with the claim that there are new motions would imply that some immaterial substance must be producing them; some substance other than matter must exist to possess the active powers. Taking those principles as given, however, would be a resort to metaphysics.[484] Since Newton does not permit himself such metaphysical assertions, he cannot postulate an immaterial medium to be the bearer of active powers.

There is no empirical solution either, however. It is difficult to see how there could be any empirical means of associating properties with different kinds of substances that could be in the same place at the same time. Suppose we wanted to determine whether air is necessary to gravitational effects. We could test this by setting up some experiment in which we release a ball within a glass container that has been evacuated of air. When we see that the ball gravitates to earth in the absence of air, just as it does in the presence of air, we conclude that the air particles are not part of gravity's causal story. They are not a catalyst, for instance, needed to produce the gravitational effect. But could we perform this same experiment with the aether, to see whether it is part of the causal story? This cannot be done, because according to Newton's speculations, an immaterial aether might be able to penetrate glass. So if we attempted to remove the aether from

[484] Interestingly, in a letter written well before the *Principia*, Newton appears to allow that hypotheses may play some role in explaining the properties of things, though not in determining the properties of things, except insofar as they furnish experiments. Does he mean that while physical hypotheses may furnish experiments, metaphysical hypotheses too may be allowed some role, namely that of helping explain the properties of things? If so, does he allow metaphysical hypotheses that role because he is confronting the question I have been raising, namely, how do we determine which things are the property-bearers? Newton's remarks in the letter are too brief to provide answers. The text to which I refer is the following passage from Newton's Letter to Oldenburg, for Pardies, of 10 June, 1672: "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." (Letter to Oldenburg. London, 1672, *Newton's Philosophy of Nature: Selections from his Writings*, 5-6.) Another translation of the same passage leaves somewhat less room for the possibility I have sketched: "For hypotheses should be subservient only in explaining the properties of things, but not assumed in determining them; unless so far as they may furnish experiments." (Newton to Oldenburg, for Pardies, 10 June, 1672, in *Philosophical Transactions,* 85, 5014; quoted in Harper and Smith's "Newton's New Way of Inquiry", 120.)

the container in the way we removed the air, new aether might rush in through the glass walls of the container. Since we cannot remove the aether, we cannot know whether the ball would fail to gravitate toward other material bodies in its absence. In general, if immaterial substances can penetrate and share space with matter, we have no way of isolating an immaterial substance, and testing to see what happens in its absence. So there does not seem to be any empirical means of discovering whether there is an aether, or whether the active powers belong to it rather than to matter.

To conclude, then, Newton's problem about gravity seems to be problem of discovering a medium that would preserve his expectation that matter cannot act distantly, and would do so by bearing the active powers that he avoids attributing to matter. Yet his claim that substances of different kinds might be able to co-occupy place gives rise to a more fundamental problem. He has rejected metaphysical (non-empirical) principles as grounds for determining how many substances exist, and which sort of properties a substance might bear. Instead, he holds that we infer the existence of substances on the basis of the properties we perceive. Given these grounds for inferring the existence of substances, once Newton allows the possibility that substances of different kinds might be able to co-occupy place, he leaves himself no means of determining how many substances are present in a given region of space, or how the properties perceived in that space are to be apportioned to different substances. And if he has no grounds for saying how many substances are present in a given region of space, or of apportioning perceived properties among substances that might co-occupy place, then so long as he continues to eschew metaphysical grounds, he has no means for saying that active powers belong to an immaterial medium rather than to matter. In this way, the Substance Counting Problem renders Newton's quest for gravity's causal explanation a problem that cannot be solved.

REFERENCES

Alexander, H.G., ed., *The Leibniz-Clarke Correspondence*, Manchester: Manchester University Press, 1956.

Cohen, I. Bernard, "A Guide to Newton's *Principia*", with contributions by Michael Nauenberg and George E. Smith, in Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I.Bernard Cohen and Anne Whitman, Berkeley: University of California Press, 1999.

Cohen, I. Bernard, "Newton's concepts of force and mass, with notes on the Laws of Motion", in I. Bernard Cohen and George E. Smith (eds.), *Cambridge Companion to Newton*, Cambridge: Cambridge University Press, 2002, 57-84.

Descartes, Rene, *Principles of Philosophy*, in *The Philosophical Writings of Descartes*, trans. John Cottingham, Robert Stoothoff, and Dugald Murdoch; Vol. I, Cambridge: Cambridge University Press, 1985/1999.

DiSalle, Robert, "Newton's Philosophical Analysis of Space and Time", in I. Bernard Cohen and George E. Smith (eds.), *Cambridge Companion to Newton*, Cambridge: Cambridge University Press, 2002, 33-56.

Garber, Daniel et al., "New Doctrines of Body and its Powers, Place and Space", in Daniel Garber and Michael Ayers (eds.), *The Cambridge History of Seventeenth Century Philosophy*, Vol. 1, Cambridge: Cambridge University Press, 1998, 553-623.

Grant, Edward, *A History of Natural Philosophy*, New York: Cambridge University Press, 2007.

Hawes, Joan L., "Newton's Revival of the Aether Hypothesis and the Explanation of Gravitational Attraction", *Notes and Records of the Royal Society of London* 23:2 (Dec., 1968), 200-212.

Henry, John: "'Pray do not ascribe that notion to me': God and Newton's Gravity", in James E. Force and Richard H. Popkin (eds.), *The Books of Nature and Scripture: Recent Essays on Natural Philosophy, Theology and Biblical Criticism in the Netherlands of Spinoza's Time and the British Isles of Newton's Time*, Dordrecht: Kluwer Academic Publishers, 1994, 123-147.

Henry, John, "Occult Qualities and the Experimental Philosophy: Active Principles in Pre-Newtonian Matter Theory", *History of Science* 24 (1986), 335-381.

Hesse, Mary, "Action at a Distance in Classical Physics", *Isis* 46:4 (Dec. 1955), 337-353.

Hill, James, "Locke's Account of Cohesion and its Philosophical Significance", *British Journal for the History of Philosophy* 12:4 (2004), 611-630.

Jammer, Max, *Concepts of Mass*, Cambridge: Harvard University Press, 1961.

Locke, John, *An Essay Concerning Human Understanding*, collated and annotated by Alexander Campbell Fraser, New York: Dover, 1959.

Locke, John, *Mr. Locke's Reply to the Right Reverend the Lord Bishop of Worcester's Answer to His Second Letter*, in *The Works of John Locke* in nine volumes, 12th edition, London: C. and J. Rivington, 1824.

McGuire, J.E., "Force, Active Principles, and Newton's Invisible Realm", *Ambix* 15 (1968), 154-208.

McGuire, J.E., "Transmutation and Immutability: Newton's Doctrine of Physical Qualities", reprinted in J.E. McGuire, *Tradition and Innovation: Newton's Metaphysics of Nature*, Boston: Kluwer Academic Publishers, 1995.

McMullin, Ernan, *Newton on Matter and Activity*, Notre Dame: University of Notre Dame Press, 1978.

Newton, Isaac, *Opticks, Or A Treatise of the Reflections, Refractions, Inflections & Colors of Light*, based on the fourth edition of 1730, New York: Dover, 1952.

Newton, Isaac, *Newton's Philosophy of Nature: Selections from his Writings*, New York: Hafner Publishing Co., 1953

Newton, Isaac, *Correspondence of Isaac Newton*, ed. H.W. Turnbull *et al*., Cambridge: Cambridge, 1959-1971.

Newton, Isaac, *Unpublished Scientific Writings of Isaac Newton*, ed. A.R. Hall and Marie Boas Hall, Cambridge: Cambridge University Press, 1962.

Newton, Isaac, *Isaac Newton's Papers & Letters on Natural Philosophy*, 2nd edition, ed. I. Bernard Cohen, Cambridge, Mass.: Harvard University Press, 1978.

Newton, Isaac, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I.Bernard Cohen and Anne Whitman, Berkeley: University of California Press, 1999.

Newton, Isaac: *Newton: Philosophical Writings*, ed. Andrew Janiak, Cambridge: Cambridge University Press, 2004.

Smith, George and Harper, W., "Newton's New Way of Inquiry", in Jarrett Leplin, (ed.), *The creation of ideas in physics: studies for a methodology of theory construction*, Boston: Kluwer Academic Publishers, 1995.

Stein, Howard, "Newton's Metaphysics", in *Cambridge Companion to Newton*, I. Bernard Cohen and George E. Smith (eds.), Cambridge University Press, 2002, 256-307.

Westfall, Richard S., "The foundations of Newton's philosophy of Nature", *British Journal for the History of Science*, Vol. 1, No. 2 (Dec., 1962), 171-182.

Westfall, Richard S., *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century*, London: Macdonald and Co.; New York: American Elsevier Publishing Company, 1971.

Wilson, Margaret Dauler, 1979, "Superadded Properties: The Limits of Mechanism in Locke", reprinted in *Ideas and Mechanism: Essays on Early Modern Philosophy*, Princeton: Princeton University Press, 1999.

Woolhouse, Roger S., "Locke and the Nature of Matter", *Early Modern Philosophy* 20 (May 2005), 142-161.

APPENDIX:

Query 31's Two-Globe Case

As Newton describes the case, the sum of the motions of the two globes will be bigger when the slender rod connecting them lies with the right line along which the center of gravity moves, than when it lies perpendicular to that right line. Assuming that the globes have equal mass, one must take the numerical sum rather than the vector sum in order to produce Newton's result.[485] Let us consider the case first by taking the vector sum, and then by taking the numerical sum.

1) Vector sum

Suppose we take the vector sum, assigning the values stated below.

m_b: mass of blue globe
m_r: mass of red globe
$\mathbf{V}_{cm}$: velocity of the system's center of mass as it moves in a right line
$\mathbf{v}_b$: tangential velocity of blue globe
$\mathbf{v}_r$: tangential velocity of red globe
$\mathbf{p}_b$: momentum of blue globe
$\mathbf{p}_r$: momentum of red globe
$\mathbf{x}$: unit vector, x direction
$\mathbf{y}$: unit vector, y direction
Let $\mathbf{V}_{cm} = \mathbf{v}_b = \mathbf{v}_r = 5\text{m/s}$
Let $m_b = m_r = 1$ kg

Right Orientation

$\mathbf{v}_b = 5\mathbf{x} + 5\mathbf{y}$ and $\mathbf{p}_b = (1)(5\mathbf{x} + 5\mathbf{y})$
$\underline{\mathbf{v}_r = 5\mathbf{x} - 5\mathbf{y}}$ and $\mathbf{p}_r = (1)(5\mathbf{x} + 5\mathbf{y})$
$\mathbf{v}_b + \mathbf{v}_r = 10\mathbf{x} + 0\mathbf{y}$ and $\mathbf{p}_b + \mathbf{p}_r = 10\mathbf{x} + 0\mathbf{y}$

$|\mathbf{v}_b + \mathbf{v}_r| = 10$ and $|\mathbf{p}_b + \mathbf{p}_r| = 10$

Perpendicular Orientation

$| \mathbf{v}_b = 5\mathbf{x} + 5\mathbf{x} + 0\mathbf{y} = 10\mathbf{x}$
$\underline{\mathbf{v}_r = 5\mathbf{x} - 5\mathbf{x} + 0\mathbf{y} = 0}$
$\mathbf{v}_b + \mathbf{v}_r = 10\mathbf{x} + 0\mathbf{y}$

$|\mathbf{v}_b + \mathbf{v}_r| = 10$ and $|\mathbf{p}_b + \mathbf{p}_r| = 10$

[485] For this example, I assume that the globes have equal masses, a natural assumption, given that Newton does not indicate otherwise. However, the general proof that follows this example applies to cases of unequal as well as equal masses.

The quantities of motion are equal for both orientations, then, given the values assigned to the parameters. Will the quantities of motion be equal for any values of those parameters? The following general proof establishes that they will be.[486]

ω = angular velocity of the rotating rod
v_b = tangential velocity of blue globe
v_r = tangential velocity of red globe
m_b = mass of blue globe
m_r = mass of red globe
x_b = distance from center of mass to blue globe
x_r = distance from center of mass to red globe

Since $m_b x_b = m_r x_r$, then $x_b = m_r x_r / m_b$. (This follows from the definition of center of mass.)

Also: $v_b = \omega x_b$; $v_r = \omega x_r$.

Hence: $m_b v_b = m_b \omega x_b = m_b \omega m_r x_r / m_b = m_r \omega x_r = m_r v_r$.

So the magnitudes of the tangential momentums of the two globes are equal. It follows immediately from the geometry of the situation that these two tangential momentums point in opposite directions. Therefore, the two vectors sum to zero. The only remaining component of the system's motion is the linear motion of the center of mass. So the total momentum of the system must be equal to the component of its momentum corresponding to this component of its motion:

$$\mathbf{P} = (m_b + m_r)\mathbf{V_{cm}}$$

That expression has the same value no matter what orientation the rod is in; right, perpendicular or otherwise. Nothing in the proof depends on the values of m_b and m_r, or whether they are equal or unequal. So this is a completely general proof that Newton's claim that the quantity of motion

[486] I thank John Roberts for supplying the general proof that follows. The proof holds for cases of unequal masses as well as for the case of equal masses that I have assumed Newton to intend.

varies would be incorrect if by “quantity of motion” he meant momentum considered as a vector quantity.

2) Numerical sum

Suppose now that Newton is performing a numerical rather than a vector sum, taking the magnitude of each globe's momentum and then adding those magnitudes. This produces Newton's result that the sum is greater when the rod connecting the globes lies with the right line of absolute translation rather than perpendicular to it. Assigning the same quantities as in the example above, the sum of the magnitudes of the motions (momenta) is $10(2)^{1/2}$ when the rod lies along the right line, but only 10 when it lies perpendicular to it.

Right Orientation

$\mathbf{v}_b = 5\mathbf{x} + 5\mathbf{y}$
$|\mathbf{v}_b| = [(5^2 + 5^2)]^{1/2} = 5(2)^{1/2}$

$\mathbf{v}_r = 5\mathbf{x} - 5\mathbf{y}$
$|\mathbf{v}_r| = [(5^2 + (-5)^2)]^{1/2} = 5(2)^{1/2}$

$|\mathbf{v}_b| + |\mathbf{v}_r| = 5(2)^{1/2} + 5(2)^{1/2} = 10(2)^{1/2}$

and $|\mathbf{p}_b| + |\mathbf{p}_r| = 10(2)^{1/2}$

Perpendicular Orientation

$\mathbf{v}_b = 5\mathbf{x} + 5\mathbf{x} + 0\mathbf{y} = 10\mathbf{x} + 0\mathbf{y}$
$|\mathbf{v}_b| = (10^2)^{1/2} = 10$

$\mathbf{v}_r = 5\mathbf{x} - 5\mathbf{x} + 0\mathbf{y} = 0\mathbf{x} + 0\mathbf{y}$
$|\mathbf{v}_r| = (0^2)^{1/2} = 0$

$|\mathbf{v}_b| + |\mathbf{v}_r| = 10 + 0 = 10$

and $|\mathbf{p}_b| + |\mathbf{p}_r| = 10$

As the dumbbell rotates while moving along a right line, then, the quantity of motion changes; motion is "got and lost". So Newton is taking the numerical sum, and the case therefore contests both of the Cartesian claims.