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Local Motion and the Principle of Inertia: Aquinas, Newtonian Physics, and Relativity

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ABSTRACT: I argue that the Aristotelian definition of motion, "the act of what exists potentially insofar as it exists potentially," and the mover causality principle, "whatever is moved is moved by another," are compatible with Newton's First Law of Motion, which treats inertial motion as a state equivalent to rest and which requires no sustaining mover for such motion. Both traditions treat motion as such as requiring an initial, generating mover but not necessarily a sustaining motor. Through examining examples of motion as treated by Newtonian physics, and through arguing that potential energy is Aristotelian potentiality, I argue that the First Law is understandable according to the Aristotelian definition as an incomplete act with a twofold ordination of the same potentiality. I then propose that, through the notion of spacetime, Special and General Relativity instantiate motion as a unity of differentiated prior and posterior parts that do not coexist in reality.

ARISTOTLE DEFINES motion as "the act of what exists potentially insofar as it exists potentially."[1] About this definition, Aquinas comments that "it is altogether impossible to define motion by what is prior and better known other than as the Philosopher here defines it."[2] Outside Thomism, however, hardly anyone currently accepts this definition. One reason for this situation is the widespread belief that Aristotle's definition is part of an archaic physics that the Scientific Revolution and the progress of science have long ago shown to be useless and false.[3]

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[1] Aristotle, *Phys*. III.1.201a10. For Aristotle and Aquinas, "motion" (strictly speaking) means any of three different kinds of accidental change: local motion, growth and diminution, and, alteration. Substantial change is sometimes, in a loose sense, also called motion. See Aristotle, *Phys*. III.1.201a5–6 and Aquinas, *In III Phys.*, 286. Of the three kinds of motion, local motion is primary. It is first in the order of being. See Aristotle, *Phys*. VII.2.243a10; *Phys*. VIII.7.260a26–261a28; Aquinas, *In VII Phys.*, 898; *In VIII Phys.*, 1087–96. Because of its primacy, an understanding of local motion is especially important to the knowledge of nature qua nature.

[2] St. Thomas Aquinas, *Commentary on Aristotle's Physics*, trans. Richard J. Blackwell, Richard J. Spath, and W. Edmund Thirlkel (New Haven: Yale Univ. Press, 1963) III.285. All English quotations from Aquinas's *In Octo Libros Physicorum Aristotelis Expositio* are from this work. Aquinas's detailed treatment of Aristotle's definition of motion occurs in this commentary, and much of it is repeated in the *Commentary on Aristotle's Metaphysics*. Although some thinkers may question the extent to which the commentaries represent Aquinas's own views, Aquinas clearly speaks for himself in the passage quoted above.

[3] Anthony Flew, *An Introduction to Western Philosophy* (Indianapolis: Bobbs-Merrill, 1971) 192–94. One translator of the *Summa Contra Gentiles* refuses even to translate the whole of Aquinas's argument for the existence of God from motion on the grounds that its physics is thoroughly antiquated: "I refrain from translating the rest of this lengthy argument, based upon the treacherous foundation of Aristotelian

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Nevertheless, Aristotle's definition of motion is a philosophical definition of great generality. As such, it is independent of the specialized ancient and medieval sciences in which it was originally instantiated. In other words, Aristotle's conception of what motion is as such does not depend upon his views about gravity, levity, projectile motion, the celestial spheres, or the location of the earth. Thus, although Aristotle's specific physical sciences were quite limited and frequently mistaken, his general principles of nature remain sound. Consequently, I propose to apply Aristotle's definition of motion, as understood by Aquinas, to a fundamental problem about motion that originates in the sciences and pertains to the conflict between modern physical science and Thomistic natural philosophy. This problem concerns Newton's First Law of Motion, also known as the principle of inertia, which is often given as one of the chief objections to Aquinas's conception of motion.[4] In Aristotle's definition, motion involves a continuous actualization of a potency in a moveable object.[5] Accordingly, motion, as understood by Aquinas, implies the mover causality principle "whatever is moved is moved by another."[6] However, Newton's First Law, "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," treats inertial motion as a state equivalent to rest.[7] Consequently, no mover is required to sustain inertial motion. Thus, the principle of inertia seems incompatible with the definition of motion accepted by Aquinas.[8]

Physics. . . . Whoever will derive an argument for the divine existence from the mechanism of the heavens must take his principles from Newton, not from Aristotle. . . . Aristotle knew nothing of gravitation; and knew only half the *inertia* of matter declared by Newton's first law of motion. He supposed that motion, of its own nature, not only needed starting but also needed continual keeping up by some continually acting cause. He did not know that the question with a moving body is, not what there is to keep it in motion, but what there is to stop it." Joseph Rickaby, S.J., *Of God and His Creatures: An Annotated Translation of the Summa Contra Gentiles of Saint Thomas Aquinas* [1905] (Westminster: The Carroll Press, 1950) 11–12.

[4] The "first proof, or the proof from motion, is open to the objection, first brought against it by Duns Scotus and William of Ockham, that the principle *omne quod movetur ab alio movetur*, on which the whole argument depends, is irreconcilable with sound dynamical science, and is therefore false." Sir Edmund Whittaker, *Space and Spirit: Theories of the Universe and the Arguments for the Existence of God* (Hinsdale: Henry Regnery Co., 1948) 45–46. Whittaker was a physicist and a member of the Pontifical Academy of Sciences. Historian A. C. Crombie makes the same criticism in terms of the Aristotelian conception of motion: "Local motion, like other kinds of change, was a process by which a potentiality towards motion was made actual. Such a process necessarily required the continued motion of a cause and when the cause ceased to operate, so did the effect. All moving bodies which were not alive thus received their motion from a mover distinct from themselves and the mover necessarily accompanied the body moved." A. C. Crombie, *From Augustine to Galileo* (London: Falcon Press, 1957) 82.

[5] Aquinas, *In III Phys.*, 297–307.

[6] Aquinas argues for the mover causality principle from the definition of motion in several places. See, for example, *In VIII Phys.*, 1053; *SCG* I.13.9; *ST* I.2.3.

[7] Isaac Newton, *The Principia. Mathematical Principles of Natural Philosophy. A New Translation*, trans. I. Bernard Cohen and Anne Whitman assisted by Julia Budenz; preceded by *A Guide to Newton's Principia*, I. Bernard Cohen (Berkeley: Univ. of California Press, 1999) 416. All English quotations of Newton's *Principia* are from this translation.

[8] Objections to the Thomistic conception of motion have also been made because it treats motion teleologically. Such objections are not addressed in this paper, which is concerned with defending the Aristotelian definition of motion with respect to the more frequently mentioned objections concerning efficient causality and the conception of motion as a process in which a potency is actualized.

Furthermore, the First Law played, and continues to play, an important role in the interpretation of the Scientific Revolution and the developments and discoveries associated with it. Most especially, the First Law seemingly lends itself to atomist and otherwise anti-Aristotelian interpretations of the universe.[9] These tendencies have been only partly corrected by developments related to Special and General Relativity, Big Bang cosmology, and quantum mechanics.[10] Therefore, I will argue that Newton's First Law and the Aristotelian definition of motion are compatible and that the Aristotelian definition need not be rejected on account of the First Law.[11]

AQUINAS AND NEWTON ON MOVER CAUSALITY

I will begin with the oft-discussed conflict between the mover causality principle,"whatever is moved is moved by another," and the principle of inertia. In recent history, James Weisheipl deserves much credit for showing that Aquinas and Aristotle never held that a body in motion requires the constant contact of a mover to keep it in motion.[12] Weisheipl's view, as he himself argues, is not original. Domingo de Soto in the sixteenth century, as well as other Thomists of that time and earlier, understood that, for Aquinas, the nature of motion as such does not require that a body in motion be kept in motion by a continuously acting motor cause. For example,

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[9] See, for example, Alexandre Koyré, *Newtonian Studies* (Cambridge: Harvard Univ. Press, 1965) 66–68, 84.

[10] Although Special and General Relativity depend upon the principle of inertia, both theories involve notions of space, time, and matter that differ from those of Newton. See Richard P. Feynman, Robert B. Leighton, and Matthew Sands, *The Feynman Lectures on Physics* (Reading: Addison-Wesley, 1963) I.7-1C7-11, 15–17 and II.42-1C42-14; hereafter *FL*. See also Hans C. Ohanian and Remo Ruffini, *Gravitation and Spacetime*, 2nd ed. (New York: W. W. Norton & Co., 1994) 21–54.

[11] This paper builds on the work of a previously published article, Thomas J. McLaughlin, "Aristotelian Mover-Causality and the Principle of Inertia" *International Philosophical Quarterly* 38 (1998) 137–51. The previous article argued that purely inertial motion as such is not a continuous actualization of a potency and that the mover causality principle and a broadly Aristotelian conception of motion are nevertheless compatible with the dynamical equivalence of uniform rectilinear motion and rest, an equivalence that is at the heart of an inertial physics.

[12] James A. Weisheipl, O.P., *Nature and Gravitation* (River Forest: Albertus Magnus Lyceum, 1955) 1–64; "The Principle *Omne quod movetur ab alio movetur* in Medieval Physics," *Isis* 56 (1965) 26–45; "Galileo and the Principle of Inertia" in *Nature and Motion in the Middle Ages*, ed. William Carroll (Washington, D.C.: Catholic Univ. Press, 1985) 58–62; "The Specter of *Motor Coniunctus* in Medieval Physics" in Carroll, 99–120; "Aristotle's Concept of Nature: Avicenna and Aquinas" in *Approaches to Nature*, ed. Lawrence D. Roberts (Binghamton: Center for Medieval and Early Renaissance Studies, 1982) 137–160. Some contemporary Thomists have accepted Weisheipl's position. See, for example, Antonio Moreno, O.P., "The Law of Inertia and the Principle *Quidquid Movetur Ab Alio Movetur*," *The Thomist* 38 (1974) 306–331; Eric A. Reitan, O.P., "Thomistic Natural Philosophy and the Scientific Revolution," *The Modern Schoolman* 73 (1996) 265–281; Richard F. Hassing, "Thomas Aquinas on *Phys.* VII.1 and the Aristotelian Science of the Physical Continuum" in *Nature and Scientific Method*, ed. Daniel O. Dahlstrom (Washington, D.C.: Catholic Univ. of America Press, 1991) 109–56. Independently of Weisheipl's work, other twentieth century Thomists also argued that the mover causality principle does not require that a body in motion be kept in motion by a continuously acting motor cause. See, for example, James J. McWilliams, S.J., *Physics and Philosophy: A Study of St. Thomas' Commentary on the Eight Books of Aristotle's Physics* (Washington, D.C.: Catholic Univ. of America, 1945) 14–19; Henry J. Koren, C.S.Sp., S.T.D., *An Introduction to the Philosophy of Nature* (Pittsburgh: Duquesne Univ., 1960) 94–97.

Aquinas thought that one kind of local motion, the natural upward and downward motion of heavy and light bodies, did not require a continuous, conjoined mover. I do not intend to repeat Weisheipl's lengthy presentation and analysis of various Thomistic texts and arguments, but I will give three quotations to support this claim. The first is taken from Aquinas's *Commentary on Aristotle's Treatise On the Heavens*:

> He [the Philosopher] says, therefore, that what has been said is manifested by the fact that natural bodies are not borne upward and downward as though moved by some external agent. By this is to be understood that he rejects an external mover which would move these bodies per se after they obtained their specific form. For light things are indeed moved upward, and heavy bodies downward, by the generator inasmuch as it gives them the form upon which such motion follows, but they are moved per accidens, and not per se, by whatever removes an obstacle to their motion. However, some have claimed that after bodies of this kind have received their form, they need to be moved per se by something extrinsic. It is this claim that the Philosopher rejects here.[13]

The downward motion of a heavy body requires a generator but does not require a continuously operating extrinsic mover. Furthermore, since the generator is the mover, the downward motion of a heavy body does not involve a continuous intrinsic mover, a point that Aquinas states explicitly in his *Commentary on Aristotle's Physics*:

> However, in heavy and light bodies there is a formal principle of motion. . . . However, the natural form is not the mover. Rather the mover is that which generates and gives such and such a form upon which such a motion follows.[14]

The natural form of an elemental body is the principle from which the motion of such a body follows. Nevertheless, the natural form is not a mover nor is it some kind of efficient agent of an elemental body's motion. The elemental bodies are not, so to speak, self-propelled.[15] Throughout his various works, Aquinas states at least forty-six times that the generator is the per se efficient cause of the motions of heavy and light bodies.[16]

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[13] St. Thomas Aquinas, *Exposition of Aristotle's Treatise On the Heavens*, trans. R.F. Larcher, O.P. and Pierre H. Conway, O.P. (Columbus: College of St. Mary of the Springs, 1963) I.175.

[14] Aquinas, *In II Phys.*, 144. The following parenthetical passage is not included in the translation quoted above: "(But a formal principle of this sort cannot be called the active potency to which this motion pertains. Rather it is understood as passive potency. For heaviness in earth is not a principle for moving, but rather for being moved.)" For textual and other difficulties related to the parenthetical passage, see Weisheipl, *Nature and Gravitation*, 25–26.

[15] "The small error in the beginning which proves so big in the end is the failure to understand the precise meaning of *principle* as distinct from a *cause*. This failure has led many modern commentators—and some scholastics—into error and has created the specter of a *motor coniunctus* even in the free fall of heavy bodies and the rising of light." Weisheipl, "Specter of *Motor Coniunctus*," 100. On the distinction between a principle and a mover and the tendency to reify principles, see Weisheipl's previously cited work. See also Patricia Reif, "The Textbook Tradition in Natural Philosophy, 1600–1650" *Journal of the History of Ideas* 30 (1969) 17–32.

[16] Brian T. Kelly, "Aquinas on Gravitational Motion: An Investigation." Ph.D. dissertation, University of Notre Dame, 1994, 224. See, for example, *In II Phys.*, 180; *In IV Phys.*, 535; *In VIII Phys.*, 1029–36; *In II De Caelo*, 594; *SCG* III.67.2; *SCG* III.69.14; *SCG* I.13.8; *SCG* III 82.7; *SCG* III.84.5; *Quaestiones Disputatae De Potentia*, 3,7c and 5,5c; *ST* I.18.1 ad2 and ad3; *ST* I.105.2.

Someone might argue, however, that since the mover and the moved must be together, a body can be kept in motion only by the continuous action of a mover in contact with it during the entirety of its motion.[17] In his work, *On the Power of God*, Aquinas explicitly rejects such an argument:

> An instrument is understood to be moved by the principal agent so long as it retains the power [virtutem] communicated to it by the principal agent; thus the arrow is moved by the archer as long as it retains the force [vis] wherewith it was shot by him. Thus in heavy and light things that which is generated is moved by the generator as long as it retains the form transmitted thereby: so that the semen also is understood to be moved by the soul of the begetter, as long as it retains the force [virtus] communicated by that soul, although it is in body separated from it. And the mover and the thing moved must be together at the commencement of but not throughout the whole movement, as is evident in the case of projectiles.[18]

According to Aquinas, the mover and the body moved must be together only at the beginning of a body's motion. They need not be in contact throughout the entire motion. Therefore, Aquinas did not maintain that a body must have a mover in continuous contact with it to keep it in motion.

Of course, Aquinas did hold that some kinds of local motion do require continuous, conjoined movers. For example, projectile motions require continuous, conjoined movers because they are contrary or violent to the nature of the body that is moved.[19] The circular motions of the celestial spheres require movers that operate by continuous contact because the celestial spheres do not possess an intrinsic, active, formal principle of nature by which they move. And because the celestial spheres are not generated, their movers cannot be the generators of their forms.[20] However, the motions of projectiles and of the spheres require continuously operating movers because of the kinds of motions that they are and not because of a general conception of the nature of motion itself. In this respect, projectile and celestial motions resemble accelerated motions in Newtonian physics, for accelerated motions require a force to act on a body throughout the time that it is accelerating.

Newton also accepts a version of the mover causality principle. In Newtonian physics, as is evident from the statement of the First Law, a body that changes its state of rest or of uniform rectilinear motion must be acted upon by a force. Also, in practice, departures from purely inertial motion are treated as due to some efficient cause.[21] For example, perturbations in Uranus's orbit led to the discovery of Neptune, and in the case of Mercury's orbit, a new theory of gravity (General

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[17] "Having removed this difficulty, he concludes that the mover and the moved are together and there is no intermediate between them." Aquinas, *In VII Phys.*, 908.

[18] St. Thomas Aquinas, *On the Power of God*, 3, 11 ad5, trans. Dominican Fathers (London: Burns Oates & Washbourne LTD., 1933).

[19] Aquinas, *In VIII Phys.*, 1024, 1160–63; *Exposition of Aristotle's Treatise On the Heavens*, III.590–94.

[20] Aquinas, *SCG* III.22 and 23.

[21] "In order to use Newton's laws, we have to have some formula for the force; these laws say *pay attention to the forces*. If an object is accelerating, some agency is at work; find it. Our program for the future of dynamics must be to *find the laws for the force*." *FL* I.9-3C9-4.

Relativity) led to the discovery that the Sun—not the hypothetical planet Vulcan—is the cause of its precession.

More importantly, according to Newton, the nature of inertia is such that all true motions must have some cause, even if that cause operated at some prior time in a body's motion:

> 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 could never 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.[22]

Since inertia is passive and does not move a body, a body cannot set itself in motion nor can it entirely account for its motion on the basis of its own inertia. By virtue of its inertia alone, a body could not be in motion. Thus, a body's motion must be due to another. In fact, for Newton, motion ultimately comes from God:"Whereas the main Business of natural Philosophy is to argue from Phaenomena without feigning Hypotheses, and to deduce Causes from Effects, till we have come to the very first Cause, which certainly is not mechanical."[23]

Newton's argument for the existence of God will not be examined here, nor do I intend to compare Newton's argument with Aristotle's or Aquinas's arguments for the existence of God from motion.[24] The point is that for Newton, whatever is moving received its motion from another, although this other need not be a mover that is continuously in contact with the body in motion. Consequently, for Newton, whatever is moved is moved by another, for a body in motion must have been put in its state of motion by something besides itself.

The history of science shows that, with the possible exception of quantum mechanics, scientists actively seek the generating cause of a motion.[25] This emphasis on a causal origin for a given motion may be seen both in the examples that scientists use to explain the principle of inertia and in their actual scientific research. In typical examples of the principle of inertia, Galileo rolls balls along inclined planes, someone slides blocks along a table or some icy surface, projectiles are fired from a cannon, or a bomber drops a "stick" of bombs. In each of these examples, some originating cause initiates the motion.

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[22] Sir Isaac Newton, *Opticks*, Bk.III Q.31 (New York: Dover Publications, 1952) 397.

[23] Newton, *Opticks*, L.III Q.28, 369. "This concludes the discussion of God, and to treat of God from phenomena is certainly a part of natural philosophy." Newton, *Principia*, General Scholium, 943.

[24] For an exposition and discussion of Newton's argument for the existence of God, which interestingly enough, is not an argument for a deistic God that gives motion merely at the beginning of the universe, see Michael J. Buckley, *Motion and Motion's God: Thematic Variations in Aristotle, Cicero, Newton, and Hegel* (Princeton: Princeton Univ. Press, 1971) 159–204. For a treatment of the mover causality principle and Aquinas's argument against an infinite regress of movers, see Patterson Brown, "Infinite Causal Regression" *The Philosophical Review* 75 (1960) 510–25.

[25] Of course, for many purposes, scientists can and do ignore the inertial component of a motion and its origin.

In their actual research, astronomers, for example, want to discover, not only the causes that make the Moon orbit the Earth and depart from its uniform motion in a straight line, but also the causes of the uniform motion from which the Moon departs. Thus, theories of the Moon's origin must account for the inertial component of the Moon's orbit.[26] Similarly, theories of solar system[27] and galactic[28] formation also seek to account for the generation of inertial components of orbital motion. Also, the Big Bang explains the expansion of the universe and the continuous recession of the galaxies in terms of an original cause or "bang." This practice is consistent with Newton's view of the nature of inertia and with the mover causality principle.

Therefore, contrary to what many thinkers have believed, both Aquinas and Newton would agree that motion as such does not require a continuously acting motor to sustain it, although motion as such does at least require an initial, generating mover. The basic differences between Aquinas's natural philosophy and Newton's First Law do not concern the necessity of an efficient cause for motion considered simply as such.

THE ARISTOTELIAN DEFINITION OF MOTION AND NEWTON'S FIRST LAW

I will now argue that the principle of inertia and the Aristotelian definition of motion are compatible. Aristotelian procedure requires beginning from what is manifest, evident, and complex *quoad nos* and proceeding to principles that are per se simple, evident, and prior in themselves.[29] Newton's own examples of inertial motion are a useful starting point. In the *Principia*, Newton follows his statement of the First Law with a brief paragraph that explains or illustrates this law by means of several common motions:

> *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.*
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> Projectiles persevere in their motions, except insofar as they are retarded by the resistance of the air and are impelled downward by the force of gravity. A spinning hoop, which has parts that by their cohesion continually draw one another back from rectilinear motions, does not cease to rotate, except insofar as it is retarded by the air. And larger bodies—planets and comets—preserve for a longer time both their progressive and their circular motions, which take place in spaces having less resistance.[30]

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[26] John A. Wood, "Moon Over Mauna Loa: A Review of the Hypotheses of Formation of Earth's Moon" in *The Origin of the Moon*, eds. W. K. Hartmann, R. J. Phillips, and G. J. Taylor (Houston: Lunar and Planetary Institute, 1986) 19–38.

[27] William K. Hartmann, *Moons and Planets* (Belmont: Wadsworth Publ. Co., 1983) 61–62 and 123–26.

[28] Donald H. Menzel, Fred L. Whipple, Gerard de Vaucouleurs, *Survey of the Universe* (Englewood Cliffs: Prentice-Hall Inc., 1970) 785–87.

[29] Aristotle, *Phys.* I.1.184a15–21; *Post. Anal.* I.2.71b35–72a6. Aquinas, *On Being and Essence*, Ch.1.1.

[30] Newton, *Principia*, Law I, 416.

Although projectile motion was the paradigmatic case out of which the First Law developed, Newton uses not only projectile motion as an example of the First Law but also uses rotational and orbital motion as well. Indeed, Newton regarded the orbital motions of the planets and comets as the best evidence for the First Law because these motions are less resisted and continue for a much greater time than terrestrial motions.[31] Rotational and orbital motion, however, and projectile motion insofar as air and gravity act upon projectiles, are not uniform motions in a straight line. How can Newton claim that motions that are neither uniform nor rectilinear are evidence for the principle of inertia? Answering this question requires the fundamental distinction between a state of uniform rectilinear motion and a changing state of accelerated motion.

Uniform rectilinear motion is motion at a constant speed in a straight line, which means that a body moves through equal distances in equal times.[32] The two notions of constant speed and constant rectilinear direction are combined in the single notion of velocity. A body's velocity is constant if both its speed and its direction of motion remain the same. Newtonian physics treats uniform rectilinear motion as an unchanging state and not as a process. As a state, uniform rectilinear motion is dynamically equivalent to rest and, like rest requires no continuous efficient cause.[33] Consequently, a body in uniform rectilinear motion requires no *net* force to keep it moving at a constant velocity. A body maintains its state, whether of rest or of uniform rectilinear motion, by its inertia. Inertia is a real, physical, inherent, and quantifiable property of a body by which it tends to persevere in its state of uniform rectilinear motion or rest, resists efforts to change its state of uniform rectilinear motion or rest, and, in resisting, endeavors to change the state of the body acting upon it. Inertia is not, however, a mover.[34] Since a body maintains its state by its inertia, uniform, rectilinear motion is also called inertial motion.

Inertial motion is paradoxical, as indicated by the very term, "inertial motion." "Inertia," which usually means inactivity, absence of motion, or resistance to change, seems to have a meaning opposed to that of "motion," which usually means some kind of change. Indeed, the point of claiming that uniform rectilinear motion is an unchanging state equivalent to rest is to deny that such motion is a coming to be in a mobile object. This claim avoids two opposite errors. The first error is that motion without a continuously acting mover is self-motion. Since inertial motion is not a coming to be, a body in inertial motion is not moving itself. The second error is that motion without a continuous mover implies that something can come from nothing. Since purely inertial motion is not a coming to be in a mobile object,

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[31] I. Bernard Cohen, *The Birth of a New Physics* (New York: W. W. Norton, 1985) 159–60, 182, 222–23.

[32] The problems involved in the determination of "straight line," "equal distances," and "equal times" are not addressed here. These problems include issues concerning absolute and relative motion and the question of the reference frame(s) with respect to which straight lines, equal distances, and equal times are or are not determinable.

[33] Galileo Galilei, *Dialogue Concerning Two Chief World Systems—Ptolemaic and Copernican*, 2nd ed., trans. Stillman Drake (Berkeley: Univ. of California Press, 1967) 186–87. See also, I. Bernard Cohen, *The Newtonian Revolution* (Cambridge: Cambridge Univ. Press, 1980) 182. See also n11.

[34] Newton, *Opticks*, Bk.3, Q.31, 397; *Principia*, Def. III, 404–05.

no ongoing cause is required for such motion precisely because there is nothing new in the body for which to account. The inertial physics of Newton respects the principle "ex nihilo, nihil fit."

Uniform rectilinear motion is contrasted with accelerated motion. An accelerated motion is a motion in which a body's velocity changes. A body's velocity changes if either its speed or its direction of motion changes. For example, a body that moves in a straight line but increases or decreases its speed moves with an accelerated motion. Circular motion, or motion in any kind of curve, is also an accelerated motion, for even if the speed of a body moving in a circle is uniform, its direction is continually changing.

An acceleration of a body, i.e., changes in either its speed or direction, requires a force to produce that acceleration. Throughout the time that a body is accelerating, an impressed force must act upon it. According to Newton,

> *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 a 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.[35]

An impressed force is an action exerted on a body by some physical source extrinsic to the body acted upon. The impressed force changes a body's state. According to Newton's Second Law, a change in a body's state is proportional to the quantity of the force impressed on the body and is in the rectilinear direction according to which the force is impressed.[36] A change in a body's state of motion or rest (i.e., its acceleration) also depends upon the quantity of the body's inertia. All other things being equal, the same force accelerates a pebble much more than a boulder.

The motions that Newton gives as examples of his First Law are composite motions compounded of two sorts of principles, external force principles and a conservative inertial principle. These are the relatively simple principles that determine the complex motions of Newton's examples. Insofar as the motion of projectiles, tops, or planets is not uniform and rectilinear but is accelerated, forces act upon these bodies. The action of various forces, however, does not fully account for the motion of these bodies. Their motion also consists of a component that is not due to the

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[35] Newton, *Principia*, Def. IV, 405. Newton's notion of a change of state would not seem to be consistent with his corpuscularianism, for an impenetrable corpuscle cannot gain or lose a state. Newton does not admit the principle of potency implied by the notion of a change of state produced by the action of a force.

[36] Newton, *Principia*, Law II, 416–17. By a "change in motion" Newton means what is now called "change in momentum." In Newtonian physics, the momentum of a body equals its mass (i.e., its inertia) multiplied by its velocity. Newton's Second Law is usually formulated as F=ma where "F" equals the force exerted upon a body, "m" equals the mass of the body upon which the force acts, and "a" equals the acceleration of the body on which the force acts. For a number of difficult issues related to the interpretation of the Second Law in Newton, see I. B. Cohen, "Newton's Second Law and the Concept of Force in the Principia" in *The Annus Mirabilis of Sir Isaac Newton 1666–1966* (Cambridge: M.I.T. Press, 1970) 143–77.

acceleration being caused by impressed forces. By virtue of this inertial component, the bodies in Newton's examples tend to continue moving uniformly and rectilinearly, even though these bodies are no longer in contact with the efficient cause of that inertial component.

For example, a pitcher throws a baseball to a catcher. The pitcher exerts a force on the ball when he throws it and is clearly the efficient cause of its motion. The ball's motion and the effect produced in the ball differ depending upon whether the pitcher is Nolan Ryan or a little leaguer and whether the pitcher throws a fastball, a curveball, a knuckleball, a slider, or a spitball. The air through which the ball moves also acts upon the ball. The action of the air helps make the ball curve, knuckle, drop, or otherwise become difficult to hit. Moreover, the thin, dry air of Denver acts on the ball differently than the thick, humid air of Houston. Thus, the air too is a causal principle determining the baseball's motion. In addition, the ball is in the Earth's gravitational field, and so the Earth in some way also acts upon the ball to determine its motion. On the Earth, in contrast to a small asteroid, baseballs cannot be thrown into orbit or into the depths of space. Finally, the catcher also acts upon the ball when he stops it with his glove.

In this example, the pitcher, the air, the catcher, and the Earth's gravity all determine the motion of the ball. The ball's motion would not be what it is without their action upon it. Furthermore, each of these causal principles acts through contact with the baseball. In the case of gravity, physicists and astronomers maintain that a gravitational field is actually in contact with the ball and is the medium by which the Earth acts upon it.[37]

Force principles do not entirely account for the ball's motion. Another principle is also present, namely, the inertial principle. The inertial principle conserves an already attained state produced in the ball by the previous action of a force. It explains the continuing motion of the ball after being released by the pitcher. The air and the Earth's gravity then tend to change the ball's state of motion. The ball, by virtue of its inertia, tends to persist in the further state of motion produced in it by these forces. At any given part of its motion, the ball's state of motion is a cumulative effect produced in it. The pitcher, in throwing the ball, produces a certain state in it.

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[37] The notion of a "field" was formulated to overcome the problem of action-at-a-distance initially suggested by the forces of electromagnetism and gravity. Newton himself did not accept the notion of action at a distance, but was unable to discover a medium or mechanism by which gravitational force is conveyed. Initially, Michael Faraday, who considered the field a physical entity, developed the notion of a field for electricity and magnetism. See John Meurig Thomas, *Michael Faraday and the Royal Institution* (Bristol: Adam Hilger, 1991) 43–45. Later, the notion of a field was extended to gravitation. See Albert Einstein, *Relativity: The Special and General Theory*, 16th ed. (New York: Crown, 1961) 63–64. A field is an extended "entity that conveys the force from one particle to another particle by contact. . . . Fields are a form of matter—they are endowed with energy and with momentum and they therefore exist in a material sense." Hans C. Ohanian, *Physics* II (New York: W. W. Norton & Co., 1985) 546–49; hereafter *OHP*. Ohanian is an associate editor of the *American Journal of Physics*. See also, A. P. French, *Newtonian Mechanics* (New York: W. W. Norton & Co., 1971) 462–64; *FL* I.12-7C12-9 and 14-7C14-8. The real existence of fields raises numerous ontological issues. Einstein himself notes that the theory of fields is not complete. See Albert Einstein, "Remarks Concerning the Essays Brought Together in this Co-Operative Volume" in *Albert Einstein: Philosopher-Scientist*, ed. Paul Arthur Schilpp (New York: Harper and Row, 1951) 675.

The air and the Earth, in acting upon the ball, continually modify its state of motion. Thus, the ball's state of motion, at any given part of its motion, is a compound of a prior state of the ball and an additional determination received from the further action of an impressed force.[38] The baseball, by virtue of whatever state of motion exists in it at a given part of its motion, tends to persist in moving at the velocity characteristic of that state.[39]

An additional principle, a principle of potency, is also present in the ball's motion, a principle not considered by Newton but implied by his analysis. A principle of potency is implied because the forces acting on the ball are continuously changing its state of motion. A body could not undergo such a change of state unless it possessed a principle of potency by which it could be changed.

Someone might object that classical physicists did not admit a principle of potency. Newton did not accept a principle of potency, while LaPlace and other physicists viewed motion as something fully determinate and complete. Similarly, when Heisenberg famously says that quantum mechanics gives Aristotelian potency a fundamental status in nature he is assuming that an Aristotelian principle of potency was not already present in classical physics. Nevertheless, under the notion of "potential energy," a principle of potency is indeed present within classical physics.

Etymologically, the term "energy" is Aristotelian in origin.[40] The notion of energy is not present in Newton's *Principia* or elsewhere in Newton's work, although it is now part of Newtonian physics.[41] Energy is usually defined as the capacity to do

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[38] "If some force generates any motion, twice the force will generate twice the motion, and three times the force will generate three times the motion, whether the force is impressed all at once or successively by degrees. And if the body was previously moving, the new motion (since motion is always in the same direction as the generative force) is added to the original motion if that motion was in the same direction or is subtracted from the original motion if it was in the opposite direction or, if it was in an oblique direction, is combined obliquely and compounded with it according to the directions of both motions." Newton, *Principia*, Law II, 416–17.

[39] In addition, the ball's state of motion is not entirely passive. The baseball, by virtue of its inertia, and insofar as it is in a certain state, acts upon the air, the catcher, the pitcher, and even the Earth. Various other factors, such as surface texture, spin, compressibility, grease, and the threads on the outside of the ball also affect the motion of the ball and the effects the ball produces on the bodies that move it. The physics of baseball is very much more complicated than this discussion indicates. See Robert K. Adair, *The Physics of Baseball*, 2nd ed. (New York: HarperCollins, 1994).

[40] The word "energy" derives "from the Greek *energeia* (*en*, in; *ergon*, work), originally a technical term in Aristotelian philosophy denoting 'actuality' or 'existence in actuality,' means, in general, activity or power of action. In the physical sciences it is defined as the capability to do work, as accumulated work or, in the words of Wilhelm Ostwald, as 'that which is produced by work or which can be transformed into work.'" Max Jammer, "Energy" in *The Encyclopedia of Philosophy*, Vol.2, ed. Paul Edwards (New York: Macmillan Publ. Co., 1967) 511. Etymologically, potential energy is potential actuality.

[41] "In the whole of the *Principia*, with its awe-inspiring elucidation of the dynamics of the universe, the concept of energy is never once used or even referred to! For Newton $F=ma$ was enough. But we shall see how the energy concept, although rooted in $F=ma$, has its own special contributions to make." French, 368. According to Jammer, "energy considerations were rarely found in theoretical or even practical mechanics prior to the middle of the nineteenth century. Before the development of the steam engine and the rise of thermodynamics, industry had little interest in energy calculations: force, not its integrated form, counted in the use of simple machines. The primary object of theoretical mechanics, moreover, was still celestial dynamics, where, again, energetics was of little avail. This certainly is also one of the reasons why Newton's *Principia* contains practically no reference to the concept of energy or to any of its applications." Jammer, 512. See also Cohen, *Guide to Newton's Principia*, 119–22.

work.[42] The potential energy of a body is the energy that a body has in virtue of its position considered with respect to some other position and with respect to a force.[43] For example, an apple hanging on a tree has a certain gravitational potential energy by virtue of its position on the tree with respect to the ground and with respect to the force of gravity that would act upon it if it fell.[44] As the apple falls, gravity does work on the apple, and the apple's potential energy decreases and becomes kinetic energy, the energy a body has in virtue of its motion.

Although scientists often say that something "exchanges" its potential energy for kinetic energy, or that potential energy is "transformed" into kinetic energy, such expressions should not be taken literally. Strictly speaking, gravity does not cause a falling apple to "exchange" its gravitational potential energy for kinetic energy since potential energy is not an actual something such that it can be exchanged. Physicists sometimes interpret potential energy as a kind of latent energy or stored work, and a body in a certain position may be said to have latent energy or stored work inasmuch as work had to be done on the body to raise it some distance above the surface of the Earth.[45] The body, however, possesses this latent energy or stored work in the position it actually occupies and after being moved by a force. By contrast, the body has potential energy by virtue of a position it does not occupy and by virtue of a force that can move it but has not. The sense in which the body has stored work is distinct from the sense in which it has potential energy much like the sense in which an actual block of bronze is potentially a statue.[46] Thus, the apple hanging on the tree has both stored work and potential energy, but the two are distinct, even if this distinction is often blurred or not recognized. This distinction is evident inasmuch as potential energy does not itself do work. It must become something else in order to do work, in which case it is no longer potential energy. By contrast, kinetic energy need not become anything else to do work.

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[42] "Energy. In physics this is defined as the capacity to do work, that is, the capacity to exert a force on an object and move it." Delo E. Mook and Thomas Vargish, *Inside Relativity* (Princeton: Princeton Univ. Press, 1987) 290.

[43] The "kinetic energy represents the capacity of a particle to do work by virtue of its velocity. We will now become acquainted with another form of energy that represents the capacity of the particle to do work by virtue of its position in space. This is the *potential energy*." *OHP*, 163. In practice, especially when using conservation laws, physicists can and often do ignore the force. *OHP*, 180–84; French, 428.

[44] Expressed mathematically, the gravitational potential energy of the apple with respect to the ground equals mgh (for small displacements near the Earth's surface) where m is the mass of the apple, g is the acceleration produced by gravity near the surface of the Earth, and h is the height of the apple above the ground. Since mg equals the force of gravity on the apple, the apple's potential energy with respect to the ground equals the force of gravity on the apple multiplied by its height above the ground.

[45] *OHP*, 164–65. The idea that what we now call potential energy is some kind of latent actuality probably originated with Leibniz and Leibnizians such as Johann Bernoulli. See G. W. Leibniz, "Specimen Dynamicum" [1695] in *Leibniz: Selections*, ed. Philip P. Wiener (New York: Charles Scribner's Sons, 1951) 119–37 and Jammer, 512–13.

[46] "And although the same thing exists both in potency and in act, to be in potency and to be in act are not the same according to nature. Thus, bronze is in potency to statue and is bronze in act, yet the nature of bronze insofar as it is bronze and insofar as it is a potency for statue is not the same." Aquinas, *In III Phys.*, 289–90.

In addition, potency, unlike actuality, is not intelligible just by itself. A potency, Aquinas maintains, is intelligible with respect to some correlative actuality or actualities, and therefore, is always referred to some sort of act.[47] Not surprisingly, potential energy is classified not in itself but with respect to some form of energy or with respect to some kind of force. Thus, one speaks of potential energy with respect to any conservative force, such as gravitational potential energy, electrical potential energy, or nuclear potential energy.[48] By contrast, kinetic energy is just kinetic energy no matter what force produces it or what work the kinetic energy does.[49] Kinetic energy has its own universal formula, but potential energy as such has no universal formula.[50]

Therefore, properly speaking, potential energy is not a form of energy but a potency to a form of energy. The potential energy of the apple is not actual energy just as a child sitting in a classroom immediately before beginning to study mathematics does not actually know mathematics. The apple, in virtue of its position and because of gravity, can actually have energy, just as the child, by virtue of his intellect, a relation to a teacher, and some previous learning can eventually know mathematics. This does not mean that potential energy is mere logical possibility. Potency is real in things. The child's dog, unlike the child himself, is not in potency to mathematical knowledge. And just as the child may never learn mathematics, the apple may not fall to the ground. Consequently, bodies are in potency to act inasmuch as they have potential energy. Thus, classical physics, *pace* classical physicists, does admit a principle of potency in the Aristotelian sense. A principle of potency is, then, present in the motion of a baseball thrown by a pitcher.

The Aristotelian definition of motion may now be applied to motion as treated by Newtonian physics. Motion is "the act of what exists potentially insofar as it exists potentially." This definition indicates that motion is a continuous actualization of a potency. A body's motion is a process stretched out, as it were, in a differentiated continuum in which each part of the continuum is related to a prior part as act to potency and is related to a posterior part as potency to act.

Newtonian physics treats real motions as continuous actualizations of a potency. A body, insofar as it has potential energy, is in potency to some actuality. The forces operating on the body throughout its motion continuously actualize that potency. The baseball's state of motion is continuously changed by the action of various forces upon it. These forces, from pitcher to catcher, continuously produce something new, a new part of the baseball's motion. Consequently, any prior part of the baseball's motion differs from any posterior part of its motion. This difference may be determined in terms of its speed, direction, momentum, kinetic and potential energy, work, or its location in a gravitational field.

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[47] Aquinas, *In IX Meta.*, 1824, 1844–51.

[48] *OHP*, 174–81, 184–85.

[49] "Of course, the fact that motion has energy has nothing to do with the fact that we are in a gravitational field. It makes no difference where the motion came from." *FL* I.4–6.

[50] "We express the kinetic energy by the formula $K=1/2mv^2$. We cannot give a similar universal formula by which potential energy can be expressed." David Halliday and Robert Resnick, *Fundamentals of Physics* (New York: John Wiley & Sons, 1970) 117.

Furthermore, every real motion is a continuous actualization of a potency, for in all real motions, the body in motion is always continuously subject to the action of forces. Accordingly, in keeping with the Aristotelian definition of motion, any body in real motion is the subject of a continuous actualization of a potency. The veracity of this claim can be made evident by considering one of the most frequently made objections to the principle of inertia, namely, that *purely* inertial force-free motion cannot actually occur in the universe. This objection is not merely the claim that such motion has never been observed. The claim is the much stronger assertion that force-free inertial motion is impossible and necessarily cannot occur in the universe.[51] Such motion is impossible because a moving body is never left to itself; some force is always acting upon it.

Newton's Universal Law of Gravitation implies that no body would be entirely free from gravity, so that no body would ever move in the complete absence of impressed forces.[52] According to Einstein's General Theory of Relativity, gravity is the curvature of spacetime.[53] The mass of a body and its mass equivalent in energy curve spacetime at the body's location. Although mass curves spacetime locally, the local curvature produced by the presence of a mass curves a nearby region of

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[51] "And any particle one wishes to describe as moving uniformly and rectilinearly, *must* then be but one particle in a universe containing at least five; the specimen-particle and the four coordinate-fixers. But no particle within a five particle universe can be free of external, unbalanced forces—a simple inference from another cornerstone of classical mechanics, the Law of Universal Gravitation: 'Any two particles in the universe are such that they attract each other directly as their masses, and inversely as the square of the distance between them.'

So the counter-factual character of the Law of Inertia stands out now not merely as an observation of the fact that no bodies are ever found to be force-free, but rather as a *logical* consequence of the fact that no body whose motion could meaningfully be described as uniform and rectilinear could *possibly* be force-free. Any alternative interpretation would crush the gravitational cornerstone of mechanics, something few physicists would be prepared to countenance just to avoid the necessarily counter-factual character of the Law of Inertia. Any appraisal of the Law's logical status is immediately pierced by this point. The Law is thus revealed as referring to entities which are *not* such that although never observed they remain observable, i.e., that we know *what it would be like* to encounter such entities. No. Rather, the Law refers to entities which are unobservable as a matter of physical principle: either the Law conflicts with our conceptions of physical meaning, or it conflicts with other Laws of Mechanics. Either way, it is difficult to understand." Norwood Russell Hanson, "The Law Of Inertia: " Philosopher's Touchstone," *Philosophy of Science* 30 (1963) 112–13.

[52] Newton's Universal Law of Gravitation states that the gravitational force between two bodies of masses m_1 and m_2 is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them. No matter how great the (finite) distance separating two bodies, Newton's law predicts at least some force between them. In certain cases, however, a body does move uniformly in a right line without any *net* force acting upon it. For example, after jumping out of an airplane, a skydiver may reach a terminal velocity in which the force of gravity is balanced by the equal and opposite force of the resisting air. No *net* force then acts on the skydiver, and he falls at a constant speed in a straight line.

[53] "Gravity is a *local* something, and this *local* something is spacetime curvature." John Archibald Wheeler, *A Journey into Gravity and Spacetime* (New York: Scientific American Library, 1999) 70. The geometric conception of gravity as a curvature of spacetime especially invites analysis in light of the Thomistic notion of a mathematical consideration of nature, a consideration that is materially physical but formally mathematical. Such an analysis will not be undertaken here. See, however, Aquinas, *The Division and Methods of the Sciences: Questions V and VI of his Commentary on the De Trinitate of Boethius*, Q5 A3, esp. replies 5–7, trans. with introduction and notes by Armand Maurer, 4th rev. ed. (Toronto: Pontifical Institute of Mediaeval Studies, 1986); *FL* II.42-1C42-8; Einstein, *Relativity: The Special and General Theory*, 90.

spacetime.[54] In turn, the curvature of the nearby region of spacetime communicates a curvature to a neighboring, surrounding region, which in turn communicates curvature to evermore distant regions of spacetime. The amount of curvature that is imparted diminishes with increasing distance from a central mass but does not entirely disappear at any finite distance.[55] Although curved spacetime is not a force in the Newtonian sense, it acts locally on a body and directs its motion.[56] Consequently, on a general relativistic account, no body in our universe is free of gravity, and no body moves with a gravity-free uniform rectilinear motion. Also, unlike electromagnetic forces, gravity has never been successfully shielded. Thus, current empirical evidence, Newtonian physics, and General Relativity imply that no place in the universe is gravity-free. The notion of a body left entirely to itself in force free, purely inertial motion is a theoretical idealization, for a body in motion is always being acted upon by gravity.

As noted earlier, the action of a force on a body in motion means that the body also has potential energy. Thus, since a force of some sort is always acting upon a body, a principle of potency is present in all local motions. For example, since gravity is ubiquitous, a body being acted upon and moved gravitationally must also always have a principle of gravitational potentiality energy. The ubiquity of gravitational forces implies the corresponding presence of gravitational potential energy. Thus, inasmuch as a principle of potency is present throughout the real motions of all bodies, and inasmuch as impressed forces operate throughout the entirety of all real motions, contemporary physics treats all real motions as continuous actualizations of a potency.

In explaining Aristotle's definition of motion, Aquinas maintains that motion is both actual and potential:

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[54] The "analogy between spacetime and a trampoline provides us with a happy doorway to a second new insight. The deformation of the trampoline in the region where the jumper lands brings about a curving of the fabric even outside the zone of impact. Likewise the bending of spacetime geometry *inside* the Earth forces bending on the spacetime geometry *outside* the Earth. For that reason spacetime finds itself curved in regions totally free of mass." Wheeler, *Journey into Gravity and Spacetime*, 84.

[55] "How does Einstein's local-only action explain Newton's faraway action? Briefly stated, mass *there* bends *local* spacetime there. This faraway spacetime forces a slightly lesser bending on the *local* spacetime immediately around it—even though this space is free of mass. This curvature, still faraway, in turn imparts a curvature—a still smaller one—to the *local* space still farther out from the mass. And so on, all the way out to the *here* where we are and where we see 'gravity' showing itself. As Einstein describes gravity, all the way from the mass there to us here, every action is a *local* action." Wheeler, *Journey into Gravity and Spacetime*, 68.

[56] "In brief, *spacetime grips mass, telling it how to move*. If spacetime grips matter, telling it how to move, then it is not surprising to discover that matter grips spacetime, telling it how to curve. To understand this corollary notion, let's imagine what free-float spacetime-driven motion would look like if spacetime were not curved. Every object in free float would move in a straight line with uniform velocity forever and ever. The Earth and the other planets would not enjoy the companionship of the Sun . . . Conceivable though such a universe is, it is not the universe that we know. Faced with this difficulty, we could give up the idea that spacetime tells mass how to move. But if we want to retain this idea, despite the observed curvature of planetary orbits and the identical curvature of the tracks of a ball and a bullet through spacetime, we will say, with Einstein, that spacetime itself is curved. In brief, *mass grips spacetime, telling it how to curve*." Wheeler, *Journey into Gravity and Spacetime*, 11–12.

> [T]o be only in act is one thing, to be only in potency is another, and to be a mean between potency and act is a third thing. . . . That, therefore, is moved which is a mean between pure potency and pure act, which is, indeed, partly in potency and partly in act.[57]

Motion is neither only actual nor only potential but is a "mixture of act and potency."[58] Since Aristotle's definition considers motion as both actual and potential, it seems to be a contradiction. Aquinas further explains how the definition avoids a contradiction:

> Motion is neither the potency of that which exists in potency, nor the act of that which exists in act. Rather motion is the act of that which exists in potency, such that its ordination to its prior potency is designated by what is called "act," and its ordination to further act is designated by what is called "existing in potency."[59]

Aristotle's definition avoids a contradiction because motion is actual and potential in different respects. The motion of a body is two-faced. It has two ordinations of a potentiality. One ordination is with respect to a prior place from which the body has moved. With respect to the potency the body possessed in this prior place, the body's motion is an act. This is indicated by the "act of a being in potency" part of the definition. Without such an ordination to prior potency, there is no motion, for the body has not yet moved.[60]

The other ordination of potentiality is with respect to the posterior place to which the body is moved. With respect to the place to which the body is moved, the body is in potency to further, posterior act. This is indicated by the "insofar as it is in potency" part of the definition. Without an ordination to posterior potency, there is no motion, for the body's motion has ended.[61] Furthermore, the two ordinations of potency are not two different potencies, one actualized and one still in potency. The two ordinations of potency refer to the same potency considered in different respects. This one potency is the potency that, for example, the apple has for the ground when it is hanging on the tree.

The Newtonian analysis of motion treats motion as something that is both potency and act, that is, as a third thing that is a mean between potency and act. Since an inertial principle, force principles, and a potential energy principle are all present in a real motion, a real motion is both potency and act. A baseball, after being thrown by a pitcher, is partially in potency, for part of the potential energy that the ball had while in the pitcher's hand remains. The baseball's remaining potential energy is

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[57] *In III Phys.*, 285.

[58] *In III Phys.*, 296.

[59] *In III Phys.*, 285.

[60] "Likewise, if the imperfect act were considered only in its ordination to further act, insofar as it has the nature [ratio] of a potency, it would not have the nature [ratio] of motion, but of a principle of motion. For heating can begin from the tepid as well as from the cold." *In III Phys.*, 285.

[61] "For if this ordination to further act were removed, that act [which it already has], however imperfect, would be the end of the motion and not the motion, as happens when something is partially heated." *In III Phys.*, 285.

its motion insofar as it is in potency with respect to what is posterior in its motion and ultimately with respect to the catcher's glove. This remaining potential energy is a potency to further act, a further act that has not yet been brought about by the operation of a force.

A baseball, after being thrown by a pitcher, is also in act with respect to what was prior in its motion. The potential energy the ball had while in the pitcher's hand is now partially actualized. It has been partly actualized by the prior action of forces. The inertial component of a motion is something already done in the body being moved, for as Aquinas argues, "it is true to say that in the state of 'being changed' there is a previous 'having been changed.'"[62] The inertial component fits Aquinas's statement that "not only is it necessary that whatever is being changed already has been changed, but it is also necessary that whatever has been changed was previously being changed."[63] Thus, the inertial component of a body's motion, insofar as it is an act already brought about in a body, is no longer a continuous coming to be in that body, for it *was* a coming to be in that body. Insofar as a body is moving inertially, no potency is being actualized.

In a real motion, a body's inertia and the efficient causality of other bodies operate together. Insofar as a moving body is undergoing a change of state, a force, such as gravity or air pressure, is acting upon it, and the body is having some potency reduced to actuality. But insofar as a body is moving by virtue of its inertia, the body continues in motion without being kept in motion by a continuously acting force. No potency is actualized, and, thus, no mover is required. The body's motion follows from an already actualized potency, from a previously generated state of motion. In this manner, the requirements of the mover causality principle are met in a way that is consistent with the definition of motion and the principle of inertia.

An inertial physics is like house building. The inertial component of a motion is analogous to a previously built section of a house under construction. In building a house, the first floor, once built, need not be continuously rebuilt. It tends to persist without the continued action of a builder. Requiring a continuous, conjoined mover to keep a body in motion would be requiring an efficient cause to continuously do what has already been done. It would be as if someone were necessarily always building the first floor of a house while the second and third floors, the roof, and other sections were being built. However, after the first floor of a house is built, someone must still build the upper floors and the roof. Denying the necessity of further forces would be like asserting that the upper floors and the roof could build themselves and that no additional actions by a builder were necessary.

The building of a house, inasmuch as it proceeds toward a goal, raises the issue of final causality. The idea that natural processes tend toward genuine goals in nature is one of the distinctive features of Aquinas's natural philosophy. In addition, final causality is the most important of the four Aristotelian causes because the final cause

[62] Aquinas, *In VI Phys.*, 838.

[63] *In VI Phys*, 832.

is the cause of the causality of the other three kinds of causes.[64] Also, according to Newton, the principle of inertia allows for the possibility of motion *ad infinitum*, which might be regarded as a kind of motion that has no final cause.

Final causes, on Aquinas's account, are more difficult to determine than the other kinds of causes, and final causes concerning inanimate things are even more difficult.[65] In light of these difficulties, one way to approach issues about final causality is to establish the operation of efficient causes and the presence of a principle of potency first and then argue backwards for final causes. For Aquinas, efficient and final causes are reciprocal and mutual. An efficient cause cannot operate unless it aims at something. Thus, for Aquinas, efficient causality implies final causality, for just as no actual goal is achieved without an efficient cause that brings about that goal, no efficient cause can act without a goal toward which to act, since to act is to act in some determinate way and not in others.[66]

Also, according to Aquinas, the attainment of an end by a body is not due to the nature of motion considered as motion. Instead, the attainment of an end is due to the agent that moves a body to a final cause.[67] Therefore, in determining the final cause of local motions, a helpful strategy would be to consider the agent that exerts the force that moves a body. In the case of inertial motion, one need consider the force that put a body in motion and the additional forces that further shape that motion. Concerning motion *ad infinitum*, the expansion of the universe is the one instance in which modern science has discovered what might be an actual instance of such motion. However, in this case, the force originating the Big Bang is unknown.

A consideration of the efficient causes of a motion is especially important because at least three of the four fundamental forces are attractive and repulsive, or in the case of gravity, only attractive.[68] The motion of bodies toward or away from each other or a place suggests some sort of teleology. Furthermore, establishing a principle of potency is a step toward developing a treatment of motion in terms of final causality, for the actualizing of a potency helps indicate the forward reaching nature of efficient causality. A body moves in some determinate direction toward something not yet actualized. For example, because of the force of gravity, an apple falls toward a definite place on the ground with respect to which it has potential

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[64] *In II Phys.*, 186. Aquinas, *The Principles of Nature*, Chap. 4 in Joseph Bobik, *Aquinas on Matter and Form and the Elements: A Translation and Interpretation of the 'De Principiis Naturae' and the 'De Mixtione Elementorum' of St. Thomas Aquinas* (Notre Dame: Univ. of Notre Dame Press, 1998) 60–62.

[65] Aquinas, *In II Phys.*, 181, 259, 265; *SCG* III.2.2, 6.

[66] Aquinas, *ST* I–II.1.2; *SCG* III.2; *In II Phys.*, 241–74.

[67] "For when a thing is moved, it recedes from a disposition which it formerly had. But that it should acquire a disposition is not due to the nature [ratio] of motion insofar as it is motion, but insofar as it is finite and completed. Motion has this perfection from the intention of the agent which moves a thing to a determinate end." Aquinas, *In IV Phys.*, 621.

[68] "Yet, at a fundamental level, this bewildering variety of forces involves only four different kinds of force. . . . The *gravitational force* is a mutual attraction between all masses. . . . The *electromagnetic force* is an attraction or repulsion between electric charges. . . . The *"strong" force* acts mainly within the nuclei of atoms. . . . It can be either attractive or repulsive: the strong force will push the protons apart if they come too near each other, and it will pull them together if they begin to drift too far apart. Finally, the *"weak" force* only manifests itself in certain reactions among elementary particles." *OHP*, 120–21.

energy. Put more accurately, gravity acts in such a way as to move the apple and the Earth towards their mutual center of gravity, a place to which they are in potency and which is the goal of their motion.

AQUINAS AND RELATIVITY

For Aquinas, a body's motion is a continuous process, and it must be grasped as a continuum. By treating motion as an act with a twofold ordination of the same potency, Aquinas treats motion as a process stretched out in a continuum and avoids treating it as a series of instantaneous snapshots.[69] However, on Aquinas's view, motion is a continuum or a "stretch" of differentiated parts that cannot exist as simultaneous modifications of a body. For any and every part of a body's motion, what is prior to that part of the motion is no longer the state of the body and what is posterior to that part of the motion is not yet the state of the body. Motion is an act with respect to something that no longer exists and is a potency with respect to something that does not yet exist. For this reason, Aquinas calls motion an incomplete being.[70] How, then, is motion understood by a definition expressing the totality of a motion, given that the very manner in which motion exists is not as a totality? How is motion to be grasped as a continuum when its parts do not coexist?

Aquinas maintains that understanding motion requires a cognitive being to compare the prior and the posterior in motion and bring them together as a totality: "motion does not have a fixed existence in things. Nor is anything concerning motion actually found in things except a certain indivisible part of motion, which is a division of motion. But the totality of motion is established by a consideration of the soul which compares a prior disposition of the mobile object to a later one."[71] Understanding motion requires unifying into a totality parts that are no longer, an indivisible part that is, and parts that are not yet. The totality of this double ordination of the same potentiality is grasped and established in a consideration by the soul because in reality what is prior and posterior in motion do not exist together.[72]

Some thinkers, such as Leibniz, while maintaining that motion is an incomplete being, have then thought that motion must be mind-dependent and not real, a view that is certainly not that of Aquinas.[73] Although memories require a soul or a cognitive being with the ability to remember, that which is remembered need not depend upon a soul. Likewise, something that is anticipated and that potentially exists need not depend upon a soul, although anticipation as such does depend upon a soul. A hunter leading a duck in flight remembers the duck's motion that has already occurred and

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[69] Yves Simon, *The Great Dialogue of Nature and Space*, ed. Gerard J. Dalcourt (Albany: Magi Books, 1970) 71–74.

[70] *In III Phys.*, 296; *In IX Meta.*, 1831; *ST* I.7.3ad4. Simon, 66–71.

[71] *In III Phys.*, 629.

[72] Simon, 89–111.

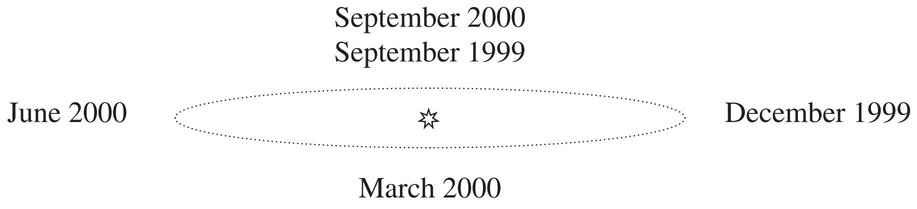
[73] "Thus, strictly speaking, motion just like time, when reduced by analysis to its elements, has no existence as a whole so long as it possesses no co-existing parts. And thus there is nothing real in motion itself apart from the reality of the momentary transition which is determined by means of force and a nisus for change." Leibniz, "Specimen Dynamicum," 120.

anticipates the motion of the duck that can occur, but the duck's motion and the prior and posterior parts of its motion do not depend upon the hunter. The hunter, however, grasps the duck's motion as a totality, even though duck's motion does not exist as such in reality. Aquinas is pointing out that because the parts of a motion do not exist together, our souls must unite them in cognition in order to understand motion. Understanding what is motionless does not require our souls to unite in cognition parts that do not exist together, since the parts of what is motionless do exist together.

By unifying what does not exist together in reality, the soul does not consider the nature of motion falsely because the soul's consideration of motion includes the fact that it is uniting prior and posterior dispositions that do not co-exist as a totality in the moving body. The soul unites what cannot co-exist in reality precisely as not co-existing in reality. It unites what is continuous but is not a continuum of parts existing together. In this way, motion considered as the twofold ordination of the same potency captures the dynamic and fluid act that is motion. For example, when we represent motion in a still picture, we typically blur the image of the moving object or show the object in multiple, closely overlapping positions that are of greater and lesser intensity. These techniques, which of course must be properly interpreted, aim at capturing the dynamism and fluidity of motion and at depicting motion as a differentiated stretch or continuum whose parts do not exist together even though they appear together in the picture. What one must avoid is the temptation to treat this unity of the prior and posterior in our concept of motion as if it were the same as the unity of an unchanging object and thereby project into nature a view of motion that is in truth immobile.

Is there anything in modern physics that instantiates this notion of the totality of an incomplete act having a twofold ordination of the same potency? I propose that Special and General Relativity instantiate this aspect of the Aristotelian definition of motion. They do so through the notion of spacetime.[74]

A consideration of two diagrams indicates that spacetime instantiates motion as a unity of differentiated prior and posterior parts that do not coexist. The first diagram, drawn below, shows a planet in a Newtonian orbit around a star.



The diagram shows a nearly side-on view of the planet in an elliptical orbit as seen from a reference frame at rest with respect to the star. The position of the planet is

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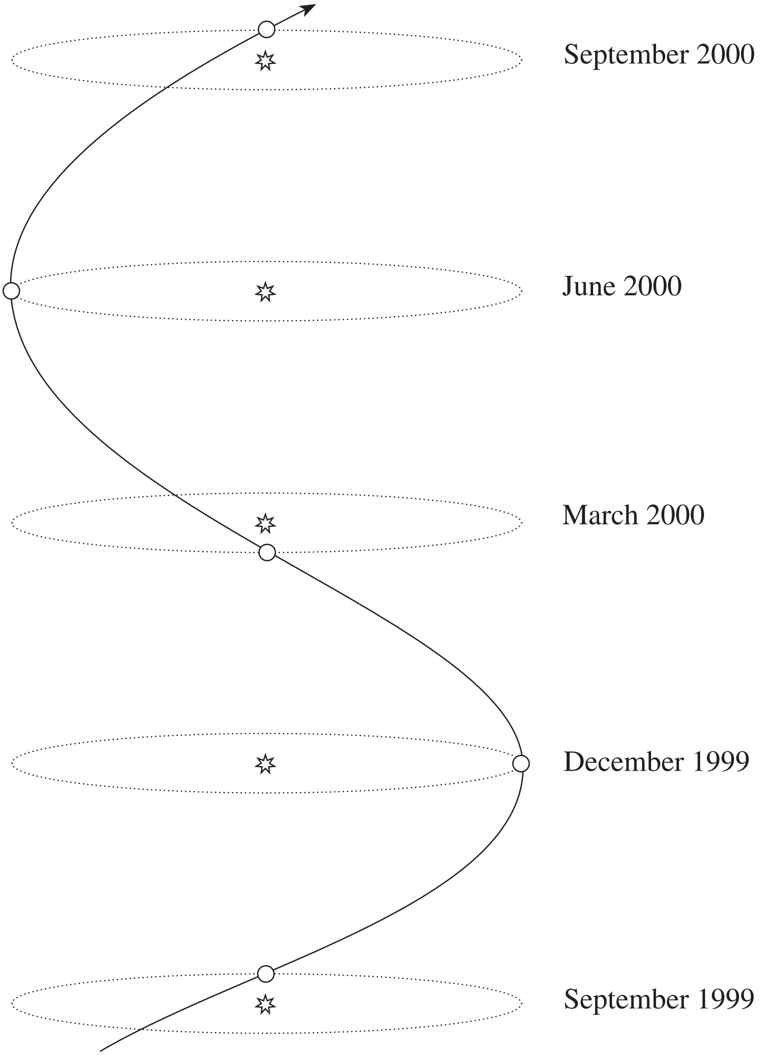
[74] Newtonian physics can be formulated according to a spacetime, although it need not be. General Relativity, however, must be formulated in terms of spacetime. The spacetime of Newtonian physics, called Newtonian or Galilean spacetime, also differs in other ways from the spacetime of General Relativity. See Robert Geroch, *General Relativity from A to B* (Chicago: The Univ. of Chicago Press, 1978); Howard Stein, "Newtonian Space-Time," *Texas Quarterly* 10 (1967) 174–200.

plotted in terms of three (x, y, z) spatial coordinates (not shown). Each coordinate axis is set at right angles to the others. As the planet orbits the star, it changes its position. The time at which a planet is at a given x, y, z position in its orbit is not itself included as a coordinate, nor is time included in the orbital path. Instead, time is added as an additional, external element or layer, as if by setting a transparent overlay on top of the orbital path or by attaching a set of labels. One could omit time from the diagram altogether and simply show the orbital path. Time, on the Newtonian view, is extrinsically related to the orbit.

The second diagram, drawn below, shows a planet orbiting a star according to Einstein's General Relativistic view of orbital motion. Five Newtonian orbits are included in the diagram to facilitate a comparison of the two treatments of orbital motion.[75]



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[75] The diagram, including the Newtonian orbits, is adapted from George Gamow, "The Evolutionary Universe" in *Cosmology + 1: Readings from Scientific American*, ed. Owen Gingerich (San Francisco: W. H. Freeman & Co., 1977) 12–19.

The diagram shows the "orbit" of the planet as a helical line, called a "worldline," in a four-dimensional coordinate system called spacetime.[76] The notion of a worldline is further explained as follows:

> Consider the collection of all events which occur in the immediate presence of the particle. . . . This is the set of events which would be described if one continually followed the particle around throughout its life, snapping one's fingers on it. The resulting collection of events would be described by a line drawn in space-time. . . . This single line, called the world-line of the particle, completely describes everything one could want to know about the particle, for it tells us all the events experienced by the particle, that is, "where the particle is at all times."[77]

The "where of the planet at all times" is plotted in terms of four coordinates—three spatial (x, y, and z) coordinates and one time (t) coordinate. The time coordinate, which is the vertical axis in the diagram above, is treated like a fourth spatial coordinate.[78] Each of the four coordinate axes (not shown) is set at right angles to the others, although in the above diagram one of the spatial coordinates has been left out. A four-dimensional spacetime cannot be literally pictured, but a representation that shows three dimensions nevertheless provides some understanding of it.[79] The diagram includes a series of vertically placed Newtonian orbits that help indicate how time is treated as an additional dimension of a single continuum. The planet's

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[76] "The motion of an object in the spacetime continuum can be represented by a curve called the object's 'world line.' For example, the world line of the earth's travel around the sun in time is pictured in the drawing on this page. . . . Einstein declared, in effect: 'The world line of the earth is a geodesic in the curved four-dimensional space around the sun.' In other words, the line ABCD in the drawing corresponds to the shortest *four-dimensional* distance between the position of the earth in January (at A) and its position in October (at D)." Gamow, 13–15. According to Einstein, "Space-time does not claim existence on its own, but only as a structural quality of the field." Einstein, *Relativity: The Special and General Theory*, 155.

[77] Geroch, 9.

[78] The speed of light links the three space dimensions and time by representing time by a spatial magnitude and enabling it to be included in the diagram as a fourth dimension. A "kilometer of time" equals the time required by light to travel one kilometer. Consider, for example, two events that occur three kilometers of time apart. The speed of light in conventional units is about 300,000 kilometers per second. Three kilometers of time equals 3km/300,000km per sec, which equals 1/100,000 or 0.00001 seconds. See Edwin F. Taylor and John Archibald Wheeler, *Spacetime Physics* (San Francisco: W. H. Freeman and Co., 1966) 17–20; Gamow, 13. Astronomers use the speed of light to represent a distance by time (i.e., "light year"). Spacetime uses light to do just the opposite: represent a time by a distance. Consider, in this context, Aquinas's view that time and motion are convertible: "He [the Philosopher] says, therefore, first that not only do we measure motion by time, but we also measure time by motion, because they are defined by each other. For it is necessary to take the quantity of one according to the quantity of the other. Time determines motion because it is the number of motion. But conversely motion determines time in respect to us. . . . As motion imitates magnitude in quantity, continuity, and divisibility, so also time imitates motion. For these things are found in motion because of magnitude, and in time because of motion. Moreover, we measure magnitude by motion and motion by magnitude. For we say that a road is long when we perceive that our motion was long; and conversely, when we consider the magnitude of the road, we say that our motion is long. And this is also true of time and motion." Aquinas, *In IV Phys.*, 598–99.

[79] "[S]ince the orbit of the Earth around the Sun lies in a single plane, the omission is unimportant." Gamow, 15.

position at some time during a given year is shown on each vertical orbit and on the planet's worldline. Unlike the Newtonian view of the first diagram, time is included as one of the coordinates and is partly constitutive of the curved spacetime over which the planet's worldline is drawn. Space and time are connected. The worldline includes not only the spatial locations through which a body moves but also includes the times at which it moves through those locations.[80] The worldline is, however, not a path along which the planet literally moves:

> There is no dynamics within space-time itself: nothing ever moves therein; nothing happens; nothing changes. In figure 9 [not shown], for example, a certain amount of action is represented—particles moving about, collisions, and so on. Yet this dynamic, ongoing state of affairs, is represented, past, present, and future, by a single, unmoving space-time. Imagine a film has been taken of what occurs in the world, that this film has been cut into its individual frames, and that these have been stacked on top of each other. The result is similar to space-time. In the case of the film, "dynamics" is only recovered by comparing successive frames in the stack; in the case of space-time, by comparing the situation as recorded on several horizontal 3-planes. In particular, one does not think of particles as "moving through" space-time, or as "following along" their world-lines. Rather, particles are just in space-time, once and for all, and the world-line represents, all at once, the complete life history of the particle.[81]

The planet's worldline represents all times, and a body does not literally move from one time to another. If the planet were at rest with respect to the star, its spacetime interval would be a straight vertical line, parallel to the time axis. All the events and the planet's entire history are shown at once, as if one could view the movie version of the planet's history in a single glance, or as if one had an eternal, Godlike view of the universe from outside of time.[82] Nevertheless, motion and dynamical qualities, such as momentum and energy, are grasped by comparing different three-dimensional slices of the diagram. In other words, one grasps the motion of the planet by comparing prior and posterior three-dimensional positions along the worldline.

Geroch's statement and the diagram above may give the impression that the time dimension is essentially the same as the space dimensions and that the worldline depicts a body as a four-dimensional whole whose temporal "parts" coexist in the way that the spatial parts of a body coexist. On such an account, a worldline does not show any relations of potentiality or any true sense of coming-to-be. This interpretation of the time dimension often leads to the notion that the universe, as depicted by spacetime, is a complete and fully realized four dimensional "block," a neo-Par-

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[80] The spatial distance and the temporal separation of any two events on the planet's worldline are different when measured from different reference frames. From all reference frames, however, the spacetime interval between two events on the planet's worldline has the same magnitude. A difference in time is compensated for by a corresponding difference in space and vice versa.

[81] Geroch, 20–21.

[82] Aquinas, *Compendium of Theology*, trans. Cyril Vollert, S.J. (St. Louis: B. Herder Book Co., 1949) I.133; *ST* I.14.13c.

minidean One that treats time and motion as phenomenal.[83] The neo-Parminidean interpretation partly results from treating the unity of the prior and posterior in our concept of motion as if it were the same as the unity of an unchanging object and thereby projects an immobile view of motion into nature. In order to avoid such misunderstandings, the following passages from several different physicists should be considered:

> One remark should be made in connection with this four-dimensionality. The view has for some reason come to be widely held that the "fourth dimension" is a deep and mysterious thing which permits extraordinary happenings in the world, and which only a few people can really understand. We emphasize that this is just not true. We now already have "four dimensions." On the other hand, we have not yet introduced a single statement about the way the physical world operates that was not known to all of us since childhood. True, we have perhaps been more careful and precise in our discussion than we might have been previously, yet the fact remains that, with no additional contributions whatever to our basic fund of physical information, we have arrived at a description in terms of four dimensions. . . . All of us, I can assure you, now understand "the fourth dimension" as well as anybody.[84]

With respect to worldlines and spacetime diagrams, the difference between space and time is reflected in the mathematics of the spacetime interval:

> Impressed by this formula, Minkowski wrote his famous words, "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." Today this union of space and time is called spacetime. . . . Space is different for different observers. Time is different for different observers. Spacetime is the same for everyone. Minkowski's insight is central to the understanding of the physical world. It focuses attention on those quantities, such as the interval, which are the same in all frames of reference. It brings out the relative character of quantities, such as velocity, energy, time, distance, which depend upon the choice of frame of reference. Today we have learned not to overstate Minkowski's

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[83] "It appears therefore more natural to think of physical reality as a four-dimensional existence, instead of, as hitherto, the *evolution* of a three-dimensional existence." Einstein, *Relativity: The Special and General Theory*, 150. The term "neo-Parmenidean One" is adapted from Karl Popper, who in personal conversation with Einstein, called him "Parmenides," although Spinoza was the more likely influence. Einstein's interpretation of spacetime seems to have varied throughout his career. Karl R. Popper, *The Open Universe: An Argument for Indeterminism* (Cambridge: Cambridge Univ. Press, 1982, reprinted London: Routledge, 1995) 2–3. Ilya Prigogine, a 1977 Nobel Prize winner in Chemistry, quotes from a letter Einstein wrote not long before he died. The occasion of the letter was a close friend's death: "Michele has left this strange world just before me. This is of no importance. For us convinced physicists the distinction between past, present and future is an illusion, although a persistent one." Ilya Prigogine and Isabelle Stengers, *Order Out of Chaos* (New York: Bantam, 1984) 294. Prigogine is quoting from *Correspondence, Albert Einstein-Michele Besso, 1903–1955*. Many different interpretations of spacetime have been advanced, including some neo-Heraclitan views advocated by process philosophers. See, for example, the following articles in *The Concepts of Space and Time*, ed., Milic Capek (Boston: D. Reidel, 1976): Kurt Gödel, "Static Interpretation of Space-Time" 455–61; Adolf Grünbaum, "The Exclusion of Becoming from the Physical World" 471–500; Milic Capek, "The Inclusion of Becoming in the Physical World" 501–24.

[84] Geroch, 12.

> argument. It is right to say that time and space are inseparable parts of a larger unity. It is wrong to say that time is identical in quality with space. Why is it wrong? Is not time measured in meters, just as distance is? Are not the x and y coordinates of the surveyor quantities of identical physical character? By analogy, are not the x and t coordinates of the spacetime diagram of the same nature as one another? How else could it be legitimate to treat these quantities on an equal footing, as in the formula $[(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2 - (\Delta t)^2]^{1/2}$ for a spacelike interval? Equal footing, yes; same nature, no. There is a *minus* sign in this formula that no sleight of hand can ever conjure away. *This minus sign marks the difference in character between space and time*. . . . Consequently, the term $- (\Delta t)^2$ is always opposite in sign to the distance term $(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2$. No twisting or turning can ever make the two signs the same. The difference in sign between the time term and the space terms in the expression for the interval. . . .[85]

Our common notion of time and the knowledge of "the fourth dimension" that we have had since childhood are quite different from our knowledge of space:

> But the assertion [Minkowski's] seems absurd: we go on talking about space and time in much the same way as we always did, with there still being an essential difference between them, namely that we can move in any direction and at different velocities in space, but only uniformly and inexorably forwards in time. The integration of space and time into spacetime has not abolished the distinction between the spatial and the temporal, but only the claim that they are entirely independent...although the temporal dimension is still *different* from the spatial dimensions, it is, in a sense to be elucidated, not *separate* from it.[86]

In sum, although time is treated as a fourth dimension, it should not be understood as if it were a dimension in the same way in which the space dimensions are dimensions.

The notion of spacetime, as shown in the spacetime diagram, instantiates the Aristotelian definition of motion inasmuch as the worldline unites the prior and posterior in a body's motion precisely as not co-existing in reality. Since time is included in spacetime and in a body's worldline, the positions of the planet are ordered to each other as the prior to the posterior, of what no longer exists to what does not yet exist. The prior and posterior in the planet's motion are given in the worldline through comparing horizontal slices of the diagram. Because the time dimension is not of the same nature as the space dimensions, the prior and posterior in the planet's motion may be understood in terms of potency and act. The planet's motion is an act with respect to prior positions in the diagram, that is, the lower horizontal slices, and is in potency with respect to posterior positions, that is, the higher horizontal slices. The diagram presents the prior and posterior positions of the planet, and so its motion from a prior to a posterior position, as a unity given all at once on the page. This unity is not a unity at some *time* because *time* is itself

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[85] Taylor and Wheeler, *Spacetime Physics*, 37.

[86] J. R. Lucas and P. E. Hodgson, *Spacetime and Electromagnetism* (Oxford: Clarendon Press, 1990) 1–2. Peter Hodgson is a physicist engaged in theoretical nuclear physics at Oxford University.

included in the diagram. There is no time or physical vantage point from which one sees a spacetime interval or a worldline. Thus, the points on the worldline do not coexist as the spatial parts of a body may coexist. Comparing the vertical slices of the diagram requires a viewpoint that combines a prior disposition that no longer exists and a posterior disposition that does not yet exist. Therefore, I maintain that the prior and the posterior in the corkscrew-shaped worldline are brought together in a consideration by the soul. Thus, the second diagram indicates that the notion of spacetime instantiates the Aristotelian definition of motion.

In conclusion, I have argued that the mover causality principle and Newton's First Law of Motion are not opposed. Next, in analyzing one of Newton's examples of the First Law, I have sought to show that Newtonian physics treats real motions as complex phenomena determined by force principles, an inertial principle, and a potential energy principle. Potential energy, it has been argued, should be understood as a potency in the Aristotelian sense. Newtonian physics and General Relativity, I then argued, treat all real motions as continuous actualizations of a potency and, in this way, are consistent with the Aristotelian definition of motion. Furthermore, the inertial component of a motion should be understood as an act with respect to a prior potency, and the potential energy inherent in a motion combined with the further action of various forces should be understood as indicating a potency with respect to some posterior actuality. This is also in keeping with the Aristotelian definition of motion, which considers motion an incomplete act with a twofold ordination of the same potentiality. Finally, I proposed that, through the notion of spacetime, Special and General Relativity instantiate motion as a unity of differentiated prior and posterior parts that do not coexist in reality. Thus, the Aristotelian definition of motion and the principle of inertia are compatible. In light of the Aristotelian definition, a further layer of intelligibility may be grasped in the First Law. This suggests something requiring further investigation and argumentation, namely, that too much of Aquinas's view of nature was rejected at the time of the Scientific Revolution. Aristotelian cosmology, with its geocentrism, its celestial spheres, its notion of natural places, its view of gravitational acceleration as proportional to weight, and its five-element theory, was rightly overturned. However, the Scientific Revolution need not have overturned the mover causality principle, the Aristotelian definition of motion, and Aquinas's broader philosophy of nature, a natural philosophy that might yet serve as a basis for understanding the great advances in the sciences that began over four hundred years ago.[87]

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[87] An earlier version of this paper was read to the International St. Thomas Society at the Eastern Division Meeting of the APA on December 28, 2002. I am grateful to those present for their suggestions, and most especially to Fr. Norris Clarke, S.J.