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NEWTONIAN STUDIES

# By Their Properties, Causes and Effects: Newton's Scholium on Time, Space, Place and Motion—II. The Context*

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## The Cartesian Background

Descartes, Huygens, Leibniz, and Berkeley are typically cast, in contrast to Newton, as 'relationists' in terms of their views on space, time and motion. Moreover, it is usually held that a central tenet of relationism is the thesis that all motion is the relative motion of bodies with respect to other bodies. For this reason it is commonly surmised that Newton should be concerned to argue the existence of absolute motion. But, as I have construed his strategy in the scholium, the arguments from properties, causes and effects, and thus the rotating bucket experiment, do not seek to do this, but instead take the existence of absolute motion for granted. Does this not portray Newton as begging a pivotal point of contention?

My answer to this has two parts. The first is to remove potential misunderstandings concerning what relationism involves. To be sure, the above figures are all, in the terminology of Sklar,[1] anti-substantivalists, in that they reject the existence of space as an entity distinct from, but on comparable ontological footing with, bodies. Whether they thereby qualify as relationists is largely a semantic issue. The above relationist thesis concerning the nature of motion is susceptible to a variety of interpretations. On a hard-core relationist reading, it insists that an expression of the form '*x* moves' is an incomplete predicate, and so, in order to be used meaningfully, it must be construed as shorthand for '*x* moves with respect to … ', where the ellipsis is to be filled in by reference to some tacitly understood body or set of bodies. Denying

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[1] L. Sklar, *Space, Time and Space-Time* (Berkeley, CA: University of California Press, 1974), p. 161.

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absolute space does not carry with it a commitment to hard-core relationism. Historically, many of the opponents of empty space were prepared to admit, or even to insist, that '*x* moves' is a complete predicate, typically because it seemed either commonsensical or dynamically plausible that, of the many relative motions of a given body, one of them can be singled out as its proper, true, or absolute motion.

The second part of my reply is to point out that there is no evidence that, at the time of composition of the *Principia*, Newton was aware of the views of any of these figures save Descartes. The famous disputes with Leibniz erupted years later. Although there was considerable correspondence with Huygens prior to the *Principia*, none of it touched on matters of space and motion. And Berkeley was scarcely out of the cradle when the first edition received the imprimatur of the Royal Society in July of 1686. Moreover, none of these savants, with the exception of Huygens, qualifies as a hard-core relationist, and Huygens came to reject absolute motion only after the appearance of the *Principia*.

Some clue as to the background Newton might have expected from his audience, even as late as 1713, can be culled from Roger Cotes' preface to the second edition. He divides the philosophical world, like Gaul, into three parts. Besides those who profess the 'experimental philosophy' and do as Newton does, there are those who still hold to the scholastic doctrines derived from Aristotle and the Peripatetics. And then there are those who 'take the liberty of supposing whatever unknown shapes and sizes, and dubious configurations and motions, of the parts [of matter] is agreeable to them; and even of inventing various occult fluids, which freely permeate the pores of bodies, endowed with an all-powerful subtlety and agitated by occult motions ... '.[2] That Cotes has the followers of Descartes in mind is confirmed by a letter to Newton in which he suggests:

> I think it will be proper besides the account of the Book & its improvements, to add [to the Preface] something more particularly concerning the manner of Philosophizing made use of & wherein it differs from that of Descartes and Others ... [3]

Both the Aristotelian and Cartesian systems speak of true motion and rest. In the case of the Aristotelian, this is fairly evident, if only for the reason that otherwise there would have been no bite to the Copernican controversy. Furthermore, although the Cartesian system is obviously intended to implement the Copernican hypothesis, Descartes defines motion in a way that makes it possible for him to claim agreement with orthodoxy.

Descartes' identification of matter with extension in his *Principles of Philosophy* is well known. An individual body just is a certain part of space, and consequently there can be no such thing as space devoid of body. Although space does not in fact

[2] *Principia*, p. 20 (*Principia* references, unless otherwise specified, are to the critical edition of A. Koyré, I. B. Cohen, and A. Whitman (Cambridge, MA.: Harvard University Press, 1972); page numbers refer to the actual page numbers of that edition rather than those of the facsimile).

[3] Letter of 18 February 1712/13, in J. Edleston (ed.), *Correspondence of Sir Isaac Newton and Professor Cotes* (London: Frank Cass & Co., 1969), p. 151. This is a new impression of the first edition of 1850.

differ from matter, we often conceive of extension generically, as when it is said that a body comes to occupy the same portion of space as previously occupied by some other body. However, space in this sense differs from body only in the way that the genus or species differs from the individual.[4] Space in this generic sense is only a manner of our conceiving things, and not something in nature itself. Thus all that can be appealed to ultimately in speaking of motion is the successive rearrangement of the parts of material extension with respect to one another. For this reason, Descartes has often been classified as a relationist. Nonetheless, he draws a distinction between two senses of motion. Motion in the ordinary '*vulgaris*' sense is the action by which some body migrates from one place to another.[5] The operative sense of 'place' as used in this definition is discussed a bit earlier in Article 13 and has largely the sense of situation '*situs*' among other bodies. Whether or not a body changes its place in this sense depends on what other bodies are regarded as motionless.

> For instance, when a ship sails out to sea, a person stationed at the helm always stays in one place, if one considers the parts of the ship, among which he keeps the same position [*situs*]; but this same person continually changes place, if one considers the shores, since he continually recedes from the one and approaches the other.[6]

Thus, in the ordinary sense of motion, the same body can be said at one and the same time both to move and not to move.[7]

However, if motion is considered, not according to common usage, but in the truth of things, then properly speaking, each body has but a single motion peculiar to it. This motion is defined to be its translation from the vicinity of those bodies which immediately touch it and are viewed as though they were at rest, to the vicinity of others.[8] Although one can view this definition as implicitly offering a preferred definition of place in terms of the surface common to a body and those immediately surrounding it,[9] Descartes explains he has avoided the term *locus* in order to make it unambiguous that in this sense of *motus* at most one motion can be attributed to a body at a given time.[10]

Descartes' celestial mechanics relies on a vast whirlpool of subtle matter to transport the planets in their orbits about the Sun. Since, however, they are at relative rest to the ambient matter of this celestial vortex, it follows from his definition of

[4] *Principia Philosophiae*, Part II, Articles 10–12, in C. Adam and P. Tannery (eds), *Oeuvres de Descartes*, vol. VIII (Paris: Léopold Cerf, 1905).

[5] 'Motus ... ut vulgò sumitur, nihil aliud est quàm actio, quâ corpus aliquod ex uno loco in alium migrat.' *Ibid.*, Part II, Article 24.

[6] *Ibid.*, Article 13.

[7] *Ibid.*, Article 24.

[8] '... translationem unius partis materiæ, sive unius corporis, ex viciniâ eorum corporum, quæ illud immediatè contingunt & tanquam quiescentia spectantur, in viciniam aliorum.' *Ibid.*, Article 25.

[9] See Article 15, which bears the marginal heading: 'How external place is correctly understood as the surface of the surrounding body.' It may seem that Descartes invokes this definition of *locus* in his definition of motion in the proper sense. However, in the discussion that follows, he indicates that the external place of a body remains the same, provided the size and shape of the boundary between the body and its surroundings remain the same, even if what surrounds the body does not remain numerically the same. This may have been a sop to the Aristotelians. Compare with the definition given in Book IV, Chapter 4 of Aristotle's Physics: Place is the Innermost Motionless Boundary of what Contains.

[10] *Ibid.*, Article 28.

motion in the proper sense that they are at rest absolutely speaking. This includes the Earth as well, allowing him to avoid accusations of heresy. One may well wonder whether the doctrine of motion in the proper sense was not primarily a ploy to achieve verbal consistency with dogma. Descartes' dynamics, however, implicitly ascribe to each body a unique state of motion or rest. This is evident not only in his rules of collision, wherein the outcome depends on whether the larger of the two bodies is at rest or in motion, but also in the formulation of the second law of motion: that all motion, on its own account, is in straight lines, and therefore bodies in circular motion tend to recede from the centers of the circles they describe. This centrifugal endeavor, or *conatus*, of bodies, and in particular of the subtle matter of the celestial vortices, plays a central role in Descartes' explanations of the major phenomena to be accounted for in his system of the world: how the Sun and the stars are spherical and appear as luminous bodies, why the planets have the orbits they do, how comets migrate from vortex to vortex, how light is transmitted in straight lines and how the force of gravity arises. Although Descartes gives a counterfactual analysis of *conatus* in order to avoid attributing any intentionality to inanimate matter,[11] he treats it as a real physical effect. It is transmitted from globule to globule in a vortex[12] and is measurable, for example, by the tension in the rope restraining a stone in a circular path.[13] Furthermore, its magnitude is proportional to the rate of rotation.[14]

Now, in the absence of comments to the contrary, one would expect that the dynamically distinguished motions are meant to coincide with what has been defined to be motion in the proper sense. Indeed, that motion in the proper sense is meant to have dynamical significance, and is not concocted just to serve the purpose of verbal reconciliation, is suggested by the fact that, immediately after introducing its definition, Descartes ascribes to it the inertial property that no more action is required to produce motion in this sense than to bring about its cessation.[15] Unfortunately, in the application of the dynamics to the system of the world, there is a gross mismatch between dynamically distinguished motions and those prescribed by the official definition. For example, the Earth and other planets, being swept around the Sun by a celestial vortex, are assumed to have a *conatus* to recede from the center of that rotation. Yet, according to the definition of proper motion, they are, strictly speaking, at rest.

One strategy for trying to remove this apparent inconsistency would be to attribute dynamical effects, not just on the basis of the unique motion proper to the body in question, but also in virtue of the proper motions of other bodies in which it participates. This notion of participation in other motions is developed in Article 31 of Part II.

[11] The endeavor to recede consists only in being so situated and incited to motion that they would in fact recede if not impeded by other causes. See *ibid.*, Part III, Article 56.

[12] *Ibid.*, Part III, Article 60.

[13] *Ibid.*, Part III, Article 59.

[14] *Ibid.*, Part III, Articles 59 and 83.

[15] *Ibid.*, Part II, Article 26.

> Although each body has but one motion proper to it, since it is understood to move away from only those bodies contiguous to it and at rest, it nonetheless can also participate in innumerable other [motions], if in fact it is a part of other bodies having other motions. For example, if someone walking on board a ship carries a watch in his wallet, the tiny wheels of his watch move with only a single motion proper to them, but they also participate in another insofar as, being adjoined to the walking man, they form a single part of matter together with him, and in another insofar as they are adjoined to the ship tossing in the sea, and in another insofar as adjoined to the sea itself, and in yet another insofar as adjoined to the Earth itself, if indeed the whole Earth moves.

Thus, one might conjecture that the dynamically relevant motion of a body is in fact the net resultant of its proper motion with those of all bodies which include it. However, as soon as he introduces this idea of participation, Descartes dismisses its relevance:

> And all these motions will truly [*revera*] be in the these tiny wheels; but because it is possible neither to comprehend easily so many [motions] at once, nor even to recognize all of them, it will suffice to consider that single motion, which is proper to each body, in itself.

Not only would it be impossible to know all these motions, the notion of a net resultant of the totality is not well defined in the context of the Cartesian system. Since the Universe is indefinite in extent, there would be an infinite regress of bodies participating in motions of more inclusive bodies.

## De Grav

That Newton is concerned in the scholium in large part with the views of Descartes is suggested by a number of observations. Firstly, there is his concern to justify his characterization of place as the space occupied by a body in contrast to the characterizations given by Descartes in terms of either *situs* or the surrounding surface. Secondly, there is his endeavor to argue directly that the order of the parts of space cannot change. Thirdly, there are the definitions of true motion and rest he singles out for criticism. The manner of defining true rest in terms of the relative position of local bodies rejected in paragraph eight is implicitly the criterion of Descartes. So is the definition of circular motion the rotating bucket experiment is used to refute. The definition of motion against which paragraph nine is leveled, namely:

> translationem e vicinia corporum, quæ tanquam quiescentia spectantur,

is taken almost verbatim from Descartes' definition of proper motion:

> translationem ... ex viciniâ eorum corporum, quæ illud immediatè contingunt & tanquam quiescentia spectantur.

Finally, there is the implicit invective, immediately following the rotating bucket experiment and in the next paragraph, against Descartes' contention that the Earth and planets are truly at rest because of his definition and because of what the Scriptures say.

That Descartes is indeed the principal target need not be merely surmised from this. The document *De Grav*, mentioned above (in Part I), provides a direct link.[16] Each of the arguments from properties, causes and effects, as well as a number of other crucial passages, have clearly identifiable antecedents in this manuscript. Furthermore, in *De Grav* these arguments are directed expressly against Descartes.

*De Grav* represents what appears to have been intended to be a substantial work on the professed topic of the gravity and equilibrium of fluids and solids in fluids. Either much of the manuscript has been lost, or else the project was aborted at an early stage. For, after listing a total of nineteen definitions (and two axioms), the manuscript ends after demonstrating but two propositions. The bulk of the document is a long 'note' inserted between the fourth and fifth definitions, addressing the natures of space, time, motion, and body. In the fourth paragraph, Newton makes it clear that his primary purpose in this long note is to refute the Cartesian doctrine:

> Since in these definitions I have supposed that space is given distinct from body, and have determined motion with respect to the parts of space, and not with respect to the positions of contiguous bodies, lest this be taken as gratuitous against the Cartesians, I shall endeavor to dispel his fictions.[17]

After a digest of what he takes to be the elements of Descartes' theory of motion, he commences his attack, first by drawing attention to three counts on which 'Descartes, by contradicting himself, appears to acknowledge' how 'confused and contrary to reason this doctrine is', and second, by deriving from that doctrine seven 'absurd' consequences. After this, Newton elaborates at length his own doctrine of space and time. In this we find a precursor of the argument in the scholium for the immobility of space.

> The parts of space are immovable. If they were to move, either it must be said that the motion of each [part] is a translation from the vicinity of other contiguous parts, in the fashion that Descartes has defined the motion of bodies, and it has been sufficiently shown that this is absurd; or it must be said that it is a translation from space to space, that is from itself, unless it is said perhaps that two spaces everywhere coincide, one movable and the other immovable.[18]

Newton goes on to compare the immobility of space with the immutability of the order of the parts of time. What follows is a remarkable characterization of the identity conditions for the parts of space and time of considerable interest for current philosophy. Our present interest, however, is in how the absurdity of Descartes' doctrine of motion has been 'sufficiently shown' and, more specifically, in those objections that anticipate the later arguments of the *Principia*.

In the scholium, the first property invoked was that bodies which are absolutely

[16] See the transcription and English translation in A. R. Hall and M. B. Hall (eds), *Unpublished Scientific Papers of Isaac Newton* (Cambridge: Cambridge University Press).
[17] *Ibid.*, pp. 91–92. The translations throughout are mine. In some cases this has made a significant difference in the sense of the passage.
[18] *Ibid.*, p. 103.

at rest are at rest relative to one another. Put contrapositively, this is to say that if bodies do not maintain their relative distances, then at least some of them must move absolutely. The fifth absurd consequence Newton purports to derive in *De Grav* from Descartes' doctrine involves just this:

> Fifth. It appears foreign to reason that bodies, without physical motion, may change their distances and positions among themselves; but Descartes says that the Earth and the other planets and the fixed stars properly speaking are at rest, and yet they changes their positions among themselves.[19]

You will recall that in the scholium Newton reserves the application of this property to the Cartesian system until he has completed the entire series of arguments from properties, causes, and effects.[20]

The third and final count on which Newton claims in *De Grav* that Descartes contradicts himself feeds into the consideration of the properties of motion. The alleged contradiction derives from the claim that the innumerable motions, in which a body participates in virtue of being a part of other bodies, really (*revera*) are in the body. If motion-by-participation is motion properly speaking, then this contradicts the claim that each body has but a single motion in the non-vulgar sense. And if it is motion only in the vulgar sense, then it is not really in the body.

The first absurd consequence Newton saddles Descartes with follows up on the dilemma that results if Descartes were simply to retract the claim that motion-by-participation is really in the body in question. Consider the internal particles of hard bodies, which, since they are not transferred from the vicinity of immediately contiguous particles do not have a motion properly speaking, but move only by participating in the motion of the external particles. In fact, those parts of the exterior particles facing the interior do not move with a proper motion because they are not translated from the vicinity of what lies further inside. Followed to its logical conclusion, this dictates that, literally, only the outer surface of the body moves with a proper motion, and the entire internal substance, in other words the whole body, moves only by participation in the motion of the outer surface. So, Newton charges, the Cartesian definition entails that only the surfaces of bodies, and not the bodies themselves, can move in the proper sense.

One of the properties of motion invoked in the scholium is that the parts of a body which keep positions with respect to the whole participate in the motion of the whole, in the sense that they, too, move truly. If this is denied, the above consequence follows for the Cartesian definition. On the other hand, if it is not denied, the definition falsely attributes a state of rest to the relatively stationary internal parts, as the argument in the *Principia* makes clear.

Now if this property is not denied, but proper motion of a body as a whole also

[19] *Ibid.*, p. 96.

[20] It should be noted that the sixth absurd consequence is closely related to this. It levels the objection that, according to Descartes' doctrine, it is possible that several bodies maintain their relative positions, yet some move physically while others are at absolute rest.

extends to the parts of the body, Descartes risks the consequence that a body does not have a unique motion proper to it, but innumerable ones. This Newton takes up in *De Grav* as the second absurd consequence of the doctrine. Here the example of the sailor is shoved back in Descartes' face:

> This is because by the body whose motion he defines, he understands all that is transferred together, even though this itself can consist of parts having other motions among themselves; imagine the Vortex together with all the planets or a ship with all that is in it floating in the sea, or a man in the ship walking along with the things he carries, or the wheels of his watch along with the metal particles they are made of. For unless you say that the motion of the entire aggregate does not at the same time implant in the parts a motion proper and according to the truth of things, it will have to be admitted that all these motions of the wheels, the watch, the man, the ship, and the vortex truly and philosophically speaking are present in the particles of the wheels.[21]

It should not go unnoticed that this example is the very same, except for the watch, as the one used in paragraph four of the scholium to illustrate the decomposition of an absolute motion into its components. As I mentioned earlier, however, Descartes cannot extricate himself from the alleged difficulty by taking the unique proper motion of a body to be the net resultant of its immediate relative motion together with all the motions in which it participates, on pain of an infinite regress. This is not to say that in assigning centrifugal endeavors he did not implicitly follow this strategy, terminating the regress illegitimately by tacitly assigning a state of rest to the centers of the celestial vortices.[22] Newton, of course, contends that the regress can be avoided only by recourse to motionless places, which together make up absolute space. This is the argument from the properties of motion given in paragraph ten of the scholium.

The third absurd consequence attributed to Descartes clearly anticipates the first prong of the argument from causes in the scholium.

> Third. It follows from the Cartesian doctrine that motion can be generated where no force is impressed. If, for the sake of argument, God were to make it happen that the rotation of our vortex were suddenly to stop, without impressing on the Earth a force which would stop it at the same time, Descartes would say that, because of its translation from the vicinity of the contiguous fluid, the Earth would now move in the philosophical sense, just as before he said it be at rest in the same philosophical sense.[23]

[21] *Ibid.*, pp. 94–95.

[22] Later on in *De Grav*, Newton remarks:

> Thus it is necessary to refer the determination of places and local motion as well to some immobile entity such as extension alone or space insofar as it is regarded as something truly distinct from bodies. And this the Cartesian philosopher can more freely admit if he only notices that Descartes himself had the idea of this extension distinct from bodies, which he preferred to distinguish from bodily extension by calling it generic, and that the rotations of the vortices, from which he derived the force of the aether in receding from the centers, as well as his entire mechanical philosophy, is tacitly referred to this generic extension.

See *ibid.*, p. 98.

[23] *Ibid.*, p. 95.

The precursor in *De Grav* of the second prong of the argument from causes is in fact bound up with a cosmological variant on the rotating bucket experiment. This is the fourth absurd consequence of Descartes' doctrine, that God himself could not generate motion in some things even if He were to drive them with the greatest force. What follows, however, unlike the second prong in the scholium, does not show how the relevant relative motions may be preserved despite the application of forces, but depends for its polemic force on some of the subtler details of Descartes' position. Newton invites us to imagine what would happen if God were to drive the fixed stars together with the remotest parts of creation with a very great force, so as to cause them to turn about the Earth (say with a diurnal motion). Disregarding details about the orbital motions of the planets, this is in fact the basic picture assumed by both the Ptolemaic and Tychonic systems. In Article 38 of Part III of the *Principles*, however, Descartes insists that, even on the Tychonic scheme, it should not be said, properly speaking, that the Earth is at rest and the planets in motion.

> But, according to what was said earlier, [motion] should be ascribed solely to the Earth: because it involves its entire surface, and not the entire surface of the heavens in the same manner, but only the concave part, next to the Earth, which is very small in comparison to the convex [part of the heavens].

Now, Newton clearly believes it makes a crucial difference whether the force is applied to the heavens or to the Earth. (The true motion in a body is never generated or altered except by impressed forces and is always altered by impressed forces.) Furthermore, he believes that only a small force would have to be applied to the Earth in comparison to what must be applied to the heavens in order to produce the same relative motion. On this latter score he has a difference of opinion with Descartes, who claims that such a reciprocal translation requires the same force or action on the Earth as on the heavens.[24] Newton appeals to the effects of motion to adjudicate the issue:

> But who will think that the parts of the Earth endeavor to recede from the center because of a force impressed only on the heavens? Or is it not more agreeable with reason that a force applied to the heavens would cause them to endeavor to recede from the center of rotation thus created, and consequently them alone to move properly and absolutely; and that a force impressed on the Earth would cause its parts to endeavor to recede from the center of rotation so created, and consequently it alone to move properly and absolutely: even though in both cases the translation of the bodies relative to one another is the same.

The question Newton raises is not whether it is reasonable to use centrifugal endeavor as an indicator of true circular motion. This he takes for granted, as is evident from the mocking tone of his opening criticism of Descartes, accusing him of contradicting himself by assigning to the Earth and planets an endeavor to recede from

[24] See earlier in Article 38 of Part III. The claim in the general case is first made in Part II, Article 28. Dan Garber discusses the problem for Descartes of determining which body is in motion in cases such as the above, in *Descartes' Metaphysical Physics* (Chicago: University of Chicago Press, 1992).

the center of the solar vortex while insisting that they are, properly speaking, at rest.[25] The question, rather, is whether it is possible to induce a centrifugal endeavor in the parts of a body simply by virtue of creating a relative rotation between it and its surroundings, irrespective of how that rotation arises dynamically. Newton has no doubts as to the answer. But the rotating bucket experiment provides an actual experimental demonstration on a limited scale. Thus it can be seen why he devotes the attention to it he does in the *Principia*.

## Further Manuscript Material

Although the roots of the main arguments advanced in the scholium are clearly traceable to *De Grav*, the language in that earlier document is quite removed from that of the *Principia*. There is another manuscript which is relevant to the scholium, not only because of the remarkable similarity of language, but also because it sheds light on the overall structure of the scholium. This manuscript, bearing the title *De motu corporum in mediis regulariter cedentibus*, is dated by Whiteside to the winter of $168\frac{4}{5}$.[26] As remarked earlier, Newton saw fit here to begin the opening section labeled 'Definitiones' with entries for absolute time, relative time, absolute space, relative space, place, bodies (*corpora*),[27] rest, motion, and so on. Not only do the definitions read very much like the corresponding characterizations given in the *Principia*, but various portions of the commentary from paragraphs five to twelve inclusive of the scholium are positioned with the definition of the relevant quantity. So for example, 'Def. 1' mentions the equation of time, later expanded on in paragraph five of the scholium:

> Absolute time is that which by its own nature without relation to anything else passes uniformly. It is such, whose equation Astronomers investigate, and by another name is called duration.[28]

Similarly, the definition of absolute space is immediately followed by the argument for its immobility almost verbatim as it appears in paragraph six of the

[25] 'He says that the Earth and other planets are not moving properly speaking and in the philosophical sense, ... But later on he attributes to the Earth and planets an endeavor to recede from the Sun just as if it were a center around which they move. Then what? [*Quid itaque*?] [I]s this endeavor supposed to derive from the 'true and philosophical' state of rest Descartes attributes to them, or from a motion in the ordinary [*vulgi*] and 'non-philosophical' sense?' *Op. cit.*, note 16, pp. 92–93.

[26] See J. Herivel, *The Background to Newton's Principia* (London: Oxford University Press, 1965), and D. T. Whiteside (ed.), *The Preliminary Manuscript for Isaac Newton's 1687 Principia* (Cambridge: Cambridge University Press, 1989).

[27] In the *Principia*, Newton identifies *corpus* with quantity of matter in Def. 1.

[28] The similarity of language is quite evident from the Latin: 'Tempus absolutum est quod sua natura absque relatione ad aliud quodvis æquabiliter fluit. Tale est, cujus æquationem investigant Astronomi, alio nomine dictum Duratio.'
See Herivel, *op. cit.*, note 26, p. 304. All translations are my own.

scholium.[29] Interestingly enough, included after the definition of relative space is an argument meant to show that absolute space is distinct from any relative space.

> These spaces, however, are distinguished from one another *ipso facto* by the descent of heavy bodies which in absolute space seek the center in a straight line but are deflected to the side in a relative space which rotates absolutely.[30]

This coriolis effect, which Newton proposed to Hooke in 1679 as a way of demonstrating the diurnal motion of the earth,[31] is unfortunately far too small to have been readily susceptible to experimental demonstration. Hooke attempted the experiment shortly after Newton had suggested it, but without confidence that his results were not swamped by systematic errors.[32] This, or subsequent acrimony with Hooke, or both, may have contributed to its omission from the *Principia*.

Of obvious interest are the comments accompanying the definition of 'motus':

> Absolute motion, however, is distinguished *ipso facto* from relative motion in rotations, by the endeavor to recede from the center, which, of course, is null in purely relative rotation.[33]

Between this and the next line and running off into the margin, Newton inserts an addendum to this sentence:

> in relative rest it can be very great, as in the heavenly bodies which in the opinion of the Cartesians are at rest, yet endeavor to recede from the Sun.[34]

Newton continues on in the margin:

> This always definite and determinate endeavor shows there to be a definite and determinate quantity of real motion in individual bodies, dependent in no way on the relations which are innumerable and which give rise to as many relative motions.

The main body of the text then turns to an abbreviated forerunner of the argument from causes:

[29] However, the final sentences in the two cases are different. Recall that paragraph six of the scholium concludes: 'These are therefore absolute places, and only translations from these places are absolute motions.' The final sentence of the earlier manuscript provides an additional argument: 'Moreover, if by an impressed force one part of space were to be moved, then by a force of such magnitude applied to all parts to infinity the whole [of space] will be moved, which again is absurd.' See *op. cit.*, note 26, p. 305.

[30] *Ibid.*

[31] Letter of 28 November 1679, No. 236, in H. W. Turnbull (ed.), *The Correspondence of Isaac Newton*, vol. I (Cambridge: Cambridge University Press, 1959), pp. 300–304.

[32] The easterly deviation should be about 1.5 cm for an object dropped from a height of 100 m. Newton thought that the effect might be discernible in a free fall of only 20 or 30 yards. Within two months, Hooke reported back that he had:

> ... made three tryalls of the Experiment of the falling body in Every of which the Ball fell towards the south east of the perpendicular and that Very considerably the Least being about a quarter of an inch, but because they were not all the same I know not which was true. What the Reason of the Variation was I know not, whether the unequall sphæicall figure of the Iron Ball, or the motion of the air, for they were made without-doors, or the insensible vibration of the Ball suspended by the thread before it was cutt.

Letter of 6 January 1679/80, No. 239, in *ibid.*, p. 310.

[33] See Whiteside, *op. cit.*, note 26, p. 31.

[34] *Ibid.*

> Moreover, that motion and rest absolutely speaking do not depend on the position and relation of bodies to one another is obvious from the fact that these are never changed except by forces impressed on the body itself in motion or at rest, and are always subsequently changed by such forces; but relative [motion and rest in a body] can be changed by forces impressed only on the other bodies to which [the body in question] is related and left unchanged by forces impressed on both so that relative position is preserved.

Before turning to the the section titled 'Laws of Motion', Newton concludes his presentation of the 18 definitions given with a summary paragraph which sheds further light on the structure of the scholium of the *Principia*. This paragraph begins very much like the beginning of that scholium:

> It has been appropriate to explicate all these at some length in order that the reader may approach what follows freed from certain common prejudices and instilled with the distinct concepts of the principles of mechanics.[35]

The verb construction *explicare visum est* is the same, and so is the notion of freeing the reader from certain common preconceptions. This phrase *prœjudeiis quibusdam vulgaribus liberatus*, incidentally, is a later substitution in the manuscript for the simple adjective *claris*. The initial meaning of the passage was that these definitions are set out at length so that the reader might proceed with *clear and distinct ideas*—a not very subtle poke at Descartes.[36] The paragraph continues in a way that foreshadows the penultimate paragraph of the scholium, ridiculing Descartes' attempt to reconcile philosophy with Scripture.

> For it is necessary [in mechanics] to distinguish rigorously the absolute and relative quantities from one another, because all phenomena depend on the absolute. The vulgar, however, who have not learned to separate reasoning from perception[37] always speak of the relative, and so invariably that it would be absurd for wise men or prophets as well to speak to them otherwise. Wherefore both the sacred letters and theological writings are always to be understood in terms of the relative, and he who would thence occasion disputes about the absolute motions of natural things labors under a crude prejudice.[38]

It is evident from this that the opening paragraph of the scholium and the penultimate paragraph 13 serve to frame the intervening material, antecedents of which had been presented in the sequence of definitions in this earlier manuscript. This reinforces what the text of the scholium itself suggests, namely, that the final paragraph 14 presenting the example of the globes addresses an issue distinct from the line of inquiry up to that point.

[35] 'Haec omnia fusius explicare visum est ut Lector præjudeiis quibusdam vulgaribus liberatus et distinctis principiorum Mechanicorum conceptibus imbutus accederet ad sequentia.' See Herivel, *op. cit.*, note 26, p. 306, and Whiteside, *op. cit.*, note 26, p. 32.

[36] The substitution of the longer phrase does not really take back the gibe. In Part I of the *Principles*, Descartes speaks repeatedly of the need to free our minds of various prejudices. See Articles 16, 47, and 71–73.

[37] Note how this phrase—*a sensibus abstrahere*—anticipates paragraph seven of the scholium, viz., *in philosophicis autem abstrahendum est a sensibus.*

[38] Newton has crossed out a subsequent sentence which appears to read: 'Just as if anyone would propose to consider (in Genesis[?]) the moon in size not apparently but absolutely between two full moons [*maxima lumina*].'

## Mach's Legacy

Mach's critique of Newton in *Die Mechanik in ihrer Entwicklung* has had an enormous influence on how the scholium has been read since. As Karl Menger reminds us in his introduction to the sixth American edition: 'The latter critique is quoted in almost every presentation of the theory of relativity.'[39] Unfortunately, by the use of ellipsis in extensively quoting from the *Principia*, Mach made it seem as though Newton's discussion continues seamlessly from the rotating bucket experiment to the case of the globes, cutting out not only the intervening paragraph 13, but even the conclusion of the argument from the rotating bucket, viz., that true circular motion cannot be defined in terms of relative rotation with respect to immediately contiguous bodies. Gone as well are the four paragraphs addressed to the properties and causes of motion and rest. Mach, as is well known, had a specific philosophical agenda and did not hesitate to conjecture history to suit his convenience. Concerning Newton, he writes:

> We must of necessity suppose that the transformation in the conception of the world-system which was initiated by Copernicus left deep traces in the thought of Galileo and Newton. However, while Galileo in his theory of the tides chose the stationary sphere of fixed stars for the new coordinate system in a completely naïve fashion, we notice with Newton doubts as to whether a given fixed star is only apparently or really at rest (Newton, *Principia*, 1687, p. 11).[40] This appears to him to raise the difficulty of distinguishing between true (absolute) and apparent (relative) motion. Thereby, he was also compelled to formulate the concept of absolute space. In further pursuing the matter, he discusses the experiment of the rotating globes tied together by a cord and that of the rotating water bucket, and believes that although in fact no absolute translation can be established, perhaps an absolute rotation can.[41]

It is understandable that such major philosophers as Reichenbach and Nagel who were deeply influenced by the positivist tradition, which considered Mach a patron saint, should subscribe to this reading.[42] But even the 'new' generation of philosophers of space and time, critical of that tradition in so many ways, has uncritically perpetuated the main features of the myth. For example, in Sklar's influential and in other ways admirable *Space, Time and Space-Time* we read:

> Newton says this: Many of the relations that material objects bear to space itself have, it

[39] *The Science of Mechanics*, 6th edn, with revisions through the 9th German edn, translated by Thomas J. McCormack (La Salle, IL: Open Court, 1960), p. vi.

[40] The reference is to the final paragraph of the scholium.

[41] Seventh German edn (Leipzig: 1912), p. 223. The paragraph quoted appears to have been added by Mach sometime between the 2nd and 7th edns. Although Mach refers by page number to the 1st edn of the *Principia* and in footnotes occasionally quotes the Latin, this does not establish that he was familiar with the Latin text. The extensive quotations in German are not his own translation, but were taken without acknowledgement from that of J. Ph. Wolfers, published in 1872 with the title *Sir Isaac Newton's Mathematische Principien der Naturlehre* (Berlin: Robert Oppenheim). This is a translation of the 3rd edn, although it bears some of the same vestiges of the 2nd edn, as does Motte's, suggesting that Wolfers may have relied to a certain extent on the latter.

[42] See H. Reichenbach, *The Philosophy of Space and Time* (New York: Dover, 1957), pp. 210–218, and E. Nagel, *The Structure of Science* (New York: Harcourt, Brace and World, 1961), ch. 9.

> is true, no observational consequences. However, the *acceleration* of a material object relative to space itself does have observational consequences. From these observational consequences one can infer, in the same way theoreticians frequently infer unobservable entities from their observable consequences, to the existence of space itself.... Two thought experiments Newton proposes are crucial.[43]

There follows a rehersal of the rotating bucket experiment and the example of the globes. Although Sklar might confess to indulging in historical fiction, John Earman writes, in his recent monograph on the history and philosophy of the absolute–relational controversy, as though he is explicating the text:

> ... before getting involved in the difficulties of the doctrine of absolute motion, let us explore the structure of the Scholium a little more fully.
>
> After defining absolute space and time Newton admits that 'because the parts of [absolute] space cannot be seen or distinguished from one another by our senses, therefore in their stead we use sensible measures of them.' But he urges that 'in philosophical disquisitions we ought to abstract from our senses, and consider things in themselves, distinct from what are only sensible measures of them,' and he goes on to say that absolute and relative motion can be distinguished from one another 'by their properties, causes, and effects.' Newton's subsequent discussion of the properties and causes of motion do little to support his doctrine of absolute motion, but the effects of absolute motion are a different matter.[44]

Nor have historians done better. Some, such as Jammer, Alexander, and Koyré do not even mention the arguments from properties, but concentrate their attention on the causes and effects of motion, only to dismiss the former as ineffective. In his commentary, Koyré indirectly misquotes Newton: 'It is only by their causes and effects that absolute and relative motions can be distinguished and determined.'[45] Then, after quoting in full the Motte–Cajori translation of the argument from causes, he comments:

> Thus it is only in the cases where our determination of the forces acting upon the bodies is not based upon the perception of the change of the mutual relations of the bodies in question that we are actually able to distinguish absolute motions from relative ones, or even from rest. Rectilinear motion, as we know, does not offer us this possibility. But circular or rotational motion does.[46]

Similarly, Jammer refers to the argument from causes as 'Newton's first argument with regard to absolute motion', and dismisses it as 'based on the traditional metaphysics, the inclusion of which in the framework of physical explanation is

[43] L. Sklar, Space, Time and Space-Time (Berkeley: University of California Press, 1974), pp. 182–183.

[44] J. Earman, *World Enough and Space-Time: Absolute versus Relational Theories of Space and Time* (Cambridge, MA: MIT Press, 1989), pp. 61–62.

[45] A. Koyré, *From the Closed World to The Infinite Universe* (Baltimore: Johns Hopkins University Press, 1957), p. 166.

[46] *Ibid.*, p. 167. His treatment in *Newtonian Studies* (Cambridge, MA: Harvard University Press, 1965) is similar.

strongly objected to by Newton himself'.[47] In his introduction to *The Leibniz–Clarke Correspondence*, H. G. Alexander writes:

> In the rest of the scholium [Newton] explains this distinction [between absolute and relative quantities] and indicates certain cases in which absolute motions can, in practice, be distinguished from relative motions.[48]

A few pages later he remarks:

> Newton suggests in the scholium that there are two ways of distinguishing absolute accelerations and rotations from relative. The first is if one can observe the action of forces; for real forces produce real and not merely relative accelerations. Later it was seen that this method was theoretically impossible.[49]

Those historians who have seen fit to acknowledge the arguments from the properties of motion dismiss them as well. In *The Metaphysical Foundations of Modern Science*, E. A. Burtt quotes extensively from the passages concerned with properties and then comments:

> This section begins with great promise, but so far our difficulties are hardly explained.... However, Newton next proceeds to discuss the causes and effects of motion. Here we shall perhaps find a more helpful clue.[50]

Concerning the argument from causes, he remarks: 'In the light of the scientific advance since Newton, it is difficult to see any cogency in this part of the argument.'[51] Finally, Westfall, who with the rest understands Newton's arguments from properties, causes, and effects to address the problem of how it is possible to determine absolute motion and rest by empirical means, also concludes that the first four fail to establish anything positive:

> In the *Principia*, Newton detailed three criteria by which absolute and relative motions can be distinguished—their properties, causes, and effects. It is a property of rest that bodies truly at rest are at rest in respect to each other. This is the criterion of translation or kinematics alone; and true to his unchanged conviction, Newton pointed out the impossibility of ever determining if a given body that might serve as a reference point is truly at rest. The causes of true motion are forces impressed on bodies to alter it. This criterion is no better than the last. It speaks solely of changes in motion, and is helpless

[47] M. Jammer, *Concepts of Space*, 2nd edn (Cambridge, MA: Harvard University Press, 1969), p. 106. That Jammer takes this to be an argument *for* the existence of absolute motion is clear from what he says further down the page: 'The second argument for the existence of absolute motion proceeds from the effects that such motion produces....'

[48] (Manchester: Manchester University Press, 1956), p. xxxiv.

[49] *Ibid.*, p. xxxvii.

[50] Revised edn (New Jersey: Doubleday & Co., 1954), p. 250. Actually, Burtt badly mangles the text by quoting the conclusion of the first argument from properties (that absolute rest cannot be determined from the positions of bodies in our regions) in order to set up the question he assumes the arguments from properties, causes, and effects addresses.

[51] *Ibid.*, p. 253.

> to determine absolute motion itself. The effects of true motion are forces of recession from axes of circular motion. Here in fact was the gravamen of Newton's argument.[52]

Here, however, is an intimation that Newton simply toyed with his readers, holding his cards close to his vest until the very last moment.

Now, what I shall call the Machian legacy is the assumption that Newton found it incumbent to provide arguments for the existence of absolute motion. To what extent Mach himself is responsible for the legacy remains to be investigated. There are other factors possibly contributing to the dominance of received view. One is the fact that commentators have invariably relied on the Motte or the Motte–Cajori translation with its unfortunate rendering of '*definire*' as 'to determine' at critical junctures. Another is the shifting semantics of the term 'absolute motion'. Originally, it was a synonym for 'true motion', 'motion properly speaking', 'motion in the philosophical sense' and related expressions, a concept whose analysis was up for grabs in the seventeenth century. With the great success of the *Principia*, however, its meaning, as determined by use, came to be restricted narrowly to the sense proposed by Newton in the scholium as its adequate explication.

That these latter two factors have had a grip independent of the Machian legacy is shown by an interpretation offered by Ronald Laymon.[53] One of the virtues of Laymon's interpretation is that he does not see the rotating bucket and the example of the globes as just two instances toward the same end, since this would have been redundant in the overall strategy of the scholium. Moreover, contrary to the Machian legacy, he claims it is the function of neither to establish the existence of states of absolute rotation:

> The function of the bucket experiment is primarily to illustrate how the effects of real circular motion, namely, centrifugal forces, can be used to distinguish real from relative motions. The bucket experiment also, as an incidental benefit, can be used to refute Descartes's theory of true and philosophical motion. The function of the two globes experiment is to illustrate how the properties, causes and effects of motion can be used to distinguish real from relative motions. It is not intended by Newton that these experiments have as their conclusions the existence of absolute space, since this existence is already assumed by their explanation. The only support that these experiments give for the existence of absolute space is that they show that this concept does have some application and is part of a successful scientific theory.[54]

The functions Laymon assigns to the bucket and the globes, however, are essentially the same, namely, that of illustrating how true motion can be determined by empirical means. The only difference he sees is that the former appeals only to the effects of motion, while the latter, he claims, sums up what has gone before by

[52] R. S. Westfall, *Force in Newton's Physics* (New York: American Elsevier, 1971), p. 443.

[53] Ronald Laymon, 'Newton's Bucket Experiment', *Journal of the History of Philosophy* **16** (1978), 399–413. As examples of the persistence of the influence of Mach, the reader is invited to consult J. B. Barbour, *Absolute or Relative Motion?*, vol. 1 (Cambridge: Cambridge University Press, 1989), and C. Ray, *The Evolution of Relativity* (Bristol: Adam Hilger, 1987).

[54] Laymon, *ibid.*, pp. 410–411.

illustrating the use of properties, causes and effects together. In defense of the latter he appeals to Newton's choice of vocabulary:

> Newton consistently used 'distinguish' (*distinguo*) throughout the scholium to describe his intentions. The introduction to the two globes experiment, then, apparently is to be a *summary* of what has so far been said.[55]

But, despite the Motte–Cajori translation, Newton himself does not use the verb in that paragraph. He writes, rather:

> *Motus quidem veros corporum singulorum cognoscere, & ab apparentibus actu* discriminare, *difficillimum est.*[56]

That Laymon is under the spell of the Motte–Cajori translation is clear when he insists:

> By 'distinguish' Newton means that, *assuming* his theory of dynamics, one can *determine* absolute motions from knowable properties, causes and effects.[57]

Laymon's interpretation also serves to illustrate a further point. He contends that it is not Newton's concern to argue the existence of absolute space. This is certainly so with the case of the globes. But it is his concern to do so, at least indirectly, with the rotating bucket experiment. To this extent, the customary interpretation is correct, although for the wrong reasons. By endeavoring to show that it is unreasonable to think that true motion can be adequately characterized as some preferred instance of the relative motion of bodies, Newton does seek to defend his own analysis of the concept, which requires absolute places and hence absolute space. In fact, the third argument attempts to derive the existence of absolute places directly from the property of motion invoked.

This suggests one final factor that potentially interferes with an understanding of the scholium. To argue that absolute space is distinct from any relative space is surely tantamount to arguing the existence of absolute space, in so far as it follows that there is an immobile space distinct from body. So, to a certain extent, to argue that true motion is distinct from any special type of the relative motion of bodies, is to argue that there is a genus of motion in addition to relative motion and hence to argue the existence of absolute motion in the restricted sense of change of absolute place. It should be kept in mind, though, that this is a matter of arguing that something acknowledged to exist (true motion) is in fact identical to something not necessarily acknowledged to exist (motion with respect to absolute space).[58]

[55] *Ibid.*, p. 408.

[56] I am not claiming that 'to distinguish' is not a reasonable translation of '*discriminare*', or that Newton had a 'private lexicon' according to which '*distinguere*' and '*discriminare*' have distinct technical meanings. Rather, it seems to be Laymon's contention that Newton used '*distinguere*' in a special sense throughout the scholium, namely, in the sense of differentiating specifically by means of empirical criteria.

[57] *Ibid.*, p. 402.

[58] It might be asked, when Newton argues that absolute time is distinct from any relative time, does he argue that there exists something in addition to what is already acknowledged to exist, or does he argue that something already acknowledged to exist is in fact something not necessarily acknowledged to exist? There was no Cartesian distinction between 'time in the vulgar sense' and 'time properly speaking'.

## Newton's Contemporaries

Much has been written about Berkeley, Huygens and Leibniz as precursors of Mach and it is widely taken for granted that these individuals understood the rotating bucket experiment and the globes as an argument for absolute motion in the same way as Mach. If they did read the scholium in this fashion, we cannot blame it on the influence of Mach or the interference of the Motte translation. Moreover, they should be expected to have had a grip on the notion of true motion, independent of Newton's explication of it in terms of absolute place. One must be careful, though. This does not entail that in certain contexts they might not use the term '*absolute* motion' to refer specifically to Newton's proposed definition of the term, or that the term did not begin to become entrenched with this specific meaning within Newton's lifetime.

The reactions of Newton's contemporaries deserve to be examined in greater detail than they have been. This is especially so if the reading of the scholium I have suggested is on target. I have not examined the sources extensively or systematically and offer here some comments using mostly the more commonly quoted passages. I am not proposing to use the reactions of Newton's contemporaries as 'test cases' for my reading of the scholium. It is possible that Newton's strategy was misunderstood for other reasons yet to be identified. (Did Newton's antagonists always grasp his meaning?) However, it would be significant if the contemporary reading deviated systematically.

Let me begin with the exchange of letters between Huygens and Leibniz in 1694. Since these have been extensively discussed and quoted from by a number of recent commentators, I will here only summarize the gist.[59] On 29 May, Huygens writes:

> I have noticed in your notes on Descartes that you believe it to be disagreeable that no real motion is given but only relative. Yet this is something I hold very firmly, and am not stopped by the line of reasoning and experiments of Newton in his Principles of Philosophy, which I know to be in error ... [60]

Leibniz writes back on 12/22 June:

> As to the difference between absolute and relative motion, I believe that if movement or rather the moving force of bodies is something real as it seems that one must recognize, it is quite necessary it have a subject.... but you not will deny, I believe, that in truth each [body] has a certain degree of motion or, if you wish, of force; notwithstanding the equivalence of hypotheses.... Mons. Newton recognizes the equivalence of hypotheses in

[58]*continued*
Newton's appeal to the astronomical tradition, wherein there is a preferred (measure of) time in contrast to commonly used measures, fills this void. Thus, he first seeks to establish, or to remind the reader, that there is a preferred time widely acknowledged, and then to establish that this is identical to something not necessarily acknowledged to exist.

[59] For further discussion and quotations see H. Stein, 'Some Philosophical Prehistory of General Relativity', in J. Earman, C. Glymour and J. Stachel (eds), *Foundations of Space-Time Theories*, Minnesota Studies in the Philosophy of Science, vol. VIII (Minneapolis: University of Minnesota Press, 1977), pp. 3–49; H. Bernstein, 'Leibniz and Huygens on the "Relativity" of Motion', *Studia Leibnitiana*, Sonderheft **13** (1984), 85–101; and J. Earman, *op. cit.*, note 44, pp. 66–67.

[60] C. Huygens, *Oeuvres Complètes*, vol. X (La Haye: Martinus Nijhoff, 1905), p. 614.

> the case of rectilinear motions; but in regard to circular, he believes the effort which revolving bodies have to recede from the center or the axis of rotation makes known their absolute motion.[61]

In a letter of 24 August, Huygens confesses:

> I was once of the opinion of Mr Newton, as far as circular motion is concerned. That is true, and it was only 2 or 3 years ago that I discovered what is more to the truth, which it seems you are not far from now, except you want to say that when a number of bodies are in relative motion among themselves, each has a certain degree of true motion, or of force, in which I am not of your point of view.[62]

Then, on 4/14 September, Leibniz reminds Huygens:

> When I said to you one day in Paris that it is hard to know the true subject of motion, you replied that this can be done by means of circular motion, which surprised me; and I remembered it when reading almost the same thing in the book of Mons. Newton; but this was when I already believed I saw that circular motion has no privilege in this.[63]

Two observations are significant. Firstly, Leibniz holds that motion has a subject, even though he denies both that space is something real and that the true subject of motion can be known even in the case of circular motion. Secondly, Huygens had believed not too much earlier that true motion can be known by means of centrifugal endeavor but, after the appearance of the *Principia*, came to deny that motion has a true subject, even in the case of circular motion.

Concerning the second observation, Howard Bernstein asks:

> Is there not something paradoxical in Huygens' change of views? One would have expected Newton's Scholium not to discourage but rather to confirm Huygens in his previous conviction about so-called true motion.[64]

This change of view is indeed paradoxical if it is assumed that Huygens read the rotating bucket argument as an argument for the existence of absolute rotation. If instead he had understood the arguments of the scholium as claiming that absolute motion cannot be defined in terms of the relative motion of bodies but requires the affirmation of absolute space, his change of view can be more readily understood as an attempt to counter Newton by developing an account which, *pace* those arguments, reduces all instances of motion to the relative motion of bodies. Huygens answer was, in effect, to generalize what it means for a pair of bodies to be in motion with respect to one another. Previously, he had taken for granted that relative motion consists entirely in a change of relative positions. Part of his response to Newton was to broaden the concept of relative motion, so that, even if bodies maintain a fixed

[61] *Ibid.*, p. 645.
[62] *Ibid.*, pp. 669–670.
[63] *Ibid.*, p. 681.
[64] *Op. cit.*, note 59, p. 88.

distance with respect to one another, they count as being in relative motion provided they *would* change their relative positions if not restrained from doing so.

Huygens was led to this analysis by considering what we should say if two unconstrained bodies move toward one another uniformly in parallel lines and, at the point of minimum separation, are caught by hooks attached to a rigid connection so that they are then constrained to rotate about a common center. It is counterintuitive to think that the mere introduction of a rigid connection could destroy the quantity of relative motion that existed beforehand, so they should be deemed to continue to move relative to one another, despite the fact they no longer change their relative positions. In retrospect, Huygens can be seen to have been groping towards a conception of the total angular momentum of a system.[65]

Before considering Leibniz, I want to take a look at Berkeley, since his criticisms speak to the scholium directly. In Article 111 of his *Principles of Human Knowledge*, published in 1710, he presents Newton's definition of absolute motion and then summarizes, reasonably accurately, the features of motion by which Newton sought to distinguish absolute from relative motion:

> And the true, we are told, are distinguished from apparent or relative motions by the following properties. First, in true or absolute motion, all parts which preserve the same position with respect to the whole, partake of the motions of the whole. Secondly, the place being moved, that which is placed therein is also moved: so that a body moving in a place which is in motion, participates in the motion of its place. Thirdly, true motion is never generated or changed, otherwise than by force impressed on the body itself. Fourthly, true motion is always changed by forces impressed on the body moved. Fifthly, in circular motion barely relative, there is no centrifugal force, which nevertheless in that which is true or absolute, is proportional to the quantity of motion.[66]

He then registers his disagreement with Newton in Article 112:

> But notwithstanding what has been said, it does not appear to me, that there can be any motion other than *relative*: so that to conceive motion, there must be at least conceived two bodies, whereof the distance or position in regard to each other is varied. Hence if there was only one body in being, it could not possibly be moved. This seems evident, in that the idea I have of motion does necessarily include relation.

At the beginning of Article 113, however, Berkeley goes on to profess in so many words that none the less, motion has a true subject:

> But though in every motion it be necessary to conceive more bodies than one, yet it may be that one only is moved, namely that on which the force causing the change of distance is impressed, or in other words, that to which the action is applied.

Here, Berkeley has in effect proposed his own definition of true motion and that there is indeed a true subject of motion he takes to be quite obvious:

[65] This tacit appeal to conservation of angular momentum, of course, ultimately begs the question. For it implicitly assumes that angular momentum is an absolute quantity, and it can then be asked why this is any less objectionable than admitting rotation as an absolute quantity of motion.

[66] See the edition edited by R. Woolhouse (London: Penguin Books, 1988), p. 94.

Now I ask anyone, whether in his sense of motion as he walks along the streets, the stones he passes over may be said to *move*, because they change distance with his feet? To me it seems, that though motion includes a relation of one thing to another, yet it is not necessary that each term of the relation be denominated from it. As a man may think of something which does not think, so a body may be moved to or from another body, which is not therefore itself in motion.[67]

After discussing how the motion attributed to a body varies according to how its place is assigned, e.g. with reference to a ship, the Earth, or the fixed stars, Berkeley confronts the rotating bucket experiment:

As to what is said of the centrifugal force, that it does not at all belong to circular relative motion, I do not see how this follows from the experiment which is brought to prove it. (See *Philosophiae naturalis principia mathematica*, scholium to definition 8.) For the water in the vessel, at that time where it is said to have the greatest relative circular motion, has, I think, no motion at all: as is plain from the foregoing section.[68]

Berkeley's point is that, although the experiment may show that the water's centrifugal endeavor is not correlated with the greatest degree of relative motion between the water and the bucket, this relative circular motion is not to be ascribed to the water unless the force responsible for that relative motion has in fact been applied to the water. As he explains:

For to denominate a body *moved*, it is requisite, first, that it change its distance or situation with regard to some other body; and secondly, that the force or action occasioning that change be applied to it. I grant indeed, that it is possible for us to think a body, which we see change its distance from some other, to be moved, though it have no force applied to it (in which sense there may be apparent motion), but then it is, because the force causing the change of distance is imagined by us to be applied or impressed on that body thought to move. Which indeed shows we are capable of mistaking a thing to be in motion which is not, and that is all.[69]

Berkeley does not dispute the premises of Newton's arguments. He claims earlier in Article 114 that 'to this kind of relative motion, all the abovementioned properties, causes and effects ascribed to absolute motion, will, if I mistake not, be found to agree.' And although he does not explicitly say so, it is evident that when the water has its greatest centrifugal endeavor, his conditions of motion have been met. For the water has a relative rotation (with respect to either the Earth or the fixed stars) and this relative rotation has resulted from an application of force (via the sides of the bucket) to the water (rather than to the Earth or the fixed stars). In this sense, centrifugal force can be said to belong to circular relative motion.

Berkeley's later critique of the rotating bucket experiment in *De Motu* is along the

[67] Article 113.
[68] Article 114.
[69] Article 115.

same lines, but without explicit mention of his own definition of motion. When he says there of the rotating bucket that 'From which experiment it by no means follows, that absolute circular motion is necessarily indicated by the forces of the motion receding from the axis',[70] he means to deny that absolute circular motion, specifically in the sense of motion with respect to absolute space, is so indicated. In other words, he denies that the argument succeeds in showing that circular motion (as he would grant bodies move circularly) is not a particular type of the relative motion of bodies with respect to one another.

Unlike the case with Berkeley, we do not have from Leibniz a critique specifically of the arguments in the scholium, although the opportunity certainly arose in the correspondence with Clarke. In the fourth paragraph of his third reply to Leibniz, Clarke tried his hand at a dynamical argument for the existence of absolute space:

> If space was nothing but the order of things coexisting; it would follow, that if God should remove in a straight line the whole material world entire, with any swiftness whatsoever; yet it would still always continue in the same place: and that nothing would receive any shock upon the most sudden stopping of that motion.[71]

Leibniz responded in his next letter by appealing to the identity of indiscernibles and the principle of sufficient reason. In reply, Clarke complained:

> To this argument, no answer has ever been given. It is largely insisted on by Sir Isaac Newton in his *Mathematical Principles* (Definit. 8) where, from the consideration of the properties, causes and effects of motion, he shows the difference between real motion, or a body's being carried from one part of space to another; and relative motion, which is merely a change of the order or situation of bodies with respect to each other. This is a mathematical one; showing, from real effects, that there may be real motion where there is none relative; and relative motion, where there is none real: and is not to be answered, by barely asserting the contrary.[72]

This is in fact a faithful description of Newton's strategy in the scholium, except for Clarke's insistence that his argument is one 'largely insisted on' by Newton himself. Newton did not give this argument, and it is dubious that he would have insisted on it.[73] As is evident from Corollary V to the laws of motion,[74] it cannot be inferred in the example that the supposed 'shock' is due to a 'sudden stopping' of the world, as opposed to a sudden acceleration in the opposite direction. Moreover, Corollary VI undermines the grounds for supposing that there would be such a 'shock'

[70] G. N. Wright (ed.), *The Works of George Berkeley*, vol. II (London: Thomas Tegg, 1848), p. 100.
[71] H. G. Alexander (ed.), *op. cit.*, note 48, p. 32.
[72] *Ibid.*, p. 48.
[73] See A. Koyré and I. B. Cohen, 'Newton & the Leibniz–Clarke Correspondence', *Archives Internationales d'Histoire des Sciences* **15** (1962), 63–126, for evidence of Newton's involvement in the conduct of the correspondence. Note, in particular, what they say on p. 79: 'We do not rule out the possibility that in discussing the replies to Leibniz, Clarke must have made a real contribution of his own, and did not act merely as Newton's secretary. We have found no evidence to make precise the degree of either Newton's participation in the 'Leibniz–Clarke correspondence' or of Clarke's participation in Newton's letters to Conti.'
[74] Cor. V: 'The motions of bodies included in a given space are, among themselves, the same whether that space is at rest or whether it moves uniformly in a line without circular motion.'

in any event, since the shock we habitually associate with sudden changes in motion arises only when differences in relative motions are produced by a differential application of accelerative forces.[75] Clarke failed to isolate an effect of absolute motion which, even by Newtonian lights, distinguishes it from relative motion.

Whether or not Leibniz recognized this is uncertain. His rejoinder addresses Newton's scholium, not Clarke's argument:

> I find nothing in the Eighth Definition of the *Mathematical Principles of Nature*, nor in the scholium belonging to it, that proves, or can prove, the reality of space in itself. However, I grant there is a difference between an absolute true motion of a body, and a mere relative change of its situation with respect to another body. For when the immediate cause of the change is in the body, that body is truly in motion; and then the situation of other bodies, with respect to it, will be changed consequently, though the cause of that change be not in them.[76]

There is a prevailing impression, predicated on the assumption that the rotating bucket is an argument for the existence of absolute motion, that Leibniz exemplifies here the sort of behavior that Clarke had accused him of, namely, of rejecting arguments without answering them. But if Leibniz read the arguments of the scholium as I have suggested they were intended, then the proposed relational definition of absolute motion does present a serious objection, although Leibniz might have helped his case by developing the details.

Leibniz has traditionally presented an enigma because he held there is no basis on which finite minds can discern in which bodies the immediate cause of the change lies. In this regard, he held that there is a 'general equivalence of hypotheses' concerning which bodies are at rest and which are in motion. Thus, not only would he have objected that the bucket experiment fails to show that true circular motion is not a species of relative motion, but, unlike Berkeley, he denied the major premise that centrifugal endeavor is a criterion of true circular motion. Of course, Leibniz is traditionally read as taking this to be the conclusion of the argument. There is one passage that might suggest this. Toward the end of his two-part essay *Specimen Dynamicum*, he writes:

> From these considerations it can be understood why I cannot support some of the philosophical opinions of certain great mathematicians on this matter, who admit empty space and seem not to shrink from the theory of attraction but also hold motion to be an absolute thing and claim to prove this from rotation and the centrifugal force arising from it [*idque ex circulatione indeque nata vi centrifuga probare contendunt*].[77]

[75] Cor. VI: 'If bodies, moving in whatever way among themselves, are driven by equal accelerative forces in parallel lines, they all will continue to move in the same way among themselves as if they had not been acted upon by those forces.'

[76] H. G. Alexander (ed.), *op. cit.*, note 48, p. 74.

[77] Part I of the essay was published in 1695. The second part remained unpublished. The translation is taken from L. Loemker (ed.), *Philosophical Papers and Letters*, 2nd edn (Dordrecht, Holland: D. Reidel, 1969), p. 449.

However, other interpretations are available. Leibniz may be speaking of motion as something 'absolute' in the narrow sense of change of absolute place. For, earlier in the *Specimen*, he characterizes motion as something unreal:

> For like time, motion taken in an exact sense never exists, because a whole does not exist if it has no coexisting parts. Thus there is nothing real in motion itself except that momentaneous state which must consist of a force striving toward change.[78]

If so, then what he says is reconcilable with a faithful reading of the scholium. Or, it may be that Leibniz has in mind the example of the rotating globes and is registering his disagreement with Newton's claim there that centrifugal force can be used to differentiate between true and merely apparent circular motion.

There is one additional passage that should be discussed, since its author, Henry Pemberton, served as Newton's editor for the third edition of the *Principia*. During the year following Newton's death, Pemberton brought out a non-technical introduction to Newtonian science under the title *A View of Sir Isaac Newton's Philosophy*.[79] At the end of the second chapter, he addresses the distinction between absolute and relative time. Absolute time, Pemberton explains, passes equably without relation to anything external, yet is ordinarily conceived by us in relation to some succession in sensible things. Our initial idea of time has its origin in the succession of our own thoughts, but some men's thoughts flow on more swiftly than others, nor is this flux constant in the same individual. Even the length of the day as measured by the Sun has been shown by astronomers to be unequal and they correct for this by means of the equation of time, in order to arrive at a true measure of duration.

Pemberton then turns to the distinction between absolute and relative motion:

> And as we ordinarily make no distinction between apparent time, as measured by the sun, and the true; so we often do not distinguish in our usual discourse between the real, and the apparent or relative motion of bodies; but use the same words for one, as we should for the other.... However, philosophers must not reject all distinction between true and apparent motions, any more than astronomers do the distinction between true and vulgar time; for there is as real a difference between them, as will appear by the following consideration.[80]

Without relating absolute and relative motion to absolute and relative space or even

[78] *Ibid.*, p. 436.

[79] (London: S. Palmer, 1728). Pemberton was a young man who had much to gain from his association with Newton, and did not hesitate to draw attention to it. In the Preface he speaks of the 'years I was happy in his friendship' and does not hesitate to convey Newton's opinion of him:

> The Remarks I continually sent him by letters on his *Principia* were received with the utmost goodness. These were so far from being any ways displeasing to him, that on the contrary it occasioned him to speak many kind things of me to my friends, and to honour me with a publick testimony of his good opinion. He also approved of the following treatise, a great part of which we read together.

Pemberton is at times patronizing. Elsewhere in the Preface he writes of Newton that: 'Though his memory was much decayed, I found he perfectly understood his own writings, contrary to what I had frequently heard in discourse from many persons.'

[80] *Ibid.*, p. 113.

mentioning the latter, Pemberton proceeds to argue the former distinction. Although the argument he gives appears to be of his own design, it appeals implicitly to the causes of motion:

> Suppose all the bodies of the universe to have their courses stopped, and reduced to perfect rest. Then suppose their present motions to be again restored; this cannot be done without an actual impression made upon some of them at least. If any of them be left untouched, they will retain their former state, that is, still remain at rest; but the other bodies, which are wrought upon, will have changed their former state of rest, for the contrary state of motion. Let us now suppose the bodies left at rest to be annihilated, this will make no alteration in the state of the moving bodies; but the effect of the impression, which was made upon them, will still subsist. This shews the motion they received to be an absolute thing, and to have no necessary dependence upon the relation, which the body said to be in motion has to any other body.[81]

The gist of the argument appears to be that the true motion of a body does not consist of its relation to other bodies, since we can imagine those other bodies annihilated without changing the state of true motion. Pemberton next appeals to the effects of motion:

> Besides, absolute and relative motion are distinguishable by their Effects. One effect of motion is that bodies, when moved round any center or axis, acquire a certain power, by which they forcibly press themselves from that center or axis of motion. As when a body is whirled about in a sling, the body presses against the sling, and is ready to fly out as soon as liberty is given it. And this power is proportional to the true, not relative motion of the body round such a center or axis. Of this Sir Isaac Newton gives the following instance.[82]

The instance in question is the rotating bucket. Pemberton recounts the major features of the experiment, but before reporting on the shape of the water's surface at the various stages, breaks off the description in order to set out Descartes' doctrine on motion:

> Now the definition of motion, which Des Cartes has given us upon this principle of making all motion meerly relative, is this: that motion, is a removal of any body from its vicinity to other bodies, which were in immediate contact with it, and are considered as at rest. And if this be compared with what he soon after says, that there is nothing real or positive in the body moved, for the sake of which we ascribe motion to it, which is not to be found as well in the contiguous bodies, which are considered as at rest; it will follow from thence, that we may consider the vessel as at rest and the water as moving in it.[83]

Pemberton now reports that the surface of water is initially flat but later becomes concave as a result of the endeavor of the water to recede from the axis of motion. At this point, all the elements are in place to pass judgment on the Cartesian doctrine as patently inadequate and thus to conclude that true circular motion cannot be defined in terms of such relative motion. However, this is not quite the conclusion Pemberton delivers. Instead, he writes:

[81] *Ibid.*, p. 114.
[82] *Ibid.*, pp. 114–115.
[83] *Ibid.*, pp. 115–116.

> and therefore this force of receding from the axis of motion depends not upon the relative motion of the water within the vessel, but on its absolute motion; for it is least, when that relative motion is greatest, and greatest, when that relative motion is least, or none at all.[84]

The ugly fact is that what I have claimed is a premise of Newton's argument, namely, that centrifugal force is an effect of absolute rotation, appears here, at least on the face of it, as part of the conclusion. This has puzzled me at length, not because it inclines me to think otherwise of the structure of the argument presented in the *Principia*, but because it makes it difficult to account for this apparent lapse on Pemberton's part without simply writing him off as confused. It is clear, I think, that he means to present the experiment as controverting Descartes, almost as though he had been coached to do so. Yet, it is not obvious from what he says how he understands it as doing so. There may be a clue in the fact that he refers to Descartes' definition of motion in the proper sense not as a definition 'of true motion' or 'of absolute motion', but simply 'of motion', and subsumes it under 'this principle of making all motion meerly relative'. This suggests that from the outset Pemberton reserves the term 'absolute motion' to refer to those motions of the bodies relative to the so-called lab frame in virtue of the fact that these are the motions induced by the application of forces to those bodies in the course of the experiment. With this in mind, the experiment straightforwardly establishes that the centrifugal force of the water is due to its absolute motion and not its motion relative to the vessel and Descartes is controverted in so far as it is thereby shown that this force does not necessarily depend on the motion of water according to his definition of motion. The argument is basically the same as Newton's, although the shift in semantics might lead one to think otherwise. This shows how easily arguments, like rumors, can assume a life of their own.

## Conclusion

Let me sum up briefly what I have attempted to establish in the foregoing. Newton's scholium usually has been understood to advance arguments for the existence of absolute motion based on the centrifugal effects manifested in such instances as the rotating bucket experiment and the example of the globes. I have argued at length that this is a misunderstanding of Newton's strategy. The argument from the rotating bucket is the last of a sequence of five, all of which seek to show that the true motion or rest of a body cannot be defined as some preferred type of motion relative to other bodies as proposed, most notably, by Descartes. Each of these arguments presupposes, as do the debates over the chief world systems, that 'to move' and 'to be at rest' are complete predicates and thus that each body has a unique state of true motion or rest, however this is to be analyzed. The cumulative purpose of the arguments is to convince the reader that true motion and rest can be adequately understood only with reference to motionless places, and hence to absolute space, as

[84] *Ibid.*, p. 116.

characterized earlier in the scholium. Newton offers the example of the globes only after this line of argument has been brought to a close, and then for the purpose of *illustrating* how it is possible in certain cases to acquire evidence concerning the true motions of individual bodies, given that the absolute space in which they move cannot be perceived.

This understanding of the scholium helps to clarify the reactions of some of Newton's contemporaries, although a systematic investigation has yet to be done. And, although the writings of Mach, together with an infelicitous choice of translation in the widely used Motte–Cajori translation, are partly responsible for the entrenchment of the currently received interpretation, there is a semantic ambiguity between the use of 'absolute motion' to mean specifically motion with respect to absolute space and a more generic and theory-neutral sense of the term available in the seventeenth and early eighteenth centuries, which also figures large. It is possible that this ambiguity began to affect the understanding of the rotating bucket argument well before Mach, even perhaps during Newton's lifetime.

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