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By Their Properties, Causes and Effects: Newton's Scholium on Time, Space, Place and Motion—I. The Text

*Robert Rynasiewicz**

Introduction

The scholium following the eight opening definitions of the *Principia* sets out Newton's views on absolute time, space, place and motion and proceeds to argue those views. The key argument, it is typically thought, appeals to the centrifugal effects of rotation, as manifested in the rotating bucket experiment and the example of a pair of revolving globes, in order to establish definitive instances of absolute motion. From this, the existence of absolute space is presumed to follow as a matter of course, since absolute motion, as defined earlier in the scholium, is just motion with respect to absolute space. A great deal of effort has been expended in attempts to reconstruct meticulously just how the argument is supposed to work. Critics such as Mach and Reichenbach, who regarded absolute time and space as metaphysical excesses, savaged the move from inertial effects to absolute motion as a deductive *non sequitur*. More recent commentators have suggested that the argument should be understood as an inductive one, along the lines of an inference to the best explanation, and that, so construed, it is a rather reasonable one at that.

All this has been largely wasted effort if what is at stake is an understanding of Newton himself rather than the construction of some fictitious advocate of absolutism. The argument from the rotating bucket is the last of a sequence of arguments introduced by the words: "But we may distinguish rest and motion, absolute and relative, one from the other by their properties, causes, and effects"[1] It is commonly thought that Newton thereby intends to argue that

*Department of Philosophy, The Johns Hopkins University, 347 Gilman Hall, 3400 N. Charles Street, Baltimore, MD 21218, U.S.A.

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[1]This is taken from Florian Cajori's revised translation (Berkeley: University of California Press, 1934) of Andrew Motte's translation of the *Principia* (London: Benjamin Motte, 1729). A facsimile of the latter, together with an introduction by I. B. Cohen has been reprinted (London: Dawsons of Pall Mall, 1968). I shall refer hereafter to the Cajori version as Motte–Cajori. For a discussion of the circumstances of its production, see I. B. Cohen, 'Pemberton's Translation of Newton's *Principia*, With Notes on Motte's Translation', *Isis* **54** (1963), 319–351. Professor Cohen is presently completing a much needed modern English translation of the *Principia*.

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there are various empirical criteria sufficient to detect and thus to prove the existence of absolute motion. Unfortunately, it is not readily apparent how the four arguments, involving properties and causes, that precede the argument from effects with the rotating bucket contribute to this end, and commentators have typically either passed over them in silence or else dismissed them as obscure, ineffectual, or beside the point. An appreciation of these earlier arguments, however, is essential for understanding the structure and function of the argument from the rotating bucket, and when comprehended, it becomes evident that the customary interpretation of what the latter seeks to do is largely a folk myth. Neither the argument from the rotating bucket nor any of the preceding arguments from the properties and causes of motion and rest seek to demonstrate or to marshal evidence for the existence of absolute motion. Nor is it their purpose to argue that the properties, causes, and effects in question afford empirical criteria for determining states of absolute motion or rest. This is not to say that Newton has no suggestions as to how it is possible to have knowledge of the absolute motions of individual bodies, and in practice to differentiate between them and the merely apparent motions. Indeed, the example of the globes is meant to illustrate how this can be done in certain cases, but this is a matter taken up only after the line of reasoning from properties, causes, and effects has been concluded.

Nowhere in the scholium does Newton seek to establish that each body has a state of true or absolute motion unique to it. Rather, this is taken for granted in each of the arguments mentioned above. On the face of it this may seem absurd. Doesn't the existence of absolute space follow by definition from the existence of states of absolute motion, and thus its assumption simply begs the whole matter? Those who are familiar with the writings of Descartes, Huygens, Leibniz, and Berkeley on the nature of motion, however, will appreciate that in the seventeenth and early eighteenth centuries the idea that motion has true subject, or in other words, that an expression of the form '*x* moves' constitutes a complete predicate, held considerable sway even among those who adamantly rejected the existence of such a thing as space distinct from body. Granted, many of those whom we now tend to style as relationists would have insisted that there is no such thing as motion that is not an instance of the relative motion of bodies with respect to other bodies. This, however, does not entail that they rejected the idea of true motion. Rather, it gives an indication of how they thought that concept should be analyzed. When Newton asserts that absolute motion and rest are distinguished from their relative counterparts by their properties, causes, and effects, he means to adduce reasons for believing absolute motion and rest are not special instances of the relative motion or rest of a body with respect to other bodies. The arguments that follow thus do not presuppose that absolute motion is by definition motion with respect to absolute space.

Instead, they seek to justify that definition by showing that the absolute quantities are not definable in terms of the relative.

It has been suggested previously that Newton's scholium is best read against the backdrop of Descartes' views on motion and rest.[2] That recommendation is born out fully here. One might even surmise that Newton chose the title *Philosophiae Naturalis Principia Mathematica* in conscious contrast to Descartes' *Principia Philosopiae* as a way of underscoring his intention to replace the latter with an entirely new foundation for natural philosophy.[3] It is natural then that in elaborating upon the senses in which he would have *tempus*, *spatium*, *locus* and *motus* understood in that work, he should take particular pains to dismantle the Cartesian orthodoxy concerning these notions. One should not be surprised to find there a sequence of arguments intended to show that true motion cannot be adequately defined as some distinguished form of motion relative to other bodies, but must be analyzed instead in terms of an absolutely immobile space, distinct from body, extending from infinity to infinity.

There are two parts to this paper. The first develops the reading of the scholium advocated here by examining the text. The second (to follow in the next issue of this journal) explores the Cartesian background, brings to bear antecedent manuscript materials, and considers how others, Newton's contemporaries included, have read and reacted to the scholium.

Difficulties with the Customary View

The usual reading of the scholium raises a number of awkward questions. To begin with, if the rotating bucket experiment and the example of the revolving globes are both supposed to argue that centrifugal effects in cases of circular motion are due to an absolute rotation, is not the detailed presentation of both a bit redundant? If the two are supposed to serve essentially the same end, why is the flow of the discussion from one to the other interrupted by the insertion of a paragraph addressed to unrelated issues of semantics and scriptural interpretation? No doubt, even great works may contain their share of infelicities, but we should not casually assign idiosyncrasies or deficiencies simply to suit our expectations about what they ought to say. What textual grounds are there for linking the bucket and the globes?

[2]See especially H. Stein, 'Newtonian Space-Time', in R. Palter (ed.), *1666: The Annus Mirabilis of Sir Isaac Newton* (Cambridge, Mass.: MIT Press, 1970), pp. 258–284. See also J. B. Barbour, *Absolute or Relative Motion*? (Cambridge: Cambridge University Press, 1989), which in fact faults Newton for being too concerned with Descartes.

[3]I. B. Cohen explores this theme in a survey of the various title pages of the different editions of the *Principia* in 'The *Principia*, the Newtonian Style, and the Newtonian Revolution in Science', in P. Theerman and A. F. Seeft (eds), *Action and Reaction* (Newark: University of Delaware Press, 1993), pp. 61–104.

Unlike the *Opticks*,[4] no English language version of the *Principia* appeared during Newton's lifetime. Two years after his death in 1727, Andrew Motte, about whom little is known, brought out an English translation, which served as the basis of the now widely used Cajori editions.[5] According to the Motte–Cajori translation, the final paragraph of the scholium, which presents the example of the globes, begins:

> It is indeed a matter of great difficulty to discover, and effectually to distinguish, the true motions of particular bodies from the apparent; because the parts of that immovable space, in which those motions are performed, do by no means come under the observation of our senses.[6]

There may appear to be a resonance between this and a passage roughly midway through the scholium which reads:

> But because the parts of space cannot be seen, or distinguished from one another by our senses, therefore in their stead we use sensible measures of them.... And so, instead of absolute places and motions, we use relative ones; and that without any inconvenience in common affairs; but in philosophical disquisitions, we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them.[7]

Newton might be read here as posing a question for the reader. If absolute places and motions cannot be directly perceived, what are the grounds in 'philosophical disquisitions' for positing them? The beginning of the next paragraph then seems to address this question.

> But we may distinguish rest and motion, absolute and relative, one from the other by their properties, causes, and effects.

So the answer appears to be that, though absolute motion is not directly observable, it can be indirectly detected in various ways, and thus shown to exist. Looking ahead to the discussion of the rotating bucket, we find in apparent confirmation:

> This ascent of the water shows its endeavor to recede from the axis of its motion; and the true and absolute circular motion of the water, which is here directly contrary to the relative, becomes known, and may be measured by this endeavors.[8]

And this seems to be the same point addressed by the globes.

> For instance, if two globes, kept at a given distance one from the other by means of a cord that connects them, were revolved about their common centre of gravity, we

[4]The *Opticks* was composed in English. After publication, the first edition was translated into Latin by Samuel Clarke.

[5]*Op. cit*, note 1.

[6]Motte–Cajori, p. 12. The revisions by Cajori in this and the next quotation involve only punctuation and capitalization.

[7]*Ibid*., p. 8.

[8]*Ibid*., p. 10. Motte's translation reads 'discovers itself' for 'makes known'.

> might, from the tension of the cord, discover the endeavor of the globes to recede from the axis of their motion, and from thence we might compute the quantity of their circular motions.[9]

As we shall see later, the received view of the scholium has been supported primarily by this cut and paste method.

The rotating bucket experiment addresses how the effects of absolute motion distinguish it from relative motion. What about its properties and causes? The Motte–Cajori translation has Newton advancing various conclusions about the possibility of determining absolute rest or motion, reinforcing the impression that he is addressing the question of how these can be *empirically* distinguished from relative rest and motion. But perplexingly, the conclusions drawn concerning properties are *negative*, as though Newton were pretending to undermine his own cause. According to the first argument from properties, "it follows that absolute rest cannot be determined from the position of bodies in our regions".[10] The second argument instructs us that "the true and absolute motion of a body cannot be determined by the translation of it from those which only seem to rest; for the external bodies ought not only to appear at rest, but to be really at rest". Unfortunately, the preceding argument has told us only how absolute rest *cannot* be determined. The next argument makes solution of the problem seem entirely out of reach. It draws the conclusion: "Wherefore entire and absolute motions can be no otherwise determined than by immovable places." Recall that only three paragraphs earlier, our attention was called to the fact that immovable places, i.e. the parts of absolute space, "cannot be seen or distinguished from one another by our senses."

It could be conjectured that Newton wants first to brush aside the properties of rest and motion as ineffectual, raising the suspense before getting on with a solution of the problem in terms of the rotating bucket and the revolving globes. But this renders rather disingenuous the assertion that we may distinguish absolute motion and rest from their relative counterparts by their properties, causes, and effects. Nor does it square at all with the conclusion just quoted, namely, that absolute motions can be *no otherwise* determined than by immovable places. Moreover, it becomes cryptic indeed why, immediately following this, Newton should proceed to pride himself: "and for that reason I did before refer those absolute motions to immovable places, but relative ones to movable places".

We become even more befuddled moving on to the next paragraph dealing with the causes of motion. Nothing is said explicitly about how absolute motion can or cannot be determined. The conclusion reads:

[9] *Ibid.*, p. 12.
[10] *Ibid.*, p. 9.

> And therefore any relative motion may be changed when the true motion remains unaltered, and the relative may be preserved when the true suffers some change. Thus, true motion by no means consists in such relations.[11]

Do the causes of motion permit us to distinguish empirically between absolute and relative motion, or not? Does Newton expect us to be able to construct our own answer to this, or has he changed the subject?

The answer is neither. The first three arguments do not advance conclusions about the empirical determinability of states of absolute motion or rest by means of their properties, but, like the argument from the causes of motion, address the issue of what in fact absolute rest and motion consist of. This is readily apparent from the Latin text. The conclusion of the first argument reads:

> ... quies vera ex horum [i.e., corporum in regionibus nostris] situ inter se *definiri* nequit.[12]

True rest cannot be *defined* from the positions of bodies in our regions relative to one another. The relevant passage from the second argument is:

> Et propterea motus verus & absolutus *definiri* nequit per translationem e vicinia corporum, qua tanquam quiescentia spectantur.[13]

And for this reason true and absolute motion cannot be *defined* in terms of translation from the neighborhood of bodies which are regarded as being at rest. Similarly, from the third argument we find:

> Unde motus integri & absoluti non nisi per loca immota *definiri* possunt.[14]

Whence, entire and absolute motions can be *defined* only in terms of motionless places. And for this reason, indeed, did Newton at the outset relate absolute motions to motionless places and relative motions to movable places!

The English verbs 'define' and 'determine' have enough overlap in meaning that in certain contexts they are interchangeable. Although this is not one of them given twentieth-century usage, there is evidence that in the seventeenth and eighteenth centuries the overlap was much broader, so that Motte's translation would count as permissible. (See the Appendix.) It is more difficult to say what might have steered his choice in the matter. For oddly enough, later on he translates the same Latin construction 'definiri nequit' as 'cannot be defined'. This occurs in the long paragraph addressed to the effects of motion and the rotating bucket. After presenting a detailed description of the experiment and emphasizing how the endeavor of the water to recede from the

[11] *Ibid.*, p. 10.

[12] See the critical edition of A. Koyré, I. B. Cohen and A. Whitman, vol. I (Cambridge, Mass.: Harvard University Press, 1972), p. 49. This is a facsimile reproduction of the third edition, with variant readings. I shall subsequently refer to this simply as *Principia*. Page numbers refer to the actual page numbers of that edition rather than those of the facsimile.

[13] *Ibid.*

[14] *Ibid.*, p. 50.

axis of rotation is in fact *anti*-correlated with its relative rotation with respect to the bucket, Newton writes:

> Quare conatus iste non pendet a translatione aquæ respectu corporum ambientium, & propterea motus circularis verus per tales translationes definiri nequit.[15]

> Whereby an endeavor of this sort does not depend on the translation of the water with respect to ambient bodies, and for this reason true circular motion cannot be defined in terms of such translations.

Now, if one thinks Newton had any sense at all for parallel construction, it is this that should be recognized as the obviously intended conclusion of the argument from the rotating bucket. Indeed, the arguments from the properties, causes, and effects of motion and rest have a remarkably tight parallel structure. Before examining this in detail, however, it will be worthwhile reviewing what Newton does in the scholium leading up to those arguments.

The Initial Parts of the Scholium

In discussing the scholium, it is convenient to fix a canonical apparatus for referring to its individual paragraphs. There are fifteen in all. Since Newton himself uses Roman numerals one through four to mark off the second to fifth paragraphs, it is best to enumerate the paragraphs by starting from zero, in order to avoid confusion. So, by paragraph zero, I mean the first paragraph; by paragraph three, the fourth, which is labeled by Newton with the Roman numeral three; and, by paragraph fourteen, the fifteenth and final paragraph.

There are no significant alterations in the text from the first edition to the third. The only difference of any potential note occurs in the opening paragraph. Newton begins by remarking that up to this point it has been advisable to explicate (*explicare*) lesser known terms in the sense in which they are to be taken in what follows. The first and second editions continue that, since *tempus*, *spatium*, *locus* and *motus* are very well known to all, he shall not define them. Only it should be noted that because certain prejudices arise from the fact that these are commonly conceived in no way other than by relation to perceptible things (*sensibilia*), it is appropriate (in order to remove these prejudices) to distinguish these into absolute and relative, true and apparent, and mathematical and common. The third edition drops the disclaimer that the terms will not be defined and instead simply says that they are very well known to everyone.

One may well wonder whether the next four paragraphs do not in fact present definitions of these terms. Paragraph one announces that absolute, true, and mathematical time, in itself and of its own nature without relation to anything external, passes uniformly, and by another name is called duration (*duratio*).

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

Relative, apparent, and common (*vulgare*) time is any perceptible and external measure of duration by means of motion (whether accurate or nonuniform) generally used in place of true time (e.g. the hour, the day, the month, the year). In a similar vein, paragraph two says that absolute space, of its own nature without relation to anything external, always remains similar and immovable. In contrast (a) relative space is any movable measure or dimension[16] (*dimensio*), which is defined (*definitur*) by our senses by its situation (*situs*) with respect to bodies and is commonly used in the place of immobile space. Examples are the measurement of (a) subterranean, aerial, or celestial space defined (*definita*) by its position (*situs*) with respect to the Earth. Absolute and relative spaces are the same in size and shape, but do not always remain numerically the same. There follows an illustration: if, for the sake of argument, we take the Earth to be moving, a space of our air, which relative and in respect to the Earth remains always the same, will at one time be one part of the absolute space through which the air passes, at another time another of its parts, and so always changes absolutely.

It might be said that Newton's strategy here, true to what he says in the first two editions, is to assume that the genera *tempus*, *spatium*, *locus* and *motus* are already understood and then to define in terms of them the absolute and relative species of each. However, in turning to *locus* and *motus* he does provide what, according to any reasonable standard, would qualify as definitions of the genera. In paragraph three, place is said to be the part of space which a body occupies, and is absolute or relative according to the space in question; in paragraph four, motion is in effect defined as change of place: absolute motion is transference from one absolute place to another, relative motion from one relative place to another. This strategy accords to an extent with Newton's manner of proceeding in an earlier manuscript bearing the incipit *De gravitatione et aequipondio fluidorum et solidorum*, dated by most Newton scholars to the late 1660s or early 1670s.[17] There, the section titled 'Definitiones' begins with the comment that the names of quantity, duration, and space are too well known for it to be possible to define them by means of other words. In the definitions that follow, we then find entries for *locus*, *quies* and *motus*. However, in a later manuscript,

[16]This is in the sense of the dimensions of a room.

[17]Following the custom of some, from here on I will refer to this manuscript as De Grav. A transcription and English translation appears in A. R. Hall and M. B. Hall (eds), *Unpublished Scientific Papers of Isaac Newton* (Cambridge: Cambridge University Press, 1962). A facsimile of the autograph with an accompanying German translation by G. Böhme has appeared with the title *Über die Gravitation...* (Frankfurt: Vittorio Klostermann, 1988). As I. B. Cohen points out (private communication), the title 'On Gravitation' may give a false impression as to the contents of the manuscript. It should be mentioned also that there is some controversy as to the dating of the manuscript. See B. J. T. Dobbs, 'Newton's Alchemy and His Theory of Matter', *Isis* **73** (1982), 511–528, as well as R. Palter, 'Saving the Text: Documents, Readers, and the Ways of the World', *Studies in History and Philosophy of Science* **18** (1987), 385–439.

drafted a few years before the *Principia*, definitions of absolute and relative time, space, and so on are explicitly set out as such.[18]

I will not conjecture on why in the first and second editions of the *Principia* Newton claims not to define time, space, place and motion, and then drops this disclaimer in the third. What is important is that he does give characterizations of the absolute and relative variants of these, and that in offering these characterizations he has two concerns. One is to make clear, by way of elaboration or illustration, the content of the distinctions introduced. This we have already seen in the cases of time and space. In paragraph four, following the characterization of absolute and relative motion, there is an extended illustration, in which the absolute motion of a sailor on board a ship is decomposed into the vector sum of the relative motions of the sailor with respect to the ship, the ship with respect to the Earth, and the Earth with respect to absolute space.

The other concern is to justify or defend the characterizations given. So, for example, immediately upon describing *locus* in paragraph three as the part of space occupied by a body, Newton remarks: "The part, I say, of space, not the position [*situs*] of the body, or the surrounding surface." He goes on to say why. The places of equal solids are always equal, but their surfaces are usually unequal on account of the dissimilitude of their figures (shapes); and in fact, positions, properly speaking, are not quantitative, nor are they places so much as properties of places. Although the reasoning here is not immediately obvious, Newton appears to assume, as a condition of adequacy for any definition of *locus*, the requirement that if two solids are of equal quantity, then their places must also be of equal quantity. Applying the appropriate measures—volumes for solids and areas for surfaces—the surrounding surface cannot be identified with the place of a body, since, quite obviously, equal volume does not entail equal surface area. What is said about position is then also fairly straightforward. In the same paragraph Newton proceeds to give a second rationalization for his characterization of place, invoking a principle fundamental to his approach to kinematics: the motion of the whole coincides with the sum of the motions of the parts. If, no matter how place is to be defined, motion is presumed to involve translation from place to place, this implies that the translation of the whole from its place is identical to the sum of the translations of the parts from their places. Consequently, the place of the whole is the same as the sum of the places of the parts, and, hence, is internal and in the entire body.

Paragraphs five to twelve are further concerned with matters of justification. It is quite clear that Newton sets his primary task to be that of providing

[18]This is *De Motu Corporum in medijs regulariter cedentibus*, transcribed and translated in J. Herivel, *The Background to Newton's Principia* (London: Oxford University Press, 1965). A facsimile of the autograph is included in D. T. Whiteside (ed.), *The Preliminary Manuscripts for Isaac Newton's 1687 Principia* (Cambridge: Cambridge University Press, 1989), pp. 28–33.

grounds for his contention that the absolute quantities are genuinely distinct from their relative counterparts. This is to say that, even if a relative quantity in fact happens to provide an accurate or faithful measure of the corresponding absolute quantity, it does not necessarily do so, and thus the absolute quantity is not the numerically same thing and is not definitionally reducible to any of its relative counterparts.

This is fairly evident in paragraph five, which returns to the topic of time, and addresses the grounds for maintaining that absolute time is not reducible to any of its perceptible measures. It starts with an appeal to scientific practice. In astronomy, absolute time is distinguished from relative time by the 'equation of common time'. The natural days, which people ordinarily take to be of equal length, are in fact unequal, and astronomers correct for this inequality in order to measure celestial motions by means of a truer time. By the 'natural day', Newton means the true solar day, which can vary as much as thirty minutes over the course of the year due to the combined effects of the variation in the Sun's angular velocity along the ecliptic and the inclination of the ecliptic to the celestial equator. The equation of time, extending back at least to Ptolemy, calculates the difference between the true solar day and the mean solar day (and thus corrects for the inequality of the former). Newton then introduces general grounds for maintaining the distinction. It is possible that there should be no uniform motions by which time may be measured accurately.[19] All motions can be speeded up and slowed down, but the passage of absolute time cannot be changed. Duration, or the preservation of the existence of things is the same, whether the motions are fast, slow, or null, and, hence, is justly (*merito*) distinguished from these latter by the astronomical equation. Newton concludes the paragraph by pointing to recent empirical considerations which show the necessity for this equation: the experiments with the pendulum clock and the eclipses of the moons of Jupiter.[20]

[19]The modality here is that of physical possibility, not epistemic uncertainty. Proposition 17 (Theorem 15) of Book III asserts that the diurnal rotations of the planets on their axes are in fact uniform.

[20]Part I of Huygens' *Horologium Oscillatorium* (1673) contains a 'Table of the Equalization of the Days', which is "established by assigning to each day what we have found is needed to make our clock agree with the sun or with a sundial". See Christiaan Huygens', *The Pendulum Clock or Geometrical Demonstrations Concerning the Motion of Pendulum as Applied to Clocks*, translated by R. J. Blackwell (Ames: The Iowa State University Press, 1986), p. 24. The pendulum clock is calibrated to assign a period of 23 hours 56 minutes 4 seconds for the passage of a fixed star from zenith to zenith. Once established, the Table of Equalization can also be used to calibrate a pendulum clock using a sundial or the sun itself. Newton received a copy of the treatise from Huygens himself in 1673. See the letter of Newton to Oldenburg of 23 June 1673 in H. W. Turnbull (ed.), *The Correspondence of Isaac Newton*, vol. I (Cambridge: Cambridge University Press, 1959), p. 29 ff.

Although the uniformity of the rotation of the celestial sphere (or equivalently of the Earth) had been assumed in the tradition from Ptolemy to Copernicus, both Tycho and Kepler, for reasons of lunar theory, introduced modifications of the equation of time which, in effect, amounted to a rejection of this assumption. Kepler proposed a dynamical explanation for a variable rate of the Earth's diurnal rotation in terms of an excitement of the Earth's 'vegetative soul' when closer to

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The justificatory goals of paragraphs six and seven are not as perspicuous, in part because comments concerning space, place, and motion are mingled together, and in part because it is not clear that the considerations adduced directly address the theme of distinguishing absolute from relative quantities. It is clear, however, that paragraph six seeks to provide support for the earlier contention that absolute space remains similar and immobile. Moreover, it is safe to surmise that Newton is concerned to deny here, not something as foresighted as the possibility that the metric structure of space changes with time, but rather the picture presented by Descartes' system of the world, according to which the parts of space reconfigure themselves over time. It is this he has in mind when he asserts that, just as the order of the parts of time is immutable, so is the order of the parts of space. The reason he gives is that were the latter to move from their places, they would move (as it were) from themselves. Newton fleshes out the argument, exploiting the analogy between the order of time and the order of space. Everything (*universa*) is located in time, as to order of succession, and in space, as to order of position (*situs*). This includes the parts of time and space as well, which consequently are their own places as well as places of everything else. That they are places is essential to them: and for what are fundamentally places to move is absurd (else they would have to be said to move from themselves). These are, therefore, absolute places, and (since motion is translation from place to place) only translations from these places are absolute motions.

It is not obvious what, if anything, paragraph seven is concerned to argue. It begins by pointing out that, because these parts of space cannot be seen, and

footnote 20 continued from previous page
the Sun. See J. L. E. Dreyer, *A History of Astronomy from Thales to Kepler*, 2nd edn (New York: Dover Publications, 1953), pp. 389, 404. Since the traditional dynamical grounds for assuming a uniform apparent rotation of the fixed stars were undermined with the 'destruction' of the celestial spheres towards the end of the sixteenth century, the door was left open to consider alternatives to the traditional equation of time, and a number of non-standard schemes appeared in the course of the seventeenth century. Flamsteed's *Diatribe*, appended to Jeremiah Horrox's *Opera Posthuma*, edited by John Wallis (London, 1673), defended the ancient practice, although Flamsteed assumed the uniformity of the Earth's diurnal rotation without direct empirical support. This he sought in earnest after his appointment as the first Royal Astronomer in 1675, installing at the newly built Greenwich Observatory a pair of Tompion pendulum clocks expressly for that purpose. By 1678, Flamsteed believed he had sufficiently established the result, although it appears he never published it. Newton may have been aware of these experiments either through his own conversations with Flamsteed or through intermediaries such as Hooke.

There was considerable seventeenth-century interest in accurate prediction of the eclipses of the satellites of Jupiter as a practical method for the determination of longitude, which is equivalent to the problem of the accurate determination of 'local time'. On 24 November 1679, Hooke wrote to Newton:

> I am informed likewise from Paris that they are there about another work vizt of setling ye Longitude & Latitude of the most considerable places: the former of these by the eclips of ye Satellites of Jupiter. Mr Picart & De la Hire travell & Monsieur Cassini & Romer observe at Paris.

See Turnbull (ed.), *op. cit.*, note 20, vol. II (1960), p. 298. Failure to take into account the equation of time (as well as the finite speed of light) can lead to an inaccuracy of as much as 15 minutes, and thus an error of over 200 miles.

distinguished from each other by our senses, we use perceptible measures instead. This provides occasion for Newton to rehearse the general procedure. We define a system of (relative) places from positions and distances to some given body, which we regard as immobile, and then we judge all motion in terms of these places, in that we imagine bodies to be transferred from them. He goes on to remark that the use of relative places and motions suffices for ordinary life, but in (natural) philosophy one has to abstract from perception. The final sentence explains why: it is possible for it to be the case that there would be no body truly at rest to which to refer places and motion. The line of reasoning, presumably, is that if there is no body truly at rest, then no system of relative places and relative motions defined in terms of such will accurately represent the true places and motions.

The Arguments from Properties and Causes

Paragraphs eight to twelve, however, explicitly argue that the properties, causes, and effects of motion establish that absolute rest and motion are genuinely distinct from relative rest and motion. After announcing this in so many words, paragraph eight takes up the case of rest. The property of rest invoked is that bodies which are truly at rest are also at rest with respect to one another. The argument is given in one long sentence:

> And therefore, since it is possible that some body in the region of the fixed stars, or even further away, is at absolute rest; yet it is not possible to know from the positions of bodies among one another in our regions, whether or not some of these maintain a given position with respect to that far distant body; true rest cannot be defined from the positions of these among themselves.

The upshot is this. Suppose you were to define absolute rest using a local criterion involving only relative position with respect to nearby bodies, e.g. that x rests absolutely just in case x is at rest with respect to the bodies which immediately surround it. Such a definition is inadequate since it does not entail that the above property of rest is always satisfied. For it does not exclude the possibility that some distant body α and some body β near to us both satisfy the local criterion (applied to each body's respective locale) and yet are in motion with respect to one another.

The next two paragraphs take up the properties of motion. Paragraph nine states that it is a property of motion that parts which maintain given positions with respect to totalities participate in the motion of those totalities. Newton cites in support of this that in (absolute) rotation all the parts endeavor to recede from the axis of motion, and in progressive motion the impetus (of the whole) arises from the conjunction of those of the individual parts. The gist of the argument is given rather quickly:

> Thus, a body, which is at rest with respect to those surrounding it, is in [absolute] motion if the surrounding bodies are in [absolute] motion. And for this reason true

> and absolute motion cannot be defined in terms of translation from the neighborhood of bodies, which are viewed as being at rest.

Newton elaborates. First is some clarification regarding the composition of motions.

> For the external bodies should not only be viewed as though they were at rest, but also to be truly at rest. In general, everything included, in addition to its translation from the vicinity of the surroundings, participates also in the true motion of the surroundings; and, if that translation is taken away, it is not truly at rest, but will only be viewed as though at rest.

The problem with the definition is that it fails to take into consideration the component of absolute motion a body shares with those surrounding it, unless the latter truly are at rest. The remainder of the elaboration speaks of how it is that a body together with the surrounding bodies fit the model of part and whole.

> For the surrounding bodies are to those contained as the external parts of the whole to the internal parts, or as the shell to the core. If the shell moves, then the core also moves as a part of the whole, unless it is translated from the vicinity of the shell.

The definition of motion criticized here is nearly verbatim that of Descartes and entails the sort of local criterion of absolute rest rejected in the first argument.

The next argument directly argues that absolute motion and rest require for their definition reference to motionless places. Newton invokes a property he says is related to the preceding, namely, that if a place moves, what is located there moves together with it. In particular, a body, which moves from a moving place, participates also in the motion of its place. Newton uses this to generate a regress, which, he believes, must eventually terminate in places which do not move.

> Therefore all motions, which take place from moving places, are only parts of entire and absolute motions, and every entire and absolute motion is composed from the motion of the body from its immediate place, and the motion of this place from its place, and so on; successively until one arrives at a motionless place, as in the example of the sailor mentioned above. Wherefore entire and absolute motions can be defined only in terms of motionless places: and for this reason I related them before to motionless places and relative motions to movable places.

Newton wraps up the paragraph by commenting on how such motionless places together make up absolute space.

> Motionless places, however, are none other than those which from infinity to infinity maintain given positions with respect to one another; and insofar as they remain always motionless, they constitute what I call immobile space.

Paragraph eleven turns to the causes which distinguish true and relative motion from one another. These are the forces impressed on bodies in the generation of motion. There are two prongs to the argument. The first begins by assuming that true motion is neither generated nor altered, except by the application of forces to the very body in motion. Newton then argues that, in contrast, its relative motion can be generated or altered without applying a force specifically to it. For it suffices to apply forces solely to the other bodies to which its relative motion has been referred, so that in their yielding to these forces the relations which are constitutive of the body's relative rest or motion are changed. The second prong begins with the premise that true motion is invariably altered by forces applied to the body in motion, and then goes on to explain why relative motion is not necessarily altered by such forces. For if the same (accelerative) forces are also applied to the other bodies to which it is related, so that the relative positions remain the same, the relations constitutive of the relative motion will remain the same. Newton then puts the two prongs together.

> Therefore, it is possible to change any relative motion while preserving the true, and to preserve the relative while altering the true; and for this reason true motion in no way consists in such relations.

So here is a general argument that absolute motion cannot be defined as some preferred mode of relative motion with respect to other bodies.

The Argument from Effects

This brings us to the argument from the famed rotating bucket experiment. Since Newton's presentation is somewhat longer and more elaborate than in the preceding arguments, it will do us well to pause and gather together what has been gleaned so far. The preceding four arguments share a number of features. First, in none of them is it argued that absolute motion exists. Instead, this is taken for granted. The properties and causes invoked are not adduced as empirical criteria in virtue of which absolute motion can be detected or established to exist. In each case, that absolute motion or rest indeed has the property or causes in question is not something the argument seeks to show, but serves instead as a premise. Nor is it assumed that absolute motion is, by definition, motion with respect to absolute space. Rather, the purpose is to justify this characterization of absolute motion, either by impugning the adequacy of alternative definitions, or, as in the case of the third argument, attempting to support it directly. It is in this sense that the properties or causes distinguish absolute rest and motion from their relative counterparts. Given these common features, it would be extraordinary if the argument from the effects of motion were to break with the pattern. As it happens, if it is read without the expectation of finding an argument for the conclusion that centrifugal effects must be due to an absolute rotation and thus that absolute motion exists, then a structure parallel to the preceding four arguments becomes apparent.

Newton begins by announcing that the effects which distinguish absolute from relative motion are the forces of receding from the axis of circular motion.

> Effectus, quibus motus absolute & relativi distinguuntur ab invicem, sunt vires recedendi ab axe motus cirularis.

This echoes, *mutatis mutandis*, the first sentence of the preceding paragraph eleven.

> Causæ, quibus motus veri & relativi distinguuntur ab invicem, sunt vires in corpora impressæ ad motum generandum.

Newton continues,

> For in purely relative circular motion these forces are null, but in true and absolute motion are greater or less according to the quantity of motion.

Now, you will recall that each prong of the argument from the causes of motion began with a parallel claim about the behavior of absolute and relative motion in connection with the application of forces. In the first prong it is a premise that true motion in a body is neither generated nor altered except by the impression of forces on that body, and it is subsequently argued that its relative motion can be generated or altered without impressing a force on it. Similarly, in the second prong, it is a premise that true motion in a body is always changed by the application of a force to the body, and it is then argued that its relative motion is not necessarily altered by the application of such forces. Pursuing the parallel, we should expect that what Newton says about forces of recession and absolute rotation—that they are an effect of absolute circular motion in proportion to the quantity of the motion—plays the role of a premise in the argument to be developed; and we should expect that what he says about relative motion—that when it is merely relative these forces are entirely absent—is something to be demonstrated in what follows. Newton describes the experimental setup in one very long sentence:

> If a vessel is hung by a very long cord, and turned round and round, until the cord becomes quite stiff from being twisted, then is filled with water, and kept stationary together with the water; and afterward by some force is suddenly set turning in the opposite direction, and with the cord unwinding itself, is kept in this motion for a rather long time; the surface of the water at first will be flat, in the same way as before the vessel was set in motion: But after this, the vessel, by gradually impressing a force on the water, causes it, too, to begin to perceptibly rotate; little by little it recedes from the center, and ascends the sides of the vessel, taking on a concave shape, (as I have found from experience) and always the more rapid the motion the higher and higher it ascends, until it undergoes revolutions in equal time with the vessel, and is at rest relative to it.

He then begins to analyze the results.

> This ascent reveals an endeavor to recede from the axis of motion, and by such an endeavor the true circular motion of the water is discerned and measured, and these [are] entirely contrary to the relative motion.

Now, it is crucial to distinguish here between interpretive assumptions Newton brings to bear on the experiment and what in consequence he takes the experiment to establish. Quite obviously, that the ascent of the water up the sides of the vessels is due to an endeavor to recede from the axis is not offered as something we learn from the experiment. Rather, this ascent is assumed to be an indicator of the endeavor to recede. Moreover, as the preceding four arguments have led us to expect, it is a premise that the magnitude of the recessional endeavor is positively correlated with the quantity of true circular motion (and thus the ascent of the water is also an indicator of its absolute motion). The experimental result is given by the final conjunct of the above quoted sentence: the relative motion of the water is in fact *anti*-correlated with all of these. This is what Newton draws attention to as he reviews the various stages of the experiment.

> Initially, when the motion of the water relative to the vessel was the greatest, that motion caused no endeavor to recede from the axis: the water did not seek the circumference by ascending the sides of the vessel, but remained flat, and for this reason its true circular motion had not yet begun. But after this, when the relative motion of the water had decreased, its ascent up the sides of the vessel revealed an endeavor to recede from the axis; and this endeavor showed its true circular motion continually increasing, and at last made greatest when the water was at rest relative to the vessel.

At this point, Newton is satisfied that he has shown what he set out to demonstrate, namely that centrifugal endeavor is not an effect of purely relative rotation, and proceeds to draw his conclusion for what this shows about how absolute rotation can be defined.

> Consequently this endeavor does not depend on the translation of the water with respect to ambient bodies, and for this reason true circular motion cannot be defined in terms of such translations.

Having shown how the effects of motion show that absolute motion cannot be reduced in this instance of relative motion, Newton, as in a number of the preceding arguments, proceeds to elaborate, explaining why we should not be surprised that purely relative rotation produces no centrifugal effects.

> There is only one true circular motion of each revolving body, corresponding to a single endeavor as its characteristic and matching effect: but the relative motions [in each body] are innumerable according to the multiplicity of the relations [it bears] to external things; and, having the character of relations, they are utterly devoid of true effects, except insofar as they participate in that true and unique motion.

Without mentioning him by name, Newton concludes the paragraph by castigating Descartes for holding that the planets and individual parts of the heavens are, properly speaking, at rest:

> And so in the system of those, who deem our heavens below the heavens of the fixed stars to revolve in circles, and to carry the planets with them; the individual parts of the heavens, and the planets which are at rest relative to those heavens in their [immediate] proximity, move truly. For they change their positions with respect to one another (contrary to what would happen if they were truly at rest) and in being carried along with the heavens participate in their motion, and as parts of revolving wholes, endeavor to recede from the axes [of rotation of the wholes].

Note that in this criticism, Newton appeals, by way of summary, to properties of rest and motion, as well as the effects of motion.

The Globes

The next paragraph clearly signals the end of the line of inquiry so far. It begins by reiterating the general conclusion for which Newton has argued:

> Therefore the relative quantities are not those quantities themselves, whose names they share, but are those perceptible measures of them (accurate or inaccurate) which are commonly used in place of the quantities measured.

Having finished the task, he turns to a point of semantics. If the primary signification of words is determined by their use, then the names of time, space, place and motion should be understood to denote the relative quantities, unless contra-indicated by the context, in which case "the discourse will be contrary to custom and plainly mathematical". For this reason, those who interpret the scriptures to speak of the absolute quantities, do an injustice to them. Nor less do those who confuse the true quantities with their relational and commonplace measures corrupt mathematics and philosophy. As others have pointed out, this is again a gibe at Descartes.[21] But more on this below.

The paragraph that follows, the final paragraph fourteen, in no way indicates that Newton wishes to reopen the line of inquiry from the properties, causes, and effects of rest and motion. Rather he begins by raising an epistemological issue perhaps hinted at earlier in paragraph seven, but which he has not yet explicitly addressed:

> Admittedly, it is very difficult to know the true motions of individual bodies and in practice to differentiate these from the apparent; for the reason that the parts of that immobile space, in which bodies truly move, do not impinge on the senses.

Having already presented his case that true motion is distinct from apparent motion, the term *motus oerus* can now be understood to refer specifically to motion with respect to absolute space. He continues:

[21] See, for example, Stein, *op. cit.*, note 2.

Nevertheless the situation is not entirely hopeless. For we can select evidence,[22] partly from the apparent motions which are the differences of the true motions, partly from the forces which are the causes and effects of motion.[23]

To illustrate, Newton introduces the case of the revolving globes:

For example, if two globes, at a given distance from one another connected by a cord running in between, rotate about their common center of gravity; the endeavor of the globes to recede from the axis of motion may become known from the tension of the cord, and hence the quantity of circular motion may be calculated.

This displays the utility of those forces which are the effects of true motion. Newton next illustrates how applied forces can be used to learn furthermore whether the rotation is in the clockwise or counterclockwise direction. By applying equal forces on the opposite faces of the respective globes, the tension in the cord will thereby be either increased or diminished, thus revealing the direction of rotation:

In this way it may be possible to discover both the quantity and the direction of this circular motion in a vacuum, however immense, where there may exist nothing external and perceptible with which the globes can be compared.

However, if there are other bodies with which to compare them, such as the fixed stars, then, even though one could not infer the quantity of true circular motion from the relative rotation with respect to these, nonetheless, if it has already been established by centrifugal forces that the globes are in a state of circular motion, the direction of this motion can be inferred alternatively by means of the apparent motion against the background of the fixed stars. Newton sums up and concludes the scholium:

But how to infer the true motions from their causes, effects, and apparent differences, and conversely, either the true or apparent from their causes and effects, will be taught at further length in what follows. For this is the end to which I composed the following treatise.

Summary

As I have read the scholium, it divides into three main parts, not including the introductory paragraph. The first consists of paragraphs one to four in

[22]In the third edition, this reads "Nam argumenta desumi possunt", whereas the first two editions have instead "Nam suppetunt argumenta", i.e. evidence is available.

[23]It is interesting that in the manuscript 'De Motu Corporis Liber Primus' which is essentially a preliminary draft of Books I and II of the *Principia* and which was deposited by Newton as his 'Lucasian Lectures' for the years beginning October 1684 and 1685, this sentence replaces one whose initial portion is no longer legible, but finishes "...and this partly from the forces which are the causes and effects of true motion, and partly from the apparent motions which are the differences of the true motions, we can sometimes infer something [...idque partim ex viribus quae sunt motuum verorum causae et effectus, partim ex motibus apparentibus qui sunt motuum verorum differentia, possumus aliquid nonnunquam colligere]". A facsimile of the manuscript appears in D.T. Whiteside (ed.), *op. cit.*, note 18, pp. 36–215; see, in particular, p. 46. Apart from minor stylistic changes, the scholium as it appears in this manuscript reads the same as in the first edition.

which Newton sets out his characterizations of absolute and relative time, space, place, and motion. Although some justificatory material is included here, notably in paragraph three, the second part is reserved for the business of justifying the characterizations he has presented. The main object is to adduce grounds for believing that the absolute quantities are indeed distinct from their relative measures and are not reducible to them. Paragraph five takes this up for the case of time. Paragraphs eight to twelve endeavor to do this for rest and motion by appealing to their properties, causes and effects. In arguing that absolute motion (or rest) is not reducible to any particular form of the relative motion (or rest) of bodies with respect to one another, and thus, as is directly argued in the third argument, must be understood in terms of motionless places, Newton thereby constructs an indirect case that absolute space is indeed something distinct from any relative space. Paragraph thirteen functions as conclusion to this line of inquiry and comments on how, in the light of this, the names of these quantities are to be interpreted in the scriptures. The third and final part consists of paragraph fourteen alone, and addresses the question: given that true motion is motion with respect to absolute space, but the parts of the latter are not perceivable, is it possible for us to know the true motions of individual bodies? Newton illustrates how this may be done from the evidence provided by their apparent motions and the forces which are the causes and effects of true motion. This forms a bridge to the body of the work insofar as the purpose of the *Principia*, according to Newton, is to show how this, and the converse problem, of inferring true and apparent motions from the forces, can be dealt with.

Part II of this paper will appear in the next issue of *Studies in History and Philosophy of Science*.

APPENDIX: MATTERS OF TRANSLATION

I. B. Cohen has unearthed a number of mysteries surrounding the origins of Motte's translation.[24] The issue of the *Journal des Sçavans* for June 1727 (three months after Newton's death) contains an announcement of Motte's intention to publish an English translation of the *Principia* including the remark: "Cette traduction aura l'advantage d'avoir été faite sous les yeux suivant les avis de M. Newton." The published edition, however, contains no mention of either collaboration or approval on Newton's part, although, as Cohen points out, the title page and dedication seek to establish some connection, however tenuous, with the Royal Society. Officially, the translation is of the third edition, but in many places, the scholium in particular, the second edition has been used. Suspiciously missing from Motte's translation of the Preface of the third edition

[24]See Cohen, *op. cit.*, note 1, as well as his introduction to the 1963 reproduction of the first printing of the Motte translation.

is the credit to Henry Pemberton for preparing the edition and Newton's praise for him as a man most skilled in these matters. As it turns out, Pemberton, who had become a confidant of Newton, had announced in March of 1727 plans to bring out an English translation of the *Principia*. In the preface of his *A View of Sir Isaac Newton's Philosophy* (London: S. Palmer, 1728), he refers to the translation as one "which I have had for some time". Motte was very likely aware of the threat of what would appear to be an authoritative translation and beat Pemberton to the punch. It may be that if Motte had ever had Newton's approval, the support was subsequently withdrawn.

This is not to imply that Motte's rendition of *definire* as 'to determine' in the passages quoted is a mistranslation, given English usage of the period (although I do think the translation in general is not as faithful as it might have been). The modern reader will be amused by such archaisms as the 'congress' rather than the 'collision' of bodies. As mentioned previously, the English words 'define' and 'determine' still have considerable overlap in meaning, depending on context. For example, Newton's characterization of relative space in paragraph two reads:

> Relativum est spatii hujus mensura seu dimensio quælibet mobilis, quæ a sensibus nostris per situm suum ad corpora *definitur*,...

Yet it is perfectly reasonable to render the relative clause as "which our senses determine by its position to bodies" (as did Motte). Another example occurs in paragraph seven:

> Ex positionibus enim & distantiis rerum a corpore aliquo, quod spectamus ut immobile, *definimus* loca universa.

Surely it is natural to say in this regard 'we *determine* all places'. Finally, it might be noted that in my running free translation of paragraph thirteen I rendered "At si ex usu *definiendæ* sunt verborum significationes" as "if the significations of words are to be *determined* from usage".

A quick survey suggests an even greater overlap in usage in the seventeenth and eighteenth centuries for both the English and Latin variants of these terms. There are three other known translations or paraphrases into English, from the eighteenth century, of the scholium. One of these is a translation of Book I of the *Principia* by the Rev. John Thorpe, published in 1777, which is clearly based on Motte.[25] The other two, however, are independent. The first is in William Whiston's *Sir Isaac Newton's Mathematick Philosophy More Easily Demonstrated*, which begins by rearranging and essentially translating the material found in the definitions and the scholium from the first edition.[26] The other

[25](London: W. Strahan and T. Cadell, 1777), reprinted with an introduction by I. B. Cohen (London: Dawsons of Pall Mall, 1969).

[26](London: J. Senex and W. Taylor, 1716), reprinted with an introduction by I. B. Cohen (New York: Johnson Reprint Corporation, 1972). The text is Whiston's translation of his lectures given in Latin from 1704 to 1708 as Newton's successor as Lucasian Professor at Cambridge.

source is an introduction for the non-mathematical reader to Newton's philosophy by John Clarke, brother of Samuel, bearing the title *A Demonstration of Some of the Principle Sections of Sir Isaac Newton's Principles of Natural Philosophy*.[27] The opening gives a free translation of the scholium from the third edition. The following Table shows how each of these sources has translated *definire* and its derivatives throughout the scholium. (The verb *determinare* is not used by Newton in the scholium.) I have included not only Motte, but for those also interested in the sources available to Mach, the German translation by J. Wolfers bearing the title *Sir Isaac Newton's mathematische Principien der Naturlehre* (Berlin: Robert Oppenheim, 1872).

	¶2a	¶2b	¶7	¶8	¶9	¶10	¶12	¶13
Motte	determine	determined	define	determine	determine	defined	define	determined
Thorpe	define	determine	define	determine	determine	defined	define	determined
Clarke	define	determine	define	determine	determine	determine	determine	define
Whiston	define or determine	defined	define	define	define	define	define	define
Wolfers	bezeichnet	bestimmt	erklären	abgeleitet werden	ableiten	erklärt	erklärt	definirt

There remains the possibility that Newton's own usage would have been systematic. However, there are reasons to doubt this. In Book I of the *Principia*, Propositions 36 and 37 use *determinare* and *definire* to the same end, namely, that of determining the solution to a geometrical problem.[28] As for Newton's English usage, it should be noted that there are examples in the *Opticks* where he uses 'define' in cases where we would find 'determine' more natural. For example, Proposition 3, Problem 1 of Book I, Part 2 (second edition) states: "To *define* the refrangibility of the several sorts of homogeneal light answering to the several colours." And later on in the description of Experiment 7 that follows, we find: "And by the like limits above-mentioned were the refractions of the rays belonging to the rest of the colours *defined*...." The wider overlap in usage of these terms in the seventeenth and eighteenth centuries, however, does not excuse the preservation of 'determine' for 'define' in the Motte–Cajori translation where inappropriate according to modern usage. Just as the 'congress' of bodies was replaced with the 'collision' of bodies, so this archaism too should have been replaced.

[27](London: James and John Knapton, 1730), reprinted with an introduction by I. B. Cohen (New York: Johnson Reprint Corporation, 1972).

[28]Interestingly enough, Motte translates these as 'determine' and 'define', respectively.