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The Controversy on the Conceptual Foundation of Space-Time Geometry

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According to historical commentators such as Newton and Einstein, bodily behaviors are *causally* explained by the geometrical structure of space-time whose existence analogous to that of material substance. This essay challenges this conventional wisdom of interpreting space-time geometry within both Newtonian and Einsteinian physics. By tracing recent historical studies on the interpretation of space-time geometry, I defends that space-time structure is a by-product of a more fundamental fact, the laws of motion. From this perspective, I will argue that the causal properties of space-time cannot provide an adequate account of the theory-change from Newtoninan to Einsteinian physics.

key words: Space-Time Geometry, Substantivalism, Curved Space-Time, The Theory-Change from Newtonian Physics to Einsteinian Physics

1. Introduction

The theory-change from Newtonian to Einsteinian physics is viewed by philosophers of science, historians and even physicists as an eloquent example of *scientific revolution*. According to the physicist Max Born, it signifies the 'Einsteinian revolution,' (Born 1965, 2) while the philosopher Karl Popper is of the view that Einstein 'revolutionised physics.' (Withrow 1967, 25) Thomas Kuhn, on his part, holds in his *Structure of Scientific Revolutions*, that the theory-change from Newtonian to Einsteinian physics provides a strong case for the occurrence of a revolution with obvious 'paradigm changes.' (Kuhn 1962):

> One [set of scientists] is embedded in a flat, the other in a curved, matrix of space. Practicing in different worlds, the two groups of

> scientists see different things when they look from the same point in the same direction. (Kuhn 1962, 150)

Misner, Thorne, and Wheeler (1973, 5) famously summarize this revolutionary feature of Einstein's space-time theory as "space acts on matter, telling it how to move. In turn, matter reacts back on space, telling how to curve." Within Einstein's general theory of relativity, the gravitational interaction emerges from space-time of which geometry satisfies the laws of non-Euclidean geometry. In contrast, its predecessor, the Newtonian theory of gravitation, adopts the gravitational interaction (i.e., the gravitational field) posited independently from rigid space-time whose geometry satisfies the law of Euclidean geometry:

> The EEP [Einstein' s Equivalence Principle] arises from the idea that gravity is universal; it affects all particles (and indeed all forms of energy—momentum) in the same way. *This feature of universality led Einstein to propose that what we experience as gravity is a manifestation of the curvature of spacetime.* The idea is simply that something so universal as gravitation could be most easily described as a fundamental feature of the background on which matter fields propagate, as opposed to as a conventional force. (Carroll 2003, 151, my italics)

This seems to suggest that Einstein's space-time theory can be viewed as revolutionary in terms of different understanding of the relationships between the gravitational field and space-time geometry (i.e., between matter and space-time).

Einstein himself, however, seldom employed the word 'revolution' to characterize the special and the general theories of relativity. (Cohen 1985) In fact, he warned that the word 'revolution' mischaracterizes the way that his two theories were developed. Their development is viewed rather as one that "slowly leads to a deeper conception of the laws of nature," as the result of "the best brains of successive generations." (Klein 1975, 113) So, it seems that Einstein considered the theory-change as an evolutionary one.

This essay critically examines this Einstein's intuition - that the development of his two theories of relativity is not in fact revolutionary - in criticizing his own evolutionary interpretation of the causal role of space-time from the historical and conceptual perspectives. In this course, we will challenge a conventional wisdom that interprets the relationships between Newtonian and Einsteinian physics through the ontological status of space-time emphasizing its causal structure.

In order to reassess Einstein's evolutionary claims by means of the ontological status of space-time, we will consider the controversy over the ontological foundation of space-time geometry. The ontological foundation of space-time geometry has been debated as a part of the "substance-relation controversy." The dispute is basically over the nature of space-time. *Substantivalism,* which is the established wisdom in interpreting both Newtonian and Einsteinian space-time, is the view that space-time has an existence analogous to that of material substance. In contrast, *relationism* denies that space-time has an independent existence, and instead maintains that space-time is simply a set of relations between material bodies or physical events.

> The absolute—relational contrast represents a debate about the ontological status of space—time structure: whether theories ostensibly about space—time structure are merely theories about the spatio—temporal relations between physical objects, or whether they describe independently existing entities - space, time, or space—time - in which physical objects are located. (Friedman 1989, 62)

The nature of the theory-change from Newtonian to Einsteinian physics has accordingly been discussed within this context. Substantivalism concerning both Newtonian and Einsteinian space-times entails that we can capture the continuity between them by means of the mode of existence of space-time as substance, which causes a given body to follow its trajectories according to laws of motion:

> [T]he metric field $g_{\mu\nu}$ of General Relativity is properly viewed as the modern representer of substantival spacetime. … It determines the spacelike-timelike distinction, determines the affine connection or inertial structure of spacetime (i.e. defines which motions are accelerated and which are not), and determines distances between points along all paths connecting them. In all these ways, the metric is perfectly analogous to Newton' s absolute space and time. (Hoefer

1998, 459)

On the contrary, the relationist interpretation of curved space-time in the general theory argues for the occurrence of an essential change of the mode of existence of space-time as compared to its predecessor theory. While space-time and matter in Newtonian mechanics and special relativity have independent existence, they do not have independent existence in the interpretation of space-time in general relativity, which "describes the world as a set of interacting fields including $g_{\mu\nu}$." (Rovelli 2001, 107)

There are two different ways for substantivalists in order to attempt to underpin an evolutionary account of the theory-change from Newtonian to Einsteinian physics. Firstly, space-time as the substantival entity "ether" might be alleged to provide the evolutionary element. (Einstein 1922) Secondly, the metric field $\boldsymbol{g}$ of the general theory might be alleged to be the successor of Newtonian space-time. (Hoefer 1996, 1998) By tracing recent historical studies on the interpretation of space-time geometry, this essay will argue that the first alternative is an interpretation that has no physical foundation; while although the second one supports an evolutionary view, it does so only when the metric field $\boldsymbol{g}$ is viewed from the perspective of what space-time does (i.e., the codification of the behaviours of a body), rather than what space-time is (i.e., its mode of existence). Accordingly, it will be argued that these ontological interpretations concerning the mode of space-time fail to deliver adequate accounts of the theory-change from Newtonian to Einsteinian physics.

2. Space-time Substantivalism and Newton-Einstein Theory Shift

Although Einstein considered the ether as superfluous within the special theory, the existence of the ether became an issue when he attempted to capture the physical interpretation of the metric field $\boldsymbol{g}$. (Einstein 1922) In this context, the development of the concept of space-time is related to the mode of existence of the alleged substantial entity "ether":

According to [the general theory] the metrical qualities of the continuum of space-time differ in the environment of different points of space-time, and are partly conditioned by the matter existing outside of the territory under consideration. This space-time variability of the reciprocal relations of the standards of space and time, or, perhaps, the recognition of the fact that “empty space” in its physical relation is neither homogeneous nor isotropic, compelling us to describe its state by ten functions (the gravitational potentials $g_{\mu\nu}$), has, I think, finally disposed of the view that space-time is physically empty. But therewith the conception of the ether has again acquired an intelligible content, although this content differs widely from that of the ether of the mechanical undulatory theory of light … (Einstein 1922, 18)

Lorentz’s ether theory assumes an ether pervading space, through which electrically charged particles move. The physical interactions between the ether and matter are governed by Lorentz’s theory of electrons; the electrically charged particles generate excited states of the ether, corresponding to the electromagnetic fields. In comparison with mechanical theories that are interested in the mechanical properties of the ether, Lorentz’s theory is based on the electromagnetic worldview, and all mechanical properties of the ether except its immobility are eliminated. Yet the electromagnetic ether can be interpreted as a substantival entity due to its interaction with matter.

Given that the ether is transparent to uncharged matter and is not influenced by the existence of matter, Lorentz’s contemporaries identified the ether with empty space. In a similar spirit, Einstein stressed the roles of the ether in the development of relativity in “Ether and the Theory of Relativity.” Here the evolution of both theories of relativity is described as the modification of the physical properties of the ether, which Einstein identified with the properties of space-time. First of all, Einstein viewed the ether as possessing the physical properties of Newton’s absolute space. Accordingly, “Newton might no less well have called his absolute space ‘Ether.’” (Einstein 1922, 17) Einstein indeed continued to discuss the development of the theories of relativity from the perspective of the change of the properties of the ether:

[T]he special theory of relativity does not compel us to deny ether. We may assume the existence of an ether; only we must give up

> ascribing a definite state of motion to it, … the ether of the general theory of relativity is a medium which is itself devoid of all mechanical and kinematical qualities, but helps to determine mechanical (and electromagnetic) events. … the ether of the general theory of relativity is the outcome of the Lorentzian ether, through relativ[iz]ation. (ibid., 18−20)

The special theory of relativity is considered as removing "the last mechanical characteristic" of Lorentzian ether, "the ether velocity," without denying the existence of the ether itself. Given that in the general theory of relativity, Einstein attempted to relativitize all kinematical concepts, it seems, then, that the gradual modification of the concept of the substantival ether provides an evolutionary account of this theory-change.

Given that Lorentzian ether is identified with space-time, it is necessary to clarify in what sense the two entities are identified. In the history of the development of mechanics, two different properties of the ether have been identified with properties of absolute space. First, Lorentzean ether has been identified with absolute space since these entities have the property of absolute rest. According to Lorentz, absolute rest implies that the order of parts of the ether is unchanged with respect to its other parts:

> If for brevity' s sake I say that the Aether is at rest, it is thereby meant only that one part of this medium is not displaced with respect to another and that all observable motions of the heavenly bodies are relative motions with respect to the Aether. (Lorentz 1895, 4, quoted from Rynasiewicz 1996)

The concept of absolute rest of the ether does not mean complete rest, which is vulnerable to the argument of infinite regress. As Rynasiewicz points out, "to speak of the absolute rest or motion of X would be to speak of X's motion with respect to a tertium quid Y, and so on." (Rynasiewicz 1996, 289) In fact, this property is what Newton in De Gravitatione attributed to space. According to Newton, the order of the parts of space, which does not change, characterizes absolute space:

> It is only through their reciprocal order and position that the parts of … space are understood to be the very ones that they truly are; and they do not have any other principle of individuation beside this order and position, which consequently cannot be altered. (Hall and Hall 1962, 103, trans. by Torretti)

This property of the ether, that of being at absolute rest, can be considered as providing a privileged frame of reference, with respect to which the spatial distance between two events can be determined.

The second property that allegedly allows the ether to be identified with absolute space is as follows: absolute space can be identified with the ether because of its causal property of generating inertial structure. In other words, absolute space is a causally efficient entity - it causes material bodies to follow their trajectories in accordance with the laws of inertia and acceleration. From their reading of Einstein's works, Brown (2005) and Rynasiewicz (1996) claim that what Einstein had in mind when he claimed the identity of absolute space with the ether was the causal sense of absoluteness, rather than the existence of the privileged frame.

> The inertia-producing property of this ether [absolute space], in accordance with classical mechanics, is precisely not to be influenced, either by the configuration of matter, or by anything else. For this reason, one may call it 'absolute.' That something real has to be conceived as the cause for the preference of an inertial system over a non-inertial system is a fact that physicists have only come to understand in recent years. (Einstein 1924, Saunders and Brown eds. 1991, 15-16)

The causal property of the ether was characterized by Einstein as being causally absolute, i.e. as "having a physical effect, but not itself influenced by physical conditions." (Einstein 1921) And casual absoluteness is one of the elements that made Einstein modify the concept of space-time. For, "it is contrary to the mode of thinking in science to conceive a thing (the space-time continuum) … which acts itself, but which cannot be acted upon." (ibid., 55-6)

Also, following the special theory of relativity, the ether was absolute,

> because its influence on inertia and light propagation was thought to be independent of physical influences of any kind. … The ether of the general theory of relativity … differs from that of classical mechanics or the special theory of relativity respectively, in so far as it is not 'absolute,' but is determined in its locally variable properties by ponderable matter. (Einstein 1924, Saunders and Brown eds. 1991, 17-8)

It can be argued, then, that these causal properties of this inertia-producing entity illuminate "the gradual modifications of our idea of space resulting from the influence of the relativistic view point." (Einstein 1961, 161) This aspect seems to capture at least one important continuity in the theory-change from Newtonian to Einsteinian physics:

> The general theory of relativity formed the last step in the development of the program of the field-theory … Space and time were thereby divested not of their reality but of their causal absoluteness - i.e., affecting but not affected - which Newton had been compelled to ascribe to them in order to formulate the laws then known … [Thus] the elements of Newtonian theory passed over into the general theory of relativity. (idid., 254)

To the extent that the concept of ether experiences a modification of its central causal property in order to satisfy the action-reaction principle in the general theory, we can see the evolutionary development in the theory-change.

The above account of the conceptual development can also be further clarified from the viewpoint of the modern geometric formulation of space-time. Given that what was at issue concerning the physical properties of the ether is "the cause for the preference of an inertial system over a non-inertial system", what Einstein referred to as the ether in classical dynamics was not the entire absolute space. Rather it is inertial structure within absolute space. In the modern geometric formulation of space-time theories, inertial structures are implemented by geometric entities, i.e., the four-dimensional affine connection in Newtonian space-time, and the connection and the conformal structure in Minkowskian space-time. The connections determine the inertial trajectories of particles, and the conformal structure determines the propagation of light. So, it seems that the ether is viewed as substantial space, because both geometric entities can be seen as "inertia-producing entities."

Furthermore, the above causal account of space-time seems to reflect well the evolution of the general theory of relativity. The space-time metric field g, which is interpreted as the ether, determines the connection. A non-singular metric g uniquely determines the (torsion free) connection, through the condition of metric compatibility, which requires that the parallel transport of a vector should preserve its length. In other words, with the metric compatibility condition, along with the assumption of vanishing torsion, the metric field g completely determines the inertial structure in the general theory. Accordingly, given that the inertial structure is determined by the metric field, which in turn is determined by material processes, it seems that the ether can be identified as substantial space-time, which realizes the action-reaction principle:

> I admit that the general theory of relativity is closer to the ether hypothesis than the special theory. This new theory, however, would not violate the principle of relativity, because the state of this $g_{\mu\nu}$ = ether would not be that of a rigid body in an independent state of motion, but every state of motion would be a function of position, determined through the material processes. (Einstein 1922, quoted from Rynasiewicz 1996, 295)

3. A Critique against Space-time Substantivalism

A problem with Einstein's evolutionary view is that the causal element of space-time does not provide any physical foundation for the laws of motion. Despite the prevailing belief among the physics community of the time, the history of science seems to attest that the ether has not yet provided any physical mechanism whatsoever, which explicates the law of inertia. (Sklar 1972 and Hoefer 1998) Although it was widely believed that inertia could be explained by acceleration with respect to the ether, this turns out to be a merely "wishful thinking." (Sklar 1972, 289) Instead, the explanation of laws of motion is related to the kinematical properties of Newtonian space-time.

> How does the introduction of absolute space provide Newton with the wherewithal to explain the dynamical effects? Since the parts of absolute space endure through time, they provide a reference frame by which distance relations can be defined not only between bodies at a time but also between bodies at different times. … [But] Newton's ability to account for inertial effects does not immediately depend on the postulation of space as a substance. Substantival absolute space serves only as a means of extending the domain of the distance relation to include pairs of nonsimultaneous events. (Maudlin 1993, 186-7)

In a similar vein, Brown claims that regarding absolute space as a substance is by no means essential in comprehending the workings of Newtonian physics:

> For Newton, the existence of absolute space and time has to do with providing a structure, necessarily distinct from ponderable bodies and their relations, with respect to which it is possible systemically to define the basic kinematical properties of the motion of such bodies. For Newton, space and time are not substances in the sense that they can act, but are real things nonetheless. (Brown 2005, 142)

Along the same lines, DiSalle offers an argument that substantivalism fails to capture the way space-time explains the laws of motion. The confusion underlying substantivalism, according to DiSalle, stems from the view that space-time is a substantial entity that causes a body to move in accordance with the laws of motion. He provides an analogy between space-time and Euclidean geometries to illustrate this point:

> To claim that space is Euclidean only means that measurements agree with the Euclidean metric; Euclidean geometry, if true, can't causally explain those measurements, because it only expresses the constraints to which those measurements will conform. (DiSalle 1995, 324)

And:

> Because the physical foundations of spatial geometry have been relatively clear, only a confused person would ask whether Euclidean geometry is really the cause of differences in length; that the differences can be measured, and that the measured results agree with the Euclidean metric, is all that anyone ever meant by the claim that space is Euclidean. … [I]t is equally confused to ask whether spacetime is the cause of the distinctions between states of motion that its theory entails. (DiSalle 1992, 187)

In the case of Euclidean geometry, its geometric structure by no means causally explains its “laws” such as the Pythagorean theorem. Instead, the axioms of Euclidean geometry encode “the constraints to which those measurements will conform” (DiSalle 1995, 324). Accordingly, theories that assumes that physical space is Euclidean by no means imply that Euclidean space exists as a separate entity. Instead, the success of Euclidean geometry stems from the fact that its laws codify physical measurements and processes. DiSalle then claims that the same thing can be said in the case of space-time theories:

> [T]he nature of spacetime is a question, not of whether a theoretical entity provides a causal explanation for appearances, but of whether the physical processes of measurement conform to geometric laws … Spatial measurement has been defined by coordination with a basic physical process (motion of rigid bodies). (DiSalle 1995, 323–324)

No casual property of space-time then, according to DiSalle, elucidates the connection between the laws of motion and space-time. In the same vein, Brown points out that the causal property of space-time is superfluous, and even problematic in the general theory:

> In 1924, Einstein thought that the inertial property of matter … requires explanation in terms of the action of a real entity on the particles. It is the space–time connection that plays this role: the affine geodesics form ruts or grooves in space–time that guide the free particles along their way. In GR, on the other hand, this view is at best redundant, at worst problematic … For it follows from the form of Einstein’ s field equations that the covariant divergence of the

> stress-energy tensor field $T_{\nu\mu}$ vanishes, that object which incorporates the ‘matter’ degrees of freedom, vanishes. (Brown 2005, 141)

It will be argued in the next section that we can say the same thing in the causal relationship between the curved space-time and the movements of material bodies in the general theory. Actually, this feature of Einstein’s general theory, which famously summarized as “space acts on matter, telling it how to move. In turn, matter reacts back on space, telling how to curve” (Misner et al. 1973, 5), is the most often mentioned one that characterizes the way space-time causes bodily motions. According to this argument, the gravitational interaction emerges from causal structure of curved space-time. We will argue that the curved space-time within Einstein’s general relativity by no means cause bodies move just like its counterpart in Newtonian mechanics, i.e. Newtonian space-time.

4. Einstein’s Curved Space-Time *Does Not* Cause Bodies to Move

We can have the better understanding of the workings of curved space-time from the dynamical perspective of space-time suggested by DiSalle and Brown, rather than from the causal view of curved space-time. According to this view, it is dynamical laws, rather than the mode of existence of space-time, that provide the foundation of space-time geometry. The advocates of this view criticize the traditional understanding of the relation between space-times and dynamical laws.

According to DiSalle, the spatio-temporal relationship between events within Newtonian space-time is in fact defined by the movements of bodies, which are expressed as the laws of motion. In the same way, what the spatio-temporal relationship between events within the general theory of relativity, i.e. curved space-time, exhibits is the fact that the trajectories of two neighbouring free-falling bodies are encoded within the geometry of curved space-time. As a result of Einstein’s equivalence principle (which plays the role of a dynamical law within general relativity), free-fall trajectories of bodies are identified as their inertial motions within the general theory. Accordingly, the curvature of space-time in fact encodes the information that the free-falling trajectories of two nearby particles exhibit relative acceleration. And this idea is clearly captured by Misner et al:

> [I]t was the whole point of Einstein that physics looks simple only when analyzed locally. To look at local physics, however, means to compare one geodesic of one test particle with geodesics of other test particles travelling (1) nearby with (2) nearly the same directions and (3) nearly the same speeds. Then one can "look at the separations between these nearby test particles and from the second time-rate of change of these separations and the 'equation of geodesic deviation' … read out the curvature of spacetime. (Misner et al 1973, 33)

So, when Misner et al (ibid., 5) wrote "space acts on matter, telling it how to move," they were in fact summarizing the following dynamical information of the general theory:

> (1) [L]ocally, geodesics appear straight; (2) over more extended regions of space and time, geodesics originally receding from each other begin to approach at a rate governed by the curvature of space-time, and this effect of geometry on matter is what we mean today by that old word 'gravitation.' (ibid.)

Hence, if we attempt to look for the continuity in the theory-change from Newtonian to Einsteinian physics, we need to make a careful look at the continuity within the information the structure of space-time tries to capture. As DiSalle and Brown point out, space-times have their specific geometrical structures in order to define the motions of bodies, which satisfy the laws of motion. Just as the geometries of Newtonian and Minkowski space-times encode information about the law of inertia that inertially moving particles move straight lines with constant velocity, the curvature of space-time of the general theory encodes the information that neighbouring inertially moving particles exhibit a relative acceleration. Accordingly, we need to turn our attention from the structure of space-time to the dynamical information in order to consider the theory-change from Newtonian to Einsteinian physics. We can see that Ellis and Williams (2000) capture this essential role of inertial motions within the context of the theory-change.

> As in the case of particle world-lines, the relative separation of neighbouring light rays can be used to detect space-time curvature, … *In the space-time context, Euclid' s axiom that parallel straight lines never meet is replaced by an equation (the equation of geodesic deviation) determining how the distance between neighbouring geodesics varies as a result of space-time curvature.* In the case of light rays, these effects are directly observable by measuring apparent angular diameters of distant objects. (Ellis and Williams 2000, 213, my italics)

This line of thought can also be found in Hoefer's view, which holds that the continuity between Newtonian and Einsteinian space-time can be found within the metric field g of the general theory. When Hoefer claims that "the metric field $g_{\mu\nu}$ of General Relativity is properly viewed as the modern representor of substantival spacetime" (Hoefer 1998, 459), it seems that he might advocate the traditional category of space-time substantivalism. Yet his argument shows that this is not in fact the case:

> [W]hy is it proper to view $g_{\mu\nu}$ as the representor of substantival spacetime? The metric' s role is explicitly to give us the details of the structure of 4-D, curved spacetime. It determines the spacelike-timelike distinction, determines the affine connection or inertia structure of spacetime (i.e. defines which motions are accelerated and which are not), and determines distances between points along all paths connecting them. In all these ways, the metric is perfectly analogous to Newton' s absolute space and time. (ibid.)

So, the metric g is by no means interpreted as "the representor of substantival space-time" because of the mode of existence of the entity. It is instead the commonality of function of the metric g which determines the space-timelike distinction and the affine connection of space-time. Hoefer admits that the general theory of relativity is "an awkward theory to comprehend using traditional [substantivalist] concepts of space-time." (Callendar and Hoefer 2002, 178)

Hoefer thus expresses his sympathy for DiSalle's view as "a realist about space (or space-time)'s structure, without making the mistake of inappropriate reification." (Callender and Hoefer 2002, 179) In fact, it is not difficult to find similarities between Hoefer's view and DiSalle's.

> Einstein believed in the reality of space−time, as ascribed in GTR by the metric field g, because of its apparently ineliminable role in the *description* and *prediction* of metrical, inertial, and gravitational phenomena. (Hoefer 1996, 27, my italics)

> The metric … serves to *define* absolute accleration and rotation, a function that Descartes' s relationism could not allow any material thing, no matter how pervasive, to perform. (Hoefer 1998, 460, my italics)

> Absolute space … is the theory that rest and motion can be distinguished; if we could *define* rest and motion physically so that they could be distinguished unambiguously, we would have a perfectly good reason to claim that physical events exhibit the structure of absolute space. We would not thereby be explaining that distinction, as Einstein thought. Instead we would only be using some physical distinction to define the difference between motion and rest. (DiSalle 1992, 187, my italics)

So, space-time exists not because of what it is, but because "space-time is [what] space-time does." (Hoefer 1996, 26)

4. Conclusion

It seems that the dynamical perspective of space-time has a clear advantage of explicating the relationship between space-time geometry and the laws of motion. Given that this view considers that space-time geometry stems from the laws of motion, there is no mystery about a claim that the behaviours of a given body exhibit the geometric structure of space-time.

Accordingly, from this new perspectives, we can figure out what Einstein's evolutionary account of the theory-change misses in understanding the theory-change from Newtonian to Einsteinian physics. Given that the dynamical laws and principles play a foundational role within space-time geometry, neglecting their importance in interpreting the continuity between Newtonian and Einsteinian physics will provide incomplete accounts. By following the traditional explanatory scheme, Einstein's evolutionary account falls short of capturing the physical foundation of space-time theories.

Now we can see that space-time, in opposition to Einstein's claim, is not in fact an inertia-generating entity in either Newtonian or Einsteinian physics. In other words, it is not a causally efficient entity whose geometric features causes material bodies to move in accordance with the laws of motion. An alternative account of the workings of space-time theory points out that it is not the mode of existence of space-time that explains the laws of motion. So, the causal assertions about space-time, in Kitcher's terms, are by no means "working parts," which "occur in problem solving-schemata." Rather they are at best"presuppositional posits" - "entities that apparently exist if the instances of the schemata are to be true." (Kitcher 1995, 149) Accordingly, we cannot expect that the causal properties of space-times provide an adequate evolutionary account of theory-change from Newtonian to Einsteinian physics.

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시공간 기하학의 개념적 기초에 대한 논쟁

양경은 (연세대학교)

뉴턴과 아인슈타인의 시공간에 대한 표준적 해석에 의하면 독립적으로 존재하는 시공간이란 존재자가 물체의 운동을 인과적으로 설명한다. 이 논문은 뉴턴과 아인슈타인의 시공간을 해석하는 이 견해를 비판적으로 고찰한다. 이 두 이론에서 시공간을 해석하는 최근 과학사와 과학철학의 연구를 중심으로 필자는 시공간 구조가 운동법칙의 부산물이지 그 반대가 아님을 주장한다. 이러한 시공간의 동역학적 견해를 통해 시공간이 가지는 인과적 속성이 뉴턴물리학에서 아인슈타인 물리학으로의 이론변화의 발전에 의미 있는 기능을 하지 못하였음을 주장할 것이다.

주제어: 시공간의 기하학, 실체론, 휘어진 시공간, 뉴턴 물리학에서 아이슈타인 물리학으로의 이론변화

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