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**DISCUSSION:
UNIFIED FIELD THEORY AND THE CONVENTIONALITY
OF GEOMETRY***

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The existence of fields besides gravitation may provide us with a way to decide empirically whether spacetime is really a nonflat Riemannian manifold or a flat Minkowskian manifold that appears curved as a result of gravitational distortions. This idea is explained using a modification of Poincaré's famous 'diskworld'.

Consider a 'world' which is made of a two-dimensional flat disk of radius R . The center of the disk is kept at a constant temperature T_0 and the edge of the disk at absolute zero. The temperature at a distance r from the center is given by the formula $T_r = T_0 [1 - (r/R)^2]$. Suppose, furthermore, that all 'matter' in that universe shrinks (or expands) uniformly and linearly with the temperature (and virtually shrinks to size zero as one approaches the edge of the disk). The 'natural' geometry of this world, argued Poincaré,¹ will not be Euclidean. Thus, for example, the (two-dimensional) inhabitants of the diskworld will conceive of their universe as infinite in size and their 'straight lines' (the shortest path between two given points) will correspond to the straight lines (of a certain model) of Lobachevskian geometry. It is therefore natural to expect that the diskworld mathematicians, when they come to summarize their geometrical knowledge, will write down the axioms of hyperbolic rather than Euclidean geometry. Suppose, however, that at a certain point in time an original diskworld scientist proposes an astonishing theory: "Our world is, in fact, a finite disk and its true geometry is flat (Euclidean). There is a universal field on the disk which distorts all matter uniformly and causes us to perceive our universe *as if* it is infinite in size and obeys the rules of hyperbolic geometry." This new and strange explanation is, no doubt, theoretically different from the straightforward geometric one but both theories generate precisely the same observable consequences. Which is the true theory? From the diskworld perspective, argued Poincaré, both theories are equally true and the choice of one or the other geometry is

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¹Poincaré 1902. The present exposition is based on Sklar 1974.

a matter of convention. In this sense there is no ‘real’ geometry of the diskworld.

Poincaré’s example, despite its ingenuity (it was conceived before the discovery of relativity), falls short of being a faithful analogy with the real physical world. The point is that in our universe there are other (non-universal) fields besides gravitation and this fact, in itself, may provide a way to decide empirically whether spacetime is really a Riemannian manifold with a nonflat connection or whether it is a flat Minkowskian manifold which *appears* curved as a result of the distortions caused by gravitational forces. I believe that this view may be attributed to S. Weinberg, who writes:

Of course this *was* Einstein’s point of view and his preeminent genius necessarily shapes our understanding of the theory he created. However, I believe that the geometrical approach has driven a wedge between general relativity—and the theory of elementary particles. As long as it could be hoped, as Einstein did hope, that matter would eventually be understood in geometrical terms. It made sense to give Riemannian geometry a primary role in describing the theory of gravitation. But now the passage of time had taught us not to expect that the strong weak and electromagnetic interactions can be understood in geometrical terms, and too great an emphasis on [Riemannian] geometry can only obscure the deep connections between gravitation and the rest of physics. (Weinberg 1972, Introduction)

On the positive side and more concretely Weinberg notes:

This [field theoretic as opposed to geometric] approach naturally leads us to ask *why* gravitation should obey the Principle of Equivalence. In my opinion the answer is not to be found in the realm of classical physics and certainly not in Riemannian geometry but in the constraints imposed by the quantum theory of gravitation. It seems to be impossible to construct a Lorentz invariant quantum theory of particles of mass zero and spin two unless the corresponding classical field obeys the Principle of Equivalence. (Weinberg 1972, Introduction)

Weinberg’s contention is that spacetime is *really* a flat Minkowskian manifold which *appears* Riemannian because of the validity of the Principle of Equivalence. This principle, in turn, should not be taken as an axiom but should rather be reduced to the more profound principles of an appropriate unified quantum field theory (which presupposes the flat spacetime of *special* relativity). If indeed Weinberg is correct and the deep connections between gravity and ‘the rest of physics’ can be explained by a unified theory of elementary particles, then the geometry of

spacetime may be decided empirically. Minkowskian geometry may turn out to be the only spacetime structure compatible with the unification scheme² and the equivalence of gravitational and inertial mass may be explained as a peculiar, perhaps even accidental, feature caused by a 'spontaneous breakdown' of the unified field into its currently observable components.

In order to understand this proposal in greater detail we can modify Poincaré's example and introduce a nonuniversal field into the diskworld. Suppose that in addition to their hyperbolic geometry (the temperature field), the diskworld scientists observe the following phenomenon: When pieces of a certain form of matter (call it 'iron') are suspended without support in the diskworld, they start to move in concentric circles (concentric circles are also circles in the Lobachevskian sense). This phenomenon causes the scientists to postulate that their world does indeed have a 'center'. The scientists also note that the angular acceleration of the suspended pieces depends on the radius in some definite way.

We humans, with our God-like perspective, understand the cause of this phenomenon: There is a temperature field on the disk; 'temperature', however, is nothing but the mean kinetic energy of the 'particles' from which the disk is made. As a result of the heat source at the center, free particles are boosted along radial trajectories. As it happens, there is an excess of positively charged particles in the disk (this is a case of a 'symmetry breakdown'). Hence there is a positive radial current in the disk, a current which induces a magnetic field orthogonal to it.³ No wonder 'iron' moves in concentric circles.

This indeed is 'our' explanation. There is, however, no reason to assume that the diskworld scientists could not come up with this or a similar theory. If they do so, they may also predict and observe new phenomena; for example, they may detect certain definite patterns of 'Brownian motion' in their world. Two points should be stressed at this stage:

- (a) Even in the absence of predictions the above 'unified field theory' has a clear theoretical advantage over the old 'geometric' view. According to the latter the magnetic field is entirely un-

²This statement must be qualified. One can always introduce a superfluous homogeneous universal field which has no local, and therefore, no observable effects and then claim that the geometry is 'really' non-Euclidean. The introduction of such an entity is, however, incompatible with a basic premise of quantum field theory, namely that the action of every field is mediated by a particle and thus every field produces local effects that are observable in principle.

³For the sake of exposition I have slightly twisted the laws of physics. Magnetic induction is a three- (in fact four-) dimensional phenomenon. My story, however, is consistent with a 'limit' procedure whereby one conceives of the disk as a very thin cylinder with a radial current on its middle slice. Note also that Poincaré's 'abuse' of physical law is no less radical. The temperature effects that he describes could not exist in principle.

related to the geometry of space. The unified view, on the other hand, reduces both the magnetic field and the apparent structure of space into one basic principle: motion of particles.

- (b) Even in the presence of new predictions and observations the geometric view might still be saved. Thus, for example, ‘Brownian motion’ in the diskworld may be explained in terms of ‘local fluctuations of the metric’ (not unlike the quantum fluctuations of the metric by which some authors attempt to incorporate quantum effects into the general relativistic framework).

It follows that a decision between the two rival theories is not entirely a matter of ‘observation’; nor is it, I believe, a matter of conventional choice. As Friedman has argued, from a methodological (and not merely aesthetic) standpoint, theoretical unifications have a clear advantage.⁴

One may object that by introducing ‘magnetic fields’ and ultimately ‘particles’ into the story I have changed completely the character of Poincaré’s example. This is true enough but neither Poincaré nor anyone else is inventing the rules of the real game, namely: There are fields besides gravitation and there are also particles in our universe. It is the conventionalist, not the realist who is begging the question. The conventionalist is rejecting the possibility that certain theoretical constructions, which appear today as components of our mathematical representations, might, tomorrow, acquire direct physical meaning by way of the principles of a seemingly unrelated theory.

Weinberg was perhaps overly confident when he asserted: “The geometric interpretation of the theory of relativity has dwindled into a mere analogy, which lingers in our language in terms like ‘metric’, ‘affine connection’ and ‘curvature’ but is not otherwise very useful.” He immediately added a warning: “These views are heterodox and would meet with objections from many general relativists” (Weinberg 1972, p. 147). Indeed physicists no longer consider the geometry of spacetime as a subject of metaphysics. Basic assumptions concerning the *real* structure of spacetime have their ‘operational’ consequences, the unmistakable differences between say the physics of S. Weinberg and the physics of J. A. Wheeler,⁵ can only be superficially explained in terms of ‘conventional choices’.

⁴Friedman 1983. Friedman is arguing in favor of the geometric view and he would have been right if general relativity was the end of the story. In spite of this difference I agree with the basic realistic view that is defended in this remarkable monograph.

⁵Misner, Thorne, and Wheeler 1970 is the most detailed account of the geometric view. Different ideas concerning the structure of spacetime also entail different approaches to the problem of ‘quantizing gravitation’. Compare the article by S. Weinberg with the paper by S. W. Hawking in Hawking and Israel 1974.

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