BOOK REVIEW

Hermann Minkowski and modern relativity theory

Vesselin Petkov (ed.): Minkowski spacetime: A hundred years later. Dordrecht: Springer, 2010. xlii+326pp, €128,35 HB

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Contrary to popular belief, the emergence of the special theory of relativity is not the result of a single stroke of genius, all set and done with the 1905 paper on the "electrodynamics of moving bodies" by an unknown Bern patent clerk. The importance of Albert Einstein's groundbreaking contribution, against the background of no less important earlier or parallel work by Hendrik A. Lorentz, Henri Poincaré, and others, is undisputed. But it took further developments to mold the theory into the elegant shape we recognize today. One such development concerned the mathematical formulation, and with mathematical sophistication came the realization of further conceptual implications as well. Hermann Minkowski's contribution proved to be of paramount importance in both respects. His adaptation of Einstein's theory from the perspective of someone who was at ease with the most advanced mathematical theories and concepts of the time further helped to carve out the conceptual core and lasting innovation of the special theory of relativity. Had he not died, unexpectedly and tragically, in early January 1909 at the age of 44 years of a ruptured appendix, who knows what else he might have contributed to the further development of physical theory.

Minkowski's work on special relativity is widely recognized, if only unconsciously, by physicists who refer as "Minkowski spacetime" to the four-dimensional, differentiable manifold endowed with a globally flat, pseudo-Euclidean metric of Lorentz signature, the mathematical representation of space and time for all special-relativistic physics. But the term is well justified. Minkowski published a hefty, technical treatise on "the basic equations for the electromagnetic processes in moving bodies" in 1908, and another paper of the same caliber appeared posthumously in 1910. To the wider scholarly audience, however, he is best known for a famous lecture, which he gave on September 21, 1908 to the annual conference of German scientists

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and physicians under the title of "Space and Time." It is the hundredth anniversary of this lecture that provided the occasion for the publication of this volume on Minkowski's original work and lasting influence. The Cologne lecture is reprinted in the volume both in the original German and in a new English translation by Dennis Lehmkuhl. It begins with what may well be some of the most frequently quoted lines in history of science, and indeed, these lines are quoted again in eight of the fourteen contributions assembled in this volume. Let me quote them here, too, in Lehmkuhl's excellent translation:

"Gentlemen! The views on space and time which I wish to lay before you have sprung from the soil of experimental physics. Therein lies their strength. Their tendency is radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

The notion that relativistic physics combines space and time to a four-dimensional spacetime, the reinterpretation of time as a fourth dimension, the interpretation of Lorentz boosts as rotations in a four-dimensional vector space, the geometric representation of Lorentz contractions in spacetime diagrams, and, in general, the mathematical representation of four-dimensional vector calculus that goes with these interpretations and indeed only makes them operational, all of these innovative aspects of special relativity are associated with Minkowski's intervention, and if they do not go back directly to his work, at least their recognition by a wider scientific community was immensely furthered by his famous Cologne address.

The volume opens with two historical papers by Leo Corry and Scott Walter. Corry reminds us of the biographical and cultural background for Minkowski's work in relativity, his roots in the Göttingen mathematical community and, in particular, his resonance with David Hilbert's program of an axiomatization of physics. Walter gives an eye-opening interpretation of Minkowski's scientific rhetoric in this lecture, which he shows must have been provoking and disturbing on many levels to the ears of his contemporaries, thereby explaining the huge immediate success and influence of this address, which is, in Walter's words, "a magnificent example of scientific agitprop."

Six papers discuss the implications of Minkowski's work for today's theoretical physics. Domenico Giulini expounds the rich mathematical and conceptual structure of Minkowski spacetime. As Giulini shows, it has already an amazingly rich structure notwithstanding the fact that, from a general relativistic point of view, it is only the simplest model of a spacetime. Giulini begins his detailed mathematical exposition with the insightful observation that a modern discussion of the mathematical structure of Minkowski spacetime, bottom-up as it were, by adding more and more structure to a bare manifold does not provide an adequate historical interpretation of Minkowski's views. While modern theory regards Minkowski spacetime as a model of empty spacetime devoid of any material content, Minkowski himself explicitly made it clear that he considered space to be filled always and everywhere with fields and matter. With that historical caveat in mind, Giulini gives a most useful, detailed discussion of the metric, affine, and causal structures of Minkowski spacetime, explains how the law of inertia, the principle of relativity, the concept of simultaneity, and the problem of rigid motion are

understood nowadays from a modern, set-theoretic, group-theoretic, and analytic point of view. Similarly, Graham Hall gives an exposition of today's understanding of Minkowskian electrodynamics.

W.G. Unruh addresses the—apparent—incompatibility of Minkowski spacetime with quantum mechanics. By a standard argument, non-relativistic quantum mechanics distinguishes the time coordinate and therefore violates Minkowski's "world postulate" of treating space and time coordinates on the same footing. Unruh reconsiders various arguments along these lines and argues that they all are invalid and do, in fact, not prove any such inconsistency. To what extent these arguments carry over to the general relativistic case and have an impact on the problem of quantum gravity, however, he leaves for consideration as an open question. Interpretational issues of quantum mechanics and the puzzle of quantum gravity then are the themes of papers by Rudolfo Gambini and Jorge Pullin, by Abhay Ashtekhar, and by Martin Bojowald. Gambini and Pullin focus on the concept of undecidability and argue that the use of realistic clocks against the background of quantum mechanics implies both a necessary modification of Minkowski spacetime as a static fixed entity and opens up an interpretation of quantum mechanics without a reduction process. Ashtekhar discusses quantum spacetimes and their significance for the interpretation of singularities, Bojowald discusses spacetime extensions and loop quantum cosmology.

A third group of papers deal with conceptual and philosophical issues. Dennis Dieks takes issue with an often repeated reading of Einstein's original papers of special relativity which takes the operationalist arguments for the definition of space and time at face value. Dieks argues, quite convincingly, that the operationalist suggestions in those papers were crafted to undermine a belief in the naturalness of classical concepts, rather than intended as a foundation for the construction of space and time with a full-fledged philosophical underpinning. Similarly, Minkowski did not so much supplant Einstein's instrumentalist interpretation of rods and clocks with a realist spacetime account of a four-dimensional "absolute world." Dieks suggests that here again a substantivalist reading of Minkowski is less historically adequate than one in which the form of physical laws plays a fundamental role. These exegetic arguments obviously have implications for the debate about the conventionality of simultaneity. Yvon Gauthier draws an interesting historical and systematic parallel between Minkowski's physical geometry and one of his major mathematical achievements, the creation of what he called the geometry of numbers. Orfeu Bertolami takes a bird's eye view of the new concept of time in Minkowskian physics, putting it into a cultural context that spans from Greek concepts of chronos via Leibniz and Kant to modernity and underpins modern discussions of the arrow of time, closed time-like curves, time travel, and cyclic time. Vesselin Petkov takes up Minkowski's suggestion that physical laws involving material particles should adequately be formulated in terms of the particles' world lines, and investigates to what extent this idea can and should be carried over to other fields of physics. Paul Wesson and Herbert Pietschmann finally discuss the concept of time as an illusion and the consequences of Minkowski's four-dimensional unification of space and time for a philosophy of nature.

Vesselin Petkov, the editor of the volume, has succeeded in assembling a number of interesting, enlightening, and thought-provoking papers, all of them authored by

competent experts in their fields, which illuminate various aspects of the concept of Minkowski spacetime. The collection transcends the disciplinary boundaries of theoretical physics, history of science, and philosophical reflection in a most productive way.