Renn, Jürgen (ed.); **Schemmel, Matthias (ed.)**; **Norton, John D. (ed.)**; **Janssen, Michel (ed.)**; **Sauer, Tilman (ed.)**; **Stachel, John (ed.)**

The genesis of general relativity. Sources and interpretations. Vol. 1 and 2: Einstein's Zurich notebook: introduction and source. Vol. 3 and 4: Gravitation in the twilight of classical physics: between mechanics, field theory, and astronomy. (English) Zbl 1216.83015

Boston Studies in the Philosophy of Science 250. Dordrecht: Springer (ISBN 978-1-4020-3999-7/hbk; 978-1-4020-4000-9/ebook). xxix, 1212 p. (2007).

Volume 1 consists of three papers and Einstein's Zürich Notebook together with an introduction to Volumes 1 and 2 by Janssen and others. From today's perspective, Einstein's theory represents the basis for modern astronomy, astrophysics, cosmology and cosmogony. Yet little of the knowledge that makes relativity theory a central asset of modern physics was available when Einstein completed his theory by publishing his celebrated paper on general relativity in late 1915. Now a question occurs how it was then possible for Einstein without this knowledge to formulate a theory that has since withstood not once but several revolutions of astronomy and its instrumentation, including the development of radio-, X-ray and space-borne astronomy. Renn's paper entitled "Classical Physics in Disarray" is an attempt to prepare the answers to this question. It is generally warranted that Einstein's development of general relativity is to be compared to a three-act drama. The first act is the formulation of the basic idea (1907), which is to be referred to as the equivalence principle. The second act is the mathematical representation of the gravitational field by a symmetric second rank tensor field (1912). The third act is the formulation of so-called Einstein equations for the metric field and use of a spherically-symmetric solution to explain the anomalous procession of the perihelion of Mercury (1915). Stachel's paper is concerned with the first two acts. Renn and Sauer's paper entitled "Pathways out of Classical Physics" is intended to show that the history of Einstein's search for a gravitational field equation can, against the background of the Zürich Notebook, be written as that of a mutual adaption of mathematical representation and physical meaning. Only by analyzing the intricate architecture of these shared knowledge resources is it possible to understand in which sense classical and special-relativistic knowledge about gravitation and inertia, energy and momentum conservation, and the relation between different reference frames was turned into a heuristic framework for Einstein's search. This paper is the longest (200 pages!) and most ambitious essay in the first volume, elaborating on "Classical Physics in Disarray" and presenting a comprehensive version of the third act of the genesis of general relativity within a framework of historical epistemology that integrates historical analysis, epistemology and cognitive science.

Volume 2 consists of four papers, namely, Janssen and others' long paper entitled "A Commentary on the Notes on Gravity in the Zürich Notebook", Norton's "What Was Einstein's 'Fatal Prejudice'?", Janssen's "What Did Einstein Know and When Did He Know It?" and Janssen and Renn's "Unifying the Knot: How Einstein Found His Way Back to Field Equations Discarded in the Zürich Notebook". The first paper is intended to draw attention to a few that are crucial to understanding the essays complementing the commentary in the first two volumes. In particular, the authors flesh out the distinction between "the mathematical strategy" and "the physical strategy" in Einstein's search for field equations. Pursuing the mathematical strategy, Einstein scoured the mathematical literature for expressions containing derivatives of the metric that could be used as building blocks for his gravitational field equations. Pursuing the physical strategy, Einstein struggled to find such building blocks drawing on the analogy between the gravitational field in his own new theory and the electromagnetic field in the classical electromagnetism of Maxwell and Lorentz. Einstein vacillated between these two approaches. The distinction between the two approaches plays a key role in the fourth paper. The second paper analyzes the role of coordinate restrictions in Einstein's work. It also reviews why Einstein's use of them is credible, even though they differ tremendously from the routine modern usage. The third paper claims that more room needs to be made for the role of prejudice, wishful thinking, and opportunism in Einstein's work towards general relativity.

Volume 3, entitled "Gravitation in the Twilight of Classical Physics: Between Mechanics, Field Theory and Astronomy", consists of 5 parts together with an introduction to Volumes 3 and 4 by Renn and Schemmel. Part 1, entitled "The Gravitational Force between Mechanics and Electrodynamics", consists of four classical papers (Zemneck's "Gravitation", *H. A. Lorentz*' [Amst. Ak. Versl. (Proc.) 2, 559–574 (1900; JFM 31.0748.01)], *B. Friedlaender* and *I. Friedlaender*'s [Absolute oder relative Bewegung? Berlin: Leonhard Simion (1896; JFM 27.0571.01)] and Föppl's "On Absolute and Relative Motion") together with Renn's guidance on the third way to general relativity. Part 2 consists of Schwarzschild's classical "Things at Rest in the Universe" and Schemmel's expert explanation on the continuity between classical and relativistic cosmology. Part 3 consists of three classical papers (*H. Poincaré*'s [Palermo Rend. 21, 129-175 (1906; JFM 37.0886.01)], *H. Minkowski*'s "Mechanics and the Relativity Postulate" appended to [Gött. Nachr., 53–111 (1908; JFM 39.0909.02)], and *H. A. Lorentz*' [Phys. Z. 19, 1234–1257 (1910; JFM 41.0912.05)]) preceded by Walter's instructive explanation on the four-dimensional movement in gravitation 1905-1910. Part 4 consists of four classical papers by Max Abraham ("On the Theory of Gravitation", "The Free Fall", "A New Theory of Gravitation" and "Recent Theories of Gravitation") together with Renn's readable preface. Today Abraham is famous for his achievements in the field of electrodynamics (cf. [*M. Abraham*, Die elektrischen Schwingungen um einen stabförmigen Leiter, behandelt nach der Maxwell'schen Theorie. Berlin: Mayer u. Müller (1897; JFM 28.0804.01); Theorie der Elektrizität. Erster Band. Einführung in die Maxwell'sche Theorie der Elektrizität von *A. Föppl*. Leipzig: B. G. Teubner (1907; JFM 38.0857.01), (1912; JFM 43.1029.01), (1930; JFM 56.1265.01); Zweiter Band. Elektromagnetische Theorie der Strahlung. Leipzig: B. G. Teubner (1908; JFM 39.0904.08)]), but he is largely forgotten as a pioneer of relativity theory. In hindsights Abraham's attempt to formulate a field theory of gravitation in the framework of Minkowski formalism would lead to a dead end, but his bold step encouraged some others such as Gunnar Nordström to pursue his endeavor through more appropriate means or such more courageous others as Einstein to take even bolder steps. Part 5 is divided into two subparts. The first subpart consists of three classical papers by Nordström ("The Principle of Relativity and Gravitation", "Inertial and Gravitational Mass in Relativistic Mechanics" and "On the Theory of Gravitation from the Standpoint of the Principle of Relativity") and *A. Einstein*'s [Phys. Z. 14, 1249–1266 (1913; JFM 44.0890.01)] together with Norton's good preface on the early demise of scalar, Lorentz covariant theories of gravitation. The second consists of two papers of Einstein ("On the Relativity Problem" and [Äther und Relativitätstheorie. Berlin: J. Springer (1920; JFM 47.0777.03)]) together with Barbour's excellent preface.

Volume 4, entitled "Gravitation in the Twilight of Classical Physics: The Promise of Mathematics", is divided into three parts. The first part entitled "From an Electromagnetic Theory of Matter to a New Theory of Gravitation" presents Gustav Mie's classical works [*G. Mie*, Ann. Phys. (4) 37, 511–534 (1912); (4) 39, 1–40 (1912; JFM 43.0910.04); Phys. Z. 15, 115–122, 169–176 (1914; JFM 45.1122.03); Elster-Geitel-Festschrift, 251–268 (1915; JFM 45.1123.01)] together with Max Born's comments on the momentum-energy law in Mie's electrodynamics and a readable preface by Christopher Smeenk and Christopher Martin. Mie's approach to the problem of gravitation stands in sharp contrast to Einstein's. Mie pointedly criticized Einstein's requirement of general covariance and commented that Einstein might have missed his theory of gravitation since it was tucked away in a work on a comprehensive theory of matter. Mie believed firmly that a comprehensive theory of matter would resolve the problem of gravitation, and he was not convinced by Einstein's attempt to link issues in the foundations of mechanics to the problem of gravitation. Part 2 is concerned with "Including Gravitation in a Unified Theory of Physics". The first paper is well-chosen extracts based on [*L. Corry*, David Hilbert and the axiomatization of physics (1898–1918). From Grundlagen der Geometrie to Grundlagen der Physik. Dordrecht: Kluwer Academic Publishers (2004; Zbl 1081.01019)], in particular, its Chapters 2, 3 and 5. The fourth, fifth and sixth papers are David Hilbert's Foundations of Physics (Proofs of First Communication, First Communication and Second Communication), which is preceded by Renn and Stachel's long second paper on them. The third paper by Tilman Sauer is a reprint of [Arch. Hist. Exact Sci. 59, No. 6, 577–590 (2005; Zbl 1080.01007)]. Part 3 is concerned with "From Peripheral Mathematics to a New Theory of Graviation", consisting of four source texts (Hermann Grassmann's "On the Relation of Non-Euclidean Geometry to Extension Theory", Tullio Levi-Civita's "Notion of Parallelism on a General Manifold and Consequent Geometrical Specification of the Riemannian Curvature", Hermann Weyl's "Purely Infinitesimal Geometry" and Elie Cartan's "The Dynamics of Continuous Media and the Notion of an Affine Connection on Space-Time") and John Stachel's long paper is intended to advocate the three theses: 1. The concepts of parallel displacement in Riemannian geometry and of a non-metrical affine connection were developed postmaturely.

2. The appropriate mathematical context for implementing the equivalence principle is the theory of affine connections on the category of frame bundles, with the bundle morphisms induced by diffeomorphisms on the base manifold.

3. Had the concept of an affine connection been developed in a timely manner, the affine formulation of Newtonian gravitation theory, which was actually developed only after the formation of general relativity, could have been developed before the formation of special relativity.

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MSC:

83C05	Einstein's equations (general structure, canonical formalism, Cauchy problems)
01A60	Mathematics in the 20th century
83-03	Historical (relativity)

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