Geometrization vs. Unification. The Reichenbach–Einstein Quarrel about the *Fernparallelismus* Field Theory

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This study reconstructs the 1928–1929 correspondence between Reichenbach and Einstein about the latter's latest distant parallelism-unified field theory, which attracted considerable public attention at the end of the 1920s. Reichenbach, who had recently become a Professor in Berlin, had the opportunity to discuss the theory with Einstein and therefore sent him a manuscript with some comments for feedback. The document has been preserved among Einstein's papers. However, the subsequent correspondence took an unpleasant turn after Reichenbach published a popular article on distant parallelism in a newspaper. Einstein directly wrote to the Editorial Board complaining about Reichenbach's unfair use of off-the-record information. While Reichenbach's reply demonstrates a sense of personal betrayal at Einstein's behavior, his published writings of that period point to a sense of intellectual betrayal of their shared philosophical ideals. In his attempts to unify both electricity and gravitation, Einstein had abandoned the physical heuristic that guided him to the relativity theory, to embrace a more speculative, mathematical heuristic that he and Reichenbach had both previously condemned. A decade-long personal and intellectual friendship grew fainter and then never recovered. In addition to Giovanelli, 2016a, this study, relying on archival material, aims to revisit the Reichenbach–Einstein relationship in the late 1920s in light of Reichenbach's neglected contributions to the epistemology of the unified field theory program. Thus, this study hopes to provide a richer account of Reichenbach's philosophy of space and time.

Introduction

According to his recollections, Einstein (1949a, 73-75) had always considered his 1915 field theory of gravitation, the general theory of relativity, as nothing but a stepping stone toward a 'unified field theory',[1] which would somehow integrate both gravitational and electromagnetic fields into a single field structure. In his later years, Einstein tended to downplay his initial skepticism toward this endeavor. However, it is undeniable that his quixotic[2] quest for the final field theory spans over most of Einstein's professional life right from 1919 (Einstein, 1919) till his death in 1955 (Einstein and Kaufman, 1955).[3] Seldom, it is noted that Hans Reichenbach was possibly the only philosopher who, alongside his well-known work on relativity theory, possessed the epistemological insight and mathematical knowledge to find his bearings within the intricacies of the various unification attempts. Indeed, Reichenbach was closer to the historical events than almost all others. He witnessed the dawn of the unified field theory program in the late 1910s when he attended the Berlin lectures of a still cautious Einstein; and, back again in Berlin as a professor in the late 1920s (see Hecht and Hoffmann, 1982), he observed its twilight, when Einstein had become the increasingly isolated practitioner of a non-mainstream research program.

Although most of Reichenbach's critical remarks on the unified field theory program appeared in published writings, the personal and philosophical motivations of his mistrust toward the field–theoretical undertake emerges more clearly in the letters he exchanged with some of the major figures of physics research of those years. For a general overview, Reichenbach's reflections on the unified field theory

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[1] In the following, I will freely draw from the standard literature on the unified field theory program: Vizgin, 1994Goenner, 2004Goldstein and Ritter, 2003.

[2] The expression is used by Einstein himself on several occasions; see e.g., Einstein to Besso, Apr. 15, 1950; Speziali, 1972, Doc. 172; Einstein to Laue, Jan. 17, 1951; EA, 16-168; Einstein to Bohm, Nov. 24, 1954; EA, 8-055; Einstein to Born; (Born and Einstein, 1968–1971, Doc. 93, undated).

[3] For an overview of Einstein's work on unified field theory program, see Sauer (2014); for the philosophical background of Einstein's search for a unified field theory see Dongen (2010); on Einstein's philosophy of science Ryckman (2017).

program can be organized around three correspondences, which, as I will explain, roughly seem to revolve around three different conceptual issues:

(i) Reichenbach–Weyl correspondence (1920-1921)

(ii) Reichenbach–Einstein correspondence (1926-1927)

(iii) Reichenbach–Einstein correspondence (1928-1929)

The recognition of the significance of episode (i) has been an important result of the Reichenbach scholarship of the last few decades (Ryckman, 19951996).[4] In the early 920s, Weyl and Reichenbach could be considered as Einstein's 'agonists'–, i.e., champions of two different 'Einsteins' (Ryckman, 2005)—, debating over the role of *coordination* of geometrical structures and measuring devices, whether the latter must be described in the framework of general relativity or not (see also Giovanelli, 2013).

However, the latter two episodes are not well known. The correspondence (ii) has been rediscovered and published (CPAE, Vol. 15, Docs. 224. 230, 235, 239, 244) only recently (Giovanelli, 2016a). After some discussion on a note (HR, 025-05-10) that Reichenbach sent to Einstein for feedback, they agreed that general relativity should *not* be considered a 'geometrization' of physical fields (Lehmkuhl, 2014). The note was then included in a long technical Appendix to the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a, §§46-50)–Reichenbach's major work on the philosophy of space and time in which general relativity is presented as a 'physicalization of geometry' rather than a '*geometrizaton* of gravitation' (Giovanelli, 2021).

This study aims to add the final piece of the puzzle by analyzing the philosophical implication of the third correspondence (iii) that has just been published (CPAE, Vol. 16, Docs. 284, 292, 384, 390, 391). In the late 1920s, Reichenbach realized that, in Einstein's mind, the actual aim of the unified field theory program was not the geometrization, but the *unification* of two different fields, an undertaking for the sake of which Einstein was ready to embrace a strongly speculative approach to physics. This letter exchange marked both the decline in their personal friendship and the end of their philosophical kinship. At the end of the decade, the 'Einstein' Reichenbach had championed in the early of 1920s was not the 'Einstein' he had met again in Berlin at the end of the decade.

A few months after publishing the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a), Einstein launched yet another attempt at a unified field theory, the so-called *Fernparallelismus*- or distant parallelism-field theory[5](Einstein, 1928ec) based on a Riemannian geometry with distant parallelism in which two vectors can be compared both as to their lengths and their directions. Reichenbach, now back in Berlin, discussed the new theory in person with Einstein and sent him few pages of comments. The unpublished manuscript is still extant (Reichenbach, 1928b). The correspondence that ensued, however, soon took a negative turn. Einstein, annoyed by the unwanted attention of the press, angrily reacted to Reichenbach's article in a newspaper (Reichenbach, 1929c), which seemed to anticipate the last version of the theory (Einstein, 1929g). Without alerting Reichenbach, he directly wrote a strongly worded letter of complaint to the Editorial Board. Reichenbach perceived Einstein's behavior as a *personal betray* and replied with a sense of indignity, reminding Einstein, somewhat inelegantly, of his service in defending and popularizing relativity theory. The feud was quickly mended; however, their personal relationship never fully recovered.

This quarrel on a rather mundane matter might have coupled with a sense of a deeper intellectual estrangement. As Reichenbach had come to realize, along with Einstein's engagement with the unified field theory program, their philosophical views had grown apart and had become hard to reconcile. In the 1920s, Reichenbach was possibly the only philosopher able to discuss eye to eye with the working physicists on this matter. Reichenbach hoped that his critical epistemological reflections could have served, so to speak, to tie physicists to the mast of empiricism such that they could resist to "the sirens' enchantment [*Sirenenzauber*] of a unified field theory" (Reichenbach, 1928a, 373). If relativity theory had taught us to separate mathematics from physics, in Reichenbach's view, the unified field theory program represented the seducing temptation to absorb physics into mathematics. To Reichenbach's dismay, it was Einstein himself who did not remain deaf to sirens' song and gave in to the lure of mathematical simplicity as the key to physical reality. Thus, Reichenbach seems to have experienced a sense of *intellectual betray* of their once-shared philosophical principles.

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[4]For another aspect of the Reichenbach–Weyl correspondence, see Rynasiewicz, 2005.

[5]In modern literature the expression 'teleparallelism' is used. In the following, in briefly outlining Einstein's theory, I rely primarily on the standard historical work on the topic Sauer (2006); for an anthology of papers on distant parallelism, see Delphenich (2013). For recent applications of this formalism, see Aldrovandi and Pereira, 2013; for a philosophical appreciation, see Knox, 2011.

Amidst the turmoil of the 1930s, a decade of intense personal friendship and intellectual exchange came to an end. Paradoxically, when, in 1934, Hugo Dingler (1933, 37) launched a political attack on Reichenbach, labeling him despairingly 'Einstein's self-appointed personal philosopher,' Einstein and Reichenbach's philosophical views had become nearly irreconcilable. However, if the falling-out with Einstein was certainly a bitter moment in Reichenbach's intellectual biography, it was interwind with one of Reichenbach's unsung philosophical achievements. Over the years, somewhat on the margins of his primary philosophical work on relativity theory, Reichenbach had managed to provide the first, and possibly only, overall philosophical reflection on the unified field theory program at that time of its peak. In this manner, Reichenbach, somewhat unwittingly, was able to formulate a sort of 'theory of spacetime-theories' (Lehmkuhl, 2017b).

His well-known philosophical appreciation on general relativity was embedded in the larger context of an often technically detailed analysis of the alternative theoretical paths that were explored in the 1920s. Reichenbach attempted to unravel the key to Einstein's success in formulating a field theory of gravitation by uncovering the reasons for the failure of subsequent unification attempts. In doing so, Reichenbach produced some of the most significant examples of his style of doing philosophy, based on a detailed logical analysis of concrete physical theories rather than on a broadly stroked investigation of the nature of scientific thought. As Reichenbach (1936) himself emphasized, it was this approach that set apart the 'logical empiricism' of his 'Berlin group' from both traditional philosophy and the 'logical positivism' of Moritz Schlick's 'Vienna Circle' (Milkov, 2013Uebel, 2013).

Ultimately, as his American students had reported later, it was this philosophical style that Reichenbach brought with him when he moved to the United States in 1938, influencing generations of philosophers of science on the other side of the pond (Rescher, 2006Salmon, 1999). Unfortunately, when, in 1958, the translation of *Philosophie der Raum-Zeit-Lehre* was published (Reichenbach, 1958); the Appendix was not included. This decision left subsequent generations of scholars mostly unaware of one the most interesting aspects on Reichenbach's early work, thus providing a somewhat impoverished image of Reichenbach's philosophy of space and time. The importance of Reichenbach's debate with Weyl was not completely appreciated, and his relationship with Einstein was seriously misunderstood. In celebrating Reichenbach's legacy, I hope that this study will contribute to re-establish, at least in part, a more well-rounded account of Reichenbach as a philosopher of physics.

The structure of the paper is as follows. After setting the stage (section 1), this study analyzes two sets of documents roughly written during the span of few months between the end of 1928 and the beginning of 1929, both of which are related to Einstein's *Fernparallelismus* field theory: (a) Reichenbach's private correspondence with Einstein (section 2, section 3) (b) Reichenbach's published writings on the unified field theory program (section 4). These two sets of documents constitutes, so to speak, the direct evidence on which the present study relies. The documents (a) uncover a *personal* quarrel between Einstein and Reichenbach; the documents (b) testify to a *philosophical* disagreement about the value of the unified field theory program. The indignant tone of Reichenbach's reply in his letter to Einstein suggests that the personal disgruntlement might have been entangled and possibly amplified by an underlying feeling of intellectual estrangement. At around the same time, also the members of the Vienna circle, such as Moritz Schlick[6] and Philipp Frank,[7] seem to have been both baffled and disappointed by Einstein's anti-positivistic and rationalistic rhetoric. *On top of that*, Reichenbach might have felt unjustly mistreated by Einstein. However, reasonable doubts can be raised against this additional conjecture which is based at most on circumstantial evidence. Indeed, the personal quarrel might have taken place in the absence of any philosophical disagreement and vice versa. Thus, the readers who are less inclined to indulge in academic 'gossip' from late of 1920s might skip over section 3 and still appreciate the philosophical points raised by Reichenbach in some of his lesser-known papers on the philosophy of space and time.

1   Einstein's Review of the *Philosophie der Raum-Zeit-Lehre*

Einstein read the manuscript of the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a) on his way to Brussels to attend the fifth Solvay Congress (Bacciagaluppi and Valentini, 2009). In a letter to his second wife Elsa after his arrival, he appeared impatient toward Reichenbach's assertive style: "I finished reading Reichenbach. To be so delighted with oneself must be pleasing, but less so for other people" (Einstein to Elsa Einstein, Oct. 23, 1927; CPAE, Vol. 16, Doc. 34). After some weeks, in December,

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[6] For Schlick's reaction to Einstein's self-characterization as a 'metaphysician' (Einstein to Schlick, Nov. 28, 1930; EA, 21-603; m.e.; part. tr. in Howard, 2014, 371), see Fruteau de Laclos (2007).

[7] For Frank's reaction to Lanczos's (1932) characterization of Einstein as metaphysical realist, see Frank (1947, 215) and Frank and Kuhn (1962).

Reichenbach wrote to Einstein that Paul Hinneberg, the editor of the *Deutsche Literaturzeitung* had told him that Einstein intended to write a review of his forthcoming book, *Philosophie der Raum-Zeit-Lehre*. Reichenbach sent him the galley proofs and added that he would send an Appendix in the coming days (Einstein to Reichenbach, Dec. 1, 1927; CPAE, Vol. 16, Abs. 295). Einstein's review appeared in the first 1928 issue of the *Deutsche Literaturzeitung* (Einstein, 1928d).

The review was little more than a short summary. However, Einstein emphasized two philosophically significant issues both concerning the Appendix of the book. (1) "In the Appendix, the foundation of the Weyl–Eddington theory is treated in a clear manner and in particular the delicate question of the *coordination* of these theories to reality" (Einstein, 1928d, 20; m.e.). Reichenbach had claimed that, as in any other theory, in unified field theory, one should give physical meaning to the variables used ($g_{\mu\nu}$, $\Gamma^\tau_{\mu\nu}$, etc.) from the outset before starting to search for the field equations. Einstein did not comment on this issue, probably because, over the years, he had come to realize that this requirement was too strict. However, Einstein was in complete agreement with the second point made by Reichenbach: (2) In the Appendix, "in my opinion quite rightly—it is argued that the claim that general relativity is an attempt to *reduce physics to geometry* is unfounded" (Einstein, 1928d, 20; m.e.). As reported, Reichenbach and Einstein had already discussed this topic in a private correspondence less than two years earlier (Giovanelli, 2016a). Therefore, Einstein immediately perceived the importance of this theme in Reichenbach's book, a theme that later readers often overlooked (Giovanelli, 2021).

The issue of 'geometrization' was indeed close to Einstein's heart at that time (Lehmkuhl, 2014). In the weeks he wrote Reichenbach's review, Einstein (Einstein to Meyerson, Dec. 24, 1927; EA, 18-294) provided final authorization for the publication of another, more extensive review of *La déduction relativiste* written by the French philosopher Émile Meyerson (Meyerson, 1925). The review was published in Spring 1928 in French (Einstein, 1928a). In the book, Meyerson had considered relativity as a central stage in the process of progressive geometrization of physics, which had started with Descartes and that promised to go on with the theories of Weyl and Eddington. In the context of an otherwise laudatory review, Einstein strongly disagreed. According to Einstein, "the term 'geometrical' used in this context is entirely *devoid of meaning*" (Einstein, 1928a, 165; m.e.). Historical reasons aside, there was no real ground to define $g_{\mu\nu}$, the gravitational field, as a geometrical field, and, say, the $F_{\mu\nu}$, the electromagnetic field, as a non-geometrical field. The aim of the unified field theory program was not to 'geometrize' both fields but to 'unify' them to show that they are nothing but two aspects of a unique 'total' field of unknown structure. Without the equivalence principle, mathematical simplicity had become the only guide in the quest for the fundamental field structure. Therefore, however, Einstein very much appreciated Meyerson's insistence on 'the deductive-constructive character' of relativity theory (on this episode see Giovanelli, 2018).

After the review, Einstein complained "that the works of M. Schlick and H. Reichenbach[8] seem to have escaped Mr. Meyerson" (Einstein, 1928a, 166). Nevertheless, the nearly contemporary publication of the Reichenbach and Meyerson reviews represents—somewhat symbolically—a reconfiguration of Einstein's system of philosophical alliances. Indeed, for a brief time period, Meyerson became Einstein's reference philosopher, a position once proudly held by Schlick and Reichenbach.[9] The Einstein–Reichenbach falling out was, however, somewhat more dramatic, as testified by their early 1929 correspondence. As we shall see, in these letters, a minor academic quibbling seems to have been superimposed to a deeper philosophical tension concerning the very nature of physics' enterprise. Over the years, Reichenbach had believed himself to have given a philosophical voice to Einstein's insistence on the separation between pure mathematics and physics. However, back in Berlin, he found him expressing a quasi-religious belief in the mathematical simplicity of the real as the true motivation for doing research. Einstein had become weary of the *positivism*, that he saw spreading among the younger generation of quantum physicists. Einstein often insisted that physics is ultimately a form of *metaphysics*, borne out of a deep-rooted requirement to understand the real and not simply make correct predictions (Giovanelli, 2018).

2   Einstein's *Fernparallelismus*-Field Theory and Reichenbach's Objections

The reasons behind Einstein's philosophical turn will become apparent in the immediate following months as Einstein started to work on his next unified field theory. During a period of prolonged convalescence, Einstein explored a generalization of Riemannian geometry that he considered as unknown, in which a notion of parallelism between vectors at two distant points can be defined. In a note presented at the

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[8]The name of Reichenbach was added in the last draft possibly after Reichenbach read the *Philosophie der Raum-Zeit-Lehre* on his way to Bruxelles.

[9]On this point see also section IV of the 'Introduction' to CPAE, Vol. 16.

Academy on June 7 (Einstein, 1928e), he introduced a new formalism, based on the concept of *n-Bein* (or *n*-legs), *n* unit orthogonal vectors representing a local coordinate system attached at a point of *n* dimensional continuum. The *n-Bein* is called *Vierbein* for four dimensions.[10] Let A_a be the components of a vector A with respect to the *n*-bein. For describing a finite region, one can introduce a so-called Gaussian coordinate system[11] x^ν. Then, A^ν are the components of the vector A with respect to x^ν. Thus, if one define the h_a^ν as the ν-component of the a *n*-bein, one has $A^\nu = h_a^\nu A_a$. Thus, in Einstein's notation, Greek letters denote the coordinate indices (*Koordinaten-Indizes*) and Latin letters *n*-bein indices (*Bein-Indizes*).

By postulating the existence of the *n*-bein field h_a^ν, Einstein could introduce the notion of distant parallelism of such vectors. Two vectors A and B at distant points can be considered as equal and parallel if they have the same local coordinates with respect to their *n*-bein. The metric can be written as the product of two *n*-beins:

$$g_{\mu\nu} = h_{\mu a} h_{\nu a}. \qquad [1]$$

in which a is to be summed over. In addition to the usual affine connection $\Gamma_{\mu\nu}^\tau$ determined by the metric $g_{\mu\nu}$,[12] one can define the notion of parallel transport through the *n*-bein, introducing thereby a separate connection[13] which is not symmetric in the lower indices:

$$\Delta_{\mu\sigma}^\nu = h^{\nu a} \frac{\partial h_{\mu a}}{\partial x^\sigma}. \qquad [2]$$

From the connection coefficients one can build the Riemann tensor

$$R_{k,lm}^i = -\frac{\partial \Delta_{kl}^i}{\partial x^m} + \frac{\partial \Delta_{km}^i}{\partial x^l} + \Delta_{\alpha l}^i \Delta_{km}^\alpha - \Delta_{\alpha m}^i \Delta_{kl}^\alpha \equiv 0,$$

which identically vanishes (Einstein, 1928e, 219). Because the *n*-bein determines the metric, but not the other way around, it provides more degrees of freedom—16 components of the vierbein compared to the 10 of the metric. Einstein expected that the former could be exploited to incorporate the electromagnetic field alongside the gravitational field.

A second note was presented a few days later on June 14 (Einstein, 1928c). Einstein noted that the non-symmetric part of the displacement $\Lambda_{\alpha\beta}^\nu = \Delta_{\sigma\mu}^\nu - \Delta_{\mu\sigma}^\nu$[14] could serve to describe electromagnetic field potential. A 'pure gravitational' field is present when $\varphi_\mu = \Lambda_{\mu\alpha}^\alpha = 0$, where φ_μ is the electromagnetic four potential. Thus, the vierbein-field h_a^ν defines both the metric tensor $g_{\mu\nu}$ and the electromagnetic four-potential φ_μ. Its sixteen components can be considered as the fundamental dynamical variables of the theory. The question arises as to the field equations that determine the vierbein-field. Similar to multiple previous field theories, the field equations were supposed to be derived from a variational principle, $\delta \int \{\mathcal{H}d\tau\} = 0$, where $\mathcal{H}$ depends on the *n*-bein field. By taking the variation of the action with respect to the variable h_a^ν, both Einstein and Maxwell field equations were recovered in first-order approximation (Einstein, 1928c, 226). Einstein concluded that the separation of the gravitational and electromagnetic field becomes arbitrary. An invariant difference between the two fields manifests itself only in the special case of weak fields (Einstein, 1928c, 227).

2.1 Reichenbach's Letter on Fernparallelismus-Field Theory and the Manuscript

As reported, at that time, Reichenbach was probably the only 'professional' philosopher that could make his way through the mathematical intricacies of such a theory. The attention of the actual work of scientists characterized the philosophical style of Reichenbach and the group of scholars that gathered around him in Berlin (Danneberg, Kamlah, and Schäfer, 1994Milkov and Peckhaus, 2013): a concrete, internal analysis of the structure of the latest scientific theories, rather than an abstract, external investigation of scientific reasoning as such (McMullin, 1970). As Reichenbach had done little more the two years before—after Einstein had published his affine-metric theory (Einstein, 1925b)— he was quick in reviewing Einstein's papers (Einstein, 1928ce) by sending him a few comments to receive some feedback:

> Dear Herr Einstein,
> I did some serious thinking on your work on the field theory and I reported that the geometrical

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[10] The terms *n*-bein, vielbeins, and vierbein are still in usage in English-speaking literature, although the expression 'tetrad' seems to have prevailed over vierbein.

[11] A generalization of the geodesic polar coordinates introduced by Gauss (1828) in his theory of surfaces; fo the use of such coordinate system in a relativistic setting, see e.g., Hilbert, 1917.

[12] The so-called Levi-Civita connection.

[13] The so-called Weizenböck connection.

[14] A three-index tensor called the 'the torsion tensor' in modern language.

construction can be presented better in a different form. I send you the ms. enclosed. Concerning the physical application of your work, frankly speaking, it did not convince me much. *If geometrical interpretation must be, then I found my approach simply more beautiful in which the straightest line at least means something.* Or do you have additional expectations for your new work? (Reichenbach to Einstein, Oct. 17, 1928 EA, 20-92; m.e.).

With his characteristic self-confidence, Reichenbach was blunt to express skepticism toward Einstein's and other attempts at a unified field theory. There are two aspects of this passage that should be separately considered.

In the first part of the passage, Reichenbach addresses the mathematical-geometrical aspect of Einstein's approach. Reichenbach, in the Appendix of the *Philosophie der Raum-Zeit-Lehre*, had provided a sort of classification of geometries based on the relations between the metric and the affine connection (or displacement) (Reichenbach, 1928a, §46; see Giovanelli, 2021). He regarded Einstein's new geometrical setting as nothing but a variation of the Weyl–Eddington–Schouten line of thought[15] , and thus naturally entered in his classification of geometries: it was a metrical space with vanishing curvature with a non-symmetric affine connection. Reichenbach's insistence on this point was probably related to Reichenbach's second point. If *Fernparallelismus* was nothing but one of the possibilities to explore in the Weyl–Eddington–Schouten lineage, Reichenbach could raise the same objection against Einstein's new theory that he had raised against the previous theories by Weyl (1918; 1921), Eddington (1921), and Einstein (1923; 1925).

Assume one wants to give a geometrical interpretation of a combined gravitational/electromagnetic field using the affine connection as a fundamental variable; in that case, one should at least provide a coordinate definition of the operation of parallel displacement of vectors before starting to search for the field equations. Otherwise, it is hard to understand in which sense one could test whether the latter made correct predictions. In particular, Einstein's geometry implies the existence of a straight line, a line of which all elements are parallel to each other, which is not identical with a geodesic (Einstein, 1928c, 224). However, as Reichenbach reported, the latter has no physical meaning in Einstein's theory. From this point of view, the toy theory he proposed in the §49 of Appendix to the *Philosophie der Raum-Zeit-Lehre* was preferable. Indeed, Reichenbach had used a geometrical setting cognate to that of Einstein's—a non-flat metric space with a non-symmetric connection. In such a geometry, the straightest and shortest lines were different. However, they were both physically 'realized,' in the paths of charged and uncharged test particles under the influence of electromagnetic and gravitational fields.

2.2 The Manuscript

The details of both arguments were presented in a typewritten manuscript (see fig. 1) enclosed in the letter, which has been preserved among Einstein's papers (Reichenbach, 1928b). It bears the title "Zur Einordnung des neuen Einsteinschen Ansatzes über Gravitation und Elektrizität." The first part of the manuscript introduces a classification of geometries. It is an early draft of the paper that Reichenbach submitted toward the end of January 1929 and was later published in the same year (Reichenbach, 1929d). The published paper differs mostly in the last part in which Reichenbach draws certain philosophical conclusions from his analysis. In the following, I will present the content of the manuscript. Reichenbach's exposition is straightforward but quite elliptic. Reichenbach could assume that the reader was familiar with the fundamental concepts of differential geometry and possibly with his presentation of the latter in the Appendix of the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a, §46). Because the latter has not been translated, in the ensuing pages, I will follow roughly Reichenbach's line of reasoning but introduce some explanatory remarks.

Reichenbach's Classification of Geometries. According to Reichenbach, the way Einstein introduced his Riemannian geometry with distant parallelism (Einstein, 1928ce) could lead to the impression that it was "a conceptual construction not yet covered by the previously developed geometric theory" (Reichenbach, 1928b, 1). In particular, the title of Einstein's study seems to connect, somewhat paradoxically, Riemannian geometry and parallelism at a distance, whereas Riemannian geometry is usually characterized by the absence of such parallelism. It seems then that Einstein had introduced "a hitherto unheard-of intermediate

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[15]I borrowed the expression "Gedanken–Reihe Weyl—Eddington–Schouten" from Einstein (Einstein to Besso, Jun. 5, 1925; CPAE, Vol. 15, Doc. 2). All these researchers retained the four-dimensional characteristic of physical spacetime, but introduced a manifold with a more general affine connection: by weakening the compatibility condition between the metric and affine connection, and thus introducing two sorts of curvature (Weyl, 1918b); by adopting a symmetric affine connection as the fundamental variable without reference to the metric (Eddington, 1921); by dropping the symmetry of the connection (Schouten, 1924).

Zur Einordnung des neuen Einsteinschen Ansatzes über Gravitation und Elektrizität.

Von Hans Reichenbach, Berlin.

§1. Die geometrische Grundlage.

Der neue Versuch Einsteins[*]), durch Abänderung der Riemannschen Geometrie zu einem Raumtyp zu gelangen, in dem neben der Gravitation auch die Elektrizität gefaßt werden kann, könnte die Vermutung erwecken, daß es sich hier um eine von der bisher entwickelten geometrischen Theorie noch nicht erfaßte Begriffsbildung handelt; insbesondere möchte man nach dem paradoxen Titel, der Riemann-Geometrie und Fernparallelismus vereinigt, vermuten, daß es sich hier um ein bisher nicht gekanntes Zwischengebilde zwischen Riemannscher und Euklidischer Geometrie handelt. Im folgenden soll gezeigt werden, daß dies nicht der Fall ist, daß vielmehr der neue Einsteinsche Raum in dem Gebäude der Weyl-Eddingtonschen Geometrie bereits seine genau (kennzeichnende logische Stelle besitzt.

Ich möchte zu diesem Zwecke an eine Darstellung [**]) anknüpfen, in der ich den erweiterten Raumbegriff, unter Benutzung Eddingtonscher Rechnungen, in seinem logischen Aufbau entwickelt habe. Der entscheidende Grundgedanke Weyls in seiner Erweiterung scheint mir der zu sein, daß er die Unabhängigkeit der durch die $\Gamma_{\mu\nu}^{\tau}$ gegebenen Verschiebungsoperation von der durch die $g_{\mu\nu}$ gegebenen Metrik erkannte; auf diesen Gedanken läßt sich die allgemeine Behandlung des Raumproblems aufbauen. Man denke sich, nachdem durch ein Koordinatensystem die topologische

[*]) A. Einstein, Riemann-Geometrie mit Aufrechterhaltung des Begriffes des Fernparallelismus. Berl.Ber.1928,Phys.-Math.Kl.XVII. Zitiert als E.I. A.Einstein, Neue Möglichkeit für eine einheitliche Feldtheorie von Gravitation und Elektrizität. Berl.Ber.1928,Phys.-Math.Kl.XVIII.Zitiert als E.II.
[**]) H.Reichenbach,Philosophie der Raum-Zeit-Lehre,Berlin 1928, de Gruyter. Zitiert als Ph.

construct [*Zwischengebilde*] between Riemannian and Euclidean geometry" (Reichenbach, 1928b, 1). Reichenbach aimed to demonstrate that this was not the case. According to Reichenbach, "Einstein's space has its precisely defined logical place in the structure [*Gebäude*] of the Weyl–Eddington geometry" (Reichenbach, 1928b, 1). To prove his point, Reichenbach resorted to the classification of non-Riemannian geometries that he had outlined in the Appendix to the *Philosophie der Raum-Zeit-Lehre*. The manuscript offers a more streamlined presentation of the lengthy §46 of the latter (Reichenbach, 1928a, §46; see Giovanelli, 2021 for more details). As in the book, Reichenbach presented Weyl's separation between the metric and the affine connection or displacement but using a notation taken from the German translation (Eddington, 1925) of Eddington's textbook on relativity (Eddington, 1923). However, Reichenbach generalized Eddington's presentation with Schouten (1922; 1922)'s idea that the affine connection can be non-symmetric.

Reichenbach attributes to Weyl (1918a) what he considered the fundamental achievement of modern differential geometry, the recognition of the independence of the so-called 'displacement' $\Gamma^\tau_{\mu\nu}$ and the metric $g_{\mu\nu}$. To briefly introduce these two notions, Reichenbach proceeds as follows. Let us assume that an arbitrary coordinate system is spread over a region such that each point is identified by a set of n numbers x_ν (where $\nu = 1, 2, 3, 4, \dots$). Riemannian geometry is based on the hypothesis that, in Einstein's notation (where summation over repeated indices is implied), the squared distance ds between two neighboring points, x_ν and $x_\nu + dx_\nu$ is given by:

$$ds^2 = g_{\mu\nu}dx_\mu dx_\nu \, . \qquad [3]$$

The coefficients $g_{\mu\nu} = g_{\nu\mu}$ are the components of the metric (or measurement) tensor—a set of $n(n+1)/2$ independent functions that serve to convert coordinate distances dx_ν between two closed-by spacetime points into actual distances. As the coordinates x_ν and $x_\nu + dx_\nu$ of two neighboring the numerical value of the distance ds between them can be obtained from [3]. A unique measure (up to a global choice of unit of measure) can be given to the so-called 'line element' ds, such that any distance can be compared with any other distance. In Euclidean geometry, it is always possible to introduce a coordinate system, the so-called Cartesian coordinate system, in which $g_{\mu\nu}$ are constant, but this is not so in the general case.[16]

It is the merit of Weyl to have introduced a generalization of such geometrical setting into relativistic literature. One can think of dx_ν as the components of a (contravariant) vector A^τ, n numbers A^μ ($A^1, A^2, A^3, A^4, \dots A^n$) that we associate with some point P and transform as per certain rules by the change of coordinates. In Euclidean geometry, it is always possible to introduce a Cartesian coordinate system in which two vectors are equal and parallel when they have the same components. However, this relation does not hold if we introduce curvilinear coordinates, e.g., polar coordinates. Although parallel vectors are still parallel in the new coordinate system, the equality of the components of two parallel vectors attached to two different points in space is not preserved.[17] Consequently, vectors at different points can no longer be directly compared. If one displaces a vector to a neighboring point dx_ν, one does not know whether the vector has remained the 'same' by simply examining its components. The

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[16]From the $g_{\mu\nu}$, one can calculate the

$$\Gamma^\tau_{\mu\nu} = -\begin{Bmatrix} \mu\nu \\ \tau \end{Bmatrix} = \frac{1}{2}g^{\tau\sigma}\left(\frac{\partial g_{\mu\sigma}}{\partial x_v} + \frac{\partial g_{\nu\sigma}}{\partial x_\mu} - \frac{\partial g_{\mu\nu}}{\partial x_\sigma}\right) \, . \qquad [4]$$

The $\Gamma^\tau_{\mu\nu}$ vanish identically in Euclidean geometry in Cartesian coordinates but not in non-Cartesian coordinates where the $g_{\mu\nu}$ are functions of the coordinates. We might want to determine whether it is possible to transform a given $g_{\mu\nu}$-system into the normal matrix $\bar{g}_{\mu\nu}$ with constant coefficients. By a suitable choice of the coordinate system, it is always possible to introduce the $\bar{g}_{\mu\nu}$ for a single point. However, one cannot establish in which case the variability of the $g_{\mu\nu}$ can be transformed away over larger regions of spacetime by simply examining the components of the $g_{\mu\nu}$. One requires to introduce a formal criterion. The latter was reported to be a certain combination $g_{\mu\nu}, \partial g_{\mu\nu}/\partial x_\sigma, \partial^2 g_{\mu\nu}/\partial x_\sigma \partial x_\tau$. It is called the Riemann tensor and can be considered as the gradient of the $g_{\mu\nu}$. If one uses the Christoffel symbols as a shorthand for the first derivates of the $g_{\mu\nu}$, the Riemann tensor can be written as follows:

$$R^\tau_{\mu\nu\sigma}(g) = -\frac{\partial}{\partial x_\tau}\begin{Bmatrix} \mu\sigma \\ \rho \end{Bmatrix} + \frac{\partial}{\partial x_\sigma}\begin{Bmatrix} \mu\tau \\ \rho \end{Bmatrix} - \begin{Bmatrix} \mu\sigma \\ \alpha \end{Bmatrix}\begin{Bmatrix} \alpha\tau \\ \rho \end{Bmatrix} + \begin{Bmatrix} \mu\tau \\ \alpha \end{Bmatrix}\begin{Bmatrix} \alpha\sigma \\ \rho \end{Bmatrix} \, . \qquad [5]$$

$R^\tau_{\mu\nu\sigma}(g)$ has n^4 components. The vanishing of the Riemann tensor is the necessary condition that, by an appropriate choice of coordinates, the metric coefficients assumed the values $\bar{g}_{\mu\nu}$.

[17]E.g., consider two unit vectors A^τ and $A^{*\tau}$ on a plane pointing along the x direction: one at the point at $(0, 1)$ and another at $(1, 0)$ in Cartesian coordinates. In this coordinate system, A^τ and $A^{*\tau}$ have the same components, i.e., they are equal and parallel. However, in polar coordinates r, ϑ (where r represents distance from the origin, and ϑ represents the angle that the point makes with the origin and the positive x-axis), A^τ has only a r component, whereas $A^{*\tau}$ has only a ϑ component. Nevertheless, they are still equal and parallel. Indeed, the vector $A^{*\tau}$ can be obtained by displacing A^τ parallel to itself along a circle. In polar coordinates, the components A^τ change at each point even though its length and direction remain the same.

'connection' (*Zusammenhang*) from a point to another is lost. Because the affine geometry is the study of parallel lines, Weyl (1918c) used to speak of the necessity of establishing an 'affine connection' (*affiner Zusammenhang*). However, because it is a relation of 'sameness' rather than parallelism that is relevant in this context, others, such as Reichenbach, prefer to speak of the operation of 'displacement' (*Verschiebung*), where the latter indicates the small coordinate difference dx_ν along which the vector is transferred.

Displacement. To reinstate the 'connection' one requires to introduce a rule for comparing vectors at infinitesimally separated points. Given a vector A^τ at x_ν in an arbitrary coordinate system, we need to determine the components of the vector $A^{*\tau}$ at $x_\nu + dx_\nu$ that is to be considered the 'same vector' as the given vector A^τ. The vector A^τ at the point $P(x^\nu)$ and the vector $A^\tau + dA^\tau$ at the point $P^*(x^\nu + dx^\nu)$ are the 'same vector,' if they satisfy the condition:

$$dA^\tau = \Gamma^\tau_{\mu\nu} A^\mu dx_\nu \,. \tag{6}$$

The quantity $\Gamma^\tau_{\mu\nu}$ is known as the affine connection or displacement. It has three indices, i.e., entails τ possible combinations of $\mu \times \nu$ coefficients, which can vary arbitrarily from point to point, i.e., in the general case, are functions of x_ν. Because in general $\Gamma^\tau_{\mu\nu} \neq \Gamma^\tau_{\nu\mu}$, the $\Gamma^\tau_{\mu\nu}$ has $n \times n^2$ coefficients.

Starting with a vector A^τ at a point P with coordinates x_ν, one may transfer it along dx_ν to the point P^* with coordinates $x_\nu + dx_\nu$; using [6], one can compute the components of the vector $A^{*\tau}$ at P^* that is equal and parallel to A^τ at P in any coordinate system. One can continue this process step after step from A^τ to $A^{*\tau}$ to $A^{**\tau}$; as the size of each displacement goes to 0, one obtains a continuous curve $x_\nu(s)$:

$$\frac{dA^\tau}{ds} = \Gamma^\tau_{\mu\nu} A^\mu A^\nu \,. \tag{7}$$

If a vector is given at P, this vector may be moved parallel to itself along the curve from P to P^*; for given initial values of A^τ, [7] yields the unknown components of the vector $A^{*\tau}$, which is being subjected to a continuous parallel displacement, in which each step is labeled by the parameter s. Thus, [7] picks up the *straightest among all possible curves* between P and P^*. The vector A^τ at P and $A^{*\tau}$ at P^* are defined to be the 'same' vector at different points along the same straightest line, i.e., they are equal in direction and length. Thus, the displacement allows for comparing lengths, albeit only along the same straightest line. In general, the vector $A^{*\tau}$ at P^*, at a definite distance from P, is coordinated to the vector A^τ at P by:

$$A^{*\tau} - A^\tau = \int_s \Gamma^\tau_{\mu\nu} A^\mu dx_\nu \tag{8}$$

where the integral s depends on the path (i.e., we will get a different vector $A^{*\tau}$ if we choose a different path). Thus, in general, it is meaningless to speak of the 'same vector' at different distant points. If two vectors are equal in direction and length ($A^{*\tau} - A^\tau = 0$) at P, whether they are equal in direction and length at P^*, depends on the path they are transported along. In the general case, parallel transport is non-integrable (Reichenbach, 1928b, 2). Thus, the operation of displacement is inherently *near-geometrical*.

Metric. The displacement allows to establish whether two vectors are the 'same,' i.e., having the same length and the same direction. However, it does not provide a measure of the length of differently directed vectors. For this purpose, the notion of dot product of two vectors must be introduced, which, taking the components of the two vectors, returns a single number. In particular, the squared length l of a vector is given by the dot product of the vector with itself l^2. In an arbitrary coordinate system, the latter takes the form:

$$l^2 = g_{\mu\nu} A^\mu A^\nu \,, \tag{9}$$

where the $g_{\mu\nu}$ is the metric. If A^τ is considered to correspond to dx_ν, [9] is nothing but [3] and l corresponds to ds. However, this notation is more general. One can take A^τ to be dx^ν/ds, (where ds is the timelike interval, which is an element of the four-dimensional trajectory of a moving point), l is the length of the four-velocity vector u^ν, d^2x^ν/ds^2 is the four-acceleration vector. Using a somewhat idiosyncratic language, Reichenbach calls the *metric* the operation of *distant-geometrical* comparison of lengths of vectors:

$$l^* - l = \sqrt{g_{\mu\nu} A^\mu A^\nu} - \sqrt{g^*_{\mu\nu} A^{*\mu} A^{*\nu}} \,. \tag{10}$$

In other words, if two vectors are of equal length ($l^* - l = 0$) at P, they will be equal length at P^*, irrespective of the path they are transported along. According to Reichenbach's parlance, for a manifold to be a metrical space, it is insufficient that the dot product is defined at every point (i.e., it is possible to compare the lengths of vectors at the same point in different directions); moreover, the dot product should not change under parallel transport. In this case, the length of vectors is said to be 'integrable.'

Relation between metric and displacement. Reichenbach had defined two operations, a near-geometrical operation of comparison of vectors, i.e., the displacement, and a distant-geometrical operation, i.e., the metric. The two operations relate to two different subjects: "the metric says nothing about the comparison of direction, while the displacement does not provide a measure of the vector length" (Reichenbach, 1928b, 1). Nevertheless, "the two operations can meet if the length of two vectors A^τ and $A^{*\tau}$ is compared at different locations" (Reichenbach, 1928b, 1). Although the purely affine notion of vectors is insufficient to define the length of a vector in general, it does allow for comparing lengths of parallel vectors. In this case, the two operations, the displacement and the metric, refer to a common subject. Therefore, they might contradict each other. Two vectors at different points that are of unequal lengths $l^* - l \neq 0$ as per [10] might be of equal lengths $A^{*\tau} - A^\tau = 0$ as per [8] depending on what the path is selected between these two points (Reichenbach, 1928b, 2).

The most general method of avoiding this difficulty would be to consider the two operations—the metric and the displacement—as two mutually independent operations. However, Reichenbach considered it reasonable to single out the class of '*balanced spaces*' (*ausgeglichener Raum*), i.e., spaces in which certain degree of compatibility between the metric and displacement is assured. The metric and displacement are two independent geometrical operations. Thus to define a 'balanced space,' one requires to impose their compatibility as a separate condition (Reichenbach, 1928b, 2-3). Following Eddington (1921), Reichenbach introduced a mathematical object that determines how much the length l of a vector changes $d\left(l^2\right)$ under parallel transport:

$$d\left(l^2\right) = (\underbrace{\frac{\partial g_{\mu\nu}}{\partial x_\sigma} + \Gamma_{\mu\sigma,\nu} + \Gamma_{\nu\sigma,\mu}}_{\longrightarrow\ K_{\mu\nu,\sigma}})A^\mu A^\nu dx_\sigma \tag{11}$$

The tensor[18] $K_{\mu\nu,\sigma}$ measures the degree compatibility of metric and connection. The metric and connection are completely compatible, if [11] vanishes:

$$K_{\mu\nu,\sigma} = 0. \tag{12}$$

A space in which the condition [12] holds is called a 'metric space,' otherwise a 'displacement space.' Reichenbach emphasized that "[i]t is of considerable importance that this condition does not directly lead to a Riemannian space," because "the latter requires an additional restrictive condition" (Reichenbach, 1928b, 3):

$$\Gamma^\tau_{\mu\nu} = \Gamma^\tau_{\nu\mu}. \tag{13}$$

By imposing this condition, one obtains the Riemann connection:[19]

$$\Gamma^\tau_{\mu\nu} = -\left\{\begin{matrix}\mu\nu\\\tau\end{matrix}\right\} \tag{14}$$

The components of $\Gamma^\tau_{\mu\nu}$ have the same numerical values of the so-called Christoffel symbols of the second kind (up to a sign) because they are calculated from the metric $g_{\mu\nu}$ and its first derivatives.[20] If one starts with a symmetric metric $g_{\mu\nu}$, the Christoffel symbols are, so to speak, indeed the only possible choice; thus, the complete compatibility of the metric and the connection is assured from the outset. However, if one defines the operation of displacement independently from the metric, the Riemannian connection [14] appears only as a special case that is achieved by introducing a series of arbitrary 'specializations.' Therefore, Weyl's formalism opened a vast array of possibilities that physicists hoped to exploit to accommodate the electromagnetic field in the geometrical structure of spacetime. In this particular context, it is important to realize that "*[t]he general metric space*" given by [12] is "*different*

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[18]The non-metricity tensor in modern parlance.
[19]Also called the Levi–Civita connection.
[20]See above, fn. 16.

from the Riemannian space; the Riemannian space is the specialization of the metric space given by [13]"
(Reichenbach, 1928b, 3).

While previous approaches used a type of displacement space (Weyl)[21] or were even satisfied with
an unbalanced space (Eddington),[22] the 'new' Einstein's approach uses a metric space. According to
Reichenbach, "Einstein's idea in [Einstein, 1928e] comprises introducing a different specialization of the
general metrical space [13]. He requires that beyond the condition [12], one demands that the transfer of
direction given by [6] is integrable" (Reichenbach, 1928b, 3). If the transfer of length and direction is
integrable, a vector set up in P denotes a 'congruent' vector in every other place without reference to a
path of transportation. Integrability occurs only in a particular class of spaces in which it is allowable
to speak of the 'same' vector at two different distant points P and P^*. Spaces in which the direction is
integrable are characterized by the fact that $\Gamma^\tau_{\mu\nu}$ can be made to vanish everywhere by a suitable choice of
coordinates, i.e., by introducing linear coordinates (such as Cartesian coordinates). To determine whether
this is the case, from the connection alone, one can construct the following tensor:

$$R^\tau_{\mu\nu\sigma}(\Gamma) = \frac{\partial \Gamma^\tau_{\mu\nu}}{\partial x^\sigma} - \frac{\partial \Gamma^\tau_{\mu\sigma}}{\partial x^\nu} + \Gamma^\tau_{\alpha\nu}\Gamma^\alpha_{\mu\sigma} - \Gamma^\tau_{\alpha\sigma}\Gamma^\alpha_{\mu\sigma}\,, \qquad [15]$$

which is required to vanish:

$$R^\tau_{\mu\nu\sigma}(\Gamma) = 0\,. \qquad [16]$$

As Reichenbach reported, it is important that the condition [16], the vanishing of the Riemann tensor, "can
be formulated as a condition only for the $\Gamma^\tau_{\mu\nu}$, *without* making any assumption about the relations of the
$\Gamma^\tau_{\mu\nu}$ to the $g_{\mu\nu}$. It is important that for [16], the symmetry $\Gamma^\tau_{\mu\nu}$ as per [13] is not assumed" (Reichenbach,
1928b, 4).

Usually, one introduces the additional specialization "[16] only when one goes from the Riemannian
space to the Euclidean space" (Reichenbach, 1928b, 3). However, because the condition of symmetry is
not imposed, Einstein could introduce an alternative geometry. Einstein's space is thus characterized by
the conditions [12] and [16]; the latter is a condition for the $\Gamma^\tau_{\mu\nu}$ alone while the former is a rule for the
relationship between the $\Gamma^\tau_{\mu\nu}$ and $g_{\mu\nu}$. It is a metric space with a distant parallelism; however, it differs
from the Euclidean space by the asymmetry of the $\Gamma^\tau_{\mu\nu}$. Only by imposing the conditions [12], [13], and
[16], one obtains the Euclidean space. Reichenbach summarizes his classification in fig. 2. As one can
infer from this scheme, according to Reichenbach, the *Fernparallelismus* space "is not a special case of the
Riemannian space," as Einstein had claimed, "but should be placed near to him" (Reichenbach, 1928b, 5).
Its possibility is based on what Reichenbach called the *exchangeability of the specializations*, "leading from
the metric to the Euclidean space" (Reichenbach, 1928b, 5). Indeed, because it is shown in fig. 2, there
are two paths from the general metrical space to the Euclidean space. They are defined by *exchanging* the
order of the conditions [13] and [14]. From a geometrical point of view, Einstein's space can be described
as a space in which there are parallels but not parallelograms. In this type of space, "as in general metric
space, the straightest lines and the shortest lines fall apart" (Reichenbach, 1928b, 6).

Einstein's Unified Field Theory. Using this semi-technical presentation, Reichenbach was able to show
that Einstein's *Fernparallelismus* geometry was simply one of the possibilities implicit in the Weyl–
Eddington–Schouten classification. Starting from the two structures $g_{\mu\nu}$ and $\Gamma^\tau_{\mu\nu}$, one can decide to drop
the condition [12] or [13] or [16]. In this manner, one can envisage at least four possibilities (see Infeld,
1928). Einstein's *Fernparallelismus* was just one of them that had not yet been exploited. The continuity
with the previous attempts was obscured by the fact that Einstein introduced an unsual formalism in
which the $\Gamma^\tau_{\mu\nu}$ and the $g_{\mu\nu}$ are considered as functions of a set of parameters h^ν_α (the ν projections on the
α orthogonal unit vectors forming the so-called n-bein):[23]

$$g_{\mu\nu} = h_{\mu\alpha}h_{\nu\alpha} \qquad \Gamma^\tau_{\mu\nu} = -h^\tau_\alpha \frac{\partial h_{\mu\alpha}}{\partial x_\nu}$$

It can be shown that this *Ansatz* satisfies the condition [12] and [16] (Reichenbach, 1928b, 6). The $\Gamma^\tau_{\mu\nu}$
corresponds to $\Delta^\nu_{\mu\sigma}$ in Einstein's paper (see eqs. [1] and [2]).

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[21]By relaxing the metric-compatibility condition $K_{\mu\nu,\sigma} = \kappa_\sigma g_{\mu\nu}$, one arrives at a 'displacement space.' If one imposes the
condition $\Gamma^\tau_{\mu\nu} = \Gamma^\tau_{\nu\mu}$, one obtains Weyl space as a special case.

[22]Eddington (1921) moved beyond Weyl, introducing a symmetric $\Gamma^\tau_{\mu\nu}$ without reference to the metric. Lengths, even at
the same point in different directions, are not comparable.

[23]Unlike Einstein, Reichenbach assigned Greek letters to both the *Koordinaten-Indizes* and *Bein-Indizes*.
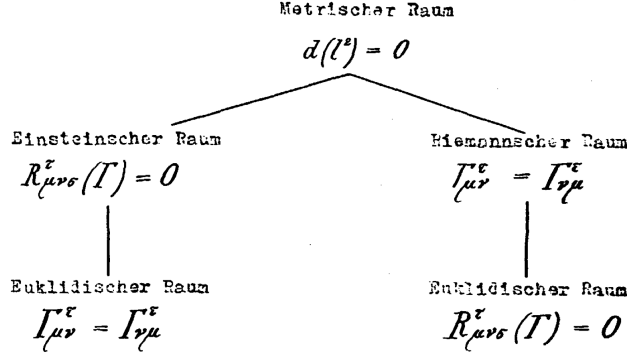
Figure 2: Diagram of Reichenbach's classification of geometries Reichenbach, 1928b, 5

After having presented the n-bein mathematical apparatus very briefly, Reichenbach raised certain concerns about its physical interpretation. In addition to complaining about the typographical errors in certain formulas (Goldstein and Ritter, 2003, 121), Reichenbach was ultimately not very impressed by Einstein's results. As he rightly reported, "[t]he derivation of the Maxwellian and gravitational equation from a variational principle was already achieved by other approaches" (Reichenbach, 1928b, 6), like, say, Einstein–Eddington purely affine theory. Moreover, in the first part of the manuscript, Reichenbach had demonstrated that Einstein's theory could be classified as yet another variation of the Weyl–Eddington approach, based on the independence of two operations of comparison of vectors based on the $g_{\mu\nu}$ and $\Gamma^\tau_{\mu\nu}$. According to Reichenbach, as in previous theories, a "real physical achievement is obtained only if, moreover, the operation of displacement is filled with physical content" (Reichenbach, 1928b, 7). In Reichenbach's view, unless the geometrical operations introduced into the foundations of the theory can be directly identified with the behavior of real objects, the theory, once the field equations have been found and suitable solutions calculated, cannot be compared with experience. The success of relativity theory lay in the fact that spacetime measurements performed with real physical systems (rods and clocks, light rays, free-falling particles, etc.) are better predicted than in previous theories. However, in Einstein's *Fernparallelismus* theory, the $\Gamma^\tau_{\mu\nu}$ did not have any physical meaning from the outset.

However, Reichenbach proudly claimed that "it was previously shown by me that the latter result can be achieved," (Reichenbach, 1928b, 7)—in §49 of the Appendix of the *Philosophie der Raum-Zeit-Lehre*. Reichenbach noted the similarity between Einstein and his approach. In the book, he had used a metric space with a non-symmetric connection. Einstein's space is simply characterized by an additional condition that the Riemann tensor vanishes [16]. Another similarity is that "skew-symmetric part of the $\Gamma^\tau_{\mu\nu}$ is used to characterize the electrical field" (Reichenbach, 1928b, 7) even in a different manner. However, Reichenbach had suggested that one can tentatively adopt the velocity four-vector u^τ as the physical realization of the operation of displacement $\Gamma^\tau_{\mu\nu}$. In this manner, this geometrical structure has a clear physical meaning. Because the $\Gamma^\tau_{\mu\nu}$ is non-symmetric, straightest and shortest lines do not coincide. Charged mass points move (i.e., their velocity four-vector is parallel-transported) along the straightest lines, and uncharged particles move along the straightest lines that are at the same time the shortest ones (or rather, the timelike worldlines of extremal length).[24] Thus, Reichenbach insisted that it would be preferable if one could provide a physical interpretation "of the so sharply distinct straightest line" (Reichenbach, 1928b, 7). However, Reichenbach concluded he had been "not able to identify a sharply distinguished interpretation of the operation of displacement for the new Einsteinian approach"

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[24]In a manuscript (HR, 025-05-10) that he had sent to Einstein (Einstein to Reichenbach, Mar. 24, 1926; CPAE, Vol. 15, Doc. 235) and later became §49 of the Appendix to *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a, §49), Reichenbach came out with the following theory. He introduced a non-symmetric affine connection $\Gamma^\tau_{\mu\nu}$, which is the addition of a symmetric displacement (the Christoffel symbols) and a skew-symmetric tensor with two lower indices:

$$\Gamma^\tau_{\mu\nu} = \gamma^\tau_{\mu\nu} + \varphi^\tau_{\mu\nu} \qquad [17]$$

$$\gamma^\tau_{\mu\nu} = -\begin{Bmatrix} \mu\nu \\ \tau \end{Bmatrix} \qquad \varphi^\tau_{\mu\nu} = -g_{\mu\sigma}f^\tau_\nu \frac{\partial f^{\sigma\rho}}{\partial x_\rho} \qquad [18]$$

$\varphi^\tau_{\mu\nu}$ entails the left-hand side of Maxwell's equations with sources. In the presence of charge, the $\Gamma^\tau_{\mu\nu}$ is non-Riemannian, charged particles move on the straightest lines, and uncharged particles on the shortest lines. In the absence of charge, $\varphi^\tau_{\mu\nu}$ vanishes, and the connection reduces to that of Riemannian geometry. Einstein criticized this definition for being overly artificial (Einstein to Reichenbach, Mar. 31, 1926; CPAE, Vol. 15, Doc. 239). However, Reichenbach wanted to demonstrate that most 'geometrizations' were indeed artificial (Reichenbach to Einstein, Apr. 4, 1926; CPAE, Vol. 15, Doc. 244).

(Reichenbach, 1928b, 7).

2.3 Einstein's Reply and his Comments on Reichenbach's Manuscript

Reichenbach's claim that, in his unified field theory, the straightest lines have physical meaning was certainly questionable. Einstein had already reported a few years before that Reichenbach's theory was untenable (Giovanelli, 2016b). The charged particles of different charge-to-mass ratio e/m, starting from the same initial conditions, cannot travel on the same paths of the 'same' connection. However, more generally, Einstein disagreed with Reichenbach's philosophical requirement that the geometrical/kinematical concepts should receive a coordinate definition, *ex ante*, separately from the dynamical equations of the theory. At first sight, this requirement might sound rather 'Einsteinian.' However, Einstein had later insisted that possible experiences must correspond not to geometry as an isolated part of a physical theory but only to the theory as a whole (Einstein, 19211923a19241925c1926). Thus, Einstein did not comment on Reichenbach's epistemological remarks. However, he expressed certain mild skepticism toward Reichenbach's classification of geometries:

> Dear Mr. Reichenbach,
>
> In my opinion, the logical presentation of the theory that you proposed is possible; however, it is not the simplest from a logical point of view. The best logical classification, in my view, seems to be the following: One consider theories in which the local comparison of vector length is given as meaningful (zero-metric the $g_{\mu\nu}$ are given only up to a factor). For the manifolds of this type, additional specializations are possible.
>
> 1. Neither the comparison of length at distance nor of direction is meaningful (Weyl)
> 2. Comparison at distance of length but not of direction is meaningful (Riemann)
> 3. Comparison at distance of directions but not of lengths (not considered yet)
> 4. Comparison at distance of length and of direction is meaningful (Einstein)
>
> Of course, one can start with the displacement law and specialize it, on the one hand, with the introduction of a metric, and, on the other hand, with the introduction of integrability properties as you have done; however, this is less simple and natural.
>
> The naturalness of the case of field structure that I have considered seems undeniable to me. Whether this construction contains deeper traits of reality might become clear to me only in the next months because the decision of the problem to solve are in no way simple (Einstein to Reichenbach, Oct. 19, 1928; CPAE, Vol. 16, Doc. 292)

Einstein preferred to present his geometrical settings not as a type of affine space but as an intermediate case, situated between Riemannian and Euclidean geometry. Weyl's geometry does not allow a comparison of either lengths or directions of vectors at a finite distance. Riemann's geometry only permits a comparison of lengths. Einstein's 'new' geometry allows both. According to Einstein, Reichenbach's classification was possible but not natural. This opinion, however, strikes with the modern point of view, which would identify Einstein's classification possible but Reichenbach's more natural (Goldstein and Ritter, 2003, 121Sauer, 2006). Einstein probably was keen to present *Fernparallelismus* with its new n-bein formalism as an alternative rather than a continuation of the failed Weyl–Eddington–Schouten approach. However, Reichenbach had the opposite interest in insisting on the continuity of the new *Fernparallelismus* approach with previous unification attempts. In this manner, he could hit them all out with one strike using the same argument.

To mitigate his criticism, in a note added by hand to the typescripted letter, Einstein invited over Reichenbach and his second wife for tea on November 21, adding that Erwin Schrödinger would attend. Although the details of this meeting are not known, as one can infer from the subsequent turn of the events, they probably discussed Einstein's last work; it is hard to imagine that the difference of their philosophical approaches did not emerge during those conversations. A few weeks after he wrote to Reichenbach, Einstein was asked to contribute to a *Festschrift* on the occasion of the seventieth birthday of Aurel Stodola, Professor of Mechanical Engineering at the ETH (Honegger to Einstein, Nov. 2, 1928; CPAE, Vol. 16, Doc. abs. 732; Einstein to Honegger, Nov. 14, 1928; CPAE, Vol. 16, Doc. abs. 750; cf. Einstein, 1929d). Einstein agreed to contribute with a semi-popular review article on his new theory, *Über den gegenwärtigen Stand der Feldtheorie* (Einstein, 1929f). The manuscript was submitted on December 10 (see Sauer, 2006). Einstein's philosophical stance took a turn that Reichenbach probably did not predict.

Einstein insisted on the speculative nature of the new theory, which, however, he presented as a continuation of the same strategy that was successful in his search for the field theory of gravitation:

individuate a suitable field structure, the $g_{\mu\nu}$, and search for simplest differential generally covariant equations that can be obeyed by the $g_{\mu\nu}$. For general relativity, the choice of the $g_{\mu\nu}$ was suggested by a physical fact, the equivalence principle. However, in the search for a more general mathematical structure that would include the electromagnetic field, Einstein continued, "the experience does not give—so it seems—any starting point" (Einstein, 1929f, 128). Thus, the only hope is to develop a theory "in a speculative way" (Einstein, 1929f, 128). To solve this problem, the physicist must venture along "a purely intellectual path" having as only motivation the deep conviction of the "formal simplicity of the structure of reality" (Einstein, 1929f, 127). The belief in the fundamental simplicity of the real is "so to speak, the religious basis of the scientific endeavor" (Einstein, 1929f, 127).

Indeed, for *Fernparallelismus*, no attempt was made to give a direct physical meaning to the fundamental field variables h_a^ν. One starts from this mathematical structure and then searches for the simplest and most natural field equations that the vierbein-field can satisfy (Einstein, 1929f, 131). The physical soundness of the field equations thus found can be confirmed only by integrating them, which was usually a very difficult task. Einstein warned his readers of the dangers of proceeding "along this speculative road" (Einstein, 1929f, 127). In a footnote, Einstein even endorsed "Meyerson's comparison with Hegel's program [*Zielsetzung*]" which "illuminates clearly the danger that one here has to fear" (Einstein, 1929f, 127).

3 The *Vossische Zeitung* Affair. The Einstein–Reichenbach Falling-Out

3.1 *Fernparallelismus in the Daily Press*

At about the same time, Einstein's theory had started attracting irrational attention in the daily press. On November 4, the *New York Times* announced the prospect of another epoch-making breakthrough in an article bearing the tabloid-like headline: 'Einstein on Verge of Great Discovery; Resents Intrusion.' The author of the piece, Paul D. Miller, gave an account of how he had succeeded in visiting Einstein in his Berlin home. Despite expressing resentment for being interrupted by reporters, Einstein did not hesitate to feed the press's need for sensationalism. He told Miller that he was "treading on the edge of a great scientific discovery, one that will startle the world far more than the relativity theory" (Miller, 1928). Einstein was, however, "unwilling to speak" about the details "until he is satisfied with the presentation" (Miller, 1928). Indeed, 10 days later, on November 14, the *New York Times* doubled down with an article entitled "Einstein Reticent on New Work; Will Not 'Count Unlaid Eggs'" (cit. in Pais, 1982, 346).

As it turned out, difficulties with the theory had started to become apparent by the end of 1928. A few days after sending his manuscript for the Stodola *Festschrift*, he wrote to Hermann Müntz that he had the "insolent idea [*freche Idee*]" of throwing "the Hamiltonian principle overboard" because it allowed too many possibilities. This alternative approach (see Sauer, 2006, 4.3) turned out to be "a more subtle task" than Einstein initially considered. Thus, a few days in late December, he got back to the "old Hamilton method once again" (Einstein to Müntz, Dec. 18, 1928; CPAE, Vol. 16, Doc. 341). However, toward the end of the year, Einstein gave up again on the 'variational approach' (Einstein to Müntz, Dec. 27, 1928; CPAE, Vol. 16, Doc. 351). The new result was presented in a brief paper, completed by January 5, 1929. Einstein anticipated the skepticism of his colleagues because the theory was incapable of addressing the quantum problem. However, he was confident that the spacetime approach would come back in fashion again and the "statical craze"[25] would fade (Einstein to Besso, Jan. 5, 1929).

The manuscript was submitted on January 10 for publication in the *Sitzungsberichte* Prussian Academy (Einstein, 1929g). On January 11, 1929, Einstein issued a brief statement to the press (CPAE, 16; abs. 822). The *New York Times* immediately followed up with a another sensationalistic article: "the length of this work—written at the rate of half a page a year is considered prodigious when it is considered that the original presentation of his theory of relativity filled only three pages" (*New York Times*, January 12, 1929, cit. in Pais, 1982, 346). Indeed, it was puzzling that an abstract theory might identify such resonance among laypeople. Surprised by this reaction, Einstein issued a new statement to the *Jewish Telegraphic Agency* on January 14, insisting that the theory was a "purely mathematical extension of the general theory of relativity"; there was nothing "to be excited about it", and he could not understand "why the newspaper should take an interest in it" (CPAE, Vol. 16, Doc. 370). In private correspondence, he admitted his partial responsibility for the craze because he "may have alluded to it in speaking with one or another of my friends" (Einstein to Kerkhof, Jan. 16, 1929; CPAE, Vol. 16, Doc. 373). Although Einstein himself made certain revelation to the press, he could not have been the only source of these rumors, which were often misleading (see Pais, 1982, 346). As seen, Einstein had discussed the theory with Reichenbach in late 1928, in the presence of Schrödinger, and indeed, he will soon be accused of being one of the 'leakers.'

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[25]That is the new quantum mechanics.

In this atmosphere of excitement, Reichenbach was asked by the *Vossische Zeitung*—at that time the most renowned German daily newspaper—to write a brief account of Einstein's new theory. Taking advantage of his insider knowledge, Reichenbach had, in fact, continued to work on *Fernparallelismus*. On January 22, he submitted to the *Zeitschrift für Physik* an extended version of the fairly technical manuscript that he had sent to Einstein in October (Reichenbach, 1929d). On the same day, he finished a less technical paper for the *Zeitschrift für Angewandte Chemie* that was published at the beginning of February (Reichenbach, 1929b). Moreover, Reichenbach was quick to put on paper a more popular exposition of the theory that was published in the *Vossische Zeitung* on January 25 (Reichenbach, 1929c). The *Vossische Zeitung* premised the article, claiming that it was meant to give the readers an account of "Einstein's new work [. . .]—if only to prevent the emergence of public misunderstanding about the contents of the theory, which is above all of a purely factual interest" (Reichenbach, 1929c).

3.2 Reichenbach's Article for the Vossische Zeitung

Reichenbach's article does not seem, at first, particularly noticeable. With his usual clarity, he gave an overview of the unified field theory program. "The aim of the new theory," he wrote, "is not so new at all—it has been pursued with great tenacity by a number of mathematicians and physicists for 10 years now" (Reichenbach, 1929c; tr. 1978, 1:261). The great achievement of relativity theory was the combination of a series of physical facts about the gravitational field under a single law; yet, the theory could not incorporate the electromagnetic field. "Thus, two vast bodies of laws stood at the pinnacle of physics," Einstein's gravitational field equations and Maxwell's electromagnetic field equations (Reichenbach, 1929c; tr. 1978, 1:261). However, these two sets of equations had "nothing to do with each other; the world of physics was divided into two kingdoms: one ruled by Einstein, and the other by Maxwell" (Reichenbach, 1929c; tr. 1978, 1:261). As Reichenbach rightly noticed, "[t]he temptation to attempt a supreme union was irresistible: however, nature proved to be more stubborn than had been anticipated" (Reichenbach, 1929c; tr. 1978, 1:261).

Reichenbach introduced the readers of the *Vossische Zeitung* to Weyl's (1918a) "initial attempt to develop a unified field theory for gravitation and electricity", by creating "the apparatus of which others subsequently made use, including, finally, Einstein himself" (Reichenbach, 1929c; tr. 1978, 1:261). A series of approaches were attempted along these lines, he continued, most notably by Eddington (1921). "Einstein attempted out a number of theories, all tending in this same direction", initially following Weyl–Eddington line[26] but without success (Reichenbach, 1929c; tr. 1978, 1:261). "But today," Reichenbach went on, "Einstein has taken a new step, deviating somewhat in its mathematical apparatus from his previous accounts, and this time he is firmly convinced of its significance" (Reichenbach, 1929c; tr. 1978, 1:262). As Reichenbach reported, the theory seems to have reached results that went beyond those of previous unification attempts:

> Indeed, the new theory succeeds in *uniting* the fundamental laws of relativity mechanics and the fundamental laws of electricity into a single formula. As per this formula, there is only one substance, the 'field,' and only one law of the universe; the field is composed of electrical and gravitational components, and all these components are united under a single formula. *Einstein was able to show that the previously known laws can be derived from this formula such that it signifies the subordination of the two formerly divided realms under a higher law. Yet, the* new *formula achieves still more*; it represents the older theory of two systems as a special case and makes *new* assertions concerning the relation between gravitation and electricity in relatively complicated fields. Thus, *the new theory is of more than merely formal significance because it asserts the existence of an effect of gravitation upon electrical events and vice versa.* It is not yet possible to form a picture of how this connection will work out in detail from a physical standpoint. In particular, it remains an open question whether the new theory will enable scientists to solve the puzzle of quantum theory, which itself represents a peculiar combination of mechanics and electricity theory (Reichenbach, 1929c; tr. 1978, 1:262; m.e.).

This seemingly descriptive passage contains a philosophically relevant point that is worth highlighting. Reichenbach reported that the novelty of *Fernparallelismus* consisted in the fact that it no longer seeks to establish a formal synthesis between already established theories; instead, it produces new laws, of which gravitational and electromagnetic field equations are only a first approximation. For strong fields, there would be a much closer interdependence between electromagnetism and gravitation. In principle, the theory could receive experimental proof if the effects predicted did not remain beyond the threshold of experimental detection. However, the problem of the constitution of matter or the quantum problem

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[26]Reichenbach probably refers to Einstein (1923; 1923; 1923; 1925), in which Einstein explored different theories based on non-Riemannian four-dimensional geometry. Reichenbach never mentions Einstein's interest for Riemannian 5D theories (Einstein, 1927Kaluza, 1921).

were far from being satisfactorly addressed. Thus, Reichenbach concluded that "for the time being, no pronouncement can be made concerning the physical significance of the theory" (Reichenbach, 1929c; tr. 1978, 1:262).

Reichenbach was keen on emphasizing that the present situation "was different when the general theory of relativity made its first public appearance" (Reichenbach, 1929c; tr. 1978, 1:262). Einstein's theory of gravitation was "worked out in all its consequences, which had already passed its first great empirical test and therefore justly deserved widespread public interest" (Reichenbach, 1929c; tr. 1978, 1:262). However, "the latest extension of the theory is only a first draft, lacking the *convincing power* of the original relativity theory because of the very formal method by which it is established" (Reichenbach, 1929c; tr. 1978, 1:262; m.e.). This criticism was not new, and Reichenbach had denounced the lack of 'convincing power' of the previous unified field theories as well.[27] However, in this context, Reichenbach wanted most of all to exert a calming influence on the public discussion. Surely, because "the hypothesis is presented by a man of the experience and theoretical insight of Einstein, it must be taken completely seriously as science" (Reichenbach, 1929c; tr. 1978, 1:262). However, until "the new theory has been thoroughly worked over, no leads are available for the public discussion of this matter" (Reichenbach, 1929c; tr. 1978, 1:262).

3.3 Einstein's Reaction and Reichenbach's Reply

On the January 25, 1929, the very same day Reichenbach's article was published, Einstein sent an angry letter to the editorial office of the *Vossische Zeitung*: "I was surprised," he wrote, "that your normally very respectable newspaper has facilitated a colleague's tactless behavior toward me" (Einstein to Vossische Zeitung, Jan. 25, 1929; EA, 73-229). As Einstein recounted, "Dr. Reichenbach asked me for information about my new work and I willingly provided him with the information he requested" (Einstein to Vossische Zeitung, Jan. 25, 1929; EA, 73-229). However, Reichenbach, "[w]ithout waiting for the work to appear, without asking me or even notifying me," made this information public. According to Einstein, this behavior "was absolutely contrary to academic mores" (Einstein to Vossische Zeitung, Jan. 25, 1929; EA, 73-229).

Einstein's reaction caught the editors of the *Vossische Zeitung* by surprise. Montague 'Monty' Jacobs, the responsible of the *Feuilleton*, that is, the cultural pages of the *Vossische Zeitung*. Jacobs apologized and rushed to defend the newspaper's behavior (Jacobs to Einstein, Jan. 26, 1929; CPAE, Vol. 16, Doc. 383). He forwarded a copy of Einstein's letter to Reichenbach who was dumbfounded by the allegations. As Reichenbach wrote to Jacobs on January 27, he was deeply upset by Einstein's letter, especially "after years of work for his theory and the recognition of his person" (Reichenbach to Jacobs, Jan. 21, 1929; EA, 20-098). On the same day, Reichenbach replied with a long and very forthright letter to Einstein himself:

> Dear Mr. Einstein, [...]
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> I am deeply hurt by your behavior toward me. If you thought you ought to bring any reproach against me, you should have obviously addressed me directly and not the *Vossische Zeitung*. The responsibility for my article falls on me and not on the newspaper. I have deserved that much personal respect—after all that I have done for the theory of relativity and the recognition of your personal achievements in public—that you cannot simply bypass me. Nevertheless, I would like to reply to you directly because I cannot accept that you will insert a third party between us.
>
> When I recently came to you so that you could tell me something about your new theory, I did really come out of scientific interest—you can believe me. In the next few days, I received some requests for information based on the sensational press releases published up to then. After I received numerous such inquiries, since, after all, I write a lot for the general public, I have written the requested articles. The deciding factor was the hope that I could do you a service. I imagined that you must have not liked the sensational presentation of the previous reports and that nothing would matter more to you than to keep the public opinion from interfering in a matter that belongs to the experts. Let's be honest: if anyone was entitled to take a stand on a matter concerning relativity theory—which by now has become a public concern—it was me; there is hardly anyone who has attempted as much to gain the broadest public understanding of relativity theory as I have (Reichenbach to Einstein, Jan. 27, 1929; CPAE, Vol. 16, Doc. 384).

Reichenbach's philosophy was strongly related to, if not, to a certain extent, parasitic on, Einstein's work in relativity. Reichenbach acted as (a) a popularizer of Einstein's relativity theories, and (b) as their defender against attacks and misunderstanding coming from experts and non-specialists alike (c) as

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[27]See Reichenbach (1922, 367) and Reichenbach to Einstein, Mar. 16, 1926; CPAE, Vol. 15, Doc. 224; a similar expression was used by Pauli (1921, 763) with reference to Weyl's theory.

a philosopher providing an epistemological analysis of Einstein's theories. Because of his indefatigable productions of essays in periodicals and newspapers, Reichenbach reached a vast readership and integrated his low income as a non-tenured extraordinary professor. At the same time, he marked his academic career by publishing numerous technical articles in academic journals and three monographs on relativity (Reichenbach, 192019241928a). As his response to Einstein testifies, Reichenbach was completely aware of his prominence within the 'protective belt' that was erected around Einstein (Hentschel, 1990ab), a position that had defined his role as *public intellectual*.[28] However, most of all, his detailed, technical analysis of Einstein's theories had defined his profile as *academic intellectual* with respect to both traditional German philosophy and, increasingly, with respect to the scientific philosophy as practiced by Schlick or Carnap.

Consequently, Einstein's reaction was a 'bitter blow' for Reichenbach. As he rightly reported, his article did not refer to any specific details of Einstein's last paper (Einstein, 1929g), which indeed was not feasible of being popularized. Thus, Reichenbach wondered whether Einstein was "hurt because I did not support the new theory with the same warmth as I always defended the old one" (Reichenbach to Einstein, Jan. 27, 1929; CPAE, Vol. 16, Doc. 384). However, Reichenbach had expressed caution toward Einstein's *Fernparallelismus* precisely to "rescue the theory from the press' requirement for sensation" (Reichenbach to Einstein, Jan. 27, 1929; CPAE, Vol. 16, Doc. 384). Reichenbach's critical attitude toward unified field theory program was not a well-maintained secret and should not have come as a surprise to Einstein who was completely aware that their philosophical views had grown apart.

Ultimately, Reichenbach could not identify a reasonable justification for Einstein's public accusations and firmly reacted: "But you call my behavior tactless, and you even mention this to other people. This—Mr. Einstein, I have not deserved this" (Reichenbach to Einstein, Jan. 27, 1929; CPAE, Vol. 16, Doc. 384). Reichenbach's role as Einstein's public defender became an integral part of his intellectual identity; however, it damaged his position within the academic philosophy (mostly dominated by Kantians) because he could not obtain the position of full professor. "I have never blamed you in the slightest if, despite everything, I never found your recognition and help for my work that I had hoped for" (Reichenbach to Einstein, Jan. 27, 1929; CPAE, Vol. 16, Doc. 384). Reichenbach was, after all, aware that Einstein had only a secondary interest in philosophical matters; however, Einstein's recent behavior was too much to bear: "But that you now want to shake me off in public as a 'tactless colleague' (without deigning me a direct message) because I wrote a newspaper article that you do not approve—well, I will not put up with that" (Reichenbach to Einstein, Jan. 27, 1929; CPAE, Vol. 16, Doc. 384). A few days later, Einstein—not without somewhat enjoying the response he had elicited—explained to Reichenbach the motivations of his forthright letter to the *Vossische Zeitung* (Einstein to Reichenbach, Jan. 30, 1929; CPAE, Vol. 16, Doc. 390). Einstein felt besieged by the press and possibly anticipated an increase in unwanted attention because of his fiftieth birthday in March. In this atmosphere, Einstein must have been annoyed that even a colleague like Reichenbach contributed to the latest craze by leaking information to a newspaper about a yet to be published scientific paper. Einstein concluded the letter with a note of reconciliation by appealing to the natural weakness of all human beings (Einstein to Reichenbach, Jan. 30, 1929; CPAE, Vol. 16, Doc. 390). After Einstein's explanation, Reichenbach, without stepping back, decided to deescalate the conflict and to clarify his complaints about Einstein's unappreciativeness:

> Dear Mr. Einstein,
>
> I see from your letter that my essay caused you some inconvenience. I really regret this from the bottom of my heart, and you can believe me that I would not have written anything if I had the slightest inkling of the situation you have just described to me. But I really could not have known about the agreement that you had with the press, particularly because you did not give me the slightest hint of secrecy.
>
> I still have to get one thing right, though. In my letter, I did not hold you against 'favors' that I would have done you because I have not 'done you any favors.' The last sentences in my letter should only remind you that, because of the nature of my work, there was a relationship of trust between us, which you seem to have forgotten, after you wrote directly to the *Vossische Zeitung* in this manner, by bypassing me. If I may interpret your letter, and particularly your closing remarks, to mean that you too now consider it more appropriate to resolve such issues directly between us, then perhaps I may now consider the matter settled (Einstein to Reichenbach, Jan. 31, 1929; CPAE, Vol. 16, Doc. 391)

To some extent, this letter marks the end of an era in the history of the philosophy of space and time (see Hentschel, 1990a, §3.4.3). Although Einstein and Reichenbach occasionally came in contact after this abrupt worsening of their relationship, a nearly 10-year period of a lively exchange of ideas and

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[28]Reichenbach's role has been described in detail by Klaus Hentschel (1982). See also Hentschel, 1990a, §3.4.3. A recent collection of Reichenbach's less known essays of relativity has been aptly entitled *Defending Einstein* (Reichenbach, 2006).

respectful feedback between a physicist and philosopher ended. After 1929, Reichenbach seems to have lost interest in spacetime theories and primarily worked on the refinement of a theory of probability (Reichenbach, 1935), its application to the general philosophy of science (Reichenbach, 1938) and to the interpretation of quantum mechanics (Reichenbach, 1944). Indeed, one can surmise that Reichenbach might have compounded what seemed like a minor quibble with a more profound philosophical estrangement. Similar to Reichenbach's private letters expressing Reichenbach's woe for Einstein's betrayal of their personal relationship of trust, his published writings point to his disappointment for Einstein's betrayal of their shared philosophical ideals. Einstein was drifting away from the epistemological principles that Reichenbach had found inspiring a decade earlier and for which he had fought for in both academic and non-academic settings. In turn, Einstein felt that Reichenbach's type of philosophy was ultimately superficial and incapable of grasping the deeper-seated motivation that drove physicists' research.

4 Geometrization vs. Unification. Reichenbach's Technical Articles on *Fernparallelismus*-Field Theory

The brief January 25 article in the *Vossische Zeitung* was not meant to adequately address the philosophical issues at stake, but only to introduce the cultured layman to the 'mysteries' of contemporary physics. However, it is revealing that Reichenbach did not present Einstein *Fernparallelismus*—as it would been more natural in a popular writing—as an attempt of a *geometrization* of the electromagnetic field on par with the previous geometrization gravitational field achieved by general relativity. On the contrary, he decided to present *Fernparallelismus* in terms of an attempt of *unification* of two separate fields on par with a similar unifications operated by special and general relativity. Reichenbach's presentation choice was, of course, not fortuitous. Indeed, the interplay between 'geometrization' and 'unification' was addressed more in detail in the two technical papers on *Fernparallelismus* that Reichenbach had concluded on the same days—both dated January 22, 1929 but published in the following months.

The first article of the order of publication was entitled "Die neue Theorie Einsteins über die Verschmelzung von Gravitation und Elektrizität" (Reichenbach, 1929b) and would appear in February in the *Zeitschrift für Angewandte Chemie*. The second article was an extended version of the manuscript that Reichenbach had sent to Einstein in October and bore the same title "Zur Einordnung des neuen Einsteinschen Ansatzes über Gravitation und Elektrizität" (Reichenbach, 1929d). It was published only in September in the *Zeitschrift für Physik*. These articles represent Reichenbach's last important contribution to issues related to relativity theory and spacetime theories. On the one hand, Reichenbach attempted to make his previous reflections about the unified field theory program in the Appendix to the *Philosophie der Raum-Zeit-Lehre* to bear fruit (Reichenbach, 1928a, §46). On the other hand, he added new elements of clarification by clearly distinguishing the 'geometrization program' and the 'unification program.'

4.1 From Geometrization to Unification

In the first paper for the *Zeitschrift für Angewandte Chemie*, Reichenbach introduced the history of the unified field theory in an entirely different manner than before. The brief history of the unified field theory program appeared to him as the progressive *downfall* of the geometrization program and the concurrent *rise* of the unification one. The considerable success that Einstein had attained with his geometrical interpretation of gravitation, Reichenbach explained, initially led other physicists to believe that similar success might be obtained from a geometrical interpretation of electromagnetism. With ten coefficients $g_{\mu\nu}$ in Riemannian geometry, "the supply of elements [*Bestimmungsstücken*] was exhausted, and consequently there were no more geometric quantities available that could have been used to characterize the electric field" (Reichenbach, 1929b, 122).

It was Weyl who suggested considering a more general geometrical framework. By weakening the compatibility conditions between the $\Gamma_{\mu\nu}^{\tau}$ and $g_{\mu\nu}$, Weyl introduced, in addition to the tensor $g_{\mu\nu}$, a four-vector φ_{μ} of equally fundamental standing.[29] In this manner, he opened "up the possibility of using those other geometrical elements [*Bestimmungsstücke*] to characterize the electric field, i.e., to identify certain geometrical parameters apt for characterizing the fundamental electric quantities—i.e., the electric potentials φ_{μ}, whose derivation determine the field strengths" (Reichenbach, 1929b, 122). Thus, similar to "in the gravitational field $g_{\mu\nu}$ is the determination factor of the length [of a vector] at one point, and the electric field φ_{μ} is the determination factor of the change of length by transportation" (Reichenbach, 1929b, 122).

In analogy with general relativity, Weyl introduced what, in Reichenbach's parlance, amounts to a

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[29]See above fn. 21. φ_{μ} corresponds to κ_{σ}.

coordinative definition of the operation of displacement of vectors. In Weyl's geometry, spacetime lengths of vectors at the same point in different directions can be compared, but the length of vectors at distant points is path-dependent. It was then natural to assume that the length of vectors could be measured by rods and clocks. Consequently, "one would surmise an influence of the electric field on transported rods and clocks " (Reichenbach, 1929b, 122). However, as it turns out, rods and clocks under the influence of the electromagnetic field does not behave as predicted by Weyl's theory. This argument is the gist of Einstein's so-called 'measuring rod objection.' The fact that the atoms that we use as clocks have sharp spectral lines, Einstein (1918) argued, disproves Weyl's theory (see Ryckman, 2005, §4.2.4).

According to Reichenbach, Weyl (1920), rather than abandoning the theory, decided to simply forego such a coordinative definition of the process of displacement in terms of rods-and-clocks readings. The selection of Weyl geometry rather than Riemannian geometry would be justified only after the field equations are established, usually by way of an action principle (Weyl, 1921ab). From the latter, one should have been able to deduce the behavior of the material structures that one uses as rods and clocks, which, however, would have nothing to do with the law of parallel transport of vectors that lies at the basis of the theory. In a somewhat disguised form, Weyl's strategy was ultimately adopted by physicists working on the unified field theory program (Eddington, 19211923). In this manner, however, Reichenbach concluded, the 'geometrization program' was implicitly abandoned and substituted by a new, different 'unification program':

> However, mathematicians did not give up on the new idea. If a direct physical interpretation of Weylean space was impossible, they attempted an indirect approach. They considered Weyl's space as a type a mathematical apparatus that provided the means for novel mathematical operations and, therefore, at least formally, opened the possibility for a unification of the electrical and gravitational equations. *The actual geometrical sense of Weyl's approach was therefore completely abandoned*, and the extended type of space was only used, so to speak, in the sense of a *calculating machine*, from whose internal lawlikeness one expected the solution of a riddle, which has been impossible to master with direct, intuitive thinking. [...] In fact, it has already happened several times that the human-made 'conceptual device' becomes, so to speak, smarter than its creator, leading automatically to results that the more down-to-earth researchers would not have guessed. [...] Multiple influential researchers have attempted to develop Weyl mathematics into a physical theory, in addition to Weyl, the English astronomer Eddington, who significantly expanded the mathematical foundations, and Einstein himself. (Reichenbach, 1929b, 122; m.e.).

Most physicists, including Einstein (1923; 1925) considered this strategy legitimate. It was preferable to sacrifice the geometrical interpretation—i.e., to relinquish the coordination of geometrical notion of parallel transport of vectors with the behavior rods and clocks—and then to use the geometrical variables ($\Gamma^\tau_{\mu\nu}$, φ_ν and so on) as 'calculation device' for the greater good of finding the field equations. From the field variables, one has to attempt to establish the simplest differential invariants that can be used as an action function.

Einstein had convinced himself several times to have found the solution to the conundrum; however, he changed his mind shortly after. "The last stage on this path is the new work that [Einstein] recently presented to the Academy"[30] (Reichenbach, 1929b, 123). Reichenbach gives a brief description of the mathematical apparatus of *Fernparallelismus* but emphasized that this was not the crucial point. The latter has become nothing more than a 'calculation device.' "The relevant issue," he continued, "is that from the equation that is placed at the top of the theory, *one can derive both* the gravitation equations of today relativity theory and Maxwell's equations" (Reichenbach, 1929b, 123; m.e.).[31] Reichenbach characterized the results that the *Fernparallelismus* theory aimed to achieve as follows:

– The field variables do not receive a geometrical interpretation. Rather, "Einstein was guided" by abstract mathematical considerations "about invariants in Weylean space[32] and the possibilities of deriving equations from them" (Reichenbach, 1929b, 123). Therefore, the new theory has a "very formal character" (Reichenbach, 1929b, 123). The success was obtained, so to speak, by placing the cart before the horses, i.e., by selecting a geometrical structure such that it would lead to a set of field equations of which the already known electromagnetic and gravitational field equations as special cases for weak fields.

– Electromagnetic field and gravitational field are unified. "The formal aim of merging both systems

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[30] Reichenbach refers to Einstein (1929g).

[31] Actually, Einstein recovered Maxwell's equation and Newton–Poisson equations; see Einstein (1929g, 6-7).

[32] Reichenbach uses the expression 'Weylean space' to indicate the non-Riemannian geometries that can be obtained by weakening or cutting the compatibility condition between the metric and the affine connection. 'Weyl geometry' is only an example of this more general category.

of equations into one has thus been achieved" (Reichenbach, 1929b, 123). However, a similar juxtaposition of the two fields had already been achieved by previous theories. Thus, Reichenbach insisted that *Fernparallelismus* appears as both a formally satisfying unification and a real step forward beyond previous unification attempts. According to Reichenbach, "the most important thing is that a certain concatenation of both systems of equations occurs in such a manner that a physical dependence between electricity and gravity is asserted" (Reichenbach, 1929b). The distinction between the electromagnetic and gravitational field occurs in the linear approximation. For strong fields, this independence no longer holds, and electromagnetism induces a gravitational field and the other way around. However, this dependence is weak, and the experimental confirmation of such effects seems to be out of reach.

– The separation between the field equations and equations of motions is overcome. In a field theory, usually there are two separate parts: (a) the partial differential equations relating the field to its sources—the so-called field equations (b) the total differential equations governing the motion (positive and negative) electrons—the so-called equation of motion. For a long time, Reichenbach writes, Einstein "has pursued the goal of proving this law [of motion] as a mathematical consequence from the field equations" (Reichenbach, 1929b, 123) but has managed to do so only of singularities (Einstein, 1928bEinstein and Grommer, 1927; see Lehmkuhl, 2017a). The new theory seems to have given him the opportunity to derive the behavior of elementary particles, even if "for the time being [Einstein] cannot state how this is to be mathematically performed" (Reichenbach, 1929b, 123). This method could have led to a unification of the foundations in that it would have made special equations of motion for electrons superfluous. From this point of view, a moving electron would be nothing but a field of changing intensity.

Thus, Reichenbach concluded that, along with the *Fernparallelismus*-field theory, the proper *geometrical interpretation* of the field has become irrelevant. The only aim has become the proper *unification* of two fields and possibly of field and matter: (I) the electromagnetic and gravitational field should become only one total field; (II) the very difference between the matter and field should disappear. The attainment of (I) seems to be necessary to explain elementary particles' stability and accomplish (II). In turn (II) is the only warranty that (I) has been achieved.

The proof that the field equations are correct ultimately depends on whether they have singularity-free solutions corresponding to elementary particles that behave in accordance with our experimental knowledge. Of course, this result has not been achieved, as Reichenbach remarked with a thinly veiled skepticism. Thus, he again concluded the brief paper with an *argumentum ad verecundiam*: "The strongest argument that one can presently provide for the new theory is that Einstein is convinced of its importance" (Reichenbach, 1929b, 123). It is hard to deny that this sounds like a backhanded compliment. A theory whose only motivation is the importance of the physicist who put it forward does not seem very promising.

4.2 The Duality of Unifications

Reichenbach had come to understand that, in Einstein's view, the aim of the unified field theory program was not the geometrization of the electromagnetic field alongside the gravitational field; it was the unification of the electromagnetic and gravitational field. Thus, Reichenbach's concern became to explain what 'unification' means in this context. The problem was addressed in detail in the more technical paper, which grew out of the manuscript that Reichenbach had sent to Einstein (Reichenbach, 1929d), which was submitted on January 22 bearing the same title "Zur Einordnung des neuen Einsteinschen Ansatzes über Gravitation und Elektrizität" as the manuscript (Reichenbach, 1928b). As we have mentioned, the first part of the paper reproduces the manuscript he sent to Einstein, with minor changes. Reichenbach did not consider Einstein's objection discussed above (see section 2.3), and reproduced the same classification of geometries that was presented in the manuscript. The last part of the article was instead substantially reworked and integrated with some reflections about the concept of unification in physics. Similar considerations can be observed in the chapter on the epistemology of physics that Reichenbach had written for *Handbuch der Physik*, which had just been published (Reichenbach, 1929a).[33] From a *technical* point of view, the concepts of unification applied to a field theory is varied. One can, for example, look at the properties of the field structure itself, or at the property that the field equations (Lehmkuhl, 2021). However, Reichenbach attempted to provide a more general 'epistemological' definition of unification.

As Reichenbach put it, the goal of physics is to gain true propositions about reality. However, we should distinguish between the *breadth* (the number of true assertions) and the *depth* of knowledge (the combination of a number of propositions into a single proposition) (Reichenbach, 1929a, 36; tr. 1978,

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[33]Reichenbach wrote it some years before, probably in 1925, see HR, 044-06-25.

1:165). The increase of the breadth might be called the *acquisition* of knowledge, whereas the increase in the depth of knowledge is called *explanation*. The acquisition of new facts, an increase in the direction of breadth, does not explain, but rather requires explanation; an increase in explanation is a progressive step of knowledge in the direction of depth (Reichenbach, 1929a, 36; tr. 1978, 1:165). Physical explanation searches for the most general laws of physics from which all others can be derived (Reichenbach, 1929a, 36; tr. 1978, 1:165-166). In his paper, on *Fernparallelismus* Reichenbach slightly adapt this reasoning by distinguishing two types of *unification*[34]:

(a) *formal unification*: the new theory does not claim more than the available theories combined. This type of unification plays only a minor role in physics. Formal simplification is only of secondary importance in increasing knowledge, although it can be useful to make a theory logically more transparent or introduces a powerful mathematical formalism (Reichenbach, 1929a, 37; tr. 1978, 1:166). E.g., the four-dimensional geometry introduced into relativity theory by Minkowski (1909) can be seen as merely a reformulation of Einstein's (1905) special relativity using a more sophisticated mathematical apparatus. The unification of this type applies to cases in which the physical theories compared are *empirically equivalent*, i.e., correspond in all observable facts. Minkowski's formulation of special relativity is simpler than Einstein's original one, but this is merely a matter of descriptive simplicity, which adds nothing to its truth.

(b) *inductive unification*: the new theory claims more than the available theories combined. This form of unification is more important in physics' practice. The progress of physical knowledge comprises establishing a more general law, for which the previous laws are special cases. For example, Newton's laws of gravitation is a special case of general relativity for the limit of slow motions and slowly changing gravitational fields. Indeed, already to the first order approximation, general relativity predicted new effects that were not entailed in Newton's theory, like the 'anomalous' precession of the perihelion of Mercury, the bending of light in gravitational fields, and the gravitational redshift. In this case, unification power determines a choice between two *empirically nonequivalent* theories. The two theories correspond to the observed measurements, but they differ as to future predictions (Reichenbach, 1929a, 37; tr. 1978, 1:166).

This distinction between two types of unification mimics Reichenbach's more famous distinction between two types of simplicity (Reichenbach, 1924, 91929a, §11). The former is an application of the latter to the case of unified field theories.

As we have seen, Reichenbach had shown that *Fernparallelismus* was, after all, not a new geometrical setting, but it was already implicit in Weyl–Eddington–Schouten–Reichenbach's classification of geometries. Einstein's *Fernparallelismus* geometry went first unnoticed, and, Reichenbach insisted, that other options have not been taken into consideration (Reichenbach, 1929d, 687). In this way, Reichenbach's new *Fernparallelismus* approach became directly comparable to previous unifications. In particular, Reichenbach could suggest a comparison between Einstein *Fernparallelismus*-field theory and his unified theory published as §49 of the Appendix to the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a, §49). The two theories were, after all, similar from a geometrical point of view. Both used a metrical space endowed with a non-symmetric affine connection. Einstein's theory imposed the additional restriction of the vanishing Riemann tensor. Moreover, in Reichenbach's view, it could be said that both theories achieved a unification of electromagnetic and geometrical field.[35] Nevertheless, the two theories were significantly different from an epistemological point of view.

According to Reichenbach, his §49-theory was able to provide a *proper* geometrical interpretation of the combined gravitational/electromagnetic field. However, the theory could achieve only a *formal* unification (a) because no new testable predictions were made:

> The author [Reichenbach] has shown that the first approach can be realized in the sense of a combination of gravitation and electricity to one field, which determines the geometry of an extended Riemannian space; it is remarkable that *the operation of displacement receives an immediate geometrical interpretation via the law of motion of electrically charged mass points.* The straightest line is identified with the path of electrically charged mass points, whereas the shortest line remains that of uncharged mass points. In this way, one achieves *a certain parallelism to Einstein's equivalence principle*. By the

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[34]Reichenbach suggests that the example of axiomatization in mathematics can help to clarify this distinction. I will not follow this analogy here; see (Reichenbach, 1929a, 36; tr. 1978, 1:165-166) for more details.

[35]The two unifications were achieved by very different means. Reichenbach's theory modified only the equations of motion, whereas Einstein's theory introduced a new set of field equations. For Einstein's standards, Reichenbach's theory could not be considered a unified field theory in the proper sense of the expression (Einstein to Reichenbach, Mar. 31, 26; CPAE, Vol. 15, Doc. 402). However, Reichenbach remained silent about this issue.

way [the theory introduces] a space which is cognate to the one used by Einstein, i.e., a metrical space with non-symmetrical $\Gamma^\tau_{\mu\nu}$. The aim was to show that the geometrical interpretation of electricity does not mean a physical value of knowledge per se (Reichenbach, 1929d, 688; m.e.).

Reichenbach insisted that his theory was a proper geometrical interpretation because both the affine connection and the metric (the fundamental mathematical structures of the theory) received a physical interpretation from the outset (Reichenbach to Stoltz, Jun. 13, 1929; HR, 014-17-18). Nevertheless, the theory achieved only *formal unification* of the descriptions of two physical fields in a common geometrical setting without adding anything new, i.e., without making new predictions about the behavior of rods and clocks, light rays, and test particles. Reichenbach's theory was precisely meant to show that a successful geometrical interpretation alone is not sufficient to achieve a substantive unification. For Reichenbach, this should have been a warning that the very hope that the geometrical interpretation of a physical field itself was the key to new physical insights was misplaced.

However, Reichenbach reported that physicists reacted to the failure of their geometrization program by completely foregoing to the geometrical interpretation of $g_{\mu\nu}$, the $\Gamma^\tau_{\mu\nu}$, φ_μ as the case may be, and used them merely as calculation tools to construct a suitable Lagrangian. Following this non-geometrical approach, they aimed to recover the already known gravitational and electromagnetic field equations in first order approximation such that new effects could be predicted in the presence of strong fields. Einstein *Fernparallelismus*-field theory is an instance of this second approach, which claims to achieve (b), an inductive unification, by renouncing to the geometrical interpretation:

> However, Einstein's approach, of course, uses the second way since it is a matter of increasing physical knowledge; it is the aim of Einstein's new theory to find such a concatenation of gravitation and electricity, that only in first approximation it is split in the different equations of the present theory, while is in higher approximation reveals a reciprocal influence of both fields, which could possibly lead to the understanding of unsolved questions, like the quantum puzzle. However, it seems that this aim can be achieved only *if one dispenses with an immediate interpretation of the displacement, and even of the field quantities themselves.* From a geometrical point of view, this approach looks very unsatisfying. Its justification lies only on the fact that the above-mentioned concatenation indicates more physical facts than those that were required to establish it (Reichenbach, 1929d, 688; m.e.).

Einstein's theory claimed to be an *inductive unification* of the dynamics of two physical fields, i.e., a unification of the fundamental interactions described by a single, non-decomposable set of field equations. In Reichenbach's view, *Fernparallelismus* appeared not only as a formally satisfying unification but as a real advance over the available theories. It entails some coupling between the two fields that was not present in the given individual field theories. However, Reichenbach argues that Einstein could only achieve this result at the expense of a physical interpretation of the fundamental geometrical variables, the h^ν_a. This approach, however, made the theory impossible to be confirmed or disproved experimentally by observing the behavior of suitable indicators. Indeed, Einstein had always insisted that the physical test of the field equations ultimately depends on the construction of exact solutions that reflect the behavior of known elementary particles (Einstein, 1930b, 24). One cannot define the field quantities in advance in terms of the behavior of test particles, as in other field theories. The laws governing the latter are unknown before integrating the field equations (Einstein to Cartan, Jan. 7, 1930; Debever, 1979, A-XVI).

4.3 Explaining the Success of General Relativity

In Reichenbach's diagnoses, the stagnation of the unified field theory program depended on the presence of a sort of *trade-off between geometrization and unification* of which physicists were only partially aware. General relativity was the only theory that was able to combine both virtues: (a) the theory provided a proper *geometrical interpretation* of the gravitational field because it introduced a coordinative definition of the field variables $g_{\mu\nu}$, in terms of the behavior of those that were traditionally considered geometrical measuring instruments, such as rods and clocks (b) the theory provided a *proper unification* by predicting that the gravitational field had certain effects on such measuring instruments that were not implied by previous theories of gravitation—such as gravitational time dilation (Reichenbach, 1928a, 350). Successive attempts to include the electromagnetic field in the frame of general relativity failed to uphold this standard. According to Reichenbach, the reason for this failure was ultimately the lack of a proper analogon of a physical fact that plays the role of the *equivalence principle*.[36] As is well known, the *empirical fact* of the equality of inertial and gravitational mass implies that free-fall is locally

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[36]Reichenbach (misleadingly) indeed claims that in his theory there is something comparable to the equivalence principle. However, he reports that this analogon is simply a reformulation of the well-known effects of the electromagnetic field on charge test particles and does allow to make any new predictions. See Giovanelli, 2021 for more details.

indistinguishable from inertial motion. The equivalence principle is the *physical hypothesis* that this indistinguishability can be extended to all non-mechanical phenomena (Reichenbach, 1928a, 264; tr. 229f.). Because of the equivalence principle, gravitation is a *universal force* that cannot be neutralized or shielded. Thus, there is no way to separate the geometrical measuring instruments that are not affected by the field (rods and clocks, light rays, force-free particles) from the dynamical ones that react to the field (charged particles). Consequently, it becomes more convenient to *decide* to set universal forces equal to zero. The geometrical measuring instruments became at once indicators of the gravitational field.

Because of the equivalence principle in the presence of the sole gravitational field, rods and clocks, light rays, on the one hand, and particles (like planets), on the other hand, agree on the *same* geometry, a generally non-flat-Riemannian geometry. Such a geometrical interpretation accounts for old inconsistencies in Newton's theory concerning the irregularities of Mercury's orbit motion and allows for new predictions like a more pronounced deflection of light by the Sun. Measurements carried out with real physical systems, rods and clocks, light rays, free-falling particles, etc., seem to have confirmed the theory's predictions. Thus, in the case of general relativity, the *geometrical interpretation* had indeed been instrumental in achieving an *inductive unification*, providing a smooth interpolation within a domain of observations. However, the effective interplay between geometrization and unification did not seem reproducible without the equivalence principle. Thus, to replicate the success of general relativity, physicists were forced to make a choice. Two strategies seem to have been available, which ultimately depended on physicists' interpretation of Einstein's theory of gravitation:

(a) *geometrization strategy*: general relativity was a successful theory *because* it had provided a geometrical interpretation of the gravitational field; then, one could hope to obtain the same success by geometrizing the electromagnetic field as well. Still, if one attempts to provide a similar geometrical interpretation of electromagnetism, one must search for a similar physical fact that relates the electrical field to the behavior of geometrical measuring instruments, like rods and clocks. However, the fundamental fact that would correspond to the principle of equivalence is lacking.

(b) *unification strategy*: general relativity was a successful theory *because* it had achieved the unification of two different fields, gravitational and inertial field. In this way, however, the gravitational/inertial field was provisionally isolated from a more general field of unknown mathematical structure, encoding quantities corresponding to the electromagnetic field. The search for this mathematical structure was worth pursuing, but its geometrical interpretation was immaterial. However, without a physical fact corresponding to the equivalence principle, one does not know what such a mathematical structure might be, if it exists at all.

Like many others, Reichenbach believed that without a new *physical hypothesis*—that is a physical fact that played the role of the strict equality of inertial and gravitational mass—, both strategies, (a) and (b) had little hope of success.

However, in Reichenbach's reconstruction, after Weyl's failure of pursuing (a), most physicists, and in particular Einstein, opted for (b). Einstein seemed to believe that (b) could be justified based on a different ground, assuming that nature satisfies the simplest imaginable mathematical laws. This assumption was the new *physical hypothesis* on which the strategy (b) could be based (see Reichenbach, 1928a, §50). One searches for the most natural field structure, and the simplest field equations that such structure satisfies. After all, Einstein could claim, this is how physics has always been done: Maxwell's equations are nothing but the simplest laws for antisymmetric tensor field $F_{\mu\nu}$ which is derived from a vector field; Einstein's equations were the simplest generally covariant laws that govern a Riemannian metric $g_{\mu\nu}$ and so on. The only warranty of the success of this speculative groping in the chaos of mathematical possibilities was the unification power of the field equations obtained. The latter should have predicted some unknown coupling between the electromagnetic field and the gravitational field, which ultimately would have served as the basis of a theory of matter. This was indeed the case of the *Fernparallelismus*-field theory.

To Reichenbach's dismay, Einstein had abandoned the *physical heuristic* that leads him to general relativity in the name of a *mathematical heuristic* that was not different from Weyl's speculative approach that he had dismissed a decade earlier.[37] Einstein's philosophical volte-face might have appeared to Reichenbach as a sort of *trahison des clercs*, an unacceptable intellectual compromise. (a) The core of Reichenbach's philosophy was the *separation of mathematical necessity and physical reality*. Reichenbach had always perceived this separation as nothing more than a philosophical distillation of Einstein's scientific practice. (b) In the search of a unified field theory, Einstein had come implicitly to question this very

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[37]See Weyl to Einstein, May 18, 23; CPAE, Vol. 13, Doc. 30 and Weyl to Seelig, May 19, 1952, cit. in Seelig, 1960, 274f..

distinction, ultimately pleading for a *reduction of physical reality to mathematical necessity*[38] . Einstein put it bluntly in his Stodola-*Festschrift*'s contribution—that he sent for publication toward the end of January (Einstein to Honegger, Jan. 30, 1929; CPAE, abs. 864). The ultimate goal of understanding reality is achieved when one could prove that "even God could not have established these connections otherwise than they actually are, just as little as it would have been in his power to make the number 4 a prime number" (Einstein, 1929f, 127). In this sense, Einstein's God indeed resembles Spinoza's God (Einstein, 1929b), for whom the laws of nature are necessary, and rather than, say, Leibniz's God for whom the laws of nature are contingent.

Conclusion

On January 30, 1929, Einstein's rumored new derivation of the *Fernparallelismus*-field equations was published in the Proceedings of the Berlin Academy with the ambitious tile *Zur einheitlichen Feldtheorie* (Einstein, 1929g). Despite his anger toward Reichenbach's 'leaks,' Einstein did not hesitate to feed the hopes of the general public by popularizing his new theory in the daily press. On February 2, 1929, in its section "News and Views" (1929), *Nature* reported an interview of Einstein published in the *Daily Chronicle*, on January 26, 1929, a day after the publication of Reichenbach's infamous article in the *Vossische Zeitung*. Einstein's quarrel with Reichenbach had deeper philosophical roots that went way beyond questions of academic etiquette. A few days later, Einstein wrote a popular account of the new theory (Einstein, 1929a). Its English translation was published on the first page of their Sunday supplement of the *New York Times* on February 3 and in *The Times* of London in two installments on February 4 and 5 (Einstein, 1929ce; also published as Einstein, 1930a).

Einstein insisted on "the degree of formal speculation, the slender empirical basis, the boldness in theoretical construction, and finally the fundamental reliance on the uniformity of the secrets of natural law and their accessibility to the speculative intellect" (Einstein, 1930a, 114). This "speculative method", Einstein claimed, was the same that lead to to success of general relativity: "Which are the simplest formal structures that can be attributed to a four-dimensional continuum, and which are the simplest laws that may be conceived to govern these structures?" (Einstein, 1930a, 115). In trying to defend this epistemological stance, Einstein was not afraid to side with "Meyerson in his brilliant studies on the theory of knowledge" who had emphasized the 'Hegelian' nature of such enterprise, "without thereby implying the censure which a physicist would read into this" (Einstein, 1930a, 115).

The fact the Einstein chose to mention Meyerson rather than Reichenbach as a philosophical reference in a popular presentation of his last theory for a major newspaper cannot be underestimated. Of course, Einstein was well aware of Reichenbach's technically informed work on this very subject, having discussed it with him in the previous months. Nevertheless, as he did in the contribution for the Stodola-*Festschrift* (see above section 2.3), Einstein preferred to side with Meyerson's less detailed, but, in his view, a more profound philosophical outlook—endorsing even his somewhat outrageous comparison with Hegel (Giovanelli, 2018). After a decade of personal friendship and intellectual exchange that had shaped the history of 20th-century philosophy of science and, to a certain extent of 20th-century physics, a minor squabble had unwittingly revealed a nearly unbridgeable philosophical divide.

Reichenbach invited Einstein to contribute to the newly founded journal *Erkenntnis* published by Felix Meiner and edited with Carnap (Reichenbach to Einstein, Apr. 25, 1930; EA, 73-226). However, to no avail. Nevertheless, when Hugo Dingler (1933), a few years later, launched a political attack against the journal, he mocked Reichenbach as "Einstein's self-proclaimed personal philosopher [*Leibphilosoph*]" who replaced logic with the authority of a great physicist (Dingler, 1933, VI). As we have seen, besides the deterioration of their personal relationship, Einstein's extreme rationalism in those years (Einstein, 1933a) could not be more distant from Reichenbach's inductivism (Reichenbach, 1931; see Galavotti, 2009). But Dingler did not mean to open a scholarly dispute (Howard, 2003). Reichenbach replied from his Turkish exile, insisting on the political independence of journal (Reichenbach, 1934). However, the situation rapidly deteriorated, and the seventh volume of *Erkenntnis* (1937-1938) was edited by Carnap alone.

Reichenbach's initial enthusiasm for Turkey soon waned and he tried to obtain a position in Princeton, where Einstein had settled in 1933 (Verhaegh, 2020). However, Reichenbach feared Weyl's opposition: "He is my adversary since a long time," he wrote to the American philosopher Charles W. Morris, a supporter

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[38] Already in his habilitation, Reichenbach, although rather in passing, accused Weyl of attempting to deduce physics from geometry, by reducing physical reality to 'geometrical necessity' (Reichenbach, 1920, 73). However, the greatest achievement of general relativity, Reichenbach claimed, was to have shifted the question of the truth of geometry from mathematics to physics (Reichenbach, 1920, 73). Einstein was now committing the very same "old mistake" again (Reichenbach, 1920, 73). On Reichenbach's habilitation, see Padovani (2009).

of a form a "mathematical mysticism" that was "very much opposed to my empiricistic interpretation of relativity" (Reichenbach to Morris, Apr. 12, 1936; HR, 013-50-78). Thus, in April 1936, Reichenbach turned to Einstein to ask his support: "I surmise that Weyl's opposition persists to these days and therefore I'd be grateful if you could put a word in my favor" (Einstein to Reichenbach, May 2, 1936; EA, 20-118). By this time, it was ironically Einstein the one indulging in the sort of mathematical mysticism that Reichenbach attributed to Weyl. As Einstein famously confessed to Lanczos, his work on general relativity had made him "a believing rationalist" (Einstein to Lanczos, Jan. 24, 1938; EA, 15-268), convinced that physical truth lies in mathematical simplicity (Ryckman, 2014). However, he continued, the mathematical formulation of the laws of nature need not to be of "*geometrical* nature" (Einstein to Lanczos, Jan. 24, 1938; EA, 15-268).

Only in 1938, because of Morris' mediation, Reichenbach managed to move to the United States (Verhaegh, 2020). The American years did nothing to bridge the philosophical cleavage that had emerged during their late Berlin time. Einstein (1949b; 1949c) praised Reichenbach's (1949)'s contribution to the volume in his honor of the series *Library of Living Philosophers* edited by Paul Schilpp (1949). However, the self-described "tamed metaphysician" had grown increasingly impatient toward any philosophy that smelled of 'positivism' (Einstein, 1950, 13). When in 1953 Schilpp asked Einstein for contributing to the volume of the same series in honor of Carnap (Schilpp to Einstein, May 11, 1953; EA, 80-539), he famously declined. After "Reichenbach's death (a few weeks ago),"[39] Schilpp wrote, Carnap was the most important exponent of logical empiricism (Schilpp to Einstein, May 11, 1953; EA, 42-534). Although Einstein agreed with this assessment, he expressed disenchantment toward that type of philosophy that Schlick, Reichenbach, and Carnap represented: "the old positivistic horse, which originally appeared so fresh and frisky, has become a pitiful skeleton" (Einstein to Schlipp, May 19, 1953; EA, 42-534; quot. and tr. in Howard, 1990, 374)

When, in 1958, *The Philosophy of Space and Time* (Reichenbach, 1958), the English translation of *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a), was published, and the Appendix on the unified field theory program was not included. Reichenbach's articulate critique of the unified field theory program fell into oblivion at the very moment when a new geometrization/unification attempt was emerging in the form of the so-called 'geometrodynamics' (Misner and Wheeler, 1957; see Stachel, 1974). Because Reichenbach's *The Philosophy of Space and Time* for better or worse dictated the agenda of the philosophy of space and time in the following decades (Grünbaum, 1963Fraassen, 1970Sklar, 1974) this loss should not be underestimated. Certain key documents to understand Reichenbach's role in the major debates on relativity in the 1920s never received mainstream attention. The importance of Reichenbach's antagonism with Weyl was not appreciated (cf. Coffa, 1979), and most of all Reichenbach's relationship with Einstein was seriously misunderstood. When Nicholas Rescher (2006) celebrated the enormous influence of Reichenbach's school in the on American philosophy of science, opening the study, he could simply *define* the Berlin group as a "philosophical movement that was erected on foundations laid by Albert Einstein," whom the members of the group considered a "hero among philosopher-scientists" (Rescher, 2006). As this paper has tried to show, this assessment, at first sight was so obvious, that it becomes surprisingly problematic without specifying which 'Einstein' they were worshiping. Reichenbach's 'Einstein' was indeed not Weyl's 'Einstein' (Ryckman, 1996). Furthermore, when Reichenbach moved closed to his 'hero' in Berlin in the late 1920s, he soon realized, much to his dismay, that his 'Einstein' was considerably different from the one the real Einstein had become.

Abbreviations

CPAE   Albert Einstein (1987–). *The collected papers of Albert Einstein*. Ed. by John Stachel et al. 15 vols. Princeton: Princeton University Press, 1987–.
EA   *The Albert Einstein Archives at the Hebrew University of Jerusalem*.
HR   *Archives of Scientific Philosophy* (1891–1953). *The Hans Reichenbach Papers*. 1891–1953.

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[39]Reichenbach died on April 9, 1953.

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