Coordination, Geometrization, Unification. An Overview of the Reichenbach–Einstein Debate on the Unified Field Theory Program

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Keywords: Reichenbach • Einstein • Weyl • Unified Field Theory • General Relativity • Geometrization • Unification • Coordination

Introduction

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Einstein-Reichenbach debate of Weyl's theory (1920-1922). In his 1920 habilitation, Reichenbach, although rather in passing, accused Weyl of attempting to deduce physics from geometry, by reducing physical reality to 'geometrical necessity' (Reichenbach, 1920b, 73). On the contrary, the greatest achievement of general relativity, Reichenbach claimed, was to have shifted the question of the truth of geometry from mathematics to physics (Reichenbach, 1920b, 73). That the separation . Einstein seemed to agree. Reichenbach that After their correspondence, Reichenbach (1922a, 367–368) accepted Weyl's (1921c) counterargument that the geometry of spacetime has nothing to do with behavior of rods and clocks, but complained about the overly formal nature of the theory (Reichenbach, 1922a, 367).
The ideea of coordinate, seems Einstein, Einstein seems also agree, that have become hard to dey that Einstein poisiton as fundametanl, had become actually very different from what Kant had imagnined. It was Reichenabch that seems to indudec Einstin to take a philosopjical position

Reichenbach-Einstein correspondence (1926-1927). In March 1926, after making some critical remarks on Einstein's newly published metric-affine theory (Einstein, 1925a), Reichenbach sent Einstein a 10-page 'note' (Reichenbach to Einstein, Mar. 24, 1926; CPAE, Vol. 15, Doc. 224). In it, he constructed a mock unification of the gravitational and electricity in a single geometrical framework, thereby showing that the 'geometrization' of a physical field was a mathematical trickery rather physical achievement. After a back and forth Einstein seemed to agree (Lehmkuhl, 2014). The note was later included as section §49 in a long technical Appendix to the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a, SS46-50) in which general relativity is presented as a 'physicalization of geometry' rather than a '*geometrizaton* of gravitation' (Giovanelli, 2021).

Reichenbach-Einstein correspondence (1928-1929). A few months after the publication of the *Philosophie der Raum-Zeit-Lehre* (Reichenbach, 1928a), Einstein (1928b,d) launched yet another attempt at a unified field theory, the so-called distant parallelism-field theory. Reichenbach, now back in Berlin, discussed the new theory in person with Einstein and sent him once again a manuscript with some comments. The unpublished manuscript is still extant (Reichenbach, 1928c). This exchange of letters marked the cooling of Einstein's and Reichenbach's personal friendship but also the end of their philosophical kinship. In the late 1920s, Reichenbach (1929b,c,d) came to realize that in Einstein's mind, the actual goal of the unified field theory-project was not the geometrization, but as the *unification* of two different fields, an undertaking for the sake of which Einstein was ready to embrace a strongly speculative approach to physics (Dongen, 2010).

The present paper does bring new material. It has the ambition to provide. The recognition of the importance of this episode has been an important result of the Reichenbach-scholarship of the last decades (Ryckman, 1995, 1996). The correspondence has been rediscovered and published (CPAE, Vol. 15) only recently (Giovanelli, 2016a). The third episode is forthcoming (**Giovanelli2022**). However, we hope to this isolated episodes into a analysis. One the key theme of Reichenbach's philosophy is separation between mathematics and physics. Ultmiately, consider mathematical simplicty and the key two physical reality.

The electromagnetic field. On the background The in terms of test particles. Field equaitons in fourm. The makes then prediction on the values. General relativity $g_{\mu\nu}$ with the gravitational fiedd, that are both and rods and clocks. That the geometry of spacetime. The field equatiosn could also be derived by variational principle.

To impose on the structure of the universe the additional conditions that will lead to the electromagnetic field, we cannot stay in purely Riemannian space. The electromagnetic field cannot be described in it by increasing the number of dimensions of a Riemannian space, in particular to five dimensions. Einstein explped on serveal. by going into a more general variety of spaces with any affine connection $\Gamma^{\tau}_{\mu\nu}$ which will give us more latitude in the definition of the parallel displacement of a vector along an infinitely small closed contour. Indeed, to e.g. that does not depend to $g_{\mu\nu}$ at all, dropping the conditions of symmetry, etc. This second line of Weyl-Eddington-Schouten lineage and will attract our interest since, indeed also Einstein to this tradiation. The notion of parallel displacement of vectotrs is the the fundamneatl prtagonist of this history

- Weyl by notn ly on the $g_{\mu\nu}$ but also on a four vector φ_{ν} Eddington to use the $\Gamma^{\tau}_{\mu\nu}$, Einstein $\Gamma^{\tau}_{\mu\nu}$ and $g_{\mu\nu}$ as non-symmetric. Einstein last attempt to use $\Gamma^{\tau}_{\mu\nu}$ which is flat but non symmetric. The question of the physical interpreation concern; however, in later theory the question seems to have been abandoned.
- This very convenient way of searching for the 'right' field-equations (you just have to search scalar density $\mathcal{H}$ has been widely adopted, and there are general reasons for believing that it is justified. demanding that the space-time integral of an invariant density , taken over any fixed region, be from the dynamical quantities then finds the conditions needed demanding that the space-time integral of an invariant density $\int \mathcal{H}$, taken over any fixed region, be stationary. Variation with respect to som of the fundemntal variables or both. The trick (and a trick it is) is to find the right $\mathcal{H}$ and the right dynamical quantities to produce the desired equations, to reconver Einstein and Maxwell equations at least in approximate form, valid for weak fields.
- Usually only after the field equations has been established, the field components which they connect (which are either the original basic geometrical

field-quantities or, more often, vectors and tensors built up from them) have to be identified, the components of the gravitantinal and electromagnetic tensors. In Eddington theory non-symmetric Ricci tensor if starts $g_{\mu\nu}$ the it is natural to identiy with affine, etc.

– since the fundamental field quantities have usually no physical meaning, the test electromagnetic field indirect way. Most such a way that they possess only one or at most a small number of static spherically symmetric solutions and their laws of motion. E.g. would represent 1) uncharged point masses 2) at rest with respect to each other, the theory would contradict experience.Thus it is clear that prior to the solution of this problem the behavior of a corpuscle in a field (its equations of motion) cannot be tackled And without the solution of this problem, the truth of the theory cannot be tested!

Ultimately, the motivation wa not real That this skeme presented sveral eepsistemological deifficultis, the meaning of the fundamental field equantis, to derive ... was measru formal; the testing of the theory appead to be queite inderect.

1 Coordination. The Weyl-Reichenbach Correspondence

After serving in World War I, from 1917 until 1920 Reichenbach worked in Berlin as an engineer specializing in radio technology to support himself after the dearth of his father. Nevertheless, in winter term 1917–1918 and in summer term 1919, he attended Einstein's Berlin lectures on special and general relativity. Einstein and We posses three sets of Reichenbach's undated student notes (HR, 028-01-04, 028-01-03, 028-01-01). A set of notes (HR, 028-01-01) seems to be very similar to Einstein's own lecture notes from 1919(Einstein, 1919).[1] In presenting general relativity, Einstein's lectures follow roughly the corresponding sections of his previous published presentations of relativity theory (Einstein, 1916, 1914). The mathematical apparatus of Riemannian geometry is introduced by starting from the metric $g_{\mu\nu}$ as the fundamental concept, that is from the formula to calculate the squared distance $ds^2 = g_{\mu\nu}dx_\mu dx_\nu$ between two neighboring points x_ν and $x_\nu + dx_\nu$ in any coordinate system. From the $g_{\mu\nu}$ the one calculate the so-called Christofell symbols $\left\{ \begin{matrix} \mu\nu \\ \tau \end{matrix} \right\}$, which enters in the geodesic equation, and Riemann tensor $R^\tau_{\mu\nu\sigma}$ which generalized the Gaussian notion of curvature.

However, both Reichenbach's and Einstein's notes show in the lectures May-June 1919 Einstein used for the first time the interpretation of the curvature in terms of the parallel displacement of vectors, which was introduced by Tullio Levi-Civita (1916) and applied to relativity theory by Hermann Weyl (1918b). Both names are mentioned explicitly (HR, 028-01-03, 33). Instead of using

[1]Further information about Einstein as an academic teacher, see Vol. 3, the editorial note, "Einstein's Lecture Notes,"pp. 3-10, and for a survey of Einstein's academic courses, see Vol. 3, Appendix B..

the metric as a fundamental concept, it is more convenient to start by the the coordinate-independent condition that two vectors at neighboring points x_ν and $x_\nu + dx_\nu$ are parallel $dA^\mu = \Gamma^\tau_{\mu\nu} A^\nu x_\nu$ (HR, 028-01-03, 33).[2] The $\Gamma^\tau_{\mu\nu}$, which is supposed to be symmetrical in the lower indexes, is the so-called affine connection (*Zusammenhang* or displacement (*Verschiebung*).[3] The metric could be introduced at further stage by defining the squared length of vectors $l^2 = g_{\mu\nu} A^\mu A^\nu$ in a manner independent of the choice of the coordinates. By imposing the condition that the length of vectors does not change under parallel transport the $\Gamma^\tau_{\mu\nu}$ have the same numerical values of the Christoffel symbols (up to a sign). The structure of the Einstein-Riemann geometry is then completely determined without any reference to the metric $g_{\mu\nu}$. It differs from the Euclidean structure by the fact that when a vector is transported along a closed curve, it will acquire a rotation determined whose amount Riemann tensor $R^\tau_{\mu\nu\sigma}(g)$.

This technical innovation in differential geometry played a fundamental role, not only in successive formulations of general relativity, but more prominently in the development of the unified field theory-project. If one starts with a symmetric $g_{\mu\nu}$ the road is, so to speak, marked. The Christoffel symbols are the only possible destination. However, if one defines the displacement $\Gamma^\tau_{\mu\nu}$ independently from the metric $g_{\mu\nu}$, the Riemannian connection $\Gamma^\tau_{\mu\nu} = \left\{ \begin{matrix} \mu\nu \\ \tau \end{matrix} \right\}$ appears only as a special case that has been achieved by introducing a series of conditions. In particular, Weyl (1918a, 1919a) was bothered by the asymmetry of the comparison of direction of vectors which is path-dependent could not be the comparison their lengths was distant-geometrical. To compensate for this 'mathematical injustice,' Weyl could introduced a more general affine connection depending not only the metric/gravitational tensor $g_{\mu\nu}$ but also the four-vector φ_ν. For formal reason, the latter could be identified with electromagnetic four-potential. Weyl could then conclude that just like general relativity represented a geometrization of gravitational phenomena, his theory represented a unified geometrization of both gravitational and electromagnetic phenomena, which were, at that time, the only kind known. Weyl did not hesitate to declare that "Der Traum des Descartes von einer rein geometrischen Physik" had be fulfilled (Weyl, 1919b, 263).[4]

Einstein had repeatedly criticized Weyl's attempt (Einstein, 1918a). However, by the spring of 1919, after a correspondence with Theodore Kaluza he had started to show more interest for the the unified field theory-project (Wünsch,

[2] I have uniformized the notation used by Reichenbach (1928a) which in turn is based on Eddington (1923, 1925).

[3] The affine geometry is the study of parallel lines, Weyl (1918c) hence the expression 'affine connection' (*affiner Zusammenhang*), where connection refers to the comparison at close points. 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. The word displacement also refers to the vector dx_ν. To avoid confusion the world transfer *Übetragung* was also used.

[4] Concluding the 1919 edition of the book, Weyl could declare that "physics and geometry coincide with each other".

2005). The question fell into the background after the success of the eclipse expedition was announced in November 1919 (Dyson, Eddington, and Davidson, 1920). By the end of the year, Einstein was turned into an international celebrity leaving him little time to work (Einstein to Fokker, Dec. 1, 1919; CPAE, Vol. 9, Doc. 187, Einstein to Hopf, Feb. 2, 1920; CPAE, Vol. 9, Doc. 295). The German philosophical community started to show increasing interest in the theory (Hentschel, 1990). The question whether was compatible with Kant's philosophy became pressing. Reichenbach was aware of the fact he had acquired a technical knowledge of the new theory that was not comparable to that of any philosophers of his time. Thus, it was nearly inevitable that in February or March 1920 Reichenbach, who has just moved to Stuttgart, decided to write his habilitation on this topic.. In the preceding months, he had further worked on the theory "also according to Weyl" (HR, 044-06-23). The Kapp-Pusch coup on March of 1920 gave Reichenbach a few days of leave from Huth radio industry were he was employed (HR, 044-06-23). Thus, he could work without interruptions and in ten days he completed an early draft. The manuscript was then typed and shown among others to Einstein. Thanks to the mediation of Arnold Berliner, the influential editor of the *Naturwisseschaften*, Reichenbach obtained a publication agreement with Springer (HR, 044-06-23).

Reichenbach's habilitation has recently attracted great attention (Friedman, 2001). Reichenbach borrowed from Schlick (1918) that idea that physical knowledge is ultimately (*Zuordnung*), the process of relating an axiomatically defined mathematical structure to concrete empirical reality. However, Reichenbach attempted to give this insight a 'Kantian' twist. According to Reichenbach, in a physical theory beside the 'axioms of connections' (*Verknüpfungsaxiome*) encoding the mathematical structure of a theory, one needs special class of physical principles the 'axioms of coordination' (*Zuordnungsaxiome*) to ensure a univocal coordination of that structure to reality (Padovani, 2009). For the young Reichenbach, the latter axioms are *a priori* in the sense that they are 'constitutive' sense of the object of a physical theory. However, they are not apodeictic, or valid for all time. As it is well known, Reichenbach will soon abandon the project of a constitutive but relativized *a priori*. However, he firmly maintained the separation between the mathematical framework of a theory (the 'defined side') and the way it related to empirical reality (the 'undefined side') (Reichenbach, 1920b, **; tr. 1969 42) as an essential feature of his philosophy.

1.1 Reichenbach's Habilitation and his critique of Weyl Theory

According to Reichenbach, relativity theory made this division of labor in the realm of geometry inevitable. The possibility of non-Euclidean geometries had already indicated that the *a priori* character of Euclidean geometry had no longer been taken for granted (Reichenbach, 1920b; tr. 1969 3). Relativity theory has now shown *a posteriori* that the theorems of Euclidean geometry do not apply to the physical space. It became necessary to distinguish between pure geometry as an uninterpreted formal system and applied geometry as an empirical theory of physical space (Reichenbach, 1920b; tr. 1969 76). The propositions of pure geometry are neither true nor false. The question of the truth of geometry pertain to physics alone. However, rather in passing, Reichenbach indicated Weyl's theory as an example of how easy was to neglect this epistemological achievement. Weyl once again believed to have found a certain geometry that, for its intrinsic mathematical appeal, must be true for physical reality. "In this way the old mistake is repeated" (Reichenbach, 1920b; tr. 1969 76)

Reichenbach's brief outline of Weyl's theory is sufficient to grasp the gist of his argument. As Reichenbach's put it, "Weyl's generalization of the theory of relativity [...] abandons altogether the concept of a definite length for an infinitesimal measuring rod" (Reichenbach, 1920b, **; tr. 1969 **). In Euclidean geometry a vector can be shifted parallel to itself along a closed curve so that upon its return to the point of departure it has the same direction and the same length. In the Einstein-Riemannian geometry it has merely the same length, no longer the original direction, after its return. In Weyl's theory it does not even retain the same length. As we have seen, in this way, in addition to the 'metric tensor' $g_{\mu\nu}$, a 'metric vector' φ_ν is introduced that, for formal reasons, could be identified with electromagnetic potential. Reichenbach conceded that Weyl's theory represented a possible generalization of Einstein's conception of spacetime which, "although not yet confined empirically, is by no means impossible" (Reichenbach, 1920b, **; tr. 1969 **).

Reichenbach seemed to have been aware of Einstein's main objection to Weyl's proposal (Einstein, 1918a, see). In general relativity, the length ds of the time-like vector dx_ν is measured by a physical clock, e.g., by the crests of waves of radiation were emitted by an atom. If we maintain this interpretation, then Weyl's theories implies that "the frequency of a clock is dependent upon its previous history" (Reichenbach, 1920b, **; tr. 1969 **). Two atomic clocks at one place, will in general not tick at the same rate when they are separated brought back together. This result appears to be contradicted by a vast amount of spectroscopic data shown that all atoms of the same type have the same systems of stripes in their characteristic spectra independently of their past history. Reichenbach conceded to Weyl that these effects might "compensate each other on the average" (Reichenbach, 1920b, **; tr. 1969 **). Thus, the fact that "the frequency of a spectral line under otherwise equal conditions is the same on all celestial bodies" could he interpreted as an approximation, rather than being a consequence of the Riemannian nature of space-time (Reichenbach, 1920b, **; tr. 1969 **). This, remark anticipates to a certain extent Weyl's line of defense. Reichenbach considered unacceptable was Weyl's justification for the choice of a more general geometry as the actual geometry of spacetime.

According to Reichenbach, Weyl seems to imply that his non-Riemannian geometry must be true *physically* because it is *mathematically* superior to Riemannian geometry, being a true realization of the principle of locality. As we have seen, in Weyl geometry a vector moving close loop which would same length but different direction in Riemannian geometry, different length and different direction in Weyl's geometry. Thus, Weyl geometry eliminated the last distant-geometrical treatment of Riemannian geometry. Weyl geometry seems to be the most 'general geometry,' a purely infinitesimal geometry. Thus, there would be no reason to assume from the outset that a more special geometry like that of that of Riemann applies to reality. However, Reichenbach had already surmised that this generalization can be continued. In Weyl's geometry lengths can be compared at the same point in different directions, but not at distant points. “The next step in the generalization would be to assume that the vector changes its length upon turning around itself” (Reichenbach, 1920b, **; tr. 1969 **). Probably, more complicated generalization could be thought of. “Nothing may prevent our grandchildren from being confronted some day by a physics that has made the transition to a line element of the fourth degree” (Reichenbach, 1920b, **; tr. 1969 **).[5] Thus, there is no “‘most general’ geometry” that in and by itself must be physically true. No matter one pushes further the level of mathematical abstraction, “the difference between physics and mathematics” cannot be eliminated; geometry alone can never be sufficient to establish the reality of physical space (Reichenbach, 1920b, **; tr. 1969 **).

Weyl seemed to have forgotten the importance of the philosophical lesson of general relativity, the unbridgeable “difference between physics and mathematics”. A mathematical axiom system is indifferent with regard to the applicability and “never leads to principles of an empirical theory” (Reichenbach, 1920b, **; tr. 1969 **). “Only a physical theory could answer the question of the validity of a particular geometry” for physical space:

> [Thus] it is incorrect to conclude, like Weyl[6] and Haas,[7] that mathematics and physics are but one discipline. The question concerning the validity of the axioms for the physical world must be distinguished from that concerning possible axiomatic systems. It is the merit of the theory of relativity that it renowned the question of the truth of geometry from mathematics and relegated it to physics. If now, from a general geometry, theorems are derived and asserted to be a necessary foundation of physics, the old mistake is repeated. This objection must be made to Weyl's generalization of the theory of relativity [...] Such a generalization is possible, but whether it is compatible with reality *does not depend on its significance for a general local geometry.* Therefore, Weyl's generalization must be investigated from the viewpoint of a physical theory, and only experience can be used for a critical analysis. Physics is not a ‘geometrical necessity’; whoever asserts this returns to the pre-Kantian point of view where it was a necessity given by reason (Reichenbach, 1920b, **; tr. 1969 **).

. To a certain extent, this objection contains the backbone of Reichenbach's criticism of the unified field theory-project in the following decade. Weyl seems to have misunderstood the fundamental lesson of Einstein's theory. The question

[5] $ds^4 = g_{\mu\sigma\sigma\tau} dx_\mu dx_\nu dx_\sigma dx_\tau$ instead of $ds^2 = g_{\mu\nu} dx_\mu dx_\nu$ as in Riemannian geometry.

[6] (Weyl, 1918b, 227). In the 1919 edition of the book, Weyl included a presentation of his theory. He concluded the book with an even more inspired rhetoric: “physics and geometry coincides with each other” (Weyl, 1919b, 263). The tendency of physicalizing geometry that have prevailed leading protagonists of the 19th century from Gauss to Helmholtz seemed to superseded have of geometrizing physics that run from Riemann to Einstein: “geometry has not been physics but physics has become geometry” (Weyl, 1919b, 263).

[7] (Haas, 1920).

concerning the "validity of axioms for the physical world" must be distinguished from that concerning possible axiomatic systems is happened to be in reality. It is true that it is "a characteristic of modern physics to represent all processes in terms of mathematical equations", and, one might add, progressively more abstract mathematics. Still, "the close connection between the two sciences must not blur their essential difference" (Reichenbach, 1920b, **; tr. 1969 **). The truth of mathematical propositions depends upon internal relations among their terms; the truth of physical propositions, on the other hand, depends on relations to something external, on a connection with experience. "This distinction is due to the difference in the objects of knowledge of the two sciences" (Reichenbach, 1920b, **; tr. 1969 **). The mathematical object of knowledge is uniquely determined by the axioms and definitions of mathematics. The definitions indicate how a term is related to that Schlick (1918) had called "implicit definitions" (Reichenbach, 1920b, **; tr. 1969 **).

As it is well-known, Reichenbach will abandon the Kantian framework in which this distinction was initially presented. However, he never abandoned the idea that the separation between mathematics and physics was of paramount epistemological importance: mathematical necessity must be sharply distinguished form physical reality. The latter was the irreversible conceptual shift produced that relativity theory had forced upon philosophy. On June 24, 1920, Einstein praised Reichenbach's *Habilitationschrift* in a letter to Schlick (Einstein to Schlick, Apr. 19, 1920; CPAE, Vol. 9, Doc. 378). A few days later, Reichenbach asked Einstein to dedicate the book to him, insisting on the philosophical significance of relativity theory: "very few among tenured philosophers have the faintest idea that your theory performed philosophical act and that your physical conceptions contain more philosophy than all the multivolume works by the epigones of the great Kant" (Reichenbach to Einstein, Jun. 13, 1920; CPAE, Vol. 10, Doc. 57). Einstein conceded, that the theory might have had philosophical relevance: "The value of the th. of rel. for philosophy seems to me to be that it exposed the dubiousness of certain concepts that even in philosophy were recognized as small change [*Scheidemünzen*]" (Einstein to Reichenbach, Jun. 30, 1920; CPAE, Vol. 10, Doc. 66). Alleged *a priori* principles are like those parvenu that are ashamed of their humble origin and try to deny it: "[c]oncepts are simply empty when they stop being firmly linked to experience" (Einstein to Reichenbach, Jun. 30, 1920; CPAE, Vol. 10, Doc. 66).[8] This remark, which Reichenbach would later quote in a published writing (Reichen-

[8]Einstein used a similar wording by commenting on the manuscript of Cassirer's 'Kantian' booklet on relativity. "Conceptual systems appear empty to me, if the manner in which they are to be referred to experience is not established" (Einstein to Cassirer, Jun. 6, 1920; CPAE, Vol. 10, Doc. 44). In particular, "[w]ith the interpretation of the ds as a result of measurement, which is obtainable by means of measuring rods and clocks the general theory of relativity as a physical theory stands or falls" (Einstein to Cassirer, Jun. 6, 1920; CPAE, Vol. 10, Doc. 44). The gravitational redshift, can be taken as an empirical confirmation of general relativity only because different atoms of the same substance can be regarded as identically constructed clocks reproducing the identical unit of time. For this reason it is possible to 'normalize' the absolute value of ds by counting the wave crests on atom. According, Weyl's theory deprived the ds of any physical meaning. However, real rods and clocks behave differently than predicted by Weyl theory forcing Weyl to assume an inconsistent position. According to

bach, 1922b, 354), seals a sort of philosophical alliance between Reichenbach and Einstein. Against the Weyl's speculative style doing physics which reduced physical reality to geometrical necessity, relativity theory had has introduced a clear cut separation between between geometrical necessity and physical reality. As we shall see, this philosophical covenant will be broken less then a decade later.

1.2 The Reichenbach-Weyl Correspondence

Reichenbach's book was published a few months later just on that occasion the 86th Assembly of the *Versammlung der Gesellschaft Deutscher Naturforscher und Ärzte* in Bad Nauheim in September 1920. This meeting of fundamental importance for in the history of relativity theory, at least the famous debate between Einstein and Philipp Lenard. Reichenbach met Weyl there for the first time, where the latter gave a talk on his theory (Weyl, 1920a). Reichenbach might have assisted at the debate that followed in which Einstein rehearsed his objections against Weyl,[9] and the same time defended the possibility of a field theory of matter against Pauli.[10] Just after Bad Nauheim Moritz Schlick, who was at that time the leading philosophical authority in relativity theory wrote to Einstein about Reichenbach's book complaining about his critique of conventionalism (Schlick to Einstein, Sep. 23, 1920). The five letters that Reichenbach

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Einstein, line general relativity, Weyl's "theory is based on a measuring rods geometry", that is it presupposes the comparability of lengths. However, it entains only "thought measuring rods [*nur gedachte Massstäbe*]" that behave differently from the real ones. "This is repugnant" (Einstein to Besso, Aug. 26, 1920; CPAE, Vol. 10, Doc. 85; m.e.).

[9]Commenting on Weyl's talk, he pointed out once again that the "arrangement of [his] conceptual system," "it has become decisive [*massgebend*] to bring elementary experiences into the language of signs [*Zeichensprache*]" (Einstein et al., 1920, 650). For Einstein, "temporal-spatial intervals are physically defined with the help of measuring rods and clocks", under the assumption that "their equality is empirically independent of their prehistory" (Einstein et al., 1920, 650). Einstein insisted that precisely upon this assumption rests "the possibility of coordinating [*zuzuordnen*] a number ds to two neighboring world points"; if this were impossible, general relativity would be robbed of "its most solid empirical support and possibilities of confirmation" (Einstein et al., 1920, 650)..

[10]In is interesting to notice, that Einstein already showed a more flexible attitude replying to Pauli's remarks during the same discussion. Pauli reiterated his objection based on his 'observability' criterion. Just as the field strength in the interior of the electron is meaningless because there is no smaller test particle than the electron, "one could claim something similar concerning spatial measurements, *since there are no infinitely small measuring-rods*" (Einstein et al., 1920, 650). Einstein replied to Pauli that "with the increasing refinement of the system of scientific concepts, the manner and procedure of associating the concepts with experiences becomes increasingly more complicated" (Einstein et al., 1920, 650). In particular, he recognized that in cases such as that of the continuum theories, "one finds that a definite experience cannot be associated any longer with a concept" (Einstein et al., 1920, 650). According to Einstein, there is an alternative: one can abandon 'continuum theories' for the sake of Pauli's observability criterion, or replace such a "system of associating concepts [with experiences] with a more complicated one" (Einstein et al., 1920, 650). Einstein's in his contributions to the the discussion which followed Max von Laue's (1920)'s Bad Nauheim paper. Einstein, however, in the very same sentence, did not hesitate to admit that "[it] is a logical shortcoming of the theory of relativity in its present form to be forced to introduce measuring rods and clocks *separately instead of being able to construct them as solutions to differential equations*" (Einstein's reply to Laue, 1920, 662; m.e.).

and Schlick exchanged between October and November of 1920[11] turned out to be of fundamental importance in Reichenbach's intellectual biography. Reichenbach was confronted with Schlick's objection that his 'axioms of coordination' were nothing but 'conventions.' Reichenbach offered some resistance,[12] since it seems to make physical geometry empirically meaningless. However, Einstein's famous lecture on 'geometry and experience' of the end January of 1921 *Geometrie und Erfahrung*[13] seemed to have tipped the scale in Schlick's favor (Reichenbach, 1921b).[14]

Reichenbach must have sent a copy of his *Relativitätstheorie und Erkenntnis apriori* (Reichenbach, 1920b) also to Weyl despite the rather severe critiques he had expressed in the book. Weyl replied with some delay in February 1921. He did not appear to be upset by Reichenbach's objections and replied rather amicably to some issues "which concern less the philosophical than the physical" (Weyl to Reichenbach, Feb. 2, 1921; HR, 015-68-04). In particular Weyl denied to have ever claimed that physics has been absorbed into mathematics:

> It is certainly not true, as you say on p. 73, that, for me, mathematics (!!, e.g. theory of the ζ-function?) and physics are growing together into a single discipline. I have claimed only that the *concepts* in *geometry* and field physics have come to coincide [...] As for my extended theory

[11]Schlick to Reichenbach, Sep. 25, 1920; HR, 015-63-23 Schlick to Reichenbach, Nov. 26, 1920; HR, 015-63-22 Schlick to Reichenbach, Dec. 11, 1920; HR, 015-63-19 Reichenbach to Schlick, Nov. 29, 1920 Reichenbach to Schlick, Sep. 10, 1920.

[12]In particular Reichenbach complained the notion of convention put too much on the arbitrariness of the principles, making even claims like the earth is round empirically not testable. The notion of simplicity seemed to Reichenbach to vague to allow for theory choice. In Poincaré conventionalism, Reichenbach missed claim that "the arbitrariness of the principles is constrained, if the principles are combined" Schlick to Reichenbach, Nov. 26, 1920; HR, 015-63-22.

[13]On January 14, 1921 Einstein, while in Vienna, released the following declaration: "A theoretical system can only claim completeness if the relationships of the concepts to the facts that can be experienced are clearly established. It is not enough, for example, to base the theory of relativity on a mathematical fundamental invariant [ds]. It must also be clear how this invariant is related to the observable facts as [that](2) [happened] for the fundamental concepts of Maxwell's theory by Heinrich Hertz. If one disregards this point of view, one can only arrive at unrealistic systems" (Doc. 50a]CPAE). A few days later January 27, 1921 Einstein held *Geometrie und Erfahrung* in Berlin. the lecture ultimately meant to address precisely this issue although in a popular form. (a) the invariant ds is measured by ideal rods and clocks, like the electric field strengths are measured by charged test particles (b) ideal rods and clocks do no exist in nature (as pointed out by Poincaré). Conclusion: *sub specie aeterni* geometry cannot be tested separately from the rest of physics (the famous $G + P$ formula). The choice of a particular geometry is ultimately justified by its success of delivering a good physical theory. It is assumed that solutions to the appropriate dynamical equations exist that can serve as rods and clocks. In Weyl's theory, however, real rods and clocks would behave differently differently from the ideal rods and clocks in Weyl geometry. This incosistensy was the point that Einstein find unbearable. Thus, March 1921 Einstein preferred to suggest a theory in which there were no transportable ideal rods at all; only $ds = 0$ would have physical meaning (Einstein, 1921b).

[14]Reichenbach seems to have ultimately translated the Einstein's $G + P$ formula into his $G + F$ formula, where F is a 'universal force' affecting all bodies in the same way. By setting $F = 0$ geometry becomes empirically testable. Reichenbach could embrace conventionalism, without having to accept that the proposition of geometry are empirical meaningless.

of relativity, so I cannot admit that the epistemological situation is in any way different from that of Einstein. [...] *Experience* is in no way anticipated by the assumption of that general metric; that the laws of nature, to which the propagation of action in the ether is bound, can be of such a nature that they do not allow any curvature. [...] What I stand for is simply this: The integrability of length transfer (if it exists, but I don't think so, because I don't see the slightest dubious reason for it) does not lie in the nature of the metric medium, but can only be based on a special law of action.[15] If the historical development had been different, it seems to me that no one would have thought of considering the Riemannian case from the outset. As far as the notorious 'dependence on previous history' is concerned, I probably expressed my opinion clearly enough in Nauheim (Weyl to Reichenbach, Feb. 2, 1921; HR, 015-68-04).

In Bad Nauheim, Weyl outlined a now well-known speculative explanation for the discrepancy between the behavior of 'ideal' and 'real' rods. Roughly, Weyl suggested that the atoms we use as clocks might not *preserve* their size if transported, but *adjust* it every time to some constant field quantity, which he could identify with the constant radius of the spherical curvature of every three-dimensional slice of the world. The geometry read off from the behavior of material bodies would appear different from the actual geometry of space-time, because of the 'distortion' due to the mechanism of the adjustment. In 1921, the 'pivotal year' for unified field theories (Vizgin, 1994, ch. 4), Weyl (followed to some extent by Eddington, 1921a,b) reacted by expanding his strategy of 'doubling the geometry,' the real 'aether geometry' and the 'body geometry' distorted by the mechanism of adjustment, in three papers intended for different audiences, February (Weyl, 1921e), May (Weyl, 1921b) and July (Weyl, 1921d). In the July paper Weyl also addresses Reichenbach's criticism publicly:

From different sides[16] it has been argued against my theory, that it would attempt to demonstrate in a purely speculative way something *a priori* about matters on which only experience can actually decide. This is a misunderstanding. Of course from the epistemological principle [aus dem erkenntnistheoretischen Prinzip] of the relativity of magnitude does not follow that the "tract" displacement [Streckenübertragung] through "congruent displacement" [durch kongruente Verpflanzung] is not integrable; from that principle that no *fact* can be derived. The principle only teaches that the integrability *per se* must not be retained, but, if it is realized, it must be understood as the *outflow* [Ausfluß]*of a law of nature* (Weyl, 1921a, 475; last emphasis mine).

Weyl never claimed that his geometry entails in its mathematical structure alone the *a priori* justification of its physical truth. On the very contrary, he questioned the alleged *a priori* status of the assumption that the comparison of lengths is path-independent. Weyl did not deny that empirical fact that two

[15] That is on the field equations of the theory which in turned can be derived from an 'action principle'.

[16] The reference is to Reichenbach, 1920b and Freundlich, 1920 who however refers to Haas, 1920.

atoms of the same chemical substance placed identically in the same conditions, is independent of their prehistory. However, the behavior of atoms does not have nothing to do with the abstract notion of parallel transport of vectors.[17]

1.3 The Weyl-Reichenbach Appeasement

Weyl's paper referencing Reichenbach appeared at beginning of September. A few week later Reichenbach and Weyl met again in Jena on occasion of the first *Deutsche Physiker- und Mathematikertag* the first national scientific meeting held independently from the meetings of the *Gesellschaft Deutscher Naturforscher und Ärzte.* Weyl gave a talk in which he tried to provide a mathematical justification for the quadratic nature of the metric.[18] Reichenbach presented a report of is work on the axiomatization of relativity. This report is the first testimony of the development of Reichenbach's philosophy after the Schlick-correspondence. Reichenbach suggested that in a physical theory one should distinguish the *axioms* as empirical proposition about light rays, rods and clocks , etc. and the *definitions* that establish the conceptual framework of the theory (Reichenbach to Einstein, Dec. 5, 1921; CPAE, Vol. 12, Doc. 266). After the conference, Reichenbach, sent Weyl a copy of the paper that came out in October (Reichenbach, 1921a) possibly including a personal retraction of his criticisms, a few by writing to him a few months later from January 8, 1922 keeping him up to date on the development of his axiomatics. This latter, which Weyl received only months later, is no longer extant. However, Reichenbach soon issued a public retraction.

At about the same time, he started to work on a long review article on philosophical debate on relativity, that was finished in Spring 1922. On March 24, 1922. Erwin Freundlich sent to Einstein "die Druckbogen einer kritischen Untersuchung von Reichenbach auf dessen Wunsch". Einstein expressed his general agreement with Reichenbach's analysis of the philosophical implications of relativity and praised its clarity (Docs. 119 and 366). The paper goes through from Schlick to Cassirer. However, the it also included a last section on Weyl's unified field theory: Man darf eine Darstellung der relativistischen Philosophie

[17]In September 1921, Pauli's encyclopedia article on relativity theory (which was finished in December, but underwent some improvements in April and May) was finally published, as part of the fifth volume of the *Enzyklopädie der Mathematischen Wissenschaften*, and later as a book with an introduction by Pauli's mentor, Arnold Sommerfeld (Pauli, 1921). The article was unanimously considered a masterpiece, in particular by Einstein himself (Einstein, 1922). Pauli introduced here the idea that Weyl provided two different versions of the theory. If Weyl's theory seeks to make predictions that are closely linked with the behavior of measuring rods and clocks, just like Einstein's theory, then the theory is clearly wrong. Not only should the effect of the electromagnetic field be noticeable in the spectral lines of a given substance, but, as Pauli shows, "the differences would increase indefinitely in the course of time" (Pauli, 1921, 763; tr. 1958, 196). If one renounces this interpretation, as Weyl later suggests, then the theory loses its physical meaning, becoming just a mathematical scheme that furnishes only "formal, and not physical, evidence for a connection between [the] world metric and electricity" (Pauli, 1921, 763; tr. 1958, 196). In this form the theory loess its "convincing power [*Uberzeugunggkraft*]" (Pauli, 1921, 763; tr. 1958, 196).

[18]I assume that this talk would have again bee suspiction since the local is intrinscally mathematical reason. Indeed, in Reuchenbach view there was no reason.

nicht abschließen, ohne der wichtigen Erweiterung zu gedenken, die vor 3 Jahren Weyl dem Raumproblem zuteil werden ließ (Reichenbach, 1922b).

Reichenbach appears to be fully of his towards conventionalism. The choice between Euclidean and non-Euclidean geometries is conventional, that is depends on which rods are rigid.[19] However, however, all these 'rods' are assume to posses a common property. If coincidence can be obtained in one place between a pair of points of one rod and a pair of points of the other, this coincidence will be possible at any other place and time, no matter how their prehistory might be. This might be calle the axiom of the Riemann class. The merit of Weyl is to have shown that even this axiom is not necessary: "Die grosse Entdeckung Weyls besteht darin, daß er einen allgemeineren Mannigfaltigkeitstypus aufdeckte, von dem auch der Riemannsche Raum nur ein Spezialfall ist" (Reichenbach, 1922b, 365). From this point of view, Weyl's theory is a purely mathematical discovery; it indicates a more general type of manifold that can be applied to reality when the Riemann class of axioms is not satisfied for natural rods. The fact he tried to follow this path, regardless of its empirical correctness, was a "genial advance [*genialer Vorstoß*]" in the philosophical foundation of the relations between geometry and physics (Reichenbach, 1922a, 367f.). Concerning the application of this mathematical apparatus to reality, Reichenbach embraces the two-theory interpretation[20]:

W-I: In Weyl geometry, like in Riemannian geometry the length of vectors $l^2 = g_{\mu\nu}A^{\nu}A^{\mu}$ can be compared at the same point in different directions. Weyl dropped the assumption that l remains unchanged under parallel transport at a distant point. If a vector of length l is displaced from x_ν to $x_\nu + dx_\nu$, it will in general have a new length $l + dl$, so that $dl/l = \varphi_\nu dx_\nu$. "The change in scale is measured by 4 quantities φ_μ forming a vector field". As Reichenbach pointed out, "this procedure is a purely mathematical discoery" (Reichenbach, 1922b, 366), and as such is neither true nor false. It can applied to reality, if one coordinates the length l as reading of some physical measuring instruments. As we have seen, in general relativity the length ds of the time-like vector dx_ν is measured by a clock, e.g.the spectra lines of an atomic clock. If this coordination is maintained so that "still possible to measure also in this case" (Reichenbach, 1922b, 366). However, the existence of atoms with the same spectral lines shows that clocks behave differently than predicted by Weyl theory. If atomic clocks

[19] Reality does not unambiguously prescribe one geometry and that, in choosing the definition of congruence, we have it in our power to determine the nature of the geometry that will subsequently emerge. A deviation from Euclidean geometry, then the preceding argument means that we must interpret this deviation as action of a force that deforms the measuring rods; but to admit the existence of such universal forces in physics would be to introduce uncertainty into all practical measurements. By excluding this kind of forces from the outset one fixed the definition of geometry. This was for Reichenbach essentially the proposition that only physics and geometry taken together as a whole is subject to the test of experience. As we shall see this was probably not Einstein's intention. Indeed, atomic clocks there is littler room for decision.

[20] Reichenbach might have been inspired by Pauli (1921). However, his name is not mentioned.

changed their periods as a function of their spacetime paths, one would expect that atoms with different pasts would radiate different spectral lines. However, this is not the case.[21] Thus, it turned out that this axiom "is quite well fulfilled in reality, so that the first way of generalization seems unsuitable. The latter was therefore rejected by Weyl" (Reichenbach, 1922b, 366)

W-II: Weyl adopted a different strategy. He "defines an ideal process of scale transfer, which however has nothing to do with the behavior of real scales" (Reichenbach, 1922b, 367). He needs this "Verpflanzungsprozeß" only because, he "he wants to identify the vector field φ_ν with the electromagnetic potential", like in general relativity the $g_{\mu\nu}$ where identified with the gravitational potentials (Reichenbach, 1922b, 367). Once one has individuated the basic geometrical field-quantities, the next step is to find the field equations "then obvious forms for the most general physical equations arise" via "the 'action principle' [*Wirkungsprinzip*]" (Reichenbach, 1922b, 367)—a variational principle applied to the invariant integral $\int \mathfrak{W} dx$ for a specific Lagrangian $\mathfrak{W}$. According to Reichenbach, however, in this way the "theory loses its convincing character [*überzeugenden Charakter*] and comes dangerously close to a mathematical formalism"[22] (Reichenbach, 1922b, 367). For this reason, according to Reichenbach, "Weyl's theory is viewed very cautiously by physicists (especially by Einstein)" (Reichenbach, 1922b, 367)

Ultimately, Reichenbach seems to imply that both strategies led to a dead end. From the point of view of **??** W-I: Weyl geometry is empirically inadequate from that of **??** W-II:, it does not have empirical content. Nevertheless, Reichenbach conceded that his original objections against Weyl's theory missed the point. Neither **??** W-I: nor **??** W-II: can be considered attempts to prove *a priori* that Weyl's non-Riemannian geometry must be true for reality for *a priori* reasons:

> However, I have to retract my earlier objection [(Reichenbach, 1920a, 73)] that Weyl wants to deduce physics from reason, after Weyl has cleared up this misunderstanding [(Weyl, 1921a, 475)]. Weyl takes issue with the fact that Einstein simply accepts the unequivocal transferability of the standards. He does not wish to dispute the Riemann-class axiom for natural standards, but only to demand that the validity of this axiom, since it is not logically necessary, should be understood as 'a consequence of a law of nature.' I can only agree with Weyl's demand; it is the importance of mathematics that they are. I can only agree with Weyl's demand; it is the importance of mathematics that, in uncovering more general possibilities, it marks the special facts of experience as special and thus preserves physics from naivity [*Simplizität*]. Admittedly, Weyl succeeds in explaining the unambiguous transferability of natural standards only very imperfectly. But the fact that Weyl tried to go this way, regardless of the

[21] This is, of course, the celebrated objection against Weyl's theory Einstein's (1918b).

[22] This choice of words is practically similar who claims the in the second form the theory lost his *Uberzeugunggkraft* (Pauli, 1921, 763; tr. 1958, 196).

empirical correctness of his theory, remains an ingenious advance towards the philosophical foundation of physics (Reichenbach, 1922b, 367f.).

Weyl's point was not that the axiom of Riemann class is necessarily false for *a priori* reasons, but that is not necessarily true: It cannot be a coincidence if two measuring rods placed next to each other are of the same length regardless of their location; this coincidence cries out for an explanation. Weyl's explanation of the apparent Riemannian behavior of "durch Einstellung der Maßstäbe auf den Krümmungsradius der Welt«" (Reichenbach, 1922b, 368; fn. 1) only means posing a problem rather than providing an answer. The problem could be solved only by developing a proper theory of matter. However, according to Weyl, it was legitimate to deduce the Riemannian behavior of real clocks from a theory based on the non-Riemannian behavior of geometrical vectors. In this way, however, the "stellung« nichts zu tun mit seiner kongruenten Verpflanzung, so dass diese physikalisch leer bleibt" (Reichenbach, 1922b, 368; fn. 1). If the non-Riemannian congruent transplantation of vectors must be, then the real rods should better behave in a non-Riemannian way.

Thus, Reichenbach concluded, the main achievement of Weyl was mathematical. As usual mathematics serve to enlarge the range of possibilities among which physicists can chose. This processes is however far from being concluded with Weyl's rather special affine connection:

> The philosophical significance of Weyl's discovery consists in the fact that it proved that the problem of space cannot be closed even with Riemann's concept of space. If the epistemology of today wanted to extend the assertion of Kant's transcendental aesthetics to the point that the geometry of experience must in any case at least have a Riemannian structure, it is held back by Weyl's theory. For that Weyl's space is at least possible for reality cannot be denied. One must not even believe that Weyl's theory has reached the highest level of generality. Einstein has shown (14) that Weyl's requirement of the relativity of magnitude can also be satisfied without making use of Weyl's method of measurement. After that, Eddington (15) again developed a generalization of which Weyl's space class is only a special case, and Eddington's space class is again included as a special case in a more general one found by Schouten. The merit of Schouten's theory is that it gives the conditions under which the class of space developed is the most general; they are very general conditions, like differentiability and the like. But of course there is no absolutely most general space class; and the history of the mathematical problem of space may teach epistemology never to make general claims. There are no most general terms (Reichenbach, 1922b, 368; fn. 1).

This passage shows that Reichenbach was now familiar with some of the latest advances in differential geometry. Not only with Weyl, but also with Eddington's (1921a) recent theory in which length cannot be compared even not at the same place in different directions. Moreover Reichenbach was familiar with Schouten's (1922) classification of connections. Thus, he was already aware that also the tacit assumption that the connection is symmetric could be dropped. In general by further relaxing the constraints on symmetry and on the relationship between the connection and the metric, a great number of ways to incorporate the electromagnetic field. In Reichenbach's view one should be free to chose among all these mathematical possibilities; however, mathematics alone cannot provide a criterion of choice for which possibility is realized in nature. Indeed, there was nothing special in Weyl geometry. Mathematics is the science of possibility, physics only is the science of reality.

For Reichenbach there should have been no limit, in the choice of what mathematical structure one can chose. However, Reichenbach believed to be essential to provide geometrical structure it was essential to give it a physical interpretation in advance, before starting doing physics as in **??** W-I:. Indeed, in this form the makes predictions that could be confirmed and disconfirmed empirically. Embracing **??** W-II: Weyl have unwittingly a sort of Poincareain move introducing a universal distortion of all measuring instruments, thus depriving geometry of any empirical content.[23] However, Weyl's stance was very different. In a latter written when the review article was already in press, Weyl confessed to Reichenbach that he never abandoned **??** W-I: in favor of **??** W-II: since he never adopted **??** W-I: in the first place: "Den Plan, starre Maßstäbe mit meiner Verpflanzımg zu identifizieren, habe ich aufgegeben. weil ich ihm nie gehabt habe"; on the contrary, "ich war überrascht, als ich salı, daß Physiker das in meine Worte hineininterpretiert hatten" Weyl to Reichenbach, May 20, 1922; HR, 015-68-02. The atoms the we use as clocks are physical systems like any other that do not have in principle much to do with abstract mathematical structure one uses. It is the theory that decides whether we should is them as reliable clocks or not. In general, one starts from a certain mathematical structure; a physical interpretation in terms of rods and clocks, test particles can only be provisional. Ultimately one has to find the field equations, and require that solutions to this equations exist exhibiting the postulated behavior of rods and clocks. This reasoning applies to Einstein and Weyl's theory: "Einstein has to show that from the dynamics of the rigid body it follows that the rod always has the same length, measured in his ds. Similarly, I have to show that the rod has always has the same length normalized ds normalized by $R = const$" (Weyl to Reichenbach, May 20, 1922; HR, 015-68-02). In both cases the behavior of rods and clocks comes out as a byproduct of the theory. The unit of time should defined a certain number of spacing between the atoms of a cubic crystal system; each of atom in turn consists of electrons and protons arranged according to a specific law. A specific solution to the field equations must provide information about all the details of this arrangement. The unit of time is a certain multiple of the vibration in an hydrogen atom, which in turn corresponds to a solution of the field equations.

[23] Indeed Weyl seem to introduce a sort of universal force that distorts all measuring instruments so that they behave in a Riemannian way, while the true geometry of spacetime is non-Riemannian. A different approach was suggested by Eddington, which considered non-Riemannian geometries as mere 'graphical representation' that serve to organize different theories into a common mathematical framework. The "natural geometry" remains Riemannian (Eddington, 1921a).

2 Geometrization: The Reichenbach-Einstein Correspondence 1926–1927

Up to this point, Reichenbach had good reasons to believe that these considerations were broadly in agreement with that of Einstein, who had continued to express skepticism towards Weyl's attempt (Einstein to Weyl, Jun. 6, 1922; CPAE, Vol. 13, Doc. 219 (Einstein to Zangger, Jun. 18, 22; CPAE, Vol. 13, Doc. 241)). The situation changed by the end of the 1922, when Einstein, during a trip to Japan, started to believe that Eddington's theory had potentialities that had not be exploited. On the shipboard he dotted down a five-page manuscript dated January 1923, from Singapore. Curiously, the third, fourth, and fifth pages were written on the back of the beginning of a typescript of Reichenbach's Jena's talk (Reichenbach, 1922a). Eddington (1921a) had extended Weyl's approach, but starting with the solo affine connection $\Gamma^{\tau}_{\mu\nu}$ without making any assumption about the relationship between the latter and the metric $g_{\mu\nu}$. In this context, vectors have no lengths, thus the theory avoided Weyl's inconsistency of having geometrical lengths behaving differently by real rods and clocks.[24] Einstein was ready to embrace a more speculative strategy in the search for a unified field theory. He did not give any physical meaning to the symmetric affine connection $\Gamma^{\tau}_{\mu\nu}$ and simply used it find a suitable Lagrangian $\mathcal{H}$. The comparison with experience would take place only *a posteriori* by integrating such equations and finding solutions corresponding to elementary particles.

Einstein published this idea soon returning from Japan (Einstein, 1923a,b). On May 2, 1923, Reichenbach requested a copy of Einstein's paper for the Proceedings of the Prussian academy (Reichenbach to Einstein, May 2, 1923; EA, 20 080). In the meantime, Reichenbach had concluded the manuscript of his book on the axiomatic and asked for Einstein's help in finding a publisher. Do to lack of founding, Reichenbach managed to publish the book only a year later on March 1924. With the *Axiomatik der relativistischen Raum-Zeit-Lehre* Reichenbach (1924) Reichenbach's philosophy started to assume a more recognizable contour. In particular Reichenbach introduced the distinction between conceptual definitions used in mathematics and coordinate definitions used in physics which relate the concept of a theory to a "piece [*Ding*] of reality" (Reichenbach, 1924, 5; tr. 1969, 8). There is little doubt that Reichenbach believed that this epistemological model was Einsteienan in spirit. However, at about that time Einstein explicitly confessed that he has changed in mind on the topic (Einstein, 1924, 1692, see Giovanelli, 2014). In particular, Einstein seemed that every concept of a theory, and in particular those pertaining to geometrical structure should receive a coordinative definition.[25] Ultimately only geometry

[24] See **??**.

[25] "In particular, I would like to mention that criticism was rightly aimed against one statement by the reviewer: that a concept should only be permissible in physics when it can be established whether or not it applies in concrete cases of observation; [9] it is objected that, in general, it is not to an individual concept that possible experiences must correspond but to the system as a whole" (Einstein, 1924, 1691).

and physics taken together could be compared with experience.[26]

Weyl's negative review of (Weyl, 1924) put an end to their previously amicable relationship. Reichenbach felt that Weyl—who showed some sympathies for phenomenology—had used his authority as mathematician to attack his philosophical reading of relativity (Reichenbach, 1925). What was worse, Reichenbach must have sensed that Weyl's speculative style of doing physics had become more prevalent. Einstein's last works seemed to show that he had also come under its spell. It is not surprising that Reichenbach might have felt necessary to make the case for an empiricist reading of relativity theory in a more popular form. At about the same time, Reichenbach, decided to write a book with the title *Philosophie der exakten Naturerkenntnis*, which will then divided in two parts of which only the first one on space and time will be published. He wrote the first chapters in March 1925. During those same months, Reichenbach, despite the support of Max Planck, was struggling to obtain his *Umhabilitation*[27] from Stuttgart to Berlin in order to be appointed to a chair of natural philosophy that had been created there (Hecht and Hoffmann, 1982). Reichenbach had been attacked for his pacifists positions during the war. After the situation seemed to turn for the best, in October 1925 he started to work ??? more consistently on the book. He interrupted the drafting of the manuscript to follow the emerging quantum revolution at the turn 1926. As he further wrote: "March-April 1926 Weyl's theory was worked on and the peculiar solution of §49 was found. The entire Appendix was also written at that time. (Correspondence with Einstein)". The correspondence with Einstein has been preserved. It testifies about Reichenbach's concern Einstein's style of doing physics becoming progressively more speculative. better

2.1 Reichenbach's Geometrization of the Electromagnetic Field

During a trip to South America in 1925 Einstein indeed became interested in the rationalistic and realistic reading of relativity proposed by Émile *La déduction relativiste* (Meyerson, 1925) CPAE, Vol. 14, Doc. 455, 6; March 12 who could provide for the search of a unified field theory.[28] However he also realized that the Weyl-Eddington-Schouten line had dry up (CPAE, Vol. 14, Doc. 455,

[26] In general relativity that the $g_{\mu\nu}$ had a physical meaning from the outset *ex ante* that is the rods and clocks that they can be measured with rods and clocks with respect to given coordinate system. In his recent theory, Einstein started from the $\Gamma^{\tau}_{\mu\nu}$ without giving to this quantity any physical meaning. If using the $\Gamma^{\tau}_{\mu\nu}$ leads to the right set of field equations, then the use of $\Gamma^{\tau}_{\mu\nu}$ as a fundamental variable is justified *post facto*. In this sense only geometry ($g_{\mu\nu}$ $\Gamma^{\tau}_{\mu\nu}$, etc.) and physics (field equations) together could be compared with experience (finding appropriate exact solutions corresponding to electrons).

[27] The process of obtaining the *venia legendi* at another university.

[28] Meyerson rationalistic realism that well supported the unified field theory-project. In particular, to philosophical alternative to both empiricists and positivists. Against the positivists he defended the logical independence of concepts from sensory experiences; against the Kantians that uses non-empirical 'ideal' conceptual constructions were mere conventions. Against both Meyerson justified that the physicists are justified to assume that certain conceptual construction exist in reality, say electromagnetic field, electron independently of observation.

9; March 17).[29] By returning from South America he embraced what he considered to be a new approach. He introduced non-symmetric $\Gamma^{\tau}_{\mu\nu}$ and the $g_{\mu\nu}$ to be treated as independent fields in the variation. The antisymmetric part of the $g_{\mu\nu}$ was the natural candidate for the representation of the electromagnetic field, at least for infinitely small fields. The physical test depended, as usual, on the construction of exact regular solutions corresponding to elementary particles. The paper was published in September of 1925 with the ambitious title "Nichteuklidische Geometrie und Physik" (Einstein, 1925b). However, by that time Einstein seemed to have already lost his confidence in that approach and moved on.[30]

At the turn of the year, after working on the new quantum mechanics must have come to read Einstein's new paper. On March 16, 1926, Reichenbach sent a letter to Einstein in which, after discussing his academic misfortunes, he made some critical remarks (Einstein, 1925a). Reichenbach was quite skeptical of the viability of Einstein's current style of doing physics:

> I have read your last work on the extended Rel. Th.[31] more closely, but I still can't get rid of a sense of artificiality which characterizes all these attempts since Weyl. The idea, in itself very deep, to ground the affine connection independently of the metric on the $\Gamma^{\tau}_{\mu\nu}$ alone, serves only as a calculation crutch here in order to obtain differential equations for the $g_{\mu\nu}$ and the φ_{ν} and the modifications of the Maxwell equations which allow the electron as a solution. If it worked, it would of course be a great success; have you achieved something along these lines with Grommer? However, the whole thing does not have the beautiful convincing power [*Ueberzeugungskraft*] of the connection between gravitation and the metric based on the equivalence principle of the previous theory (Reichenbach to Einstein, Mar. 16, 1926 EA, 20-83).

Reichenbach's objections are quite sensible. In general relativity the choice of the $g_{\mu\nu}$ as fundamental variables anchored in the principle of equivalence. The latter justified the double meaning of the $g_{\mu\nu}$, as determining the behavior rods and clocks, as well as the gravitational field. On the contrary, Einstein's new theory introduces the non-symmetric affine connection $\Gamma^{\tau}_{\mu\nu}$ independently of the metric $g_{\mu\nu}$ without giving to these field variables any physical motivation. The separate variation of the metric and connection was nothing more than a

[29] These doubts became certainty when Einstein returned to Europe. "On June 1, I got back from South America," Einstein wrote to Besso, "I am firmly convinced that the whole line of thought Weyl-Eddington-Schouten does not lead to anything useful from a physical point of view and I found a better trail that is physically more grounded" (Einstein to Besso, Jun. 5, 1925; CPAE, Vol. 15, Doc. 2).

[30] In July he was still convinced that he had "really found the relationship between gravitation and electricity" (Einstein to Millikan, Jul. 13, 1925; CPAE, Vol. 15, Doc. 20). However, during the summer, Einstein had already started to nurture some skepticism (Einstein to Ehrenfest, Aug. 18, 1925; CPAE, Vol. 15, Doc. 49; Einstein to Millikan, Jul. 13, 1925; CPAE, Vol. 15, Doc. 20; Einstein to Ehrenfest, Sep. 18, 1925; CPAE, Vol. 15, Doc. 71). The paper was published at the beginning of September, and by that time, Einstein probably already moved on (Einstein to Rainich, Sep. 13, 1925; CPAE, Vol. 15, Doc. 106; see Einstein, 1927).

[31] Einstein, 1925a.

'calculation device' to find the desired field equations. Only in hindsight, for formal reasons, the symmetric part was identified of $g_{\mu\nu}$ was identified with the gravitational field and antisymmetric with the electromagnetic field. In this form the theory has little he 'convincing power' (*Überzeugungskraft*)—-the same expression that Reichenbach (1922a, 367) had used for characterizing Weyl's theory in his second form. Reichenbach would have been ready to retract his cricitism, if Einstein's theory delivered the 'electron.' This concession, however, barely hide his skepticism that his was a concrete possibility

Einstein replied on March 20 that he agreed with Reichenbach's 'Γ-Kritik': "I have absolutely lost hope of going any further using these formal ways"; "without some real new thought" he continued, "it simply does not work" (Einstein to Reichenbach, Mar. 20, 1926; EA, 20-115). Einstein's reaction reflects his disillusion with the attempts to achieve the sought-for unification of gravitational and electromagnetic field by searching form some combination of $\Gamma^{\tau}_{\mu\nu}$ and $g_{\mu\nu}$. He would have probably been less ready to embrace the actual implications of Reichenbach's Γ-critique, the requirement that the operation of parallel displacement of vectors should received a 'coordinative definition' fro the outset. Reichenbach took the opportunity of Einstein's positive reaction and on March 31, 1926 he sent him a note in which he developed the Γ-critique in details. note In the note—which is extant—Reichenbach had developed his own unified field theory, a theory that upheld the Γ-requirement.

The content of the note has been presented in details elsewhere (Giovanelli, 2016b), however the basic idea can be easily summarized. As it is well known, in general relativity, uncharged particles under the influence of gravitational and electromagnetic field describe are not attracted by a force, but move along the straightest line defined by the $\Gamma^{\tau}_{\mu\nu}$. On the contrary, charged particles accelerate with respect to a given geodesic. Thus, one can say that gravitation has been 'geometrized,' but electromagnetism has been not. In order to geometrize the electromagnetic field as well, Reichenbach introduced a more general affine connection $\bar{\Gamma}^{\tau}_{\mu\nu}$ in which the length of vectors is preserved under parallel transport but the condition of symmetry is abandoned $\bar{\Gamma}^{\tau}_{\mu\nu} \neq \bar{\Gamma}^{\tau}_{\nu\nu}$. The abstract notion of parallel-transported vectors were coordinated with the physical notion of the velocity vector $u^{\tau} = dx_{\nu}/d\tau$ of a charged mass point. In Riemannian geometry the straightest lines are identical with the shortest lines. If the connection is non-symmetric, the straightest lines do not generally coincide with its geodesics, that is with the shortest lines. Reichenbach's connection $\bar{\Gamma}^{\tau}_{\mu\nu}$ was so defined that mass points of unit mass move (or their velocity four-vector is parallel-transported) along the straightest lines, and uncharged particles move on the straightest lines that are at the same time the shortest ones. Thus, both the gravitational and the electromagnetic field had been geometrized.

Einstein was not impressed (Einstein to Reichenbach, Mar. 31, 1926; CPAE, Vol. 15, Doc. 239). The definition of the tensorial part of the connection tensor, he argued, was arbitrary. Most of all, Reichenbach's equations of motion can be valid only for a certain charge-density-to-mass-density ratio ρ/μ[32] (Einstein

[32]In a given displacement, there is only one straightest line passing through a point in

to Reichenbach, Mar. 31, 1926; CPAE, Vol. 15, Doc. 239). Reichenbach rushed to point out that Einstein had misunderstood the spirit of the typescript. As Reichenbach explained, he was working on a philosophical presentation of the problem of space. "Thereby I wondered what the geometrical presentation of electricity actually means" (Reichenbach to Einstein, Apr. 4, 1926 EA, 20-086) . Reichenbach wanted to challenge the idea that geometrizing a field is per se a useful heuristic strategy. Thus, Reichenbach decided to provide a toy model of a proper geometrization. Update letters

The theory starts with a non-symmetric $\Gamma^{\tau}_{\mu\nu}$, a choice that is also arbitrary. In comparison with Eddington or Einstein's last theory, however, Reichenbach's approach had "the advantage over other geometrical representations in that *the operation of displacement possesses a physical realization [Realisierung]*" (Reichenbach to Einstein, Apr. 4, 1926 EA, 20-086; m.e.) , namely, the velocity-vector of charged mass particles. In this way, the geometrical predictions of the theory were suitable to be tested empirically. For this reason, in Reichenbach's view his geometrization was very similar to that provided by general relativity in which the predicted $g_{\mu\nu}$ are in principle comparable with the observed $g_{\mu\nu}$ measured by rods and clocks. Nevertheless, Reichenbach's theory, did not lead to any new physical prediction. Thus, Reichenbach concluded, a successful geometrization does not lead to a successful physical theory. Although Einstein probably continued to find the technical details of Reichenbach's attempt questionable, his philosophical point clearly resonated with Einstein:

> You are completely right. It is incorrect to believe that 'geometrization' means something essential. It is instead a mnemonic device [*Eselsbrücke*] to find numerical laws. If one combines geometrical representations [*Vorstellungen*] with a theory, it is an inessential, private issue. What is essential in Weyl is that he subjected the formulas, beyond the invariance with respect to [coordinate] transformation, to a new condition ('gauge invariance').[33] However, this advantage is neutralized again, since one has to go to equations of the 4. order,[34]which means a significant increase of arbitrariness (Reichenbach to Einstein, Apr. 8, 1926 EA, 20-117).

Einstein seem endorsed Reichenbach's claim that a 'geometrization' is not an essential achievement of general relativity. However, it is worth noticing, however, that Einstein goes further an claims that very notion of 'geometrization,' and for that matter the very notion of 'geometry' is meaningless (Lehmkuhl, 2014). The $g_{\mu\nu}$, $\Gamma^{\tau}_{\mu\nu}$, etc. are ultimately multi-components mathematical ob-

a given direction, but different test particles with different charge-to-mass ratios accelerate differently in the same electric field. Thus they cannot all travel on the same straightest line of the *same* connection. In Reichenbach's theory particles with different charge-to-mass-ratio would travel on geodesic of a *different* connections. This clearly make the theory anodyne.

[33]That is, invariance by the substitution of g_{ik} with λg_{ik} where λ is an arbitrary smooth function of position (cf. Weyl, 1918b, 468). Weyl introduced the expression 'gauge invariance' (*Eichinvarianz*) in Weyl, 1919a, 114.

[34]Cf. Weyl, 1918b, 477. Einstein regarded this as one of the major shortcomings of Weyl's theory; see Einstein to Besso, Aug. 20, 1918; CPAE, Vol. 8b, Doc. 604, Einstein to Hilbert, Jun. 9, 1919; CPAE, Vol. 9, Doc. 58.

jects characterized by their transformation properties under coordinate transformation. There is nothing 'geometrical' about those quantities. Einstein's point is only apparently similar to that of Reichenbach. Einstein declared that the difference between geometry and rest of mathematics was inessential. On the contrary, as we shall see, Reichenbach intended to show that difference between geometry and physics was essential. Einstein's argument was meant to provide a support of the unified field theory-project. Against those that believed that geometrization program could not be extended beyond the gravitational field, he could argue that geometrization has never been the issue in the first place.[35] Reichenbach's argument was on the opposite an attack on the unified field theory-project since it was based on the idea the geometrization in itself would have led to physical results.

2.2 The Appendix to the Philosophie der Raum-Zeit-Lehre

Strengthened by Einstein's apparent support in May Reichenbach presented the note in Stuttgart at the regional meeting of the German physical Society (Reichenbach, 1926). In the following Reichenbach must have further work on the manuscript and by the end of the year, he could write to Schlick, keeping him up to date with his book project: "The first volume that deals with space and time," he wrote, "is finished" (Reichenbach to Schlick, Dec. 6, 1926; SN). Reichenbach hoped to publish the book in the forthcoming Springer series 'Schriften zur wissenschaftlichen Weltauffassung' directed by Schlick and Philipp Frank. However, Springer rejected the book as being too long. By July Reichenbach could announce to Schlick that he had reached a publication arrangement (Reichenbach to Schlick, Jul. 2, 1927; SN). The publisher agreed to publish only the first volume under the title *Philosophie der Raum-Zeit-Lehre.* According to Reichenbach's later recollections, the manuscript of the first volume was not changed significantly after February 1927. The drafts were finished in September and the preface was dated October 1927. The note that Einstein had sent to Einstein became the §49 of the Appendix of the book bearing the title. Most readers have insisted on Reichenbach's on the problem problem of the *coordinative* in the philosophy of geometry. However, the book is also an attack on the *geometrization* in physics.

The core of he general theory of relativity was the equivalence principle. The latter is based on the *empirical fact* of the equality of inertial and gravitational mass implies that free-fall is locally indistinguishable from inertial motion. The equivalence principle is the *physical hypothesis* that this indistinguishability can

[35]Pauli's (1926) review of the German translation of Eddington (1925) is a typical example of this type of criticism: "This natural geometry with the gravitational field and is based on the empirical fact of the equality of heavy and inert mass. An attempt at an anatogenic geometrical interpretation of the electromagnetic mass is now faced with the difficulty that there is no empirical fact corresponding to the equality of heavy and inert mass, which would make such an interpretation appear "natural". One has therefore helped oneself by taking a sufficiently general geometry as a basis, which initially makes no mention of a direct connection between the introduced geometric quantities and the observed behavior of the scales and clocks".

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). One does not speak of the deformation of our measuring instruments "produced by the gravitational field", but we regard "the measuring instruments as 'free from deforming forces' in spite of the gravitational effects" (Reichenbach, 1928a, 294; tr. 256). The same measuring instruments as those used for geometry are at once indicators of the gravitational field. Rods and clocks are coordinated with $ds \pm 1$

In this respect, Reichenbach continues, "we may say that gravitation is *geometrized*" (Reichenbach, 1928a, 294; o.e.; tr. 256). However, Reichenbach wants to disabused the readers for taking this conclusion. The presence revealed by, and not defined by the geometry, it is revealed by their behavior of geometrical measuring instruments. Besides serving in their usual capacity of determining the geometry of space and time, they serve, therefore, also as indicators of the gravitational field. The geometrical interpretation of gravitation is consequently an expression of a real situation, the universal nature of gravitation. Measuring instruments made of whatever fields and particles can be used to explore the gravitational field, and the result of such measurements is independent of the device. "It is not the theory of gravitation that becomes geometry, but it is geometry that becomes an expression of the gravitational field". In this sense, "The theory of relativity did not convert a part of physics into geometry. On the contrary, even more physics is involved in geometry". The gravitational field has not become geometry as many have claimed; the gravitational field has a causal influence on the geometrical instruments used in geometry rods and clocks, light rays, test particles, etc. The Appendix was nothing but the continuation of this line argument. "The geometrical interpretation of gravitation is merely the visual cloak in which the factual assertion" encoded by the equivalence principles. The cloak might be conceived a as an inextensible network of rods and clocks, that have to be tailored to the body of the gravitational field. "It would be a mistake to confuse the cloak with the body which it covers; rather, we may infer the shape of the body from the shape of the cloak which it wears. After all, only the body is the object of interest in physics". The fact that an Euclidean cloak, so to speak, does not fit the body of a real gravitational field allows to now something new about shape of the body, that is to make the new predictions.

Unfortunately, physicists have misunderstood the lesson of theory. "The great success, which Einstein had attained with his geometrical interpretation of gravitation" led many "to believe that similar success might be obtained from a geometrical interpretation of electricity" (Reichenbach, 1928a, 352; tr. [491]). After general relativity was accepted by the physics community, the search for a suitable geometrical cloak that could cover the naked body of the electromagnetic field began. The separation of the 'operation of displacement of vectors' $\Gamma^{\tau}_{\mu\nu}$ from the operation of comparison of length at distance $g_{\mu\nu}$ gave physicists new mathematical degrees of freedoms that could be exploited to accommodate the electromagnetic field alongside the gravitational field. “However, the fundamental fact which would correspond to the principle of equivalence is lacking”. Thus, physicists needed proceed by trial and error in the search for suitable geometrical-field variables.

Initially attempts were made to identify these geometrical structures with ‘true’ the geometry of spacetime. The latter was supposed to be endowed with a more general general affine structure. To give this claim empirical content, Weyl initially provided a “realization of the process of displacement” in terms of the behavior of rods and clocks. Weyl’s project failed, since rods and clocks did not behave as predicted by the theory. “This means that we have found a cloak in which we can dress the new theory, but we do not have the body that this new cloak would fit” (Reichenbach, 1928a, 353; tr. [493]). Nevertheless, physicists did not abandon the geometrization program. Rather they came to the conclusion that that “such ‘tangible’ realizations does not lead to the desired field equations”.

Thus, theories were proposed by “Weyl, Eddington and Einstein” which “renounced such a realization of the process of displacement”. The geometrical structure chosen did not have the ambition to the geometrical structure of spacetime and does not have any physical meaning from outset. “Einstein, in particular, has devised several new formulations in which the geometrical interpretation is reduced to the role of a mathematical tool”. The trick was to ‘guess’ the right action and the right dynamical quantities to produce the desired equations, that is Maxwell and Einstein’s field equations in first approximation. Practitioners of the unified field theory-project seemed convinced that, “[[...] [i]n this ‘guessing’ the geometrical interpretation of electricity is supposed to be the guide”. The fundamental geometrical field quantities have no physical meaning, thus the prediction of the theory cannot be directly compared with experience as in the case of general relativity. The unified field theory can be confronted with reality indirectly only *post facto* by delivering the electron: “The resulting differential equation would have to have a solution corresponding to the electron, and would have to show the discreet nature of the electron as a mathematical necessity”

In Reichenbach’s assessment, this post-general-relativistic style of doing physics was ultimately motivated by the misunderstanding that the success of general relativity was due to the fact that it geometrized the gravitational field and that thus the geometrization of other fields would have lead to similar results. Reichenbach conceded that general relativity was indeed a geometrical interpretation of the gravitational field. However, this interpretation was possible due to rather peculiar circumstances. The geometrical interpretation of relativity theory was (a) *physically motivated* since the equivalence principles justified the use of geometrical indicators like rods and clocks for the gravitational field (b) *heuristically powerful*, it made new predictions, which were confirmed by measurements carried out with real physical systems. In absence of an anlogon equivalence principle the geometrical interpretation of electricity can indeed be carried through. This was what Reichenbach tried to show in section §49 by providing a toy-geometrization of the electromagnetic field. A geometrization of a field is always possible, e.g. by introducing a suitable definition of the affine connection. One can even provide a geometrical interpretation in which the operation of parallel-transport of vectors has a physical meaning. However a successful geometrization does not necessarily lead to a successful physical theory.

Reichenbach was quite skeptical that the geometrization program was very improbable that geometrization program was worth pursuing. “The many ruins along this road urgently suggest that solutions should be sought in an entirely different direction”. Why did physicists still persist? Reichenbach quite perspectively grasped their psychological motivation: “It is not the geometrical interpretation of electricity” but a deeper assumption which lies at the basis all these attempts; namely, “the assumption that the road to a simple conception, in the sense of a geometrical interpretation, is also the road to true relationships in nature”. The point of departure in this approach is “the (unwritten) assumption that whatever looks *simple* and *natural* from the viewpoint of the geometrical interpretation will lead to the desired changes in the equations of the field”. Indeed, by reading papers on the unified field theory one is struck by the fact that they are full of expressions like ‘most natural assumption,’ ‘simplest invariant’ , etc. “It is this assumption which constitutes the *physical hypothesis* contained in these attempts”. General relativity was based on physical hypothesis based on the equivalence principle, which was hover based on an empirical fact, the identity of gravitational and inertial mass. The unified field theory-project is is based a different physical hypothesis of more speculative nature that the world is geometrically simple. Needless, to say the idea that the ‘simplicity’ of mathematics could have have bearing for the truth of the theory was Reichenbach the consequence of a sever conceptual mistake *Philosophie der Raum-Zeit-Lehre*****, in which again the separation between mathematics and physics was not taken into considerations.

“The final decision regarding this new physical territory must be left to the physicist, whose physical instinct provides the sole illumination”. However, ultimately scientists’ “physical instinct” pertains to the real of the logic of discovery and thus lies completely outside epistemology. However, Reichenbach made no mysteries that he hoped that his epistemological analysis could tie scientists to the mast of empiricism protecting them from “the sirens’ enchantment [*Sirenenzauber*] of a unified field theory” (Reichenbach, 1928a, 373). *Philosophie der Raum-Zeit-Lehre* was not only a book about the problem of the *coordination* between geometry and reality. It was an attack against the rhetoric of the *geometrizaton* of physics that seemed to have started to dominate the relativistic community. If there is something we can learn from general relativity, Reichenbach argues, it is that abstract geometry has been lowered to physics, and certainly not that physics has been absorbed into geometry. 1929

3 Unification: Reichenbach-Einstein Correspondence 1929–1930

In October 1927, Reichenbach moved back to Berlin where he took the position of as an "unofficial associate professor" (Hecht and Hoffmann, 1982). At about the same time, Einstein read the manuscript of the *Philosophie der Raum-Zeit-Lehre* while on his way to Brussels to attend the fifth Solvay Congress (Bacciagaluppi and Valentini, 2009) (Einstein to Elsa Einstein, Oct. 23, 1927; CPAE, Vol. 16, Doc. 34). Soon thereafter he wrote a short review. Einstein was quite perceptive in pointing out the two themes that Reichenbach had treated in the Appendix: (1) "In the Appendix, the foundation of the Weyl-Eddington theory is treated in a clear way and in particular the delicate question of the *coordination* of these theories to reality" (Einstein, 1928c, 20; m.e.). As we have seen, Reichenbach had complained about the tendency of modern physicist claimed that, as in any other theory, also in unified field theory, one should give physical meaning the operation of displacement from the outset, before starting to search for the field equations. Einstein did not comment further on this issue, probably because, over the years, he had come to realize that this requirement was too strict. However, Einstein seemed to be in full 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, 1928c, 20; m.e.). As we have seen, Reichenbach and Einstein had already discussed this topic in a private correspondence less than two years earlier (Giovanelli, 2016a).

Simultaneously with Reichenbach's review, after a nearly a year-long correspondence, at the end of 1927, Einstein (Einstein to Meyerson, Dec. 24, 1927; EA, 18-294) gave 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 reveals how Einstein was had become on both issues. He embraced Meyerson's rationalist philosophy, insisting on the deductive-speculative nature of physics enterprise. He insiste again that geometry in this context is "*devoid of meaning*" (Einstein, 1928a, 165; m.e.). However, he also clarified the motivations against the critique of the geometrization program: "The essential point of the theories of Weyl and Eddington", was not to geometrize the electromagnetic field, but to "represent gravitation and electromagnetic under a unified point of view, whereas beforehand these fields entered the theory as logically independent structures" (Einstein, 1928a, 165). Einstein's further attempts at unified field theory testifies to his better

In spring 1928, during a period of rest, Einstein came up with a new proposal for a unified field theory. On June 7, 1928 he presented a note to the Prussian Academy on a 'Riemannian Geometry, Maintaining the Concept of Distant Parallelism' (Einstein, 1928d), a flat space-time that is nonetheless non-Euclidean since the connection is non-symmetrical. 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. Vectors at distance points considered as equal and parallel if they have the same local coordinates with respect to their n-bein. 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. On June 14, 1928 he submitted a second paper in which the field equations are derived from a variational principle (Einstein, 1928b).

A few months later, Reichenbach managed to read this paper and prepared a type-scripted note (Reichenbach, 1928b) with some comments that he send Einstein for feedback:

> Dear Herr Einstein,
> I did some serious thinking on your work on the field theory and I found that the geometrical 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 further expectations for your new work? (Reichenbach to Einstein, Oct. 17, 1928 EA, 20-92; m.e.).

In this passage, Reichenbach makes two apparently unrelated points, which are however part of single two-step argument. In the note sent to Einstein Reichenbach had shown that, if one lets aside from the n-bein formalism, Einstein's new geometrical settings could be easily inserted into the Weyl–Eddington–Schouten lineage as a special case, that is is a particular case of a flat space with a non-symmetric affine connection.[36] If this is the case, then the Reichenbach could rase the same objection he had raised against most unified field theory field theory. According to Reichenbach, "real physical achievement is obtained only if, moreover, the operation of displacement is filled with physical content" (Reichenbach, 1928c, 7). Einstein's geometry, being flat, 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, 1928b, 224). However, as Reichenbach reported, the latter has no physical meaning in Einstein's theory. "If geometrical interpretation must be", Reichenbach concluded, then his §49-theory was preferable since the straightest lines and shortest line correspond to the motion of charged and uncharged test particles under the influence of the combined gravitational-electromagnetic field. Once again, Einstein's goal was to use this geometrical apparatus a starting point find the right action. However, Reichenbach commented, nothing new came out of it: "[T]he derivation of the Maxwellian and gravitational equation from a variational principle was already achieved by other approaches" (Reichenbach, 1928c, 6), like, say, Einstein–Eddington purely affine theory.

In the subsequent letter, Einstein defended his classification of geometries, but did not comment on Reichenbach's objection. However, he invited Reichen-

[36] One starts from a general non-symmetric affine $\Gamma^\tau_{\mu\nu}$ connection, and imposes the condition that length of vectors does not change under parallel transport. Then Einstein and Riemann space could be obtained "exchangeability of the specializations" (Reichenbach, 1928c, 5). If one imposes that the Riemann tensor vanish one obtain Einstein space; if one impose that the connection is symmetric one obtains Riemannian space.

bach and his first wife Elisabeth for a cup of tea on November 5, 1928. On that occasion, Einstein might have informed Reichenbach about his plan to abandon the variational strategy to find the field equations. However, it is quite probable that Einstein might have explained to Reichenbach that his goal was *not* to provide a *geometrization* of the electromagnetic field, but to provide their *unification* of both fields. Thus, Einstein's choice of the field-structure was not motivated by geometrical considerations, nor had a geometrical meaning, but exclusively the goal to find the right field equations. The field equations yield classical equations of gravitation and of electromagnetism only to first order. That this they should predict *new* effects in the case of strong fields. To obtain this result, Einstein was ready to adopt a whatever-it-takes strategy. Not only he was ready to forgo any physical interpretation of the fundamental variables was not physically motivated; he was even ready to abandon the variational approach as in the paper he was working on.

It is hard to imagine that their philosophical disagreement did not emerge at this point. In a semi-popular paper Einstein had submitted a few week later. *Festschrift* on the occasion of the seventieth birthday of Aurel Stodola, Einstein insisted on the speculative nature of the new theory. Indeed, for *Fernparallelismus*, no attempt was made to give a direct physical meaning to the fundamental field variables h^{ν}_{a}. One starts from this mathematical structure and then searches for the simplest and most natural field equations that the vierbein-field can satisfy (Einstein, 1929c, 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, 1929c, 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, 1929c, 127).

3.1 Reichenbach's Articles

In the late 1920s Reichenbach was a regular contributor to the *Vossische Zeitung*, at that time Germany's most prestigious newspaper; not surprisingly he was asked for a comment on Einstein's theory, which had started attracting irrational attention in the daily press (see Pais, 1982, 346). With the advantage of having personally discussed the topic with Einstein a few weeks earlier, Reichenbach published a brief didactic paper on Einstein's theory on January 25, 1929 (Reichenbach, 1929c). Reichenbach seems to have indeed profeted from the conversation with Reichenbach Reichenbach did not present anymore the unified field theory-project as a geometrization program. 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.[37] For strong fields, there would be a much closer

[37]It might be indeed argued that this is true for previous theories. However, Reichenbach seems to share Eddington (1923, 84)'s analysis that most of those theories were primarily

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 were far from being satisfactorily 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).

Einstein was very upset for Reichenbach's decision to leak a private conversion to the press. The exchange of the letters that ensued put a serious strain in their personal relationships.However, also their philosophical views that have become irreconciliable. By the time of the publication of the article for the *Vossische Zeitung*, Reichenbach had already written two papers on the *Fernparallelismus*. 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*. 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-project 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.'

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. In the Appendix to the *Philosophie der Raum-Zeit-Lehre* the history of the unified field theory-project program was ultimately as linear history of the geometrization program, which had progressively became more abstract and speculative for the sake of the geometrizing the field. Now Reichenbach describes the history of the unified field theory as the progressive *downfall* of the geometrization program and the concurrent *rise* of the unification one. Most physicists, including Einstein (1923, 1925) considered 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. The test of the theory can happen only in hindsight, by finding the solutions and equations of motions corresponding to elementary particles.

Reichenbach had come to understand that, in Einstein's view, the aim of the

'graphical representations' of the relations between certain quantities (Reichenbach, 1928b, §15 and §50). Eddington (1929, 281) considered Einstein's *Fernparallelismus*-field theory as a mere graphical representation: the graph of a moving particle with time and space as coordinates is no better than one using velocity and curvature as coordinates. However, Reichenbach seems to considered it as the a proper non-geometrical unification. See also Goldstein and Ritter, 2003, 121f..

unified field theory-project 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, 1928c). The first part of the paper reproduces the manuscript he sent to Einstein, with minor changes. In the second, part Reichenbach introduced the distinction between a formal formal and inductive unification, which mimics Reichenbach's more famous distinction between two types of simplicity (Reichenbach, 1924, 9, 1929a, §11). The former is an application of the latter to the case of unified field theories. In this way Reichenbach could describe to opposite approaches to the unified field theory-project. In this setting, his §49-theory came handy. The theory uses a similar geometrical setting of Einstein theory. Both use a non-Symmetric affine connection, but Einstein impose the further conditions that the geometry is flat, that is allow for distant parallelism.

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 **??** because no new testable predictions were made:

> The author [Reichenbach] has shown that the first way 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 thereby *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 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.).

Notice that, according to Reichenbach, the advantage of his own approach consists in the fact that it provides a physical realization of the displacement operation. 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. Reichenbach's point can be to read between the lines of his letter. 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.

Einstein *Fernparallelismus*-field theory is an instance of this second approach, which claims to achieve **??**, an inductive unification, by renouncing to the geometrical interpretation:

> On the contrary, Einstein's approach of course uses the second way, since it is a matter of increasing physical knowledge; it is the goal 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 goal can be achieved only *if one dispences 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 implies more physical facts that those that were needed 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_a^ν. 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, 1930e, 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). selfplagiarism

In Reichenbach's diagnoses, the stagnation of the unified field theory-project 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, light rays, free falling particles (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 could play the role of the *equivalence principle*.

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) Many, e.g. Weyl, considered general relativity a successful theory *because* it had provided a geometrical interpretation of the gravitational field; then, one could hope to obtain the same success by geometrization the electromagnetic field as well. (b) For others, in particular, Einstein 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. 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, **??** and **??** had little hope of success.

Einstein was caught between a rock and a hard place. Without the equivalence principle further geometrization of electromagnetic fields was should not be pursed, Einstein could counter this objections by claiming that geometrization was never goal, even not in the case of relativity theory. The achievement general relativity was have combined inertial and gravitational just like special relativity has combined magnetic and electric field. However, without an analogon of the equivalence principle, there seem to be no further justification for searching for a further unification of the electromagnetic and gravitational field. Einstein however, considered the separation as theoretically unbearable. We do not have any physical fact that gives any clue as to what may be the more comprehensive mathematical structure in which electromagnetic and gravitational field will appear as two components. Einstein ultimately *physical hypothesis* that that nature was mathematically simple. One searches for the most natural field structure, and the simplest field equations that such structure satisfies. 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.

It is not suprising that this philosophical outlook was for Reichenbach anathema. 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: "Mathematics teaches what is permissible and what is forbidden, but never what is physically correct". In the search of a unified field theory, Einstein had come implicitly to question this distinction between physics and mathematics, ultimately pleading for a *reduction of physical reality to mathematical necessity*.

Einstein put it candidly 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, 1929c, 127).

4 Conclusion

Just after the publication of the new expected derivation of the *Fernparallelismus*-field equations, (Einstein, 1929d), Einstein wrote a popular account of the theory 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, 1929a,b, also published as Einstein, 1930d). Einstein insisted on the highly speculative nature of unified field theory-project, without being afraid endorsing even his somewhat outrageous comparison with Hegel. The fact Einstein chose to mention Meyerson rather than Reichenbach as a philosophical reference in a popular presentation of his last theory for a major newspaper has of course a quiete symbolic significance. After a decade of personal friendship and intellectual exchange that had shaped the history of 20th-century philosophy of science and Einstein seems to have put into question the very core of his philosophical alliance with Reichenbach. Whereas Reichenbach considered the separation between mathematics and physics the great achievement of the theory, Einstein sa in mathematical simplicity itself the key to the unification. selplagiarism

Although Reichenbach's approach attracted the attention of mathematicians, Reichenbach's skepticism towards this approach seemed to have been shared by the physics community.[38] Einstein was fully aware of the marginality of his position, but, throughout 1929, continued express his confidence in *Fernparallelismus* program. He continued to defend the theory in public (in talks given in October and December) (Einstein, 1930a,b,c), as well as in as well in private correspondence.[39] However, only a few months later Einstein and

[38] Weyl, who had always been scolded by Einstein for his speculative style of doing physics could relaunch the accusation in a paper (Weyl, 1929) in which he had uncovered the gauge symmetry of the Dirac theory of the electron (Dirac, 1928a,b). "The hour of your revenge has come", Pauli wrote to Weyl in August: "Einstein has dropped the ball of distant parallelism, which is also pure mathematics and has nothing to do with physics and *you* can scold him" (Pauli to Weyl, Aug. 26, 1929; WPWB, Doc. 235). As Pauli complained, writing to Einstein's close friend Paul Ehrenfest, "God seems to have left Einstein completely!" (Pauli to Ehrenfest, Sep. 29, 1929; WPWB, Doc. 237).

[39] Pauli did not hesitate to describe Einstein's presentation at the Berlin Colloquium as a "terrible rubbish" (Pauli to Jordan, Nov. 30, 1929; WPWB, Doc. 238). When he received the drafts of Einstein's *Annalen* paper, he wrote only slightly more politely. Pauli wrote that he did not find the derivation of the field equations convincing; they show "no similarities with the usual facts confirmed by experience" (Pauli to Einstein, Dec. 19, 1929; WPWB, Doc. 239). In particular, Pauli missed the validity of the classical tests of general relativity, perihelion motion and gravitational light bending: "These results seem to be lost in your sweeping dismantling of the general theory of relativity. However, I hold on to this beautiful theory, even if it is betrayed by you!" (Pauli to Einstein, Dec. 19, 1929; WPWB, Doc. 239).

Walther Mayer presented a new approach (Einstein and Mayer, 1931) that, by generalizing the n-bein formalism to five dimensions. The optimism once again faded away quickly, since the theory was unable to solve the problem of matter. In a popular talk given in Vienna towards mid-October of 1931, Einstein could only describe his field-theoretical work since general relativity as a "cemetery of buried hopes" (Einstein, 1932, 441).

Einstein's philosophical outlook[40] appeared as quite quite scandalous to his philosophical allies like Frank.[41] In 1933 Einstein gave the his famous Oxford address: "Nature is the realization of the most simple mathematical ideas" (Einstein, 1933a). Experience remains the sole criterion of the physical adequateness of a mathematical construction, but the creative role belongs to mathematics: "I hold it to be true that pure thought is competent to comprehend the real, as the ancients dreamed" (Einstein, 1933a, 167). After all the search field theories has always followed the same heuristic pattern: "the theorist's hope of grasping the real in all its depth" lies "in the limited number of the mathematically existent simple field types, and the simple equations possible between them" (Einstein, 1933a, 168). Maxwell's equations are the simplest laws for an anti-symmetric tensor field which is derived from a vector, Einstein's equations are the simplest equations for the metric tensor, etc. This strategy applies to Einstein's last attempt at a unified field theory on a theory based on semi-vectors. After ordinary vectors, the simplest mathematical fields that are possible in four

When Einstein expressed caution towards the definitive validity of his equations, he, "so to speak, took the words right out of my mouth of criticism-loving physicists" (Pauli to Einstein, Dec. 19, 1929; WPWB, Doc. 239). Pauli knew that Einstein would not have changed his mind, but he was ready to "make any bet" that "after a year at the latest you will have given up all the distant parallelism, just as you had given up the affine theory before" (Pauli to Einstein, Dec. 19, 1929; WPWB, Doc. 239). Einstein complained that Pauli's remarks were superficial and asked him to return on the issue after some months (Einstein to Pauli, Dec. 19, 1929; WPWB, Doc. 140). Although the unified field theory-project was disavowed by its own initiators (Weyl, 1931), Einstein insisted in the pursuit of *Fernparallelismus* discussing with Mayer two solutions of his last field equations (Einstein and Mayer, 1930).

[40]However, if many readers might have easily recognized someone like Pauli in Lanczos's 'positivist,' other were baffled to find out Einstein located among the 'metaphysicians.' At the beginning of 1932 the introduction of Lanczos's 1931 paper was published at Berliner's suggestion as a *seperatum* in the *Die Naturwissenschaften* "to make it available to a larger public" (Lanczos, 1932, 113; fn. 1).

[41]It is probably this article of Lanczos that Frank read with some bewilderment, as he reports in his Einstein's biography (Frank, 1947). Frank was "quite astonished" to find the theory of relativity characterized as the expression of a realist program "since I had been accustomed to regarding it as a realization of Mach's program" (Frank, 1947, 215). However, when Frank met Einstein in Berlin at around the same time, he found out that Lanczos had indeed well characterized Einstein's point of view (Frank, 1947, 215f.). According to his recollection, Einstein complained that "[a] new fashion" had arisen in physics according to which quantities that in principle cannot be measured do not exist, and that to "to speak about them is pure metaphysics" (Frank, 1947, 216). Frank objected that this was the very same philosophical attitude that led to relativity theory. By contrast, Einstein insisted, the essential point of relativity theory is to "regard an electromagnetic or gravitational field as a physical reality, in the same sense that matter had formerly been considered so" (Frank, 1947, 216). The theory of relativity teaches us the connection between different descriptions of one and the same reality. Was not a theory about the behavior of rods and clocks, but a unification of two fields.

dimensions, and seems to describe certain properties of elementary particles. One has to search for the the simplest laws these semi-vectors satisfy (Einstein, 1933a, 168).

Einstein left for soon thereafter for Princeton, and Reichenbach for Istambul. After the initial enthusiasm, Reichenbach later tried to obtain a position in Princeton as well (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 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. Einstein answered that he had heard from Rudolf Carnap that Princeton did not want to hire more Jews: "also up here not all that glitters is gold," he remarked bitterly (Einstein to Reichenbach, May 2, 1936; EA, 20-118). selfplagiarim

In 1938 Reichenbach managed to move to the United States (Verhaegh, 2020). Reichenbach and Einstein entered into contact again to support Bertrand Russell . Later both contributed to the Russell to the volume in Russell's honor ?? for the series *Library of Living Philosophers* edited by Paul Schilpp (1944). Reichenbach was asked collaborate for a similar volume in honor of Einstein a few years later (Schilpp, 1949). In some unpublished notes about Reichenbach's contribution, Einstein (1949b) recognized the merits: "Hans Reichenbach is so famously distinguished by many of his colleagues by the fact that he never seek for the universality of knowledge by sacrificing clarity". However, Einstein disagreed that the conceptual basis of general relativity was the recognition of definitional nature if congruence. The latter result serves only to create the necessary freedom in the choice of the fundamental concepts. The definition of congruence in terms of rigid bodies could not be considered at most as psychologically necessary. Indeed, there are no truly rigid body in nature. If so Reichenbach's claim "'the meaning of a statement is reducible to its verifiability'[42]" appears to be problematic; in particular Einstein found "dubious whether this conception of 'meaning'[43] can be applied to the single statement[44]".

As is well-known, Einstein reformulate this line of argument Reichenbach in the Schilpp volume by staging a dialogue between Reichenbach-Helmholtz (rigid rods exists), Poincaré (rigid rods do not exist), and an anonymous non positivists (only geometry and physics can be compared with experience). The question at stake, Einstein put it jokingly, was Pilates famous question 'What is truth'? However, the importance of this issue cannot be fully understood if one does not appreciate it goes to the roots of Einstein's work on the unified field theory. At that time, Einstein had returned to his 1925 metric-affine

[42]In English in the text.
[43]In English in the text.
[44]In English in the text.

approach introducing non-symmetric $g_{\mu\nu}$ and $\Gamma^{\tau}_{\mu\nu}$ as fundamental variables. It is maybe not surprising that Besso raised against Einstein a similar objection that Reichenbach had raised over twenty years earlier. The symmetric part of the $g_{\mu\nu}$ should define a geodesics. Do these geodesics represent the trajectories of particles What is their meaning? Einstein's reply reveals his fundamental philosophical concern.

> Your questions are fully legitimate, but not answerable for the time being [...] This is because there is no real definition of the field in a consistent field theory. It is true that this puts you in a Don Quixotic situation, in that you have absolutely no guarantee whether it ever possible to know if the theory is 'true.' *A priori* there is no bridge to empiricism. For example, there isn't a 'particle' in the strict sense of the word because, the existence of particles doesn't fit the program of representing reality by everywhere continuous, even analytic functions. For example, in theory there is a symmetric $g_{\mu\nu}$ and then a geodesic line. But from the outset one has no clue that these lines have any physical meaning, not even approximately [...] It boils down to the fact that a comparison with what is empirically known can only be expected from the fact that strict solutions of the system of equations can be expected found, that reproduce the behavior of empirically 'known' structures and their interactions. Since this is extremely difficult, the skeptical attitude of contemporary physicists is probably is completely understandable. In order to really grasp this conviction of mine, you must read my answer in the anthology [Einstein, 1949a].

This passage many of the themes between Reichenbach and Einstein; why Einstein did not believe anymore that of coordinates while, the geometrical meaning of the fundamental variables of the theory was inessential; ultimately was only the mathematical simplicity that could serve as a guide. In popular paper written at about the same time, Einstein described himself as a *tamed metaphysician* (Einstein, 1950, 13) that mathematical simplicity as a key to physical reality, which existen independently of the subject.

Replying to Reichenbach paper Einstein described himself as 'non-positivist,' that only geometry cannot separately from the rest physics, Einstein did not that the coordination of the geometrical with reality was the necessary of theory. Thus, no real definition of such quantities seems to be possible: "To really understand my point of view you must read my answer in the [Schilpp]-volume [Sammelband]" (Einstein to Besso, Apr. 15, 1950; Speziali, 1972, 438–439). Neverhtesl "Don Quixotian situation" in which one finds oneself in the search for a unified, non-dualistic, field theory.

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.*
ECW	Ernst Cassirer (1998–). *Gesammelte Werke. Hamburger Ausgabe.* Ed. by Birgit Recki. 26 vols. Hamburg: Meiner, 1998–.

HR	*Archives of Scientific Philosophy* (1891–1953). *The Hans Reichenbach Papers.* 1891–1953.
SN	*Schlick Nachlass.* Noord-Hollands Archief, Haarlem.
WPWB	Wolfgang Pauli (1979–). *Wissenschaftlicher Briefwechsel mit Bohr, Einstein, Heisenberg u.a.* Ed. by Karl von Meyenn. 4 vols. Berlin/Heidelberg: Springer, 1979–.

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