Coordination, Geometrization, Unification. The Reichenbach–Einstein Debate on the Unified Field Theory Program

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Keywords: Reichenbach • 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, 1920, 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, 1920, 73). That the separation . Einstein seemed to agree. Reichenbach that After their correspondence, Reichenbach (1922, 367–368) accepted Weyl's (1921b) 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, 1922, 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). The correspondence has been rediscovered and published (CPAE, Vol. 15) only recently (Giovanelli, 2016). In March 1926, after making some critical remarks on Einstein's newly published metric-affine theory (Einstein, 1925b), 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 (1929a,b,c) 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).

This episodes has been analyzed more extensively. the goal of this paper is two the result a complex overvieew. I think that a clarification emerge on what the matter of cntention. One the key theme of Reichenbach's philosophy is separation between mathematics and physics. In 1920 axiom and axiom. Th elatter as *a priori* principles. Weyl's theory that physically true because it was mathematically necessary. After a discussion with Schlick, Reichenbach abandoned this approach. However, he never abandoned the of the separation between mathematics and physics. The further developmen of the unified field theory-project appead Eddington ahd Einstein himslef. They what was mathematically was most simple from a geometrical point of view, was also true from a physical point of view. "The general theory of relativity by no means turns physics into mathematics. Quite the opposite: it brings about the recognition of a physical problem of geometry". The defence to supprot relativity theory but also. What was the actual reason for the succes of relativity theory. ERichenach a fundamental position, it was EInstein who progressively was ready to philosophical compromise for the sake of physocs. Einstein was ready to abanonde that geometry tested speartey from the rest of physics, was ready to the very idea was essential to, that mathematical simplicty was in tisef the key to realtiy. REichennach was that ultimatly more plalta taht tha of stin

1 Coordination. Einstein, Reichenbach and Weyl Theory

After serving in World War I, Reichenbach attended Einstein's lectures on special and general relativity in Berlin. We posses three sets of Reichenbachs of undated notes (HR-028-01-04, HR-028-01-03, HR-028-01-01). A set notes seems to corresponds are very similar to Einstein's own notes to the Einstein's lecture on spring term 1919 (Einstein, 1919a).[1] In the lectures follow the corresponding sections Einstein's previous published presentations of relativity theory (Einstein, 1916, 1914). However, both Reichenbach's and Einstein's lecture notes show in the 1919 lectures Einstein also used for the first time new interpretation of the curvature in terms of the parallel displacement introduced by Tullio Levi-Civita (1916) and applied to relativity theory by Hermann Weyl (1918). Both names are mentioned explicitly.

In the original presentation of relativity theory, Einstein started the metric $g_{\mu\nu}$ the distance ds of two nearby points dx_ν from its coordinates x_ν indepnednly of the choce coordinate systems. In the lectures showed how. dx_ν are the componennt of vectros A^τ. One can start with so called affine connection $\Gamma^\tau_{\mu\nu}$ for the conditions for a coordinate independent condition, that two vectors of equal and parallel two vectors at neighboring points are equal and parallel. As

[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 size of each displacement goes to zero, this broken line becomes a continuous curve. If we use a parameter λ to designate points along the curve a vector $dx\nu$, then $dx_\nu/d\lambda$ is a vector that indicate the direction of the curve at a certain point. Thus parallel-transporting parallel to its self one can determine the straightest line among to points. The connection is curved if one parallel displaces along different paths, one gets, in general, a different vector at a distant point (HR, 028-01-03, 37). Einstein was very impressed The fundamental notions of could be recovered without any reference to the metric. The metric could be inserted separately. The length of vectors $l^2 = g_{\mu\nu}A^\mu A^\nu$, can be introduced separately to compare the length of non-parallel vectors. Indeed, by assuming that the length does not change under parallel transport one can recover Riemannian geometry.

From discussions with Einstein, Reichenbach might have become immediately aware that he was skeptical possible generalization as the premise of unified field theory-project. Weyl was bothered by asymmetry comparison of direction of vectors which is path-dependent could not be the comparison their lengths was distant-gemetrical. To overcome this mathematical injustice, beside the affine connection Weyl also a introduced 'metric connection.' 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 $dl/l = \varphi_\nu dx_\nu$. In this way, in addition to the 'metric tensor' $g_{\mu\nu}$, a 'metric vector' φ_ν of the same importance is introduced. That the $g_{\mu\nu}$ are identified with the potentials of the gravitational field because of a *physical fact* the equivalence principles. The φ_ν could be identified with the potentials electromagnetic field because of the *mathematical fact* that the $F_{\mu\nu}$ is the curl of the φ_ν, like in the first two Maxwell equations.

Just like general relativity represented a geometrization of gravitational phenomena, Weyl's theory represented a unified geometrization of both gravitational and electromagnetic phenomena, which were, at that point, the only kind known. Weyl hoped to achieve a purely field-theoreticl representation of matter, Matter had seemingly become an epiphenomenon of the 'world metrics.' In this way, Weyl concluded "physics and geometry coincide with each other", "geometry has not been physicalized but physics has been geometrized" (Weyl, 1919b).

1.1 Reichenbach's Habilitation and his critique of Weyl Theory

Between 1918 and 1919, Einstein criticized repeatedly the theory. The most famous, but by no means only objection. Since we use atomic clocks with to measure the length ds of the time-like displacement vector dx_ν, the theory should have predicted that the rate of ticking of atomic clocks should depend on the electromagnetic field they have ben through in the past. However, atomic spectroscopic overwhelmingly show that spectral lines of atoms are well-defined. In general, Einstein was initially rather cautious about the unification project that he seemed to have thought to be premature. In spring 1919, however, Einstein reoriented his views, probably after a correspondence with Theodore Kaluza, who suggested a unified field theory based on Riemannian geometry with five dimensions (Wünsch, 2005). Einstein ultimately decided not publish Kaluza's paper. However, at about the same he submitted a paper what can be considered his first attempt to find a connection between general relativity and the structure of matter (Einstein, 1919b). better

These attempts were interrupted by the confirmation of the Dyson-Eddington expedition. By the end of 1919, Einstein was turned into an international celebrity. Philosophers also to work on the theory. In February or March 1920 Reichenbach decided to write his habilitation.. Reichenbach felt that he was in had detailed technical knowledge that was not comparable to that of any philosophers, possibly including Schlick. As he later recalled "Vorlesungen bei Einstein gelegt, aus welchen meine Kenntnis der Th. herrührt", and he the previous "in den Monaten vorher Relth. gearbeitet, auch nach Weyl". Moreover, he was clearly already following early attempts at unified field theory-project. E.g. was aware that "neuen Einsteinschen Auffansung" in which "bei der innerhbalb des Elcktroms wicder die nicht-Euklid. Geometric gilt" (HR, 028-01-04, Randbemerkung zu Blatt 18). check

The Kapp-Pusch coup on 13 March 1920, gave Reichenbach a few days of leave from Huth radio industry were he was employed. Thus, he could work without interruptions and in ten days he completed the manuscript, which was submitted in April The book was an attempt to 'save Kant from Kantians' check that Reichenbach carried out in his habilitation has recently attracted renewed attention. Kantian theory in a limited way with the theory of relativity by distinguishing two senses of the *a priori*. provisionally adopted axiom of coordinations. While a priori in the constitutive sense, the coordination principles are contingent, process of a construction of a representation is hidden behind the idea of 'coordination.' . However, we will consider Reichenbach's early work ?? only in as much as it includes his first critique to the unified field theory-project. Reichenbach abandoned his 'Kantinanism' but will remain faithful to this line of criticism in the following years. The separation was the an essential part of the book. And it is precisely in ths context that Weyl cites Weyl theory as a counter exaple.

Reichenbach alludes briefly to "Weyl's generalization of the theory of relativity which abandons altogether the concept of a definite length for an infinitesimal measuring rod" (Reichenbach, 1920, **; tr. 1969 **). Reichenbach conceded that Weyl's theory represents a possible generalization of Einstein's conception of spacetime which, "although not yet confined empirically, is by no means impossible" (Reichenbach, 1920, **; tr. 1969 **). Reichenbach reiterated Einstein's main objection that the theory would imply that "the frequency of a clock is dependent upon its previous history" (Reichenbach, 1920, **; tr. 1969 **). This result appear to be contracted by experience. However, Reichenbach conceded to Weyl, that "these influences compensate each other on the average" (Reichenbach, 1920, **; 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, 1920, **; tr. 1969 **). What Reichenbach considered unacceptable was Weyl's justification of his purely infinitesimal geometry.

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 vector moving close loop which would same length but different direction in Riemannian geometry, different length and different direction in Weyl's geometry. Thus, in the new Weyl geometry last remanent of distance of Riemannian geometry had been eliminated. Weyl geometry seems to be the most 'general geometry.' There would be no reason to assume that a more general geometry applies to reality. However, Reichenbach, had already surmised that this generalization can be continued. In Weyl's geometry the length 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, 1920, **; tr. 1969 **). Probably, more complicated generalization could be thought of. Thus, there is no "'most general' geometry" that 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, 1920, **; tr. 1969 **).

A mathematical axiom system is indifferent with regard to the applicability and "never leads to principles of an empirical theory" (Reichenbach, 1920, **; tr. 1969 **). The axioms of Euclidean geometry are neither true nor false and only physics can decide whether Euclidean geometry applies to reality. This applies to more complicated geometrical systems as well:

> [Thus] it is incorrect to conclude, like Weyl[2] and Haas,[3] 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, 1920, **; tr. 1969 **).

[2] check

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[3] (Haas, 1920).

. This objection contains the backbone of Reichenbach's criticism of the unified field theory-project over the years. The question concerning the "validity of axioms for the physical world" must be distinguished from that concerning possible axiomatic systems. Weyl seems to have unlearned precisely the fundamental of Einstein's theory who had showed the question whether the geometry of spacetime is Euclidean or not is a physical question.

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, 1920, **; 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, 1920, **; 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, 1920, **; tr. 1969 **). The nature of physical space cannot be determined by such definitions. It is a thing of the real world, not an object of the logical world of mathematics. In such a system is a statement regarding the significance of physics, the assertion that the system of equations is true for reality. This relation is totally different from the internal simplicity of mathematics.

However never abandoned the separation between mathematics and physics that will become one of central claims of the logical empiricism. What is more he believed that precisely this separation was most important results of relativity theory. On May 24, 1920, The copy in Einstein's library contains some marginal annotations by hand, for example "sehr gut" on p. 74 to Reichenbach's contention that it is impossible to infer *a priori* principles. 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: "Philosophen eine Ahnung davon haben, dass mit Ihrer Theorie eine philosophische Tat getan ist, und dass in Ihren physikalischen Begriffsbildungen mehr Philosophie enthalten ist, als in allen vielbändigen Werken der Epigonen des grossen Kant". Indeed the old *a priori* for which Euclidean geometry is itself the geometry of reality had become untenable. Einstein's seemed to agree on this point. Der Wert der Rel.Th. für die Philosophie scheint mir der zu sein, dass sie die Zweifelhaftigkeit gewisser Begriffe dargethan hat, die auch in der Philosophie als Scheidemünzen anerkannt waren. In this sense, Einstein found Kant's apriorism untenable. Einstein insisted that "Begriffe sind eben leer, wenn sie aufhören, mit Erlebnissen fest verkettet zu sein".

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1.2 The Reichenbach-Weyl Correspondence

Reichenbach met Weyl for the first time at the 86th Assembly of the *Versammlung der Gesellschaft Deutscher Naturforscher und Ärzte* in Bad Nauheim in September 1920. Reichenbach where he might have assisted ad the discussion between Einstein, Pauli and Weyl following the latter talk (Weyl, 1920a). Immediately, thereafter, Reichenbach must have sent a copy of his *Relativitätstheorie und Erkenntnis apriori* (Reichenbach, 1920). Weyl replied with some delay in February 1921 since he was in Barcelona in the meantime. Weyl was not upset by Reichenbach's criticisms and replied rather amicably to some issues "which concern less the philosophical than the physical" (Weyl to Reichenbach, Feb. 2, 1921; HR, **). In particular for our goals it is interesting to consider the following point made by Weyl.

> 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 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 alone is this: The integrability of length transfer (if it exists, I think uielıt. 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. 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.

That is on the field equations of the theory which in turned can be derived from an action principles

. In his talk in Bad Nauheim Weyl (1920b) introduced the distinction between *Einstellung* and *Beharrung* to explain away the discrepancy between the non-Riemannian behavior of the 'ideal' time-like vectors implied by his theory and the Riemannian behavior of the 'real' clocks that are actually observed. That the geometry of spacetime is non-Riemannian, in spite of the fact that the rods and clocks behave in a Riemannian way. Thus in spite a non-Riemannian behavior it might came out at the end the rods and clocks will show a Riemannian one. He suggested that atomic clocks might not *preserve* their Bohr radius 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, furnishing a natural unit of length. Weyl had developed this idea of doubling the geometry, in several papers published in 1921. In the July paper Weyl also address in public Reichenbach's criticism

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> From different sides[4] it has been argued against my theory, that it would attempt to demonstrate in a purely speculative way something *a priori*

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

> 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's theory would have its reason for being only if one could, by some means, deduce from this theory that the equality of two objects of nature, for example the rigorous equality of two atoms of the same chemical substance placed identically in the same conditions, is independent of their prehistory. This independence is one of the most solidly established experimental facts. To in the possibility (of arriving) of demonstrating this independence by logical or mathematical means, starting from the theory of Weyl in its present form. If this achieved, that a theory in which the behavior of vectors is Riemannian, but the behavior appears not to be. However, the same problem should have emerged in Einstein theory, which also ultimately should provide a theory of matter from which the Riemannian behavior of clocks should be derived.

1.3 The Weyl-Reichenbach Appeasement

In September 1921, Reichenbach presented the first report on axiomatics of special relativity at the Physicists' Day in Lena (Reichenbach to Einstein, Dec. 5, 1921; CPAE, Vol. 12, Doc. 266), where he met Weyl again. He worked further on the project on a mono Septer 1922. The correspondence with Weyl that ensued turned out to be less amicable, since the latter raised sever criticism. ?? Reichenbach might ahve also sent Weyl a personal retraction, possibly in lost latter from 8.1.1922. The letter had been forwarded from Zurich to Barcelona, where Weyl was giving his Catalonian Lectures (Weyl 1923). However, Reichenbach di issue a public retraction. At about the same time, he started to work on a long review articles on relativity, that was finished in Spring 1922. On March 24, 1922. Erwin Freundluch sent to Einstein "die Druckbogen einer kritischen Untersuchung von Reichenbach auf dessen Wunsch". The presentation entails also a long, a more balanced review of Weyl theory.[5] By the time. Reichenbach has now abandoned his Kantianism, and to develop a form conventionalism to translate in a form of geometrical empiricism. Geometry and experience became for Reichenbach of the separation between geometry and physocs. Reichenach that this separation was in the wrok as he have leard from personal conservations.

The class (a) of Riemannian geometries is fixed by the axiom that lengths do not depend on their prehistory. "zwei natürliche Maßstäbe, die sich einmal zur Deckung bringen lassen, lassen sich auch nach dem Transport auf verschiedenen Wegen wieder zur Deckung bringen". The (b) choice among geometries is

[5] which was surprisingly excluded from the translations of this writing in the 1970s.

ultimately conventional, that we consider rigid. The convention can be fixed by eliminating what we later will called forces of type X. After that the question whether is euclidean or not is empirical question, that can be answered by carefully by shielding from differential forces. Thus the sum, $G+P$ ultimately fixes the convention of (b). it may well also have Euclidean relations with the field $X=0$, but this is a point which we can never know a priori. The merit of Weyl to have shown that the assumption (a) was not necessary. The first way to show it, in two ways Reichenbach seems to espouses that idea of the two versions of Weyl theory:

– This procedure is first of all a purely mathematical discovery; it indicates a more general type of manifold that can be applied to reality when the Riemann class axiom is not satisfied for natural scales. hat length of limes using a measuring isntumes, and this would give different results if would a different length a different prehisory. 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". This is a mathematical discovery that it is neither true nor false. It cab applied to reality, if one coordinates the length l as reading of some physical measuring instruments. In this case makes predictions about the behavior of rods and clocks. If one interpretes the φ_μ as the electromangetic field potnetials. Then would have that would depend on their prehistory. however, that this axiom is quite well fulfilled in reality, so that the first way of generalization seems unsuitable. Indeed, the existence of atoms with the same spectral lines shows that clocks behave differently that predicted by Weyl, theory, whereas Einstein's prediction about the behavior of clocks has been confirmed.

– Way reintroduced as a mathematical aid; it defines an ideal process of transfer of length which, however, has nothing to do with the behavior of real rods and clocks. He needs this engraftment process because he wants to identify the vector field φ_ν with the electromagnetic potential, and then obvious forms for the most general physical equations arise (for the 'action'). the second step is find the field equations, via the 'action principle.' One constructs a scalar quantity (the action) from the dynamical quantities $g_{\mu\nu}$ and φ_ν then finds the conditions needed to restrict the scalar to an extremum (a maximum or minimum) with respect to variations in those dynamical quantities. The problem the right action and the right dynamical quantities to produce the desired equations, that is to recover Einstein and Maxwell field equations. To test theory its capacity do deliver such explaining the existence of electrons of the same charge and size. With this, however, the "theory loses its convincing character and comes dangerously close to a mathematical formalism", that unnecessarily complicates physics for the sake of elegant mathematical principles; and because of this thought, "Weyl's theory is viewed very cautiously by physicists (especially by Einstein)".

Thus Weyl1 that rods and clocks and empriical content; since he recongiszx that rods and clocks simpy complciated. That the behavior of rods and clocks cannot be from. Unfortunately, however, the theory does not agree with the physical facts. Even if the electromagnetic field is introduced, the behavior of rods and clocks is still integrable. This is confirmed by a large amount of experimental knowledge about spectral lines of atoms that are typically employed as clocks. Those spectral lines are always sharp, well-defined spectral lines. If atomic clocks changed their periods as a function of their aths, one would expect that atoms with different pasts would radiate different spectral lines (Reichenbach, 1928a, 355; tr. [494]).[6] However, Weyl's had then to explain Weyl's explanation, according to which the unequivocal transferability takes place by adjusting the standards to the radius of curvature of the world, "is essentially just another linguistic expression for the facts at hand, not a reduction to a more general law". Most of all the theory would, a succesful expation. In particular, this 'setting' has nothing to do with its "congruent transplantation, so this remains physically empty".

Still the objection was intrinsically mathematical was not fair, wanted to derive physical reality from pure mathematics:

> However, I have to retract my earlier objection (47, p. 73) that Weyl wants to deduce physics from reason, after Weyl has cleared up this misunderstanding (72, p. 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, be understood as "the emanation of a law of nature." I can only agree with Weyl's demand; it is the importance of mathematics that they are with the. gesetzes verstanden werde«. Ich kann dieser Forderung Weyls nur zustimmen; es ist die Bedeutung der Mathematik, daß sie mit dem Aufdecken allgemeinerer Möglichkeiten die speziellen Tatbestände der Erfahrung als speziell kennzeichnet und SO die Physik vor Simplizität bewahrt.

But the only fact that he had tried to follow this path, regardless of its empirical correctness, was a genial advance [genialer Vorstoß] in the philosophical foundation of physics (Reichenbach, 1922, 367f.). However, Reichenbach that he clearly he initially attributed to Weyl. Weyl had not showen being truly infinitesimal and myst be true *a priori* for reality, it that that given a geometry there always a more general one. Still Weyl's theory has a profound philosophical meaning. Eiclidea geometry was not ovious the discovery of non-Riemannian gemetory

> 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

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

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 (63). 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.

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This passage that the physicssts as the largest freedom in the choice of the mathematical strucure. At this point was aware fo Schouten and suggested the possibility of abandoning that the connection was symmetric. This procedure howver, Reichenbach felt that a coordinate definition was necessary; whatever choice the first step to coordinate this with a piece of realty. Or to follow Weyl 2 and procede As it turned out, Weyl did not actually agree with the the double approach interpretation: "Den Plan, starre Maßstäbe mit meiner Verpflanzımg zu identifizieren, habe ich aufgegeben. weil ich ihm nie gehabt habe", sondern "ich war überrascht, als ich salı, daß Physiker das in meine Worte hineininterpretiert hatten" (Weyl to Reichenbach, May 20, 1922; HR, 015-68-02). However, will that this was for him exactly the problem the second version of Weyl's theory will open the gate for increasingly more. Indeed, Reichenach reaslisd that Einstein had precisley taken this path.

2 Geometrization: Reichenbach's Correspondence with Einstein

By the end of the 1922, Einstein had started to find Eddington's theory appealing. Semi-metrical theory, that is was the reason why Einstein. The manuscript consists of five pages. Ironically, the third, fourth, and fifth pages were written on the back of the beginning of a typescript of Reichenbach's contribution to the meeting of German physicists in Jena. Einstein, why he was skeptical of Weyl's approach. The reason was only superficially similar to that of Einstein. Weyl's theory was semi-metrical. It assumed the assumption of the transportability of geometrical lengths, and only forgo that this is path independent. Since actual rods and clocks that we are transportable, real rods behave differently from geometrical lengths. Einstein1923d This inconsistency was for Einstein unacceptable. He considered preferable to forgo the very idea of comparability of lengths. Following Eddington a very general affine connection in which the length of vectors is not defined. That to start from the a general affine connection $\Gamma^{\tau}_{\mu\nu}$. Any physical interpretation. From this one Differently the tensor is not further if is symmetric. From one can obtained the Riemann and Ricci tensor, that can be split it into two parts that, could be The latter can be split into parts den Komponenten dr. des Linienelementes die Invariante $Rdx.dx$, liefert.. that behave as elementary particles. Einstein published thereafter, into two papers. EInstien conceded that the choice of $\Gamma^{\tau}_{\mu\nu}$ as fundamental variable is not physically motivated, and $\Gamma^{\tau}_{\mu\nu}$ has no physical meaning tat all "an dem zentral-symmetrischen Falle ihre Vereinbarkeit mit der Erfahrung zu prüfen. (121 Ich glaube aber nicht, dass man auf diesem Wege zu einer u",

Einstein published two papers on this theory (Einstein, 1923b,c) Reichenbach asked requested copies of his papers (Abs. 44) on also searching form help to publish his axiomatization book (Reichenbach, 1924). Reichenbach, as others probably found the entire procedure questionable. As Pauli's requirement that an abstract concept, like the $\Gamma^{\tau}_{\mu\nu}$ and the to deduce the $F_{\mu\nu}$ from it that are observable. Ultimately, it should only be permissible in physics when it can be established whether it applies in concrete cases of observation. This requirement does not seem far from the view that Einstein often defended in the past. However, Einstein realized that this requirement was too severe. In several writings of those years Einstein had repeatedly insisted geometry cannot be tested separately from physics. The choice was not even physically motivated (Einstein, 1923a). Possible experiences, he claimed, must correspond not to an individual concept but to the system as a whole (Einstein, 1924, 1692; cf. Giovanelli, 2014). If starting from $\Gamma^{\tau}_{\mu\nu}$ leads to a promising set of field equations, then the use of $\Gamma^{\tau}_{\mu\nu}$ as a fundamental variable is justified that lead to new results this choice can be justified *post facto*

It is against this background that Einstein became interested in in the rationalistic reading of relativity suggested by *La déduction relativiste* (Meyerson, 1925). Einstein still found Meyerson's account "unfair" "as the escapades by Weyl and Eddington are considered to be essential parts of the theory of relativity" (CPAE, Vol. 14, Doc. 455, 6; March 12). However, he will soon embrance ... The interest soon fadered. "Night, sweating properly [...] the conviction of the impossibility of the field theory in the current sense becomes stronger" (CPAE, Vol. 14, Doc. 455, 9; March 17).

These doubts became certainties 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[7]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). As he explaiend to besso to use both $\Gamma^{\tau}_{\mu\nu}$ and $g_{\mu\nu}$ but were not symemtric. At the beginning of July of 1925, Einstein presented at the Academy of Science the new trail he anticipated to Besso, a further attempt at a unified field theory (Einstein, 1925b), in which both the affine connection and the metric were considered as fundamental variables without assuming their symmetry. Einstein commented to Millikan with the usual initial enthusiasm: "I now think I have really found the relationship between gravitation and electricity" (Einstein

metric affine theory

[7]Schouten (1924) claimed that it was possible to overcome a shortcoming of Einstein-Eddington's affine theory (in which no electromagnetic field can exist in a place with vanishing electric current density) by dropping the assumption of the symmetry of the affine connection.

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).

2.1 The Einstein-Reichenbach Correspondence

Probably, to write Entsprechend sollte das Buch heißen: "Philosophie der exakten Naturerkenntnis" u. das Gesamtgebiet behandeln. Später (1926) entstand dann der Plan, es in 2 Bände zu teilen, u. den 1. Bd. mit dem Untertitel "Raum und Zeit" schon für sich erst mal herauszubringen. Der Verzicht auf die Zusammenfassung in Werk und die Wahl des Titels "Phil. d. R.-Zt.L." geschah erst im Mai 1927 auf Wunsch Dr. Lübkes im Verlag de Gruyter, der es nicht für ratsam hielt, zwei zeitlich so getrennte Bände in 1 Werk zusammenzufassen.. Im März 1925 wurden nur die ersten §§ niedergeschrieben. During those same months, Reichenbach, despite the support of Max Planck, was struggling to obtain his *Umhabilitation*[8] from Stuttgart to Berlin in order to be appointed to a chair of natural philosophy that had been created there (Hecht and Hoffmann, 1982). Im Okt. 1925 begann dann die erste große Arbeit an dem Buch; der Abschnitt Raum wurde hier im wesentlichen geschrieben, after having work on the new quantum theory. März-April 1926 wurde die Weylsche Theorie bearbeitet u. die eigentümliche Lösung des § 49 gefunden. Auch wurde damals der ganze Anhang geschrieben. (Korrespondenz mit Einstein). On March 16, 1926, Reichenbach sent a letter to Einstein in which, after discussing his academic misadventures, he remarked on the new 'metric-affine' theory (Einstein, 1925b):

> I have read your last work on the extended Rel. Th[9] 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 Γ^i_{kl} alone, serves only as a calculation crutch here in order to obtain differential equations for the g_{ik} and the φ_{ik} 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).

The 'convincing power' (*Überzeugungskraft*) of general relativity (Reichenbach, 1922, 367), in which the identification of the g_{ik} with the gravitational potentials was anchored in the principle of equivalence, that justified the connection and the behavior of rods and clocks. Einstein's theory introduces the

[8]The process of obtaining the *venia legendi* at another university.
[9]Einstein, 1925b.

affine connection independently of the metric. However, it does not attribute any physical meaning to neither of the; the separate variation of the metric and connection was nothing more than a ‘calculation device’ to find the desired field equations. Only in hindisight the symmetric part was indetified of the $g_{\mu\nu}$ and antisymmetic with the electromagnetic field, and merely for formal reasons. Reichenbach, however, was ready to revise his negative judgment if Einstein’s theory delivered the ‘electron,’ althogith he was probably very skeptical that this was possible (Reichenbach, 1926)

On March 20, 1926 Einstein replied 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)][20-115][EA] Einstein’s reaction reflects his disillusion with the attempts to achieve the sought-for unification of gravitational and electromagnetic field via some generalization of Riemannian geometry. He would have probably been less ready to embrace Reichenbach’s critique if he had knew what the latter exactly had in mind, that is the requirement that $\Gamma^{\tau}_{\mu\nu}$ had to be given a physical meaning in advanced. Reichenbach took the opportunity of Einstein’s positive reation and on March 31, 1926 that se sent him a note in which he has elaborated this criticism in details.

The metric $g_{\mu\nu}$ is measured not only by rigid rods but also by ideal clocks, which give physical meaning to the length of the four-dimensional vector l. A similar coordinative definition should be provided for the displacement $\Gamma^{\tau}_{\mu\nu}$. Since we have to maintain the direction of a four-dimensional vector, Reichenbach suggested that one can tentatively adopt the velocity four-vector u^{τ} of charged mass points as the physical realization of the displacement (Eddington, 1923,). The vector with physical meaning that vector is the four-velocity page $u^{\tau} = dx_{\nu}/d\lambda$. By parallel-displacing a vector u^{τ} indicating the direction of a curve $x_{\nu}(\lambda)$ at any of its points, one can define a special class of curves, the straightest lines. When the particle is not accelerating (that is, it moves inertially), the direction of the velocity vector does not vary. Thus, the motion of force-free particles can be used to define physically the straightest line between two spacetime points. The motion of charged particles under the influence of electromagnetic field deviate from the geodesics. In general relativity the motion of particles under the combined action of the gravitational and electromagnetic field is the following force equation:

$$\frac{du^{\tau}}{d\lambda} - \overbrace{\Gamma^{\tau}_{\mu\nu}}^{\text{Levi-Civita connection}} u^{\mu}u^{\nu} = \underbrace{\frac{\rho}{\mu} f^{\mu}_{\tau} u^{\tau}}_{\text{force term}}$$

Since the gravitational charge is the same to all particles, the mass coupling factor can be eliminated from the geodesic equation. Planet describes a trajectory check which itself is assigned because it is attracted by the force of the sun, but we say: the planet moves along the straightest line defined by the $\Gamma^{\tau}_{\mu\nu}$. The force term indicates that the force experienced by charged particles is directly proportional to the charge and inversely proportional to the mass. Thus gravitation appears to be geometrized, but not electromagnetism does not. In order to geometrize the latter as well to absorbed the force term into the definition of the affine connection. To this purpose Reichenbach introduced a non-symmetric affine connection $\bar{\Gamma}^{\tau}_{\mu\nu}$ in which however the lengths of vectors is maintained. Indeed, the velocity vector of particles is per definition always equal 1 and only the direction indicate the change of velocity. Every is the sum of and a non-symmetric tensor. With some change in notation, the definition looks as follow:

$$\bar{\Gamma}^{\tau}_{\mu\nu} = \overbrace{\Gamma^{\tau}_{\mu\nu}}^{\text{Levi-Civita connection}} + \underbrace{\frac{\rho}{\mu} f^{\mu}_{\tau} u^{\tau}}_{\text{skew-symmetric tensor}}$$

In this form one can see by simple inspection the force term in the definition of the of the affine connection uncharged particles travel and charged particles on the shortest line, that a different affine connection for every particle. By substuting $\bar{\Gamma}^{\tau}_{\mu\nu}$ into **??** one eliminate the force term equations and turn the force equation into geodesic equations. The stragirest of this continuum do not generally coincide with its geodesics, that is with the shortest lines. In the presence of charge, from every point, in every direction, an autoparallel and a geodesic emerge, which generally diverge. This divergence is an index of the presence of charge..

Einstein was not impressed. The definition of the tensorial part of the connection tensor was clearly arbitrary. Most of all, Reichenbach's equations of motion can be valid only for a certain charge-density-to-mass-density ratio ρ/μ.[10] However, Reichenbach rushed to point out 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) .

After Weyl also Eddington and Einstein had attempted to geoemtrized the electromagnetic field. In all unified field theory has now implemented Weyl's second strategy. One starts to find a suitable geometrical structure the $g_{\mu\nu}$ and ϕ_{μ}, as in Weyl geometry, symmetric $\Gamma^{\tau}_{\mu\nu}$ in Eddington's theory, etc., non-symmetric $g_{\mu\nu}$ and $\Gamma^{\tau}_{\mu\nu}$ in Einstein's theory, etc. Those variables have however

[10]In a given displacement, there is only one straightest line passing through a point in 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. Every particle would travel have with different curvature. This clearly make the theory anodyne.

no physical meaning and there is no attempt to provide a physical interpretation. By borrowing an expression of Eddington graphical only 'graphical representations' (*graphische Darstellungen*)—an expression he evidently borrowed from Eddington (1925, 294ff.). The theory helps just like a graph provide useful economical device to organize physical already known knowledge, however non of those theories has brought anything new Reichenbach adopted a different strategy, by attempting to get back to Weyl's original approach. The theory starts with a non-symmetric $\Gamma^{\tau}_{\mu\nu}$. It has "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; my emphasis) , namely, the velocity-vector of charged mass particles. In Eddington's parlance is a 'natural geometry,' that is it is a proper geometrical interpretation interpretation of the electromagnetic field. However, also this strategy does no bring anything new, physically.

Thus Reichenbach was able to provide a proper geometrical interpretation of the electromagnetic field in itself does not lead to any new physical results. Thus geometrization is not itself a However, Reichenbach's theory and nevertheless did not bring any new result. Reichenbach's 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').[11] However, this advantage is neutralized again, since one has to go to equations of the 4. order,[12]which means a significant increase of arbitrariness (Reichenbach to Einstein, Apr. 8, 1926 EA, 20-117).

Einstein not only endorsed Reichenbach's claim that a 'geometrization' is not an essential achievement of general relativity, but also questioned the meaning of the notion of 'geometrization,' and for that matter the very notion of 'geometry' (Lehmkuhl, 2014). The declare that the difference geometry and rest of mathematics was irrelevant. Reichenbach that difference between geometry was essential. As we shall see, Einstein's argument was an argument in favor of the unified field theory-project; on the contrary Reichenbach had the very opposite goal to attack the program. Reichenbach offered to send Einstein the corresponding epistemological sections of the text on which he was working (possibly §50 of the Appendix). There Reichenbach that the problem, . It is interesting to notice have fully perceived the of the unified field theory-project. The manurscript will become part of a longer appendix. That the message not

check final

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

[12]Cf. Weyl, 1918, 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.

absoerd into geoemtry, but lowered geometry into the to physocs. In this way, hoed to save "the sirens' enchantment [*Sirenenzauber*] of a unified field theory" (Reichenbach, 1928a, 373).

3 Unification: Reichenbach and Einstein in Berlin

On May 26, 1926 Reichenbach presented the note in Stuttgart at the regional meeting of the German physical sosciety. In August 1926, Reichenbach was granted teaching privileges as an "unofficial associate professor" (*nichtbeamteter außerordentlicher Professor*) at the University of Berlin (Hecht and Hoffmann, 1982). The discussion seminar that he started to hold in October became soon the basis of the so-called 'Berlin group,' which, together with Schlick's cognate 'Vienna circle' has marked the history of 20th century 'scientific philosophy' (Danneberg, Kamlah, and Schäfer, 1994, Milkov and Peckhaus, 2013). By the end of the year, Reichenbach wrote to Schlick, keeping him up to date with the progress of a two-volume book he was writing, which was supposed to bear the title *Philosophie der exakten Naturerkenntnis.* "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. According to Reichenbach's later recollections, the manuscript of the first volume was not changed significantly after February 1927. 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.* The drafts were finished in September and the preface was dated October 1927.

If one reads that that reduciton to geoemtry, but on the very opposite. The was not absored binto. The exaple of precisely meant to be shown that was like the

So far, we have always that a simple physical realization must be given for the process of displacement. In our example we ourselves gave such a realization and we obtained, in this way, an actual geometrical interpretation of electricity. Attempts which were made by Weyl, Eddington and Einstein, on the other hand, renounced such a realization of the process of displacement. It is generally believed that such 'tangible' realizations does not lead to the desired field equations.

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), and wrote a review. The review was little more than a short summary. However, Einstein emphasized two philosophically significant issues, both concerning the Appendix of the book, that is precisely that we have so far. (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; my emphasis). Reichenbach had claimed that, as in any other theory, also in unified field theory, one should give physical meaning to the variables used ($g_{\mu\nu}$, $\Gamma^{\tau}_{\mu\nu}$, etc.) from the outset, before starting to search for the field equations. Einstein did not comment further on this issue, probably because, over the years, he had come to realize that this requirement was too strict. However, Einstein was 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; my emphasis). As we have mentioned, Reichenbach and Einstein had already discussed this topic in a private correspondence less than two years earlier (Giovanelli, 2016). For this reason, Einstein immediately perceived the importance of this theme in Reichenbach's book, a theme that later readers often overlooked (Giovanelli, 2021).

Simultaneously with Reichenbach's review, after 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 was published in Spring 1928 in French (Einstein, 1928a). As we have seen, Einstein's disagreed with first issue, indeed that a physical meaning. (1) Geoemtry and physics as a whole, the Zuordning, and ineed it will be ultimately the mathematical simplicity that would to right field equations Without the equivalence principle, mathematical simplicity of the thoery as whole become the only guide in the quest for the fundamental field structure. For this reason, however, Einstein very much appreciated Meyerson's insistence on 'the deductive-constructive character' of relativity theory (on this episode see Giovanelli, 2018). The geoemtrical nature of those concepts was not signifciatn. However, in the context of an otherwise laudatory review, Einstein strongly disagreed. (2) According to Einstein, "the term 'geometrical' used in this context is entirely *devoid of meaning*" (Einstein, 1928a, 165; my emphasis). The goal of the unified field theory-project was not to 'geometrize' both fields but to 'unify' them, to show that they are nothing but two aspects of a unique 'total' field of unknown structure. This was then sense of Einstein's argument, that geoemtry was inessetial for this project; objections that geometrization has become, could retort that geoemtrization have never been the point.

This will soon become evident. In spring 1928, during a period of rest after a circulatory collapse, Einstein, as he wrote to Besso, "laid a wonderful egg in the area of general relativity" (EA, 40-69) . 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. In a note presented at the Academy on June 7 (Einstein, 1928d), 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. Two vectors *A* and *B* at distant points can be considered as equal and parallel if they have the same local coordinates with respect to their *n*-bein. The metric and the affine connection would be written in terms of the n-bein. Because the n-bein determines the metric, but not the other way around, it provides more degrees of freedom—16 components of the vierbein compared to the 10 of the metric. Einstein expected that the former could be exploited to incorporate the electromagnetic field alongside the gravitational field. Thus, the vierbein-field h_a^ν defines both the metric tensor $g_{\mu\nu}$ and the electromagnetic four-potential φ_μ. Its sixteen components can be considered as the fundamental dynamical variables of the theory. The question arises as to the field equations that determine the vierbein-field. On June 14, 1928 he submitted a second paper in which the field equations are derived from a variational principle (Einstein, 1928b).

Reichenbach again managed to read also this paper and wrote to Einstein with some comments on the theory on October 17, 1928:

> 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; my emphasis).

There are two aspects of this passage that only apparently unrelated. In the manuscript to which Reichenbach refers has been preserved, however we cannot of the manuscript here:

- Reichenbach in fact defines a metrical space by imposing the condition $d(l^2) = 0$ to the displacement space $\Gamma^\tau_{\mu\nu}$, which in general is non-symmetrical; he then obtains Einstein space by requiring that the Riemann tensor $R^\tau_{\mu\nu\sigma}(\Gamma)$ vanishes.[13] One starts from a general affine connection had can introduced two different specializaiton. One can impose the is falt, or impose and rich Euclidean geometry.
- This, however, was only a minor point. He could extened the same critigue, that he had raised previous theories Reichenbach's further remark concerning the physical application of Einstein's geometrical setting is, from a philosophical standpoint, more interesting, even if Einstein did not comment on it, that is in Reichenbach's theory the straight liens have no physical meaing, Reichenbach claims that, if one really wants to provide a geometrical interpretation of gravitation and electricity, then his own approach was better after all. While had used a affine connection, an non-flat, that Einstein did not have provide a coordinate definition, that was without any meaning.

In the subsequent letter, Einstein defended his classification of geometries, but did not comment of Reichenbach's objections. In a note added by hand at

[13] The Γ alludes to the fact that this condition can be defined without reference to the $g_{\mu\nu}$.

the bottom of the typewritten letter, Einstein invited Reichenbach and his first wife Elisabeth for a cup of tea on November 5, 1928, mentioning that Erwin Schrödinger[14] would also be present (Reichenbach to Einstein, Oct. 17, 1928; EA, 20-92). Einstein might have with some techinical details. However, that a phylosophical disctussion mtigh have ensued. Reichenbach was very different that the one he had imagined. A few weeks after he wrote to Reichenbach, Einstein had submitted *Festschrift* on the occasion of the seventieth birthday of Aurel Stodola, Professor of Mechanical Engineering at the ETH (Honegger to Einstein, Nov. 2, 1928; CPAE, Vol. 16, Doc. abs. 732; Einstein to Honegger, Nov. 14, 1928; CPAE, Vol. 16, Doc. abs. 750; cf. Einstein, 1929d), in which Einstein's philosophical point more very velear

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

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

3.1 Reichenbach's Articles

At about the same time, Einstein's theory had started attracting irrational attention in the daily press. 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. With the advantage of having personally discussed the topic with Einstein, Reichenbach published a brief didactic paper on Einstein's theory on January 25,

[14]Schrödinger succeeded Max Planck at the Friedrich Wilhelm University in Berlin in 1927. He held his inaugural lecture on July 4, 1929 (Schrödinger, 1929).

1929 (Reichenbach, 1929b). 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.[15] For strong fields, there would be a much closer interdependence between electromagnetism and gravitation. In principle, the theory could receive experimental proof if the effects predicted did not remain beyond the threshold of experimental detection. However, the problem of the constitution of matter or the quantum problem 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, 1929b; tr. 1978, 1:262).

However, this in personal relationship. However, was that philosophical outset has become progressively more complicated. The first article of the order of publication was entitled "Die neue Theorie Einsteins über die Verschmelzung von Gravitation und Elektrizität" (Reichenbach, 1929a) and would appear in February in the *Zeitschrift für Angewandte Chemie*. The second article was an extended version of the manuscript that Reichenbach had sent to Einstein in October and bore the same title "Zur Einordnung des neuen Einsteinschen Ansatzes über Gravitation und Elektrizität" (Reichenbach, 1929c). It was published only in September in the *Zeitschrift für Physik*. These articles represent Reichenbach's last important contribution to issues related to relativity theory and spacetime theories. On the one hand, Reichenbach attempted to make his previous reflections about the unified field theory-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. The brief history of the unified field theory-project appeared to him as the progressive *downfall* of the geometrization program and the concurrent *rise* of the unification one. In this manner, however, Reichenbach concluded, the 'geometrization program' was implicitly abandoned and substituted by a new, different 'unification program.' Most physicists, including Einstein (1923, 1925) considered this strategy legitimate. It was preferable to sacrifice the geometrical interpretation—i.e., to relinquish the coordination of geometrical notion of parallel transport of vectors with the behavior rods and clocks—and then to use the geometrical variables ($\Gamma^{\tau}_{\mu\nu}$, φ_{ν} and so on) as 'calculation device' for the greater good of finding the field equations. From the field variables, one

[15]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 '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..

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 will return to this different programs, in the following article a proper geometrizaiton withut unificaiton. These theories, provide a but this does to any phsical reaslt. The very difference between and geometrization program. The first approach was the one used by Reichenbach himself in his own 'unified field theory':

> 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, 1929c, 688; my emphasis).

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. The disadvantage is that it is only a *unification of the representations* of two physical fields in a common geometrical setting, which as mearely an economical meaning.

The second class of theoriesm in which there is unficaiton without geometrizatio, The second approach is the one used by Einstein, and it presented the opposite characteristics:

> 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, 1929c, 688; my emphasis).

Einstein's theory was claimed to be a *unification of the dynamics* of two physical fields, i.e., a unification of the fundamental interactions. However, Reichenbach argues that Einstein could achieve this result only at the cost of dispensing with a physical interpretation of the fundamental quantities.

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

To Reichenbach's dismay, Einstein had abandoned the *physical heuristic* that leads him to general relativity in the name of a *mathematical heuristic* that was not different from Weyl's speculative approach that he had dismissed a decade earlier.[16] Einstein's philosophical volte-face might have appeared to Reichenbach as a sort of *trahison des clercs*, an unacceptable intellectual compromise. (a) The core of Reichenbach's philosophy was the *separation of mathematical necessity and physical reality*. Reichenbach had always perceived this separation as nothing more than a philosophical distillation of Einstein's scientific practice: "Mathematics teaches what is permissible and what is forbidden, but never what is physically correct". Are necessary but are not.

(b) In the search of a unified field theory, Einstein had come implicitly to question this distinction between geometry and mathematics, ultimately pleading for a *reduction of physical reality to mathematical necessity*[17] . Einstein put it bluntly in his Stodola-*Festschrift*'s contribution—that he sent for publication toward the end of January (Einstein to Honegger, Jan. 30, 1929; CPAE, abs. 864). The ultimate goal of understanding reality is achieved when one could prove that "even God could not have established these connections otherwise than they actually are, just as little as it would have been in his power to make the number 4 a prime number" (Einstein, 1929f, 127). In this sense, Einstein's God indeed resembles Spinoza's God (Einstein, 1929b), for whom the laws of nature are necessary, and rather than, say, Leibniz's God for whom the laws of

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

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

nature are contingent.

3.2 A Parting of The Ways. Positivists and Metaphysicians

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

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

The fact the Einstein chose to mention Meyerson rather than Reichenbach as a philosophical reference in a popular presentation of his last theory for a major newspaper cannot be underestimated. Of course, Einstein was well aware of Reichenbach's technically informed work on this very subject, having discussed it with him in the previous months. Nevertheless, as he did in the contribution for the Stodola-*Festschrift* (see above section 3), Einstein preferred to side with Meyerson's less detailed, but, in his view, a more profound philosophical outlook—endorsing even his somewhat outrageous comparison with Hegel (Giovanelli, 2018). After a decade of personal friendship and intellectual exchange that had shaped the history of 20th-century philosophy of science and, to a certain extent of 20th-century physics, a minor squabble had unwittingly revealed a nearly unbridgeable philosophical divide. Einstein seems to have put into question the very core of philosophical their alliance. Reichenbach was to avoid to reduce physics to geometry. For Einstein was to geometry was different from the rest of mathematics. It is worth noticing that this devide was part of a larger cultural devide.

After 1919 Einstein benefited from a universal acclaim among the general public; however his positions among the physics community became progressively more isolated. Till 1925-1926 the unified field theory-project was pursued by scholars of the stature by Weyl and Eddington, but was also regarded as a viable options by leading quantum theoreticians (Vizgin, 1994, 209). Even, after the 1925–1927 rapid advance in quantum mechanics, were made of relate unified theories to quantum theory (Klein, 1926). However, most leading physicists soon started to perceive the program as obsolete. Einstein was fully aware of the marginality of his position, but, throughout 1929, continued express his confidence in *Fernparallelismus* program. In the second paper of this year finished in August—the fourth in the series in the Berlin Academy—which reflects the priority dispute with Élie Cartan (Debever, 1979), Einstein returned to the Hamiltonian principle after objections raised by his collaborators Lanczos and Müntz (Einstein, 1930a). In spite of the many doubts, Einstein was finally convinced that he had "found the simplest legitimate characterization of a Riemannian metric with distant parallelism that can occur in physics" (Einstein to Cartan, Aug. 25, 1929; Debever, 1979, Doc. V).

However, like Reichenbach, fellow physicists were not impressed, in particular given the growing success of quantum mechanics-program. 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). Although Einstein's papers had been discussed widely especially among mathematicians, Einstein was aware of the poor reception that his work had especially among the colleagues that he probably felt has his peers (Goldstein and Ritter, 2003). 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).

Nevertheless, Einstein continued to defend the theory in public (in talks given in October and December) (Einstein, 1930b,c,d), as well as in as well in private correspondence. However, 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 that he no longer believed that the quantum theory might be an argument for the distant parallelism after Weyl's work on Dirac theory had shown that Dirac's electron theory could be incorporated into a relativistic gravitation theory if the vierbein are introduced but the equations remain invariant if the vierbein at distant points are rotated in arbitrary manner. Pauli also 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). 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). However, Pauli would have clearly won the bet. Only a few months later Einstein and Walther Mayer presented a new approach (Einstein and Mayer, 1931) that, by generalizing the n-bein formalism to five dimensions, may have appeared more promising. This approach was ideally connected with that of Kaluza, but the shortcoming of that theory "by sticking to the four-dimensional continuum, but with vectors with five components" at each point of four-dimensional space-time (Einstein and Mayer, 1931, 377). 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).

field equations admitted at least one unphysical solution, namely, a static configuration of uncharged, gravitating bodies.

A few days later, Lanczos wrote to Einstein from the United States (Lanczos to Einstein, Oct. 20, 1931; EA, 15-243) where he had just taken a position at Purdue University. Lanczos told Einstein that, at Arnold Berliner's suggestion, the influential editor of the *Die Naturwissenschaften*, he had prepared a semi-popular presentation of *Fernparallelismus* approach for the *Ergebnisse der Exakten Wissenschaften*, a series sponsored by Berliner's journal (Lanczos, 1931). Lanczos had worked on the topic during his time as Einstein's assistant. The Lanczos/Einstein relation had become somehow strained (Stachel, 1994), and Lanczos was not fully convinced by Einstein's approach. However, he was confident to have found "a tone that should correspond to your conviction as well. I think that, deep down, we have something in common" (Lanczos to Einstein, Oct. 20, 1931; EA, 15-243). Lanczos presented *Fernparallelismus* as a completion rather than an generalization of Riemannian geometry; nevertheless he also recognized the correctness of Reichenbach's approach (Lanczos, 1931, 118). What is more important, he opened the paper with some general considerations which give a glimpse in the philosophical atmosphere which pervaded the physics community. Lanczos distinguished between two "spiritual attitudes" towards relativity:

1. a *positivist-subjectivist* insistence that physics has to do with observable quantities, and what cannot be observed is not part of physics. This "rig-

orous and therefore more intolerant form of positivism" (Lanczos, 1931, 104), defended in particular by quantum theoreticians, lead to the rejection of the unified field theory program as such. Since a field is nothing but a tool to describe the behavior of test particles, rods and clocks and so, it is vain to search for solutions of the field equations that correspond to protons and electrons. In fact, the fields inside of elementary particles "could never in their details become the object of observation" (Lanczos, 1931, 104), since there are no test particles or measuring scales smaller than the electron itself.

2. A *metaphysical-realistic* perspective, based on the conviction that physical reality exists independently of the possibility of measuring or observing it. If special relativity seemed to be close to the positivistic/operationalistic ideals, with Minkowski the theory underwent a "'metaphysical' turn" in favor of a "logical-constructive understanding [*Verstehen*]" (Lanczos, 1931, 103). General relativity had finally brought "the logical-deductive exploration into the depths of nature, under the presupposition of its universality and understandability, and with faith in the laws of mathematics" (Lanczos, 1931, 102).

The positivist described by Lanczos could be easily identified with Pauli, who had indeed raised similar objections against Weyl's theory early on (Pauli, 1919, see Hendry, 1984, 13). However, Pauli, by reviewing Lanczos article, did not fully recognize himself in the portrait of the 'positivist' (Pauli, 1932). Such labels, he argued, "are highly subjective and arbitrary"; it is obvious that in order to gain new scientific insights one does not only requires inductive generalizations, but also logical-constructive imagination. Pauli mocked the *Naturwissenschaften* for having published the paper in series entitled 'Results in exact sciences' (*Ergebnisse der Exakten Wissenschaften*). Indeed, Einstein published this sort of theories at rhythm of one each year and in every case he claims that it is the definitive solution: "Einstein's new field theory is dead, long live Einstein's new theory!".

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). 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.

4 Conclusion

Lanczos' reconstruction is too broadly stroked to be fully accurate; nevertheless it undeniably grasps something of the intellectual mood (*geistige Einstellung*) of the time. Reichenbach, like Pauli, would not have been entirely pleased of having been cast among the 'positivists,' with whom he was in conflict for quite some time. however, like Frank, he would have been puzzled, if not appalled, by seeing Einstein categorized among the 'metaphysicians.' However, Einstein's lecture from 1933 leaves no doubt that Lanczos reconstruction of accurate. The most simple realization of mathematical ideals. In Oxford, he instead proclaimed that all one needed to do in order to arrive at the general theory of relativity, was to "ask what are the simplest laws which a [Riemannian] metric can satisfy. To further justify his methodological conviction, Einstein gave two more examples. The first of these was the set of Maxwell's equations; they are the simplest laws for an anti-symmetric tensor field which is derived from a vector. Then, he turned to the subject that he was deeply involved in at the time of the Oxford lecture; the law that describes the dynamics of electromagnetically charged particles, the Dirac equation. To the audience in Oxford, he announced his latest, most appealing result: the simplest laws these semivectors satisfy elucidate the dual existence of "two sorts of elementary particles, of different ponderable mass and equal but opposite electrical charge." The semivector was thus an outstanding example to support his view that "in the limited number of the mathematically existent simple field types, and the simple equations possible between them, lies the theorist's hope of grasping the real in all its depth."19 In the end, it was this conviction that gave Einstein the strength to maintain for some thirty odd years that his program in classical field theory provided a viable alternative to the quantum theory. That mathematical necessity is the key two reality. There is non separation between mathematics and physics. Clearly Reichenbach's battle against to convince Einstein's himself, who in Reichenbach's eyes was the very origin.

Einstein left for soon therefart, Reichenach for Turkey. Reichenbach's initial enthusiasm soon waned and he tried to obtain a position in Princeton (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. As Einstein famously confessed to Lanczos, his work on general relativity had made him "a believing rationalist" (Einstein to Lanczos, Jan. 24, 1938; EA, 15-268), convinced that physical truth lies in mathematical simplicity (Ryckman, 2014). However, he continued, the mathematical formulation of the laws of nature need not to be of "*geometrical* nature" (Einstein to Lanczos, Jan. 24, 1938; EA, 15-268).

In 1938 Reichenbach managed to move to the United States (Verhaegh, 2020). The American years did nothing to bridge the philosophical cleavage that had emerged during their late Berlin time. Even the point on which Einstein and Reichenbach seemed to have agreed in 1926, the fact that that the mathematical formulation of the laws of nature need not to be of "*geometrical* nature" (Einstein to Lanczos, Jan. 24, 1938; EA, 15-268), was based on a fundamental misunderstanding. While Reichenbach had used the argument against the unified field theory program, Einstein's relied on it to defend it. While Reichenbach feared the absorption of physics into geometry, Einstein questioned the separation geometry and mathematics (Einstein to Lanczos, Mar. 21, 1942; EA, 15-294; Einstein to Barrett, Jun. 19, 1948; EA, 6-58).

Einstein (1949a, 1949b) praised Reichenbach's (1949)'s contribution to the volume in his honor of the series *Library of Living Philosophers* edited by Paul Schilpp (1949). On those occasion, famously Einstein reestablished a dialogue with Reichenbach (Helmholtz) and Poincaré. Indeed, that *ds* was As we have, here introduced a third figure non-positivist, that the separation. Howver, that he did not agree that single mathematical.

It was mainly the unified field theory-project.

That only the whole, the issue of coordination was then in a quite different way. The choice of $g_{\mu\nu}$, the choice is not justified, by the direct physical meanig. The question of identification, was only after the integration of the field equaitons. these would have ... The only guardeed was indeed mathematicla, that only semplicity, was the garantiee of realty. Einstein was not only a non-positivist the coordination and reality. He was a non ... However, the self-described "tamed metaphysician" (Einstein, 1950, 13). However, an even was.

Reichenbach the separation of mathematics and physics Reichenbach replied in 1953 When in 1953 Schilpp asked Einstein for contributing to the volume of the same series in honor of Carnap (Schilpp to Einstein, May 11, 1953; EA, 80-539), he famously declined. After "Reichenbach's death (a few weeks ago),"[18] Schilpp wrote, Carnap was the most important exponent of logical empiricism (Schilpp to Einstein, May 11, 1953; EA, 42-534). Although Einstein agreed with this assessment, he expressed disenchantment toward that type of philosophy

[18]Reichenbach died on April 9, 1953.

that Schlick, Reichenbach, and Carnap represented: “the old positivistic horse, which originally appeared so fresh and frisky, has become a pitiful skeleton” (Einstein to Schlipp, May 19, 1953; EA, 42-534; quot. and tr. in Howard, 1990, 374).

The of general relativity was also a about unified field theory field theory. Indeed, that skeleton was ultimatly been. Einstein only partially conceed that the problem of coordination of mathematical strutucs with reality; the apparent geometrization . The third issue of unification was by Reichenbach intudictive; was mathemtical unificaiton in which of mathematical simplicity. A complex interppaly in

Abbreviations

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