Unified field theories and Einstein

S. C. Tiwari
Department of Physics, Institute of Science, Banaras Hindu University, and Institute of Natural Philosophy, Varanasi 221005, India

Einstein’s contribution to relativity is reviewed. It is pointed out that Weyl gave first unified theory of gravitation and electromagnetism and it was different than the five dimensional theory of Kaluza. Einstein began his work on unification in 1925 that continued all through the rest of his life. A discussion is presented on the recent advances in Weyl theory, and also on the unification approach in which space-time is believed not to be fundamental. The significance of the gravitational waves observed recently seems to indicate a new paradigm of unification. It is suggested that the nature of time is the most fundamental issue for a break-through in the unification quest..

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I. INTRODUCTION

Metaphysical concepts have an important role in science; however relativity and quantum revolutions have introduced avoidable weirdness and mystery in physics. News media and popular scientific literature alone cannot be blamed for this. Of late, the science journals and scientists themselves have been promoting cult figures and mysticism. UK astrophysicist Barrow [1] says that unlike the scientific celebrities Newton and Darwin, Einstein has become an icon as ‘Einstein restored faith in the unintelligibility of science.’ Does incomprehensible science not contradict the basic tenet of science? It is true that there are many scientists who subscribe to Barrow’s view, but then the whole raison d’etre of scientific pursuit would become questionable. Synge writing on general relativity [2] states: “The name is repellent. Relativity? I have never been able to understand what that word means in this connection. I used to think that this was my fault, some flaw in my intelligence, but it is now apparent that nobody ever understood it, probably not even Einstein himself. So let it go. What is before us is Einstein’s theory of gravitation”. It is not that Synge’s is an isolated skepticism expressed in 1966, the foundations of general relativity have been criticized since 1917 beginning with the objections raised by E. Kretschmann [3]. In quantum mechanics, Copenhagen interpretation defies scientific logic, and many physicists approvingly quote Feynman’s verdict that no one really understands quantum mechanics, see a critique in [4]. An individual is free to idolize Einstein or Bohr; however the purpose of science would be served better if the charismatic spell is kept out of the scientific discussions. Scientific spirit demands us to take cognizance of the struggle of the finest minds that laid the groundwork for the creation of relativity and quantum theory, and to recognize the importance of constructive criticisms and dissent on the foundational issues. I vividly recall the inaugural lecture of V.V. Narlikar at the Einstein Centenary Symposium [5] in which he remarked, ‘Einstein was a rebel and a creator...’ Let us try to understand Einstein’s role in the creation of relativity, and his place in the development of classical unified theories.

II. CREATION OF RELATIVITY

It is now well established [2, 6] that Michelson-Morley experiment was known to Einstein before his 1905 relativity paper appeared and that since 1895 he had been occupied with the problem of the propagation of light if an observer followed the light beam with the same speed. Poincare and Lorentz made seminal contributions to the relativity theory, and in spite of the fact that Einstein did not cite their work even the title of this paper is inspired by the titles of the papers of Lorentz and Poincare. Whittaker in his treatise [7] calls relativity a theory of Poincare and Lorentz. However a careful review [8] shows that the final decisive step in the creation of special relativity does belong to Einstein. It is evident that special relativity did not appear suddenly from no-where as a single man creation.

There have been extensive critiques/elaborations on the special relativity, notable among them are due to H. Dingle, M. Bunge, and H. Reichenbach, see [8] for references. In 1908 H. Minkowski introduced four dimensional space-time continuum which to Einstein appeared as ‘superfluous learnedness’. Symmetry (rotational and translational) of space-time geometry and Lorentz transformations, and the treatment of the Maxwell field equations under the wider group of conformal transformations entered later in 1910 with the work of E. Cunningham and H. Bateman. Though there exist learned discussions on the paradoxes in special relativity, I arrived at a startling conclusion: Einstein mistook measurement convention of Newton’s common time as Newtonian absolute time, and relativity does not address the question of the absolute time. I believe this misunderstanding has led to counter-intuitiveness in relativity; I refer to a detailed discussion in [8] and a short essay posted on the arxiv [9].
Historical survey by Whittaker and a scholarly review on the eight decades of dispute over the nature of general relativity show that this theory grew out of the important contributions of many scientists and its foundations are still not secure. Poincare argued that gravity must propagate with the speed of light and that Newton’s law of gravitation had to be modified. In 1907 Planck noticed the significance of the equality of the inertial mass and gravitational mass (the Eotvos experiment) suggesting that ‘all energy must gravitate’; six months later Einstein enunciated his preliminary version of the equivalence principle. Max Abraham as a powerful opponent and the mathematician Marcel Grossmann as a friendly collaborator were the key figures in shaping Einstein’s thoughts on general relativity. In the ‘Entwurf’ theory of 1913 the physical and the mathematical parts were written by Einstein and Grossmann respectively. In fact, Bateman first saw the importance of the tensor calculus of Ricci and Levi-Civita. In a series of four papers during November-December of 1915, Einstein arrived at the final form of the gravitational field equations.

There have been two crucial issues related with general relativity: (i) the role of general covariance, and (ii) the priority issue i.e. Hilbert or Einstein. In the Entwurf theory the Ricci tensor appears as the gravitational field tensor in the non-flat geometry. The role of general coordinate transformations and the Newtonian limit of the field equations became controversial. Stachel remarks that, “He remained wedded to the Einstein-Grossmann field equations and kept trying to find better and better arguments in their favor; in particular, arguments for their uniqueness and for their invariance under the maximum invariance group compatible with avoiding the ‘hole argument.’” The hole argument in essence rejects general covariance. In June-July 1915 Einstein was in Gottingen at Hilbert’s place and had intense correspondence with him until he reached the final field equations returning to general covariance. Einstein had received a draft of Hilbert’s article before 18 November, 1915 that apparently contained the correct form of the field equations derived from an action principle. On the other hand, it has been pointed out that Einstein suspected an attempt at plagiarism by Hilbert which led to the strained relationship between them. Though Stachel settles the issue in favor of Einstein, see also Mehra it is obvious that Hilbert’s pivotal role in the mathematical foundation of general relativity cannot be ignored.

In 1918 Einstein elucidated general relativity in terms of three principles: principle of relativity, equivalence principle and Mach’s principle. Since all the three principles have found varied interpretations and strong criticisms in the literature, I will make few remarks concerning the Kretschmann’s objection against general covariance and its constructive alternative in the form of ‘geometry-free physics’ initiated by F. Kottler in 1922. Kretschmann’s main argument is that all physical observations depend on purely topological relations between the objects in the space-time, and therefore no coordinate system is privileged. This implies that any theory could be so formulated mathematically that it is covariant under any group of coordinate transformations: general covariance is physically vacuous. General covariance in modern mathematical literature is called diffeomorphism: the group of transformations is differentiable point transformation on a differentiable manifold (just as isomorphism is in the vector space). Diffeo(4) in space-time manifold of general relativity takes into account accelerated or noninertial frames of reference. Post has drawn attention to what he calls KCD (Kottler, Cartan and van Dantzig) procedure for the electromagnetism. In a recent monograph Post articulated quantum cohomology as an alternative to quantum field theoretic unification schemes. In the light of current developments in the superstring theory, it is worth quoting Post on metric-free physics: “Witten calls attention to metric-free aspects of these developments. This ‘new’ metric independence has, so far, not shown an awareness of the earlier metric-independent work of the Twenties and Thirties (compare index references to metric-independence). Yet, these recent reports can be taken as an encouragement to support Witten in his call for a metric-free (extended) principle of general covariance for space-time physics, because this extended covariance permits the one and only invariant reconciliation between quantum principles and general theory of relativity”. In his 1979 article Post has rightly stressed that KCD procedure is physically more encompassing and that it was independently formulated by “three experts in the theory of differential and integral invariants”.

III. UNIFIED THEORIES

Gustav Mie’s theory was a precursor to the first attempt at a unified description of gravitation and electromagnetism by Hilbert. The nonlinear theory of Mie was aimed at explaining electron and matter from the fields, and the origin of variational principle for a world-function is due to him that became a powerful method in the hands of Hilbert and Weyl. An important advancement in mathematics was the notion of infinitesimal parallel transport of a vector by Levi-Civita in 1917. Weyl approached foundations of Riemannian geometry from this point of view, and was led to a pure infinitesimal geometry in which not only the direction of a vector under parallel transport from one point to another is changed but also its magnitude or length. Recall that in flat Euclidean geometry vectors at arbitrarily distant points can be compared as vector transference from one point to another is possible without any change in its direction and length. In the infinitesimal geometry of Riemann parallel transport of a vector from one point to another distant point rotates its direction. Weyl argued that there remained an element of finite geometry since the lengths of
the vectors at distant points could still be compared. If the length of a vector is arbitrary up to a calibration function, the wider group of transformations makes it possible to introduce a distance curvature determined by a linear one-form (or vector potential) arising out of calibration transformation. Later Weyl called it gauge invariance translating the original Eichin-varianz. Weyl was not content with this geometry as being just a mathematical curiosity: he interpreted the distance curvature as physical electromagnetic field tensor and the generalized geometry as a unified theory of gravitation and electromagnetism. Hendry gives an account of Einstein-Weyl correspondence on this theory when in March 1918 Weyl sent his work to Einstein. At first Einstein was greatly impressed but soon raised physical objections: the change in the length of a vector should show up in the atomic spectra as the period of clocks would change over a lapse of time, however no such observation exists. In May 1918 Weyl wrote to Einstein that he was reluctant ‘to accuse God of mathematical inconsistency’ to which Einstein responded saying, ‘It seemed to him just as bad to accuse God of a theoretical physics that did not do justice to human observations’. Weyl’s metaphysical arguments on mathematical laws of nature appealed to Eddington, but he rejected Weyl’s theory on both physical and mathematical grounds and proposed a generalized theory in which the assumption of the gauge invariance of zero length of a vector was removed.

Today we know that Weyl abandoned his original gauge theory in favor of phase transformations in Schroedinger and Dirac quantum theory, and it is this version that represents modern gauge field theories. Historically Fock in 1926 gave the first treatment of U(1) gauge transformation, and in 1927 F. London proposed quantum mechanical interpretation of Weyl’s gauge theory. However two papers written in 1929 by Weyl are considered as landmark in the development of modern gauge theories. The beauty of original Weyl geometry attracted Dirac to revive it in 1973. I have attempted to show that change of the length of a vector under parallel transport in complex space could be affected in such a way that the quantum state space retains typical phase characteristics. In later years, for a while, Einstein also returned to this geometry in the search for a unified theory.

Th. Kaluza in 1921 introduced fifth dimension to the space-time and originated a new direction to dissolve the duality of gravitation and electricity for a unified picture of nature. Weyl’s theory of 1918 was characterized by him as a ‘surprisingly courageous attack’ to the unification problem. In Kaluza’s theory the fifth coordinate is a new parameter and it is assumed that the derivatives with respect to this coordinate vanish (i.e. the cylinder condition); three-index Christofell symbol is sought to be interpreted as electromagnetic field tensor. Kaluza recognized physical and epistemological difficulties in his theory, mentioned the importance of quantum theory, and concluded that, “If it would be proven some day that there exists more behind the presumed relations than merely meaningless formalism, then this would certainly imply a triumph for Einstein’s general theory of relativity whose appropriate application to the five-dimensional world is at issue”. O. Klein in 1926 inspired by the new quantum theory (i.e. the wave mechanics) of de Broglie and Schroedinger re-interpreted Kaluza’s theory treating the fifth dimension ‘purely harmonic with a definite period related to the Planck constant’. Klein made an interesting insightful comment: the observed motion of a particle could be considered as the projection of wave motion in five dimension on the four dimensional space-time. In the current literature it is essentially due to the superstrings that Kaluza-Klein theory is widely known. Note that Weyl’s was the first unified theory, and it was entirely different than the higher dimensional theory of Kaluza.

It is curious that the papers of both Weyl and Kaluza were communicated by Einstein; he had serious doubts on these theories; and he himself was a late entrant to the quest of unification. Just before his death, Einstein revised the appendix on non-symmetric field in his book with the remarks: “The last step of the theory concerns the unification of the field concept, which is characterized by the transition to non-symmetric fields. The difficulty in the choice of the field laws has been fully overcome only in the last few months. The arguments essential for this are presented in detail in Appendix-II”. Beginning with non-symmetric metric tensor field in 1925 Einstein explored many ideas for unifying gravitation and electromagnetism all through the rest of his life, and on several occasions he thought he had reached the goal but soon found them unsatisfactory. I think quite succinct opinion on this phase of Einstein’s struggle is that of V.V. Narlikar: “The creation of the complete theory or the total field theory was the first priority programme of Einstein from 1925 to 1954 before any application to cosmology or to situations demanding a quantum theory of gravity could be thought of. By total field Einstein originally meant a generalized field including both gravitational and electromagnetic fields and their interactions. Later he imposed a requirement whereby the theory included the Planck’s constant h in an unforced manner...... Einstein, in his last paper on the subject, admitted that perhaps the concept of field was inadequate for the unified theory which he was seeking”.

Eddington, Einstein, and later Schroedinger investigated purely affine theory, and for generalized theory dropped the assumption of symmetric affine connection. Recently I became aware of a revealing correspondence between Cartan and Einstein on the origin of absolute parallelism. I quote from Cartan’s 8 May, 1929 letter, ‘In my terminology, spaces with a Euclidean connection allow of a curvature and a torsion: in the spaces where parallelism is defined in the Levi-Civita way, the torsion is zero; in the spaces where parallelism is absolute (fem parallelismus) the curvature is zero, thus these are spaces without curvature and with torsion’. Cartan pointed out that Einstein’s new theory of generalized relativity introducing fem parallelismus in his 1928 papers was a special case of Cartan’s 1922 paper published in Comptes Rendus. Cartan also drew attention of Einstein to the discussion on this issue with
him at Hadamard’s home in 1922. Einstein in his reply accepted the priority claim of Cartan, and admitted that he did not understand Cartan’s explanations in 1922 (at Hamamard’s home). At the end of the letter he wrote, “Asking you to forgive my inadvertent plagiarism and to help me settle the matter satisfactorily to everyone’s benefit”. For a recent extensive review on unified theories I refer to Goenner’s article [24].

IV. DISCUSSION AND CONCLUSION

Serious and inquisitive reader would do well to study the original literature for a balanced and accurate view on Einstein and his work. Some of the original papers are cited here, and others could be found in the reviews/books referred to here. In a letter of 2 May, 1920 [25] Einstein wrote to Bohr, “Not often in life was I so delightfully impressed already by the mere presence of somebody as by yours”. Contemporary generation of physicists/philosophers look Einstein with awe, and barring few, have failed to raise basic questions on the relativity revolution. Should modern physics be allowed to remain captive to Einsteins charm and ensuing weird physics? Remember that Einstein, though admired Bohr, continued to sharpen his arguments against Copenhagen interpretation of quantum mechanics. An objective assessment on Einstein, not anti-Einsteinian, rather than eulogizing him as a superman would surely serve the science and future generations better. In my opinion, reflecting upon the development of special relativity (from 1895 to 1905) and general relativity (from 1907 to 1915), and perusal of historical literature and Einstein-Cartan correspondence, Einstein emerges as a slow learner with average mathematical abilities but possessing an uncanny trait for perseverance in attacking the most difficult problems in physics. It is his imagination power and the courage to break from the trodden path at crucial juncture which set him apart from others; however he needed a framework for a zig-saw puzzle assembled by others from different pieces to take lead in making a complete picture. In the case of unified field theories such a framework did not exist, and Einstein himself had to struggle to reach at the different strands of unity. Single-minded pursuit in this endeavor makes him a thought personified.

Let us have a brief discussion on recent unification efforts most prominent of them being the superstring theory. In spite of great expectations from the superstrings, I believe this theory cannot represent physical reality, and simple ideas which make drastic revision of the space-time structure of relativity would be needed [26]. Atiyah et al. [27] celebrate 50 years of twistor theory admitting that this theory could merely reformulate known physical theories so far, but suggest holomorphic string theory in twistor space hold promise for future progress in unification. This article rightly notes impressive advances in mathematics inspired by twistors, however I think in view of the fact that compact holomorphic curves in a complex 3-fold in the twistor space is fundamental and space-time is secondary this approach may not represent physical reality. Initially Penrose [28] set the objective to be the reformulation in an approach where continuum is replaced by discrete structures, for example, spin network, and construct space from this. The combined algebra for linear momentum and angular momentum is the algebra of twistors: twistor is a spinor in the 6 dimensional pseudo-orthogonal group O(4,2). In [29] the Editor remarks that, 'did Penrose put the space-time structure into his theory or did he deduce it from the theory'. Reading [27] we find that this question remains unanswered even now.

The fundamental problem may lie in the concept of time. I suggest Einstein’s relativistic time is not physical; it is not that we will return to Newtonian absolute time and pre-1905 physics, the role of time as a profound embodiment of creation and manifestation of universe would play a crucial role in future development of physics [29]. Even original Weyl geometry for unification has immense potential for new physics in relation to quantum theory and general relativity; I refer to a review by Scholz [30]. Note that Scholz’s review is incomplete: a generalization to Weyl-Kaehler space [19] and new action principle generalizing Weyl-Dirac theory [31] also deserve attention [32].

The discovery of gravitational waves in 2015 at the LIGO detectors [33] is likely to introduce new dimension to unification paradigm. Does this observation validate Einstein’s general relativity? This is a complex question. Recall that though Einstein introduced gravitational waves in 1916, he arrived at a result in 1936 that they do not exist in an unpublished paper written with N. Rosen, see Kennefick [34]. In the later published version this result was altered, however one needs to explore the possibility for alternative explanation of gravitational waves. In fact, an interesting approach seems to be to use Kerr-Schild form of the metric tensor in the flat space-time [32].

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[1] J.D. Barrow, Einstein as icon, Nature, 433(7023) 218, (2005)
[2] J. L. Synge, in Perspectives in Geometry and Relativity, ed. B.Hoffmann (Indiana University Press, 1966) pp.7-15
