Unified Field Theory: Envisioned by Einstein

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"All of science is nothing more than the refinement of everyday thinking."

- Albert Einstein on science.

Abstract

This paper is a small review of Einstein's Unified Field Theory program. Here, the presentation covers the initiation, his visualization, attributes and postulates of the program, his successful contributions of the special relativity theory unifying space and time, general theory of relativity and the relativistic field theory of gravitation resolving the conceptual contradictions between classical gravitation theory and the Maxwellian theory of the electromagnetic field. The paper also discusses Einstein's attempts at various other concepts of five-dimension, affine connection, distant parallelism, co-vectors, and asymmetric theory, either proposed by other researchers, or generated by his own original ideas, till the last day of his life.

Key Words: *Unified Field Theory, Einstein's attributes, Special relativity theory, General theory of relativity, Relativistic field theory of gravitation, Asymmetric theory, Five-dimensional approach, Affine connection.*

Introduction

This paper starts from the conclusion of my last paper published in this journal on the subject of placement of the statue of Nataraja at CERN [Paramguru 2025, 232]. In order to start in a clear note, I cite that portion of the text here:

> 'In conclusion, two issues can be put forth. The first one is that – "The conception of physical things and phenomena as transient manifestations of an underlying fundamental entity is not only a basic element of quantum field theory, but also a basic element of the Eastern world view" [Capra 1975, 211]. Scientists of high standing such as Einstein, as well as the Eastern mystics, are of the view that – this underlying entity is the only reality; all its phenomenal manifestations are

transitory or illusory. The scientists are attempting to unify the various fields into a single fundamental field, called 'unified field' which would incorporate all physical phenomena…' [242].

From the above statement, I developed interest in the specific part represented by the last line, and looked to the available literature on 'unified field theory'. I could find a good number of interesting papers and books; and felt that, probably, since the unified field theory is also a domain of unification of sciences, my readers will also be interested in reading them, if I can provide in a suitable format. What can be a better format than as paper(s) in this particular journal? Hence, I decided to write a series of (very brief) review papers, for our journal, on 'unified field theory'; and this is the first one, naturally scheduled to present how Albert Einstein (1879-1955), the German-born theoretical physicist, arguably the initiator of the idea of 'unified field theory', visualized this idea and pursued it during the last few decades of his life. Of course, this will be based on the available literature.

The beginning of the vision

Historically, the credit for publishing the first paper related to classical unified field theory goes to the Scottish physicist and mathematician, James Clerk Maxwell, for his paper "A Dynamic Theory of the Electromagnetic Field" [1865], where he showed that electricity and magnetism were not separate phenomena but rather different aspects of the same force, and, in the same paper, he provided the mathematical description of electromagnetic field through equations. However, Albert Einstein is credited to have coined the term 'unified field theory' for the first time [Sauer 2007]. Tilman Sauer (1963-), a German theoretical physicist and historian of natural sciences with specific expertise on the history of the development of general relativity theory, besides many publications on the subject, have published specific papers related to Einstein's unified field theory program [2007], Einstein's Washington Manuscript on unified field theory [2020], and also a chapter in the book *The Cambridge Companion to Einstein* [2014]. He straightaway reports that "Einstein explicitly used the term 'unified field theory' in the title of a publication for the first time in 1925." [2007, 1]. This paper, published in the journal of Prussian Academy, was in German language, and hence, the title mentions 'Einheitliche Feldtheorie ...', the English translation of which is 'Unified Fieldtheory ...' [Einstein, 1925]. Sauer [2007] goes on to provide further details that Einstein, though used the term in the title for some ten more papers immediately after that first paper, had dealt with the subject already in about "half a dozen" publications before 1925 without using the term in the title. This is in print, on the other hand, Jeroen van Dongen has also told about Einstein's first positive public utterance about the unification program in 1920 [2002, 186]. In any case, Sauer reports that Einstein wrote, in total, "more than forty technical papers on the subject" [2007, 1].

The basic concept of a unified field theory is to describe all fundamental forces and particles within a single framework that is a single type of field. In terms of modern physics, the forces, instead of being transmitted directly between interacting objects, are described and interpreted by intermediary entities called fields. Thus, there are various fields in physics, such as, vector fields (electromagnetic field), spinor fields (fermionic particles like electrons), and tensor fields (the metric tensor field that describes the shape of space-time and also gravitation in general relativity). Further, according to quantum field theory, particles are treated themselves as quanta of fields. Unified field theory attempts to organize these fields, namely four fundamental forces (strong interaction, weak interaction, electromagnetic interaction, and gravitational interaction), and matter (electrons, quarks, neutrinos etc.) including Higgs bosons, into a single mathematical structure.

Against the basic objective of 'unified field theory' as depicted above, it is highly significant to identify the specific features; we may call it attributes of Einstein's visualization of the same theory. Of course, the very first attribute of his vision must take into account his naming of such a theory with this very specific title which speaks volumes with width and depth. The second attribute of Einstein's work on a unified field theory was what Sauer termed as "dimensions", such as "conceptual, representational, biographical, and philosophical dimensions." [2007, 1]. As usual, the first one refers to the problems and solutions within the knowledge of physics, the second one describes mathematical representations of physical phenomena, the third one from a historical perspective of various approaches made to work out the theory on a historical time frame, and the last one is the philosophical outlook of Einstein. In the words of Sauer "(T)he space spanned by these four dimensions constitutes Einstein's unified field theory program." [1]. When we come to identify the third attribute, Einstein's philosophical outlook comes into picture, because it is very specific. It is true that the theories usually constitute some/many general laws which would explain various phenomena; however, Einstein being Einstein, his basic philosophical outlook is significantly different. When we would express, in general terms, our own understanding of the theories, and their explanations; Einstein would include 'human reasoning' within the understanding. Sauer terms "Einstein's unification program was a program of reflection", and Einstein's motivation for such a program of reflection was in Sauer's own words: "a conception of the task of human reasoning that would be adequate to a holistic understanding of a nature in which human beings live their lives." [2]. This philosophical outlook of Einstein, as Sauer argues, holds well, not just for this work, but for the entire carrier's work of Einstein. The fourth attribute, may also be taken as a corollary of this philosophical outlook, because Einstein always used to have strong confidence in all his programs, similarly, he had a strong "insistence" that such a unified field theory is very much "possible" and "desirable" for mankind and would bring in successful result [1]. The last and, also the fifth attribute is, for Einstein, "unification efforts had to start from a theory of the gravitational field and hence be general relativistic" [8]. Sauer has further linked "historical continuity" to this attribute, because, scientific developments have always followed this path in the time-frame of historical perspective; and according to him, it is that historical continuity that has "placed the endeavor of finding a unified field theory above the theory of gravitation implied by general relativity", and "it was this conviction that separated Einstein from the majority of contemporaries" [26].

Einstein's special relativity theory

As stated earlier, the journey of classical unified field theory started with the unification of electricity and magnetism within the dynamic theory framework of the electromagnetic field published by Maxwell during 1865. Hardly forty years hence, in 1905, Einstein brought out two ground-breaking theories in physics. The first one was his explanation of the photoelectric effect by using Planck's constant h which paved the way for the development of quantum theory. Of course, for some reasons, Einstein was not much interested to use this concept for unification of field theory, nor we intend to follow on this, rather, our interest is his second theory of that time, namely, special theory of relativity. According to Peter Gabriel Bergmann (1915-2002), a German – American physicist and also an assistant to Einstein, most of physics around that time was dominated by Newtonian mechanics which quantitatively explained the working of the solar system [1979, 9]. As regards the absolute properties of space and time, Newton's laws required states of uniform rectilinear motion usually satisfied by inertial frames of reference. However, the electromagnetic field formulated by Faraday, Maxwell and Lorentz involved a dynamic state where electromagnetic waves move at a velocity equal to the speed of light. These two situations contradict each other, and at this stage, the brilliance of Einstein solved the issue through his notion of special theory of relativity. The basic postulates of special relativity are [Bergmann 1979, 10; Felker 2005, 16-33; Sauer 2007, 3]: (i) the notion of space and time changed into a single entity space-time, later known as Minkowski's four-dimensional space-time model; (ii) the concept of simultaneity in moving frames of reference was redefined; (iii) the constancy of the velocity of light (also constancy of the basic existences such as mass and charge including the laws of conservation), whatever may be the reference frame, was explained; and (iv) this constancy of speed of light was used to provide a conceptual justification for Maxwell's theory as well as Lorentz transformations. Through this theory, Einstein could unify not only space and time into space-time, but also, classical principle of relativity of mechanics and the laws of electrodynamics, two major fields of physics.

Einstein's general relativity theory

While using Minkowski's four-dimensional space-time concepts, unification of two major fields of physics could be obtained, however, a new contradiction was surfaced. Special relativity requires an inertial reference frame and the existence of an absolute and finite limit to the speed of any signal transmission; this later one was violated by Newtonian gravitation theory. Along with this conceptual conflict, another inherent difference, as discussed earlier between the Newtonian gravitational interaction with static inter-particle processes and Maxwellian electromagnetism dealing with dynamic waves, also persisted. A possible solution to resolve this conceptual contradiction needed a relativistic gravitational field, and Einstein once again brought out another of his brilliant discoveries that acceleration and gravitation are almost the same thing, and it must also be remembered that gravitation is not a force, though it appears so. With this analogy he could explain that the local gravitational acceleration for all bodies is uniform, and hence, the frames of reference are precluded by local means. Thus, Einstein's general theory of relativity, also known as, theory of the gravitational field was born. In essence, his special relativity theory is expanded to a description of gravity; the gravitational interaction was conceptualized as a dynamic field; accelerating reference frames were incorporated; and the flat space-time of Minkowski was replaced with the curving geometry of Riemannian space-time [Bergmann 1979, 11; Sauer 2007, 4; Felker 2005, 34-35]. This theory came into effect during 1915 and is considered as the third ground-breaking theory of Einstein in theoretical physics.

After Einstein's general theory of relativity as discussed above, Bergmann's statement: "The quest for unity had apparently reached its objective" [1979, 13], should indicate that Einstein's unification program reached its successful end. "However, it is not so." He further states that: "But there are several hairs in the ointment" [13], and Sauer also states that the most desirable cases of unified description "has never been achieved" [2007, 5]. Such statements indicate that there remains some 'desirable cases' to be satisfied in Einstein's unified theory program. According to Sauer, although there was no compelling reason, Einstein himself felt that "the new understanding of gravitation demanded further unification with classical Maxwellian theory of the electromagnetic field" [4]. Also, there was apparently a need for the unification to predict new physical effects arising out of unification, and there was always a necessity to take care of the representation of matter within unification. Therefore, Sauer has given a list of possible postulates to be included within Einstein's unified field theory program [2007]. Those are: (i) "a unified description that would both yield the known laws of gravitation and electromagnetism and would also predict new effects, arising from a combination of the fields inherent in the unified description, that would also be compatible with known empirical facts" [5], (ii) "to account for the existence of only a proton and an electron, ---, i.e. proton mass and electron mass, and one elementary charge" [7], and (iii) "(t)he explanation of quantum mechanics within a unified field theory remained a programmatic desideratum in Einstein's work" [8]. Einstein, though was involved in bringing out the quantum theory, was never in favor of this theory since it is not deterministic, but statistical mechanics. However, the last postulate was included because in presence of elementary material mass and charge, this may help in bringing continuous conceptualization of matter; and after all, Einstein did not ignore this possibility [7].

Einstein's UFT pursuit beyond 1915: response to others' approaches

After successful demonstration of general theory of relativity, Einstein continued to pursue his dream of UFT because that would address the above mentioned postulates; and further, many other physicists were also motivated to conduct research on UFT, and hence, as the pioneer, he would react to their results. That way, he continued in spite of his ill-health during 1928, and the events; such as Nazis' rise to power, cruel persecution of Jews, 2nd World War, the holocaust, and use of 1st atom bombs; due to which he resigned from Prussian Academy, left Germany and lived in United States of America since late 1933; yet, he never stopped research, and maintained developing ever-new approaches for his dream UFT till his death [Bergmann 1979 and Sauer 2007]. Of course, his research engagements have also produced significant results in the area of general relativity, besides in UFT. This section intends to present some of his UFT endeavors during this period, mostly his reactions to other's approaches.

The first reaction of Einstein was to the proposition of Hermann Weyl during 1918, which was generally concerned to Riemannian geometrization, specifically to parallel vector transport. Basically, his approach was to introduce a vector "length connection" to the Riemannian geometry structure keeping the four-dimensionality of space-time intact. Though Einstein was initially attracted towards the idea, very quickly he could find out the setbacks. He had specific objections to the existence of parallel transportable measuring lengths as a fundamental assumption of general relativity

[Einstein 1921]. Then onwards he did not consider Weyl's approach having any value for UFT.

His second reaction was to Theodor Kaluza's 'five-dimensional theory' proposed in 1919. Though, like his previous reaction to Weyl's approach, he could quickly find set-backs in this theory also; yet, he has examined/re-examined this five-dimensional approach a number of times: first in 1919-23, then in 1927, 1931-32, and last in 1938-41. Sauer [2007], Sauer and Schuetz [2020], and van Dongen [2002] have given a detailed description of Einstein's reactions to this theory. The reaction started when Kaluza sent him a manuscript where he introduced the fifth dimension to the Riemannian space-time manifold of general relativity. Einstein could locate several difficulties at different levels of the theory, and their initial correspondence ended in May 1919 [Sauer 2007, 13]. However, after some rethinking, Einstein invited Kaluza after around two years to resubmit his manuscript, and this time, not only he helped him publish the paper; but also, himself co-authored by Grommer published another paper investigating the problem of solutions to Kaluza's theory. After another stint in 1927 on this approach with two publications, he visited again in 1931-32, by this time it has become Kaluza-Klein theory, when, after his experience with distant parallelism, he could visualize a possibility with the application of tetrad formalism here. In association with Walther Mayer, he constructed a five-dimensional vector space at each point of four-dimensional space-time and explored the functioning of the tetrad formalism. However, this approach also ran into difficulties due to problems in accounting for the structure of matter [19]. Then in 1938, Einstein and Bergmann published the penultimate paper on reconsideration of Kaluza-Klein's five-dimensional approach [1938]; and three years later came up with the final paper [Einstein, Bargmann, and Bergmann 1941], where the authors have addressed all the problems including impossibility to describe particles by non-singular solutions [Sauer 2007, 21; van Dongen 2002, 193]. Even one of the authors of the last paper, Peter Bergmann, while describing their idea concludes: "Alas, the idea did not work out" [1979, 16].

Einstein reacted to a third approach towards UFT called affine connection proposed by Arthur Eddington, who started with a manifold equipped with a linear affine connection that allowed a Riemann curvature tensor and of a, supposedly anti-symmetric, Ricci tensor; then, he continued to treat the anti-symmetric and symmetric parts of the Ricci tensor, respectively, as the electromagnetic field tensor and usual metric tensor field. However, he did not provide field equations to determine the affine connections, which Einstein provided; yet, he experienced problems including the theory not accounting for the electron-proton mass symmetry [Sauer 2007, 14].

Einstein's UFT pursuit beyond 1915: own approaches

Thus, all the above responses of Einstein to the external propositions ended in no fruitful result; and this section will present some of his original approaches. During 1923, Einstein published an original paper, interestingly searching for a possible solution for UFT in quantum theory. Though he was expecting to account for quantum phenomena by means of differential equations, he admitted that he was still unable to solve the quantum problem. However, according to Sauer [2007, 15], he was contemplating the quantum issue as early as 1920; later on, during the early 1930s, he came out to investigate UFT where the problem of quantum theory had the most direct involvement. This happened when he came across his old professional friend Paul Ehrenfest, who brought to him the investigations of a relativistic quantum theory by Wolfgang Pauli and Paul Dirac. Einstein jumped into the investigation, worked with his coauthor Mayer using 'semi-vectors' in place of 'spinors' used earlier and published four papers during 1932 - 1934. However, fruitful results still eluded them; quantum problems remained unsolved [19].

During 1928 Einstein fell sick and was ordered strict bed rest, while taking rest, his fertile brain cooked up some interesting research idea which, after some time, he published two notes in Prussian Academy on a mathematical structure which he called *Riemannian geometry, maintaining the concept of distant parallelism*, where, he investigated if a UFT can be formulated within this geometric framework. Soon, he learned that the mathematical concept of distant parallelism had already been developed by mathematicians Roland Weitzenboch and Elie Cartan; he acknowledged their mathematics, and hopefully went ahead formulating a UFT within this structure. However, finally, the distant parallelism approach ended in an attempt only [17-18].

Accounting for matter in a UFT was posing a problem, hence, Einstein attempted to investigate this aspect in a note published during 1941 [Einstein 1941]; which was reinvestigated after two years in a joint paper with Pauli [Einstein and Pauli 1943]. Here, they could prove the non-existence of regular solutions to the vacuum field equations that would asymptotically behave like the Newtonian gravitational potential, whatever be the symmetry conditions of the field in finite field strength regions; also, this result was valid for both four- and five- dimensional theories. This means, under general conditions, a UFT on Riemann tensor would always involve singularities in particle-like solutions; and he should look for new approaches, which he did [Einstein 1943], and another with his coauthor Valentin Bargmann [Einstein and Bargmann 1943]. Here, the authors attempted at a new kind of a non-local relativistic theory of gravitation which they called 'bi-vector approach'. Apparently, the 'bi-vector approach', judging by the published record, is Einstein's penultimate distinct approach in the sequence of UFT approaches, also ran into difficulties to end in a failure [Sauer 2007, 21-22].

Now, we enter into Einstein's last approach, rather, the approach where he devoted the last ten years of his life. Incidentally and interestingly, this approach was started by him in 1925, where he used the term 'Unified Field Theory' in the title of the paper for the first time. It was also based on a local Riemannian metric but an asymmetric one. In the first paper published in 1925 [Einstein 1925], he took both a metric tensor field and a linear affine connection, both assumed asymmetric, at the same time as fundamental variables. He defined the field equations, tried to associate the gravitational and electromagnetic fields, respectively, with the symmetric and anti-symmetric parts of the metric field, and attempted to recover the known cases. Though he could get satisfactory results with respect to the gravitational case, the results with Maxwell's equations were not entirely satisfactory; he could not know how to move on from here [Sauer 2007, 15-16]. He, now, returned to investigate this problem in 1945 [Einstein 1945], and went ahead with the investigation publishing a series of papers between 1946 and 1955, most of them with himself as single author, only one with Straus, and another two with Kaufmann as his co-authors. In these papers, tentative field equations were tested for their mathematical properties, satisfactions of the criteria for a physical interpretation were checked, and as usual, his deep interests of compatibility were examined. Since the mathematics of a framework based on an asymmetric metric tensor is highly complex, he spent the rest of his life elaborating the asymmetric theory. His very last considerations in his final approach were presented by his last assistant, Bruria Kaufmann [Kaufmann 1956], at the 50th anniversary of the relativity theory in Bern in July 1955 a few weeks after Einstein's death [Sauer 2007, 22-23]. Thus, the efforts and contributions of a genius ended here, to be taken up further by other researchers in future.

Conclusion

In conclusion, one point can be clearly stressed upon that details on an account of Einstein's work on UFT would be beyond the scope of this paper. However, an honest attempt has been made to present, very briefly, the initiation of his UFT program, his attributes and postulates of the program, his successful journey through the special relativity and general relativity theories, and his genuine attempts at various approaches proposed by other researchers and also generated in his brilliant thought process, most importantly maintaining his high intellectual heritage till the last moment of his life. He is not with us since 1955, long seventy years have passed by, how his followers have followed up his ideas, will expectedly be the subject matter of next papers in this column.

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