Chapter 19

Experiments To Test The Evans Unified Field Theory And General Relativity In Classical Electrodynamics

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Abstract

It is argued that the Faraday experiment with rotating disc verifies the Evans unified field theory in classical electrodynamics, being an experiment in rotational relativity. Thus classical electrodynamics is a theory of general relativity, requiring the use of a spin connection as in the Evans unified field theory. Several other experiments are suggested with which to test general relativity in classical electrodynamics. These forge a basis for extending quantum electrodynamics to a theory of general relativity, and for incorporating gravitation into electrodynamics.

Key words: Evans unified field theory, general relativity, Faraday rotating disc experiment, new experiments in general relativity.

19.1 Introduction

The essence of relativity theory is that physics is the objective investigation of nature. This is a fundamental principle which prevents physics being subjective (all things to all observers) and incomplete. Relativity theory was forged by several investigators from about 1892 to 1915, major advances being made in 1905 by Einstein, and in 1915 by Einstein, and independently, Hilbert. From about 1925 to about 1955 Einstein, Cartan and others sought a truly objective theory of nature based on relativity applied to electrodynamics as well as to gravitation. As early as 1922, Cartan sensed that electrodynamics must be based on the torsion tensor in his newly inferred Cartan geometry. The solution to this type of unification was finally inferred from 2003 to present in the Evans unified field theory [1]– [28], based directly and straightforwardly on the well known structure [29]– [31] of Cartans differential geometry. The Evans field theory has been tested experimentally in several different ways, and has been shown to reduce to the correct mathematical structure of all the major equations of both classical and quantum physics. This paper is concerned with further testing of the theory in classical electrodynamics using available experiments and inferences of new experiments.

In Section 19.2 the new theory is applied in all theoretical detail to the Faraday rotating disc experiment of the nineteenth century. In Section 19.3 several new experiments are inferred from the new theory, to be tested at a later stage and the paper ends with a discussion of developments, notably on the interpretation of the wave-function in the Evans unified field theory, on the meaning of locality and non-locality and related topics which remain points of debate in contemporary physics. This discussion is intended to prepare the ground philosophically for the systematic extension of general relativity in classical electrodynamics to quantum electrodynamics.

19.2 Faraday Rotating Disc Experiment

On Dec 26^{th} 1831 Faraday noted in his diary the results of a new experiment in a famous series of experiments involving the interaction of electricity and magnetism. In this experiment a conducting disc was attached to a cylindrical bar magnet and separated from it by paper. The assembly was rotated and an electromotive force observed between the center of the disc and a rim of the disc. This experiment developed into the homopolar generator of contemporary engineering. Its attempted interpretation using special relativity (notably the Maxwell Heaviside field theory) has caused protracted confusion, the issue finally being settled in a series of reproducible experiments by Guala-Valverde at al. [32]– [37]. These investigators show clearly and simply that induction by a rotating disc is an example of general relativity: it is the relative angular frequency of rotation that counts. If the disc is spun with respect to a static magnet aligned in Z, the electromotive force is measured by a voltmeter at rest with respect to the spinning disc. Similarly the magnet can be spun about Z with respect to a static disc, or both magnet and disc can be spun about Z with respect to the voltmeter, as in the original experiment of Dec 26^{th} 1831. None of these experiments can be explained with special relativity because the latter does not deal with accelerations induced by rotation. In order to deal with rotational relativity [32]– [37] the Evans unified field theory is needed, the latter being a theory of general relativity. The latter theory in turn is covariant under any coordinate transformation, meaning that it can deal with accelerations in central and rotational dynamics. In gravitational general relativity the acceleration is central, reducing to Newtonian acceleration in the weak field limit. The Evans unified field theory introduces general relativity to electrodynamics, and does this via the torsion form of Cartan [1]– [28]. The unified gravito-electromagnetic field is then governed directly by the rules of Cartan geometry. The latter is rigorously equivalent to the most general type of Riemann geometry, but is much more elegant and clear.

The Faraday disc experiment is therefore governed by the field equations of the Evans theory. The electromagnetic potential is a vector valued one- form of differential geometry and is defined through the Evans Ansatz as:

$$A^a = A^{(0)} q^a \tag{19.1}$$

where $A^{(0)}$ is a scalar magnitude, a C negative number. Here q^a denotes the tetrad form [29]– [31]. The electromagnetic field is a vector valued two-form and is defined by the first Cartan structure equation:

$$T^a = D \wedge q^a = d \wedge q^a + \omega^a{}_b \wedge q^b \tag{19.2}$$

where T^a is the torsion form and $\omega^a{}_b$ is the spin connection. Here $d\wedge$ is the exterior derivative and $D\wedge$ the covariant exterior derivative of Cartan geometry. The Ansatz (1) implies that:

$$F^a = A^{(0)} T^a \tag{19.3}$$

and so Eq.(19.2) becomes:

$$F^a = D \wedge A^a = d \wedge A^{(0)} + \omega^a{}_b \wedge A^b. \tag{19.4}$$

The homogeneous field equation of classical electrodynamics is defined by the following identity of Cartan geometry:

$$\begin{aligned} D \wedge T^a =& d \wedge T^a + \omega^a{}_b \wedge T^b \\ =& R^a{}_b \wedge q^b. \end{aligned} \tag{19.5}$$

Using the Ansatz we obtain:

$$d \wedge F^a = \mu_0 j^a = A^{(0)} \left(R^a{}_b \wedge q^b + T^b \wedge \omega^a{}_b \right) \tag{19.6}$$

which in general is an equation which shows how gravitation and electromagnetism are inter-related. For the general spin connection the homogeneous current j^a in Eq.(19.6) is non-zero, but for rotational motion [1]– [28] the spin connection is dual to the tetrad, and in consequence the homogeneous current vanishes. This is the case for classical electromagnetism free from gravitation. For all practical purposes this is sufficient for macroscopic experiments in electro-dynamics, but at the electronic level hybrid effects may occur which would result in a non-zero homogeneous current.

For our purposes in this paper the homogeneous current is taken to be zero, and in consequence the homogeneous field equation is:

$$d \wedge F^a = 0. \tag{19.7}$$

The Faraday disc and Rowland experiments are therefore described by Eqs.(19.4) and (19.7) - equations of Einsteinian general relativity as required for a correctly objective description of classical electrodynamics. The index a used in this paper is the index of the complex circular basis:

$$a = (1), (2), (3). \tag{19.8}$$

In the standard model and in the Maxwell Heaviside theory of special relativity the equivalents of Eqs.(19.4) and (19.7) are:

$$F = d \wedge A, \tag{19.9}$$

$$d \wedge F = 0. \tag{19.10}$$

It is seen that the spin connection is missing and that the index a is not given. The reason for this is that the electromagnetic field in the standard model is an entity superimposed on a passive frame. In Einsteinian general relativity both gravitation and electromagnetism (and indeed any field) must be space-time in four dimensions. In consequence the electromagnetic field must be spinning space-time, and the spin connection must be used.

There is no explanation for the Faraday rotating disc experiment in the standard model, because induction is described by the Faraday law of induction:

$$\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = \mathbf{0} \tag{19.11}$$

where $\mathbf{B}$ is magnetic flux density (tesla) and $\mathbf{E}$ is electric field strength (volt/m). If $\mathbf{B}$ is aligned in Z and is static, the disc being spun, induction is observed experimentally but $\mathbf{B}$ does not change in Eq.(19.11). This means that there is no induction theoretically:

$$\nabla \times \mathbf{B} = \mathbf{0} \tag{19.12}$$

contrary to experimental data. If the magnet is spun about Z, then

$$\frac{\partial \mathbf{B}}{\partial t} = \mathbf{0} \tag{19.13}$$

and no induction occurs from Eq.(19.11). Induction is observed experimentally however. Similarly when both the disc and magnet are spun about Z, as in Faradays original experiment. In order to try to save the standard model the Lorentz force law is sometimes used in an attempt to explain the Faraday disc, but Guala-Valverde et al. [32]– [37] have shown that induction occurs even when the Lorentz force law does not apply.

In the Evans field theory the explanation of the Faraday disc experiment is as follows.

Using the complex circular basis [1]– [28], the magnetic flux density is defined by:

$$\mathbf{B}^{(1)*} = \nabla \times \mathbf{A}^{(1)*} - i\frac{\kappa}{A^{(0)}}\mathbf{A}^{(2)} \times \mathbf{A}^{(3)} \tag{19.14}$$

$$\mathbf{B}^{(2)*} = \nabla \times \mathbf{A}^{(2)*} - i\frac{\kappa}{A^{(0)}}\mathbf{A}^{(3)} \times \mathbf{A}^{(1)} \tag{19.15}$$

$$\mathbf{B}^{(3)*} = \nabla \times \mathbf{A}^{(3)*} - i\frac{\kappa}{A^{(0)}}\mathbf{A}^{(1)} \times \mathbf{A}^{(2)} \tag{19.16}$$

where

$$\kappa = \frac{\Omega}{c} \tag{19.17}$$

and where Ω is an angular frequency in radians / second. Here c is the vacuum speed of light, a universal constant of Einsteinian general relativity. When the disc is stationary the vector potential is defined by:

$$\mathbf{A}^{(1)} = A^{(0)}\mathbf{q}^{(1)}, \tag{19.18}$$

$$\mathbf{A}^{(2)} = A^{(0)}\mathbf{q}^{(2)}, \tag{19.19}$$

$$\mathbf{A}^{(3)} = A^{(0)}\mathbf{q}^{(3)}, \tag{19.20}$$

where the tetrads are [1]– [28]:

$$\mathbf{q}^{(1)} = \frac{1}{\sqrt{2}}\left(\mathbf{i} - i\mathbf{j}\right), \tag{19.21}$$

$$\mathbf{q}^{(2)} = \frac{1}{\sqrt{2}}\left(\mathbf{i} + i\mathbf{j}\right), \tag{19.22}$$

$$\mathbf{q}^{(3)} = \mathbf{k}. \tag{19.23}$$

The tetrads form an $O(3)$ cyclically symmetric group:

$$\mathbf{q}^{(1)} \times \mathbf{q}^{(2)} = i\mathbf{q}^{(3)*}, \tag{19.24}$$

$$\mathbf{q}^{(2)} \times \mathbf{q}^{(3)} = i\mathbf{q}^{(1)*}, \tag{19.25}$$

$$\mathbf{q}^{(3)} \times \mathbf{q}^{(1)} = i\mathbf{q}^{(2)*}. \tag{19.26}$$

Thus in the absence of rotation about Z:

$$\nabla \times \mathbf{A}^{(1)} = \nabla \times \mathbf{A}^{(2)} = \mathbf{0}, \tag{19.27}$$

$$\mathbf{A}^{(3)} = A^{(0)}\mathbf{k}. \tag{19.28}$$

From Eq.(19.7) and using the complex circular basis we obtain:

$$\nabla \times \mathbf{E}^{(1)} + \frac{\partial \mathbf{B}^{(1)}}{\partial t} = \mathbf{0} \tag{19.29}$$

$$\nabla \times \mathbf{E}^{(2)} + \frac{\partial \mathbf{B}^{(2)}}{\partial t} = \mathbf{0} \tag{19.30}$$

$$\nabla \times \mathbf{E}^{(3)} + \frac{\partial \mathbf{B}^{(3)}}{\partial t} = \mathbf{0} \tag{19.31}$$

Therefore from Eqs.(19.14) to (19.16) and (19.29) to (19.31) the only field present is

$$\mathbf{B}^{(3)*} = \mathbf{B}^{(3)} = -iB^{(0)}\mathbf{q}^{(1)} \times \mathbf{q}^{(2)} = B_Z^{(3)}\mathbf{k} = B_Z\mathbf{k}, \tag{19.32}$$

which is the static magnetic field of the magnet.

When the disc is rotated at an angular frequency Ω:

$$\mathbf{A}^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} - i\mathbf{j})\, e^{i\Omega t}, \tag{19.33}$$

$$\mathbf{A}^{(2)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} + i\mathbf{j})\, e^{-i\Omega t}, \tag{19.34}$$

and from Eqs.(19.14) to (19.16) and (19.29) to (19.31) electric and magnetic fields are induced in the direction transverse to Z, i.e. in the XY plane of the spinning disc. However the longitudinal magnetic flux density component in Eq.(19.32) is unchanged by the rotation, as occurs experimentally. The (2) component of the transverse electric field spins around the rim of the disc and is defined form Eq.(19.4) as [1]– [28]:

$$\mathbf{E}^{(2)} = \mathbf{E}^{(1)*} = -\left(\frac{\partial}{\partial t} + i\Omega\right)\mathbf{A}^{(2)}. \tag{19.35}$$

Its real and physical part is:

$$Real(\mathbf{E}^{(1)}) = \frac{2}{\sqrt{2}} A^{(0)}\Omega\,(\mathbf{i}\sin\Omega t - \mathbf{j}\cos\Omega t)\,, \tag{19.36}$$

and it is proportional to the product of $a^{(0)}$ and Ω as observed experimentally. It sets up an electromotive force between the center of the disc and the rotating rim, and this is measured by a voltmeter in the laboratory frame, at rest with respect to the rotating disc. As demonstrated clearly by Guala-Valverde et al. [32]– [37], this is an example of rotational relativity.

The homogeneous law (7) retains its form in any frame of reference, as required by general relativity, and in consequence the rotating electric field induces a rotating magnetic field in the frame of the mechanically rotated disc:

$$\left(\nabla \times \mathbf{E}^{a} + \frac{\partial \mathbf{B}^{a}}{\partial t}\right)_{mechanical} = \mathbf{0}. \tag{19.37}$$

This is therefore a simple and complete description of the Faraday disc experiment in general relativity. The origin of the effect is rotating or spinning space-time, induced by mechanically rotating the disc, and described by the rotating tetrads [1]– [28]:

$$\mathbf{q}^{(1)} = \mathbf{q}^{(2)*} = \frac{1}{\sqrt{2}} (\mathbf{i} - i\mathbf{j})\, e^{i\Omega t}. \tag{19.38}$$

In the same philosophy of Einsteinian general relativity, gravitation is curving space-time, again described by the tetrad appropriate to curving space-time. The philosophy is therefore self -consistent, and the results completely describe the experiment.

19.3 Suggested New Experiments

In a circularly polarized electromagnetic wave the phaseless Evans spin field is given by the spin connection of general relativity:

$$\mathbf{B}^{(3)*} = -iB^{(0)}\mathbf{q}^{(1)} \times \mathbf{q}^{(2)} \tag{19.39}$$

This field propagates with the radiation at c in free space. This field can be used in principle instead of the static magnetic field or conventional electromagnet of the homopolar generator to induce an electric field in an induction coil. The simplest design is mechanical rotation of the antenna sources of $\mathbf{A}^{(1)}$ and $\mathbf{A}^{(2)}$ at an angular frequency Ω in a clockwise or anticlockwise direction. This produces extra induction due to mechanical rotation as in Eqs.(19.33) and (19.34) leading to rotating electric and magnetic fields in the XY plane. Thus, spinning an electromagnetic field should produce induction over and above that observed in the absence of spin and careful design should produce a homopolar generator of this type without moving parts. For example phase, frequency or amplitude modulation could be used.

Consider a circularly polarized electromagnetic component propagating in the Z axis with phase $e^{i\phi}$ in the absence of rotation:

$$\mathbf{A}^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} - i\mathbf{j})\, e^{i\phi}. \tag{19.40}$$

The complex conjugate of this wave is:

$$\mathbf{A}^{(2)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} + i\mathbf{j})\, e^{-i\phi}. \tag{19.41}$$

In the absence of mechanical spin at angular frequency Ω the Evans spin field in free space is phaseless and propagates at c:

$$\mathbf{B}^{(3)*} = -i\frac{\kappa}{A^{(0)}}\mathbf{A}^{(1)} \times \mathbf{A}^{(2)} = B_Z\mathbf{k}, \tag{19.42}$$

In the presence of mechanical spin about Z the components (19.40) and (19.41) become:

$$\mathbf{A}^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} - i\mathbf{j})\, e^{i(\phi+\Omega t)} \tag{19.43}$$

and

$$\mathbf{A}^{(2)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} + i\mathbf{j})\, e^{-i(\phi+\Omega t)}. \tag{19.44}$$

The conjugate product of Eq.(19.43) and (19.44) produces an unchanged, phase free, spin field

$$\mathbf{B}^{(3)} = B^{(0)}\mathbf{k}. \tag{19.45}$$

However from Eq.(19.37) mechanical spin induces an electric field in the XY plane given by Eq(19.36) and an accompanying magnetic field spinning in the XY plane. This is the counterpart of the Faraday disc generator with the bar magnet or electromagnet replaced with a spinning electromagnetic field. Finally if the rate of mechanical spin Ω were time dependent, it might be possible to use amplitude, phase or frequency modulation techniques to monitor the induced electric field in this type of homopolar generator.

One possible way of generating a phase dependent axial magnetic field is to mechanically rotate a left circularly polarized field in the left-wise direction. The wave is given by:

$$\mathbf{A}_L^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} - i\mathbf{j})\, e^{i\phi} \tag{19.46}$$

where

$$\phi = \omega t - \kappa Z \tag{19.47}$$

is the electromagnetic phase. The mechanical rotation at angular frequency Ω induces a change in frequency of the wave:

$$\omega \longrightarrow \omega + \Omega \tag{19.48}$$

and the rotation results in the extra potential:

$$\mathbf{A}_{L,mech}^{(1)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} - i\mathbf{j})\, e^{i\Omega t}. \tag{19.49}$$

The complex conjugate of Eq.(19.46) is:

$$\mathbf{A}_L^{(2)} = \frac{A^{(0)}}{\sqrt{2}} (\mathbf{i} + i\mathbf{j})\, e^{-i\phi}. \tag{19.50}$$

A phase dependent axial magnetic field is set up through the conjugate product:

$$\begin{aligned} \mathbf{B}^{(3)*} &= -ig\mathbf{A}_{L,mech}^{(1)} \times \mathbf{A}_L^{(2)} \\ &= B^{(0)} e^{i\Omega t} e^{-i\phi}\mathbf{k}. \end{aligned} \tag{19.51}$$

The real part of this is:

$$Re(\mathbf{B}^{(3)*}) = B^{(0)}cos\,(\Omega t - \phi)\,\mathbf{k} \tag{19.52}$$

and consists of a slow modulation at frequency Ω superimposed on oscillation at frequency ω. This slow modulation could be detected in principle with a lock in amplifier, using amplitude or phase modulation techniques well known in Michelson interferometry [38].

If the static, uniform magnetic field of the Faraday disc generator were replaced by a static, uniform electric field in the Z axis, a rotating potential of type (19.49) would be set up if the disc were rotated about Z with respect to the static electric field in Z. The electric field should be well insulated from the rotating disc so that the latter would not become charged, causing possible artifacts to complicate the experimental data. An e.m.f. of the Faraday disc type would be expected between the center of the rotating disc and a rim. This effect again depends on there being two essential ingredients present, the scalar $A^{(0)}$ (this time from the electric field), and mechanical rotation at angular frequency Ω. The role of the magnetic field in the original Faraday disc experiment and of the electric field in this experiment is to supply $A^{(0)}$. Similarly a rotating electromagnetic field would supply $A^{(0)}$ through the root mean square of the oscillating potential. These are all examples of general relativity, mechanical rotation sets up a rotation of spacetime, inducing the tetrad (19.38) and the potential (19.49). The rotating electric fields in the disc back induce a Z axis magnetic field through the equation:

$$\mathbf{B}^{(3)*} = -ig\mathbf{A}^{(1)} \times \mathbf{A}^{(2)}. \tag{19.53}$$

Similarly a rotating disc made up of a dielectric spinning about a Z axis electric or magnetic field would carry the induced potential (19.49), but in this case there are no electric fields induced directly, only through polarization and magnetization effects.

In the papers by Guala-Valverde et al. [32]– [37] a description is given of induction by a long solenoid in a loop placed outside the solenoid. There is no magnetic field outside the solenoid, yet induction occurs experimentally. In this case there is a circling electric field $\mathbf{E}^{(1)} = \mathbf{E}^{(2)*}$ present in the solenoid. In general relativity this originates in the transverse tetrad (19.38). Inside the solenoid there is also a magnetic field $\mathbf{B}^3$ in the Z axis, originating in the longitudinal tetrad $\mathbf{q}^{(3)}$. Together with $A^{(0)}$, the cross product of the tetrads $\mathbf{q}^{(1)}$ and $\mathbf{q}^{(3)}$ are part of the non-local spin connection term (second term in Eq.(19.4)). This non-local term sets up the circulating magnetic fields as in Eqs(19.14) and (19.15) (second terms right hand side), and these non-local fields cause induction in an arbitrarily shaped wire as described by Guala-Valverde et al. [14]– [15]. There is no explanation for this effect in the standard model. In the latter only the local term (Eq. (19.9)) is defined and there is no induction possible from the spin connection term of general relativity (second term on the right hand side of Eq.(19.4)), the electric field of the winding of the solenoid is confined to the solenoid, and the magnetic field is confined to the Z axis inside the solenoid.

Similarly in the Aharanov Bohm effect the magnetic field is confined to the Z axis, whereas the potential causing the electron diffraction shift is non-local - another example of the spin connection at work in classical electrodynamics [1]–[28]. Finally if the solenoid were spun about its Z axis at angular frequency Ω, extra induction would be expected from general relativity. Careful experimental design is needed to observe this induction [32]– [37]. Alternatively the solenoid could generate the Z axis magnetic field in the Faraday disc experiment with solenoid static and disc spun, or vice-versa.. Other configurations of this type could be designed by the electrical engineer.

Therefore a considerable amount of experimental evidence is building up for the Evans unified field theory and rotational relativity in classical electrodynamics. This evidence provides a solid basis for a unified field theory based on Cartan geometry.

19.4 Discussion

In order to incorporate gravitational effects into classical electrodynamics a more complete description is needed of the charge current density. In the homogeneous equation this is defined as on the right hand side of Eq(19.6) and as argued already, vanishes for rotational motion because the spin connection is dual to the tetrad, and the Riemann form is dual to the torsion form. This type of duality is the same as the duality between a rank two antisymmetric tensor and an axial vector. In the presence of gravitation however the duality is no longer valid, because superimposed on the spinning is a curving. In the presence of gravitation therefore the homogeneous current j^a may not be zero indicating a violation of the Faraday law of induction due to gravitation. When the electromagnetic field interacts with matter gravitation is present because mass is present. The Evans field equation describing the interaction is the inhomogeneous field equation, the Hodge dual of the homogeneous field equation. In free space the inhomogeneous charge current density J^a is the Hodge dual of the homogeneous charge current density j^a:

$$J^a = \frac{A^(0)}{\mu_0}\left(\widetilde{R}^a{}_b \wedge q^b + \widetilde{T}^b \wedge \omega^a{}_b\right). \tag{19.54}$$

In the presence of field matter interaction the spin connection is changed from $\omega^a{}_b$ to in general. This change incorporates the ad hoc constitutive equations of non-linear optics in the standard model. In free space therefore the electromagnetic wave free of gravitational influence is given by:

$$d \wedge F^a = 0, \tag{19.55}$$

$$d \wedge \widetilde{F}^a = 0, \tag{19.56}$$

two simultaneous equations which must be solved for given initial and boundary conditions. In the presence of gravitation and field matter interaction the relevant equations become:

$$d \wedge F^a = \mu_0 j^a, \tag{19.57}$$

$$d \wedge \widetilde{F}^a = \mu_0 J^a. \tag{19.58}$$

If there is no torsion in field matter interaction then $\widetilde{R} \wedge q$ is central and:

$$d \wedge \widetilde{F}^a = A^{(0)} \left(\widetilde{R}^a{}_b \wedge q^b \right)_{central} \tag{19.59}$$

The Coulomb law in general relativity is part of Eq.(19.59) and describes the central force between two charges. Similarly the Newton inverse square law describes the central gravitational attraction between two masses. The Coulomb law in the laboratory is a very precise law (19.39) and this verifies Eq.(19.59) experimentally to high precision. However the most general form of the inhomogeneous field equation is:

$$d \wedge \widetilde{F}^a = A^{(0)} \left(\widetilde{R}^a{}_b \wedge q^b + \widetilde{T}^b \wedge \Omega^a{}_b \right) \tag{19.60}$$

and by comparison with Eq.(19.59) it is seen that extra contributions due to spacetime torsion may exist most generally. These interactions could conceivably occur in close vicinity to an electron, which curves spacetime considerably.

The discussion in this paper has been confined to the classical level, but it is known that Cartan geometry gives the mathematical structure of quantum mechanics through the standard tetrad postulate and the Evans Lemma [1]– [28] derived straightforwardly from the tetrad postulate. The wave-function of the Evans unified field theory is the tetrad for all radiated and matter fields. The tetrad is well known to be the fundamental field of the Palatini variation of general relativity. Therefore it is unsurprising that the tetrad should be the wave-function in generally covariant quantum mechanics. As discussed already, classical electrodynamics in general relativity has a local and non-local nature, well verified experimentally. It follows that the wave-function also has a local and non-local nature. The non-locality is a property of spacetime (the connection). The Evans unified field theory reduces to the Einstein Hilbert field theory of gravitation when the latter is decoupled from electromagnetism, so all that is known about gravitational general relativity can be applied to classical electrodynamics in a fully objective manner. As in all relativity theory an effect is preceded by a cause, so the Heisenberg Bohr complementarity is rejected. This is again in accord with recent data [1]– [28] which show that the complementarity idea is dubious at best.

Acknowledgments The British Government is thanked for a Civil List pension (2005). Franklin Amador is thanked for meticulous typesetting, Hal Fox for a special issue of the Journal of New Energy, Tony Craddock, Ted Annis, John B. Hart and others for funding, and the staff of AIAS for many interesting discussions. Roy Keys is thanked for directing the attention of AIAS to the work of Prof. Jorge Guala-Valverde and his group.

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