General Classical Electrodynamics

A new foundation of modern physics and technology

Koen J. van Vlaenderen

Institute for Basic Research

koenvanvla@gmail.com

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Abstract

Maxwell's Classical Electrodynamics (MCED) shows several related inconsistencies, as the consequence of a single false premise. The Lorentz force law of MCED violates Newton's Third Law of Motion (N3LM) in case of General Magnetostatics (GMS) current distributions, that are not necessarily divergence free. A consistent GMS theory is defined by means of Whittaker's force law, which requires a scalar magnetic force field, B_L. The field B_L mediates a *longitudinal* Ampère force, similar to the vector magnetic field, $\mathbf{B}_T$, that mediates a *transverse* Ampère force. The sum of transverse- and longitudinal Ampère forces obeys N3LM for stationary currents in general. The scalar field, B_Φ, is also a physical, as a consequence of charge continuity.

MCED does not treat the induction of the electric field, $\mathbf{E}_L$, by a time varying B_L field, so MCED does not cover the reason for adding $\mathbf{E}_L$ to the superimposed electric field, $\mathbf{E}$. The exclusion of $\mathbf{E}_L$ from $\mathbf{E}$ simplifies MCED to *Classical Electrodynamics* (CED). The MCED Jefimenko fields show a far field contradiction, that is not shown by the CED fields. CED is based on the Lorentz force and therefore violates N3LM as well.

Hence, we define a *General Classical Electrodynamics* (GCED) as a generalization of GMS and CED. GCED describes three types of far field waves: the longitudinal Φ-wave, the longitudinal electromagnetic (LEM) wave and the transverse electromagnetic (TEM) wave, with vacuum phase velocities respectively a, b and c. GCED power- and force theorems are derived. The general force theorem obeys N3LM only if the three phase velocities satisfy the *Coulomb premise*: $a \gg c \ \wedge \ b = c$. GCED with Coulomb premise is far field consistent, and resolves the classical $\frac{4}{3}$ energy-momentum problem of a moving charged sphere. GCED with the *Lorentz premise* ($a = c \ \wedge \ b = c$) reduces to the inconsistent MCED.

Many experimental results verify GCED with Coulomb premise, and falsify MCED. GCED can replace MCED as a new foundation of modern physics (relativity theory and wave mechanics). It might be the inspiration for new scientific experiments and electrical engineering, such as new wave-electronic effects based on Φ-waves and LEM waves, and the conversion of natural Φ-waves and LEM wave energy into useful electricity, in the footsteps of Nikola Tesla and Thomas Henry Moray.

1 Introduction

A generalization of *Maxwell's Classical Electrodynamics* (MCED) theory [26] is presented, called *General Classical Electrodynamics* (GCED), that is free of inconsistencies. For the development of this theory we make use of the fundamental theorem of vector algebra, also known as the Helmholtz decomposition theorem: a vector function $\mathbf{F}(\mathbf{x})$ can be decomposed into two unique vector functions $\mathbf{F}_l(\mathbf{x})$ and $\mathbf{F}_t(\mathbf{x})$, such that:

$$\mathbf{F}(\mathbf{x}) = \mathbf{F}_l(\mathbf{x}) + \mathbf{F}_t(\mathbf{x}) \tag{1.1}$$

$$\mathbf{F}_l(\mathbf{x}) = -\frac{1}{4\pi}\nabla \int\limits_{V'} \frac{\nabla' \cdot \mathbf{F}(\mathbf{x}')}{|\mathbf{x}-\mathbf{x}'|}\,\mathrm{d}^3x' \tag{1.2}$$

$$\mathbf{F}_t(\mathbf{x}) = \frac{1}{4\pi}\nabla \times \int\limits_{V'} \frac{\nabla' \times \mathbf{F}(\mathbf{x}')}{|\mathbf{x}-\mathbf{x}'|}\,\mathrm{d}^3x' \tag{1.3}$$

The lowercase subindexes 'l' and 't' will have the meaning of *longitudinal* and *transverse* in this paper. The longitudinal vector function $\mathbf{F}_l$ is curl free ($\nabla \times \mathbf{F}_l = \mathbf{0}$), and the transverse vector function $\mathbf{F}_t$ is divergence free ($\nabla \cdot \mathbf{F}_t = 0$). We assume that $\mathbf{F}$ is well behaved ($\mathbf{F}$ is zero if $|\mathbf{x}|$ is infinite). The proof of the Helmholtz decomposition is based on the three dimensional delta function $\delta(\mathbf{x})$ and the sifting property of this function, see the following identities:

$$\delta(\mathbf{x}) = \frac{-1}{4\pi}\Delta\left(\frac{1}{|\mathbf{x}|}\right) \tag{1.4}$$

$$\mathbf{F}(\mathbf{x}) = \int\limits_{V'} \mathbf{F}(\mathbf{x}')\,\delta(\mathbf{x}-\mathbf{x}')\,\mathrm{d}^3x' \tag{1.5}$$

Let us further introduce the following notations and definitions.

$\mathbf{x}, t = x, y, z, t$	Place and time coordinates
$\nabla = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$	Del operator (in Cartesian coordinates)
$\partial_t = \frac{\partial}{\partial t}$	Partial differential with respect to time
$\Delta = \nabla \cdot \nabla$	$\Delta\Phi = \nabla\cdot\nabla\Phi, \qquad \Delta\mathbf{A} = \nabla\nabla\cdot\mathbf{A} - \nabla\times\nabla\times\mathbf{A}$
ρ	Net electric charge density distribution
$\mathbf{J} = \mathbf{J}_l + \mathbf{J}_t$	Net electric current density distribution
Φ	Net electric charge (scalar) potential
$\mathbf{A} = \mathbf{A}_l + \mathbf{A}_t$	Net electric current (vector) potential
$\mathbf{E}_\Phi = -\nabla\Phi$	Primary electric field
$\mathbf{E}_L = -\frac{\partial \mathbf{A}_l}{\partial t}$	Field induced divergent electric field
$\mathbf{E}_T = -\frac{\partial \mathbf{A}_t}{\partial t}$	Field induced rotational electric field
$B_\Phi = -\frac{\partial \Phi}{\partial t}$	Field induced scalar field
$B_L = -\nabla\cdot\mathbf{A}_l$	Primary scalar magnetic field
$\mathbf{B}_T = \nabla\times\mathbf{A}_t$	Primary vector magnetic field
$\phi_0 \ll \epsilon_0^2\mu_0 \ Fs^2/m^3$	Polarizability of vacuum
$\mu_0 = 4\pi 10^{-7} \ H/m$	Permeability of vacuum
$\epsilon_0 = 8.854^{-12} \ F/m$	Permittivity of vacuum

The permittivity, permeability and polarizability of vacuum are constants. The charge- and current density distributions, the potentials and the fields, are functions of place and not always functions of time. Time independent functions are called *stationary* or *static* functions. Basically, there are three types of charge-current density distributions:

A. Current free charge	$\mathbf{J} = \mathbf{0}$	
B. Stationary currents	$\partial_t\mathbf{J} = \mathbf{0}$	
1. closed circuit (divergence free)	$\partial_t\mathbf{J} = \mathbf{0}$	$\wedge \ \nabla\cdot\mathbf{J} = \mathbf{0}$
2. open circuit	$\partial_t\mathbf{J} = \mathbf{0}$	$\wedge \ \nabla\cdot\mathbf{J} \neq \mathbf{0}$
C. Time dependent currents	$\partial_t\mathbf{J} \neq \mathbf{0}$	

The charge conservation law (also called 'charge continuity') is true for all types of charge-current density distributions:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{J} = 0 \tag{1.6}$$

The physics of current free ($\mathbf{J} = \mathbf{0}$) charge density distributions is called *Electrostatics* (ES): $\partial_t \rho = -\nabla \cdot \mathbf{0} = 0$. The physics of stationary current ($\partial_t \mathbf{J} = \mathbf{0}$) density distributions is called *General Magnetostatics* (GMS). A special case of GMS are *divergence free* current distributions ($\nabla \mathbf{J} = 0$), and this is widely called *Magnetostatics* (MS) in the scientific educational literature. In case of Magnetostatics, the charge density distribution has to be static as well: $\partial_t \rho = -\nabla \cdot \mathbf{J} = 0$, such that the electric field and the magnetic field are both static.

The Maxwell-Lorentz force law satisfies Newton's third law of motion (N3LM) in case of Electrostatics and Magnetostatics, however, this force law violates N3LM in case of General Magnetostatics. A violation of N3LM means that momentum is not conserved by GMS systems, for which there is no experimental evidence! This remarkable Classical Physics inconsistency is hardly mentioned in the scientific educational literature.

This is not the only problematic aspects of MCED. Jefimenko's electric field expression, derived from MCED theory, shows two longitudinal electric field terms that do not interact by induction with other fields, and nevertheless these two electric fields fall off in magnitude by distance, as far fields, which is inconsistent. A third inconsistency is the famous 4/3 problem of electric energy/momentum of a charged sphere. In the next sections we describe these related inconsistencies of MCED theory in more detail, and how to resolve them.

2 General Magnetostatics

Let $\mathbf{J}(\mathbf{x})$ be a stationary current distribution. The vector potential $\mathbf{A}(\mathbf{x})$ at place vector $\mathbf{x}$ is given by:

$$\begin{aligned} \mathbf{A}(\mathbf{x}) &= \frac{\mu_0}{4\pi} \int\limits_{V'} \frac{\mathbf{J}(\mathbf{x}')}{r} \, \mathrm{d}^3 x' \qquad (2.1) \\ \mathbf{r} &= \mathbf{x} - \mathbf{x}' \\ r &= |\mathbf{x} - \mathbf{x}'| \end{aligned}$$

Since $\partial_t \mathbf{A} = \mathbf{0}$ for stationary currents, the electric field equals $\mathbf{E} = \mathbf{E}_\Phi = -\nabla \Phi$, such that Gauss' law is given by

$$\nabla \cdot \mathbf{E}_\Phi(\mathbf{x}, t) = \frac{1}{\epsilon_0} \rho(\mathbf{x}, t) \tag{2.2}$$

The magnetostatic vector field $\mathbf{B}_T(\mathbf{x})$ is defined by Biot-Savart's law as follows:

$$
\begin{aligned}
\mathbf{B}_T(\mathbf{x}) &= \nabla\times\mathbf{A}_t(\mathbf{x}) \;=\; \nabla\times\mathbf{A}(\mathbf{x}) \\
&= -\frac{\mu_0}{4\pi}\int\limits_{V'} \mathbf{J}(\mathbf{x}')\times\nabla\left(\frac{1}{r}\right)\,\mathrm{d}^3x' \\
&= \frac{\mu_0}{4\pi}\int\limits_{V'} \frac{1}{r^3}\big[\mathbf{J}(\mathbf{x}')\times\mathbf{r}\big]\,\mathrm{d}^3x' \qquad (2.3)
\end{aligned}
$$

The magnetic field is indeed static, since the current density is stationary.

2.1 Magnetostatics

The magnetic force density, $\mathbf{f}_T(\mathbf{x})$, that acts transversely on current density $\mathbf{J}(\mathbf{x})$ at place $\mathbf{x}$, is given by:

$$
\begin{aligned}
\mathbf{f}_T(\mathbf{x}) &= \mathbf{J}(\mathbf{x})\times\mathbf{B}_T(\mathbf{x}) \\
&= \frac{\mu_0}{4\pi}\int\limits_{V'} \frac{1}{r^3}\mathbf{J}(\mathbf{x})\times\big[\mathbf{J}(\mathbf{x}')\times\mathbf{r}\big]\,\mathrm{d}^3x' \\
&= \frac{\mu_0}{4\pi}\int\limits_{V'} \frac{1}{r^3}\Big[\big[\mathbf{J}(\mathbf{x})\cdot\mathbf{r}\big]\mathbf{J}(\mathbf{x}') \;-\; \big[\mathbf{J}(\mathbf{x}')\cdot\mathbf{J}(\mathbf{x})\big]\mathbf{r}\Big]\,\mathrm{d}^3x' \\
&= \frac{\mu_0}{4\pi}\int\limits_{V'} \mathbf{f}_T(\mathbf{x},\mathbf{x}')\,\mathrm{d}^3x' \qquad (2.4)
\end{aligned}
$$

This is the Lorentz force density law for Magnetostatics; it is assumed that the electric force densities are neglibible. Notice that the integrand is non-reciprocal: $\mathbf{f}_T(\mathbf{x},\mathbf{x}') \neq -\mathbf{f}_T(\mathbf{x}',\mathbf{x})$, and that $\mathbf{r}$ changes into $-\mathbf{r}$ by swapping $\mathbf{x}$ and $\mathbf{x}'$. This means that the Lorentz force law agrees with N3LM, but only if one calculates the total force on *closed on-itself* current circuits (magnetostatics is usually defined for divergence free currents only), which is proven as follows. Consider two non-intersecting and closed current circuits C and C', that carry the stationary electric currents I and I', see for instance [38] pages 4-6. The currents I and I' are equal to the surface integral of the current density over a circuit line cross section of respectively circuits C and C'. The total force acting on circuit C is a double volume integral of the Lorentz force density. We assume that the currents in C and C' are *constant* for each circuit line cross section, therefore we replace the double volume integral by a double line integral over the circuits C and C', in order to determine the force, $\mathbf{F}_C$, acting on C:

$$
\begin{aligned}
\mathbf{F}_C &= -\frac{\mu_0 II'}{4\pi}\oint\limits_C\oint\limits_{C'} d\mathbf{l}\times(d\mathbf{l}'\times\nabla\left[\frac{1}{r}\right]) \\
&= -\frac{\mu_0 II'}{4\pi}\oint\limits_{C'}\oint\limits_{C}(d\mathbf{l}\cdot\nabla\left[\frac{1}{r}\right])d\mathbf{l}' \;+\; \frac{\mu_0 II'}{4\pi}\oint\limits_C\oint\limits_{C'}(d\mathbf{l}\cdot d\mathbf{l}')\nabla\left[\frac{1}{r}\right] \\
&= \frac{\mu_0 II'}{4\pi}\oint\limits_C\oint\limits_{C'}(d\mathbf{l}\cdot d\mathbf{l}')\nabla\left[\frac{1}{r}\right] \qquad (2.5)
\end{aligned}
$$

This is Grassmann's force law [8] for closed current circuits. Since the curl of a gradient is zero, the first integral (see expression 2.5 after derivation step 1) disappears. The final integral after derivation step 2 has a reciprocal integrand, such that the force acting on circuit C' is the exact opposite of the force acting on circuit C ($\mathbf{F}_C = -\mathbf{F}_{C'}$), in agreement with N3LM. Fubini's theorem is applicable in derivation step 1 (switching the integration order in the first integral), since it is assumed the circuits C and C' do not intersect.

The standard literature on Classical Electrodynamics usually defines Magnetostatics as the physics of stationary and *divergence free* (closed circuits) electric currents. For example, Richard Feynman defines Magnetostatics via Ampère's law ($\nabla\times\mathbf{B} = \mu\mathbf{J}$) such that Magnetostatic current is divergence free and the electric field is static as well, and such that charge density is constant in time: $\nabla\cdot\mathbf{J} = 0 = \partial_t\rho$, see [11] after eq. 13.13. Feynman further suggests that the circuits 'may' contain batteries or generators that keep the charges flowing. Sure, Feynman must have been joking [12]: "a battery delivers electric current and its charge density does not change in time" (a perpetuum mobile). Faraday's homopolar disk generator generates stationary currents, so a 'stationary closed current loop' can be induced with such a generator. One has to measure the force on the entire closed circuit that includes the generator as well, while the generator is externally driven with constant speed. Such a magnetostatic force experiment has yet to be done, so Feynman's generator suggestion was just another joke. John D. Jackson's third edition of Classical Electrodynamics postulates without proof that $\nabla\cdot\mathbf{J} = 0 = \partial_t\rho$ (charge density is time-independent anywhere in space, see [22], equation 5.3) before Jackson treats the laws of magnetostatics. David J. Griffiths' treatment of magnetostatics [16] is likewise: "stationary electric currents are such that the density of charge is constant anywhere", which is equivalent with stationary currents that are divergence free. It is the same old story with Alexander Altland's publication on Classical Electrodynamics [3]: 'statics' is defined as 'static electric fields and static magnetic fields', and again this implies that $\nabla\cdot\mathbf{J} = 0 = \partial_t\rho$. The list goes on.

It is not at all straightforward to find practical examples of a measured force exerted on a perfectly closed-on-itself *stationary* current circuit. The Meisner effect is such an example: a free falling permanent magnet approaches a superconductor, which induces a closed-circuit current in the superconductor. The magnet falls until the induced currents and magnetic field of the superconductor perfectly opposes the field of the magnet, which causes the magnet to levitate, and from that moment on the superconductor current is stationary and divergence free. Electrically charged rotating objects also represent closed-circuit currents, however, it seems impractical to measure forces on such objects while keeping the rotation speed constant during the measurements. The measurement of forces exerted on several coil windings gives the impression of perfectly closed current loops, however, this is only by approximation true.

Many stationary current experiments have been conducted to measure the force on a circuit that is *not* closed-on-itself. One can perform such experiments by applying two sliding contacts in order to enable a rotation- or translation motion of a circuit part that is non-closed, such that a force can be measured on just this movable circuit part. Faraday's homopolar disk motor is an example of this principle. Stefan Marinov's Siberian Coliu motor [25] is another example of a two sliding contacts motor, driven by a stationary current. Another type of non-closed current circuits make use of light weight movable batteries, such that sliding contacts can be avoided. This shows that the condition $\nabla\cdot\mathbf{J} = 0 = \partial_t\rho$, as well as the conditions $\nabla\times\mathbf{B} = \mu\mathbf{J}$ and $\partial_t\mathbf{E} = \mathbf{0}$, are artificial and superfluous for exploring the physics of stationary currents.

The most likely reason for reducing GMS to MS with the unnatural condition of divergence free currents, is to obscure mathematically the violation of N3LM by Grassmann's force law and by the Maxwell-Lorentz force density law. MCED has to be replaced by a theory that is consistent with Classical Mechanics, starting with a consistent GMS theory.

2.2 A consistent General Magnetostatics

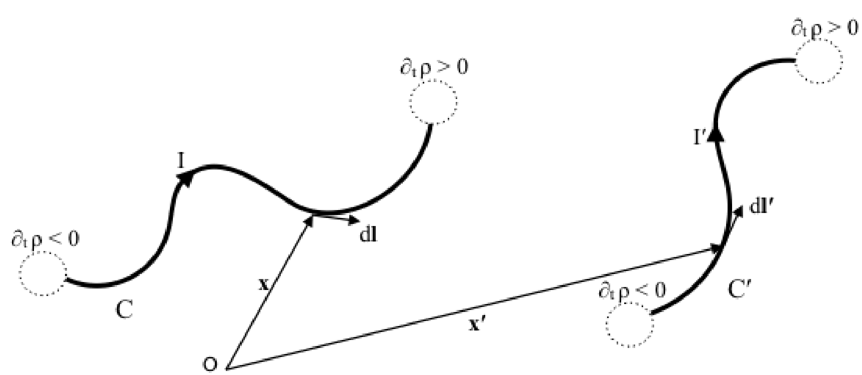

Figure 1: Open stationary current circuits

We continue first with the derivation of a consistent GMS theory that includes open circuit stationary current distributions, see Figure 1. From the continuity of charge it follows that $\mathbf{J}_l = -\epsilon_0\partial_t(\mathbf{E}_\Phi)$, hence the generalized Ampère law for GMS becomes:

$$\nabla\times\mathbf{B}_T - \frac{1}{c^2}\frac{\partial \mathbf{E}_\Phi}{\partial t} \;=\; \mu_0\mathbf{J} \tag{2.6}$$

The first suggestion, in order to fix Grassmann's force law, is simple: just drop the first integral in eq. 2.5 after derivation step 1, such that the resulting force law agrees with N3LM for open circuits. However, this force law cannot be generalized to a *field force density* law, and if we drop the concept of the magnetic field, we also do away with the successful electromagnetic free field theory. An analysis of Ampère's original force law by E. T. Whittaker [44] (p.91), resulted in the following Whittaker force law,

$$\mathbf{F}_C \;=\; \frac{\mu_0 I I'}{4\pi}\int\limits_C\int\limits_{C'}\frac{1}{r^3}\left[(d\mathbf{l}'\cdot\mathbf{r})d\mathbf{l} \;+\; (d\mathbf{l}\cdot\mathbf{r})d\mathbf{l}' \;-\; (d\mathbf{l}\cdot d\mathbf{l}')\mathbf{r})\right] \tag{2.7}$$

which is Grassmann's force law with an extra term. Both force laws predict the same force acting on closed on-itself circuits, since the line integral of the extra term over a closed circuit disappears as well. In general Whittaker's force law is reciprocal ($\mathbf{F}_C = -\mathbf{F}_{C'}$), also for non-closed circuits, and obeys N3LM. By means of the following functions, defined as follows,

$$\begin{aligned}
B_L(\mathbf{x}) &= -\nabla\cdot\mathbf{A}_l(\mathbf{x}) \;=\; -\,\nabla\cdot\mathbf{A}(\mathbf{x}) \\
&= -\frac{\mu_0}{4\pi}\int\limits_{V'}\mathbf{J}(\mathbf{x}')\cdot\nabla\left(\frac{1}{r}\right)\,\mathrm{d}^3x' \\
&= \frac{\mu_0}{4\pi}\int\limits_{V'}\frac{1}{r^3}\big[\mathbf{J}(\mathbf{x}')\cdot\mathbf{r}\big]\,\mathrm{d}^3x' &(2.8)\\
\mathbf{f}_L(\mathbf{x}) &= \mathbf{J}(\mathbf{x})B_L(\mathbf{x}) &(2.9)
\end{aligned}$$

we generalize Whittaker's force law as a double volume integral of field force densities, see [41](eq. 13), and [36]:

$$\begin{aligned}
&\int\limits_V\left[\mathbf{f}_L(\mathbf{x}) \;+\; \mathbf{f}_T(\mathbf{x})\right]\mathrm{d}^3x \;=\; \int\limits_V\left[\mathbf{J}(\mathbf{x})B_L(\mathbf{x}) \;+\; \mathbf{J}(\mathbf{x})\times\mathbf{B}_T(\mathbf{x})\right]\mathrm{d}^3x \;=\\
&\frac{\mu_0}{4\pi}\int\limits_V\int\limits_{V'}\frac{1}{r^3}\Big[\big[\mathbf{J}(\mathbf{x}')\cdot\mathbf{r}\big]\mathbf{J}(\mathbf{x}) \;+\big[\mathbf{J}(\mathbf{x})\cdot\mathbf{r}\big]\mathbf{J}(\mathbf{x}') \;-\big[\mathbf{J}(\mathbf{x}')\cdot\mathbf{J}(\mathbf{x})\big]\mathbf{r}\Big]\,\mathrm{d}^3x'\,\mathrm{d}^3x
\end{aligned} \tag{2.10}$$

This double volume integral of force densities satisfies N3LM for stationary current densities in general, since the integrand is reciprocal. The additional force density, $\mathbf{f}_L$, is called the *longitudinal Ampère force density*, which balances the transverse Ampère force density, $\mathbf{f}_T$, such that the total Ampère force density $\mathbf{f}(\mathbf{x}) = \mathbf{f}_L(\mathbf{x}) + \mathbf{f}_T(\mathbf{x})$ satisfies $\mathbf{f}(\mathbf{x}) = -\mathbf{f}(\mathbf{x}')$, see figure 2.

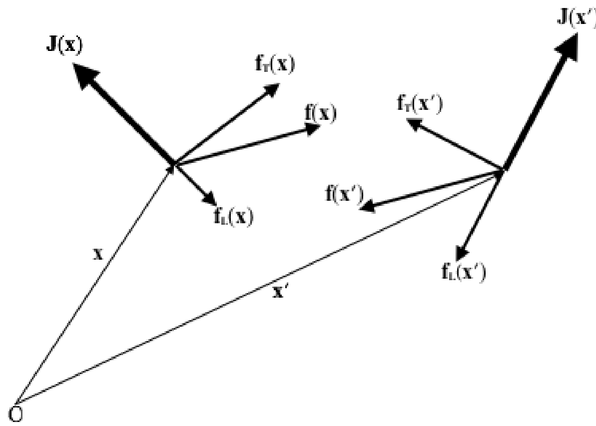

Figure 2: Total Ampère force density

It is obvious that the scalar function B_L is a *physical field* that mediates an observable Ampère force, just like the vector magnetic field $\mathbf{B}_T$, and therefore it is called the *scalar magnetic field* [29]. By means of the identities 1.4 and 1.5 and the definitions 2.3 and 2.8, we derive the following equations:

$$\nabla B_L(\mathbf{x}) + \nabla\times\mathbf{B}_T(\mathbf{x}) = -\Delta\mathbf{A}(\mathbf{x}) = \mu_0\mathbf{J}(\mathbf{x}) \quad (2.11)$$

$$\nabla B_L(\mathbf{x}) = -\nabla\nabla\cdot\mathbf{A}_l(\mathbf{x}) = \mu_0\mathbf{J}_l(\mathbf{x}) \quad (2.12)$$

$$\nabla\times\mathbf{B}_T(\mathbf{x}) = \nabla\times\nabla\times\mathbf{A}_t(\mathbf{x}) = \mu_0\mathbf{J}_t(\mathbf{x}) \quad (2.13)$$

The following GMS condition follows from eq. 2.6, 2.11 and 3.1, and is known as the Lorenz condition [24]:

$$\nabla(\ B_L + \epsilon_0\mu_0 B_\Phi\ ) = 0 \quad (2.14)$$

This GMS condition is not a free to choose "gauge" condition. If the scalar function B_L has the meaning of a physical field, then Lorenz's condition shows that the scalar function B_Φ also has the meaning of a physical field. So far we have shown a consistent GMS theory in agreement with classical mechanics.

3 General Classical Electrodynamics

We continue to develop the theory of *General Classical Electrodynamics* for the general situation of time dependent currents, taking into account the physical scalar fields B_L, B_Φ and the near field equations 2.2, 2.12 and 2.13.

3.1 Generalized secondary field induction

The field induction equations, describing the general induction of *secondary* fields by *primary time dependent* fields, follow directly from the field definitions and the fact that the operators ∇, $\nabla\cdot$ and $\nabla\times$ commute with ∂_t:

$$\nabla B_\Phi - \frac{\partial \mathbf{E}_\Phi}{\partial t} = -\nabla\frac{\partial \Phi}{\partial t} + \frac{\partial(\nabla\Phi)}{\partial t} = \mathbf{0} \tag{3.1}$$

$$\nabla\cdot\mathbf{E}_L - \frac{\partial B_L}{\partial t} = -\nabla\cdot\frac{\partial \mathbf{A}_l}{\partial t} + \frac{\partial(\nabla\cdot\mathbf{A}_l)}{\partial t} = 0 \tag{3.2}$$

$$\nabla\times\mathbf{E}_T + \frac{\partial \mathbf{B}_T}{\partial t} = -\nabla\times\frac{\partial \mathbf{A}_t}{\partial t} + \frac{\partial(\nabla\times\mathbf{A}_t)}{\partial t} = \mathbf{0} \tag{3.3}$$

This is the generalization of Faraday's law of induction [10]. A divergent electric field $\mathbf{E}_L$ is induced by a time varying scalar magnetic field B_L, see eq. 3.2. The induction of $\mathbf{E}_L$ is similar to the Faraday induction of electric field $\mathbf{E}_T$ (see eq. 3.3), and will be called *Nikolaev's electromagnetic induction*, after G.V. Nikolaev [29] who described this type of induction for the first time. Electric fields are sourced by static charges, or induced by time varying vector- and scalar magnetic fields. According to the superposition principle, a superimposed electric field is defined as $\mathbf{E} = \mathbf{E}_\Phi + \mathbf{E}_L + \mathbf{E}_T = -\nabla\Phi - \partial_t\mathbf{A}$. Notice that $\mathbf{E}_l = \mathbf{E}_\Phi + \mathbf{E}_L$ and that $\mathbf{E}_t = \mathbf{E}_T$.

3.2 A simplification of Maxwell's CED

Maxwell's famous treatise on electricity and magnetism does not define the fields B_L and B_Φ, nor does it define Nikolaev's induction of the curl-free electric field $\mathbf{E}_L$ (see eq. 3.2). Nevertheless Maxwell defined the superimposed electric field as follows: $\mathbf{E} = \mathbf{E}_\Phi + \mathbf{E}_L + \mathbf{E}_T$. This is a mistake: if the field B_L is excluded from the theory, then the electric field $\mathbf{E}_L$ should be excluded from the theory as well. The superimposed electric field can be defined only as $\mathbf{E} = \mathbf{E}_\Phi + \mathbf{E}_T$, *within the context of a theory that does not treat scalar fields.* Only this superimposed electric field is well understood by the experiments known in Maxwell's time. Disregarding the field $\mathbf{E}_L$ reduces the complexity of MCED considerably, and fixes the indeterminacy (gauge freedom) of MCED, since the electric field $\mathbf{E}_\Phi + \mathbf{E}_T$ is not invariant with respect to the "gauge" transform [1]:

$$\mathbf{E}_\Phi + \mathbf{E}_T = \mathbf{E} \tag{3.4}$$

$$\nabla\cdot\mathbf{E} = \nabla\cdot\mathbf{E}_\Phi = \frac{1}{\epsilon_0}\rho \tag{3.5}$$

$$\nabla\times\mathbf{E} = \nabla\times\mathbf{E}_T = -\frac{\partial \mathbf{B}_T}{\partial t} \tag{3.6}$$

$$\nabla\times\mathbf{B}_T - \epsilon_0\mu_0\frac{\partial(\mathbf{E}_\Phi + \mathbf{E}_T)}{\partial t} = \mu_0\mathbf{J} \tag{3.7}$$

Completed with the Lorentz force law, these field equations are simply called *Classical Electrodynamics* (CED). From the charge continuity law follows the next 'displacement current' equation:

$$-\epsilon_0 \frac{\partial \mathbf{E}_\Phi}{\partial t} = \mathbf{J}_l \tag{3.8}$$

Substraction of eq. 3.8 from eq. 3.7 gives the following equation.

$$\nabla \times \mathbf{B}_T - \epsilon_0 \mu_0 \frac{\partial \mathbf{E}_T}{\partial t} = \mu_0 \mathbf{J}_t \tag{3.9}$$

The presence of Maxwell's displacement current term $\epsilon_0\, \partial_t \mathbf{E}_T$ in eq. 3.7 and 3.9 does not follow from the charge continuity law, because its divergence is zero. The addition of this *speculative* term ($\epsilon_0\, \partial_t \mathbf{E}_T$) to the Ampère law gives the Maxwell-Ampère law (eq. 3.7), which allows for derivation of the wave equations for the transverse electromagnetic (TEM) wave. H. Hertz famously proved the existence of the TEM wave by experiment [17], and this alone justified Maxwell's speculation. Rewriting eq. 3.5 and eq. 3.9 in terms of the potentials gives:

$$-\Delta \Phi = \frac{1}{\epsilon_0} \rho \tag{3.10}$$

$$\epsilon_0 \mu_0 \frac{\partial^2 \mathbf{A}_t}{\partial t^2} + \nabla \times \nabla \times \mathbf{A}_t = \mu_0 \mathbf{J}_t \tag{3.11}$$

CED does not require "gauge" conditions in order to find decoupled inhomogeneous differential equations for the potentials. Within the context of MCED, the indeterminacy (gauge freedom) of the potentials is the direct consequence of Maxwell's illogical addition of the electric field $\mathbf{E}_L$ to the superimposed electric field. These potential equations have the following solutions.

$$\Phi(\mathbf{x}, t) = \frac{1}{4\pi\epsilon_0} \int\limits_{V'} \frac{\rho(\mathbf{x}', t)}{r} \, \mathrm{d}^3 x' \tag{3.12}$$

$$\mathbf{A}_t(\mathbf{x}, t) = \frac{\mu_0}{4\pi} \int\limits_{V'} \frac{\mathbf{J}_t(\mathbf{x}', t_c)}{r} \, \mathrm{d}^3 x' \tag{3.13}$$

$$r = |\mathbf{x} - \mathbf{x}'| \qquad c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$t_c = t - \frac{r}{c} \tag{3.14}$$

The net charge potential Φ is instantaneous at a distance, while the net current potential $\mathbf{A}_t$ is retarded with time interval r/c, relative to current potential sources at a distance r. The following expressions are Jefimenko's field solutions, derived from the retarded potentials of MCED in the Lorenz gauge:

$$\mathbf{B}_T(\mathbf{x},t) = \frac{\mu_0}{4\pi}\int_{V'}\left[\frac{\mathbf{J}_t(\mathbf{x}',t_c)\times\mathbf{r}}{r^3}+\frac{\dot{\mathbf{J}}_t(\mathbf{x}',t_c)\times\mathbf{r}}{cr^2}\right]\mathrm{d}^3x' \tag{3.15}$$

$$\mathbf{E}(\mathbf{x},t) = \frac{1}{4\pi\epsilon_0}\int_{V'}\left[\frac{\rho(\mathbf{x}',t_c)\mathbf{r}}{r^3}+\frac{\dot{\rho}(\mathbf{x}',t_c)\mathbf{r}}{cr^2}-\frac{\dot{\mathbf{J}}_l(\mathbf{x}',t_c)}{c^2r}-\frac{\dot{\mathbf{J}}_t(\mathbf{x}',t_c)}{c^2r}\right]\mathrm{d}^3x' \tag{3.16}$$

The Jefimenko field expressions do not depend on the choice for gauge condition [21]. Notice that Jefimenko's magnetic field depends only on the divergence free current density, $\mathbf{J}_t$. The second term and third term of the integrand of eq. 3.16 are longitudinal electric far fields that fall off in magnitude by r. These two far field terms represent an inconsistency, since far fields are defined as two fields that induce each other in turn, and MCED does not describe the two other far fields that mutually induce these longitudinal electric far fields. This is the *far field inconsistency* of MCED. The two missing far fields are B_Φ and B_L. We derive similar CED field functions from the potential functions 3.12 and 3.13, and definition 3.4:

$$\mathbf{B}_T(\mathbf{x},t) = \frac{\mu_0}{4\pi}\int_{V'}\left[\frac{\mathbf{J}_t(\mathbf{x}',t_c)\times\mathbf{r}}{r^3}+\frac{\dot{\mathbf{J}}_t(\mathbf{x}',t_c)\times\mathbf{r}}{cr^2}\right]\mathrm{d}^3x' \tag{3.17}$$

$$\mathbf{E}(\mathbf{x},t) = \frac{1}{4\pi\epsilon_0}\int_{V'}\left[\frac{\rho(\mathbf{x}',t)\mathbf{r}}{r^3}-\frac{\dot{\mathbf{J}}_t(\mathbf{x}',t_c)}{c^2r}\right]\mathrm{d}^3x' \tag{3.18}$$

The second term in equations 3.18 and 3.17 are the far fields of the transverse electromagnetic wave. Since these two fields induce each other and fall off by r, CED is manifestly far field consistent.

N3LM describes the motion of bodies that have mass; this law does not take into account the momentum of massless electromagnetic radiation. N3LM can be replaced by the more general principle of momentum conservation of the summation of mass- and massless radiation momentum. However, MCED violates this principle as well: *circuits of stationary currents do not send or receive free electromagnetic radiation*, and it was already shown that the Grassmann forces acting on non-closed circuits of stationary currents violate N3LM. The presented CED theory is also inconsistent with classical mechanics, in case $\mathbf{J}_l \neq \mathbf{0}$, since it is based on the Lorentz force law.

If $\mathbf{J}_l = \mathbf{0}$ then CED is a consistent theory, as a special case of a more general consistent theory. If $\mathbf{J}_l = \mathbf{0}$ then also the second and third term in the integrand of eq. 3.16 disappear, however, MCED still differs from CED: the first integrand term of eq. 3.16 is retarded, while the first integrand term of eq. 3.18 is instantaneous.

3.3 Generalized 'displacements' and wave types

In order to complete GCED, we combine the consistent GMS theory and CED theory. Since GCED also treats the interaction of the source $\mathbf{J}_l$ and the fields B_L, B_Φ, $\mathbf{E}_L$, it is necessary to define the superimposed electric field as $\mathbf{E} = \mathbf{E}_\Phi + \mathbf{E}_L + \mathbf{E}_T$. We already generalized Faraday's field induction law in §3.1. Next, we generalize Maxwell's speculative addition of the displacement current term (see eq. 3.9), as follows.

$$\nabla\cdot\mathbf{E}_\Phi - \frac{\phi_0}{\epsilon_0}\frac{\partial B_\Phi}{\partial t} = \frac{\phi_0}{\epsilon_0}\frac{\partial^2\Phi}{\partial t^2} - \nabla\cdot\nabla\Phi = \frac{1}{\epsilon_0}\rho \quad (3.19)$$

$$\nabla B_L - \lambda_0\mu_0\frac{\partial\mathbf{E}_L}{\partial t} = \lambda_0\mu_0\frac{\partial^2\mathbf{A}_l}{\partial t^2} - \nabla\nabla\cdot\mathbf{A}_l = \mu_0\mathbf{J}_l \quad (3.20)$$

$$\nabla\times\mathbf{B}_T - \epsilon_0\mu_0\frac{\partial\mathbf{E}_T}{\partial t} = \epsilon_0\mu_0\frac{\partial^2\mathbf{A}_t}{\partial t^2} + \nabla\times\nabla\times\mathbf{A}_t = \mu_0\mathbf{J}_t \quad (3.21)$$

A displacement charge, $\phi_0\ \partial_t B_\Phi$, and a second displacement current, $\lambda_0\ \partial_t\mathbf{E}_L$, are added as well. The extra theoretical predictions by GCED are testable, as before Maxwell's TEM wave prediction was tested by Hertz. The constant, ϕ_0, is called the *polarizability* of vacuum. In case of a stationary current potential ($\partial_t\mathbf{A} = \mathbf{0}$), the GCED equations 3.20 and 3.21 reduce to the GMS equations 2.12 and 2.13, such that GCED will obey N3LM for open circuit stationary current distributions by deducing the correct force theorem later on. The following inhomogeneous field wave equations can be derived from eq. 3.1, 3.2, 3.3 and 3.19, 3.20, 3.21.

$$\frac{\phi_0}{\epsilon_0}\frac{\partial^2\mathbf{E}_\Phi}{\partial t^2} - \nabla\nabla\cdot\mathbf{E}_\Phi = -\frac{1}{\epsilon_0}\nabla\rho \quad (3.22)$$

$$\frac{\phi_0}{\epsilon_0}\frac{\partial^2 B_\Phi}{\partial t^2} - \nabla\cdot\nabla B_\Phi = -\frac{1}{\epsilon_0}\frac{\partial\rho}{\partial t} \quad (3.23)$$

$$\lambda_0\mu_0\frac{\partial^2\mathbf{E}_L}{\partial t^2} - \nabla\nabla\cdot\mathbf{E}_L = -\mu_0\frac{\partial\mathbf{J}_l}{\partial t} \quad (3.24)$$

$$\lambda_0\mu_0\frac{\partial^2 B_L}{\partial t^2} - \nabla\cdot\nabla B_L = -\mu_0\nabla\cdot\mathbf{J}_l \quad (3.25)$$

$$\epsilon_0\mu_0\frac{\partial^2\mathbf{E}_T}{\partial t^2} + \nabla\times\nabla\times\mathbf{E}_T = -\mu_0\frac{\partial\mathbf{J}_t}{\partial t} \quad (3.26)$$

$$\epsilon_0\mu_0\frac{\partial^2\mathbf{B}_T}{\partial t^2} + \nabla\times\nabla\times\mathbf{B}_T = \mu_0\nabla\times\mathbf{J}_t \quad (3.27)$$

These wave equations describe the Transverse Electromagnetic (TEM) wave and two types of longitudinal electric waves. One type of longitudinal electric wave is expressed only in terms of the electric charge potential Φ, so it is not induced by electric currents, see eq. 3.22 and 3.23. It will be called a Φ-*wave*. The second type of longitudinal electric wave is associated with the curl free electric current potential, see eq. 3.24 and 3.25, and it will be called a *Longitudinal Electromagnetic* (LEM) wave. The following notations for the phase velocities of these wave types is used.

$$a = \sqrt{\frac{\epsilon_0}{\phi_0}}, \qquad b = \sqrt{\frac{1}{\lambda_0\mu_0}}, \qquad c = \sqrt{\frac{1}{\epsilon_0\mu_0}} \tag{3.28}$$

Initially we assume that the values of these phase velocities are independent constants, hence the introduction of the new constants λ_0 and ϕ_0.

3.4 Generalized power- and force theorems

Three power- and force laws can be derived that are associated with the Φ-wave, the LEM wave and the TEM wave. The power- and force law for the Φ-wave fields B_Φ and $\mathbf{E}_\Phi$ are derived from eq. 3.1 and 4.1:

$$\rho B_\Phi = -\frac{\phi_0}{2}\frac{\partial B_\Phi^2}{\partial t} - \frac{\epsilon_0}{2}\frac{\partial E_\Phi^2}{\partial t} + \epsilon_0\nabla\cdot(B_\Phi\mathbf{E}_\Phi) \tag{3.29}$$

$$\rho\mathbf{E}_\Phi = \phi_0(\nabla B_\Phi)B_\Phi + \epsilon_0(\nabla\cdot\mathbf{E}_\Phi)\mathbf{E}_\Phi - \phi_0\frac{\partial(B_\Phi\mathbf{E}_\Phi)}{\partial t} \tag{3.30}$$

The power- and force law for the LEM wave fields B_L and $\mathbf{E}_L$ are derived from eq. 3.2 and 4.2:

$$\mathbf{E}_L\cdot\mathbf{J}_l = -\frac{1}{2\mu_0}\frac{\partial B_L^2}{\partial t} - \frac{\lambda_0}{2}\frac{\partial E_L^2}{\partial t} + \frac{1}{\mu_0}\nabla\cdot(B_L\mathbf{E}_L) \tag{3.31}$$

$$B_L\mathbf{J}_l = \frac{1}{\mu_0}(\nabla B_L)B_L + \lambda_0(\nabla\cdot\mathbf{E}_L)\mathbf{E}_L - \lambda_0\frac{\partial(B_L\mathbf{E}_L)}{\partial t} \tag{3.32}$$

The power- and force law for the TEM wave fields $\mathbf{B}_T$ and $\mathbf{E}_T$ are derived from eq. 3.3 and 4.3:

$$\mathbf{E}_T\cdot\mathbf{J}_t = -\frac{1}{2\mu_0}\frac{\partial B_T^2}{\partial t} - \frac{\epsilon_0}{2}\frac{\partial E_T^2}{\partial t} + \frac{1}{\mu_0}\nabla\cdot(\mathbf{B}_T\times\mathbf{E}_T) \tag{3.33}$$

$$\mathbf{B}_T\times\mathbf{J}_t = \frac{1}{\mu_0}\mathbf{B}_T\times\nabla\times\mathbf{B}_T + \epsilon_0\mathbf{E}_T\times\nabla\times\mathbf{E}_T - \epsilon_0\frac{\partial(\mathbf{B}_T\times\mathbf{E}_T)}{\partial t} \tag{3.34}$$

Similar energy flux vectors as Poynting's vector for the TEM wave, $-\mathbf{B}_T\times\mathbf{E}_T$, can be defined for the Φ-wave: $B_\Phi\mathbf{E}_\Phi$ (see the last term in eq. 3.29 and in eq. 3.30), and for the LEM wave: $B_L\mathbf{E}_L$ (see the last term in eq. 3.31 and in eq. 3.32). For very small values of ϕ_0, the Φ-wave contribution to *momentum change* becomes very small as well, and yet the Φ-wave contribution to *power flux* might be substantial!

Notice that the fields in these power- and force theorems are not superimposed fields. The most general power- and force theorems should be expressed in terms of superimposed fields, and these are defined as follows:

$$\mathbf{E} = \mathbf{E}_\Phi + \mathbf{E}_L + \mathbf{E}_T \tag{3.35}$$
$$\mathbf{E}^* = \frac{1}{c^2}\mathbf{E}_\Phi + \frac{1}{b^2}\mathbf{E}_L + \frac{1}{c^2}\mathbf{E}_T \tag{3.36}$$
$$B = \frac{1}{c^2}B_\Phi + B_L \tag{3.37}$$
$$B^* = \frac{1}{a^2}B_\Phi + B_L \tag{3.38}$$

The field equations 3.19, 3.20, 3.21 are rewritten in terms of these fields.

$$\nabla\cdot\mathbf{E} - \frac{\partial B^*}{\partial t} = \frac{1}{\epsilon_0}\rho \tag{3.39}$$
$$\nabla B + \nabla\times\mathbf{B}_T - \frac{\partial \mathbf{E}^*}{\partial t} = \mu_0\mathbf{J} \tag{3.40}$$

General power- and force theorems follow from eq. 3.39 and 3.40:

$$\begin{aligned}\mathbf{E}\cdot\mathbf{J} + c^2B\rho &= -\frac{1}{\mu_0}[\mathbf{E}\cdot\frac{\partial \mathbf{E}^*}{\partial t} + \mathbf{B}_T\cdot\frac{\partial \mathbf{B}_T}{\partial t} + B\frac{\partial B^*}{\partial t}] \\ &\quad -\frac{1}{\mu_0}\nabla(\mathbf{E}\times\mathbf{B}_T - \mathbf{E}B)\end{aligned} \tag{3.41}$$

$$\begin{aligned}\rho\mathbf{E} + \mathbf{J}\times\mathbf{B}_T + (\frac{\epsilon_0}{\lambda_0}\mathbf{J}_l + \mathbf{J}_t)B^* &= \epsilon_0(\nabla\cdot\mathbf{E})\mathbf{E} + \frac{1}{\mu_0}(\nabla\times\mathbf{E})\times\mathbf{E}^* \\ &\quad + \frac{1}{\mu_0}(\nabla B + \nabla\times\mathbf{B}_T)\times\mathbf{B}_T \\ &\quad +(\epsilon_0\nabla B_\Phi + \frac{\epsilon_0}{\lambda_0\mu_0}\nabla B_L + \frac{1}{\mu_0}\nabla\times\mathbf{B}_T)B^* \\ &\quad -\epsilon_0\frac{\partial(\mathbf{E}B^*)}{\partial t} - \frac{1}{\mu_0}\frac{\partial(\mathbf{E}^*\times\mathbf{B}_T)}{\partial t}\end{aligned} \tag{3.42}$$

In eq. 3.42, the expression $(\frac{\epsilon_0}{\lambda_0}\mathbf{J}_l + \mathbf{J}_t)$ has to equal $\mathbf{J}$ in order to deduce the force law of eq. 2.10 that satisfies N3LM. Therefore, the following condition is generally true: $\lambda_0 = \epsilon_0$ $(b = c)$. Applying this condition, the general power- and force theorems become (if $b = c$ then $\mathbf{E}^* = \frac{1}{c^2}\mathbf{E}$):

$$
\begin{aligned}
\mathbf{E}\cdot\mathbf{J} + c^2 B\rho &= -\frac{\epsilon_0}{2}\frac{\partial E^2}{\partial t} - \frac{1}{2\mu_0}\frac{\partial {B_T}^2}{\partial t} - \frac{B}{\mu_0}\frac{\partial B^*}{\partial t} \\
&\quad -\frac{1}{\mu_0}\nabla(\mathbf{E}\times\mathbf{B}_T - \mathbf{E}B) \qquad (3.43)\\
\rho\mathbf{E} + \mathbf{J}\times\mathbf{B}_T + \mathbf{J}B^* &= \epsilon_0((\nabla\cdot\mathbf{E})\mathbf{E} + (\nabla\times\mathbf{E})\times\mathbf{E}) \\
&\quad + \frac{1}{\mu_0}(\nabla B + \nabla\times\mathbf{B}_T)\times\mathbf{B}_T \\
&\quad + \frac{1}{\mu_0}(\nabla B + \nabla\times\mathbf{B}_T)B^* \\
&\quad - \epsilon_0\frac{\partial(\mathbf{E}B^* + \mathbf{E}\times\mathbf{B}_T)}{\partial t} \qquad (3.44)
\end{aligned}
$$

If the value of the Φ-wave phase velocity 'a' is very high, then $B^* = B_L$ by approximation (see def. 3.38), such that Whittaker's reciprocal force law follows directly from force theorem 3.44. Should $a = c$ be true, or for instance $a \gg c$? From the law of charge continuity and the two scalar field wave equations (see eq. 3.23 and 3.25, and apply $\lambda_0 = \epsilon_0$), the following equation is derived:

$$
\frac{1}{c^2}\frac{\partial^2 B^*}{\partial t^2} - \nabla\cdot\nabla B = 0 \qquad (3.45)
$$

For stationary current distributions the scalar fields are independent of time, such that eq. 3.45 reduces to eq. 2.14, and such that $B = 0$ (the Lorenz condition). Plugging the Lorenz condition in the definition of B^*, we derive that $B^* = (1 - c^2/a^2)B_L$, and consequently the scalar field force density (see force theorem 3.44) equals $\mathbf{J}B^* = \mathbf{J}(1 - c^2/a^2)B_L$. Since a scalar magnetic field force density is required that is equal to $\mathbf{J}B_L$, in order to satisfy N3LM, we conclude that $a \gg c$ is *generally true*. This is the crux of GCED theory. For stationary currents, the GCED power- and force theorems reduce to:

$$
\begin{aligned}
\mathbf{E}_\Phi\cdot\mathbf{J} &= -\frac{\epsilon_0}{2}\frac{\partial E_\Phi^2}{\partial t} - \frac{1}{\mu_0}\nabla(\mathbf{E}_\Phi\times\mathbf{B}_T) \qquad (3.46)\\
\rho\mathbf{E}_\Phi + \mathbf{J}\times\mathbf{B}_T + \mathbf{J}B^* &= \epsilon_0(\nabla\cdot\mathbf{E}_\Phi)\mathbf{E}_\Phi + \frac{1}{\mu_0}((\nabla\times\mathbf{B}_T)\times\mathbf{B}_T + (\nabla\times\mathbf{B}_T)B^*) \\
&\quad - \epsilon_0\left(\frac{\partial\mathbf{E}_\Phi}{\partial t}B^* + \frac{\partial\mathbf{E}_\Phi}{\partial t}\times\mathbf{B}_T\right) \qquad (3.47)
\end{aligned}
$$

This shows that the energy flow carried by a stationary current (for example, from a battery to an energy dissipating resistor [14]) only depends on the 'static' electric field and the vector magnetic field ($\mathbf{E}_\Phi\times\mathbf{B}_T$), where stationary current forces depend also on the scalar magnetic field.

3.5 The Coulomb premise versus the Lorentz premise

We will call the generally true assumption, $a \gg c$, the *Coulomb premise*, after Charles Augustin de Coulomb, which can be expressed as $B^* = B_L$, and is not to be confused with the Coulomb "gauge" condition, $B_L = 0$. Likewise, the Lorenz "gauge" condition, $B = 0$, and is not to be confused with the assumption $a = c$ ($B^* = B$), which we call the *Lorentz premise*, after Hendrik Antoon Lorentz. The Lorentz premise reduces GCED to MCED, which disobeys the conservation of momentum, and for this reason this premise is *generally false*. This is proven as follows: with $a = c$ ($B^* = B$), eq. 3.45 becomes:

$$\frac{1}{c^2}\frac{\partial^2(B)}{\partial t^2} - \nabla\cdot\nabla(B) = 0 \tag{3.48}$$

Eq. 3.48 implies that "the superimposed scalar field only exists as a free field wave, that isn't sourced by any charge current density distribution. Without a source, B cannot exist, and therefore we can set $B = 0$". It is easy to verify that GCED with $B = B^* = 0$ reduces to MCED. The following proposition from Quantum Physics theory: 'the linearly dependent "scalar" photon and "longitudinal" photon do not contribute to field observables', is based on the false Lorentz premise as well, and therefore this statement is questionable.

Since GCED requires the Coulomb premise for consistency with Classical Mechanics, this theory is not invariant with respect to the "gauge" transform. The formal "gauge" transform is an unnecessary and needlessly confusing mathematical concept within the context of MCED, which is inconsistent anyway. The potentials of GCED with Coulomb premise are determinate and physical, such that a unique solution of charge-current potentials describes the physics of a particular charge-current distribution. Hence, the so called "gauge" conditions are *physical* conditions for physical potentials.

3.6 Retarded potentials and retarded fields of GCED

Since $a \gg c$, and $b = c$, the scalar- and vector potentials are solutions of the following decoupled inhomogeneous wave equations:

$$\frac{1}{a^2}\frac{\partial^2\Phi}{\partial t^2} - \Delta\Phi = \frac{1}{\epsilon_0}\rho \tag{3.49}$$

$$\frac{1}{c^2}\frac{\partial^2\mathbf{A}}{\partial t^2} - \Delta\mathbf{A} = \mu_0\mathbf{J} \tag{3.50}$$

The solutions of these wave equations are the following retarded potentials:

$$\Phi(\mathbf{x},t) = \frac{1}{4\pi\epsilon_0} \int_{V'} \frac{\rho(\mathbf{x}',t_a)}{r}\,\mathrm{d}^3x' \tag{3.51}$$

$$\mathbf{A}(\mathbf{x},t) = \frac{\mu_0}{4\pi} \int_{V'} \frac{\mathbf{J}(\mathbf{x}',t_c)}{r}\,\mathrm{d}^3x' \tag{3.52}$$

$$r = |\mathbf{x}-\mathbf{x}'| \qquad t_a = t - \frac{r}{a} \qquad t_c = t - \frac{r}{c}$$

The four retarded fields, derived from these potentials, are:

$$B_\Phi(\mathbf{x},t) = \frac{1}{4\pi\epsilon_0} \int_{V'} \frac{-\dot{\rho}(\mathbf{x}',t_a)}{r}\,\mathrm{d}^3x' \tag{3.53}$$

$$B_L(\mathbf{x},t) = \frac{\mu_0}{4\pi} \int_{V'} \left[\frac{\mathbf{J}_l(\mathbf{x}',t_c)\cdot\mathbf{r}}{r^3} + \frac{\dot{\mathbf{J}}_l(\mathbf{x}',t_c)\cdot\mathbf{r}}{cr^2} \right] \mathrm{d}^3x' \tag{3.54}$$

$$\mathbf{B}_T(\mathbf{x},t) = \frac{\mu_0}{4\pi} \int_{V'} \left[\frac{\mathbf{J}_t(\mathbf{x}',t_c)\times\mathbf{r}}{r^3} + \frac{\dot{\mathbf{J}}_t(\mathbf{x}',t_c)\times\mathbf{r}}{cr^2} \right] \mathrm{d}^3x' \tag{3.55}$$

$$\mathbf{E}(\mathbf{x},t) = \frac{1}{4\pi\epsilon_0} \int_{V'} \left[\frac{\rho(\mathbf{x}',t_a)\mathbf{r}}{r^3} + \frac{\dot{\rho}(\mathbf{x}',t_a)\mathbf{r}}{ar^2} - \frac{\dot{\mathbf{J}}_l(\mathbf{x}',t_c)}{c^2 r} - \frac{\dot{\mathbf{J}}_t(\mathbf{x}',t_c)}{c^2 r} \right] \mathrm{d}^3x' \tag{3.56}$$

We identify three near field terms, that fall off in magnitude by r^2, and six far field terms of the Φ, LEM and TEM waves, that fall off in magnitude by r, so GCED is far field consistent. Beside ES and GMS, we define two extra types of charge-current distributions with restricted behaviour: *Quasi Dynamics* (QD) with $a \to \infty$, and *Quasi Statics* (QS) with $a \to \infty \ \wedge \ c \to \infty$.

In case of QD, there is no noticeable retardation of the Coulomb field, $\mathbf{E}_\Phi$, and the scalar potential, Φ ($t_a = t$), which is also described as 'instantaneous action at a distance' [4]. The length of the circuit is much smaller than the wavelength of the far Φ-wave, such that detection of a far Φ potential gradient is impossible: the second term in eq. 3.56 becomes zero. The induction law 3.1 is still needed, since the secondary field B_Φ does not disappear for quasi dynamics. In case of QS, also the second term in eq. 3.54 and eq. 3.55 become zero. The induction laws for the secondary fields $\mathbf{E}_L$ and $\mathbf{E}_T$ are still required for quasi statics, since the third and fourth term in eq. 3.56 do not disappear.

3.7 The 4/3 problem of Maxwell's electromagnetism

According to MCED, the electrostatic energy, E_e, and the electromagnetic momentum, $\mathbf{p}_e$, of an electron with charge q_e (that is distributed on the surface of a sphere with classical electron radius, r_e) which has a constant speed $\mathbf{v}$, are the following expressions:

$$E_e = \frac{1}{2}\frac{1}{4\pi\epsilon_0}\frac{q_e^2}{r_e} = m_e c^2 \quad (3.57)$$

$$\mathbf{p}_e = \frac{2}{3}\frac{\mu_0}{4\pi}\frac{q_e^2}{r_e}\mathbf{v} = m_e'\mathbf{v} \quad (3.58)$$

Notice that $m_e' = \frac{4}{3}m_e$, and this is inconsistent. David E. Rutherford solved the 4/3 problem of MCED rigorously [34]. First, Rutherford reasoned that the electrostatic energy of the electron is *twice* that of expression 3.57, see [35], since the work rate (in order to charge the electron sphere with radius r_e with a charge q_e) is equal to $\partial_t(q\Phi) = \partial_t(q)\Phi + q\partial_t(\Phi)$, and not just equal to $\partial_t(q)\Phi$. This reasoning is supported by our GCED power theorem, see the left hand side of eq. 3.43. Considering only the net charge potential, Φ, the power density is: $\nabla\Phi\cdot\mathbf{J} + \partial_t(\Phi)\rho$. The electron volume integral of $\nabla\Phi\cdot\mathbf{J}$ equals $\Phi\partial_t(q)$, and the electron volume integral of $\partial_t(\Phi)\rho$ equals $\partial_t(\Phi)q$. Thus, the energy flow of charging the electron sphere equals $\partial_t(q\Phi)$. This shows that the 4/3 problem is in fact a 2/3 problem: an electromagnetic momentum of $\frac{1}{3}m_e\mathbf{v}$ is missing.

Next, Rutherford evaluates the electromagnetic momentum by using the following electromagnetic momentum density expression: $\epsilon_0(B_L\mathbf{E} + \mathbf{E}\times\mathbf{B}_T)$, see [34]. This evaluation is supported by the GCED force theorem, see the last term of eq. 3.44, and apply the Coulomb premise $B^* = B_L$. The volume integral of the extra electromagnetic momentum density $\epsilon_0(B_L\mathbf{E})$ equals the missing $\frac{1}{3}m_e\mathbf{v}$ momentum. Rutherford's expressions for the electrostatic energy and the electromagnetic momentum are:

$$E_e = \frac{1}{4\pi\epsilon_0}\frac{q_e^2}{r_e} = m_e c^2 \quad (3.59)$$

$$\mathbf{p}_e = \frac{\mu_0}{4\pi}\frac{q_e^2}{r_e}\mathbf{v} = m_e'\mathbf{v} \quad (3.60)$$

Now we have $m_e = m_e'$, which is consistent. Obviously, GCED with the Coulomb premise is the most natural theory that solves the $\frac{4}{3}$ problem. This shows that the mass of the electron is entirely electrostatic energy, and the momentum of the electron is entirely electromagnetic. Rutherford's rigorous solution of the 4/3 problem can also be understood as the *non-relativistic* GCED derivation of the famous equation, $E = mc^2$, for a moving charge with speed $\mathbf{v}$.

3.8 A distribution of identical charges

A charge density $\rho(\mathbf{x})$ and a current density $\mathbf{J}(\mathbf{x})$ can be defined in terms of the charge of particles, q_k ($k = 1, 2, ..., n$), and in terms of the velocity of particles, $\mathbf{v}_k$, where $\mathbf{v}_k$ is the velocity of the k^{th} particle. Assumed that the particles reside in a volume $V_{\mathbf{x}}$, which includes the place coordinate $\mathbf{x}$, the charge- and current density are defined as follows:

$$\rho(\mathbf{x}) = \lim_{V_{\mathbf{x}}\to 0} \frac{1}{V_{\mathbf{x}}} \sum_{k=1}^{n} q_k \tag{3.61}$$

$$\mathbf{J}(\mathbf{x}) = \lim_{V_{\mathbf{x}}\to 0} \frac{1}{V_{\mathbf{x}}} \sum_{k=1}^{n} q_k \mathbf{v}_k \tag{3.62}$$

For the special case that the particles have an *identical* charge ($q_k = q$) at all places under consideration, the charge- and current density are defined as:

$$\rho(\mathbf{x}) = \lim_{V_{\mathbf{x}}\to 0} \frac{nq}{V_{\mathbf{x}}} \tag{3.63}$$

$$\mathbf{J}(\mathbf{x}) = \lim_{V_{x}\to 0} \frac{nq}{V_{\mathbf{x}}} \frac{1}{n} \sum_{k=1}^{n} \mathbf{v}_k \tag{3.64}$$

A simple relation between charge- and current density follows from the definition of the *average velocity* distribution, $\mathbf{v}(\mathbf{x})$, for a distribution of identical charges:

$$\mathbf{v}(\mathbf{x}) = \frac{1}{n} \sum_{k=1}^{n} \mathbf{v}_k \tag{3.65}$$

$$\mathbf{J} = \rho \mathbf{v} \tag{3.66}$$

The identity $\mathbf{J} = \rho\mathbf{v}$ does not hold for a distribution of particles with dissimilar charges, for example: an electrically neutral metallic wire with $\rho = 0$ that carries a current I. However, the low resistance wires of electrical circuits usually have excess surface charge, such that Poynting's vector expresses the wire energy flow to dissipative resistors [14]. For high voltage high frequency circuits the excess surface charge is very high, such that eq. 3.66 applies. An electronic vacuum tube also shows a high excess of electrons. For a distribution of identical charges, with $\mathbf{J} = \rho\mathbf{v}$, we can express the power density or *work rate density* as the dot product of force density and average velocity, $\mathbf{f}\cdot\mathbf{v}$, at a given position and time. Within the context of GCED, the work rate density is (see eq. 3.44):

$$(\rho\mathbf{E} + \rho\mathbf{v}\times\mathbf{B}_T + \rho\mathbf{v}B^*)\cdot\mathbf{v} = \mathbf{E}\cdot\mathbf{J} + \rho|\mathbf{v}|^2 B^* \tag{3.67}$$

This expression has to be equal to the left hand side of the GCED power theorem (see eq. 3.43), which results in the following relation between B and B^*:

$$B^* = \frac{c^2}{|\mathbf{v}|^2} B \tag{3.68}$$

This identity is plugged in eq. 3.45 to obtain the following wave equations:

$$\frac{1}{|\mathbf{v}|^2}\frac{\partial^2 B^*}{\partial t^2} - \nabla\cdot\nabla B^* = 0 \tag{3.69}$$

$$\frac{1}{|\mathbf{v}|^2}\frac{\partial^2 B}{\partial t^2} - \nabla\cdot\nabla B = 0 \tag{3.70}$$

such that the fields B_Φ and B_L satisfy the following equations ($a \gg c$):

$$(\frac{|\mathbf{v}|^2}{a^2} - 1)B_\Phi = (c^2 - |\mathbf{v}|^2)B_L \tag{3.71}$$

$$\frac{1}{|\mathbf{v}|^2}\frac{\partial^2 B_\Phi}{\partial t^2} - \nabla\cdot\nabla B_\Phi = 0 \tag{3.72}$$

$$\frac{1}{|\mathbf{v}|^2}\frac{\partial^2 B_L}{\partial t^2} - \nabla\cdot\nabla B_L = 0 \tag{3.73}$$

With eq. 3.68, the field equations 3.39 and 3.40 become

$$\nabla\cdot\mathbf{E} - \frac{c^2}{|\mathbf{v}|^2}\frac{\partial B}{\partial t} = \frac{1}{\epsilon_0}\rho \tag{3.74}$$

$$\nabla B + \nabla\times\mathbf{B}_T - \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t} = \mu_0\rho\mathbf{v} \tag{3.75}$$

If it is further assumed that the charged particles all have a constant average speed $\mathbf{v}$ at all space-time coordinates, then the elimination of the field B results in a wave equation for the electric field:

$$\frac{1}{|\mathbf{v}|^2}\frac{\partial^2 \mathbf{E}}{\partial t^2} + \frac{c^2}{|\mathbf{v}|^2}\nabla\times\nabla\times\mathbf{E} - \nabla\nabla\cdot\mathbf{E} = -\frac{1}{\epsilon_0}\left(\nabla(\rho) + \frac{1}{|\mathbf{v}|^2}\frac{\partial(\rho\mathbf{v})}{\partial t}\right) \tag{3.76}$$

This equation expresses a combined LEM Φ-wave (with phase velocity $|\mathbf{v}|$) and TEM wave (with phase velocity c). GCED theory predicts that a distribution of identical charges, that have a constant average velocity $\mathbf{v}$, may naturally show a travelling LEM wave and a travelling Φ-wave, with phase velocity equal to the average particle speed, $\mathbf{v}$. In that case, the charge- and current density distribution behaves as a wave with constant phase velocity. This is known as a travelling Charge Density Wave (CDW). The combined LEM wave and Φ-wave mode in high voltage high frequency circuits explains the very high energy flow over very thin single wire transmission lines [9]. The 'density functional theory' model of a single free electron, which is a charge density oscillation-wave of only negative charge [19], could benefit from GCED theory. If we substitute $|\mathbf{v}| = c$, or $|\mathbf{v}| = a \gg c$, then eq. 3.76 reduces to well known equations.

4 Review of electrodynamics experiments

4.1 The hyperluminal Coulomb near field

Hyperluminal evanescent 'tunneling' of fields has been reported [30]. Usually such effects are explained as quantum effects, however, GCED with the Coulomb premise ($a \gg c$) explains such effects simply as a Coulomb near field with 'hyperluminal' speed, see also [45]. The authors of [33] experimentally proved that the Coulomb near field of a uniformly moving electron beam is "rigidly carried by the beam itself", which is further described as follows: the Coulomb near field travels with infinite velocity. This result can also be understood as a finite hyperluminal Coulomb field velocity. It is impossible to explain these experiments, that prove the Coulomb near field is hyperluminal, by means of the Jefimenko electric field expression, since this expression shows a Coulomb near field retardation of r/c. Hyperluminal Coulomb near field results agree with N3LM, as a matter of fact, since the Coulomb premise is required for consistency of GCED with N3LM.

4.2 General Magnetostatic force experiments

First of all, the historic Magnetostatic force experiments carried out by Ampère, Gauss, Weber and other famous scientist, are mainly examples of *open circuit* currents. It is certain that batteries or capacitor banks were used as electric current sources and current sinks that typically show time varying charge densities and divergent currents at the current source/sink interface. Specific General Magnetostatic experiments such as Ampère's historic hairpin experiment, demonstrate the existence of the longitudinal Ampère force [23] [37] [2]. In particular, Stefan Marinov [25] and Genady Nikolaev [29] published on the results of several GMS force experiments that prove the existence of longitudinal Ampère forces. Nevertheless, it is difficult to show that this force is proportional to the inverse square of the distance between interacting currents. Nikolaev pointed out that the Aharonov Bohm effect is explainable as a longitudinal Ampère force, acting on the free electrons that pass through a double slit and pass a shielded solenoid on both sides of the solenoid. Such a force does not deflect the free electrons, and it slightly decelerate (delay) or accelerate (advance) the electrons, depending on which side the electrons pass the solenoid, which explains classically the observed phase shift in the interference pattern.

4.3 Nikolaev's electromagnetic induction

As far as we know, not many experiments have been done yet to verify or falsify Nikolaev's induction law, see eq. 3.2. Primary sinusoidal *divergent* currents induce a secondary sinusoidal *divergent* electric field $\mathbf{E}_L$ and similar secondary currents (depending on the resistive load in the secondary 'circuits'), such that the secondary currents are at least 90 degrees out of phase with the primary currents.

4.4 The induction of B_Φ

The field B_Φ only exists as far field, so observable effects of this type of field are not similar to near field force interaction, but through the emission and reception of Φ-wave energy. In order to achieve high B_Φ fields, one needs to induce high electric charge potential amplitudes with high frequencies. For example, a very high voltage Tesla coil transformer, or a controlled high voltage discharge device, are suitable for this purpose. Probably the highest B_Φ fields are induced by means of collective tunneling of many electrons through a potential energy barrier, since the tunneling of electrons is practically instantaneous. The Φ-wave energy flux vector $\epsilon_0 B_\phi \mathbf{E}_\Phi$ also depends on the magnitude of the electric field, which can be optimized as well.

4.5 Longitudinal electric waves

The development of GCED was motivated by the remarkable achievements of the electrical engineer Nikola Tesla. Tesla described his long distance electric energy transport system as the transmission of *longitudinal* electric waves, conducted by a single wire or the natural media, including the aether. Mainstream physics describes a longitudinal electric wave only as a sound wave conducted by a material medium (that has a longitudinal electric field component, indeed). GCED describes the longitudinal electric LEM wave and Φ-wave through vacuum, so Tesla's reference to aether sound waves is theoretically supported by GCED. The characteristics of the Tesla coil device (the secondary coil shows a quarter wave length charge density wave distribution across the entire 'unwound' length of the coil wire) is hard to explain with conventional MCED theory, where GCED explains this wave type naturally, see §3.8. Tesla also mentioned the observation of teleforce effects by means of non-dispersive emissions from a high voltage discharge vacuum tube, quite similar to Podkletnov's superluminal gravity impulse signal. It is likely that Tesla is the original discoverer of both wireless LEM waves and wireless Φ-waves. He was far ahead of his time [42] [43].

Wesley and Monstein published a paper on the transmission of a Φ-wave, by means of a pulsating surface charge on a centrally fed ball antenna [27]. They assumed that the ball antenna does not show divergent currents ($\nabla \cdot \mathbf{J} = 0$) and emits Φ-waves only, however, this suggests a violation of charge conservation ($\nabla \cdot \mathbf{J} = 0$ and $\partial_t \rho \neq 0$). We suggest that a centrally fed ball antenna conducts curl free divergent currents that induce mainly LEM waves, and that Wesley and Monstein actually observed LEM waves in stead of Φ-waves. They tested and confirmed the longitudinal polarity of the received electric field.

Ignatiev and Leus used a similar ball shaped antenna to send wireless longitudinal electric waves with a wavelength of 2.5 km [15]. They measured a phase difference between the wireless signal and an optical glass fiber control signal (the two signals are synchronous at the sender location) at a 0.5 km distance from the sender location. They concluded from the measured phase shift that the wireless signal is faster than the optical glass fiber signal, and that the wireless signal has a phase velocity of 1.12 c. However, we assume that the 0.12 c discrepancy is due to an incorrect interpretation of the data, for instance, the optical glass fiber control signal has a phase velocity slower than c (in most cases it is 200,000 km/sec, depending on the refractive index of the glass fiber). Combining the results from the experiments by Wesley, Monstein, Ignatiev and Leus, we conclude that the results verify the existence of the longitudinal LEM wave that travels with luminal speed c in space, as predicted by GCED.

Podketnov's 'impulse gravity' generator emits far field superluminal signals with velocity of at least $64c$ [32], over a distance greater than a kilometer. The impulse gravity device is very different from a ball shaped electrical antenna: the wireless pulse is generated by means of a high voltage discharge (maximum of 2 million volt) from a *superconducting* flat surface electrode to another non-superconducting electrode. The emitted pulse travels into the direction longitudinal (parallel) to the electronic discharge direction. TEM wave radiation, transverse to the direction of discharge, was not detected. Podkletnov concludes the 'longitudinal direction' signal isn't a TEM wave, nor a beam of massive particles. We assume that Podkletnov's impulse 'gravity' device produces Φ-waves; the measured signal speed of at least $64c$ agrees with the prediction of the superluminal Φ-wave phase velocity ($a \gg c$). Secondly, Podkletnov expects that the superluminal signal frequency matches the tunneling frequency of the discharged electrons [31] (during the discharge pulse, many electrons tunnel collectively through many superconducting layers before leaving the superconductor). This implies that a high B_Φ scalar field is involved, since electron tunneling is a very fast instantaneous electronic effect. The GCED nature of the impulse signal has not yet been fully investigated by Podkletnov and Modanese.

A very efficient 'quasi-superconducting' Single Wire Electric Power System (SWEP) has been developed and tested [9], that meets the same power requirements for standard 50/60Hz three-phase AC power lines. The SWEP system applies high frequency high voltage signals that are send and received by 'tuned' Tesla coils. SWEP applications are described in [9] that do not require grounding of the SWEP system, so it is reasonable to assume the SWEP system is based on the combined LEM-Φ wave concept, see §3.8. Single wire transmission systems that require a 'ground return' are in fact two-wire system based on the TEM wave concept, such that the electric fields are perpendicular to the wire-earth.

4.6 Natural longitudinal electric waves as energy source

The most important applications of GCED might be the conversion of natural longitudinal far fields into useful electricity. The reception of Φ-waves is most likely the reverse process of the generation of Φ-waves, so theoretically, the natural reception of Φ-wave energy causes quantum tunneling of electrons through an energy barrier to a higher energy level. We will call Φ-wave stimulated quantum tunneling the 'Φ-wave electric effect', similar to the photoelectric effect of electrons emitted by a metal surface that is exposed to TEM waves. Essential to the Φ-wave electric effect is that it does not involve electric current, initially.

Dr. T. Henry Moray's radiant energy device converted the energy flow of natural 'cosmic' aether waves in fifty kilo Watt of useful electricity, day and night [28]. Moray tuned his radiant energy device into a natural high frequency signal, that we assume is a Φ-wave. Dr. Harvey Fletcher, who was the co-discoverer of the elementary charge of the electron (for which Dr. Robert Millikan won the Nobel price), signed an affidavit [13] describing that Moray's radiant energy receiver functioned as claimed. The most proprietary component of Moray's receiver was a high voltage cold cathode tube containing a Germanium electrode doped with impurities, called 'the detector tube' by Moray. This tube has been described as a 'light' valve, and its huge energy reception capability might be based on a Φ-wave electric effect. The electric potential at the first energy receiving stage were shown to be at least 200,000 volts. Very abrupt tunneling of electrons in/out of the Germanium electrode through an energy barrier explains the observed high frequencies generated/received by Moray's valve, as well as the reported *negative slope* in a part of the conduction characteristic of the detector tube. The importance of Dr. Moray's invention cannot be overstated; it dwarfs most Nobel prize discoveries in the field of physics. T. Henry Moray and Nikola Tesla were the greatest electrical engineers in world history.

The same Φ-wave electric effect might explain the excess energy detected by Dr. P.N. Correa [7], and described by Correa as an anomalous and longitudinal cathode reaction force during pulsed autogenous cyclical abnormal glow discharges in a cold cathode plasma tube. Correa observed an abnormal glow discharge in a negative slope current-voltage regime (which also shows the excess energy) that is similar to the negative slope current-voltage regime of a tunneling diode. The same 'pre-discharge' glow has been observed by Podkletnov, just before the pulse discharge of his gravity impulse device. We explain the 'abnormal glow' as an effect of tunneled electrons on gas atoms, just before an abrupt discharge from cathode to anode. The observation of a natural self-pulsed discharge frequency might be explained by the presence of a natural background Φ-wave with high intensity and with the same frequency. Very similar excess energy results were achieved by Dr. Chernetsky [6], by means of a self-pulsed high voltage discharge tube (filled with hydrogen), that generates longitudinal electronic waves in the electrical circuits attached to the tube, powering several hundred watt lamps.

5 Conclusions and discussions

The Helmholtz decomposition theorem is essential for a comprehensive treatise on CED, and its generalization, GCED. We showed that GCED with the Lorentz premise ($a = c$) reduces to MCED. Since MCED theory is inconsistent and shows indeterminate potentials, it is concluded that the Lorentz premise is false, and that the Coulomb premise ($a \gg c$) is fundamentally true. GCED with the Coulomb premise and the extra condition $\nabla \cdot \mathbf{J} = \partial_t \rho = 0$ reduces to CED. It is a wide spread mistake that stationary currents always satisfy the condition $\nabla \cdot \mathbf{J} = 0$, in stead of the charge continuity equation. GCED with the Coulomb premise is a consistent electrodynamics theory, naturally constrained by the law of charge continuity, which does not show the 4/3 problem either, another indication of its consistency. Many experimental results are in favour of GCED and falsify MCED.

GCED is based on classical principles, such as the conservation of momentum and charge, and flies in the face of modern physics, founded on MCED. The false Lorentz premise ($a = c$) is key to understand the second postulate of Special Relativity (SR) theory, which is a proposition in the following circular arguments: MCED does not predict longitudinal wave modes in vacuum, therefore vacuum isn't a physical medium (an aether model always allows for longitudinal waves), therefore a relative motion of an observer with respect to vacuum isn't possible, therefore light speed measurement data agrees only with an absolute constant value c regardless of the relative motion of light source and observer (the second SR postulate), therefore the Lorentz transform applies in stead of the Galilei transform, which further forbids velocities higher than constant c, such that $a = c$, and this reduces GCED to MCED, etc ...

The circular arguments of SR theory are based on the false Lorentz premise ($a = c$), which is the most fundamental assumption of SR, since it is also the fundamental assumption underlying Maxwell's CED. One-way TEM wave experiments prove the anisotropy of the TEM wave velocity in vacuum [5], and the recent 'gravity impulse' speed measurements by E. Podkletnov [32] indicate a superluminal speed of $64c$. These experiments falsify both the Lorentz-Poincaré SR theory and Hilbert's general relativity theory. GCED is consistent only with the Coulomb premise ($a \gg c$), so a relativity principle other than Lorentz invariance has to be found anyway, in order to describe a relativistic GCED. Heinrich Hertz and Thomas E. Phipps showed how to cast MCED into a Galilei invariant form by means of a simple replacement of the partial time differential operator by a total time differential operator [39]. GCED can be cast into a relativistic Galilei invariant GCED in this way.

The indeterminacy of the quantum wave function, ψ, is tied to the indeterminacy of the MCED potentials, Φ and $\mathbf{A}$. A gauge transform of the relativistic quantum wave equation is a transformation of the MCED potentials and the quantum wave function in Φ', $\mathbf{A}'$ and ψ', such that the phase of the transformed wave function ψ' differs a constant with the phase of the function ψ, and such that the quantum wave function is "gauge" invariant [20]. This means that the wave function ψ is also 'unphysical' and indeterminate, like the MCED potentials. The indeterminacy of ψ is interpreted as probabilistic behaviour of elementary particles (the Born rule): the particle velocity is the ψ wave *group* velocity, and is not associated with phase velocity. Gauge invariance (also known as gauge symmetry) is supposed to be the "guiding principle" of modern physics, however, gauge freedom is the consequence of a false Lorentz premise ($a = c$), which reduces GCED to the inconsistent MCED with indeterminate potentials.

Recent scanning tunneling microscope experiments falsify Heisenberg's uncertainty relations by close two orders of magnitude [18], which supports the notion of a deterministic physical quantum wave function that describes a physical electron charge density distribution of a single electron. The determinate potentials of GCED with the Coulomb premise are agreeable with a determinate quantum wave function with deterministic interpretation, such that the phase of ψ has physical meaning. The De Broglie-Bohm pilot wave theory comes into mind, in order to interpret the strange "quantum entanglement" behaviour as a physical pilot wave interaction. The unknown physical nature of the pilot wave has been an objection against the pilot wave theory ever since De Broglie offered his interpretation of Schrödinger's wave function. Caroline H. Thompson published a paper on the universal ψ function as the *Φ-wave aether* [40]. Indeed, the Φ-wave far field, acting as a particle pilot wave, is a natural suggestion. GCED describes physical far field Φ-wave that represent energy flow (it is not "ghost like"). The Φ-wave energy flow, received by a particular particle, equals the Φ-wave energy flow that is send by that particle. The quantum "non locality" and "non causality" entanglement can be mistaken for a hyper luminal 'local' and 'causal' Φ-wave interaction. So GCED offers a classical foundation for the elementary particle-wave duality. The transverse- and longitudinal electromagnetic momentum and the near Φ-potential energy describe the 'particle nature'. The far Φ-wave field interaction describes the 'quantum entanglement' behaviour. The classical electron sphere TEM:LEM momentum ratio of 3:1 probably is wrong, and this ratio can be different (1:1 for example) for an electron charge density wave.

Although a consistent and 'determinate function' foundation is the final destiny of modern physics, it is of greater importance that GCED inspires physicists and electrical engineers to review the electrodynamics experiments from the past, and perform new ones, which may birth a new era of science and technology with respect to *energy conversion*. This may bring 'balance to the force' on this planet.

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