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To the memory of Max Planck (1858 – 1947)

We owe respect to the living; to the dead we owe only truth.
(Françoise Marie Arouet de Voltaire)

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Preface

Electromagnetic theory has been based on Maxwell's equations for about a century. There is no need to elaborate the successes but from 1986 on we find publications claiming that Maxwell's equations generally do not have solutions that satisfy the causality law. Two scientists working independently and using different approaches arrived at the same result, which gives it great credibility. The mathematical investigations that uncovered the lack of causal solutions are necessarily complicated, otherwise it would not have taken a century to find this shortcoming of Maxwell's equations.

The problem could be corrected by the modification of Maxwell's equations with an added magnetic current density term. Initially this caused concern since magnetic charges or charge carriers have not been observed reliably even though there are good theoretical arguments for their existence, e.g., the quantization of the electric charge. However, it was soon realized that there was no need for *magnetic monopole currents* but that *magnetic dipole currents* were sufficient. The existence of magnetic dipoles is not disputed and their rotation can cause magnetic dipole currents just as the rotation of electric dipoles in a material like Barium-Titanate can cause *electric dipole currents.*

Electric dipole currents were always an important part of Maxwell's equations but they were called polarization currents and this choice of words obscured the unequal treatment of electric and magnetic dipoles. Electric dipole currents are needed to explain how an electric current can flow through the dielectric of a capacitor, which is an insulator for *electric monopole currents.*

The causality law is of no significance for the transmission of power and energy, or generally for steady state solutions of Maxwell's equations. But it is a must for the transmission of electromagnetic signals. Signal transmission without causality is a contradiction in terms.

We define a classical electromagnetic signal as a propagating wave that is zero before a certain time and has finite energy. All produced or observed propagating electromagnetic waves are of this type even though we often approximate them for mathematical convenience by infinitely extended sinusoidal waves. Signals are represented mathematically by functions or *signal solutions* that are zero before a certain time and are quadratically integrable. Such signal solutions satisfy the causality law and the conservation law of energy while infinitely extended periodic sinusoidal solutions satisfy neither.

The modified Maxwell equations have been applied in four books and numerous papers to problems ranging from the propagation of electromagnetic signals in seawater to their interstellar propagation over distances of billions of light years. The time has come to advance from classical physics to quantum physics.

It is one of the most basic principles of quantum mechanics that an observation interferes with what is being observed. In other words, a signal received during an observation changes what created the signal. Quantum electrodynamics should thus be a good field of application for an electromagnetic theory that permits signal solutions.

This expectation turned out to be fully justified. The first success of the use of the modified Maxwell equations was the elimination of the *infinite zero-point energy* that has been a problem for 70 years; the conventional theory can correct it only by renormalization, a process that is generally considered unsatisfactory. The infinite zero-point energy is shown to be reduced to a finite energy for both the pure radiation field and the Klein-Gordon equation.

The Hamilton function of a charged particle in an electromagnetic field derived with the modified Maxwell equations contains many more terms than the conventional Hamilton function. This provides the basis for new results, a fact of interest to those who look for topics for PhD theses.

The authors want to thank Humboldt University in Berlin for providing the computer power required for a number of complicated plots.

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Illustrations are numbered consecutively within each section, with the number of the section given first, e.g., Fig.1.1-1.

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List of Frequently Used Symbols

$\mathbf{A}_{\mathrm{e}}$	As/m	electric vector potential
A_{ec}, A_{es}	-	Eqs.(6.12-44), (6.12-45), (6.12-126)
A_{ev}	As/m	Eq.(4.1-31)
$\mathbf{A}_{\mathrm{m}}$	Vs/m	magnetic vector potential
A_{mv}	Vs/m	Eq.(4.1-31)
a	-	$1+\omega^2$, Eq.(6.1-24)
$\mathbf{B}$	Vs/m^2	magnetic flux density
b^2	-	$(2\pi\kappa)^2+4\omega^2$, Eq.(6.1-24)
c	m/s	299 792 458; velocity of light
$\mathbf{D}$	As/m^2	electric flux density
d^2	-	$4[(2\pi\kappa)^2+\rho_2^2]$, Eq.(4.1-73)
$\mathbf{E}$, E	V/m	electric field strength
E_{E}	V/m	electric field strength due to electric excitation
E_{H}	V/m	electric field strength due to magnetic excitation
E	VAs	energy, Eq.(3.3-12)
e	As	electric charge
$\mathbf{g}_{\mathrm{e}}$	A/m^2	electric current density, Eq.(1.1-2)
$\mathbf{g}_{\mathrm{m}}$	V/m^2	magnetic current density, Eq.(1.1-9)
$\mathbf{H}$, H	A/m	magnetic field strength
H_{E}	A/m	magnetic field strength due to electric excitation
H_{H}	A/m	magnetic field strength due to magnetic excitation
$\mathcal{H}$	-	Hamilton function
h	Js	$6.626\,075\,5\times10^{-34}$, Planck's constant
$\hbar=h/2\pi$	Js	$1.054\,572\,7\times10^{-34}$
j_0	-	Eq.(6.11-42)
K	-	$c^2T\|(\sigma\mu-s\epsilon)\|/4\pi$, Eq.(4.1-87); or $\ll\lambda_1/2\pi$, Eq.(5.2-40)
$\mathcal{L}$	-	Lagrange function
m	kg	mass
m_0	kg	rest mass
p	-	τ_{mp}/τ
$\mathbf{p}$	kg m/s	momentum
q	-	τ_{p}/τ
q_1, q_2	-	Eq.(4.1-106)
q_3, q_4	-	Eq.(4.1-112)
q_{m}	Vs	hypothetical magnetic charge
s	V/Am	magnetic conductivity
t	s	time variable
T	s	time interval
v	m/s	velocity
V_{e}, V_{e0}	As/m^3	Eqs.(4.1-36), (4.1-103)
V_{m}	As/m^3	Eq.(4.1-38)
$Z=\mu c$	V/A	376.730 314; wave impedance of empty space
Zec	Vm	$1.809\,513\,6\times10^{-8}$

α	-	$Ze^2/2h \approxeq 7.297\,535 \times 10^{-3}$, Eq.(3.3-49)
α_{e}	-	$ZecA_{\mathrm{e}}/m_0c^2$; Eq.(3.3-49)
γ_0	-	Eq.(5.2-27)
γ_1, γ_2	-	Eqs.(4.1-73), (6.1-24)
$\epsilon = 1/Zc$	As/Vm	$1/\mu c^2$; permittivity
ζ	-	normalized distance, Eq.(1.3-7)
$\eta = 2\pi\kappa$	-	Eq.(6.1-40)
θ	-	normalized time, Eqs.(1.3-7)–(1.3-10)
$\theta_{\mathrm{mp}}, \theta'_{\mathrm{mp}}$	-	Eq.(6.10-51)
$\theta_{\mathrm{p}}, \theta'_{\mathrm{p}}$	-	Eq.(6.10-51)
ι	-	Eq.(6.4-12)
ι_0	-	Eq.(5.2-26)
κ	-	normalized wave number; Eqs.(4.1-68),(6.1-18)
$\kappa_0 \ldots \kappa_4$	-	Eqs.(6.11-42), (6.11-47), (6.11-48), (6.11-52), (6.11-53)
$\lambda_1, \lambda_2, \lambda_3$	-	Eq.(5.2-8)
$\mu = Z/c$	Vs/Am	$4\pi \times 10^{-7}$; permeability
ρ^2	-	$\sigma s/c^2(\sigma\mu + s\epsilon)^2$, Eq.(1.3-12)
ρ_1	-	$c^2T(\sigma\mu + s\epsilon)$, Eq.(4.1-41)
ρ_2^2	-	$c^2T^2\sigma s$, Eq.(4.1-41)
ρ_{e}	$\mathrm{As/m^3}$	electric charge density
ρ_{m}	$\mathrm{Vs/m^3}$	hypothetical magnetic charge density
$\rho_{\mathrm{em}}, \rho_{\mathrm{ep}}$	-	Eq.(6.10-67)
$\rho_{\mathrm{pm}}, \rho_{\mathrm{mm}}$	-	Eq.(6.10-67)
$\rho_{\mathrm{mp}}, \rho_{\mathrm{p}}$	-	Eq.(6.10-67)
ρ_{pp}	-	Eq.(6.10-67)
ρ_{s}	-	Z/scT, Eq.(4.1-47)
ρ_σ	-	$ZTc\sigma$, Eq.(4.1-49)
σ	A/Vm	electric conductivity
ϕ_{e}	V	electric scalar potential
ϕ_{m}	A	magnetic scalar potential
ω^2	-	$s\epsilon/\sigma\mu$, Eq.(1.3-11)
ω_1	-	$[(1-\omega^2)^2 - \eta^2]^{1/2}$, Eq.(6.7-2)
ω_2	-	$[\eta^2 - (1-\omega^2)^2]^{1/2}$, Eq.(6.7-2)