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The Speed of Electricity

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***Abstract.* It was German physicist Gustav Robert Kirchhoff in the year 1857 who first identified the connection between the speed of light and the speed of electric signals in a conducting wire. Meanwhile, although charged particles in a conductor don't travel at anywhere near the speed of light, this is not considered to be a contradiction, because it is generally accepted that it is changes in the electric current, and not the electric current itself, that are propagated at the speed of light, the assumption being that a longitudinal compression wave propagates through the electron cloud in the conducting material.**

The idea of such a compression wave travelling at the speed of light is not however very convincing, because it's unlikely that such a wave would just happen to propagate through a cloud of outer shell conduction electrons at exactly the same speed as wireless radiation in space, never mind how the same approach would then also apply in an electrolytic conducting solution. This matter will therefore be investigated further.

The Speed of Light

I. In the year 1857, Kirchhoff identified the speed of light in Weber's constant. This was the first recorded identification of a connection between light and electricity, **[1]**. Weber's constant was in turn based on the force law that Wilhelm Eduard Weber had proposed in 1846, expressed by the equation below, where C_w is the constant in question,

$$F = kq_1q_2/r^2[1 - \dot{r}^2/C_w^2 + 2r\ddot{r}/C_w^2] \qquad \textbf{(1)}$$

*See **Appendix I** for the key to equation **(1)***. In 1855, along with Rudolf Kohlrausch, Weber performed an experiment aimed at enumerating this constant, **[2]**, **[3]**, **[4]**. Based on the rationale behind this experiment, Weber's constant should have been directly connected to the flow speed of electric current, since it was based on it being a unidirectional reducing speed. As it was though, Weber and Kirchhoff both subscribed to the Fechner hypothesis, **[5]**, in which electric current consists of an equal and opposite bi-directional flow of oppositely charged particles, and so they would have been distracted from making the obvious deduction. It's not that the Fechner hypothesis needs to be wrong, but it doesn't mean that there isn't also a deeper unidirectional aethereal undercurrent involved in electric current, as well as the flow of charged particles.

Kirchhoff, meanwhile, was only a few steps away from obtaining the *telegrapher's equations* that Oliver Heaviside would obtain about thirty years later, **[6]**, and he was working with Weber's equations, where Weber's constant, and hence the speed of light, were firmly planted in the magnetic domain. Weber's constant, C_w, is in fact equal to $c\sqrt{2}$, where c is the speed of light.

Kirchhoff's context was that of a single electric circuit involving electric charge and self-inductance, and an uninterrupted flow of electric current, but he made the mistake of criss-crossing the electrostatic field, $\mathbf{E_S}$, with the electric field of time-varying EM induction, $\mathbf{E_K}$, in his mathematical analysis, as though they were exactly equivalent for substitution purposes, hence confusing two separate physical concepts with each other, and so by rights, he should not have been able to derive periodic equations in the manner that he did, **[6]**. As already stated above, it should have been evident from the 1855 Weber-Kohlrausch experiment, that electric current itself actually flows at the speed of light, and that as such, in a conducting wire, changes in electric current are propagated at that speed, *with the flow*, and not as a wave. Kirchhoff believed that the changes propagated as a longitudinal wave, but as explained, his analysis was dubious.

Maxwell's Displacement Current

II. Maxwell's displacement current extended electric current beyond conducting wires and into space. While Kirchhoff used Weber's equations, which placed the speed of light firmly in the magnetic domain, Maxwell began differently in 1861, **[7]**. When Maxwell first conceived of the idea of displacement current, he placed the speed of light into the electrostatic domain through its connection with the dielectric constant. He made this connection by applying Weber's constant in electromagnetic units. However, when it came to deriving the equation for magnetic disturbances in magnetic field intensity in his 1865 paper, **[8]**, he had to shift the dielectric constant, now connected directly to the speed of light, into time-varying EM induction. And so, as in the case of Kirchhoff, Maxwell now had the speed of light entirely within the magnetic domain. But unlike in the case of Kirchhoff, Maxwell was inadvertently working in mutual inductance between tiny molecular vortices that filled all of space, and so his resulting wave equations described the relay of displacement current through this sea of miniature electric circuits, **[9]**, **[10]**, **[11]**, **[12]**.

Although Maxwell didn't explicitly identify it, the circumferential speed of his vortices would have been the speed of light, **[13]**, and this will be the average speed that the aethereal electric current swirls from vortex to vortex during the dynamic state, **[14]**, **[15]**. It's virtually the same average speed that the fundamental electric fluid flows between the two terminals in the conducting channels of a laboratory circuit.

Conclusion

III. Rather than the speed of electric current being equal to the speed of light, it is more a matter that the speed of light is primarily the speed of electric current, and that light itself is a manifestation of electric current in space. This was the conclusion that should have been drawn from the 1855 Weber-Kohlrausch experiment as soon as Kirchhoff, in 1857, identified Weber's constant with the speed of light. It was then just a matter of restricting the speed of light within the magnetic domain and deriving a wave equation on the basis of mutual induction, just as Maxwell demonstrated in his 1865 paper, **[8]**. By connecting the dielectric constant directly to the speed of light through Weber's constant, Maxwell then applied it to time-varying EM induction, and so his displacement current took electric current into space as a relay current swirling between tiny vortices that densely fill the universe, and which amount to miniature electric circuits.

Meanwhile, Kirchhoff, and later Heaviside too, while operating within a single electric circuit, erred when they criss-crossed the electrostatic field with the electric field of time-varying EM induction, as though they were equivalent and exactly interchangeable in the analysis. They were in fact mixing two separate contexts together, and while Kirchhoff at least kept the speed of light in the magnetic domain, through Weber's equations, Heaviside on the other hand split the speed of light between magnetic permeability, μ, and electric permittivity, ε, as per the equation,

$$c^2 = 1/\mu\varepsilon \qquad \textbf{(2)}$$

and placed permittivity into the realm of capacitance, and hence into the realm of electrostatics, †. It's fine for permittivity to be involved in capacitance in the context of capacitors, but not when deriving a wave equation in conjunction with EM induction. When doing so, electric permittivity needs to be brought into the domain of mutual induction. So, in purporting to derive the telegrapher's equations, Heaviside had in fact inadvertently just derived the wireless electromagnetic wave equations using exactly the same dubious substitution that the modern textbooks use in both cases.

The speed of light is the average speed that the aethereal fluid flows between a source (positive particle) and a sink (negative particle). Particle motion in electric current is only a secondary effect, with positive particles being pushed along with the flow, while negative particles eat their way in the opposite direction towards the positive source, but they will never be accelerated to anywhere near the speed of light. Meanwhile, the electric permittivity of the space surrounding a conducting wire, being a measure of displacement current leakage, should affect the speed of the conduction current, hence giving the misleading impression that Heaviside's telegrapher's equations do actually apply to conduction currents in wires.

† *Maxwell also used equation* ***(2)****, which appears as equation (71) on page 498 in his 1865 paper,* **[8]***. However, while he equated ε to 4π/k, where k is the elasticity coefficient, Maxwell equated μ to unity, which is why equation (46) on page 491 in the same paper puts the speed of light directly into the dielectric realm. He then transferred the dielectric realm into the realm of time-varying EM induction. Meanwhile, Maxwell considered the magnetic permeability, μ, to be a measure of density in his sea of molecular vortices, and so equation* ***(2)*** *is simply Newton's equation for the speed of a wave in the elastic medium that serves as the carrier of light waves.*

References

[1] Kirchhoff, G.R., ***"On the Motion of Electricity in Wires"***, Philosophical Magazine, vol. XIII, Fourth Series, pp. 393-412, (1857)
English translation by Professor A.K.T. Assis, vol. 3, chapter 8
https://www.ifi.unicamp.br/~assis/Weber-in-English-Vol-3.pdf
See page 212 for Kirchhoff's periodic equations in linear charge density and electric current. Page 213 is where he suggests an analogy between the electric charge equation and the equation for the propagation of longitudinal waves and see page 214 regarding the connection between Weber's constant and the speed of light.
Meanwhile, a summary by Professor A.K.T. Assis can be found on pp. 280-282 in this link,
https://www.ifi.unicamp.br/~assis/Weber-Kohlrausch(2003).pdf

[2] Weber, W., and Kohlrausch, R., ***"Elektrodynamische Maassbestimmungen insbesondere Zurueckfuehrung der Stroemintensitaetsmessungen auf mechanisches Maass"***, Treatises of the Royal Saxon Scientific Society, Volume 5, Leipzig, S. Hirzel, (1856)
See chapters 5, 6, and 7 in this link,
https://www.ifi.unicamp.br/~assis/Weber-in-English-Vol-3.pdf
Prof. A.K.T Assis has written an excellent summary of this work in an article entitled ***"On the First Electromagnetic Measurement of the Velocity of Light by Wilhelm Weber and Rudolf Kohlrausch"***.
https://www.ifi.unicamp.br/~assis/Weber-Kohlrausch(2003).pdf
Weber and Kohlrausch wrote a short precis of their paper, and this can be found in Poggendorf's Annalen, vol. XCIX, pp. 10-25. An English translation of this precis is presented in the appendix at the end of Prof. Assis's paper.

[3] Tombe, F.D., ***"The Commonality between Light and Electric Current"***, (2022)
https://www.researchgate.net/publication/364337354_The_Commonality_between_Light_and_Electric_Current

[4] Tombe, F.D., ***"The 1855 Weber-Kohlrausch Experiment"***, (2019)
https://www.researchgate.net/publication/332411168_The_1855_Weber-Kohlrausch_Experiment_The_Speed_of_Light

[5] Fechner, G.T., ***"On the Connection of Faraday's Induction Phenomena with Ampère's Electrodynamic Phenomena"***, (1845)
https://www.ifi.unicamp.br/~assis/Fechner.pdf

[6] Heaviside O. ***"Electrical papers"***, Volume II, p. 82, (1892)

[7] Clerk-Maxwell, J., ***"On Physical Lines of Force"***, Philosophical Magazine, vol. XXI, Fourth Series, London, (1861)
http://vacuum-physics.com/Maxwell/maxwell_oplf.pdf

[8] Maxwell, J.C**.**, ***"A Dynamical Theory of the Electromagnetic Field"***, Philos. Trans. Roy. Soc. London 155, pp 459-512, (1865)
Abstract: Proceedings of the Royal Society of London 13, pp. 531-536 (1864)
The derivation of the electromagnetic wave equation in the magnetic field begins on page 497. Note how the electrostatic component of the displacement current is eliminated after equation (68), hence leaving the elastic displacement mechanism in the wave as an effect that is connected exclusively with time-varying electromagnetic induction. Maxwell originally conceived the idea of displacement current in connection with dielectric polarization, and hence with electrostatics, but in this derivation, it is no longer applicable to polarization, but instead applies to magnetization. This swap has never been highlighted, and as such, Maxwell's displacement current transferred into the early twentieth century literation as a concept related to capacitors and transmission lines, but in order to derive the electromagnetic wave equations, we need to use the inductive form that is compatible with Faraday's law.
http://www.zpenergy.com/downloads/Maxwell_1864_4.pdf
http://www.zpenergy.com/downloads/Maxwell_1864_5.pdf
https://royalsocietypublishing.org/doi/pdf/10.1098/rstl.1865.0008

[9] Whittaker, E.T., ***"A History of the Theories of Aether and Electricity"***, chapter 4, pp. 100-102, (1910)
"All space, according to the younger Bernoulli, is permeated by a fluid aether, containing an immense number of excessively small whirlpools. The elasticity which the aether appears to possess, and in virtue of which it is able to transmit vibrations, is really due to the presence of these whirlpools; for, owing to centrifugal force, each whirlpool is continually striving to dilate, and so presses against the neighbouring whirlpools."

[10] O'Neill, John J., ***"PRODIGAL GENIUS, Biography of Nikola Tesla"***, Long Island, New York, 15th July 1944, Fourth Part, paragraph 23, quoting Tesla from his 1907 paper ***"Man's Greatest Achievement"*** which was published in 1930 in the Milwaukee Sentinel,
"Long ago he (mankind) recognized that all perceptible matter comes from a primary substance, of a tenuity beyond conception, filling all space, the Ākāśa or luminiferous ether, which is acted upon by the life-giving Prana or creative force, calling into existence, in never ending cycles, all things and phenomena. The primary substance, thrown into infinitesimal whirls of prodigious velocity, becomes gross matter; the force subsiding, the motion ceases and matter disappears, reverting to the primary substance."
http://www.rastko.rs/istorija/tesla/oniell-tesla.html
http://www.ascension-research.org/tesla.html

[11] Tombe, F.D., ***"The Double Helix Theory of the Magnetic Field"***, (2006)
Galilean Electrodynamics, vol. 24, Number 2, p.34, (March/April 2013)
http://gsjournal.net/Science-Journals/Research%20Papers-Mathematical%20Physics/Download/6371

[12] Tombe, F.D., ***"The Double Helix and the Electron-Positron Aether"***, (2017)
https://www.researchgate.net/publication/319914395_The_Double_Helix_and_the_Electron-Positron_Aether

[13] Tombe, F.D., ***"Radiation Pressure and $\boldsymbol{E} = mc^2$"***, (2018)
Sections **I** and **II**
https://www.researchgate.net/publication/325859308_Radiation_Pressure_and_E_mc

[14] Lodge, Sir Oliver, ***"Ether (in physics)"***, Encyclopaedia Britannica, Fourteenth Edition, vol. 8, pp. 751-755, (1937)
http://gsjournal.net/Science-Journals/Historical%20PapersMechanics%20/%20Electrodynamics/Download/4105
See pp. 6-7 in the pdf file in the link above, beginning at the paragraph that starts with, ***Possible Structure. −***, and note that while the quote suggests that the ether is incompressible, this is almost certainly not the case. The quote in question, in relation to the speed of light, reads,
"The most probable surmise or guess at present is that the ether is a perfectly incompressible continuous fluid, in a state of fine-grained vortex motion, circulating with that same enormous speed. For it has been partly, though as yet incompletely, shown that such a vortex fluid would transmit waves of the same general nature as light waves— i.e., periodic disturbances across the line of propagation—and would transmit them at a rate of the same order of magnitude as the vortex or circulation speed"

[15] Tombe, F.D., ***"Wireless Radiation Beyond the Near Magnetic Field"***, (2019)
https://www.researchgate.net/publication/335169091_Wireless_Radiation_Beyond_the_Near_Magnetic_Field

[16] Assis, A.K.T., ***"Centrifugal Electrical Force"***, Communications in Theoretical Physics, 18, pages 475-478, (1992)
http://www.ifi.unicamp.br/~assis/Commun-Theor-Phys-V18-p475-478(1992).pdf

[17] Tombe, F.D., ***"The Importance of Centrifugal Force"***, (2022)
https://www.researchgate.net/publication/360933238_The_Importance_of_Centrifugal_Force

Appendix I

Weber's 1846 force law took the form,

$$F = kq_1q_2/r^2[1 - \dot{r}^2/C_w^2 + 2r\ddot{r}/C_w^2] \quad \textbf{(1)}$$

where C_w, is Weber's constant, and the purpose behind the 1855 experiment was to establish a numerical value for C_w. The experiment involved transferring a quantity of electricity from a charged Leyden jar over to a 13-inch ball that was coated with tin foil, and then discharging the remainder through a conducting channel. The electrostatic force generated by the charged ball was measured using a torsion balance while the magnetic force induced by the current, due to the discharge of the Leyden jar, was measured by the deflection of the compass needle in a galvanometer. The idea behind the experiment was that since the electrostatic force was measured using electrostatic units of charge, while the magnetic force was measured using electrodynamic units of charge, then the numerical ratio between the two forces would yield the value of C_w.

The term of major interest in equation **(1)** is the middle term on the right-hand-side. This term, $\dot{r}^2/C_w^2$, is the convective term, where $\dot{r} = V_w$. It's a magnetic force which is a kind of centrifugal force, **[16]**, because it is velocity dependent and it opposes an electrostatic force of attraction, **[17]**. Weber considered V_w to be the mutual speed between two charged particles, q_1, and q_2, distance r apart, and he saw C_w as a reducing speed such that when $V_w = C_w$, then the electrostatic force would be completely cancelled.

Because the experiment begins with two unknowns, V_w, and C_w, it follows therefore that there will be a corollary to the discovery of the numerical value of C_w. This corollary was never noticed though, perhaps due to the conviction that electric current consisted in the equal and opposite flow of charged particles. But while that may well be the case, especially when a current is flowing through an electrolyte, equation **(1)** above tells us that when the electrostatic and magnetic forces are equal, then V_w must be equal to C_w, and so something must be travelling in the discharge wire at speed C_w. Had Weber and Kohlrausch used electromagnetic units of charge for the magnetic force instead of electrodynamics units, this would have exposed the speed of light directly, since C_w is equal to $c\sqrt{2}$, where c is the speed of light, and so they might then have concluded that the reducing speed was in fact very close to this speed. Instead, they thought that the reducing speed was significantly greater than the speed of light.