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The Full Significance of the Speed of Light

Frederick David Tombe,
Northern Ireland, United Kingdom,
sirius184@hotmail.com
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Abstract. **In the year 1855, German physicists Wilhelm Eduard Weber and Rudolf Kohlrausch performed a landmark experiment of profound significance. By discharging a Leyden jar (a capacitor), they linked the speed of light to the ratio between electrostatic and electrodynamic units of charge.**

This experiment was electromagnetism's *Rosetta Stone* because the result can be used to, (i) identify the speed of light as the speed of circulation of electric current, (ii) identify the speed of light as the speed of electromagnetic waves through a dielectric solid that pervades all of space, while noting that inertial centrifugal force and dipole fields share in common an inverse cube law in distance. The result can also be used to, (iii) identify magnetic repulsion as a centrifugal force, and hence to establish the double helix pattern that characterizes magnetic lines of force.

Weber's Interpretation

I. Weber and Kohlrausch's 1855 experiment involved discharging a Leyden jar (a capacitor) that had been storing a known amount of charge in *electrostatic units*, and then seeing how long it took for a unit of electric current, as measured in *electrodynamic units*, to produce the same deflection in a galvanometer [1]. From these readings they discovered that the ratio of the two systems of units was equal to $c\sqrt{2}$ where c is the directly measured speed of light, although it's not clear that they immediately noticed the numerical value of c explicitly. Had they however used *electromagnetic units* instead of *electrodynamic units* for the electric current, the result would have stood out as c exactly.

In order to make sense out of this result, Weber looked to the convective term $\dot{r}^2/C^2$ (v^2/C^2) in the force equation that he had proposed nine years earlier in 1846. This equation takes the form,

$$F = kQ_1Q_2/r^2[1 - \dot{r}^2/C^2 + 2r\ddot{r}/C^2] \qquad \textbf{(1)}$$

where C is known as Weber's constant. Weber considered C to be a kind of reducing velocity such that when $v = \dot{r} = C$, the electrostatic force will be cancelled, and he identified C with the numerical ratio $c\sqrt{2}$ that he had obtained in the above-mentioned experiment. If we ignore the obvious error in equation **(1)**, which is that the convective term should really be transverse and not radial, then this term takes on the form of a centrifugal force, [2], written as a proportion of the value of the electrostatic force that it is undermining. Weber's

constant therefore becomes a reducing velocity at which the magnetic repulsion (centrifugal force) balances with an attractive electrostatic force. This is the same principle that is observed in planetary orbits.

Kirchhoff's Interpretation

II. It's not clear when exactly Weber and Kohlrausch first noticed the connection between *C* and *c*, but in 1857, Gustav Robert Kirchhoff, using Weber's constant in the standard equations of electromagnetism **[3]**, concluded that electric signals propagate along a conducting wire at the speed of light. This would be the case if pressure changes in an electric current were to be carried with the flow, providing that the flow speed was equal to the speed of light, but this is not the basis upon which Kirchhoff derived his conclusion. Kirchhoff's derivation will be discussed at the end in the conclusion section in connection with Maxwell's displacement current.

Maxwell's Interpretation

III. In Part I of his 1861 paper ***"On Physical Lines of Force"*** **[4]**, James Clerk Maxwell attempted to physically construct the magnetic field and to then account for the magnetic forces using the idea that space is filled with tiny aethereal vortices that press against each other with centrifugal force while striving to dilate **[4]**, **[5]**, **[6]**. Equation (77) in this paper is an electromotive force equation containing a convective term $\mu\mathbf{v}\times\mathbf{H}$, which is nowadays unduly credited to Lorentz. This convective term is clearly the centrifugal force that is implicit in Weber's force equation. This is the correct form for the convective term in equation **(1)**. Maxwell's sea of tiny vortices therefore rationalizes Weber's interpretation of the 1855 experiment.

In Part III of the same paper, which is a section on electrostatics, Maxwell, convinced that we were dealing with a wave, set out to link the Weber constant to the transverse elasticity of his sea of tiny vortices, and in doing so, the sea of vortices ended up doubling for a dielectric solid. Maxwell considered the electric displacement that would arise in a dielectric in the vicinity of an electrified body. In this way he was able to establish a relationship between the dielectric constant and the coefficient in Coulomb's law when expressed in electromagnetic units of charge. The manner in which Maxwell demonstrated this follows closely on Faraday's ice pale experiment. When a charge is placed inside a hollow conducting sphere, the charge induced on the outside of the sphere is equal to the charge inside the sphere. The electrostatic force **E** causing the displacement **D** in the conducting material satisfies $\mathbf{D} = -\varepsilon\mathbf{E}$, where ε is the

electric permittivity in space. This is a form of Hooke's law and it is Maxwell's fifth equation in his original set of eight published in 1865 [7], although Maxwell worked with the dielectric constant which is reciprocally related to the electric permittivity. Since the displacement in the spherical conducting shell is $q\hat{\mathbf{r}}/4\pi r^2$, where q is the electric charge inside the shell and $4\pi r^2$ the surface area of a sphere, it follows that $\mathbf{E} = -q\hat{\mathbf{r}}/4\pi\varepsilon r^2$, and therefore we can write Coulomb's law in electromagnetic units of charge in the form $\mathbf{F} = -q_1q_2\hat{\mathbf{r}}/4\pi\varepsilon r^2$. Between equations (116) and (129) in his 1861 paper, Maxwell in effect applied this reasoning to the surrounding dielectric solid itself.

In electrostatic units of charge, Coulomb's law is written as $\mathbf{F} = -Q_1Q_2\hat{r}/r^2$. From the 1855 Weber-Kohlrausch experiment, let the speed of light c be the ratio of electrostatic to electromagnetic units of charge, hence $Q_1/q_1 = c$. It then follows from substation and comparison that $c^2 = 1/4\pi\varepsilon$. The speed of light has therefore been directly related to the elasticity of a dielectric medium. In electromagnetic units of charge, the magnetic permeability μ is unity, and since this relates to the magnetic flux density of the sea of molecular vortices, the equation $c^2 = 1/4\pi\mu\varepsilon$, being elasticity divided by density, becomes Newton's equation for the speed of a wave in an elastic solid. However, in SI units, the coefficient in the Biot-Savart law is $\mu/4\pi$ and so the 4π cancels and we end up with $c^2 = 1/\mu\varepsilon$. This equation is equivalent to $\mathbf{E} = mc^2$ in the context of electromagnetic waves, probably the only context in which it ever exists.

Conclusion

IV. Kirchhoff would have had no concept of displacement current in space because he believed that he was working on the signal within a conducting wire. He did however use the capacitance equation Q = CV which introduces the equivalent maths, bringing the permittivity into the mix, hence enabling Kirchhoff to establish the linkage to the speed of light through the 1855 Weber-Kohlrausch experiment. It is commonly believed that Kirchhoff's telegrapher's equation relates to the speed of an electric signal in a conducting wire. But since capacitance acts perpendicularly to the conducting surfaces and since the current is not being powered by the self-induced back EMF, it's hard to see how this can be so. On the other hand, since experiments tend to confirm that the speed of an electric signal along a wire is indeed in the order of the speed of light, it would seem like a coincidence if the telegrapher's equation isn't in fact applicable in the context.

The problem might be resolved to some degree by returning to the older idea that electric current in a conducting wire primarily constitutes the flow of an aethereal fluid. It is proposed that this *electric fluid* emerges from positive particle sources and disappears into negative particle sinks, and at an average speed in the order of the speed of light. Between the terminals of a battery,

positive particles in the conducting wire would be accelerated with the flow, while negative particles would eat their way in the opposite direction, but these particles would never reach the speed of the aether flow itself due to the circuit resistance R. We know that drift velocities are nowhere near the speed of light and so we should not consider the motion of charged particles to be the primary essence of electric current. However, if we consider electric current to be primarily an aethereal fluid, then changes in pressure (voltage) in an electric current would be propagated with the current flow at speeds in the order of the speed of light.

Wireless and cable telegraphy could then be reconciled on the basis that EM radiation in space is simply electric current passing at the speed of light between tiny neighbouring aethereal vortices that are acting as miniature electric circuits and filling all of space, while aligned along their mutual rotation axes as per the prevailing magnetic field **[8]**. The vector **A**, nowadays known as the magnetic vector potential, and where curl $\mathbf{A} = \mu\mathbf{H}$, would then become an electric fluid momentum equivalent to Maxwell's displacement current **[9]**.

The sea of molecular vortices advocated by Maxwell in Parts I and II of his 1861 paper can be reconciled with the dielectric solid advocated in Part III of the same paper by making the vortices into rotating electron-positron dipoles, hence leading to ***"The Double Helix Theory of the Magnetic Field"*** **[10], [11]**. Electromagnetic waves will not actually be due to dielectric polarization in a radial electrostatic field, but rather due to the EM induction force $\mathbf{E} = -\partial\mathbf{A}/\partial t$ acting transversely on the rotating dipoles. The elasticity will nevertheless be the same in each case, because in both cases we will be dealing with a torque acting on rotating dipoles.

References

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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"***.
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[2] Assis, A.K.T., ***"Centrifugal Electrical Force"***, Communications in Theoretical Physics, 18, pages 475-478 (1992)
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[3] Kirchhoff, G.R., ***"On the Motion of Electricity in Wires"***, Philosophical Magazine, Volume XIII, Fourth Series, pages 393-412 (1857)
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[4] Clerk-Maxwell, J., ***"On Physical Lines of Force"***, Philosophical Magazine, Volume XXI, Fourth Series, London, (1861)
http://vacuum-physics.com/Maxwell/maxwell_oplf.pdf

[5] Whittaker, E.T., ***"A History of the Theories of Aether and Electricity"***, Chapter 4, pages 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."

[6] O'Neill, John J., ***"PRODIGAL GENIUS, Biography of Nikola Tesla"***, Long Island, New York, 15th July 1944, 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 and filling all space - the Akasha 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

[7] Tombe, F.D., ***"Maxwell's Original Equations"*** (2011)
https://www.researchgate.net/publication/302966559_Maxwell's_Original_Equations

[8] Lodge, Sir Oliver, ***"Ether (in physics)"***, Encyclopaedia Britannica, Fourteenth Edition, Volume 8, Pages 751-755, (1937)
http://gsjournal.net/Science-Journals/Historical%20PapersMechanics%20/%20Electrodynamics/Download/4105
In relation to the speed of light, *"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"*

[9] Tombe, F.D., ***"An Interpretation of Faraday's Lines of Force"*** (2019)
https://www.researchgate.net/publication/332249473_An_Interpretation_of_Faraday's_Lines_of_Force

[10] Tombe, F.D., ***"The Double Helix Theory of the Magnetic Field"*** (2006)
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http://gsjournal.net/Science-Journals/Research%20Papers-Mathematical%20Physics/Download/6371

[11] 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