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The 1855 Weber-Kohlrausch Experiment
(The Speed of Light)

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Abstract. **In the year 1855, German physicists Wilhelm Weber and Rudolf Kohlrausch performed an experiment involving the discharge of a Leyden jar, from which they established the ratio between electrostatic and electrodynamic units of charge. This ratio became known as Weber's constant and it is numerically equal to $c\sqrt{2}$, where c is very close to the speed of light. In 1857, another German physicist, Gustav Kirchhoff, used Weber's constant to conclude that electric signals travel along a wire at the speed of light. A few years later in 1861, Scottish physicist James Clerk Maxwell was working on the physical medium responsible for magnetic lines of force and he established a linkage between its transverse elasticity and Weber's constant. On converting electrodynamic units to electromagnetic units, Maxwell exposed the speed of light directly and he connected it to the transverse elasticity of the luminiferous medium. This paper sets out to establish the fundamental origins of the speed of light.**

Electric Permittivity

I. Electric permittivity, ε, is a constant that is associated with dielectrics through James Clerk Maxwell's electric elasticity equation, $\mathbf{D} = -\varepsilon\mathbf{E}$, where $\mathbf{D}$ is the electric displacement vector, and $\mathbf{E}$ is an externally applied electric force. A form of this equation first appeared in the preamble to Part III of Maxwell's 1861 paper, ***"On Physical Lines of Force"***, [1], in connection with the concept of *displacement current*. Electric permittivity can be measured experimentally by discharging a capacitor. The ensuing electric current is measured, and the electric permittivity is established through the standard electromagnetic relationships. For details, see the appendix after the reference section at the end.

Electric permittivity is related to the speed of light through the equation,

$$\mu\varepsilon = 1/c^2 \tag{1}$$

Unlike electric permittivity, however, magnetic permeability, μ, has always been a defined quantity. Even though Maxwell attributed the physical significance of μ to the density of the sea of molecular vortices which he believed constituted the luminiferous medium, he had no way of knowing its absolute value. This however didn't matter for his purpose since he was only working with ratios, and in electrodynamic and electromagnetic units, μ is unity.

1

The origins of equation **(1)** can be traced back to the year 1855 to an experiment carried out by Wilhelm Eduard Weber and Rudolf Hermann Arndt Kohlrausch, [2]. The experiment involved transferring a quantity of electricity from a charged Leyden jar 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 a compass needle in a galvanometer. The purpose of the experiment was to determine the numerical value of the constant, C_w, in Weber's 1846 force law,

$$F = kq_1q_2/r^2[1 - \dot{r}^2/C_w{}^2 + 2r\ddot{r}/C_w{}^2] \tag{2}$$

The idea 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, which was known as Weber's constant.

The only term of major interest in equation **(2)** 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, [3], because it opposes an electrostatic force of attraction. 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 **(2)** 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, they would have concluded that the reducing speed, C_w, was in fact very close to the speed of light. Instead, they thought that the reducing speed was significantly greater than the speed of light.

In 1857, Gustav Robert Kirchhoff, while studying the motion of electricity in conducting wires, [4], identified, in German miles, what appeared to be the speed of light, c, in the relationship $C_w = c\sqrt{2}$, and he linked this to the speed of electric signals in the wire, although he did not suggest that this speed represented the actual flow speed of electric current, but only that it represented the propagation speed of any changes in the electric current. Kirchhoff was attempting to link the signal speed to wave theory.

While we all know that the electric particles that are involved in an electric current travel at nowhere remotely near to the speed of light, the implication of the Weber-Kohlrausch experiment is nevertheless that something much more subtle must be the fundamental basis of electric current, and that even if changes in electric current propagate in a wave-like form along a conducting wire at a speed close to the speed of light, that this is only because they are carried by the movement of a fluid which is itself flowing at that same speed. As to what exactly this fluid is, we should look to the electrostatic field that surrounds charged particles and consider that the inflowing or outflowing aethereal electric fluid, which is the basis of this field, is the prime candidate.

A few years later, in 1861, in the paper already mentioned, [1], Maxwell developed a model for the luminiferous medium based on the idea that space is filled with tiny aethereal vortices that press against each other with centrifugal force while striving to dilate, [5], [6]. Equation (77) in Part II is an electromotive force equation containing a convective term, $\mu\mathbf{v}\times\mathbf{H}$, which is nowadays unduly credited to Lorentz. Then in Part III in a section on elasticity and electrostatics, Maxwell set out to link the Weber-Kohlrausch ratio, C_w, to the transverse elasticity of his sea of tiny vortices. When he converted this ratio from electrodynamic units to electromagnetic units in order to get it into a workable form, he explicitly isolated c, and like Kirchhoff before him, he noticed that c was very close to the measured speed of light. But rather than linking this speed to the circumferential speed of his vortices, Maxwell was focused on elasticity and displacement, and he applied c to Newton's equation for the speed of a wave in an elastic solid. The full derivation is found in Part III, where he begins by demonstrating the linkage between the dielectric constant and the transverse elasticity. Equations (132) to (135) in this paper should leave nobody in any doubt that Newton's equation is the equivalent of both $E = mc^2$ and $c^2 = 1/\mu\varepsilon$, which are in effect one and the same equation.

In Part III, Maxwell does not resort to the specifics of the sea of molecular vortices that he postulated in Part I of the same paper. Had he done so; he could have linked c directly to the circumferential speed in his vortices. *See "Radiation Pressure and $E = mc^2$"*, [7]. Nevertheless, Maxwell still established that light is a transverse wave in the same medium that is the cause of electric and magnetic phenomena.

Electric Current

II. Maxwell and Kirchhoff both used broadly the same equations of electromagnetism in connection with the Weber-Kohlrausch numerical ratio, but they came to different conclusions. In 1857, Kirchhoff concluded that an electric signal travels along a conducting wire at the speed of light, whereas in 1861, Maxwell concluded that this speed is the speed of a wireless

electromagnetic wave through space, and he believed space to be densely packed with tiny aethereal vortices. The only way that these two seemingly contradictory positions could be reconciled is if Maxwell's aethereal vortices constitute tiny electric circulations in which the circumferential speed is the speed of light. See the paragraph below equation **(5)** in the next section. The drift velocities of charged particles in an electric current are nowhere near the speed of light, but the electric force field that drives them will have an associated aethereal momentum field which will be. This will be the magnetic vector potential **A** known to Maxwell as the *electromagnetic momentum*. Maxwell identified **A** with Faraday's *electrotonic state*. *See **"An Interpretation of Faraday's Lines of Force"**,* [8].

Centrifugal Force

III. Maxwell's convective electromotive force is a centrifugal force of the form,

$$\mathbf{E} = \mu\mathbf{v}\times\mathbf{H} = \mathbf{F}/q \tag{3}$$

See equations (5) and (77) in his 1861 paper, [4]. It is a centrifugal force by virtue of its origins in a sea of tiny aethereal vortices which are pressing against each other while striving to dilate, as like the water presses on the walls of Newton's rotating bucket. The magnetic intensity **H** is a measure of the vorticity or the angular momentum of the vortices. Electric particles at the edge of the vortices have an angular momentum $\mathbf{H} = \mathbf{D}\times\mathbf{v}$ where **D** is the displacement of these particles from the polar origin in the centre, and where **v** is their circumferential velocity. Substituting Maxwell's electric elasticity equation, $\mathbf{D} = -\varepsilon\mathbf{E}$, into $\mathbf{H} = \mathbf{D}\times\mathbf{v}$, leads to,

$$\mathbf{H} = \varepsilon\mathbf{v}\times\mathbf{E} \tag{4}$$

If we then substitute **(3)** into **(4)** we obtain,

$$\mathbf{E} = \varepsilon\mu\mathbf{v}\times(\mathbf{v}\times\mathbf{E}) \tag{5}$$

Since $\varepsilon\mu$ is equal to $1/c^2$ and since **H**, **v**, and **E**, are mutually perpendicular, then it follows that the circumferential speed of Maxwell's tiny vortices is what determines the speed of light.

If we now consider **H** in equation **(3)** to be a vector field in the vicinity of an electromagnet, we can substitute a form of the Biot-Savart law such that **v** becomes the mutual velocity as between an element of electric current in the wire, to which will be ascribed a charge q_1, and a charged particle with charge

q_2 that is moving in the magnetic field. If, based on the Biot-Savart Law, we take **H** to be,

$$\mathbf{H} = q_1\mathbf{v}\times\hat{\mathbf{r}}/4\pi r^2 \tag{6}$$

then in the special case where **v** is perpendicular to $\hat{\mathbf{r}}$, and multiplying top and bottom by ε, equation **(3)** becomes,

$$\mathbf{F} = q_1 q_2 \varepsilon\mu v^2\hat{\mathbf{r}}/4\pi\varepsilon r^2 \tag{7}$$

Substituting $\varepsilon\mu = 1/c^2$ leads to,

$$\mathbf{F} = v^2/c^2(q_1 q_2/4\pi\varepsilon r^2)\hat{\mathbf{r}} \tag{8}$$

so, when $v = c$, the magnetic force will be equal to the electrostatic force. This confirms that Weber and Kohlrausch should have used electromagnetic units for the magnetic force in their experiment, so that C_w wouldn't have been clouded by the $\sqrt{2}$ factor, and hence V_w in Weber's force law would indeed represent a reducing speed.

Equation **(8)** also identifies the physical context in which the middle term on the right-hand-side of Weber's force law, at equation **(2)**, begins to take on a higher degree of accuracy, providing that the mutual speed v is transverse, and not radial as is implied by this law. As regards an important example of where this magnetic force simultaneously equates with the electrostatic force, we will take a closer look at the stability mechanism within the rotating electron-positron dipoles that fill all of space and form magnetic lines of force.

Magnetic Force

IV. In the 2006 article entitled ***"The Double Helix Theory of the Magnetic Field"***, [9], it was argued that the electric particles that surround Maxwell's tiny vortices are in fact just a single positron and a single electron. In the equatorial plane, the escape velocity relative to the electrostatic force has been exceeded and they are hemmed into their circular orbits by centrifugal force pressing inwards from the surrounding vortices. This centrifugal pressure must be counterbalanced by electrostatic tension in the axial direction channelled along the double helix. If electrons and positrons are sources and sinks in a primary aethereal fluid, it is proposed that the rate of inflow and outflow will be proportional to the vorticity. The magnetic intensity **H** (angular momentum) will therefore determine the electrostatic charge in the axial direction. As such, we cannot simply use Coulomb's Law to calculate the spacing between the

individual vortices, because Coulomb's Law assumes that electrons and positrons have a fixed charge. In the bound state within the double helix alignment, their electric charge, which determines their magnetic charge, will not however be fixed. It will be determined by their vorticity and hence by the magnitude of the electric current that causes the magnetic field.
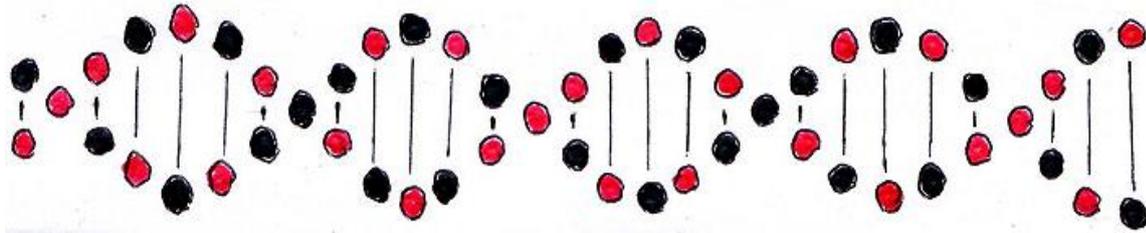
Figure 1. A close-up view of a single magnetic tube of force. Attraction along the tube is caused by electrostatic attraction between the electrons and positrons. Repulsion laterally between adjacent magnetic tubes of force is caused by centrifugal force. Within each rotating electron-positron pair, the orbital speed is what determines the speed of light.

Maxwell never knew the size of his molecular vortices, but it would be reasonable to assume that they are small enough to flow through the interstitial spaces between the atoms and molecules of ponderable matter, as like water flows through a basket. We could assume that the circumference of these dipolar vortices is equal to half of the Compton wavelength for an electron, since gamma radiation of this wavelength, or lower, can resonate with the dipoles and split them apart, as has just been explained above. This would make their diameter 0.3863 picometres, hence setting them at about one thousandth the size of the average atom. The density of the vortex sea will however be difficult to calculate because the balance between the electrostatic force in the axial direction and the centrifugal force in the equatorial plane would point to inter-particle spacings between neighbouring vortices on the femtometre scale. Since this is very much less than their actual diameters, the magnetic lines of force will in effect become *tubes of force*. Then on the issue of the density, as an absolute minimum, if we were to simply consider only the diameter of the vortices, the density of the vortex sea will already be into the region of fourteen hundred times denser than lead, but it will surely be many orders of magnitude yet higher than that still.

The presence of this dense sea of electron-positron dipoles throughout all of space, not only acts as the medium for the propagation of light, but it also causes a compound centrifugal force to act upon all bodies in motion, [10], [11], and this is what gives rise to Newton's first law of motion and the inertial path. The inertial forces on the large scale are a product of the inertial path and not, as is wrongly taught in the modern literature, a product of making observations from a rotating frame of reference. The electron-positron sea causes the inertial

forces, and hence contributes to the shape of the planetary orbital paths, as opposed to causing dissipative friction.

It's only within the context of this dense sea of rotating electron-positron dipoles that Maxwell and Kirchhoff can be reconciled, and Maxwell and Weber partially reconciled. More specifically, it's probably only on the scale of an individual rotating electron-positron dipole that we can use an inverse square law of distance in the Biot-Savart law, because it's only on this scale where the centrifugal force arises as a transverse interaction between two electric monopoles. On the large scale, inertial centrifugal force obeys an inverse cube law in distance, which is characteristic of a dipole field.

The speed of electric current should not be confused with the drift velocity of the charged particles in a conducting wire, which is many orders of magnitude less. Electric current is fundamentally a flow of the primary aethereal electric fluid from which everything is made, while the speed of light is tied up with the circumferential speed of the rotating electron-positron dipoles, [7]. In order to connect it all together, the general position is that the speed of electric current is the average speed that the electric fluid flows between a source and a sink, whether in the case of the electric current flowing between the two terminals in a conducting circuit or between a positron and a neighbouring electron in the all-pervading electron-positron sea, [12].

Conclusion

V. The speed of light, which arises in connection with both electromagnetic radiation and electric current, is a product of the velocity field of the electric field, [13], [14]. It is the average speed with which the ancient electric fluid flows from positive source particles towards negative sink particles. This is so in the case of the electric fluid emerging from one terminal of a battery and flowing back into the other terminal, and it is also the case with electromagnetic radiation in space where the electric fluid flows between neighbouring electrons and positrons. Space is densely packed with tiny dipole pairs like two-pin power points, each pair consisting of an electron in mutual orbit with a positron, circulating at the speed of light.

The velocity field is more correctly the momentum field **A** known as the magnetic vector potential, [8]. It is Maxwell's displacement current. It exists everywhere in space. In the steady state it is undergoing fine-grained circulation such that $\nabla \times \mathbf{A} = \mathbf{B}$, where **B** is the local magnetic flux density. In the dynamic state, angular acceleration of an electron-positron dipole leads to an overflow of electric fluid into the neighbouring dipole at that same average speed, [12]. This is the principle behind transverse electromagnetic waves.

In a conducting wire, where we normally denote **A** by the symbol **J**, the electric fluid imparts its acceleration to charged particles, but not its velocity.

When accelerating it would push positive particles along with it, while negative particles would eat their way towards the source. The motion of charged particles in an electric current is merely secondary to a more fundamental flow of electric fluid at average speeds in the order of the speed of light. The idea of the existence of such an electric fluid is not new, but it was abandoned in favour of the belief that electric current is in fact a flow of charged particles. The two ideas are not however mutually exclusive, but the absence of the electric fluid in modern physics is a major omission.

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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.

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"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."

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 Fourteenth Edition, vol. 8, pp. 751-755 (1937)
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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"*

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Appendix
The Experimental Determination of Electric Permittivity

A capacitor is discharged using a vibrating switch unit at a frequency f. The discharge current I is measured using a sensitive galvanometer. The capacitance equations are $C = \varepsilon A/d$ and $Q = CV$, where ε is electric permittivity, C is capacitance, A is the area of the capacitor plates, d is the separation distance between the plates, Q is charge, and V is the applied voltage. Since $Q = I/f$, we can combine these equations into $\varepsilon = Id/fVA$, and since V is known, we can numerically evaluate ε, which in SI units comes out to be 8.85×10^{-12} farad metre^{-1}.

There has been a tendency since 1983 for the textbooks to avoid treating the experimental determination of electric permittivity ε. In that year, the International Bureau of Weights and Measures, BIPM, decided to define the metre in terms of the speed of light, resulting in the fact that the speed of light itself has now become a defined quantity. This tautology has resulted in the absurd situation whereby equation **(1)** in section **I** above becomes an equation linking three defined quantities and hence loses all its physical significance. It is not widely known that the speed of light only enters Maxwell's equations through the 1855 Weber-Kohlrausch experiment. In fact, it is a common error to believe the complete opposite, which is that equation **(1)** is a consequence of Maxwell's equations. In modern textbooks, the significance of the speed of light has been shifted away from the Weber-Kohlrausch experiment and placed within the realm of Einstein's theories of relativity instead. The decision on the part of BIPM to make the speed of light a defined quantity might possibly be interpreted as a decision to consolidate Einstein's theories of relativity within the established system of units and to divert attention away from the involvement of a physical medium in the propagation of light waves.

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