

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

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Abstract. In the year 1855, German physicists Wilhelm Eduard Weber and Rudolf Kohlrausch performed an experiment with a Leyden jar and 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 the speed of light. In 1857, another German physicist Gustav Robert 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 had established a linkage between its transverse elasticity and the ratio of electrostatic to electromagnetic units of charge. Electromagnetic units of charge are related to electrodynamic units by a factor of $\sqrt{2}$. In order to evaluate this ratio, Maxwell looked up Weber's results, and on converting Weber's constant into electromagnetic units, the speed of light was exposed. This paper sets out to establish the fundamental origins of the speed of light.

Electric Permittivity

I. Electric permittivity, ϵ , is an elasticity constant that is associated with dielectrics through Maxwell's fifth equation $\mathbf{D} = -\epsilon\mathbf{E}$. This equation is a form of Hooke's Law, where \mathbf{D} is the electric displacement vector, and \mathbf{E} is an externally applied electric force. We can measure the electric permittivity experimentally by discharging a capacitor. The ensuing electric current is measured, and the electric permittivity is established using known quantities in the standard textbook equations. *For details, see the appendix after the reference section at the end.*

Electric permittivity is also a disguised value for the speed of light through the equation,

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

Unlike electric permittivity, 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.

The origins of equation (1) can be traced back to the year 1855 to an experiment carried out by Wilhelm Eduard Weber and Rudolf Kohlrausch [1]. Weber and Kohlrausch had no concept of electric permittivity. The 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 *electrodynamical units*, to produce the same deflection in a galvanometer. 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 come 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,

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

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. The convective term in Weber's equation therefore takes on the form of a centrifugal force [2] written as a proportion of the value of the electrostatic force that it is undermining.

It's not clear when exactly Weber and Kohlrausch first noticed the connection between C and c , but in 1857, Gustav Robert Kirchhoff, using the Weber-Kohlrausch ratio in the known equations of electromagnetism [3], concluded that electric signals propagate along a conducting wire at the speed of light. It's also a matter of curiosity that neither Weber nor Kirchhoff showed any great excitement about the emergence of the speed of light in the electromagnetic context.

Later, in 1861, in his seminal paper "*On Physical Lines of Force*" [4], James Clerk 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 [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.

In the same paper, in a section on electrostatics, Maxwell set out to link the Weber-Kohlrausch ratio C to the transverse elasticity of his sea of tiny vortices. When he converted the 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 unlike Kirchhoff and Weber, he was convinced that this was not just a

mere numerical coincidence. Maxwell was convinced that he was dealing with wave behaviour 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 of the 1861 paper [4] where he begins by demonstrating the linkage between dielectric constant and 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 $c^2 = 1/\mu\epsilon$, which are in effect 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 Maxwell in 1861 concluded that the speed of light is the speed of an electromagnetic wave through space, which he believed 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 velocity field which will be. This will be the magnetic vector potential \mathbf{A} known to Maxwell as the *electromagnetic momentum*. Maxwell identified \mathbf{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 \mathbf{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 \mathbf{D} is the displacement of these particles from the polar origin in the centre, and where \mathbf{v} is their circumferential velocity. The elasticity in the sea of vortices due to centrifugal pressure, is expressed by Maxwell's fifth equation (Hooke's Law) $\mathbf{D} = -\epsilon \mathbf{E}$. Substituting this into $\mathbf{H} = \mathbf{D} \times \mathbf{v}$ leads to,

$$\mathbf{H} = \epsilon \mathbf{v} \times \mathbf{E} \quad (4)$$

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

$$\mathbf{E} = \epsilon \mu \mathbf{v} \times (\mathbf{v} \times \mathbf{E}) \quad (5)$$

Since $\epsilon \mu$ is equal to $1/c^2$ and since \mathbf{H} , \mathbf{v} , and \mathbf{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 \mathbf{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 \mathbf{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 \mathbf{H} to be,

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

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

$$\mathbf{F} = q_1 q_2 \epsilon \mu v^2 \hat{\mathbf{r}} / 4\pi \epsilon r^2 \quad (7)$$

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

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

so, when $v = c$, the magnetic force will be equal to the electrostatic force. There appears to be a discrepancy between equation (8) and the convective term in Weber's equation (2) since $C = c\sqrt{2}$, but this is only because Weber chose to

identify the ratio of electrostatic to electrodynamic units of charge with the constant C in his 1846 equation. That was an arbitrary choice like choosing a system of units, and it had no bearing on any underlying physical realities. For example, Kirchhoff used Weber's ratio in his equations in 1857 when establishing the speed of a signal along a wire, and the signal speed emerged automatically as $C/\sqrt{2} = c$. There is an important difference though between Maxwell's and Weber's convective force equations, which is that the mutual velocity is radial in Weber's case, whereas it is transverse in Maxwell's case. There is undoubtedly a mistake on Weber's part in this respect.

As regards equation (8), in the case where $v = c$, the magnetic force equates with the electrostatic force, and so we need to identify a physical context in which this situation arises. We need to take a closer look at magnetic attraction.

Magnetic Attraction

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 \mathbf{H} (angular momentum) will therefore determine the electrostatic charge in the axial direction.

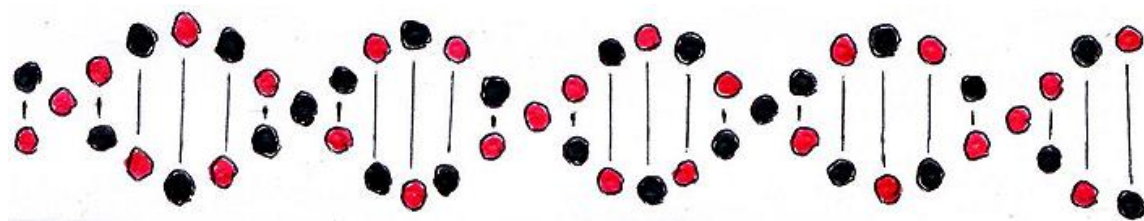


Figure 1. A close-up view of a single magnetic tube of force. Attraction along the tube is caused by electrostatic attraction between the electrons and positrons. Repulsion laterally between adjacent magnetic tubes of force is caused by centrifugal force. Within each rotating electron-positron pair, the orbital speed is what determines the speed of light.

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.

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. A credible guess might put them on the scale of the Compton wavelength for an electron, since gamma radiation of this wavelength can split an electron-positron dipole apart. This would be in the picometre range making them about one thousandth the size of the average atom, with the vortex sea being about thirty-two times denser than lead.

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 Kirchoff 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. 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 \mathbf{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 $\text{curl } \mathbf{A} = \mathbf{B}$ where \mathbf{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 call it \mathbf{J} , it 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 and the absence of the electric fluid in modern physics is a major omission.

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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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[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>

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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”*

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 $C = \epsilon A/d$ 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 $\epsilon = Id/fVA$, 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.