# Ampère's Circuital Law and Displacement Current

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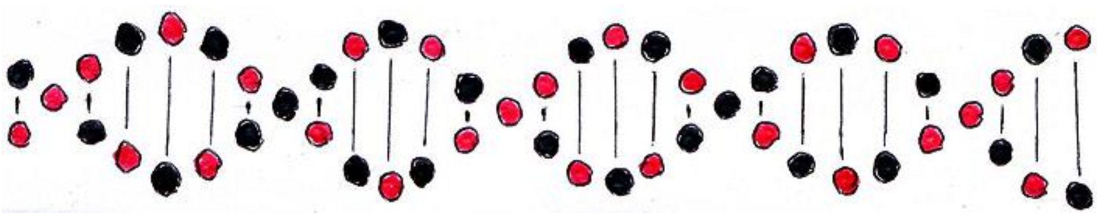

**Abstract.** ***Ampère's Circuital Law is the most controversial of Maxwell's equations due to its association with displacement current. The controversy centres around the fact that Maxwell's entire physical basis for introducing the concept of displacement current in the first place, was the existence of a dense sea of molecular vortices pervading all of space. The modern-day physical parameter known as the electric permittivity, ε, being reciprocally related to the dielectric constant, is historically rooted in the elasticity of this medium. Indeed, the dielectric constant served as the vehicle through which the speed of light was imported into the analysis from the 1855 Weber-Kohlrausch experiment, yet the medium itself has since been totally eliminated from the textbooks. In order to understand how the omission of Maxwell's vortex sea has impacted upon electromagnetic theory, this article will examine the relationship between Ampère's Circuital Law in its differential form on the one hand and the curl of the Biot-Savart Law on the other hand, with which it is generally equated. In particular, the continued use of displacement current in the dynamic state, despite the omission of its original physical basis, will be contrasted with the omission of displacement current in the steady state version of Ampère's Circuital Law as it applies in space.***

## Ampère's Force Law

**I**. *Ampère's Force Law* should not be confused with *Ampère's Circuital Law*. The force law,

$$\mathbf{F} = \mu/4\pi[I_1 I_2 \oint\oint d\boldsymbol{l}_1 \times (d\boldsymbol{l}_2 \times \hat{\mathbf{r}})/r^2] \qquad \textbf{(1)}$$

is the magnetic force which acts between two closed electric circuits. ($\mu$ is magnetic permeability, I is electric current, ***dl*** is an element of conducting wire, and $r$ is the distance between elements in opposite circuits) If we define the vector **B** as,

$$\mathbf{B} = \mu/4\pi[I_2\oint(d\boldsymbol{l}_2\times\hat{\mathbf{r}})/r^2] \qquad \textbf{(2)}$$

then equation **(1)** becomes,

$$\mathbf{F} = I_1\oint d\boldsymbol{l}_1\times\mathbf{B} \qquad \textbf{(3)}$$

which is identical in principle to the convective term in Maxwell's original electromotive force equation, see Section **VIII** below. This equation is nowadays known by the misnomer *"The Lorentz Force"*, and written as,

$$\mathbf{F} = q\mathbf{v}\times\mathbf{B} \qquad \textbf{(4)}$$

where $q$ is the electric charge of a moving particle and **v** is its velocity relative to Maxwell's sea of molecular vortices. See Section **III** below. Equation **(2)** is the integral form of the *Biot-Savart Law*.

## Ampère's Circuital Law

**II**. *Ampère's Circuital Law* is not a force law. It is a law describing the relationship between an electric current and the surrounding magnetic field. In differential form is written as,

$$\nabla\times\mathbf{B} = \mu\mathbf{J} \qquad \textbf{(5)}$$

where **J** is the electric current density. The controversy begins with the assumption that in a region of space that is free of current density, equation **(5)** becomes,

$$\nabla\times\mathbf{B} = 0 \qquad \textbf{(6)}$$

Equation **(6)** would be corroborated by taking the curl of equation **(2)**, however it must be remembered that when we take the curl of equation **(2)**, we are merely taking partial time derivatives with respect to the distance $r$ from the polar origins located in the source electric current elements. While the zero result serves to indicate a conservative force, we are ignoring the orientation of the source current elements and hence ignoring the orientation of **B**. As such we have strayed outside the spirit of Ampère's Circuital Law, and so on this basis, equation **(6)** would not be Ampère's Circuital Law. If the curl of **B** is to be Ampère's Circuital Law, then the curl must be taken in such a way as to involve the orientation of the source electric current elements. This is attempted in Section **VII** below.

One could also of course argue that equation **(6)** is simply a special case of equation **(5)** for regions of space where **J** = 0, but this then raises the problem that the derivation of equation **(5)** in the first place required the existence of a non-zero **J**. In fact, it's doubtful that there ever actually are regions of space where **J** = 0. The reason for doubting this is because in the dynamic state where time varying electromagnetic induction is occurring and electromagnetic radiation is present, then even in what is so-called free space we still have the *displacement current* $\mathbf{J} = \varepsilon\partial\mathbf{E}/\partial t$. It can hardly have just arisen out of nothing.

## Maxwell's Displacement Current

**III**. It was Maxwell's intention when first proposing the existence of displacement current in the preamble to Part III of his 1861 paper ***"On Physical Lines of Force"*** **[1]**, that displacement current was a very real electric current in an all-pervading sea of tiny aethereal vortices. Owing to the presence of this sea of molecular vortices, there will be a circulating electric current at every point in space which we will identify with the magnetic vector potential **A**, and also with Maxwell's displacement current **[2]**. Maxwell himself identified the vector **A** with Faraday's *electrotonic state* and he called it the *electromagnetic momentum*, but ironically, he never linked it with his very own displacement current. In a steady state magnetic field, we should expect displacement current **A** to be a localized fine-grained circulation of *electric fluid* such that,

$$\nabla\times\mathbf{A} = \mathbf{B} \qquad \textbf{(7)}$$

This is Maxwell's second equation in his original listing of eight, **[3]**, and it places **B** into the realm of being a vorticity/angular momentum density. It is now proposed that Ampère's Circuital Law, when applied in deep space, should take the general form,

$$\nabla\times\mathbf{B} = \mu\mathbf{A} \quad \textbf{(8)}$$

while noting that as compared with equation **(2)**, the polar origin has now been shifted from the source electric current elements into the fine-grained structure of the magnetic field itself.

In the dynamic state where time varying electromagnetic induction is occurring, then from Faraday's Law we have,

$$\mathbf{E} = -\partial\mathbf{A}/\partial t \quad \textbf{(9)}$$

and in the oscillating state, the harmonic relationship,

$$\mathbf{A} = \varepsilon\partial^2\mathbf{A}/\partial t^2 \quad \textbf{(10)}$$

will hold. The electric permittivity, $\varepsilon$, is the elastic constant, inversely related to the dielectric constant in Maxwell's original papers. Hence equation **(8)** takes on the familiar form,

$$\nabla\times\mathbf{B} = \mu\varepsilon\partial\mathbf{E}/\partial t \quad \textbf{(11)}$$

The dynamic state equation **(11)** is therefore a special case of the general equation **(8)** relating to wireless radiation, where it is proposed that the displacement current **A** involves a net flow of electric fluid from vortex to vortex while transferring mass and energy through space **[4]**, **[5]**. This would explain the ballistic nature of light. We have therefore established a continuity in Ampère's Circuital Law as between the steady state and the dynamic state, which would be impossible in a pure vacuum.

## Magnetic Attraction as a Conservative Force

**IV**. The format of Ampère's Force Law at equation **(1)** with its inverse square law in distance, along with the product of electric currents in the numerator, has got all the outward characteristics of a conservative *Gauss force* in the likeness of *Coulomb's law of Electrostatics* and *Newton's Law of Gravity*. But due to electromagnetic induction, the source electric currents change during the operation of Ampère's force and this makes it difficult to definitively formulate a theory of conservation of energy in the manner that this can be done in the other two cases. Lenz's Law would suggest that conservation of energy is not breached, but it would be helpful if we could reduce the problem to a purely electrostatic problem, and this is indeed possible in the particular case of magnetic attraction.

We saw in ***"The Double Helix Theory of the Magnetic Field"*** **[6]**, how rotating electron-positron dipoles could be arranged in a double helix fashion so as to account for the magnetic field. A rotating electron-positron dipole consists of an electron and a positron undergoing a mutual central force orbit such that the rotation axis is perpendicular to a line joining the electron to the positron. If we stack these dipoles on top of each other along their axes of rotation with the electrons placed approximately above the positrons and angularly synchronized in a twisted rope ladder fashion, we will effectively have a helical spring. These helical springs are magnetic lines of force by virtue of the fact that they channel an electrostatic Coulomb tension along a double helix alignment within a neutral electron-positron sea. See Fig.1 below,

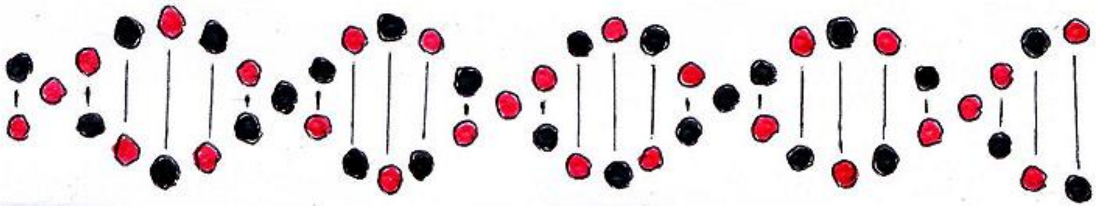

**Fig. 1. A close-up view of a single magnetic line of force. A net electrostatic force is channelled along the double helix of electrons and positrons in an electrically neutral electron-positron sea. The circumferential speed of the electrons and positrons is what determines the local speed of light.**

## Centrifugal Force and Magnetic Repulsion

**V**. The electric fluid (or aether) is the stuff that all matter is made from. Positive particles are therefore aether sources while negative particles are aether sinks. Consider two electron-positron dipoles sitting side by side while rotating in the same plane and in the same direction. When the electron of one dipole passes the positron of the other dipole in the opposite direction at closest approach, the electrostatic field lines will connect directly between the two. According to Coulomb's law there should be a force of attraction acting between them as in the case of any two particles of opposite charge. However, if the electrostatic **E** field is tied up with an aetherereal fluid momentum density field **A**, then due to the enormous mutual transverse speed as between the two particles, the flow lines between the two dipoles will split, and if this happens, the electrostatic attraction will be converted into a centrifugal repulsion. The **E** field lines will remain irrotational, but their physical cause will have changed. It will no longer be due to a tension in the fluid but instead it will be due to side pressure from the flow lines, and so we will now be dealing with centrifugal force as opposed to the Coulomb force.

The rotating dipoles in one magnetic line of force will be aligned in their mutual equatorial planes with the rotating dipoles in an adjacent line of force, and the mutual transverse velocities existing between them will cause a centrifugal repulsion that will push them apart. Since the magnetic lines of force between two like poles do not join directly together, but instead spread outwards and contact each other laterally, magnetic repulsion then occurs due to centrifugal force.

## The Significance of Ampère's Circuital Law

**VI**. When rotating electron-positron dipoles bond together along their rotation axes to form a double helical toroid with nothing in the toroidal hole in the middle, the Coulomb attraction along the double helix would tend to make the helix collapse. If the circumferential speed of each rotating dipole is **v**, then $\nabla\times\mathbf{v} = \mathbf{H}$ where **H** is the vorticity, and hence $\nabla.\mathbf{H} = 0$ meaning that **H** is solenoidal. The speed **v** represents the vortex flow of the electric fluid which constitutes an electric current. At the hole in the middle of the toroid there will be a concentration of electric fluid flowing in one direction, and the current density will be $\rho\mathbf{v} = \mathbf{J}$ where $\rho$ is the fluid density in the hole. The concentration of electric current through the hole in the toroid prevents the toroid from collapsing into the hole. Unlike in the case of fluid pouring down a sink, a toroid involves only solenoidal flow and so the fluid circulates around indefinitely. The fluid cannot pass sideways through itself inside the toroidal hole and so the toroid cannot collapse. The double helix toroid is therefore the fundamental basis for stability and the default alignment in the electron-positron sea. It corresponds to a magnetic line of force and **H** corresponds to magnetic intensity. And since **H** forms a circle around the inside of the double helix, it follows therefore that $\nabla\times\mathbf{H} = \mathbf{J}$. This is Ampère's Circuital Law which is Maxwell's third equation. See section **VIII** below.

Within the context that **v** corresponds to the circumferential current within the individual rotating dipoles that fill all of space, the vector **A** will be defined as $\mu\mathbf{v}$, where $\mu$, known as the magnetic permeability, is a measure of the flux density of magnetic lines of force in the vicinity. In a steady state magnetic field, **A** is a fine-grained *circulating current density* (or momentum density) in the electron-positron sea. The product $\mu\mathbf{H}$ is known as the magnetic flux density and written as **B**. Hence $\nabla\times\mathbf{A} = \mathbf{B}$ and Ampère's Circuital Law becomes $\nabla\times\mathbf{B} = \mu\mathbf{J}$. The equation $\nabla\times\mathbf{A} = \mathbf{B}$ is Maxwell's second equation from which $\nabla.\mathbf{B} = 0$ can be derived. Maxwell referred to the magnetic vector potential **A** as the *electromagnetic* *momentum,* and although he invented displacement current, he failed to identify it with **A**.

Ampère's Circuital Law means that when a current or a particle, neutral or otherwise, moves through the electron-positron sea, it causes the electron-positron dipoles to align with their rotation axes forming solenoidal rings around the direction of motion. This provides a circular energy flow mechanism which replaces friction with the inertial forces and magnetic repulsion. It's similar in principle to the creation of smoke rings. Maxwell explains Ampère's Circuital Law at equation (9) in Part I of his 1861 paper ***"On Physical Lines of Force"*** **[1]**.

## The Biot-Savart Law

**VII**. Returning to the question raised in Section **II** above, as regards taking the curl of the Biot-Savart Law, it was pointed out that in order for the result to correspond to Ampère's Circuital Law, it is necessary that the curl should not just act on the radial distance from the source electric current elements, but also on the electric current elements themselves. The convective component of the formula cannot be ignored if we are to get a true physical curl.

Within the context of a single rotating electron-positron dipole, the angular momentum can be written as $\mathbf{H} = \mathbf{D}\times\mathbf{v}$, where **D** is the displacement from the centre of the dipole and **v** is the circumferential velocity. When elastically bonded to other dipoles within the wider electron-positron sea, the displacement **D** will be related to the transverse elasticity through Maxwell's fifth equation, $\mathbf{D} = -\varepsilon\mathbf{E}$. (see section **VIII** below including the note on the negative sign). A full analysis can be seen in the articles ***"Radiation Pressure and E = mc²"*** **[7]**, and ***"The 1855 Weber-Kohlrausch Experiment"*** **[8]**. If we substitute $\mathbf{D} = -\varepsilon\mathbf{E}$ into the equation $\mathbf{H} = \mathbf{D}\times\mathbf{v}$, this leads to,

$$\mathbf{H} = \varepsilon\mathbf{v}\times\mathbf{E} \qquad \textbf{(12)}$$

See the appendix at the end regarding why the magnitude of **v** should be equal to the speed of light. Equation **(12)** would appear to be equivalent to the Biot-Savart Law when **E** corresponds to the Coulomb force. However, in the context, **E** will be the centrifugal force and not the Coulomb force. If we take the curl of equation **(12)** we get,

$$\nabla\times\mathbf{H} = \varepsilon[\mathbf{v}(\nabla.\mathbf{E}) - \mathbf{E}(\nabla.\mathbf{v}) + (\mathbf{E}.\nabla)\mathbf{v} - (\mathbf{v}.\nabla)\mathbf{E}] \qquad \textbf{(13)}$$

Since $\mathbf{v}$ is not a vector field, this reduces to,

$$\nabla\times\mathbf{H} = \varepsilon[\mathbf{v}(\nabla.\mathbf{E}) - (\mathbf{v}.\nabla)\mathbf{E}] \qquad \textbf{(14)}$$

Since $\mathbf{v}$ and $\mathbf{E}$ are perpendicular, the second term on the right-hand side of equation **(14)** vanishes. Finally, the $\mathbf{E}$ field corresponds to the centrifugal pressure in the equatorial plane within the rotating dipole. This differs from the Coulomb force in that it arises from the curl in the interior $\mathbf{A}$ field, whereas in Coulomb's law it is the purely radial component of $\mathbf{A}$ which is significant. The aethereal flow around the positron therefore presses laterally against the aethereal flow around the electron because the flow between the two has been cut, and in both cases has been diverted up and down into the axial direction. Nevertheless, $\mathbf{E}$ is still radial and dependent on the magnitude of the radial flow and so it is safe to suppose that $\mathbf{E}$ still satisfies Gauss's Law as per,

$$\nabla.\mathbf{E} = \rho/\varepsilon \qquad \textbf{(15)}$$

Substituting into equation **(14)** this leaves us with,

$$\nabla\times\mathbf{H} = \rho\mathbf{v} = \mathbf{J} = \mathbf{A} \qquad \textbf{(16)}$$

and hence since $\mathbf{B} = \mu\mathbf{H}$ then,

$$\nabla\times\mathbf{B} = \mu\mathbf{J} = \mu\mathbf{A} \qquad \textbf{(17)}$$

which is Ampère's Circuital Law as per equation **(8)**.

## Maxwell's Equations and Summary

**VIII**. Maxwell's eight original equations as listed in his 1864 paper entitled ***"A Dynamical Theory of the Electromagnetic Field"*** **[3]**, in a section entitled *'General Equations of the Electromagnetic Field'*, appear below in modern format. It is often claimed that there were twenty equations in the original list, however the first six of the equations below were written out three times each for each of the three Cartesian components. It is also often claimed that Oliver Heaviside is responsible for the equations that appear in modern textbooks under the heading of *"Maxwell's Equations"* and that by virtue of there only being four, that he has done something profoundly significant. In fact, Heaviside is often hailed for having hidden the very important magnetic vector potential **A** from view.

The modern textbook listings are however simply, (i) The divergence of equation **(B)** below, as in $\nabla.\mathbf{B} = 0$, which also appeared in Maxwell's 1861 paper, (ii) *Gauss's Law* exactly as shown at equation **(G)** below, (iii) Faraday's Law of Induction (time varying only), as in the curl of the second term of the right-hand side of equation **(D)** below, and (iv) Ampère's Circuital Law with Maxwell's displacement current added, as in a combination of equations **(A)** and **(C)** below, which also appeared as equation (112) in Maxwell's 1861 paper. The modern textbooks also omit equation **(D)** below while supplementing the list with an equivalent equation under the misnomer of *The Lorentz Force*. The four equations in the textbooks therefore actually hide things rather than add anything, but the biggest problem with the textbooks is that they have dropped the physical context within which Maxwell originally derived the equations. That context was the sea of molecular vortices, and it makes a mockery of displacement current to present it as a virtual concept in the context of a pure vacuum.

## Maxwell's Original Eight Equations 1864

**(A)** The Equation of Total Currents including ***"Displacement Current"***

$$\mathbf{J}_{total} = \mathbf{J}_{conduction} + \partial\mathbf{D}/\partial t$$

**(B)** The Equation of Magnetic Force

$$\nabla\times\mathbf{A} = \mu\mathbf{H}$$

**(C)** The Equation of Electric Current (Ampère's Circuital Law)

$$\nabla\times\mathbf{H} = \mathbf{J}_{total}$$

**(D)** The Equation of Electromotive Force (The Lorentz Force)

$$\mathbf{E} = \mu\mathbf{v}\times\mathbf{H} - \partial\mathbf{A}/\partial t - \mathrm{grad}\psi$$

**(E)** The Equation of Electric Elasticity (Hooke's Law)

$$\mathbf{D} = \varepsilon\mathbf{E}$$

**(F)** The Equation of Electric Resistance (Ohm's Law)

$\mathbf{E} = R\mathbf{J}_{\mathbf{conduction}}$

**(G)** Gauss's Law for Free Electricity

$\nabla.\mathbf{D} = \rho$

**(H)** The Equation of Continuity

$\nabla.\mathbf{J} + \partial\rho/\partial t = 0$

Maxwell's second equation, $\nabla\times\mathbf{A} = \mu\mathbf{H}$, was derived on the basis that **A** is a momentum density from which we can then derive the solenoidal equation $\nabla.\mu\mathbf{H} = 0$ ($\nabla.\mathbf{B} = 0$) that is familiar in the modern listings of four Maxwell's equations. Modern textbooks however reverse the reasoning and work backwards to **A**, giving no physical meaning to **A**, and in the process adding an arbitrary constant of integration and inventing a red herring topic known as *"gauge theory"*.

The Biot-Savart Law is notably absent from the list. Interestingly there is an equation of the form $\mathbf{H} = \varepsilon\mathbf{v}\times\mathbf{E}$ which has a superficial resemblance to the Biot-Savart Law and from which we can derive Ampère's Circuital Law (Maxwell's third equation) simply by taking its curl, but this equation only exists within the context of an electron-positron sea of dipoles that fill all of space and which is not acknowledged to exist by mainstream physicists. The velocity **v** term, where **v** determines the speed of light *(see Appendix)*, is the circumferential velocity of the individual rotating electron-positron dipoles, while **E** is equal to $\mathbf{v}\times\mathbf{B}$. In this context, Ampère's Circuital Law becomes $\nabla\times\mathbf{B} = \mu\mathbf{A}$, where **A** is the displacement current. One might argue that in the steady state, the circulating electrons and positrons in each of the tiny dipoles cancel each other due to their opposite charges, as this would be so if electric current were to be primarily based on the flow of charged particles. There is however a deeper flow of electric fluid which is the primary essence of electric current. In the case of conduction currents, charged particles merely get accelerated along by the electric fluid, with negative particles eating their way in the opposite direction to that of positive particles, and they never catch up with the aethereal flow due to electrical resistance in the conducting channels.

Not even Maxwell himself realized that the magnetic vector potential **A**, which he termed the *electromagnetic momentum*, in fact corresponds to his very own displacement current. The displacement current was essential in Maxwell’s derivation of the electromagnetic wave equation, but he never made the realization that the displacement current is in fact the vector **A**. The general misunderstandings surrounding displacement current is a serious problem which is fudged in the textbooks by adding a ***virtual*** displacement current as an extra term to Ampère’s Circuital Law, when in fact the original Ampère’s Circuital Law should simply be used in conjunction with the actual displacement current **A** **[2]**. In a steady state magnetic field, the displacement current **A** is undergoing fine-grained circulation with no net translation, while in the dynamic state when time varying electromagnetic induction is involved, there is a net translational flow of **A** which constitutes wireless electromagnetic radiation.

Maxwell’s fourth equation **(D)** is easily recognizable as the Lorentz force. The three components on the right-hand side of equation **(D)** appeared in equations (5) and (77) in Maxwell's 1861 paper **[1]**. If we take the curl of equation **(D)** we end up with,

$$\nabla\times\mathbf{E} = -(\mathbf{v}.\nabla)\mathbf{B} - \partial\mathbf{B}/\partial t = -d\mathbf{B}/dt \qquad \textbf{(18)}$$

See **Appendix B** in ***“The Double Helix Theory of the Magnetic Field”*** **[6]** for the full analysis. Equation **(18)** with the convective term $(\mathbf{v}.\nabla)\mathbf{B}$ removed, hence leaving only the partial time derivative $-\partial\mathbf{B}/\partial t$ term, is one of the equations in the modern listings of four Maxwell’s equations and it is known as Faraday’s Law. It deals only with time varying electromagnetic induction although Faraday’s original flux law also takes into account the convective effect $\mathbf{E} = \mathbf{v}\times\mathbf{B}$.

Maxwell’s fifth equation is a form of Hooke’s Law and it is most relevant in relation to the elasticity of the electron-positron sea. In the listing above, Maxwell seems to have dropped the negative sign. This must be a minor mistake on Maxwell’s part because the negative sign is present in his 1861 paper where he first introduced the equation in the preamble of Part III and at equation (105) **[1]**.

## References

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

**[2]** Tombe, F.D., ***“Displacement Current and the Electrotonic State”*** (2008)
http://gsjournal.net/Science-Journals/Research%20Papers-Mechanics%20/%20Electrodynamics/Download/228

**[3]** Clerk-Maxwell, J., ***"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 original eight Maxwell's equations are found in the link below in Part III entitled *'General Equations of the Electromagnetic Field'* which begins on page 480,
http://www.zpenergy.com/downloads/Maxwell_1864_3.pdf
Maxwell's derivation of the electromagnetic wave equation is found in the link below in Part VI entitled *'Electromagnetic Theory of Light'* which begins on page 497,
http://www.zpenergy.com/downloads/Maxwell_1864_4.pdf

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

**[5]** The 1937 Encyclopaedia Britannica article on *'Ether'* discusses its structure in relation to the cause of the speed of light. It says, *''POSSIBLE STRUCTURE. __* ***The question arises as to what that velocity can be due to. 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 order of magnitude as the vortex or circulation speed - - - -"***
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See also ***"The Double Helix and the Electron-Positron Aether"*** (2017)
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**[8]** Tombe, F.D., ***"The 1856 Weber-Kohlrausch Experiment"***, (2015)
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## Appendix

$\mathbf{H} = \varepsilon\mathbf{v}\times\mathbf{E}$ where $\mathbf{E} = \mu\mathbf{v}\times\mathbf{H}$ therefore $\mathbf{H} = \varepsilon\mu\mathbf{v}\times(\mathbf{v}\times\mathbf{H})$

$|H| = |\varepsilon\mu v^2 H|$ (**v**, **E**, and **H** are mutually perpendicular in the rotating dipole)

$\varepsilon\mu = 1/c^2$ and hence $v = c$