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A Short Note on Displacement Current

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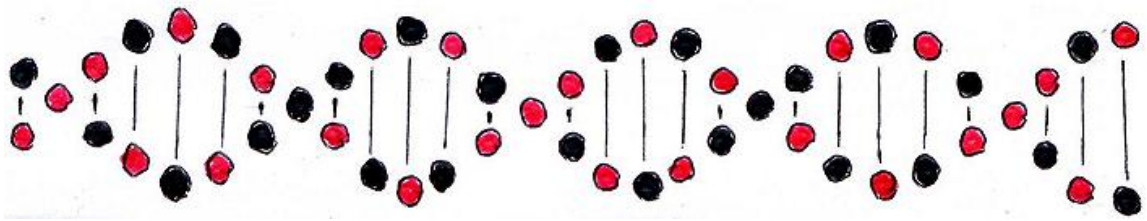
Abstract. **Maxwell's *displacement current* is a controversial topic. It has never been isolated experimentally in wireless radiation, yet its existence in space is a mathematical necessity when it comes to deriving the electromagnetic wave equations. This article will examine how we might justify its existence.**



Introduction

I. James Clerk Maxwell originally conceived the idea of displacement current in the preamble to Part III of his 1861 paper, ***"On Physical Lines of Force"***, **[1]**. He conceived it originally as a tangential or rotatory displacement of the electric particles in the sea of molecular vortices which he believed filled all of space, yet by the end of his preamble he seems to have simplified it to something akin to linear polarization in a dielectric, and he linked it to changes in the electrostatic field.

However, when it came to deriving the electromagnetic wave equation in the magnetic field in his 1865 paper, ***"A Dynamical Theory of the Electromagnetic Field"***, **[2]**, displacement current instead became linked to the electric field that arises in the case of time-varying electromagnetic induction. Maxwell, meanwhile, never elaborated on the physical meaning of displacement current in this context.

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II. In the modern era, Maxwell's dielectric sea of tiny aethereal vortices is no longer recognized to exist, and so Maxwell's original 1861 explanation for displacement current can no longer be presented in the textbooks. Instead, displacement current is justified within the context of conservation of electric charge in a charging or discharging capacitor. However, this restricted

laboratory context fails to account for how a displacement current could exist in starlight in outer space. Also, this form of displacement current is based around the electrostatic **E** field and so it can't be the displacement current which is used in the derivation of the electromagnetic wave equations, since we know that the electrostatic field is not used in these derivations. The textbooks, meanwhile, cover up this discrepancy, simply by refraining from drawing attention to the distinction between an electrostatic field, on the one hand, and an electric field that arises through time-varying electromagnetic induction, on the other hand. The two **E** fields involved in the textbook derivation of the electromagnetic wave equations are simply substituted into each other as though they are one and the same thing. They use an electrostatic field, $-\nabla\psi$, in the displacement current while using an induction **E** field, $-\partial\mathbf{A}/\partial t$, in Faraday's law, yet they treat them as though they are interchangeable.

Conclusion

III. Maxwell's displacement current, which is crucial in the derivation of the electromagnetic wave equations, cannot be derived from first principles, and neither is there any experiment that can isolate it in wireless radiation in space. Nevertheless, its existence is not in doubt, and so the onus is on us to identify the physical structure of the electromagnetic wave-carrying medium, such as would embrace a displacement current that is rooted in the time-varying electromagnetic induction process, and it seems that Maxwell himself more or less had this structure identified in Parts I and II of his 1861 paper, ***"On Physical Lines of Force"***, **[1]**, **[3]**. It would seem that Maxwell's sea of molecular vortices is actually a sea of tiny electric circulations, and that displacement current constitutes the swirling of electric fluid from vortex to vortex in conjunction with electromagnetic waves, **[4]**, **[5]**, **[6]**, **[7]**, **[8]**.

References

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[2] 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 **H** begins on page 497 in the first link.
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[3] Tombe, F.D., ***"Maxwell's Displacement Current in the Two Gauges"***, (2021)
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[4] Tombe, F.D., ***"The Double Helix Theory of the Magnetic Field"***, (2006) Galilean Electrodynamics, Volume 24, Number 2, p.34, (March/April 2013) https://www.researchgate.net/publication/295010637_The_Double_Helix_Theory_of_the_Magnetic_Field

[5] Tombe, F.D., ***"Longitudinal Magnetic Waves***", (2023) https://www.researchgate.net/publication/368460888_Longitudinal_Magnetic_Waves

[6] Lodge, Sir Oliver, ***"Ether (in physics)"***, Encyclopaedia Britannica, Fourteenth Edition, Volume 8, Pages 751-755, (1937)
The quote below is 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"
The article then goes on to cite Lord Kelvin, **"The Vortex Theory of Ether,"** *Phil. Mag.* (1887) and *Math. and Phys. Papers*, vol. iv. and passim; also G. F. FitzGerald, *Proc. Roy. Dub. Soc.* (1899), or *Collected Papers*, pp. 154, 238, 472.
http://gsjournal.net/Science-Journals/Historical%20PapersMechanics%20/%20Electrodynamics/Download/4105

[7] 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

[8] 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. It will be seen that Bernoulli is a thorough Cartesian in spirit; not only does he reject action at a distance, but he insists that even the elasticity of his aether shall be explicable in terms of matter and motion. This aggregate of small vortices, or " fine-grained turbulent motion," as it came to be called a century and a half later,* is interspersed with solid corpuscles, whose dimensions are small compared with their distances apart. These are pushed about by the whirlpools whenever the aether is disturbed, but never travel far from their original positions. A source of light communicates to its surroundings a disturbance which condenses the nearest whirlpools; these by their condensation displace the contiguous corpuscles from their equilibrium position; and these in turn produce condensations in the

whirlpools next beyond them, so that vibrations are propagated in every direction from the luminous point. It is curious that Bernoulli speaks of these vibrations as longitudinal, and actually contrasts them with those of a stretched cord, which, "when it is slightly displaced from its rectilinear form, and then let go, performs transverse vibrations in a direction at right angles to the direction of the cord." When it is remembered that the objection to longitudinal vibrations, on the score of polarization, had already been clearly stated by Newton, and that Bernoulli's aether closely resembles that which Maxwell invented in 1861-2 for the express purpose of securing transversality of vibration, one feels that perhaps no man ever so narrowly missed a great discovery. Bernoulli explained refraction by combining these ideas with those of his father. Within the pores of ponderable bodies the whirlpools are compressed, so the centrifugal force must vary in intensity from one medium to another. Thus a corpuscle situated in the interface between two media is acted on by a greater elastic force from one medium than from the other; and by applying the triangle of forces to find the- conditions of its equilibrium, the law of Snell and Descartes may be obtained. * Cf . Lord Kelvin's vortex-sponge aether, described later in this work."