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The Law of Electromagnetic Induction Proved to be False Using Classical Electrostatics

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Abstract: A new explanation to the effect of electromagnetic induction is proposed, while simultaneously rejecting the currently accepted ”Induction Law”, originally proposed by Neumann, 1845. According to the new theory, a current will be induced by any changing electric field, due to the Continuity Equation of Electricity and the Law of Electric Displacement, two of Maxwell's Equations.

It has been shown elsewhere that a current within a conductor, in spite of an overall charge neutrality, will give rise to a force upon another such current, due to Coulomb's Law, thereby rejecting the claims of the Lorentz Force. Here it is shown that the same Coulomb force can also account for electromagnetic induction. A comparison between the predicted phase shift from the primary to the secondary loop within a transformer according to this theory and according to the Induction Law gives credit to the former, while the latter fails. This result follows as a consequence of the discovery that any electric current through a resistive circuit must be proportional to the time derivative of the applied voltage, not primarily the voltage itself, as usually has been inferred from Ohm's Law. It is shown that it is only a coincidence with the fact that the time derivative of an exponential function is proportional to that same exponential function, which gives this result, usually understood as Ohm's Law.

The exponentially decaying nature of a current through a D.C. circuit is due to the continous loss of excesss charges at the poles, as the current flows, just an analog to what happens, when a charged capacitor is connected to a resistive loading.
Keywords: electromagnetic induction, Coulomb's Law, Ohm's Law, Maxwell's equations.

1. Introduction

The author has earlier succeeded in showing that the electromagnetic force between two current carrying conductors can satisfactorily be explained by using Coulomb's original force law of 1785.[1]

The Lorentz Force is no more needed. Furthermore, it even fails to predict the qualitative behaviour of the force within Ampere's Bridge, as measured by Pappas and Moyssides in the early 1980's.[2]

How Coulomb's Law can be used in order to explain the electromagnetic force between currents is thoroughly explained. Shortly, there appears a difference in the strength of the electric force, which the positive and negative charges give rise to upon the second current, due to the velocity dependent effects of retarded action. This difference can account for the force, usually explained by using Lorentz's Force Law.

In this paper the consequences of the above mentioned discovery is further developed in the case of electromagnetic induction and Ohm's Law. It is shown that in both cases there is a time dependent change in the strength of the electric field within the conductor, thus causing a current to flow as a consequence of the Continuity Equation of Electricity and the Law of Electric Displacement. The difference is that in the first case the electric field is externally induced, in the latter it comes from within, the field lines being aligned along the conductor, going between the both poles.

2. Analysis of a D.C. Circuit

If first looking at a traditional D.C. circuit, there is a D.C. voltage source, e.g. a battery, with an excess of charges at one of the poles, a deficit at the other. If they are connected by a resistive loading, a current will flow under the influence of the electric field between the poles. It ought to be noticed that in the case of a battery, with no continuous support of new charges, the strength of the current must continuously decrease, until the battery has become completely discharged. This process would best be described mathematically by using the exponential function, as in the case of a capacitor, at least when studying the steady state case. The chemical or physical properties of a battery would best be neglected here. Otherwise it is better to think of a sufficiently large capacitor such that it is capable of delivering an almost constant current, in the same way as a battery. The relevant property is the charge content of the D.C. voltage source, often expressed in amperehours. It is limited, and as the current flows between the poles, it is simultaneously decreasing slowly, a process best described by the exponential function, as when a capacitor is being discharged through a resistance.

The mathematical analysis could preferably be performed as follows:

$$\nabla \bullet \bar{j} + \frac{\partial \rho}{\partial t} = 0 \qquad \textbf{(1)} \quad .$$

This is the so-called Continuity Equation of Electricity, one of Maxwell's Equations. Thereafter is chosen

$$\nabla \bullet \bar{D} = \rho \qquad \textbf{(2)} \quad ,$$

also this one of Maxwell's Equations. If those two are combined, follows:

$$\nabla \bullet (\bar{j} + \frac{\partial \bar{D}}{\partial t}) \qquad \textbf{(3)} \quad .$$

Integration of Eq.(3) with respect to t gives:

$$\bar{j} = - \frac{\partial \bar{D}}{\partial t} + f(t) \qquad \textbf{(4)} \quad .$$

The funcion f(t) can be determined if realizing that within a closed D.C. circuit, without any externally applied electromagnetic fields, the electric displacement $\overline{D}$ will approach zero, as the current density $\overline{j}$ does. Of course, by mathematical reasons, any suitable function f(t) could be added to $\partial \overline{D} / \partial t$, but it does not make any sense. when regarding the relationship between cause and action in this special case. The fundamental physical process to be regarded is the transport of excess charges from one pole to the other, thus causing a continuous decrease in the strength of the electric field, just as Coulomb's Law prescribes. When all the excess charges have been annihilated, by mediation of the current, the current too becomes zero. Hence, in this case

$$f(t) = 0 \qquad \textbf{(5)} \quad ,$$

must be the proper choice, and accordingly

$$\overline{j} = - \frac{\partial \overline{D}}{\partial t} \qquad \textbf{(6)} \quad .$$

Apparently, the current (here defined in terms of the current density) must be proportional to the time derivative of the voltage (here defined in terms of the electric displacement).

2.1. Consequences for Ohm's Law

If assuming a resistive loading between the two poles of the D.C. source, with length L, cross section area A, using the relation

$$\overline{D} = \varepsilon_0 \ \varepsilon_r \ \overline{E} \qquad \textbf{(7)}$$

and

$$\overline{E} = - \nabla V \qquad \textbf{(8)} \quad ,$$

thereby defining directions correctly, gives

$$I = \frac{\varepsilon_0 \ \varepsilon_r \ A}{L} \frac{\partial V}{\partial t} \qquad \textbf{(9)} \quad .$$

Since $\varepsilon_0 \ \varepsilon_r$ is the coupling constant between $\overline{D}$ and $\overline{E}$ within the conducting medium, here the resistive loading betweeen the both poles of a battery, it can be inferred that the factor $\frac{\varepsilon_0 \ \varepsilon_r \ A}{L}$ before $\frac{\partial V}{\partial t}$ in Eq.(9) by virtue of dimension analysis means a capacitance. The consequence is that the relevant coupling constant between current and voltage is a capacitance, provided first the voltage is differentiated with respect to time. Assuming an exponential dependence at both the current and the voltage, as in the factual D.C. case, the time derivative any of the function happens to be proportional to that very function and hence, the current and the voltage are proportional to each other in that case, i.e. nothing else than what Ohm's Law claims.

3. A Simple Transformer

From a conductor, carrying a current I, there will arise an electric field according to Coulomb's Law, proportional to this current. This has not earlier been properly understood, but in a paper by this author[1] it is thoroughly shown, how two currents affect each other with an electric force, according to Coulomb's Law (1785). No magnetic field nor Lorentz force is needed. In this paper, however, the interesting variable is the electric field, since it has above been established that a current will flow in a circuit, due to a changing electric field. This is assumed to be the cause behind both Ohm's Law and the Induction Law by Neumann. Therefore, the expression for the Coulomb force between currents in the mentioned paper must be divided by the effective - or virtual - charge density of the second current. Eq. (25) gives the force on differential form.[1] Figure 1 is also given here for sake of clarity.

$$\frac{d^2 \overline{F}}{d x_1 \, d x_2} = \frac{(\mu_0 I_1 I_2 \cos\varphi \cos\psi)\, \overline{u_r}}{4 \pi r^2} \qquad \textbf{(10)} \;.$$

In order to attain an expression for the electric field at a specific point, one has to divide Eq.(10) with the amount of charges at the secondary conductor the first current affects by this force. This amount must be equal to the effective -i.e. virtual- charge density of the second conductor times the length element, thus using Eq.(21) and (23) of the just mentioned paper.[1] Hence,

$$\frac{d \overline{E}}{d x_1} = - \frac{(I_1 \cos\varphi)\, \overline{u_r}}{4 \pi \varepsilon_0 \varepsilon_r c r^2} \qquad \textbf{(11)} \;.$$

Still being on differential form, it is necessary to finally integrate Eq.(11) along whole the primary circuit, i.e. with respect to x_1. This gives the result:

$$\overline{E} = - \oint_{x_1} \frac{d \overline{E}}{d x_1} d x_1 \qquad \textbf{(12)} \;.$$

The details of the integration are deliberately omitted here. The important result above is Eq.(11), which clearly shows that the electric field is proportional to both the current of the primary circuit and to the inverse square of the distance, properties it shares with the magnetic field. If succeeding in falsifying the Induction Law, which is based upon the usage of the magnetic field, the model of this author remains a reliable candidate to giving the correct explanation to the very phenomenon of electromagnetic induction.

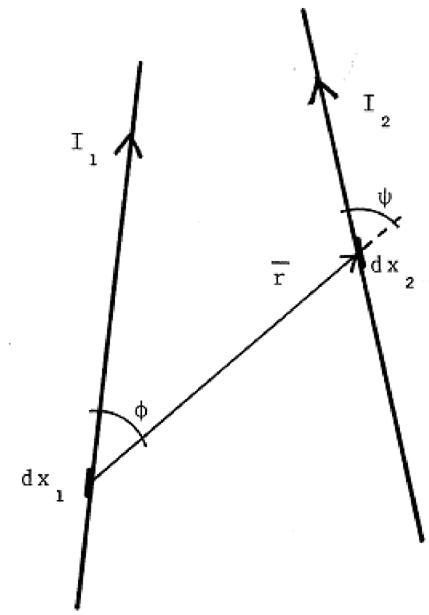
Later in this paper it will be shown that the new model is capable of predicting the observed phase shift between the primary and the secondary circuit of a transformer. If now the primary current is allowed to vary with time, so does the electric field, according to the results above. Hemce, a current will be induced according to Eq.(5) and (8), thereby taking into account Eq.(6) and (7). Hence,

$$I_2 = - \frac{\varepsilon_0 \varepsilon_r A}{L} \frac{\partial}{\partial t} \oint_{x_1} \oint_{x_2} \frac{(I_1 \cos\phi \cos\psi) \, dx_1 \, dx_2}{4 \pi \varepsilon_0 \varepsilon_r c r^2} \qquad \textbf{(13)}$$

where the integral corresponds to the induced voltage (electromotoric force, emf) of the secondary circuit. Therefore, one may shorter write:

$$I_2 = - \frac{\varepsilon_0 \varepsilon_r A}{L} \frac{\partial V_2}{\partial t} \qquad \textbf{(14)}$$

Figure 1.



Evidently, the term $\frac{\varepsilon_0 \varepsilon_r A}{L}$ corresponds to a capacitance. This was already discussed in connection with Eq.(8). For convenience, define therefore

$$C_{eq} = \frac{\varepsilon_0 \varepsilon_r A}{L} \qquad \textbf{(15)} \quad .$$

It thus appears very clearly that the result concerning Ohm's Law is valid also in this case. The fundamental cause behind any currents apparently is a varying electric field, independently of how this electric field is brought into an actual circuit; an internal source, as in the case of Ohm's Law, or external, as in the case of the Induction Law. In the following chapter it will be shown that the Induction Law according to Neumann is false and that the new model can account for the characteristic phase shift between the primary and the secondary circuit of a transformer.

4. Analysis of Voltage Measurements at the Output of the Secondary Circuit of a Transformer

4.1. The New Theory

If now connecting e.g. a volt meter to the output of a transformer, it is necessary to first make an analysis of what the instrument really is 'feeling'. In fact, a volt meter will feel the same measurable as an ampere meter, and independently of the method one prefers to use, the measurement result will be proportional to the current. In the case of an amplifier volt meter, or an oscilloscope, it is the charges, i.e. the current, which is entering the gate of the input transistor, thereby determining the output level of the screen or the volt meter scale. Hence, only a real coupling constant is multiplied with the current in order to read voltage. It would be easily realized that if only a current thus can be detected by using ordinary measurement instruments, it is not meaningful to discuss any phase shift between current and voltage, due to e.g. an oscilloscope figure. Any measured phase shift must namely be due to a phase shift between currents. But since several existing laws deal with both of them simultaneously, they must be dealt with, though carefully.

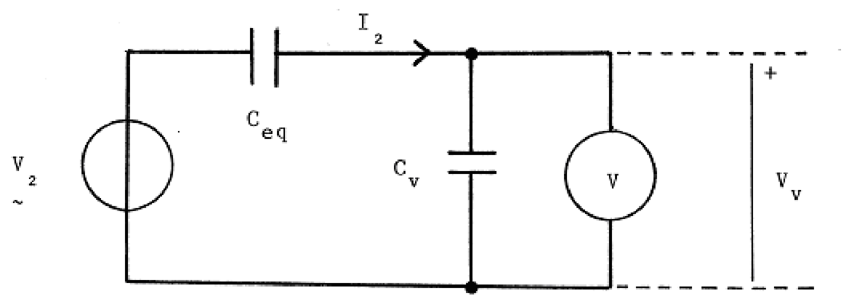
In the actual case, with a transformer, the applied volt meter at the output may best be described as a prolonged secondary loop, obeying basically Eq.(14). C_{eq} must only be replaced by an expression for the equivalent capacitance of the total circuit, including the secondary loop and the volt meter. That expression must obey the law of series connection for capacitances, or:

$$\frac{1}{C'_{eq}} = \frac{1}{C_{eq}} + \frac{1}{C_v} \qquad \textbf{(16)} \quad .$$

Accordingly, the voltmeter will show:

$$V_v = R_v \left(- C'_{eq} \frac{\partial V_2}{\partial t} \right) \qquad \textbf{(17)} \quad .$$

Figure 2.



Assuming a sine driving current of the primary circuit, as is the common praxis in case of a transformer, there will appear a -90° phase shift from V_2 to V_v, as will easliy be realized from Eq.(14)above. However, of most interest is the displayed phase shift on a typical oscilloscope. This must be between the primary current and the secondary one, according to the theses of this article, i.e. there are currents which are measured or'felt' by the instruments. According to Eq.(13) there must be a -90° phase shift from primary to secondary current and this is well in accordance with measurements.

4.2.The Induction Law

In order to show the failure of the Induction Law, one must first clarify, what quantity is really being measured in connection with this model. For convenience, the Induction Law may be written:

$$V_2 = -\frac{\partial}{\partial t}\iint_{A_s} \overline{B} \bullet d\overline{A_s} \qquad \textbf{(18)} \quad .$$

Since the magnetic field $\overline{B}$ is proportional to the primary current - and in phase with it as well -

$$\overline{B} = \frac{\mu_0}{4\pi}\oint_{x_1} \frac{I_1 \, d\overline{x_1} \times \overline{r}}{r^3} \qquad \textbf{(19)} \quad ,$$

the induced voltage lags 90° behind the primary current I_1, and hence there is a total 180° phase shift between the primary and the secondary current, and it is these two currents, which are 'felt' by the two oscilloscope inputs, according to the theses of this article. This, however, is not in accordance with measurements, and thus the Induction law has failed.

5. Conclusions

The result of the analysis above is very clear. Both Ohm's Law and the Induction law can be explained as originating from two of Maxwell's Equations: the Continuity Equation of Electricity and the Law of Electric Displacement. The first equation tells us, how a current arises, whenever an electric field is varying with time, thus acting in order to eliminate an excess of charges somewhere. The second equation expresses the relationship between the charge density and the electric field. It has been shown that these two laws give an appropriate and adequate description of what is acting behind Ohm's Law and the Induction Law.

Finally, the currently widespread concepts concerning these are finally being satisfactorilly rejected. In doing so, it appears that fundamental electrodynamics must once again become the center of interest among scientists.

References

(1) J.O.Jonson, Chinese Journal of Physics, VOL.35, NO.2, April 1997, pp.139-49.
(2) P.G.Moyssides and P.T.Pappas, J.Appl.Phys. 59,19 (1986).

Units

Throughout the article MKSA units have been used. The variables used are listed below:

A	area of the cross section of a conductor
$\overline{A_s}$	area vector of the secondary loop of a transformer
$\overline{B}$	magnetic field due to thecurrent of the primary circuit of a transformer
c	velocity of light
C_{eq}	equivalent capacitance of the secondary circuit of a transformer
C'_{eq}	equivalent capacitance of the total secondary circuit, including a connected volt meter
or an	oscilloscope
C_v	equivalent capacitance of the volt meter
$\overline{D}$	electric displacement
$\overline{E}$	electric field
$\overline{F}$	electrostatic force according to Coulomb's Law
f(t)	arbitrary function of time
I	current
I_1	primary current
I_2	secondary current
$\overline{j}$	current density per unit volume
L	length of applied resistive loading
R	resistance
R_v	resistance of the volt meter
$\overline{r}$	distance vector, defined from a current element of the primary loop to a current
element of the	secondary loop
t	time
$\overline{u_r}$	unit vector along a distance vector
V	general potential drop
V_2	induced voltage (electromotoric force, emf) of the secondary loop
V_v	registered voltage of an applied volt meter or oscilloscope, connected to the secondary
loop	
x_1	length variable along the primary loop
x_2	length variable along the secondary loop

Greek symbols

ε_0	dielectricity constant of vacuum
ε_r	relative dielectricity constant of the medium being used
ρ	cgarhe density per unit length
ϕ	angle between the distance vector and the primary current
ψ	angle between the distance vector and the secondary current
μ_0	permeability of vacuum