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Introduction to Electromagnetism

Historical Review on Classical Electromagnetism & Rational Reconstruction of Formal System

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内容提要

作为一本引论，本书可以视作对 J. C. Maxwell 所创建经典电磁场理论体系的一次逻辑梳理，同时，还是针对用于描述定义于一般 3 维空间域之中、由变化电流所激发动态电磁波的形式系统，相应构造的一次理性重建。本书的全部基础在于数学的分析或者逻辑的推理。局限于经典理论框架之内，由 Maxwell 最初提出、并且只允许当作一种纯粹人为假设来对待的位移电流，需要视为一个在形式上不可或缺的量。但是，至今无人知晓隐藏于这个形式量背后的真实物理内涵。本书逻辑地论证：这个习惯性的传统认定并不必要。一个重新建构于单个矢量势之上、可以用于描述变化电流所激发电磁场完整状态的形式系统，不仅仅仍然允许在形式上重新逻辑地退化为经典表述的 Maxwell 方程组，而且借助于双旋度算子的沿用，构造了一个可以用于直接求解 3 维空间域边值问题的 2 阶偏微分方程。相关分析还表明，随着这个用于求解一般 3 维空间域数学物理模型的建立，与求解电磁波相关的数值模拟的计算工作量可望大幅度减少。

Brief Introduction

This book, as an introduction, may be regarded as a time of logical arrangement over the classical electromagnetism, created by J. C. Maxwell, and a rational reconstruction of the formal system that can be used to describe a dynamic electromagnetic wave excited by a varying current in a general three-dimensional geometric space. It might especially lay on the deduction logic in this book. Although the displacement current, supported by Maxwell initially only as a purely artificial assumption, would be indispensable in form, nobody really knows the physical reality implied in the formal quantity. It will be logically demonstrated that the traditional assumption is unnecessary and a newly constructed vector potential can be used to express the whole state of a dynamic electromagnetic field excited by a varying current. Besides, this book also supplies a new mathematic physical model, which not only is possibly degenerated into the classical Maxwell's equation set but also corresponds with a 2-order partial differential equation by using a bispinor and, correspondingly, may be directly used to solve a three-dimensional boundary value problem. Besides, the relative analysis shows us that, while a complex three-dimensional boundary value problem is solved, the calculation of computer will be expected to decrease by a big margin.

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Dedicated to all the predecessors and friends
who have ever helped and supported me!

——At the age of 72, my Chinese year of fate

While research workers exert themselves to extend the boundary of science, other scientists are more anxious to ascertain whether the scaffolding is really solid, and whether their more and more daring and complex edifices do not risk giving way. Now the task of the latter, which is neither less important nor less lofty than that of discovery, necessarily implies a return to the past. This critical work is essentially of an historical nature. While it helps to make the whole fabric of science more coherent and more rigorous, at the same time it brings to light all the accidental and conventional parts of it, and so it opens new horizons to discoverer's mind. If that work were not done, science would soon degenerate into a system of prejudices; its principle would become metaphysical axioms, dogmas, a new kind of revelation.

... Alas, the exclusive worship of positive facts makes some scientists sink into the worst kind of metaphysics — scientific idolatry.

Fortunately, it happens at certain periods of evolution that resounding and paradoxical discoveries make an inventory and a thorough survey of our knowledge more obviously necessary to everybody. We are fortunate enough to be living at one of these critical and most interesting periods.

—— George Sarton

《The life of science — Essays in the history of civilization》

Forewords

Without doubt, the classical electromagnetic theory established by Maxwell and other pioneers in this domain should be regarded as one of the greatest achievements in the modern science-technique progress, and also as one of the branches with great attraction in the modern natural science system. And, since the famous Maxwell's equation set

$$\begin{cases} \nabla \cdot \boldsymbol{E} = \dfrac{1}{\varepsilon_0}\rho \\ \nabla \times \boldsymbol{E} = -\dfrac{\partial \boldsymbol{B}}{\partial t} \\ \nabla \cdot \boldsymbol{B} = 0 \\ \nabla \times \boldsymbol{B} = \dfrac{1}{c^2}\left(\dfrac{1}{\varepsilon_0}\boldsymbol{J} + \dfrac{\partial \boldsymbol{E}}{\partial t}\right) \end{cases}$$

is with a kind of obvious symmetry character, lots of scholars have usually eulogized it as a theorem endowed with a greatest beauty in form. Of course, a much more important and essential thing would be that all the modern life cannot leave out the inconceivably huge technique progress the theorem brings us. Then, though being not a professional electromagnetism researcher, the writer has been deeply attracted by such a successful theorem.

However, it might just originate from a kind instinct to enquire why a right science statement or theorem could completely base upon some purely artificial assumption, the writer began to pay attention to the traditional theorem with a more than one and a half century old history more than ten years ago. Or, if more strictly speaking, it was a series of strange, a little abnormal in logic, and lots of basic problems seemingly not really solved and essentially related to each other that excited my interest on this fresh and fascinating area. And, the early thinking might be focused on these different propositions as follows.

(1) Incontestably, the generally said displacement current $\partial \boldsymbol{E}/\partial t$, presented in the basic equation set and supposed by Maxwell primarily only as a pure hypothesis, plays a crucial role in the whole classical theorem. Or, provided both the $\boldsymbol{E}$ and $\boldsymbol{B}$ should be defined as two basic and necessary physical quantities to formally express the electromagnetic wave excited by a real varying electric current, such a displacement current hypothesis would be indispensable in form. But, since it was so, why cannot such an indispensable formal quantity $\partial \boldsymbol{E}/\partial t$ form a necessary response with some physical reality, though the answer of which is temporarily

unknown to us, but exist only based upon a pure artificial assumption? Equivalently speaking, we should reconsider and detect the physical reality hidden behind such an indispensable formal quantity $\partial \boldsymbol{E}/\partial t$, or we cannot but regain to carefully investigate what is the material reality that can generate the really existing influence identical to $\partial \boldsymbol{E}/\partial t$.

(2) As the unique formal foundation of the whole classical theorem, Maxwell's equation set, as same as a linear partial differential equation set, is equipped with identical numbers of independent equations and variables in appearance. Then, it usually brings us a seemingly exact imagination that the equation set would be proper or compatible in logic. But, well known, such a maybe trivial judgement belongs to the domain of algebra equations. Or, it still needs a strict demonstration in mathematics when the law is extended into the domain of differential equations. In fact, provided we remake a little deeper and more reasonable consideration from a different angle, it may be not difficult to immediately find some abnormity evidently presented in the customary cognition. That is, if any given charge and current distributions, ρ and $\boldsymbol{J}$, can be reasonably defined as two independent variables, both of which correspond to two really existing sources to excite electromagnetic field, while $\boldsymbol{E}$ and $\boldsymbol{B}$ could be simultaneously regarded as two suitable and irreplaceable dependent variables used to formally describe or uniquely specify the state of a dynamic electromagnetic field, everybody must immediately face with a huge perplexity or finite irrationality in logic: why does the former, ρ and $\boldsymbol{J}$, be of four independent scalar components while the latter, $\boldsymbol{E}$ and $\boldsymbol{B}$, be with six independent scalar components? In logic, it always is reasonable to regard both of the independent variables and dependent variables as the inverse image and the image of a certain mapping, no matter what the details of which are really. All these seemingly simple and normal phenomena usually easier neglected just show us that the observable logic inconsistence between both the independent and dependent variables must present in the classical theorem. And, how can this indisputable abnormality in logic be removed, and what is the indepth or more essential reason hidden in the abnormalities?

(3) Simultaneously, provided a kind of rational consideration coinciding with purely formal logic significance continuously made, we can further find a customarily accepted judgement, the above-mentioned Maxwell's equation set could form a proper mathematic-physical model that was possibly used to make a complete description of a dynamic varying electromagnetic field, not really exact. Only according to a common knowledge of elementary differential and integral calculus, ought to well known to everybody, when a differential equation or a set of differential equations defined as the governing equation of a properly proposed boundary value problem in mathematics, the differential equation or at least a singular equation in the set must be a second order or more than second order differential equation. Inversely, it is always impossible for the governing equation to match with a properly proposed boundary condition that is usually with a first order differential. Then, it might be reasonably pointed out that a proper mathematic-physical model to possibly correctly describe a dynamic electromagnetic field has not been really built. And, it just is the reason for almost all the

textbooks to even not directly mention any proposition dealing with a properly proposed boundary value problem about a general dynamic electromagnetic field, though which must be unavoidable and imperative to all the electromagnetism theorem, and it is also the unique reason for the modern calculation electromagnetism to not successfully assemble a united and effective calculation scheme.

(4) In principle, the basic equations presented separately in electrostatics and magnetostatics are only used to formally express some certain states of an electrostatic field and a magnetostatic field. However, it is not difficult to find that, totally differing from both the static theorems, the things the classical Maxwell's equation set might directly express would not be the state of a dynamic varying electromagnetic field but only as an electromagnetic wave excited by a varying current origin. Well known to us, any form of wave is no more than the transmission of a small perturbation in a background field. So, both the electromagnetic wave and electromagnetic field should be classified into two distinct concept domains. Then, how can we logically connect both the static and dynamic parts of a united electromagnetism? And, how can we make a reasonable distinction with certain formal significance between both the transmission of a small electromagnetic perturbation and the background field the perturbation relies upon?

(5) Recognized, a so-called inertial system concept, first introduced in Newtonian mechanics, has faced with a severe and seemingly impossibly overcome challenge: lack of the uniqueness necessary to every reasonable science statement. And, in principle, or as same as particularly pointed out in some textbooks demonstrating electromagnetic theory, the completely identical knotty has always bothered every conscious researcher in this area for any electromagnetism statement to still impossibly coincide with the indispensable uniqueness requirement. Then, how can we overcome or correct such an obviously existing insufficiency or impropriety in logic, though which maybe is too plain for lots of us to almost disregard or neglect?

(6) Besides, why can the phenomenon revealed by Michelson-Morley's experiment only possibly be regarded as abnormal and never interpretable? Further speaking, maybe most of us know, there is a light speed invariance theorem with the generally said three principles. And, we also know, a kind of phenomena for a curve electromagnetic wave trace to possibly appear in some special cases has gotten an effective empirical demonstration. But, all of them could only be accepted as some unvarying dogma, which should only originate from particular person's intuition and would not essentially differ from any secret theology. Why must it be so? It must be explained by the presence of, as said rationally by philosophers. Then, it might be better for us to first take a brief reexamination on the proposition initially supposed by Maxwell. While only for supplying "Encyclopedia Britannica" with a maybe intuitive or perceptive interpretation of electromagnetic field or ether, Maxwell constructed the test item to measure the velocity of the ether relative to the earth. Seemingly, since electromagnetic field should be regarded as a kind of new material existing form, it was well reasoned to believe the special material to

naturally pass through the earth at some finite velocity. Of course, further reasonably guessed, Maxwell did not really realize the electromagnetic field or ether, presented in his test proposition, to just coincide with a particular geomagnetic field. Clearly, in physics, a so-called geomagnetic field is just excited by the earth, while, in geometry, the field equals the extension of the earth in geometry. Then, the field must move just along with the moving earth. And, the specified light, just presented in Michelson-Morley's experiment and only regarded as the transmission of a small electromagnetic perturbation in the geomagnetic field, must be independent of any movement made by the earth. So, it might be fairly said, Maxwell did not but unconsciously make a huge joke at the whole science world in that era. As for the curve light trace demonstrated in empirical facts, its existence still needs the necessary support only logically originated from some material reality, but impermissibly only relies upon some pure artificial assumptions. And, all of these require or force us to further make perfect the classical electromagnetism created early more than one and a half century, and try to supply an as perfect as possible formal system to reasonably express the complex phenomena really presented in electromagnetic field.

(7) Maybe reasonably said, all the propositions or inquiries made here are no more than plain, simple, easier unadorned and even most traditional. The unique foundation to support all of them would only be the classical and general logic as well as the bright tradition of west philosophical thought. Or, only based on the obviously existing improprieties or abnormalities in the classical theorem, a new formal system more perfect and complete in logic is waiting us to reconstruct. Even though it is that, a desired rational reconstruction of formal system never means any simple negation to the classical theorem. Or, when Maxwell's equations have been successfully verified in lots of empirical facts and correspondingly become a set of empirical equations, any reasonably reconstructed formal system must involve these empirical equations, keep logically compatible with them in form, and should also be used to express all the phenomena the old system has fruitfully described. Inversely, the reconstruction must fail.

It is always reasonably affirmed, if blemishes, if any insufficiency and even strict mistakes presented in a theorem, the reason cannot but finally be attributed into some improprieties in the related mathematical deductions and physical concepts. We should know, in the era for Maxwell to live, a kind of customary cognition about material existence has not been gotten rid of. It was a universal consciousness that any physical reality must be connected with a geometry reality. Besides, the tensor analysis, which should be regarded as an indispensable tool in mathematics when any form of field is discussed, had not appeared until the initial of the 20th century. So, maybe believed, it would just be strange and incredible, if Maxwell and the pioneers in this area successfully built a perfect formal system. But, at the same time, it will also be inconceivable or totally impermissible for a reconstructed formal system to form a simply and rash negation against the classical theorem. Obviously, Maxwell's equations have gotten widely verified by lots of empirical facts, and might better be regarded as a set of proper and convincing empirical equations. So, in logic, a maybe said reasonably reconstructed formal

system must first involve all the legal part of the classical theorem. Or, besides possibly making same correct description on the phenomena the classical theorem has successfully revealed, any supplying some really sound interpretations for the knotty problems conscious to us, the reconstructed formal system should legally or suitably arrange other unsolved problems similar to the boundary value problem of a dynamic electromagnetic field defined in a general three-dimensional (3D) space domain.

Any advance to step-by-step deepen human's cognition may be nothing but a process accompanied with the dialectical unity of successive-criterion and critical-succession. And, in the final of these words, it might be not superfluous to alert our readers to keep enough patience while reading these maybe out-of-ordinary materials. Believed, while a theorem passes through the successive growth over the post one and half centuries, and faces with a new development, it must require the successors in this area to pay much more labors and efforts.

Of course, it is certainly not avoidable for the reconstructed formal system to still be with lots of insufficiencies, improprieties and even mistakes in logic. So, the writer sincerely and earnestly expects the readers to retake the logic criticism weapons to correct, modify and complete a building formal system.

As one of the influent philosophers in the initial of the 20th century, C. Peirce ever intelligently alerted us that

> *The method of science is built on the assumption that there are really things, which are entirely independent of our opinions about them and will affect each observer the same way. And, the method of science must be with public or community character while the conclusions of science must be the conclusions that all scientists can draw.*

Namely, within the domain of natural science, any really reasonable theorem must base upon real things and naturally show the public character. Consequently, every purely artificial thought fabrication would impermissibly be remained in a real science statement. Inversely, if a statement is only marked with an individual person's thought sign, or lacking of the necessary support that can only originate from some objectively existing physical realities, but only relying on the inspiration excited by the intuition far from rationality, it must not be science.

So, when facing with an existing-in-itself and much more complex material world, we must keep it firmly in our mind that, except making some restriction on the material object we want to describe, which would only match with a kind of idealized construction or formal definition aiming at the material object too complex to be simply equated with any pure abstract concept, there is nothing we can really do. And, every honest person devoted to natural science research should learn to make a conscious restriction on any statement made by the person himself. And, we even should form a stable rational consciousness or right judgement, that is: if a theorem constructed by us may be regarded as correct, the theorem must be endowed with some indispensable material connotation, and naturally become the one all others can also effectively

finish, provided who possess same the fundamental knowledge. In the viewpoint of natural science itself, along with a theorem rationally accomplished, successfully endowed with the necessary objective material foundation as well as the accompanied public character, the constructer itself will essentially retire backstage or naturally disappear behind the right theorem.

Great, mystery and permanent nature; slight and disappearing in a twinkle human.

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Shanghai Jiaotong University

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