Disputes existing in the Physical Natural of Electromagnetic Induction

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【Abstract】: In 1832, Faraday assumed the induction between magnet and conductor produced the induced electromotive force (e.m.f.) dU in the conductor. In 1834, Lentz considered the induction produced the induced current I in the conductor. The above are all induced matters with different causal relation. In 1865, Maxwell assumed during the magnet motion vortex electric-field (E-field) was produced around free space, which seemed to end the dispute of causal relation and yet it brought forward the question that the induction was produced in the conductor or in free space? In 1892, Lorentz created a metal electronic theory, for this reason the metal electron caused the induced current under Lorentz magnetic force, in which the nature is force $\boldsymbol{F}$ instead of field. In essence, whether coil motion or magnet motion, as long as the relative movement remains between magnetic field and conductor, the metal electron will inevitably cut the magnetic line. The essence of electromagnetic induction could be consequently integrated with Lorentz magnetic force. In early twentieth century, relative electromagnetic theory arose that included electric field E and magnetic field B. So far, the unified theory on the electromagnetic induction nature has been not established. Which is nature, which is phenomenon? Which is reason? Which is result? Which is truth? Which is mistake? It is a great problem for all of us.

【Keywords】: Lorentz magnetic force, Faraday's low, Lorentz' low, Vortex electric-field, See E and B

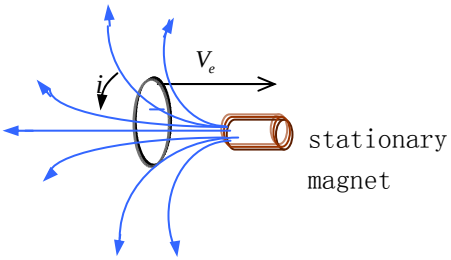
1 Introduction

With regard to the experiment of "the relative movement between conductor coil and magnetic force line", five schools of theories have different description for it. ①According to Lenz's Law it can be explained as that, firstly induced current coming from the circuit conductor to bring out electric current I ,then based on differential form $dU = \frac{-I}{\sigma s} dl$ of Ohm's law , electromotive force dU on the conductor is obtained. The physical natural would be regarded as "current before voltage". ②According to Faraday's Law it can be explained as that, duo to the magnetic flux in conductor line changing, firstly induced electromotive force dU coming from the line-winded conductor to bring out voltage, then based on differential form $I = \frac{-\sigma s dU}{dl}$ of Ohm's Law, the physical natural would be regarded as "voltage before electric current". Although these two theories belong to the ones that induction is produced in conductors, the dispute of the sequence between I and dU is just the same as the philosophy problem of "egg and chicken". ③According to Lorentz Force Law, during the conductor coil approaching or leaving the still magnet ,the metal-electron of the coil has cut the bending magnetic force line(magnetic force line is always curved),so the metal-electron is forced by

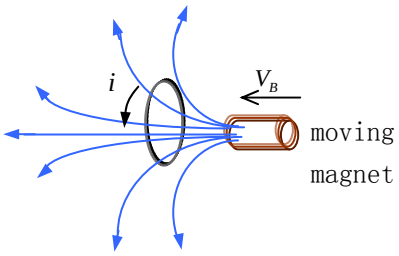
Lorentz Magnetic Force $\boldsymbol{F} = q\boldsymbol{V}\times\boldsymbol{B}$ and drift along ht conductor to form induced current. And then based on Ohm's law, there must be induced electromotive force dU_{ab} in the coil, whose physical natural is Lorentz Magnetic Force. During the conductor coil approaching or leaving the stationary magnet ,the bending magnetic force line(magnetic force line is always curved) has cut the metal-electron, whose physical natural is regard as the same of Lorentz Magnetic Force [1,2]. ④According to Maxwell's Rotation Theory , during the movement of the magnet with the bending magnetic force line, the change of magnetic field intensity leads to vortex electric field $\boldsymbol{E}$,so the contour integral of the free-space is just the electromotive force of Faraday's Law. That is to say that Maxwell's vortex electric field comes from the conclusion of Faraday's Law. However, there are essential differences in Faraday's Law, Lenz' Law, Lorentz Magnetic Force and Maxwell's vortex electric field, for the physical natural of Faraday's Law, Lenz' Law and Lorentz Magnetic Force is the induction in the conductor, while the Rotation Theory is the induction in the free space. ⑤According to Relativistic Electromagnetism, two kinds of magnetic fields are seen in the magnetic fields by the observer. As we know, physical research pursues the physical conception and physical natural, and there is essential difference between the kinds of "seen-magnetic field" and "produced-magnetic field", which belongs to the philosophic problem of "meaning" and "existence". Therefore, this paper is to introduce the natural issues of the five theories above, and interpret the theoretical disputes to offer new enlightenment to people.

As the description of the magnetic induction by Lenz's Law and Faraday's Law are widely known, the key discussion of this paper is on the essential differences among the other theories.

This paper extends discussion based on two equivalent experiments as graph 1 and graph 2 shown. In graph 1, the magnet is still while the coil moves from left to right, and the speed is V_e; in graph 2, the coil is still while the magnet moves from right to left, and the speed is V_B. It should be regarded that the magnetic induction in this two figures is equivalent. However, we will find the theories of each school are incompatible through the discussion following.



Graph 1 The coil is moving while the magnet is still



Grapy 2 The magnet is moving while the coil is still

2 on Lorentz Magnetic Force

In Graph 1, under the condition that the magnet is still (the magnetic force line is like petunia shape), and the coil moves from left to right at the speed of $\boldsymbol{V}_e$, the coil ,in fact ,the metal electron in the coil cuts the magnetic force line , and then is forced by Lorentz Force

$$\boldsymbol{F} = e\boldsymbol{V}_e\times\boldsymbol{B} \qquad (1)$$

and drift along the coil to produce induced current $I = sneu$. Pay attention to that the electron's electric

quantity is negative, while the current is defined as the flow direction of the positive charge, so the current direction is as shown in graph 1. That satisfy the Lenz's Law , in the formula, S is the cross-sectional area of the coil-conductor; n is the density of the metal electron; e is the electron's electric quantity; u is the drifting speed of the metal electron along the coil. Then by differential form of Ohm's Law, the induced electromotive force is produced, which satisfy the Faraday's Law. In the formula, σ is the conductivity; dl is the differential variable of the coil length. Pay attention to that the magnetic force line is always curved. In graph 1, the coil cuts the curved magnetic force line, and produces the induction on the effect of Lorentz Magnetic Force, which can be concluded as the explanation of Lorentz Magnetic Force[1,2,6,7].

In Graph 2, the coil is still, and the magnet moves from right to left (the magnetic force lines are like petunia shape). By comparing graph 1 with graph 2, we know that the coil moves from left to right at the speed of $\boldsymbol{V}_e$ and the magnetic force line moves from right to left, whose physical behaviors are both the same. That is to say in graph 2, the stationary coil cuts the moving magnetic force line. Due to $\boldsymbol{V}_e = -\boldsymbol{V}_B$, substitute it into formula(1), thus the metal electron in the stationary coil is forced by Lorentz magnetic force,:

$$\begin{aligned} \boldsymbol{F} &= e(-\boldsymbol{V}_B)\times\boldsymbol{B} \\ &= e(\boldsymbol{V}_e)\times\boldsymbol{B} \end{aligned} \qquad (2)$$

making the metal electron drift along the coil on the effect of $\boldsymbol{F}$ to produce induced current $I = sneu$. Pay attention to that the electron's electric quantity is negative, while the current is defined as the flow direction of the positive charge, so the current direction is as shown in graph 2. That is just the Lenz's Law. In the formula, S is the cross-sectional area of the coil-conductor; n is the density of the metal electron; e is the electron's electric quantity; u is the drifting speed of the metal electron along the coil. Then by differential form of Ohm's Law, the induced electromotive force is produced, which is just the Faraday's Law. In the formula, σ is the conductivity; dl is the differential variable of the coil length. Pay attention to that the magnetic force line is always curved. In graph 1, the coil cuts the curved magnetic force line, and produces the induction on the effect of Lorentz Magnetic Force, which can be concluded as the explanation of Lorentz Magnetic Force[3, 4].

It is worth noting the suffix in formula (2), as the moving directions of coil and magnet are opposite, we get $-\boldsymbol{V}_B = \boldsymbol{V}_E$, thus the directions of induced current produced in graph 1 and graph 2 are the same.

3 on Rotation Theory

In Graph 1, Maxwell pointed out in the article of "Discussion on Faraday's Force Line" that, due to the disturbance to the magnetic field by the coil, the Magnetic Tense State $\boldsymbol{A}$ changes in the free space($\boldsymbol{A}$ is defined as magnetic tense state, which is defined as magnetic vector potential later), and thus the electrodynamic force $\boldsymbol{E}$ ($\boldsymbol{E}$ is defined as electric field later) [5] is produced in the free space.

$$\boldsymbol{E} = -\boldsymbol{V}\times\boldsymbol{A} \qquad (3)$$

Afterwards, for some unknown reasons, Maxwell's formula (3) is abandoned and forgotten by people, maybe because it is not the rotation theory after all. If we do rotation operation to formula (3), it will go bad. What' more, the direction of the electric field is difficult to confirm if we apply formula (3).

In Graph 2, Maxwell pointed out that, when the magnet is moving, the magnetic state of the free space changes, leading to the producing of electrodynamic force in free space $\boldsymbol{E}$ ($\boldsymbol{E}$ is defined as electric field later), the ring-road integral along $\boldsymbol{E}$ is the induced electromotive force $\oint_l \boldsymbol{E}d\boldsymbol{l} = \varepsilon_V$; extracting the differential Form of Ohm's Law to $\boldsymbol{E}$, that is the induced current(density) $\boldsymbol{J} = \sigma\boldsymbol{E}$. Therefore, Maxwell

believes that the natural of electromagnetic induction is the production of $\boldsymbol{E}$ in free space, for induced electromotive force and induced current are just the expressive forms of electrodynamic force $\boldsymbol{E}$. The induced electrodynamic force intensity is $\boldsymbol{E} = -\frac{\partial \boldsymbol{A}}{\partial t}$. If we do rotation operation to both sides of the formula, we'll get

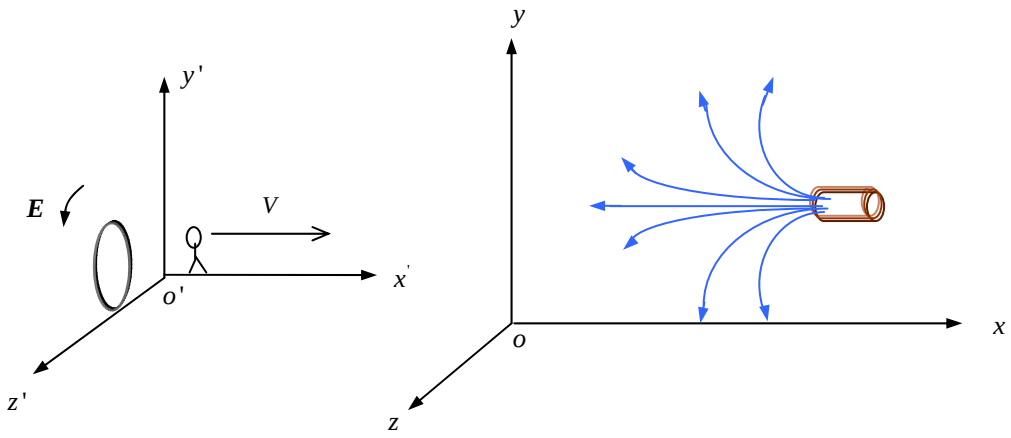
$$\nabla \times \boldsymbol{E} = -\frac{\partial \nabla \times \boldsymbol{A}}{\partial t} = -\frac{\partial \boldsymbol{B}}{\partial t} \qquad (4)$$

This is just the famous conclusion that time-varying magnetic field produces vortex electric field, whose electric field direction is the same as the current direction shown in graph 2. It seems that this conclusion has calmed down the argument that which one is the reason and which one is the result between induced current and induced voltage. In another word, induced current and induced electromotive are only expressive forms, while its rotation electric field seems to be the natural of electromagnetic induction. Please pay attention here, though formula (4) originates from Faraday's Law, Faraday's Law aims at the induction in the conductor while rotation theory aims at the induction in the free space. The meanings of these two theories are different.

4 on Relativity Electromagnetics

The Relativity Electromagetics sets up the electrodynamics equation based on two inertial frames, shown in graph 3. That means the observer has seen (or tested) the electric field (or magnetic field). [4,5]

$$E_x^{'} = E_x \qquad E_{\perp}^{'} = \frac{1}{\sqrt{1-\beta}}(\boldsymbol{E} + \boldsymbol{V} \times \boldsymbol{B})_{\perp} \qquad (5)$$



Graph 3 Relativity description of the experiment in Graph 1

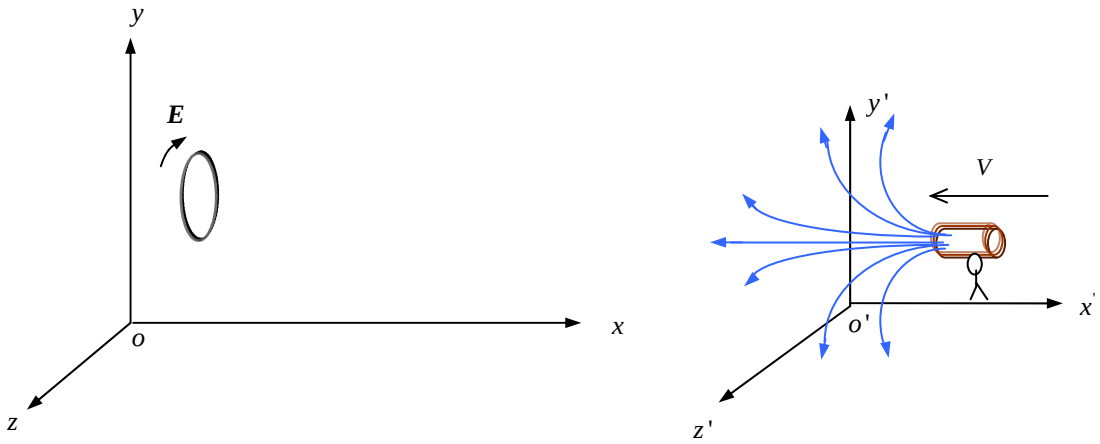
In Graph 1, supposing the stationary magnet is system S and the coil moving to positive direction of x is system $S^{'}$, thus the seen-electric field of the moving coil (or observer) is

$$E_{\perp}^{'} = \frac{1}{\sqrt{1-\beta}}(\boldsymbol{V} \times \boldsymbol{B})_{\perp} \qquad (6)$$

In Graph 2, it is worth noting that "having seen the electric field" and "having produced the electric field" belong to the philosophical problem of meaning and existence. It is normal that if it produces the electric field,

we can see (or test) it. However, it is uncertain whether there is electric field in the “having seen the electric field” transformed by math means from Relativity. In order to find out the Relativity basis of conclusion “the moving magnetic field having produced electric field”, description is as follow: supposing the coil is the stationary system S and the magnet is system S'.That means the observer carries the magnet to make it move from right to left, so the moving magnetic field cause the space in coil L to produce electric field, shown in graph 4. In this way, the assumption coordinate system in graph 4 is completely the same as the centurial experiment coordinate system in graph 2. Now let’s explore what field has been produced by the moving magnetic field in the space of the coil? According to the formula (3) of Relativity Electromagetics, applying right-hand rule of vector operation, we get the “being-produced electric field”,

$$E'_{\perp} = \frac{1}{\sqrt{1-\beta}}(\boldsymbol{V}\times\boldsymbol{B})_{\perp} \qquad (7)$$



Graph 4 Relativity description of the experiment in Graph 2

It is worth noting that, the electric field(current) direction originated from Relativity Electromagetics is opposite, which is not consistent with the experiment and violates the Lenz’ Law. Comparing graph 3 with graph 4, it is obvious that the electric filed directions in these two graphs are opposite, which is the inevitable result because Einstein haven’t pointed out clearly which one is the true moving and which one is the false one.

5 Analysis and Conclusion of the Problem

So far, description of the electromagnetic induction in graph1 and graph2 has been made by five schools of theories and opinions. Since the theories of each school are incompatible, there must be differentiation between phenomenon and natural as well as differentiation between fallacy and truth.

Firstly, induction happens in the free space or in conductor? Lenz’s Law, Faraday’s Law and Lorentz’s Law consider that the electromagnetic induction happens in the conductor while Maxwell’s theory and Relativity consider that the electromagnetic induction happens in the free space. A whale of a difference exists between these two schools of theories in its physical natural. In the same physical experiment graph1 and graph2, it is in the conductor where induction happens or the free space where the induction happens on earth, whose physical natural are entirely different. As physics workers, we should not only observe the physical

phenomenon but also explore the physical natural. On earth who is the natural and who is the phenomenon? Who is the reason and who is the result? Even who is the truth and who is the illusion?

Secondly, overall and unilateral? Our experiments prove that, in the experiments shown in graph 1 and graph 2, the current directions in the coil are the same. This indicate that: ①Lorentz magnetic force can explain the experiment in graph 1 as well as graph 2. ② Maxwell's theory can only explain the experiment in graph 2 but is difficult to explain the experiment in graph 1. That is because of Maxwell's formula(3) with experiment contrary. ③ Einstein's Relativity can only explain the experiment in graph 1, that is to say the mover in magnetic field has seen the electric field but can not explain the experiment in graph 2, in which moving magnetic field has not produced electric field.

Thirdly, physics essence? If Lorentz Magnetic Force is the physical natural of electromagnetic induction, it is obvious that Lenz's Law and Faraday's Law are just the physical phenomenon of electromagnetic induction; if Lorentz Magnetic Force is the physical reason of electromagnetic induction, Maxwell's theory and Relativity are just the physical supposition. That is to say, in the same experiment, the result is induced current, but who is the reason by means of philosophic idea? So we can find out the truth only if we find out the reason.

This paper belongs to classic physical research, and it is neither fashion nor lucrative. However, if the discussion above is correct, as a physicist, should you verdict the theoretical dispute or not? As a university professor, should you explain it clearly to your students or not? Why the physical naturals of the same experiment are entirely different? Who is the truth, and who is the illusion? The answers will be given in the following articles. (Follow-up) [18].

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