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THE METHOD OF EXPRESSING MAXWELL'S EQUATIONS IN AN ORGANIC SERIES ACCORDING TO THE RULES, LAWS AND EXPERIMENTS IN THE DEPARTMENT OF ELECTROMAGNETISM

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ABSTRACT: - The article presents opinions about the method and sequence of explanation using Maxwell's equations in the explanation of laws and regulations in the department of electromagnetism to students. In the educational process organized on the basis of the proposed sequence, students will understand all the laws of electromagnetism and will be able to apply them to natural phenomena and processes.

KEYWORDS: Maxwell's equations, displacement current, conduction current, rotor, divergence, cumulative current, voltage, current density, magnetic field, field strength, magnetic field vector.

INTRODUCTION

After Maxwell's theory of electromagnetic fields was experimentally confirmed by G. Hertz, Popov was the first to use it. The field of application of electromagnetic waves increased day by day. Nowadays, it is easier to list the field of non-application of electromagnetic waves than to list the field of application. Maxwell took a serious approach to explaining the equations in a coherent sequence, relating them to the rules, laws, and experiments in the electromagnetism section of the physics course.

In this methodical article, in the electromagnetism section of the "Physics Course", Maxwell's remarkable equations, which form the basis of Maxwell's theory of electromagnetic fields, are presented in a coherent sequence, connected to rules, laws and experiments, all from the mathematization of Michael Faraday's (1791-1867) ideas and experiments in the field of electricity. begins.

Faraday discovered the law of electromagnetic induction on October 4, 1831, and the Scottish scientist James Clerk Maxwell, who expressed it with mathematical symbols and equations, was born on June 13, 1831, before this discovery. While studying at universities, Maxwell fell in love with Faraday's book "Eksperementalnye issledovaniya po elektrichestvu". After reading and analyzing it several times, he begins to mathematicalize Faraday's ideas and experiments [1].

Faraday conducted experiments with charges and observed that two charges interact in a vacuum with some kind of electric field and was the first to introduce the concept of an electric field. Faraday represents the electric field, electric field density, electric field by lines of force, but does not denote it by any mathematical symbol or letter. It is concluded that charges interact with each other through electric field lines.

Maxwell, studying and analyzing these ideas of Faraday, introduced the following designations: the electric field designates the lines of intensity with the letter $\vec{\mathrm{E}}$, the electric field designates the induction vectors with the letter $\vec{\mathcal{D}}$ [2].

When there is a dielectric between the charges, the electric field intensity vector is deformed and jumps during transition, the slope of the lines of force decreases by ε times, the jump change of the electric field intensity lines causes some difficulties, so the concept of additional electric field induced lines of force is introduced [3].

LITERATURE ANALYSIS AND METHODS

Maxwell imagines these in space, calls it the electric field induction vector, expresses it by the letter $\vec{\mathcal{D}}$, and connects the electric field intensity vector $\vec{\mathrm{E}}$ with the electric field induction vectors, introducing $\vec{\mathrm{E}}$ and $\vec{\mathcal{D}}$ to fully express the electric field, and expresses them with the following relationship [4,5]:

$$\mathcal{D} = \varepsilon\varepsilon_0\vec{\mathrm{E}} \tag{1}$$

In this equation, $\vec{\mathcal{D}}$ is the electric field induction vector, $\vec{\mathrm{E}}$ is the electric field intensity vector, ε is the dielectric permittivity of the medium ($\varepsilon_0 = 1$ in vacuum), $\varepsilon_0 = 8{,}85 \cdot 10^{-12}\,\frac{F}{m}$ is the electric constant [6].

Using the above equation, one can find $\vec{\mathcal{D}}$ if $\vec{\mathrm{E}}$ is definite, or conversely one can find $\vec{\mathrm{E}}$ if $\vec{\mathcal{D}}$-definite [7,10].

$$\vec{\mathrm{E}} = \frac{\vec{\mathcal{D}}}{\varepsilon\varepsilon_0} \tag{2}$$

After that, Maxwell, logically continuing the Ostrogradsky-Gauss theorem, concludes with the following equation that divides the flow of the electric field around where there is a charge or charge density [8,12]:

$$\mathrm{div}\vec{\mathcal{D}} = \rho \tag{3}$$

This equation is called the differential form of Gauss' theorem. In this div – means the divergence current, $div\vec{\mathcal{D}}$

represents the flow of the electric field Induction vector, r is the volume density of charges.

After that, Maxwell analyzed Ohm's law for a part of the circuit, the current generation in the conductor when voltage is applied to a part of the conductor, and Maxwell wrote the differential form of Ohm's law as follows [9,11]:

$$\vec{J} = \lambda \vec{E} \tag{4}$$

It can be seen from this equation that the current density at a given point of the conductor depends on the strength of the electric field at that place and is directly proportional to the electric field.

In these equations $\vec{J}$ is the vector of current density, λ is the specific electrical conductivity of the conductor, $\vec{E}$ is the vector of electric field intensity at a given point.

Note that there is no derivative in this equation, but since the quantities involved in this equation refer to a small point in the field, this equation is called a differential equation.

We know that when an electric current passes through a conductor, the amount of heat is released from it, this law is written in the integral form of the Joule-Lentz tune [13]:

$$Q = J^2 R t \tag{5}$$

From this equation, it can be seen that the amount of heat released from the conductor is directly proportional to the square of the current, the resistance of the conductor, and time.

Maxwell writes this law in the following differential form:

$$\vec{q} = \frac{J^2}{\lambda} = \vec{J}\vec{\mathrm{E}} = \lambda \vec{\mathrm{E}}^2 \text{ ёки } \vec{J} = \lambda \vec{\mathrm{E}}^2 \tag{6}$$

The density of the amount of heat released from a given location of the conductor $\vec{q}$ in this is directly proportional to the square of the electric field. This is called the specific electrical conductivity of the conductor in equation (λ).

The continuity equation can be written after Ohm's and Joule-Lenz's laws.

Maxwell writes the continuity equation in the following form:

$$\frac{d\rho}{dt} + \operatorname{div} \vec{j} = 0 \tag{7}$$

Maxwell's continuity equation expresses the law of conservation of charges.

In this equation, conduction current lines are given special importance. Since the charge density is constant at all points along the conductor in the case of stationary currents

$$\frac{d\rho}{dt} = 0 \tag{8}$$

is written as and therefore the continuity equation reads as:

$$\operatorname{div}\vec{j} = 0$$

(9

This equation shows that lines of constant current do not have a beginning and an end. They can be closed lines or lines that go to infinity.

If the current is alternating, the lines of the current density are not closed, then the equation is written as follows:

$$\operatorname{div}\vec{j} = -\frac{d\rho}{dt} \neq 0 \tag{10}$$

This means that the conduction current density lines begin and end at points of change in charge density. Since current density depends on the movement of charges, it is also called conduction current density and displacement current.

Danish physicist H.K. Ersted (1777-1851) experimentally discovered the formation of a magnetic field around a current conductor in 1820 and announced it in his book [1-6].

After Oersted experimentally proved the formation of a magnetic field around a current conductor, Maxwell specified $\vec{\mathrm{H}}, \vec{\mathrm{B}}$ representing the magnetic field and wrote the following equation:

$$\vec{\mathrm{B}} = \mu\mu_0\vec{\mathrm{H}} \tag{11}$$

where $\vec{\mathrm{B}}$ is the magnetic field induction vector, $\vec{\mathrm{H}}$ is the magnetic field intensity vector, μ is the permeability of the medium, and μ_0 is the magnetic constant.

$$\mu_0 = 4\pi.10^{-3}\frac{N}{\mathrm{A}^2} = 4\pi\ 10^{-7}\left[\frac{N}{A^2}\right]$$

Faraday and Oersted studied the idea and experiments that the magnetic field formed around a current conductor is uniform, Maxwell wrote the following equation:

$$rot\vec{H}=\vec{j} \tag{12}$$

the meaning of this equation (from right to left) When current and current density pass through a conductor, a magnetic field is formed around it.

It is known that constant current does not pass through the capacitor. Therefore, the conduction current density J does not pass between the capacitor plates in the case of constant current.

If alternating current is applied to the capacitor plates, current will flow through the capacitor. It is called shear current, explaining Maxwell's mechanism.

$$\vec{J} = \frac{\partial\vec{\mathcal{D}}}{\partial t} = \varepsilon\varepsilon_0\frac{\partial\vec{\mathrm{E}}}{\partial t} \tag{13}$$

In this case, displacement current has nothing to do with conduction current by its nature.

Therefore, the displacement current density depends on the rate of change of the electric field at a given point. Therefore, this quantity is called electric current. Thus, as a result of the change in the electric field, a magnetic field is created.

Maxwell writes an equation that fully describes Oersted's experiment:

$$rot\vec{H} = \vec{J} \tag{14}$$

This equation is only for constant current, and if a constant current flows in a conductor from right to left, a magnetic field is formed around it.

If an alternating current flows through a capacitor connected in series with a conductor, then Maxwell's complete equation is written as follows:

$$rot\vec{H} = \overrightarrow{J_{\text{ўт}}} + \frac{\partial\vec{\mathcal{D}}}{\partial t} = \overrightarrow{J_{\text{ўт}}} + \overrightarrow{J_{\text{сил}}} \tag{15}$$

Therefore, a magnetic field is formed around the conduction and displacement currents.

In 1821, Michael Faraday saw the formation of a magnetic field around a current-carrying conductor of Oersted, and thought that it was impossible to generate an electric current with the help of a magnetic field. From 1821 to 1831, Michael Faraday continuously conducted experiments and created the induction Ɛ - electric driving force in a closed circuit as a result of the movement of the magnetic field. This law, discovered by Faraday, is the basis of electric generators and engines.

It can be emphasized that the phenomenon of electromagnetic induction does not depend on whether it is in a closed circuit or not.

Variation of the magnetic field in space leads to the formation of an electric field.

Thus, Maxwell's equation in differential form, which fully expresses Faraday's law of electromagnetic induction, is written as follows:

$$rot\vec{\mathrm{E}} = -\frac{\partial \vec{B}}{\partial t} \tag{16}$$

here rot – means rotor, cluster. So, if the induction vector of the magnetic field along the closed loop changes depending on time, then a lump of electric field is formed in the closed loop.

The minus sign in this equation is the induced electromotive force generated in a closed circuit with the magnetic field induction vector, which constitutes a left-handed screw system.

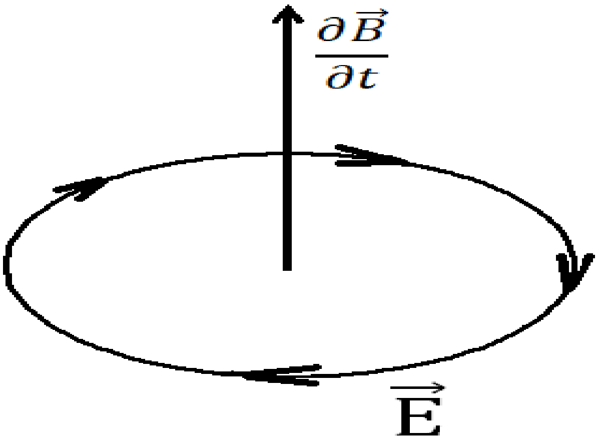

Figure 1.

If we diverge Maxwell's equation written for the law of electromagnetic induction,

$$\mathrm{divrot}\vec{\mathrm{E}} = -\mathrm{div}\frac{\partial \vec{B}}{\partial t} \tag{17}$$

$\mathrm{divrot}\vec{\mathrm{E}} = 0$ because it is,

$$0 = \mathrm{div}\frac{\partial \vec{B}}{\partial \mathrm{t}} = \frac{\partial}{\partial \mathrm{t}}\mathrm{div}\vec{\mathrm{B}} \tag{18}$$

Since $\mathrm{div}\vec{\mathrm{B}}$ does not depend on time, the next Maxwell's equation is formed:

$$\mathrm{div}\vec{\mathrm{B}} = 0 \tag{19}$$

Maxwell's equation shows that the lines of the magnetic field induction vector have no beginning and no end. This in turn confirms that magnetic charges do not exist in nature - no. As we know, a magnetic field is always created around a current conductor.

Thus, Maxwell's equations clearly expressed and recorded the rules and laws of electrodynamics, electricity and electromagnetism using mathematical equations.

Therefore, if we explain these equations by explaining the phenomena, rules and laws written in sequence in electromagnetism, following their sequence, and explaining them by writing Maxwell's equations, students will understand well.

If it were up to us, we would write Maxwell's system of equations in the following form [2-5]:

$$\vec{\mathcal{D}} = \varepsilon\varepsilon_0\vec{\mathrm{E}} \tag{20}$$

$$\mathrm{div}\vec{\mathcal{D}} = \rho, \tag{21}$$

$$\frac{\partial \rho}{\partial t} + \mathrm{div}\vec{j} = 0 \tag{22}$$

$$\mathrm{rot}\vec{H} = \vec{j} + \frac{\partial \vec{\mathcal{D}}}{\partial t} \tag{23}$$

$$\mathrm{rot}\vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{24}$$

With additional equations,

$$\vec{\mathcal{D}} = \varepsilon\varepsilon_0\vec{\mathrm{E}}\,;\ \vec{\mathrm{B}} = \mu\mu_0\vec{\mathrm{H}};\ \vec{J} = \lambda\vec{E};\ \vec{J} = \lambda\vec{E}^2 \tag{25}$$

METHOD

State Maxwell's equations in a coherent sequence, relating them to rules, laws, and experiments in electromagnetism:

1. Maxwell's equation representing the electric field:

$$\vec{\mathcal{D}} = \varepsilon\varepsilon_0\vec{\mathrm{E}} \tag{26}$$

2. Law of Conservation of Charge:

$$\frac{\partial \rho}{\partial t} + \mathrm{div}\vec{J} = 0 \tag{27}$$

3. Wherever there is a charge, there is an electric field around it:

$$\mathrm{div}\vec{\mathcal{D}} = \rho \tag{28}$$

4. Differential form of Ohm's law:

$$\vec{J} = \partial\vec{E} \tag{29}$$

5. Differential form of the Joule-Lents law:

$$\vec{J} = \partial E^2 \tag{30}$$

6. Oersted's equation in differential form, which states that where there is a current, there is a magnetic field around it:

$$\mathrm{rot}\vec{H} = \vec{J} \tag{31}$$

7. The equation representing Faraday's law of electromagnetic induction:

$$\mathrm{rot}\vec{\mathrm{E}} = -\frac{\partial \vec{B}}{\partial t} \tag{32}$$

8. The equation that represents the magnetic field lines of force have no beginning and end and magnetic charges do not exist in nature:

$$\mathrm{div}\vec{\mathrm{B}} = 0 \tag{33}$$

9. And finally, where there are conduction and displacement currents, the equation for the formation of a magnetic field around them:

$$\mathrm{rot}\vec{H} = \overrightarrow{J_{\text{ўт}}} + \frac{\partial \vec{\mathcal{D}}}{\partial t} \tag{34}$$

The above system of Maxwell's equations, with additions, is fulfilled under the following conditions:

a) all material objects on the field must be immobile;

b) ε, μ, λ, which represent the properties of the material environment, do not depend on time and the size of field vectors;

c) there are no permanent magnets and ferromagnetic substances in the field.

CONCLUSION

The description of Maxwell's equations in a coherent sequence in connection with rules, laws and experiments in the electromagnetism section of the physics course is characterized by a high level of involvement of the student in the educational process, that is, it activates their creativity and understanding to solve the task. To be able to apply the knowledge obtained as a result in the fields of science, technology and production, to be able to apply the created ideas, discoveries and achievements, to show the ability to think independently, to develop certain skills in this regard, to achieve the transformation of the skills into operational skills, in relation to students' learning internal need, interest, motivation, and also the determination of conscious attitude is achieved.

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