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Application of Analogy Method in the Electromagnetism Teaching in College Physics

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Abstract. Analogy method is a frequently-used effective teaching method. If use this method properly in teaching physical, the learning ability of undergraduate and the teaching efficiency can be improved remarkably. In electromagnetism teaching of college physics, the materiality, the external manifestation, the quantitative description, the fundamental theorem reflecting the nature of the field and the energy of electrostatic and static magnetic field aspect have similarities. By analogy, the students' familiar knowledge of electrostatic field inspires students to master the more difficult knowledge of static magnetic field; it allows students to better understand the difference and connection between electrostatic field and static magnetic field acquire the knowledge of electromagnetism more systematically and develop the students' creative thinking greatly.

Introduction

Analogy is a basic way of logical thinking by which human recognizes the objective world; it plays an active role in promoting the development of physics, especially in the process of establishing the electromagnetic field theory [1-4]. Coulomb gave the Coulomb's law with the same form of universal gravitation by analogy in 1875; Georg Simon Ohm obtained the Ohm's law experimentally on the analogy of similarities between current and thermal phenomena in 1826. Maxwell also used analogy repeatedly, so that he gradually revealed the truth science and deduced the Maxwell's equations [4]. He said: analogy can communicate research methods in different areas and provide media between analytical abstract form and assumptions methods [4]. Therefore, in electromagnetism teaching, analogy is undoubtedly the optimal teaching method.

However, in the traditional teaching of electromagnetism, teachers often overemphasized electromagnetism as a rigorous knowledge system and maturity structure theory, could not stimulate students' interest in learning, therefore, could not imparted the knowledge to the students effectively[5]. As a teacher, in order to achieve better teaching effect, choosing proper classroom teaching methods is particularly important. Teachers must find ways to make abstract concepts, law, becomes vivid, and to establish the appropriate physical models to help students understand the knowledge, eliminating errors inherent in the minds of students understanding.

In an actual classroom instruction, when teaching content to the static magnetic field portion, the students often reflect that the magnetic portion is more abstract and more difficult to understand compared to the electrostatic field. To solve this problem, it is necessary for teachers to consider which teaching methods can be adopted to overcome this problem effectively. According to recent years of teaching experience, I have found the analogy method is a prior choose for treating magnetic teaching content. Using this method adequately can inspire students' thinking, provide clues, and draw inferences about other cases from one instance [1]. Electrostatic field and static magnetic field may appear similar in material properties, external performance, quantitative description of the fundamental theorem, energy and other aspects [5-9]. Just grab these characteristics in the classroom teaching and use analogy one by one, teachers can use the students' familiar knowledge of electrostatic field to guide them to master the more difficult static magnetic field knowledge, and improve the teaching efficiency greatly.

Material Properties of Fields

Electric or magnetic field are both special form of matter, they are objective realities, and the same as substance, having general properties, including mass, energy and momentum and angular momentum in the movement embodied. But unlike substance, the electric and magnetic field have special properties, they are invisible and untouchable, it can only detect its presence through its external performance.

In addition, the field has a spatial compatibility, there may be many different fields with no mutual influence among the various fields in the same space at the same time, the field can be said to be independent.

The External Performance of Fields

The external performance of electrostatic field and static magnetic field are mainly reflected in the force and work in two ways.

Force. The electrostatic field is produced or created by relatively still charge and the static magnetic field is generated by a constant current, although they are invisible and untouchable, they all exert force on any other charge or moving charge or current which are present in them. Therefore, when test the existence of fields or explore the nature of electrostatic field, we place a test charge, according to the features of force experience by the test charge to discuss the strength and direction of the electrostatic field. While for static magnetic field, in a similar way, by analyzing the characteristics of the magnetic forces on a moving charge or current, people discuss the strength and direction of the static magnetic field.

Work. When a charged particle moves in an electric field, the field exerts a force that can do work on the particle, reflecting the energy material properties of the electric field. Similarly, when the current-carrying conductor, moving charge and current-carrying loop move in a magnetic field, the magnetic field can also do work on them, reflecting the magnetic field also has energy.

The Description of Fields

Quantitative description. For quantitative description of electrostatic field or static magnetic field, teachers often analyze the field in the view of the fields exert force on any other charge or moving charge in teaching quantitatively.

If place a test charge q_0 at a particular point in the electrostatic field, the test charge experiences an electric force $\vec{F}$, at different field point the magnitude and direction of the force $\vec{F}$ may be have the different values, but for the same field point, the magnitude of the force $\vec{F}$ is direct proportion to the charge q_0, the ratio of $\vec{F}$ two q_0 is a constant. According to this, we define the electric field $\vec{E}$ at this field point as the force $\vec{F}$ divided by the charge q_0. The electric field $\vec{E}$ does not depend on the charge q_0 but only depend on the properties of the electric field itself. The electrostatic field is a vector field. For the charge distribution, the total electric field is given by the principle of superposition of electric fields $\vec{E} = \sum \vec{E}_i$.

Like electrostatic field, to explore the nature of the magnetic field, we can define the magnetic field $\vec{B}$ to describe its own properties in the same way, that is, select a moving charge with the magnitude of charge q and the velocity $\vec{v}$ as the test element and place it in magnetic field, use the characteristics of the magnetic force on this moving charge describe the magnitude and direction of magnetic field. The magnetic field is also a vector field, can be superposed and meet the principle of superposition $\vec{B} = \sum \vec{B}_i$.

In addition, quantitative description of the electrostatic field or the static magnetic field can also start from the view of work done by field. For electrostatic field, the electrostatic force is

conservative; correspondingly the electrostatic field is conservative field. We can introduce the concepts of electric potential energy and electric potential, and the electric potential will reflect the physical nature of the electric field. However the magnetic field is not conservative and unable to introduce the concept of magnetic potential.

Visual Description. In order to describe the electric field distribution vividly, electric field lines were introduced in an electric field, electric field lines show the direction of $\vec{E}$ at each point by the tangential direction, and their spacing gives a general idea of the magnitude of $\vec{E}$ at each point, that is, where $\vec{E}$ is strong, the lines bunch closely together, and where $\vec{E}$ is weaker, they are farther apart. Similarly, we can represent any magnetic field by magnetic field lines vividly in the same manner.

The Fundamental Theorems Reflecting the Nature of the Fields

Due to magnetic and electric fields are both vector fields, the research methods are same. Treating the vector field mainly needs to grape the two aspects: one is the flux of the field vector through any closed surface (Gauss's theorem); the other is the of a vector field around closed circuit (Circuital theorem). Just as Lenin's word: the unity of nature is shown in the 'striking resemblance' of the calculus equation in various fields [10]. Many different physical phenomena in nature subject to the same or similar mathematical laws, the similar of mathematical form provide us possibility to transplant the familiar knowledge, method into new areas by analogy.

Gauss's Theorem. When explaining the Gauss's Theorem in electrostatic field, we first vividly introduce the concepts of electric field lines and electric flux, then obtain the electric flux through the Gaussian surface, finally derive Gauss's Theorem in the electrostatic field rigorously, that is, the total electric flux through a closed surface is equal to the total (net) electric charge inside the surface, divided by ε_0, in the form:

$$\oint_S \vec{E} \cdot \mathrm{d}\vec{S} = \frac{1}{\varepsilon_0} \sum q_{\mathrm{encl}} \tag{1}$$

where $\vec{E}$ is the total (resultant) electric field $\vec{E}$ at any point $\mathrm{d}\vec{S}$ of the Gaussian surface S, it is the vector sum of the $\vec{E}$ fields of the individual charges, q_{encl} is the total (net) electric charge enclosed by the Gaussian surface S. Gauss's Theorem reflects the electrostatic field is a source field; the source of a field line is charge.

Analogously, when explaining the Gauss's Theorem for magnetism, we also first vividly introduce the concepts of magnetic field lines and magnetic flux, then obtain the magnetic flux through the Gaussian surface, finally derive Gauss's Theorem for the magnetism, in the form:

$$\oint_S \vec{B} \cdot \mathrm{d}\vec{S} = 0 \tag{2}$$

The total magnetic flux through a closed surface is always zero, it reflects the static magnetic field is a source free vector field, magnetic field lines always form closed loops.

Circuital Theorem. In electrostatic field, from the characteristics of work done by electrostatic force, that is, the work done by the electrostatic force along a closed cycle is zero, we give the Circuital Theorem in the form:

$$\oint_L \vec{E} \cdot \mathrm{d}\vec{r} = 0 \tag{3}$$

It reflects the electrostatic field is a no vortex field and conservative, correspondingly the concepts of electric potential energy and electric potential can be introduced.

By analogy, the Ampere's Circuital Theorem can be deduce in static magnetic field,

$$\oint_L \vec{B} \cdot \mathrm{d}\vec{l} = \mu_0 \sum I_{\mathrm{encl}} \tag{4}$$

where $\vec{B}$ is the total (resultant) magnetic field $\vec{B}$ at any point $\mathrm{d}\vec{l}$ of the integration path L, I_{encl} is the algebraic sum of the currents enclosed or linked by the integration path L. Ampere's Circuital Theorem reflects static magnetic field is a vortex field.

The analogies of the fundamental theorems reflecting the nature of the fields also embody on the theorem application. If the charge distribution or the current distribution has enough symmetry to let us evaluate the integral in theorem, we can find the field.

The energy of Fields

Electric-field energy stored in the electric field, while the magnetic-field energy stored in the magnetic field, the corresponding expressions for electric energy density and magnetic energy density are $w_e = \varepsilon E^2 / 2$ and $w_m = B^2 / 2\mu$, respectively. We can see that the relationship for magnetic-field energy density is analogous to that for electric-field energy density in form.

Conclusions

In short, to explain the electromagnetic, the analogy method may be used almost everywhere. Teachers should pay more attention to choose the analogous objects cleverly and accurately, capture the essential nature of things. As long as the proper use of analogy, it can be less waste of words, and give good teaching results.

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