PHYSICAL SCIENCES

THE ROLE OF QUALITATIVE ANALYSIS IN PHYSICS

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Abstract

Exploring laws is the core method in natural science learning, and qualitative analysis, by virtue of its inherent characteristics, has become a research field with special value in physics. Investigating its role in physics is of great significance for the development of the discipline. Combining specific examples, this paper systematically analyzes the role of qualitative analysis in three major fields of physics: mechanics, electromagnetism, and atomic physics. The research shows that qualitative analysis plays an irreplaceable role in the discovery of physical principles, the interpretation of experimental phenomena, the simplification of complex problems, and the construction of physical concepts.

Keywords: Qualitative Analysis; Physics; Newton's First Law; Electric Field Lines

1 Introduction

Rutherford once famously said, "Qualitativeness is insufficient quantification." This statement undoubtedly reveals the awkward position of qualitative analysis in physics. Although physics has always taken the pursuit of high-precision quantitative research as its core goal, qualitative analysis is still widely applied in various branches of physics.

In fact, qualitative analysis plays a crucial role in the initial stage of in-depth understanding of physical problems. This "initial stage"—the preliminary ideas and viewpoints formed before the launch of rigorous research—is particularly important for researchers and physics teachers: it not only helps organize preliminary cognition, clarify the positioning and expression of problems, but also provides directional guidance for exploring solutions to problems and putting forward reasonable hypotheses. At the same time, qualitative analysis can effectively simplify the complexity of physical problems when addressing them, which will be demonstrated with specific examples in the following sections.

2 The Role of Qualitative Analysis in Mechanics

Physical concepts are the reflection of the common physical attributes and essential characteristics of objective things in the human mind, and are abstract generalizations of physical phenomena. Qualitative analysis is proficient in solving such abstract physical problems, and can draw conclusions through methods such as analysis, generalization, and reasoning. Newton's First Law, for example, is formed through the analysis of objective facts, followed by further generalization and reasoning. Its content states: "Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it." Since there are no objects in reality that are completely free from external forces, this law cannot be directly verified through actual experiments.

From the discovery process of Newton's First Law, it can be seen that thought experiments (ideal experiments) played a decisive role in the birth of this law. A thought experiment, relying on the logical reasoning method of qualitative analysis and giving full play to imagination, involves idealizing objective experimental conditions and research objects at the ideological level, thereby abstracting an "idealized process experiment." In the exploration of this law, Galileo designed the ideal inclined plane experiment. Since such an experiment under pure ideal conditions cannot be realized in reality, the qualitative analysis method, which focuses on theoretical analysis, solves this problem appropriately: through in-depth qualitative logical reasoning on the essence of physics to conduct scientific abstraction, key conclusions are finally drawn. Newton's First Law, summarized based on these conclusions, has also become an important foundation for the establishment of classical mechanics.

In fact, qualitative analysis also plays an increasingly important role in the discovery of principles and laws in modern physics. For instance, Einstein designed a qualitative analysis experiment on "the relativity of simultaneity." Through the qualitative study of this experiment, he established the scientific concept of "the relativity of simultaneity," which laid a crucial foundation for the creation of the special theory of relativity.

3 The Role of Qualitative Analysis in Electromagnetism

Qualitative analysis also plays an important role in describing abstract problems in physics, and the introduction of electric field lines is a typical example. As is well-known, electric field lines are not objectively existing substances; instead, they are scientific models constructed by Faraday using qualitative analysis thinking. Several curves are drawn in the electric field space, where the density of the curves represents the magnitude of the electric field intensity, and the tangent direction at each point on the curve is consistent with the direction of the electric field intensity at that point. Such curves that conform to the rules are defined as electric field lines. The introduction of this model successfully transforms the abstract and complex problem of electric fields into an intuitive and perceivable image, greatly reducing the difficulty of understanding and analysis.

Similarly, to describe magnetic fields (which are invisible to the naked eye) in a vivid and convenient way, Faraday once again used qualitative analysis thinking to introduce the magnetic field line model. In physics, the proposal of core concepts such as electric field lines and magnetic field lines lies in breaking through the limitation of "only focusing on the electric field or magnetic field itself," and instead emphasizing the core role of the "field" in the interaction of substances—this has completely revolutionized people's understanding of the essence of electric and magnetic fields. In addition, the introduction and description of abstract physical concepts such as solenoidal fields also rely on the support of qualitative analysis methods.

Case Study: As shown in Figure 1, a bar magnet is placed on a horizontal table. A long straight wire is fixed directly above the center of the magnet, and the wire is perpendicular to the magnet. If a current is passed through the wire, directed perpendicular to the plane of the paper inward, and F represents the pressure exerted by the magnet on the table, determine how F changes after the current is applied compared to before.

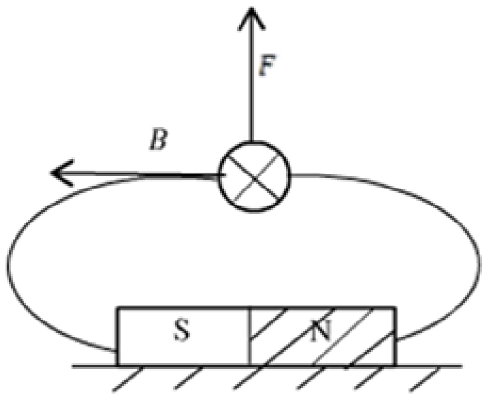

Figure 1: Bar Magnet

Analysis: Draw a magnetic field line passing through the position of the current in the figure; it can be observed that the direction of the magnetic field line at this position is horizontally to the left. According to the left-hand rule, the current in the wire will be subjected to an Ampere force in the vertically upward direction. Based on Newton's Third Law, the current will exert a reaction force on the magnet (which generates the magnetic field) that is equal in magnitude and opposite in direction—this reaction force is directed vertically downward. Since the magnet needs to balance its gravity and this reaction force in the vertical direction, it exerts greater pressure on the table. Therefore, the pressure exerted by the magnet on the table increases after the current is applied compared to before.

If we directly analyze the effect of the current's magnetic field on the bar magnet, it is difficult to draw a conclusion for this problem. However, by changing the approach—first analyzing the "effect of the magnet on the current" (which we are more familiar with), then switching the research object based on Newton's Third Law to deduce the force on the bar magnet—we can easily arrive at the answer.

When dealing with problems such as "the motion of a current-carrying conductor (or magnet) in a magnetic field under the action of Ampere force," qualitative analysis can be carried out using the equivalent analysis method. For example, a circular current can be equivalent to a small magnetic needle, and the result can be deduced through the law of interaction between magnetic poles. In addition to the equivalent analysis method, qualitative analysis in electromagnetism also commonly uses methods such as the special position method, the inference analysis method, and the research object conversion method. For instance, the part of the circuit that generates an induced electromotive force can be equivalent to a power supply; if multiple parts of the conductor in the circuit cut the magnetic field lines and are interconnected, they can be further equivalent to a series or parallel circuit of power supplies.

Furthermore, the electromagnetic induction process is often accompanied by various forms of energy conversion, which can be qualitatively analyzed from the perspective of energy. Taking the relationship between work and energy as the starting point to clarify the specific process of energy conversion is an important approach to solving energy-related problems in electromagnetic induction. When applying this approach, it is first necessary to identify the forms and types of energy involved in the conversion, and then determine which forms of energy increase and which decrease, thereby grasping the overall law of energy change.

4 The Role of Qualitative Analysis in Atomic Physics

Qualitative analysis also plays an important role in interpreting experimental phenomena related to physical laws, and the exploration process of atomic structure is a typical example. Atomic structure has long been an unknown field for human exploration; to uncover its mystery, scientists have conducted a series of studies. J.J. Thomson, who first discovered the electron, proposed an atomic model similar to a "watermelon". Later, to further explore the specific model and internal structure of the atom, physicists such as Rutherford designed the famous α-particle scattering experiment—a beam of high-speed, positively charged α-particles (with a mass much larger than that of atoms) was used to bombard a thin gold foil. Three key phenomena were observed in the experiment: most α-particles penetrated the gold foil and continued along their original direction; a small number of α-particles had their direction of motion deflected; and an extremely small number of α-particles were directly bounced back.

Through the qualitative analysis of experimental phenomena, the internal causes of the above phenomena can be gradually deduced: First, since the volume of the atomic nucleus is extremely small, there is a large amount of empty space inside the atom—thus, most α-particles can penetrate the gold foil unobstructed and continue along their original direction. Second, from the phenomenon that "a small number of α-particles have their direction of motion deflected," it can be inferred that the atomic nucleus is positively charged. Since α-particles are also positively charged, they repel each other due to like charges, generating an electric field force. When α-particles pass near the atomic nucleus, they are acted upon by this repulsive force, causing their direction of motion to change. Finally, by analyzing the phenomenon that "an extremely small number of α-particles are bounced back" in combination with the momentum theorem, it can be known that the α-particles collided head-on with the gold atomic nuclei. The result of the α-particles being bounced back also proves that their mass is much smaller than that of the gold atomic nuclei.

Based on the analytical conclusions of the experimental phenomena, Rutherford proposed the nuclear model of the atom: at the center of the atom, there is a nucleus with a very small volume; all the positive charge and almost all the mass of the atom are concentrated in the nucleus, while negatively charged electrons move in the space outside the nucleus around the nucleus.

When using qualitative analysis to discover physical principles or laws, its core advantage lies in its ability to simplify and purify problems to a degree that is difficult to achieve with real experiments, thereby exploring and revealing the inherent laws of natural things and phenomena more efficiently. In addition, interpreting physical phenomena through qualitative analysis is also an important way to put forward scientific hypotheses: on the one hand, it helps researchers deepen their understanding of real experiments, the essential attributes of research objects, and their movement laws; on the other hand, it makes the process of logical proof and refutation clearer, more intuitive, and more persuasive. Although the physical laws deduced by qualitative analysis often lack sufficient data support, throughout the development history of physics, all core conclusions obtained through qualitative analysis have stood the test of practice.

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