SYNERGETIC INTERPRETATION OF THE LAWS OF DIRECT CURRENT

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ANNOTATION

The article discusses the use of synergistic concepts and categories in the study of direct current laws of physics taught in higher technical educational institutions. Synergistic categories of self-organization, openness, non-linearity, complexity, coherence, chaos, ordering, cooperation, and other concepts are used to interpret and explain the phenomena and laws related to the subject. The formation process of dissipative structures in the metal conductor system is analyzed.

KEYWORDS: synergetics, self-organization, nonlinearity, coherence, chaos, cooperation, Bose condensation, Cooper pair, superconductivity.

INTRODUCTION

Using existing pedagogical technologies, new approaches, and methods in teaching physics in higher technical educational institutions allows for an increase in the effectiveness of education. It is possible to achieve perfection of the knowledge students acquire through a synergetic approach to education and training using its categories and concepts. Synergetics, as it is known, is considered an interdisciplinary scientific direction and emerged as a theory about the phenomenon of self-organization that occurs in open systems that are far from equilibrium. In the synergistic approach, openness, nonlinearity, continuity, coherence, cooperation, chaos, ordering, bifurcation, attractor, and other similar categories and concepts are used. Self-organization is one of the most basic concepts of synergetics. In-depth understanding and memorization of the nature of physical phenomena and laws during training in physics requires effective use of synergistic and systematic approach methods in the educational process. In complex thermodynamic systems, at small values of the external influence, flows and thermodynamic forces are linearly connected. Development processes in complex systems can occur in the form of non-linear abrupt changes.

This article discusses the issue of clarifying the essence of these laws using synergistic concepts in covering the topic of direct current laws.

MAIN PART

It is known that direct current, the amount and direction of which does not depend on time, is caused by the orderly movement of free electrons with an electric charge in conductors. From the point of view of synergetic concepts, a metal conductor consisting of electron gas, ions located at the nodes of the crystal lattice and in constant heat oscillatory motion, and defects can be considered as a complex open system. The concentration of ions and free electrons, which are one of the structural elements of this system, is around ~ 10^{-22} cm^{-3}. The openness of this system is characterized by receiving energy from an external current source and exchanging heat energy with the environment. Under the conditions of thermodynamic equilibrium, the free electrons in the system are in a state of constant irregular thermal motion, and such a set of electrons is called an electron gas. From the point of view of synergistic ideas, the disordered movement of electrons can be considered as a state of chaos observed in the system. If a potential difference, that is, a gradient, is created at the ends of the conductor using an external current source, an electric field of external forces is formed inside the conductor. As a result, a certain direction, i.e. ordering, occurs in the movement of free electrons, and an electric current begins to flow through the conductor. Such an order, arising from the chaos of electron movement, can be considered a spatially dissipative structure. In an open metal system, energy dissipation is observed, i.e., the energy of the electrons is converted into internal energy, and the released heat energy is transferred to the external environment. It is known that dissipative structures in open systems occur due to the decrease of entropy of the system, contrary to the second law of thermodynamics, which is valid for closed systems. Thus, at a certain value of applied voltage or potential gradient, self-organization occurs in an open system. At small voltage values, the current density in the conductor is linearly dependent on the electric field strength, i.e.

$$\vec{j} = \sigma\vec{E} \quad \text{or} \quad \vec{j} = \sigma\, \overrightarrow{grad\varphi}$$

This connection is called Ohm's law. The modular form of this expression is:

$$j = \sigma \mathrm{E} \quad \text{or } j_x = \sigma\frac{\partial\varphi}{\partial x}$$

When the field inside the conductor is weak, that is, at small values of the voltage, the calculated linearity coefficient σ-comparative electrical conductivity does not depend on the strength of the field. At large values of the applied voltage to the conductor, the relative electrical conductivity s depends on the field strength, and the linear connection between the current density and the field strength is broken. This distortion can be seen as a manifestation of nonlinearity in an open system. The following relationship between the current specific heat capacity w and the field strength-E, called the Joule-Lents law

$$w = \sigma \mathrm{E}^2$$

quadratic coupling can also be viewed as a nonlinear state in the system. An expression of relative electrical conductivity

$$\sigma = \frac{e^2 n}{2m^*}\tau$$

is, it depends on concentration of free electrons n, effective mass m^* and their free running time between ions t. At high voltages, as a result of the collision, the crystal lattice heats up and the amplitude of the ion's oscillatory motion increases, which leads to a change in the free running time t and a state of nonlinearity in the system. The initial temperature of the electron gas based on the classical concepts

$$\frac{mv_0^2}{2} = \frac{3}{2}kT$$

can be estimated from the formula. Here, y_0~10^6 m/s is the random thermal motion speed of electrons. If we create an electric field inside the conductor with the help of an external current source, an orderly drift of electrons occurs. Electron drift velocity

$$u = \frac{eE\tau}{m^*}$$

The electric field strength increases as E increases. When the electric field is weak, the drift speed of electrons is much smaller than the speed of their chaotic movement, and u is not taken into account, and the free running time t does not depend on the strength of the field. In this case, the linear coupling in Ohm's law is not violated. At large values of the electric field strength, the value of u becomes equal to y_0, and it is necessary to take into account the drift speed of electrons. In this case, the speed of electrons and time t depend on the intensity of the electric field, and the linear relationship between the current density and the intensity of the field is broken and a nonlinearity occurs. Orderly movement of free electrons in one direction in current generation can be considered as their cooperative, i.e. organized movement. The emergence of nonlinearity in the system at relatively high and low temperatures can also be seen in the example of the temperature dependence of the resistivity of metals. Linear

$\rho = \rho_0(1 + \alpha t)$ or $\rho = \rho_0 \alpha T$ bond is broken at high and extremely low temperatures. At temperatures T= (4.2 ÷ 20) K, electrical conductivity or electrical resistance changes dramatically. The metal goes into a state of superconductivity. From the point of view of the synergistic approach, the system moves to a qualitatively new state. A new ordered structure is created. Coherence appears in the movement of free electrons, that is, they combine into Cooper pairs.

Since electrons have a spin equal to ½, bosons with a spin equal to the whole number are formed after their combination, in which boson condensation is formed.

Concepts of generality, coherence, and continuity are also concepts related to the theory of synergetic approach. For example, Kirchhoff's first law, the continuity equation, and the law of conservation of electric charge for a branched complex electric circuit node are different manifestations of one general law according to the synergistic approach. The law of conservation of electric charge

$$q_1 + q_2 + q_3 + \cdots q_n = const$$

in appearance

$$\oint \vec{j} d\vec{s} = \frac{\partial q}{\partial t} = 0$$

both in the form of the continuity equation and Kirchhoff's

$$\sum_{i=1}^{n} I_i = 0$$

can also be expressed in the form of the law. If the electric current passing through the volume bounded by a surface of the conductor does not change, then the invariance of the amount of electric charge in this volume is explained by the equality of the amount of charge entering and leaving this volume and is expressed by the above mathematical equations.

CONCLUSION

Using synergetic concepts and categories, the topic of direct current laws, which is taught in the course of general physics, was analyzed. Such an analysis allows the systematization of knowledge about phenomena or laws with the help of synergistic views and interpretations based on a unified approach. A metal conductor can be considered an open dissipative system consisting of an electron gas and a crystal lattice and exchanging energy with the external environment. In the non-equilibrium state of the system, when the electric field is weak, there is a linear relationship between thermodynamic forces, such as potential gradient or electric field strength, and currents, in our example, current density vector flow, called Ohm's law. At large values of the calculated potential gradient of the thermodynamic force, the relative electrical conductivity, which is the proportionality coefficient of the linear connection, depends on the field strength, and the linear connection is broken, and nonlinearity appears in the system. In this system, as a result of the decrease in total entropy, self-organization phenomena are observed, that is, spatial dissipative structures are formed. Ordering in the movement of free electrons and Bose condensation of paired electrons are among such structures.

The use of synergistic categories such as chaos, non-linearity, order, coherence, and continuity in the coverage of the topic ensures that the knowledge acquired by students is perfect. As a result of the synergistic approach to the study of the laws of direct current, students deeply understand the essence of the subject.

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