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Issue Article

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METHODOLOGICAL ASPECTS OF THE LAWS OF SYMMETRY AND CONSERVATION IN PHYSICS

Abstract: *This article methodologically substantiates the epistemological significance of the laws of symmetry and conservation in the physical cognition of the Universe. In the course of the development of physical science, the heuristic nature of the principle of symmetry and the fact that any physical law has a deep connection with the property of symmetry of the universe were revealed using scientific analysis.*

Key words: *symmetry, conservation, laws of symmetry, conservation laws, invariance, order, regularity, homogeneity of time, homogeneity of space, mirror symmetry, CP-invariance.*

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Introduction.

For the human mind, symmetry seems to have a very special attractive force. We like to look at the manifestation of symmetry in nature, at the perfectly symmetrical spheres of planets or the Sun, at symmetrical crystals, snowflakes and other things that are almost symmetrical. "Symmetry is the idea through which man has been trying for centuries to comprehend and create order, beauty and perfection," said G. Weil [1.-p.7].

An analysis of the development of physics makes it possible to notice that the idea of symmetry led her along the difficult path to the ideal — a unified picture of the world. With the help of the idea of symmetry, a person tries to understand the order, beauty and perfection of nature. The original meaning of symmetry is proportionality, similarity, similarity, order, rhythm, coordination of parts in a holistic structure. Symmetry and structure are inextricably linked. If a certain system has a structure, then it necessarily has some symmetry. The idea of symmetry is also of exceptional importance as a leading principle in understanding the structure of physical knowledge. It is hardly possible to dispute the heuristic value and methodological significance of the principle of symmetry. It is known that when solving specific physical problems, this principle plays the role of a truth criterion.

Main part.

Since ancient times, the idea of symmetry has had a huge impact on the development of scientific thought. Natural philosophy, cosmology and mathematics were based on this idea even at its inception. The Pythagoreans created the first cosmological systems of a centrally symmetrical universe, they developed the teachings of proportions, musical tones and the five symmetrical polyphonies identified with the main natural elements. Hippasus coined the term "symmetry", which literally meant "proportionality". The ideas of symmetry, harmony and conservation were the main ones in the structure of ancient Greek thought and were understood as passing into each other. Anaximander, Anaximenes and Heraclitus created the doctrine of the eternal cosmos, which periodically arises and dies. The teaching of Leucippus and Democritus about emptiness and eternal and unchanging, but moving atoms is based on the idea of symmetry, harmony and conservation of matter.

The views of Pythagoras and his school were further developed in Plato's doctrine of cognition. Of particular interest are Plato's views on the structure of the world, which, according to him, consists of regular polygons with perfect symmetry. Plato is characterized by the combination of the doctrine of ideas with the Pythagorean doctrine of number.

Later naturalists and philosophers who worked on the development of the category of symmetry are R. Descartes and G. Spencer.

R. Descartes wrote: "Whatever the inequality and disorder that, as we can assume, were established by God from the very beginning between the particles of matter, almost all of these particles must, according to the laws of nature, approach the average size and average motion." Thus, according to Descartes, God, having created asymmetric bodies, gave them a "natural" circular motion, as a result of which they were perfected into symmetrical bodies.

It is characteristic that science came to the most interesting results precisely when it established the facts of symmetry breaking. The consequences arising from the principle of symmetry were intensively developed by physicists in the last century and led to a number of important results. Such consequences of the laws of symmetry are primarily the conservation laws of classical physics.

During the Renaissance, the idea of symmetry, forgotten during the Middle Ages, was revived. Nikolai Kuzansky formulates the basics of the concept of homogeneous isotropic, infinite space. Leonardo da Vinci has an idea about the homogeneity of time. Arguments based on the idea of symmetry appear in the teachings of N. Copernicus. The Copernican system plays an important role in the perception of the idea of space-time symmetry necessary for the development of classical mechanics. J. Bruno defends the idea of an infinite homogeneous isotropic space. G. Galileo formulates the principles of inertia and relativity. He, as well as I. Kepler, R. Descartes and X. Huygens develop ideas about space-time symmetry to such an extent that they become fundamental in the “Principles” of I. Newton. The introduction of the concepts of absolute space and absolute time in Newtonian mechanics leads to the unification of local and cosmological symmetries into a single symmetry.

However, the invariant-theoretic approach, which originated at the beginning of the XVII century, could not be fully developed. Later, in the era of analytical mechanics, a style was established in which physical theory was formally considered as a mathematical theory of differential equations. L. Euler, J. Dalembert, J. Lagrange brought to the fore the axioms of dynamics. The dynamic approach did not need the idea of symmetry explicitly, but relied on it implicitly. And in the second half of the XVII century. the idea of symmetry temporarily lost its fundamental and heuristic significance. Conservation laws lost their main positions and became theorems — they were calculated as integrals of motion.

This style of thinking prevailed until the beginning of our century, when the invariant-theoretic approach was again brought to the fore. It became clear that the transition from the dynamic to the theoretical-invariant style of thinking became inevitable. Even in the middle of the XIX century. gradually increased interest in the principles of symmetry and conservation. This process was the result of two factors. On the one hand, physics was being freed from the tight confines of mechanics. New fields of physics were formed and rapidly developed - thermodynamics, optics, electrodynamics. J. Mayer discovered the law of conservation and transformation of energy. On the other hand, new mathematical theories developed - group theory, non-Euclidean geometry.

In classical physics of the XVII—XIX centuries, the idea of symmetry was not explicitly connected with the principles of relativity and invariance. As you know, in physics, the term “symmetry” comes from natural philosophy and geometry, and it was used primarily in crystallography, which, unlike mechanics, was not considered fundamental. The first to use the idea of symmetry outside the framework of crystal physics was P. Curie, who argued in 1894 about the symmetry of electric and magnetic fields. But Curie's idea remained undeveloped and had no impact on the development of physics. And only recently, after the works of E. Wigner, the principles of invariance and relativity as physical laws began to be understood explicitly as the principles of symmetry.

The invariant approach is formed and approved with the advent of the special theory of relativity. Within the framework of this approach, physical theories are considered as invariant theories of certain transformation groups. The further development of the idea of relativity - the creation of a general theory of relativity, the relativization of various physical theories, the experience of developing a unified field theory, the creation of relativistic cosmology (the works of A. Einstein, V. de Sitter, A.A. Friedman) - brought new successes in this direction in the first quarter of our century. Noether found out the connection between the principle of symmetry and the principle of conservation. The invariant approach was finally established in quantum theory as well. In 1930 P. Dirac wrote: “The theory of transformations, which was primarily used in the theory of relativity, and after that in quantum theory, expresses the essence of a new method in theoretical physics. Its modern progress consists in the fact that our equations are becoming invariant with respect to an increasingly wide class of transformations.” And truly, the successes of modern particle physics are unthinkable without the theory of invariants. The principle of symmetry permeates all the structures of modern physics. As a methodological principle, it underlies various physical theories and defines the structural organization of modern physical theory as a whole.

Analyzing in detail various specific types of symmetry, N.F. Ovchinnikov came to the conclusion that, in an abstract form, the principle of symmetry is a unity of opposites: change and preservation. “The unity of conservation and movement,” he writes, "is a brief formulation of symmetry expressed on an abstract-theoretical level." This definition of symmetry seems to be the most general and applicable for every case. Symmetry means that some transformations preserve some things, properties, and relationships. Conservation means identity, and transformations correspond to the changes that this identity is experiencing. In this sense, if conservation indicates an abstract, unchanging identity, then symmetry corresponds to a concrete, changing identity. In other words, symmetry is a concrete preservation. The path of cognition from the principle of conservation to the principle of symmetry is an ascent from the abstract to the concrete.

Both the principle of conservation and the principle of symmetry, according to N.F. Ovchinnikov, are “generalizing principles". This researcher formulated the law of symmetry conservation, according to which, with every violation of symmetry, a new, higher kind of symmetry is established. The discovery of some asymmetry does not mean the negation of the principle of symmetry. “Right” and “left” are themselves asymmetric, but taken together as a unity of opposites constitute the highest symmetry. In general, asymmetry is necessary as the opposite of symmetry. Asymmetry and symmetry in unity form the highest meta-symmetry.

Analyzing the effect of the principle of symmetry in various problematic situations, V.P. Vizgin notes two additional points: on the one hand, symmetry and its violations act as a source of a problematic situation and at the same time symmetry serves as a method of overcoming it, and on the other hand, a prioriization (“freezing”) of a certain type of symmetry prevents the resolution of a problematic situation. The first step to clarify the problem is the discovery of invariance, the establishment of symmetric elements. In the most general case, the desire to restore symmetry breaking is a way to overcome a problematic situation. Such heuristic power of the principle of symmetry as a method of finding a way out of a problematic situation is perceived as an actual justification of the law of symmetry conservation formulated by N.F. Ovchinnikov in the form of a universal principle of nature and scientific knowledge.

The effect of the principle of symmetry in problematic situations can be shown by some examples. When a theoretical understanding of experimental facts leads to the establishment of some symmetrical regularity, at the same time there is a need to rethink the theory so that it explains the symmetrical dependencies between these experimental facts.

The idea of symmetry has often served scientists as a guiding thread when considering the problems of the universe. Observing the chaotic scattering of stars in the night sky, we understand that the external chaos hides quite symmetrical spiral structures of galaxies, and in them – symmetrical structures of planetary systems.

The symmetry of the external shape of the crystal is a consequence of its internal symmetry – the ordered mutual arrangement of atoms (molecules) in space. It is the crystals that bring the charm of symmetry into the world of inanimate nature. Each snowflake is a small crystal of frozen water. The shape of snowflakes can be very diverse, but they all have symmetry – 6th order rotational symmetry and, in addition, mirror symmetry. Although there is a lot of complexity in physics, there is also a lot of simplicity and grace in it, which is largely due to the symmetry of physical laws and physical systems. Therefore, the concept of symmetry not only occupies an important place in physics, but also plays a powerful role in modern physical research. In order to investigate the physical consequences of the symmetry of the system, we obviously need to learn something about transformations and especially about the set (set) of transformations that leave some functions of the potential type unchanged.

The terms "symmetry" and "invariance" are often used synonymously, at least in the physical literature, where they denote "the property of remaining unchanged with respect to one or several different operations" [2.-pp.96-99]. Symmetry or invariance of objects always takes place with respect to certain, clearly fixed operations. The common thing between symmetry and invariance is that they are applicable to the same sets of changes, transformations of some parameters of phenomena. If the symmetry of a given group of transformations is included in the content of this law, then this law is necessarily invariant with respect to the same group of transformations. The invariance of the laws of nature is a consequence of those essential symmetries, which, however, are not fully included in their content. The difference between symmetry and invariance is that the invariance of laws, in addition to symmetry, expresses the degree of generality of these laws, i.e. the limits of their applicability.

The principles of symmetry and invariance according to the assessment of the famous American physicist E. The Wigners represent a kind of superprinciple, which relates to the laws of nature in the same way as the laws of nature relate to phenomena. The laws of nature allow us to anticipate one phenomenon based on what we know about other phenomena. The principles of invariance, says E. Wigner, should allow us to establish new correlations between phenomena on the basis of already established correlations between phenomena [3.-with 70]. By correlations, he means nothing more than physical regularities, emphasizing that the laws of nature are just that regular, correct thing that exists in the behavior of an object. In quantum theory, this point of view is natural: the laws of quantum mechanics allow for an adequate formulation in terms of the correlation between successive observations of an object. These correlations according to Wigner are the patterns that are determined by the laws of quantum mechanics. The same can be said with respect to the theory of relativity.

It is known that the laws of phenomena operate under certain conditions. Indeed, each law expresses some kind of order, some kind of regularity in the spatial arrangement of phenomena and their following each other in time. For example, the laws of crystal structure express the order of arrangement of their elements: molecules, ions, atoms and their groups. The laws of chain reactions express the order of their states and stages following each other. Therefore, the main features of the laws are order, regularity in the phenomena of nature. Since this feature of laws refers to the symmetry of phenomena, the latter is very essential for understanding the laws of the phenomenon of the world. Without the category of symmetry, it is impossible to give a complete description of the category of the law, since each law includes a certain symmetry.

The principles of symmetry are beginning to play an increasingly prominent role in modern physics and often lead to certain conservation laws. The connection of conservation laws with the principles of symmetry is accepted by physicists as so fundamental that they classify the conservation laws of modern physics depending on the types of symmetry, and they identify the conservation principles themselves with the principle of symmetry in their physical contents and "do not distinguish between symmetry and conservation principles" [4. -c140]. Conservation laws are related to the existence of such transformations that are invariant (symmetric) with respect to transformations. These include:

1. The law of conservation of total energy, including rest mass, which is a consequence of symmetry with respect to time shift (time uniformity).

2. The law of conservation of total momentum, which is a consequence of symmetry with respect to parallel transport in space (uniformity of space).

3. The law of conservation of the total moment of the amount of motion, which is a consequence of symmetry with respect to rotations in space (isotropy of space).

4. The law of conservation of charge, which is a consequence of symmetry with respect to the replacement of complex parameters describing the system with their complex conjugate values (C-invariance).

5. The law of parity conservation, which is a consequence of symmetry with respect to the inversion operation (mirror symmetry, P-invariance).

6. The law of conservation of entropy, which is a consequence of symmetry with respect to the reversal of time (T-invariance).

7. The law of conservation of CPT-parity, which hides a combination of three symmetries (C-invariance, P-invariance, and T-invariance). CPT-parity is the product of three quantities – charge parity (C-parity), spatial parity (P-parity) and temporal parity (T-parity). Each of these evenness comes in as a conserved quantity corresponding to a corresponding specific discrete symmetry. Therefore, CPT-parity is an absolute conservation law.

In principle, it is impossible to deduce all sides of conservation laws from forms of symmetry, especially only from geometric ones. Conservation laws are related to symmetries not only geometric, but also dynamic. Not only certain types of symmetry and asymmetry can be compared with conservation laws, but also certain fields and their connections. Apparently, the manifestation of some types of interaction in others is a general pattern of the microcosm.

Conclusion.

The study of the interpenetration of various types of interaction will greatly contribute to the study of the interrelationships between conservation laws. For example, the conservation of leptons can be considered as analogous to the conservation of heavy particles (or baryons) in the case of light particles. The lepton charge is +1, and the lepton charge of their antiparticles is -1. According to this law, the total number of leptons before and after the interaction should be the same. Let's look at some more laws of preservation in the microcosm:

- Charge independence (often called isotopic spin conservation). This law is valid only for strong interactions. Due to the existence of electromagnetic interactions, the accuracy of the predictions obtained on the basis of this law lies in the redistribution of 1%. Charge independence predicts the identity of the forces acting between a neutron and a proton.

- Preservation of strangeness (associative birth of strange particles), symmetry of antiparticles, preservation of parity, these laws are valid for all strong and electromagnetic interactions, but are violated by weak interactions.

- The law of general symmetry of particles-antiparticles (CP-invariance) states that if any experiment is reflected in a mirror and all particles are replaced by corresponding antiparticles, then this new experiment will also be "legitimate". This law seems to be valid for all interactions.

Thus, conservation laws are associated with the presence of a certain symmetry, the role of group-theoretic understanding of them becomes clear, because group theory studies the most general consequences arising from the existence of a particular symmetry.

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