ФІЗИКО-МАТЕМАТИЧНІ НАУКИ

UDC 530.1

HISTORICAL ASPECTS OF THE DEVELOPMENT OF HIGH ENERGY PHYSICS

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The development of accelerator technology for new physical measurements is considered. The viability of the Standard Model in elementary particle physics has been confirmed thanks to the modern experimental measurements and problems that are not solved by this model are considered. Historical development of physical science from classical physics to the modern theory of D-branes and superstrings is presented. In parallel, the development of mathematical science from the geometry of Euclid to algebraic geometry and the theory of derived categories was studied. Within the framework of modern physics and mathematics, new theories are presented that solve the problems of the Standard Model.
Keywords: accelerator technique, Standard Model, elementary particle physics, development of physical and mathematical science, theory of D-branes and superstrings.

Introduction. The current development of science is connected with experimental achievements [1], that is, with the construction of new accelerators, and with the needs of new theoretical physics beyond the Standard Model (SM) [2]. The construction of the Large Hadron Collider (LHC) [3], on which it is planned to increase luminosity and energy (Fig. 1), as well as the planned construction of the International Linear Collider with energy of 500 GeV [4], other experimental constructions, is a vivid demonstration of the development of modern accelerating technology for the needs of the discovery of new particles beyond the SM [5].

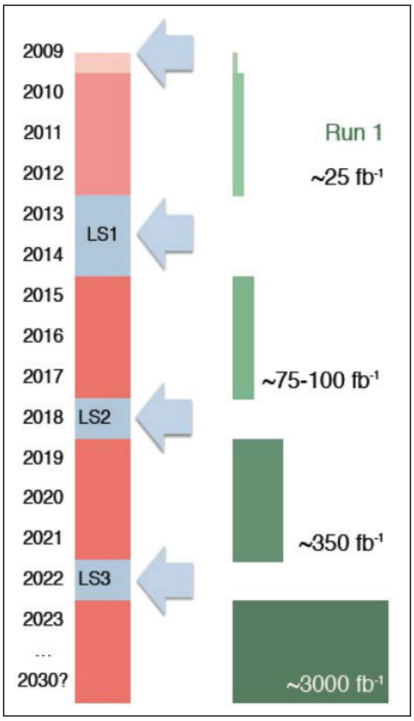

Fig. 1. Changes in the luminosity at the LHC

On the other hand, the problems of the SM inability to explain the dark matter, the problem of the hierarchy of interaction, the problem of the lack of clarity of the Higgs boson properties, and many other SM problems lead to the need for an experimental confirmation of new theoretical models beyond the SM theory: theory of D-branes and superstrings, supersymmetry, quantum gravity and so on [6]. Therefore, in order to find out further guidelines in physics, it is necessary to look at the situation from the side to understand the theoretical achievements for the further productive development of science.

Our article is devoted to the review of the development of modern physics from mathematical achievements to modern physical theories, causes and fundamental positions of modern theories, which can solve problems of Standard Model.

Development of mathematics and physics. If you look at the history of the development of mathematics and physics, then mathematics began its development much earlier. Algebraic geometry began its development from the geometry of Euclidean, which appeared about 300 years BC. Then, in 1637 year appeared analytical geometry, in the 18th century – complex algebra, in the 19th century – tensor calculus, in the early 20th century – differential forms. The modern mathematical structure is shown in Fig. 2.

Accordingly, in physics, the founder of classical mechanics was Galileo Galilei (early 17th century). Then classical mechanics passed the stages of theoretical mechanics (Euler, Lagrange, d'Alembert, Hamilton) in the 18th and 19th centuries. The mathematical apparatus of classical mechanics is the differential and integral calculus developed by Newton and Leibniz (17th-18th centuries). Classical mechanics has undergone several stages in its development, connected both with changes in sizes and with changes in speed, Fig. 3.

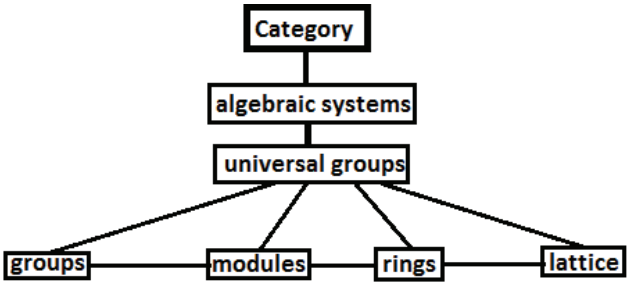

Fig. 2. The modern mathematical structure

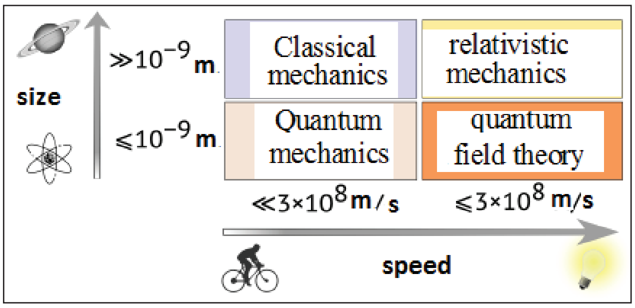

Fig. 3. Stages of the development of classical mechanics

Classical mechanics has somewhat in common with Maxwell's theory of electrodynamics (it was developed in 1862 y.), and relativistic mechanics is connected with the theory of relativity of Einstein (1915 y.). Quantum mechanics is described by the Schrödinger equation (1922–1929 y.), and quantum field theory was proposed by Yang and Mills (1954 y.) to describe elementary particles. Gell-Man classified elementary particles through group theory (1958 y.), and S. Weinberg, S. Gleeshaw and A. Salam proposed a unified theory of electroweak interaction of quarks and leptons (1968 y.). Thus, there is a gradual transition from large to small dimensions in physics and, accordingly, the transition to a new mathematical theory from ordinary equations to differential and integral, and then to the theory of groups. Thus, the SM was generally completed, and its main discoveries are as follows, Table 1.

Table 1

Steps for the discovery of SM particles

1897 y.	electron
1911 y.	nucleus
1930 y.	neutrino
1932 y.	neutron
1969 y.	quark
1983 y.	W, Z bosons
2012 y.	Higgs boson

1. Modern theoretical high-energy physics

SM model problems:

- hierarchy of interactions
- dark matter and dark energy
- radiative corrections to the mass of the Higgs boson
- CP asymmetry
- neutrino mass

led to the need of searches for new theories in high-energy physics. Modern high-energy physics is associated with the transition to very high energies (up to 14 TeV) and, accordingly, to small distances, up to 10-17 cm. The theory associated with such distances is the theory of D-brane and Superstrings (Green, Schwarz, Ramon, Nambu) [7], and the mathematical apparatus of such a theory is algebraic geometry and topological algebra, which uses the theory of derived categories. Analytical mechanics, based on the formulation of classical mechanics in the form of Lagrangian and Hamiltonian mechanics, can no longer be applied here, since we are dealing with very complex nonlinear equations that can not be solved by ordinary means. Symmetries acquire great importance in theoretical physics of high energies, including conformal symmetries, which are also associated with the searches for possible theories of quantum gravity for unification of all interactions: strong, electroweak and gravitational. In a 1997 article, which is now one of the most frequently cited in the history of physics, the theorist, Juan Maldasena, demonstrated mathematical equivalence between the conformal field theory and the gravitational space-time environment, with one additional spatial dimension [8]. Maldasena duality, the so-called AdS/CFT, binds the conformal field theory to the corresponding "anti-de Sitter space", which is connected with hologram. In AdS space there is a geometry different from the geometry of space-time in our universe, but the gravity works in AdS space as well as in our world. And since existing theories are not used in the middle of black holes (the paradox associated with the preservation of quantum information of the black hole), the solution of this paradox requires from physicists to find the quantum theory of gravity, from which the space – time picture arises at low energies, for example, outside of black holes. AdS/CFT provides a working example of quantum gravity, where everything is clearly defined. The hope lies in the fact that, based on the geometric structure, physicists will get a better idea of our Universe. Well-known physicist O. Polyakov, inspired by recent discoveries about the geometry of space, said: "There are many miracles – and, probably, we will find out why."

In the theory of strings, the graviton, as well as electrons, photons and other particles, are not pointy, but invisible tiny bands of energy or "strings" that vibrate differently. The interest to the string theory took off in the mid-1980s, when physicists realized that it gave a mathematically consistent description of quantum gravity. But five known versions of the theory of strings were "perturbative", that is, they broke in some regimes. Later, in 1995 y., physicist Edward Witten discovered a unified theory of all the theories of strings [9]. He found various indications that the theory of perturbative strings is united into a nonperturbative theory, which he called M-theory. Another explosion occurred two years after 1995 y. Physicist Juan Maldasena discovered AdS/CFT correspondence, which gives a complete definition of the M-theory for the spase-time geometries in AdS. This duality forces spase-time geometries in AdS to flex differently than our Universe. The 16,000 articles quoted by Maldasena over the past 20 years are mainly aimed at fulfilling of these calculations in order to understand AdS/CFT and quantum gravity.

Conclusions. We live in an interesting time of new discoveries, accompanied by new powerful experimental installations and new theories such as Theory of Everything. Of course, new discoveries are just around the corner. At the LHC accelerator, both technological improvements and experimental measurements related to the search for new physics beyond the Standard Model are constantly being carried out: the searches for Kaluza-Klein partners, microscopic black holes, superparticles, the extended Higgs boson sector, etc. Indirect or incomplete experimental data on the B meson decays, the top-quark interaction with the Higgs boson, the properties of the Higgs boson indicate the presence of deviations from the SM. "Ask – and they will give you, seek – and find, knock – and you will be opened," is written in the Holy Gospel of Matthew. We are on the threshold of great discoveries.

References:

1. URL: https://home.cern/about/experiments.
2. Lykken J.D. (2010). Beyond the Standard Model // CERN Yellow Report. CERN. P. 101–109. arXiv:1005.1676.
3. Giudice Gian Francesco (2010). A Zeptospace Odyssey: A Journey into the Physics of the LHC. Oxford University Press, Oxford, 288 p.
4. Komamiya S. (2016). International Linear Collider, Latest Status towards Realization. Proceedings of IPAC2016, Busan, Korea, p. 1–5.
5. Virdee T.S. Beyond the standard model of particle physics// Philos Trans A Math Phys Eng Sci. – 2016. – Aug 28. – 374(2075).
6. Gell-Mann M., Ramond P. and Slansky R. (1979). Supergravity// eds. P. van Nieuwenhuizen and D.Z. Freedman (North-Holland, Amsterdam), 315 p.
7. Green Michael B., Schwarz John H., Witten Edward. (1988). Superstring Theory: Volume 1, Introduction. Cambridge University Press, 470 p.
8. Maldacena Juan M. The Large N Limit of Superconformal Field Theories and Supergravity // Adv. Theor. Math. Phys. 1998. – 2. – P. 231–252.
9. Witten Edward. Five-branes And M-Theory On An Orbifold // Nucl.Phys. – 1996. – B463. – P. 383–397.

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ІСТОРИЧНІ АСПЕКТИ РОЗВИТКУ ФІЗИКИ ВИСОКИХ ЕНЕРГІЙ

Анотація
Розглянуто розвиток прискорювальної техніки задля нових фізичних вимірювань. Підтверджено життєздатність Стандартної Моделі в фізиці елементарних частинок завдяки сучасним експериментальним вимірам і розглянуто проблеми, які не вирішуються цією моделлю. Наведено історичний розвиток фізичної науки від класичної фізики до сучасної теорії D-бран і суперструн. Паралельно вивчався розвиток математичної науки від геометрії Евкліда до алгебричної геометрії і теорії похідних категорій. В рамках сучасних фізико-математичних досягнень наводяться нові теорії, які вирішують проблеми Стандартної Моделі.
Ключові слова: прискорювальна техніка, Стандартна Модель, фізика елементарних частинок, розвиток фізичної і математичної науки, теорія D-бран і суперструн.

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ИСТОРИЧЕСКИЕ АСПЕКТЫ РАЗВИТИЯ ФИЗИКИ ВЫСОКИХ ЭНЕРГИЙ

Аннотация
Рассмотрено развитие ускорительной техники для новых физических измерений. Подтверждена жизнеспособность Стандартной Модели в физике элементарных частиц благодаря современным экспериментальным измерениям и рассмотрены проблемы, которые не решаются этой моделью. Приведено историческое развитие физической науки от классической физики до современной теории D-бран и суперструн. Параллельно изучалось развитие математической науки от геометрии Евклида к алгебраической геометрии и теории производных категорий. В рамках современных физико-математических достижений приводятся новые теории, которые решают проблемы Стандартной модели.
Ключевые слова: ускорительная техника, Стандартная Модель, физика элементарных частиц, развитие физической и математической науки, теория D-бран и суперструн.