Physics – Uspekhi **65** (10) 1104 – 1106 (2022)

PERSONALIA

PACS number: **01.60.+q**

Aleksandr Abramovich Belavin (on his 80th birthday)

DOI: https://doi.org/10.3367/UFNe.2022.09.039241

August 28, 2022 marked the 80th birthday of the outstanding theoretical physicist, world-famous scientist, corresponding member at the Russian Academy of Sciences, chief researcher at the L D Landau Institute for Theoretical Physics Aleksandr Abramovich Belavin.

A A Belavin is a world-renowned theoretical physicist and the author of fundamental scientific results that largely determined the state of the art of quantum field theory and quantum string theory. He is the author of more than 150 scientific papers.

The world-wide recognition of these studies is evident from the high citation index (over 9500 citations). Aleksandr Abramovich is a laureate of international prizes: the Humboldt Prize, the I Ya Pomeranchuk Prize, and the L Onsager Prize.

Aleksandr Abramovich was born in 1942 in Gorky (Nizhny Novgorod). His father was head of the Design-Engineering Department at the Ordzhonikidze aviation plant and his mother was a teacher at the radio technical school. A A Belavin was a student in the Radiophysical Department at Gorky University for four years from 1960 to 1964. At that time, some leading scientists — V L Ginzburg, I E Tamm, E L Feinberg, and others — came from Moscow to give lectures to students at the radiophysical department. After one of E L Feinberg's lectures, A A Belavin decided to learn elementary particle physics. E L Feinberg said that "elementary particle physics is taught at the Moscow Institute of Physics and Technology (MIPT), but it is better to study at the Moscow Engineering Physics Institute (MEPhI)." This is how Aleksandr Abramovich found himself at MEPhI. He attended the Department of Theoretical Nuclear Physics, where teachers were, notably, I Ya Pomeranchuk, A B Migdal, A S Schwartz, V D Mur, and other prominent scientists. At the same time, Aleksandr Abramovich began attending theoretical seminars at the Institute for Theoretical and Experimental Physics (ITEP), where the head of the theoretical department was Isaak Yakovlevich Pomeranchuk. Soon, Aleksandr Abramovich became occupied with his degree thesis at ITEP under the guidance of Mikhail Vasil'evich Terentyev. When A A Belavin graduated from MEPhI, he became a postgraduate at ITEP, where later he defended his candidate thesis devoted to electroweak interaction physics under the tutorage of Yurii Igorevich Kobzarev.

Having finished the postgraduate course, Aleksandr Abramovich returned to Gorky. However, he did not break off his scientific ties to his Moscow colleagues. For example, lectures by leading scientists, in particular, A M Polyakov, were organized in Gorky with the participation of Aleksandr Abramovich. The intercourse with A M Polyakov led to the

Aleksandr Abramovich Belavin

1975 discovery of instantons in the Yang–Mills theory. These results, published in the famous paper "Pseudoparticle solutions of the Yang–Mills equations" (see A A Belavin, A M Polyakov, A S Schwartz, and Y S Tyupkin, *Phys. Lett. B* **59** 85–87 (1975)), became immediately famous all over the world. That same year, Aleksandr Abramovich moved on to work at the L D Landau Institute for Theoretical Physics (ITP), where he has been working to the present day. Connections with colleagues from ITP, in particular, with outstanding professional mathematicians, determined the range of Aleksandr Abramovich'es scientific interests for many years.

The scientific results obtained by A A Belavin changed the scientific landscape and underlay further research. For example, the discovery of instantons led, in particular, to the solution to the so-called $U(1)$ problem in quantum chromodynamics and cast new light on the problem of CP-invariance violation in the theory of strong interactions. The existence of instantons is also important for resolving the still unsolved confinement problem. The modern understanding of the

Uspekhi Fizicheskikh Nauk **192** (10) 1179 – 1180 (2022)
Translated by A N Tsaplin

Yang–Mills theory and especially its supersymmetric versions would be impossible without their allowance. Instantons and topological sectors also exist in many other quantum and statistical systems. For instance, instantons in the $O(3)$ sigma model, revealed by Belavin and Polyakov (see A A Belavin, A M Polyakov "Metastable states of a two-dimensional isotropic ferromagnet" *Pis'ma Zh. Eksp. Teor. Fiz.* **22** 503–506 (1975)), play a role in breaking long-range correlations. Different modifications of instantons in the $O(3)$ sigma model, such as baby-skyrmions, play a considerable role in solid state physics in the study of magnetic phenomena in thin films. On the other hand, the discovery of instantons and the self-duality equation presented a striking example of how topological constructions (for instance, the concept of Pontryagin class) can be useful in physics. The development of science demonstrated the importance of the self-duality equation in both physics and mathematics (e.g., the Donaldson theory in topology); this equation is still a field of active research.

The paper, "Yang–Mills Equations as Inverse Scattering Problem," by Belavin and Zakharov disclosed a deep relation between instantons and complex geometry (see A A Belavin, V E Zakharov *Phys. Lett. B* **73** 53–57 (1978)). Namely, it was shown that an instanton on a four-dimensional sphere is, in fact, a holomorphic vector bundle on a three-dimensional complex projective space with certain additional properties. It has turned out that instantons can be classified using algebraic geometry methods. Such an approach has led to a complete classification of instantons by Atiyah, Drinfeld, Hitchin, and Manin.

In 1979, Belavin obtained an exact solution of the $SU(2)$ Thirring model (A A Belavin "Exact solution of the two-dimensional model with asymptotic freedom" *Phys. Lett. B* **87** 117–121 (1979)). In particular, the solution included a draft of the method, now known as the 'hierarchic Bethe ansatz.' Belavin's solution was the basis for an exact solution to the Kondo model.

A A Belavin's contribution to the theory of integrable systems is especially worth noting. The modern theory of integrable systems includes the basic concept of the R matrix determining the algebra of fundamental observables in the theory or, in the classical limit, the corresponding Poisson structure. The R matrix satisfies the well-known Yang–Baxter equation. In his 1980 paper, "Discrete groups and integrability of quantum systems," Belavin constructed elliptic solutions of this equation (see A A Belavin *Funktsional'nyi analiz i ego prilozheniya* (*Functional analysis and its applications* **14** 18–26 (1980)). A fundamental relation between classical Yang–Baxter equations and Lie algebras was revealed in the same paper. Classification of integrable systems comes down to classification of solutions to these equations. In the quantum case, the problem largely remains open, but in the classical limit a complete solution was found in papers by Belavin and Drinfeld (A A Belavin, V G Drinfeld *Funktsional'nyi analiz i ego prilozheniya* (*Functional analysis and its applications* **16** 1–29 (1982), **17** 69–70 (1983)), where the classification of R matrices was defined in terms of simple Lie algebras. This discovery exerted great influence on the future development of the theory, including the further discovery of representations of quantum groups and Yangians.

In their well-known paper, "Infinite conformal symmetry in two-dimensional quantum field theory," Belavin, Polyakov, and Zamolodchikov proposed a general approach to investigating two-dimensional conformal quantum field theories (see A A Belavin, A M Polyakov, and A B Zamolodchikov *Nuc. Phys. B* **241** 333–380 (1984)). In this paper, they constructed an infinite set of exactly solvable nontrivial models of the two-dimensional quantum field theory, so-called 'minimal models.' A considerable advance reached in this paper was, in part, clarification of the fact that the space of states of two-dimensional conformal field theories is described with an infinite-dimensional nonabelian algebra of dynamic symmetry — Virasoro algebra. This made it possible to classify fields in a two-dimensional conformal quantum field theory using the techniques of the theory of representations of Virasoro algebra. Along with the importance of applying conformal field theory to string theory and statistical physics, one should emphasize its role for the theory of representations, especially for the theory of representations of infinite-dimensional Lie algebras. The study by Belavin, Polyakov, and Zamolodchikov also led to a mathematical theory of algebras of vertex operators and then to a geometrical version of this theory developed by Drinfeld and Beilinson, referred to as the theory of chiral algebras. Chiral algebras are now one of the main tools employed in the Langlands geometrical program.

In their paper, "Complex geometry and the theory of quantum strings," (A A Belavin, V G Knizhnik *Zh. Eksp. Teor. Fiz.* **91** 364 (1986)), Belavin and Knizhnik considered Polyakov's measure on the moduli space of closed Riemann surfaces in the theory of bosonic strings in the critical dimension $D = 26$. The calculations beyond the tree approximation include an analysis of cross sections above moduli spaces of Riemann surfaces, the integrands being defined as functional determinants. Belavin and Knizhnik obtained an analytical structure of the dependence of such determinants on the space of conformal moduli of Riemann surfaces. This result, widely known as the 'Belavin–Knizhnik theorem,' underlay string loop calculations and gave rise to new studies in mathematics.

In his paper with Zamolodchikov, "Moduli Integrals, Ground Ring and Four-Point Function in Minimal Liouville Gravity" (A Belavin, Al B Zamolodchikov *Teor. Mat. Fiz.* **147** (3) 339–371 (2006)), Aleksandr Abramovich developed a method for calculating multipoint correlation numbers in minimal Liouville gravity. This method was then used in several studies examining correlation numbers on surfaces with different topologies and different numbers of inserts of physical operators.

In his joint paper with Aleshkin, "A new approach for computing the geometry of the moduli spaces for a Calabi–Yau manifold" (see K Aleshkin and A Belavin *J. Phys. A* **51** (5) 055403 (2018)), Belavin constructed a new method to obtain an effective field theory occurring in string theory upon compactification of 6 out of 10 dimensions on the Calabi–Yau manifold. The method was then successfully applied to check the mirror symmetry hypothesis.

For many years, Aleksandr Abramovich has headed a scientific school training students, postgraduates, candidates, and doctors of science. A world-class scientist, he finds time to deliver regular lecture courses on quantum field theory, string theory, and quantum gravity, to organize scientific schools and conferences, and to conduct a seminar on quantum field theory at the L D Landau ITP. The MIPT department headed by Aleksandr Abramovich is traditionally popular with students. It annually graduates young specialists who are successfully working at leading universities all over the world.

Aleksandr Abramovich has always spent a great deal of time on popularizing science. His lectures for junior students and sometimes also for schoolchildren have always attracted young people and impelled them to take up science.

Aleksandr Abramovich's active public stance is worth special mention. In the difficult times for the country, he always demonstrated the strength of mind to be selflessly engaged in his favorite occupation — science — thus serving as an example for the young generation of scientists.

Happy birthday to you, dear Aleksandr Abramovich! Numerous colleagues, disciples, and friends wish you much health and further successful advances in science. May your scientific erudition, experience of great scientific discoveries, and pedagogical talent serve for the benefit of science!

P I Arseev, M A Vasil'ev, M I Vysotskii,
A S Gorskii, V G Drinfeld, A B Zamolodchikov,
V E Zakharov, A V Litvinov, A M Polyakov,
V A Rubakov, B L Feigin, M A Shifman